COMMONWEALTH OF AUSTRALIA
MINISTRY OF NATIONAL DEVELOPMENT
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No. 5.

AUSTRALIAN RESOURCES OF SULPHUR-BEARING MINERALS

By P. B. NYE and G. F. MEAD

Issued under the Authority of Senator the Hon. W. H. Spooner,
Minister for National Development

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Minister—SENATOR THE HON. W. H. SPOONER.

Secretary—H. G. RAGGATT.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Director—P. B. NYE.

Deputy Director—J. M. RAYNER.

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CONTENTS

PYRITE AND PYRRHOTITE OREBODIES—CONTINUED.

APPENDICES

ILLUSTRATIONS

TABLES

Summary.

Sulphur is used principally for making sulphuric acid (94% in 1949), which is one of the most important substances in modern chemical industry. Sulphuric acid is made in Australia and consumed almost entirely in the manufacture of chemical fertilizers (mainly superphosphate) for the agricultural and pastoral industries. In more industrialized countries, a considerable amount of sulphuric acid is used in heavy industries.

Sulphur-bearing materials used to make sulphuric acid include—

Brimstone—native sulphur (100% sulphur).
Pyrite or pyrite concentrates—iron sulphide (50% sulphur).
Zinc concentrate—zinc sulphide (32% sulphur).
Anhydrite—calcium sulphate (23.6% sulphur).

Brimstone is obtained mainly from the salt domes in the Gulf Coast region of U.S.A. Pyrite concentrates are obtained as by-products in the mining and treatment of ores, e.g., those of copper. Zinc concentrates are obtained in the mining and treatment of lead-zinc ores.

The production of cheap and pure sulphur in U.S.A. has dominated the world sulphur market during the last ten to twenty years. It has displaced sulphur from other countries and caused a reduction in the amount of pyrite used for making acid, but has not affected the amount of zinc concentrates used because they have to be roasted as part of the process in making metallic zinc. Advantages in using brimstone in acid and fertilizer plants are lower capital cost, lower working cost, less labour force and better working conditions.

During 1948 world production of sulphur-bearing materials included:

Native sulphur		5,300,000	tons
By-product sulphur		168,000	„
Sulphur content of pyrite	up to	4,000,000	„

About 90% of the native sulphur was produced in U.S.A.

Since 1947 the production of native sulphur has been decreasing, while world consumption has been increasing. Stocks have fallen and exports from U.S.A. have been restricted. In late 1950 the U.S.A. Government gave notice of impending export control of brimstone and warned all importers to convert their consuming industries to alternative materials. Since then, available supplies of brimstone have been allocated by the International Materials Conference, the share of all importing countries, including Australia, being considerably less than recent imports. It is possible that the ration may be progressively reduced.

There are twenty plants making sulphuric acid, but three of these plants do not make superphosphate. The total number of superphosphate plants (including two operated by companies that buy acid) is 19. The sulphuric acid plants are distributed as follows:—Queensland 1, New South Wales 4, Victoria 4, Tasmania 1, South Australia 5, Western Australia 5.

Australia has no deposits of native sulphur. It imports brimstone and also uses domestic pyrite concentrates and zinc concentrates. In 1949 the sulphur content of materials used in Australia for making acid were—

Brimstone (imported)	123,178	tons	
Spent oxide (from gas works)	2,000		(estimated)
Pyrite concentrates ..	39,439	„	
Zinc concentrates	35,038	„	

It will be seen, therefore, that 61.6 per cent of the sulphur used in Australia in 1949 was imported. The Australian sulphuric-acid industry is therefore largely dependent on imported brimstone. In view of this, and of the reductions already made in imports and those likely to be made, it is evident that the acid and chemical fertilizer industries will be seriously affected unless alternative supplies of sulphur-bearing materials are available.

Fortunately, Australia has several large deposits of sulphide materials. The largest are at Mount Isa and Mount Morgan, in Queensland, Broken Hill and Captain's Flat in New South Wales, Mount Lyell and Read-Rosebery in Tasmania, Nairne in South Australia, and Norseman in Western Australia. The total known reserves of sulphur in the deposits are—

Pyrite and pyrrhotite bodies	7,921,000 tons
Pyrite concentrates from mixed sulphide bodies	4,234,000 „
Zinc concentrates	4,213,000 „
Lead concentrates	2,052,000 „
Total	18,420,000 „

For several reasons, including cost of transport, necessity to conform to existing arrangements and technical matters, it would not be possible to use all the above. It is considered, however, that the sulphur content of reserves of sulphides available for making acid is 14,932,000 tons. The details of the deposits in which they occur are given below (figures are in thousands of long tons).

State	Locality	Sulphur in Recoverable Concentrates				Totals
		Pyrite and Pyrrhotite Orebodies	Pyrite Concs. from Mixed Sulphide Orebodies	Zinc Concs.	Lead Concs.	
Q'land.	Mt. Morgan ..		2,284			2,284
N.S.W.	Broken Hill ..			1,767	1,530	3,297
	Captain's Flat .		127			127
	Leadville.. ..	26				26
Tas.	Chester	420				420
	Mt. Lyell Mine	725				725
	Mt. Lyell and Jukes Darwin Fields..		1,305			1,305
	Read Rosebery .		184	306		490
	Renison Bell ..	283				283
S.A.	Nairne (Gibraltar	5,295				5,295
W.A.	Big Bell	47				47
	Iron King (Norseman) .	633				633
	Sulphur Content	7,429	3,900	2,073	1,530	14,932

The above amount would be equivalent to 13,500,000 tons of brimstone and would be sufficient for about 33 years' supply.

The difficulties in the use of local sulphide materials to replace imported brimstone for all except certain minor uses will be those of conversion of plant and transport of ores and concentrates. To convert brimstone-burning plants to the use of sulphide minerals is not merely a matter of building burners and disposing of calcine, but of increasing the size of the acid-making units to compensate for the lower-grade gas obtained. To move the necessary increased quantity of sulphide ores and concentrates to acid and superphosphate works will necessitate new railway rolling stock, new ships and improved facilities at certain outports. These difficulties are formidable, but they must be overcome if a superphosphate shortage is to be avoided.

INTRODUCTION

Sulphur is a non-metallic element which occurs in the free form as native sulphur and in combination with metals as sulphides and sulphates. The principal sulphide minerals used, or usable, for their sulphur content are those of iron (pyrite, pyrrhotite and marcasite), copper and iron (chalcopyrite), lead (galena) and zinc (sphalerite and the iron-bearing varieties known as marmatite). The principal sulphate minerals are those of calcium (anhydrite and gypsum) and of potassium and aluminium (alunite). Table 1 gives details of these minerals.

TABLE 1

COMPOSITION OF PRINCIPAL SOURCES OF SULPHUR

Mineral	Chemical Formula	Percentage Sulphur
Sulphur	S	100*
Pyrite and Marcasite	FeS_2	53.45
Pyrrhotite	Fe_7S_8 to Fe_4S_5	39.6 to 41.8
Chalcopyrite	$Cu\ FeS_2$	34.94
Galena	$Pb\ S$	13.40
Sphalerite	$Zn\ S$	32.90
Marmatite	$(Zn.Fe.Mn)S$	32.9 to 34.4
Anhydrite	$CaSO_4$	23.55
Gypsum	$CaSO_4 . 2H_2O$	18.62
Alunite	$KAl_3(OH)_6\ (SO_4)_2$	15.46

*Sulphur-rock as mined contains from 10% to 80% sulphur.

Free sulphur (brimstone) is marketed in several forms: Sublimed sulphur ("flowers of sulphur"), precipitated sulphur ("lac sulphur"), roll sulphur—all practically 100 per cent sulphur; crude sulphur, 90 to 99 per cent sulphur; refined sulphur, 98 to 99 per cent sulphur; ground sulphur made by powdering crude or refined sulphur; and high-grade sulphur-rock, 50 to 80 per cent sulphur. The categories "crude" and "refined" vary with the producer, American "crude" sulphur produced by the Frasch process being purer than much of the "refined" sulphur from elsewhere. By far the largest amount of sulphur sold is the so-called "crude" sulphur from U.S.A.—broken up sufficiently for ease in transport and handling—and the next largest amount sold is "refined" sulphur in the same condition. All other forms have only minor specialized uses.

Brimstone is widely used in many industries, but usages for which it is essential account for only a small part of the total amount consumed. These essential usages include the manufacture of certain medical preparations, ointments, insecticides, fungicides, carbon bisulphide, gunpowder and vulcanized rubber. Brimstone may be used as an acid-resistant cement in conjunction with either sand or bitumen. Most of the brimstone consumed in all countries is converted to sulphuric acid, which is used extensively in the fertilizer, chemical and metallurgical industries and, in smaller amounts, in other industries. The chief uses of sulphuric acid include the manufacture of superphosphate, ammonium sulphate, phosphoric acid, refined petroleum products, explosives, nitric and hydrochloric acids, rayon and other cellulose products (including photographic film), titanium white and other pigments, pickling of steel before galvanizing or tinning, and electrolytic winning and refining of metals—chiefly zinc and copper.

Sulphuric acid is also made in large quantities from sulphide minerals, either by roasting pyrite concentrates specifically for that purpose, by roasting or smelting base-metal ores and concentrates, or, in smaller quantities, from sulphate minerals as a co-product of cement manufacture.

A considerable amount of brimstone is made as a by-product of copper-smelting in Norway, Spain and Portugal. Small amounts of brimstone and considerable amounts of sulphuric acid are made from hydrogen sulphide and other sulphur compounds contained in coal gas or natural gas, and from other industrial waste gases and products.

A large quantity of sulphur dioxide, made by burning sulphur or pyrite, is used in paper-making; smaller quantities are used for textile-bleaching and refrigerating gas.

As mined, pyrite ore contains 25 to 45 per cent sulphur, but the lower grades are usually dressed into a concentrate containing 45 to 50 per cent sulphur. Principal countries producing pyrite in 1938 were Spain, Japan, Cyprus, Norway, Portugal and U.S.A. With the exception of the U.S.A. production, most of the pyrite was consumed by Germany and Italy. The 1939-45 war completely disrupted the pyrite trade, and, in 1949 pyrite production had not reached the 1938 level.

Many pyrite deposits contain gold, copper, lead, zinc or other non-ferrous metals; in fact, few pyrite deposits are mined for their pyrite content alone, because the market price for sulphur contained in pyrite is too low unless the deposits are favourably located for sea transport or political factors make its use mandatory. The presence of even a small amount of recoverable copper or gold may make it possible to mine a pyrite deposit that would otherwise be unpayable.

Before the introduction of the Frasch process, brimstone was less important than pyrite ores for making acid because of the high cost of crude methods of working native sulphur deposits. Pyrite will undoubtedly regain much of its former importance for making acid because the life of the known sulphur domes in the U.S.A. has been alarmingly reduced by the greatly increased rate of consumption of brimstone in recent years. Known native sulphur deposits outside the Gulf of Mexico region are inadequate to supply more than a small fraction of the world demand for sulphur.

TABLE 2

WORLD PRODUCTION OF NATIVE SULPHUR (1938-1948)

(Taken from U.S. Bureau of Mines' Minerals Year Books and Imperial Institute's Mineral Industry Statistical Summaries.)

Country (1)	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948
Argentina (refined)	—	—	—	367	2,148	10,649	11,092	9,072	13,000	13,000	(2)
Bolivia (exports)	1,632	2,126	4,065	2,463	3,627	7,078	6,049	640	468	2,275	2,707
Chile	20,959	26,999	28,825	24,784	29,570	32,360	30,380	28,617	15,185	11,717	13,258
China	(2)	(2)	(2)	3,393	2,176	2,500	2,229	2,000	(2)	(2)	(2)
Egypt	—	—	—	—	128	201	893	285	—	—	—
France (content of ore)	140	(2)	309	575	703	1,000	1,021	2,672	2,083	10,602	13,779
Greece	75	(2)	(2)	(2)	4,685	6,373	1,860	448	87	(3) 780	(2)
India (ore)	—	—	—	4,520	12,841	30,141	12,245	—	—	—	—
Indonesia	15,986	17,293	(2)	17,885	—	—	—	—	—	—	—
Israel	1,196	829	1,358	3,365	(4) 713	—	—	—		—	(2)
Italy (crude) (5)	374,339	350,208	325,473	294,288	220,808	(6) 91,773	(3) 37,000	(3) 80,000	140,765	145,003	170,000
Japan (refined)	233,032	196,462	188,308	193,755	165,537	149,836	75,339	37,333	21,046	28,735	40,126
Mexico	49	(2)	(2)	(2)	(4) 26,115	(4) 4,400	(4) 5,100	(4) 7,100	(2)	(2)	2,100
Peru	1,944	571	610	935	1,126	564	1,412	1,197	355	778	(2)
Spain	990	3,770	3,560	6,230	5,000	5,511	6,280	4,840	4,000	3,600	16,973
Turkey	3,684	2,402	3,608	2,142	3,051	3,326	3,348	4,088	2,970	2,620	2,369
U.S.A.	2,393,408	2,090,979	2,732,088	3,139,253	3,460,686	2,538,786	3,218,158	3,753,188	3,859,642	4,441,214	4,869,210
TOTAL	3,000,000	2,700,000	3,300,000	3,700,000	4,000,000	3,000,000	3,500,000	4,000,000	4,200,000	4,800,000	5,300,000

Footnotes: (1) Native sulphur is believed to be produced also in Cuba, Iran, Formosa and U.S.S.R. An estimate of production as well as production of Ecuador is included in total.

(2) Data not available. Estimate included in total.

(3) Estimate.

(4) Incomplete data.

(5) In addition, following quantities of sulphur rock reported:—
1938—16,545 tons. 1939—19,568 tons. 1942—30,734 tons.

TABLE 3

WORLD PRODUCTION OF BY-PRODUCT SULPHUR (1938-1947).

Country	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947
Canada (1)	26,038	(2) 30,000	(2) 42,000	(2) 52,000	(2) 50,000	(2) 47,000	—	—	—	—
Germany	70,000	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
Norway (4)	109,095	89,264	75,658	77,427	77,424	90,361	65,615	21,428	70,751	81,121
Portugal (4)	11,356	11,221	11,039	11,161	11,846	10,885	11,536	12,756	12,403	7,522
Spain (4) (5)	(2) 22,000	(2) 22,000	(2) 22,000	(2) 22,000	(2) 22,000	(2) 22,000	(2) 22,000	(2) 22,000	(2) 22,000	(3)
Sweden (6)	17,512	20,247	17,874	8,917	8,821	14,599	16,502	24,291	21,395	13,982
U.S.A. (7)	3,674	4,307	3,942	5,493	5,125	5,101	19,096	25,184	34,990	43,427
TOTAL	259,675	257,000	252,000	257,000	255,000	270,000	185,000	106,000	162,000	168,000

Footnotes:

(1) By-product of lead-zinc smelting. Estimates for 1939-1943 made from diagram in paper by W. S. Kirkpatrick. "Economic Utilization of Waste Gases at Trail, B.C." Fourth Empire Mining and Metallurgical Congress, 1949.

(2) Estimate.

(3) Data not available. Estimate included in total.

(4) Produced by "Orkla" process from smelting of cupreous pyrite ores.

(5) Estimates from totals by H. R. Potts and E. G. Lawford, "Recovery of Sulphur from Smelter Gases by the Orkla Process at Rio Tinto." I.M.M. Bull. 509. Total for years 1934-1939 inclusive, 131,296 tons, and for years 1940-1946 inclusive 150,696 tons.

(6) By-product of base-metal smelting until 1943 and of oil-shale refining thereafter.

(7) Recovered from coke-oven, refinery, natural and other gases by the Thylox, Ferrox and Nickel processes.

WORLD PRODUCTION OF SULPHUR AND SULPHUR-BEARING MATERIALS.

The latest year for which complete figures for sulphur production are available is 1948. Table 2 shows production of native sulphur for the period 1938 to 1948 for all countries for which reliable figures are obtainable. It can be seen from the table that native sulphur production in the United States of America was preponderant, even before 1939 (75 per cent of total), and was even more so in 1947 (87 per cent of total) because the sulphur industry in the two next largest producers, Italy and Japan, was disrupted towards the end of the war. Production in these two countries is now increasing, and can be expected to reach pre-war dimensions, but their relative importance will be less because U.S.A. production has increased rapidly in the last ten years.

Figures quoted by the "American Mining Congress Journal" (M.C.J., 1948) show that this rapid increase has not been maintained, production of crude sulphur in 1948 being 4,869,210 tons, and in 1949 being estimated as 4,750,000 tons. In 1948 domestic consumption in and export of suphur from U.S.A. exceeded production, and stocks fell to 10½ months' supply. The increase in consumption has continued at an accelerated rate, and, in late 1950, stocks were so low that the U.S.A. Government announced a quota system of export control, and warned all foreign customers to convert acid plants to use sulphide minerals.

A considerable amount (168,000 tons in 1947) of by-product sulphur is obtained from copper smelting, and the world production is given in Table 3.

The world production of pyrite is shown in Table 4. The figures include some cupriferous pyrite that is smelted without accompanying acid-making. On available information it is not possible therefore to state precisely how much of the sulphur content of the pyrite is used for making acid.

SOURCES OF SUPPLY OF SULPHUR USED IN AUSTRALIA

Australian supplies of sulphur and sulphur-bearing materials are obtained from imported sulphur, from gasworks' spent oxide and from sulphide ores. Imported sulphur is the most important source; spent oxide is produced and used only in minor amounts.

SULPHUR IMPORTS.

In the past Australia has imported sulphur from the United States of America, Italy and Japan. Imports from the United States of America have become increasingly important, and from 1938 to 1948, formed the only source of supply. In the

TABLE 4

WORLD PRODUCTION OF PYRITE (INCLUDING CUPRIFEROUS PYRITE (1)). YEARS 1938-1947. (SULPHUR CONTENT, 40-50 PER CENT.)

Taken from U.S. Bureau of Mines Minerals Year Books and Imperial Institute's Mineral Industry Statistical Summaries.

Country	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948
Algeria	43,256	42,951	41,366	43,974	31,425	25,186	32,385	28,818	39,800	34,780	35,300
Australia	50,277	54,729	49,653	55,993	67,885	77,417	87,617	96,071	87,632	106,391	83,075
Canada (sales)	39,825	203,246	114,076	270,857	338,833	254,086	223,278	203,324	180,299	159,164	164,347
Cyprus	972,040	839,346	249,330	9,344	7,878	9,095	12,986	35,225	289,407	602,136	369,937 (5)
Finland (pyrite only) ..	101,353	115,153	150,000	138,516	123,547	108,475	125,644	108,578	124,315	149,863	—(2)
France	144,883	177,433	206,329	195,000	211,000	203,987	111,127	167,000	216,281	193,082	176,000
Germany	457,893	551,626	966,258	1,236,238	1,196,772	1,374,996	—(2)	—(2)	235,000 (4)	319,000 (4)	377,000 (4)
Great Britain	4,282	4,733	5,430	6,379	17,180	27,197	24,409	23,069	20,628	9,946	—(2)
Greece	240,000	213,770	—(2)	10,206	7,360	3,800	4,310	6,410	78,880	15,979	15,979
Italy	915,619	962,228	1,043,818	1,006,910	953,842	—(2)	100,000 (3)	400,000 (3)	394,193	618,868	741,742
Japan	2,090,000 (3)	—(2)	—(2)	2,072,877	1,881,916	1,567,584	1,228,929	397,598	607,794	889,141	1,120,000
Norway	1,011,544	1,008,765	750,272	918,206	809,221	796,005	738,553	243,557	531,324	708,643	723,802
Poland	90,753	—(2)	—(2)	—(2)	77,000	86,000	—(2)	—(2)	27,807	39,033	—(2)
Portugal	706,769	661,829	387,658	214,133	132,784	108,257	128,075	168,267	310,000	382,686	547,348
Southern Rhodesia	26,638	26,954	33,836	41,935	37,060	34,512	33,608	32,937	24,117	16,873	13,015
Spain	2,683,934	1,523,928	946,847	565,457	617,102	867,233	504,159	885,538	1,157,403	995,009	1,093,175
Sweden	183,446	188,709	191,148	223,264	297,502	319,890	312,441	257,846	275,783	305,666	—(2)
Union of South Africa.	30,528	29,354	36,121	34,650	39,829	36,446	35,584	37,947	37,443	34,271	35,423
U.S.A.	555,629	519,497	626,640	645,257	720,363	802,384	788,530	722,596	813,372	940,652	928,528
Yugoslavia	148,027	125,970	133,000	—(2)	—(2)	—(2)	—(2)	—(2)	—(2)	—(2)	—(2)
TOTAL	11,000,000	10,000,000	9,000,000	9,000,000	9,000,000	9,000,000	7,000,000	5,500,000	7,000,000	8,000,000	8,800,000

Footnotes:

(1) Pyrite is also produced or has been produced in Belgium, Brazil, China, Czechoslovakia, Egypt, Eire, Hungary, India, Iran, Korea, Roumania and U.S.S.R. The figures are either not available or are each less than 10,000 tons annually.

(2) Not available.

(3) Estimate.

(4) British and U.S.A. zone only.

(5) Exports.

year ended 30th June, 1950, it was still the major supplier, but, in addition, 53,663 tons were imported from Italy and 13,225 tons from Norway.

TABLE 5

AUSTRALIAN IMPORTS OF SULPHUR
(1932-1950).

Fiscal Year Ended 30th June	Imports Tons	Value £A.	Price per Ton £A. f.o.b.
1932	32,917	241,728	7.34
1933	93,445	633,662	6.78
1934	67,091	365,099	5.44
1935	63,756	311,618	4.89
1936	106,762	529,694	4.96
1937	90,393	504,353	5.58
1938	141,796	664,049	4.68
1939	115,100	560,073	4.86
1940	105,345	536,811	5.10
1941	77,818	418,721	5.75
1942	41,032	240,874	5.87
1943	32,433	176,425	5.44
1944	28,233	154,731	5.48
1945	46,063	247,434	5.37
1946	81,670	476,864	5.84
1947	109,742	689,159	6.28
1948	116,752	599,487	5.13
1949	114,889	818,818	7.13
1950	177,943	2,499,695	14.05

The decrease in imports during the war was the result of decreased use of superphosphate, due to the restrictions on wheat growing. The large increase in 1950 has been caused by the increasing of stocks to an amount equal to seven months' consumption.

The U.S.A. price of sulphur has remained reasonably constant for a long time, being $18-$20 per ton for domestic consumption, and $20-$22 per ton for export. The very large rise in the f.o.b. price in the year ended 30th June, 1950, was caused by devaluation of Australian currency and by the much higher price paid for sulphur from Italy (£A.26.24 per ton, f.o.b.) and Norway (£A.17.71 per ton, f.o.b.).

All sulphur is imported by the British Phosphate Commission on behalf of the Commonwealth and is distributed to consumers without profit at a price equal to the average for all imports. The pool price was £20/10/- per ton from 1st August, 1950.

Sulphur in Spent Oxide.

Hydrated iron oxide is used at large gasworks to remove hydrogen sulphide from the gas. The material eventually contains about 46 per cent of sulphur (on a dry basis). The amount of sulphur in spent oxide produced is not large, and is not all used for making sulphuric acid. The amount of sulphur from spent oxide used annually for making acid is estimated at 2000 tons—1500 tons in Sydney, 350 tons in Melbourne, and minor amounts in other centres. If all town gas were purified before use, a further 2000 tons of sulphur would be available in the additional spent oxide produced.

SULPHIDE MINERALS.

Sulphide-bearing materials used in Australia for making acid include zinc concentrates from Broken Hill and Rosebery, and pyrite concentrates from Captain's Flat, Mount Lyell, Mount Morgan and Norseman. The zinc concentrates are major products of the Broken Hill mines operated by North Broken Hill Ltd., Broken Hill South Ltd., Zinc Corporation Ltd. and New Broken Hill Consolidated, and of the Read-Rosebery mines of the Electrolytic Zinc Co. of Australasia Ltd. Pyrite concentrates produced by the Mount Lyell Mining and Railway Co. Ltd. and Mount Morgan Ltd. are by-products of copper mining and those produced by Lake George Mines Pty. Ltd. at Captain's Flat are by-products of copper and lead-zinc mining. The Iron King Mine of Norseman Gold Mines N.L. is the only one in Australia producing pyrite only; the company supplies both pyrite concentrate and selected crushed ore.

The composition of the concentrates varies according to origin, available information being set out in Table 6.

TABLE 6

COMPOSITION OF CONCENTRATES USED FOR MANUFACTURE OF SULPHURIC ACID IN AUSTRALIA.

	Zinc Concentrates			Pyrite Concentrates		
	North Broken Hill Per cent	Zinc Corporation Per cent	Rosebery Per cent	Mount Lyell Per cent	Captain's Flat Per cent	Norseman Per cent
Sulphur . .	31.24	32.1	33.10	49.7	46.9	46.6*
Lead	0.90	1.3	2.37		1.3	
Zinc	50.90	53.3	55.40		1.7	
Copper . .	0.09	0.11	0.29		0.25	
Iron	7.08	8.76			40.2	

*Sulphur content of selected crushed ore, 34.6 per cent.

Zinc concentrates are roasted as a necessary preliminary to recovery of metallic zinc. The mining companies and fertilizer-manufacturing companies collaborate to have this roasting done at places convenient for making acid and for fertilizer-manufacture. Until 1949 some zinc concentrates were roasted to air at Port Pirie

(S.A.) and Zeehan (Tasmania), but this has since been stopped, and only small amounts were roasted to air (in Port Adelaide) in 1950.

The movements of zinc concentrates form part of the complex pattern of movements of metallic ores and concentrates to and from localities best suited to carry out certain operations. Broken Hill concentrates are roasted in small amounts at Cockle Creek, New South Wales, and the remainder at Port Pirie, Wallaroo and Port Adelaide, in South Australia, and at Risdon, in Tasmania. Only about three quarters of the sulphur content is burnt to sulphur dioxide for making acid, a small amount is oxidized to zinc sulphate, and the rest remains as unaltered zinc sulphides, sphalerite and marmatite. The roasted concentrates (calcines) are shipped to Risdon, where cheap hydro-electric power is available to operate the electrolytic-zinc process. After acid treatment and solution of zinc oxide, the unattacked zinc sulphides left by the first roasting are floated off into a "Risdon" concentrate, the concentrates are roasted, and part of the roaster gas is used for making acid.

The zinc concentrates from the Hercules and Rosebery mines of the Electrolytic Zinc Co. of Australasia Ltd. undergo a similar treatment, both the first and second roasting being done at Risdon. The first roasting was formerly done at Zeehan—and the gas wasted—but since 1949 it has been done at Risdon.

Pyrite concentrate from Captain's Flat is railed to the Port Kembla works of Australian Fertilizers Ltd. From 1942 to 1947 large amounts were railed also to the Phosphate Co-operative Co. Pty. Ltd. at Geelong, Victoria.

Small amounts of Mount Morgan pyrite concentrate have been used at Port Kembla and at the works of the Sulphide Corporation Pty. Ltd., at Cockle Creek, New South Wales. Production is on a limited scale only, but large amounts could be produced both from current ore production and from old tailing dumps.

The Mount Lyell Mining and Railway Co. Ltd. occasionally sends pyrite concentrate to Port Kembla, but the greater part of the pyrite concentrate is sent to the Yarraville works of Commonwealth Fertilisers and Chemicals Ltd. Because of shipping difficulties and limited capacity of the Mount Lyell Company's railway, a large stockpile of pyrite has accumulated at the mine and at the port of Strahan.

Pyrite concentrate from the Iron King Mine of Norseman Gold Mines N.L. is burnt at the Bassendean works of Cuming Smith and Mount Lyell Farmers' Fertilisers Ltd. and the Bayswater works of Cresco Fertilisers (W.A.) Ltd. Selected crushed ore from the same mine is burnt at the North Fremantle works of Cuming Smith and Mount Lyell Farmers' Fertilisers Ltd.

Table 7 shows the production of pyrite intended for manufacture of sulphuric acid, and of zinc concentrates actually used for the same purpose since 1932. It is not possible to obtain a figure for total usage of sulphur by adding the figures in this table to those in Table 5 because brimstone stocks have varied from year to year —they increased rapidly in 1950, and large pyrite stocks have been accumulated by the Mount Lyell Company, the latest estimate being 170,000 tons.

TABLE 7

PRODUCTION OF PYRITE AND PYRITE CONCENTRATES AND OF ZINC CONCENTRATES USED FOR MANUFACTURE OF SULPHURIC ACID (1932-1949).

Year	Pyrite Production*		Zinc Concentrates Used†	
	Amount Tons	Estimated Sulphur Content Tons	Amount Tons	Estimated Sulphur Content Tons
1932	3,329	1,648	84,858	26,306
1933	1,498	667	96,026	29,768
1934	12,030	5,955	103,619	32,122
1935	25,575	12,660	98,088	30,407
1936	35,333	17,490	114,039	35,352
1937	40,802	19,700	116,369	36,074
1938	50,277	24,887	112,624	34,913
1939	54,729	27,091	114,128	35,380
1940	49,653	24,578	116,521	36,121
1941	55,993	27,157	123,662	38,335
1942	67,885	32,924	107,434	33,304
1943	77,417	37,547	93,902	29,110
1944	87,617	41,180	103,989	32,236
1945	96,071	45,153	131,109	40,644
1946	87,632	41,187	121,467	37,655
1947	106,391	50,003	137,582	42,650
1948	105,504	49,587	144,320	44,739
1949	95,139	44,715	163,062	50,549
TOTAL	1,052,875	504,129	2,082,799	645,665

*Calendar year.
†Financial year ended 30th June.

Prices received by mining companies for the sulphur content of their concentrates are confidential—and therefore cannot be published—with the exception of Iron King concentrate and crushed ore, for which prices fixed by the Western Australian Prices Commissioner were 3/1¾d. and 2/3d. respectively per unit in late 1950.

Prices of pyrite concentrates from other mines are known to be very low, covering very little more than actual cost of recovery of concentrates from mill residues and transport to acid plants.

The arrangements for the making of sulphuric acid from zinc concentrates are the subject of agreements between the mining companies or Electrolytic Zinc Co. and the fertilizer companies concerned, and are not made public. Appendix 3 shows the shareholding of mining companies in fertilizer companies.

Enquiries made among acid manufacturers and mining companies and calculations based on the figures supplied show that, for the calendar year 1949, 63.45

per cent of the sulphuric acid manufactured was made from brimstone, 0.93 per cent from spent oxide, 18.92 per cent from pyrite concentrates, and 16.70 per cent from zinc concentrates. The amounts of acid made and the sulphur content of the materials used are shown in Table 8.

TABLE 8

MATERIALS USED FOR MANUFACTURE OF SULPHURIC ACID IN AUSTRALIA (1949).

Material	Sulphur Content Tons	Acid Made Tons	Acid (Tons) / Sulphur (Tons)
Brimstone	123,178	367,147	2.981
Spent oxide	2,000*	5,400*	2.700*
Pyrite concentrates	39,439	109,500	2.776
Zinc concentrates	35,038	96,609	2.757
TOTAL	199,655	578,656	

*Estimated.

One ton of brimstone will make a certain amount of sulphuric, but one ton of sulphur in pyrite concentrates makes a smaller amount of acid. Actually 1.11 tons of sulphur in pyrite concentrates are needed to make the same amount of acid as 1 ton of brimstone. In other words, 1 ton of sulphur in pyrite concentrates is equivalent to 0.9 ton of brimstone. The corresponding factor for sulphur in zinc concentrates is 0.72. These factors are used to determine the brimstone equivalent referred to above.

The pyrite and zinc concentrates were obtained from six areas, details of which are set out in Table 9.

TABLE 9

ORIGIN OF CONCENTRATES USED FOR MANUFACTURE OF SULPHURIC ACID IN AUSTRALIA (1949).

Type of Concentrate	Place of Origin	Sulphur Content Tons
Pyrite	Mount Morgan	397
Pyrite	Captain's Flat	6,045*
Pyrite	Mount Lyell	17,996
Pyrite	Norseman	15,001
Zinc	Broken Hill	27,160
Zinc	Rosebery	7,878
	TOTAL	74,477

*Some of this originated at Mt. Morgan or Mt. Lyell.

USES OF SULPHUR AND SULPHURIC ACID IN AUSTRALIA.

The uses of sulphur and sulphuric acid cannot be considered separately because the most important use of brimstone is in the manufacture of sulphuric acid, which in 1949 accounted for 94.16 per cent of the total brimstone used. The remainder, 7,766 tons in 1949, was used in rubber-making, sheep dips, chemicals, drugs and in making sulphur dioxide for gassing paper pulp in paper mills and ore pulps at the Mount Isa and Captain's Flat mines. This sulphur-dioxide gas could be obtained by burning or roasting sulphide minerals; for the other uses described brimstone is essential but could be extracted from smelter or some industrial gases (Appendix 5).

Table 10 shows the uses of sulphur and sulphuric acid in 1949.

TABLE 10

USES OF SULPHUR AND SULPHURIC ACID IN AUSTRALIA (1949).

State	Sulphuric Acid Used for Superphosphate Tons	Sulphuric Acid Used for Other Purposes Tons	Brimstone Used for Making Sulphuric Acid Tons	Brimstone Used for Other Purposes Tons
Queensland	n.a.	n.a.	n.a.	n.a.
New South Wales	42,035	43,561	17,674	1,737
Victoria	200,996	28,003	59,760	4,404
Tasmania	n.a.	n.a.	n.a.	n.a.
South Australia	76,910	6,421	13,397	924
Western Australia	129,734	732	30,151	26
TOTAL	484,860	94,110	125,178	7,766

n.a.—Not available for publication but included in total.

The principal use of sulphuric acid is in superphosphate manufacture, which in 1947-48 accounted for 83.5 per cent, and in 1949 for 83.74 per cent of sulphuric acid used. A subdivision of the uses of sulphuric acid in Australia for 1947-48 is given in Table 11, which is reproduced from the report of the Interdepartmental Sulphuric Acid Committee.

TABLE 11

USES OF SULPHURIC ACID IN AUSTRALIA (1947-48).

	Mono Acid Tons	Percentage of Total
Superphosphate	411,007	83.5
Sulphate of ammonia	37,650	7.5
Manufacture of other chemicals	18,714	3.8
Metal pickling, including galvanising, enamelling and electroplating	12,939	2.6
Electrolytic refining of metals	6,342	1.3
Textile industry	2,307	0.5
Storage batteries	1,029	0.8
Leather industry	964	
Food products and aerated waters	820	
Glue and gelatine	472	
Mineral-oil refining	196	
Miscellaneous	743	
	493,183	100.0

SULPHURIC ACID INDUSTRY IN AUSTRALIA.

PRODUCTION OF ACID BY STATES.

Sulphuric acid is manufactured in all States, and the latest available figures from the Commonwealth Production Statistics are given in Table 12.

TABLE 12

PRODUCTION (BY STATES) OF SULPHURIC ACID (1938-1948).

Year Ended 30th June	Queensland Tons	New South Wales Tons	Victoria Tons	South Australia Tons	Western Australia Tons	Tasmania Tons	Total Tons
1938	—	87,467	209,529	83,672	101,458	13,162	495,288
1939	—	85,501	198,521	82,762	n.a.	n.a.	489,493
1940	—	76,439	128,802	65,482	84,771	14,322	369,816
1941	—	81,469	124,136	65,921	77,113	14,357	362,996
1942	—	76,116	94,588	n.a.	59,042	n.a.	270,161
1943	—	61,181	76,325	n.a.	n.a.	n.a.	219,983
1944	—	64,700	86,900	n.a.	42,482	n.a.	237,013
1945	—	68,068	124,543	n.a.	73,098	n.a.	333,013
1946	n.a.	n.a.	146,917	n.a.	98,763	n.a.	344,134
1947	n.a.	113,572	167,237	83,014	96,224	n.a.	481,477
1948	n.a.	88,476	179,830	88,997	107,689	n.a.	490,852

n.a. Not available for publication, but included in total.

Victoria is the largest producer of sulphuric acid, and Queensland the smallest. The production depends largely upon the demand for superphosphate because, in general, superphosphate is only marketed in the State in which it is produced.

SULPHURIC ACID PLANTS IN AUSTRALIA.

The sulphuric acid plants in Australia are listed in Table 13; there are four plants in New South Wales, four in Victoria, five in South Australia, five in Western Australia, one in Tasmania, and one in Queensland.

Of the 20 plants, all except the following are engaged in the manufacture of superphosphate:—

Elliott's and Australian Drug Pty. Ltd., Rozelle, N.S.W.

Imperial Chemical Industries of Aust. & N.Z. Ltd., Deer Park, Victoria.

Broken Hill Associated Smelters, Port Pirie, S.A.

The first two companies produce acid for the manufacture of chemicals, etc., and Broken Hill Associated Smelters produce acid for sale to manufacturers of superphosphate in South Australia. Three other companies do not use for superphosphate all the sulphuric acid produced, but sell some for other purposes or to other companies making superphosphate. One of these three companies—Commonwealth Fertilisers and Chemicals Ltd.—in the period 1942-1944 sold acid to, and made superphosphate for, Cresco Fertilisers Ltd.

AUSTRALIAN RESOURCES.

NATIVE SULPHUR.

No deposits of native sulphur are known to occur on the Australian mainland or in Tasmania. Private reports suggested that there were moderate-sized deposits in Papua and New Guinea, but investigations by Fisher and Noakes (1942), Fisher (1950), and Edwards (1950) have shown that the known deposits are very small.

Outside the Commonwealth of Australia, small sulphur deposits occur on certain islands in the South Pacific. Recent examination of solfataric sulphur deposits in the New Hebrides has shown that the early reports were greatly exaggerated and that the deposits are not of any commercial importance.

On Vanua Leva, in the Banks Group, sulphur occurs in two areas as conical mounds surrounding active steam vents and as collapsed heaps over former vents. The total sulphur resources on this island are estimated at less than 1000 tons.

On the island of Tanna negligible quantities of sulphur form lenses—with a thickness of a few inches and very limited horizontal extent—in clay in the immediate vicinity of small steam vents on the slopes of Yasour, which is an active volcano.

TABLE 13

SULPHURIC ACID PLANTS IN AUSTRALIA

Company	State	Location	Materials Used				Product			
			Brimstone	Zinc Concentrates	Pyrite Concentrates	Spent Oxide	Chamber Acid	Oleum or "Contact" Acid	Superphosphate	Other Chemicals
(1) A.C.F. and Shirley's Fertilizers Ltd.	Q'land	Pinkenba	Yes	—	—	—	Yes	—	Yes	Yes
(2) Australian Fertilizers Ltd.	N.S.W.	Pt. Kembla	Yes	—	Yes	—	Yes	—	Yes	—
(3) Australian Fertilizers Ltd.	N.S.W.	Villawood	Yes	—	—	—	—	Yes	—	—
(4) Elliotts & Australian Drug Pty. Ltd.	N.S.W.	Rozelle	Yes	—	—	Yes	Yes	—	—	Yes
(5) Sulphide Corporation Pty. Ltd.	N.S.W.	Cockle Ck.	Yes	Yes	Yes*	—	Yes	—	Yes	—
(6) Commonwealth Fertilizers & Chemicals Ltd.	Victoria	Yarraville	Yes	—	Yes	Yes	Yes	—	Yes	Yes
(7) Cresco Fertilizers Ltd.	Victoria	Geelong	Yes	—	—	—	Yes	—	Yes	Yes
(8) I.C.I. of Australia & N.Z. Ltd.	Victoria	Deer Pk.	Yes	—	—	—	—	Yes	—	—
(9) Phosphate Co-operative Co. of Aust. Ltd.	Victoria	Geelong	Yes	—	**	—	Yes	—	Yes	—
(10) Electrolytic Zinc Co. of Aust. Ltd.	Tasmania	Risdon	—	Yes	—	—	—	Yes	Yes	—
(11) Adelaide Chemical & Fertilizer Co.	S.A.	Pt. Adelaide	Yes	—	—	—	Yes	—	Yes	Yes
(12) Cresco Fertilisers Ltd.***	S.A.	Pt. Lincoln	Yes	—	—	—	Yes	—	Yes	—
(13) Electrolytic Zinc Co. of Aust. Ltd.	S.A.	Pt. Pirie	—	Yes	—	—	—	Yes	—	—
(14) Wallaroo-Mt. Lyell Fertilisers Ltd.	S.A.	Birkenhead	Yes	Yes	—	—	Yes	—	Yes	Yes
(15) Wallaroo-Mt. Lyell Fertilisers Ltd.	S.A.	Wallaroo	Yes	Yes	—	—	Yes	—	Yes	—
(16) Cresco Fertilisers (W.A.) Ltd.	W.A.	Bayswater	Yes	—	Yes	—	Yes	—	Yes	—
(17) Cuming Smith & Mt. Lyell F.F. Ltd.	W.A.	Bassendean	Yes	—	Yes	—	Yes	—	Yes	Yes
(18) Cuming Smith & Mt. Lyell F.F. Ltd.	W.A.	Freemantle	Yes	—	Yes	Yes	Yes	—	Yes	—
(19) Cuming Smith & Mt. Lyell F.F. Ltd.	W.A.	Picton Junc.	Yes	—	—	—	Yes	—	Yes	—
(20) Cuming Smith & Mt. Lyell F.F. Ltd.	W.A.	Geraldton	Yes	—	—	—	Yes	—	Yes	—

* In 1949 only. ** Not since 1947. *** Cresco Fertilisers Ltd. have two other superphosphate works at Birkenhead and Wallaroo, using purchased acid only.

TERRITORY OF PAPUA-NEW GUINEA.

Mt. Garbuna (New Britain).—Sulphur occurs around fumaroles and on the ground surface; estimated reserves are about 1700 tons (Fisher and Noakes, 1942).

Mt Pago (New Britain).—A deposit of sulphur about three inches thick occurs over part of the outer slopes of the crater of Mt. Pago, and the estimated quantity is of the order of 4000 tons.

Lolobau (New Britain).—The total quantity of sulphur present is possibly not more than 1000 tons.

Pangalu (New Britain).—Sulphur reserves are only a few hundred tons.

Kasolali (New Britain).—Total quantity of sulphur is only a few tons.

Fergusson Island.—The total quantity of sulphur present is approximately 4000 tons, of which 1000 is clean sulphur that could be selected by hand.

Other localities.—Small amounts of sulphur are also found on the crater of the South Son (New Britain), in the craters of Rabalankia and Tavurvur, near Rabaul (New Britain), and on Mt. Balbi (Bougainville), but none of these is of commercial importance.

SULPHIDE DEPOSITS.

PYRITE AND PYRRHOTITE OREBODIES.

This section deals chiefly with deposits of massive pyrite and pyrrhotite, but, for convenience, includes some auriferous bodies from which pyritic concentrates could be obtained. Apart from those described, there are undoubtedly pyrite and pyrrhotite orebodies for which no information is available.

Until the development of the flotation process of concentration, low-grade disseminated pyrite bodies were not suitable for supplying pyrite for making acid. For this reason, detailed information about these disseminated bodies is almost completely lacking except for those that contain—or were suspected to contain—gold or base metals, and even for some of these there is no information about the sulphur content. Probably the only detailed estimate of the amount of pyrite in a low-grade dissemination of pyrite is that made by Blanchard and Hall (1942), who have estimated that, in the "central mineralized block" (7000 feet along the strike, 1500 feet wide and 1000 feet deep) in which the main lead-zinc orebodies occur at Mt. Isa, there are 135,000,000 tons of pyrite, pyrrhotite and marcasite in the ratio 92:19:1, amounting to 18 per cent of the total weight of this block. This proportion is too low for the ore to be considered as pyrite ore in this particular locality.

At Captain's Flat, pyritic mineralization in bands, streaks and impregnations forms a zone—200 to 500 feet wide and several thousands of feet long—in which the zinc-lead orebodies occur (Kenny and Mulholland, 1941). Information available is not sufficient to enable calculation of the amount of pyrite present, but the deposit is probably too low-grade to warrant its being worked as a source of pyrite apart from that present in the zinc-lead ore.

QUEENSLAND.

Mount Isa.—Mount Isa is situated in north-west Queensland, 603 miles by rail west of the port of Townsville. The lead-zinc and copper orebodies are estimated to contain 1,360,000 tons of pyrite and pyrrhotite in intimate association with other sulphide minerals. (See "Pyrite Concentrates from Mixed Sulphide Orebodies," page 32; "Zinc Concentrates from Mixed Sulphide Orebodies," page 42; "Lead Concentrates from Mixed Sulphide Orebodies," page 46.)

Other pyrite orebodies occur in the Mount Isa district, but outside the mine. Some have been intersected by diamond drills during the search for lead-zinc ore, but no systematic attempt has been made to test or assess them. One drill hole, thirteen miles north of Mount Isa, intersected 60 feet of pyritic lode containing 24 per cent sulphur.

Other Localities.—At Many Peaks, 58 miles south of Gladstone, and at the near-by Mount Cannindah, there are pyritic lodes containing low copper values, with possibly large reserves.

Pyritic ore occurs also at Mount Chalmers, eighteen miles by rail north-west of Rockhampton, and in the Hampden and other mines in the Cloncurry mineral field.

NEW SOUTH WALES.

Cobar and Adjacent Districts.—Copper-gold and gold-copper deposits—some with lead—occur in these districts, particularly near Cobar. The ore in the existing mines contains pyrrhotite and pyrite, but the content of these minerals is not known sufficiently well to permit reliable estimates being made. E. C. Andrews (1928) estimated that there were, in the principal mines in the Cobar-Nymagee-Mount Hope district, resources of 700,000 tons of low-grade copper ore which "would yield large quantities of sulphur fume." Although some of the mines included in his estimates have been worked in the intervening time, present reserves are at least as great as they were in 1928. A small amount of pyritic concentrate could be obtained from the tailings from the existing treatment plants.

During 1947-49, geophysical surveys over large areas in the above districts revealed magnetic anomalies. Testing by diamond drilling proved that the anomalies are due to the presence of wide zones of pyrrhotite-mineralization, one with a maximum width of 800 feet. The content of pyrrhotite is not known accurately, but in present circumstances it is too low to justify consideration of the zones as sources of sulphur.

Small amounts of pyrite have been produced from Leadville, Tottenham, Lewis Ponds, Tumut and Caleula, but only Leadville and Lewis Ponds were of any importance. The following extracts are taken from B.M.R. Summary Report No. 31, "Sulphur" (Dimmick, 1948):—

> "*Leadville* (Willan, 1925), which is situated 40 miles north of Mudgee, has produced lead, silver and pyrite. The orebodies were formed about the contact of quartz porphyry with pre-Devonian sedimentary rocks. In 1928 the ore reserves of the main lode of the Mount Stewart Mine were estimated

to be 60,000 tons, containing approximately 44% sulphur. Arsenic and bismuth were also present, but the material was considered to be suitable for acid manufacture. Production of pyrite was carried out intermittently until 1936, when the Mount Stewart Mine syndicate announced that because of the association of pyrite with zinc ore and the lack of a treatment plant, it was unable to carry on. A small quantity of pyrite was produced in 1937, when operations ceased.

"*Tottenham.*—Several pyritic orebodies in the vicinity of Tottenham, 78 miles north-west of Parkes, have been worked for copper. The ore mined in 1928 contained 2.5 to 3% copper and 37 to 38% sulphur. From 1924 to 1927 inclusive, 9072 tons of pyrite were produced for acid manufacture from the Mount Royal Mine (Andrews, 1928). There is no record of later production of pyrite.

"*Lewis Ponds.*—At Lewis Ponds, which is situated ten miles north-east of Orange, pyritic lodes were worked for copper and pyrite from 1914 to 1920, when production ceased; 53,000 tons of pyrite containing 38% of sulphur, together with gold, silver and lead, are said to have been produced (Andrews, 1928). According to the Annual Reports of the Mines Department, only 30,426 tons of pyrite were used for acid manufacture during this period."

Greta Coal Seam.—The upper portion (brassy tops) of the Greta Coal Seam—mined extensively in New South Wales—contains a considerable amount of marcasite that could be recovered as a by-product of coal mining. The Bureau has recently taken up, with the Joint Coal Board and an interested company, the question of the recovery and possible utilization of the marcasite.

TASMANIA.

Mount Lyell (Nye and Blake, 1938).—The Mount Lyell Mining and Railway Company's mines are situated near Queenstown, which is connected with Strahan by a company-owned railway 21.5 miles long. The orebodies of this field are of two types:

(a) The Mount Lyell and South Lyell orebodies were lenticular deposits of massive pyrite which were worked for copper, gold and silver, particularly during the period when pyritic smelting was conducted by the company. The Mount Lyell orebody, which cropped out, was worked by open-cutting to a depth of 350 feet, and below that depth by underground working. The South Lyell orebody did not crop out, but adjoined the Mount Lyell orebody at depth.

Work ceased on these orebodies in 1926, but 1,650,000 tons of pyrite ore remain, and production could be resumed if necessary. These reserves are estimated to contain 44 per cent sulphur, 0.5 per cent copper, and 1.5 oz. silver and 0.04 oz. gold per ton.

Prior to 1926 the Mount Lyell Mining and Railway Company despatched small quantities of pyrite obtained from these orebodies to Melbourne for the manufacture of sulphuric acid.

The pyrite obtainable from the copper orebodies now being worked is discussed under "Pyrite Concentrates from Mixed Sulphide Orebodies," page 40.

(b) In addition to the pyrite in the Mount Lyell and South Lyell bodies and to the pyrite concentrates obtainable from the copper orebodies now being worked, much pyrite exists in other orebodies and in mineralized zones—in the Mount Lyell and the adjacent Jukes-Darwin fields—not regarded at present as copper orebodies. The reserves and pyrite content have not been determined, but the quantity is considerable, and the pyrite content would probably be at least equal to that of the main copper orebodies, namely 7 per cent.

Renison Bell.—In this field, situated 79 miles south of Burnie, occur numerous small orebodies of pyrrhotite, pyrite and marcasite which have been, and are being, worked for their tin content. The orebodies are fissure lodes and "floors" (flat, lens-shaped bodies), which extend from the fissures along the bedding planes of the country-rock. Reserves (measured, indicated and inferred ore) amount to 1,000,000 tons with average sulphur content of 35 per cent. The low sulphur content of the pyrrhotite places the ore at a disadvantage as a source of sulphur compared with pyrite, which is readily available elsewhere. A pyrrhotite "concentrate," actually the cleanings from tin concentrate, is allowed to run to waste. It might be saleable if it were not for the possibility of spontaneous combustion. Dimmick (1948) states that spontaneous combustion occurred at Burnie in one shipment.

Chester.—The following extract is taken from B.M.R. Summary Report No. 31, "Sulphur" (Dimmick, 1948):—

> "The Chester Mine is situated 68 miles south-south-west of Burnie, on the Emu Bay Railway. Pyrite occurs in a gangue of pyrophyllite and quartz. The orebodies are lenticular, and are parallel to the schistosity of the country rock, which dips at 60 to 65 degrees to the south-east. The Mount Lyell Mining and Railway Company in the past worked the deposit by open cut and produced pyrite for acid manufacture. During the period 1909 to 1913 inclusive 36,964 tons of pyrite, with an average sulphur content of 37.2% were produced. High grade pyrite occurs in lenses from 1 to 5 feet thick. The reserves in 1918 were estimated at 2,800,000 tons, with an average sulphur content of 20% (McIntosh Reid, 1918)."

Zeehan.—Pyrite for acid manufacture has been produced from the Oonah, Kynance, Susanite, Queen, Mount Zeehan, Zeehan Queen, South Comstock and other mines, none of which is now operating. The orebodies were not large, and the reserves are not known, but are small.

SOUTH AUSTRALIA.

Nairne.—The Gibraltar pyrite deposit is 3½ miles north of Nairne—22 miles from Adelaide, on the main railway to Melbourne. The deposit was formed by selective replacement of pre-Cambrian quartzite; pyrite occurs in seams up to ½ inch thick and in fine dissemination through the rest of the rock. The outcrop is on the eastern side of a ridge about 400 feet high, and can be traced for about three miles; the lode dips east at 50° to 70°.

In 1917 the South Australian Mines Department drilled two diamond drill holes in the vicinity of an old adit and intersected the pyritic lode, 320 feet horizontal width averaging 7.8 per cent sulphur—the eastern 160 feet averaged 10 per cent sulphur (S.A.M.D., 1918).

A few years ago the Mines Department estimated that in a portion of the deposit 6000 feet long there were 50,000,000 tons of pyritic rock above creek level, that every 100-foot extension in depth would include 20,000,000 tons, and that further extensions in length would add at least 50,000,000 tons. The average pyritic content was taken as 16 per cent.

Between May and September, 1950, Enterprise Exploration Co. Pty. Ltd. drilled six diamond drill holes. These show that the higher grade eastern portion consists of two bands with a narrow band of lower grade material between. By taking these results in conjunction with the two Mines Department drill holes, it was estimated by the company that over the length tested—3000 feet—there are 9,500,000 tons of pyritic ore (averaging 10.5 per cent sulphur) which could be mined cheaply by open-cut methods. This amount is equivalent to 1,000,000 tons of sulphur, without considering extensions in depth or in length beyond the 3000 feet tested. Much larger tonnages of lower grade material also occur.

Enterprise Exploration Co. Pty. Ltd. recently relinquished its mining rights at Gibraltar, which will be exploited by the South Australian Government in association with Broken Hill Pty. Ltd. and the three superphosphate companies operating in South Australia.

WESTERN AUSTRALIA.

Norseman.—Norseman township is 109 miles south of Coolgardie and 460 miles by rail from Perth. The Iron King Mine, three miles from the town, is operated exclusively for pyrite by Norseman Gold Mines N.L. Intermittent mining for gold has been carried on in the oxidized zone of the Iron King Mine. In 1943, with the approval of the Commonwealth Government, the company began mining pyrite for making acid. The Western Australian State Government assisted by setting a very low rail freight for the transport of pyrite.

The ore contains only a minute quantity of gold, and the sale price of the concentrate and crushed ore has to cover the whole of the mining and treatment cost. The best grade ore is crushed and supplied for burning in a Herreshoff roaster. The remainder is finely ground and a concentrate is floated. The concentration is done in a mill designed for the treatment of gold ore, and the large amount of fine pyrite causes considerable dust nuisance in the acid plants which were designed to burn brimstone. This could be avoided by having efficient dust-collecting apparatus at the acid works, or by adopting a method of concentration that does not necessitate fine grinding. The company has planned to adopt heavy-media separation to make a preliminary coarse concentrate—containing 36 per cent sulphur—which will be re-treated in the present flotation mill modified to avoid excessive grinding of the pyrite.

Production figures in Table 14 have been supplied by the company.

TABLE 14

NORSEMAN GOLD MINES N.L.: IRON KING MINE
PRODUCTION OF PYRITE AND CONCENTRATE (1943-1950).

Year Ended 31st October	Ore Treated by Flotation		Concentrate Produced		Selected Crushed Ore	
	Tons	Sulphur Per cent	Tons	Sulphur Per cent	Tons	Sulphur Per cent
1943	2,000	30.0	702	44.5	8,403	37.6
1944	28,171	28.6	11,934	47.5	7,051	36.1
1945	53,613	25.2	24,609	47.1	9,134	34.3
1946	67,458	22.0	26,744	45.8	7,172	30.4
1947	76,371	24.4	32,808	46.6	8,415	34.06
1948	49,867	25.4	23,249	46.9	14,123	35.1
1949	35,847	25.6	17,206	46.6	12,158	34.6
1950	48,750	25.9	24,435	46.2	12,464	35.5
TOTAL	362,077		161,687		78,920	

After some initial difficulties, recovery of pyrite by flotation has been 82.5 to 84 per cent.

The orebody originally worked has been nearly exhausted above the No. 5 level (360 feet horizon), but a much larger orebody has been discovered and developed farther north, and to the east of the other orebody. Ore reserves (measured and indicated) were estimated by the Western Australian Government Geologist at 31st October, 1948, as 735,000 tons, containing about 25 per cent sulphur. A company estimate of ore reserves as at the 7th November, 1950, was 1,073,000 tons of proved and probable ore containing not less than 25 per cent sulphur. Diamond drill holes have intersected the lode 200 feet below the No. 5 level, and it appears that possible ore reserves are several million tons, and may be greater.

Yilgarn Goldfield.—In the Southern Cross district there are numerous ironstone outcrops, several of which are pyritic below the oxidized zone. The two most important are the Great Victoria lode at Nevoria and the Mount Caudan lode at Parker's Range. Information on their possibilities as a source of sulphur is limited, but indicates that they may have some importance. The total sulphur content of the sulphide deposits in the Southern Cross district cannot be estimated, but is considerable.

(a) *Great Victoria.*—The Great Victoria lode was worked for its gold content to about 100 feet below outcrop, and has been partly developed to a depth of 283 feet. A winze extends 40 feet below that horizon.

The oxidized zone extended to the 283 feet horizon. Sulphide ore from the winze was reported by the late Dr. Simpson to be mainly marcasite, but sulphide ore from a Western Australian Mines Department borehole is reported to be mostly pyrrhotite with some pyrite. This borehole was the only one to intersect the lode below the oxidized zone, the intersection being from 417 feet to 588 feet in the drill hole, representing a true width of 110 feet containing 70 feet of solid sulphide ore. The average sulphur content was 26.21 per cent and the average gold content 3.31 dwt. per ton. It is therefore possible that this lode could be worked for its sulphur content and that enough gold would be recovered to pay mining expenses, but extensive drilling and exploration would be necessary to prove ore reserves and to determine the sulphur content, the minerals in which the sulphur occurs and the possibility of concentration to a higher grade.

(b) *Mount Caudan* (Blatchford, 1915). The Mount Caudan lode crops out as a prominent ridge about 1½ miles west of Parker's Range. At the surface the lode extends for almost two miles. The exact width of the lode is not known, but it is 200 feet at the widest part and decreases towards the ends. The outcrop consists of goethite with boulders of psilomelane, and carries a little gold.

The lode was tested by two diamond drill holes. The first, five chains from the outcrop and inclined at 60°, cut 66 ft. of solid ironstone. The second, a vertical hole eight chains from the outcrop, cut 70 feet (estimated true width) of iron sulphide and magnetite between 603 feet and 707 feet. The sulphide was mostly pyrrhotite—a bulk sample assaying 28.89 per cent sulphur and 41.14 per cent iron, with only a trace of gold.

Mount MacMahon (Montgomery, 1914) is a small hill on the end of a spur of the Ravensthorpe Range. Rocks consist of chlorite schist and ferruginous quartzite. There is a large gossan outcrop, mainly hematite and limonite.

A report by the then State Mining Engineer (Montgomery, 1914) states that the Philips River Gold and Copper Company bore was drilled 490 feet in a direction N.80°E. with a dip of 45°. From 170 to 338 feet it intersected massive pyrite. The bore was drilled to prospect for copper ore, and the sections from which the highest sulphur content could be expected were not assayed for sulphur. Two parts of the core tested for sulphur and iron assayed 35.91 per cent and 30.70 per cent sulphur, and 44.37 per cent and 45.6 per cent iron, respectively.

In 1915 a Western Australian Mines Department bore was drilled 66 feet south of the company's bore and dipping at 30°. A length of 290 feet was attained, all in oxidized ground, except for 10 feet of pyrite. Another bore, 100 feet north of the company's bore and 100 feet nearer the outcrop, reached a length of only 42 feet at a dip of 45°, and was then abandoned.

Eulaminna and Murrin Murrin.—Eulaminna is situated on the Laverton railway, 538 miles from Perth, and Murrin Murrin is on the same railway and about 25 miles further from Perth. The following extract is taken from B.M.R. Summary Report, No. 31 (Dimmick, 1948) :—

> "From two mines, one at Eulaminna and the other at Murrin Murrin situated in the Mount Margaret goldfield, 74,047 tons of pyritic ore, valued at £45,496, were produced between the years 1911 and 1922, by far the greater production coming from Eulaminna.
>
> "The mine at Eulaminna has been opened up by two groups of workings to a maximum depth of 388 feet. Most of the ore has been obtained from the southern workings, in which an orebody reported to have a length of 300 feet and an average width of about 10 feet has been stoped from the 300 feet level to the surface. At the 250 feet level the orebody consisted mainly of pyrite, but also contained 1 to 10% of copper occurring as chalcocite. The orebodies in the northern workings are smaller than those in the southern workings, and appear to have yielded less ore.
>
> "No information about the mine at Murrin Murrin is available.
>
> "This pyritic ore was used by Cuming Smith and Mount Lyell Farmers' Fertilizers Ltd. for the manufacture of sulphuric acid, and typical parcels contained from 36 to 39% of sulphur and 1.36 to 3.49% of copper. Both mines were first worked for copper, but below the zone of enrichment the ore consisted mainly of pyrite with only small quantities of copper."

Western Australian Mines Department statistics show that 61,688 tons of pyrite, containing 20,136 tons of sulphur, were produced at Eulaminna, and 12,359 tons of pyrite, containing 3784 tons of sulphur, at Murrin Murrin.

Reserves of ore at the two mines are probably small.

Kalgoorlie Goldfield.

(a) *Kalgoorlie.*—Gold ore of the Kalgoorlie mines contains about 3 per cent sulphur in the form of pyrite. The mines at the southern end of the area (Golden Mile) make annually 105,000 tons of pyrite concentrates, containing 36,000 tons of sulphur, and roast them to atmosphere in the course of gold extraction. This releases large quantities of sulphur dioxide—sufficient, in fact, to make all the sulphuric acid required in Western Australia.

The amount of sulphur dioxide in the roaster gas is low, 2½ to 3 per cent—5 to 11 per cent is needed for economical acid-making—and it has been found, both experimentally and in plant operation, that any substantial rise above this figure requires an increased roasting temperature which seriously lowers gold extraction. Any idea of making acid at Kalgoorlie is eliminated by the very high rail freight to the superphosphate works where it would be used.

The only remaining possibility is that the pyrite concentrates be transported to a central roasting plant near the superphosphate works and an acid plant be built to use low-grade roaster gas. This is technically possible, but is not likely to eventuate because the attitude of gold-mining companies at present roasting pyrite is that, if they were prepared to spend the large sum of money necessary, they could put it to more profitable use at their own mines.

Table 15 shows relevant data for Kalgoorlie mines making pyrite concentrates.

TABLE 15

GOLD MINING COMPANIES PRODUCING PYRITE CONCENTRATES AT KALGOORLIE, W.A.

	Published Ore Reserves Long Tons (1949)	Annual Mill Capacity (Long Tons)		% Sulphur in Mill Feed	Sulphur Mined Annually in Ore Long Tons	% Sulphur in Raw Concentrates	% Sulphur in Roasted Concentrates	Concentrates Produced Annually Long Tons	Sulphur Discharged in Roaster Gas Annually Long Tons	% SO_2 in Roaster Gas	Volume of Flue Gas c.f.p.m. at N.T.P.
		Present Throughput	Installed or Proposed								
Lake View and Star Ltd.	3,657,000	520,000	640,000	3.2	16,600	35	1.8	44,000	14,500	2.1	53,000
Great Boulder Pty. G.M. Ltd.	2,115,000	350,000	350,000	3.0	10,500	37	3.1	23,000	7,800	2.5	18,000
Gold Mines of Kalgoorlie Ltd.	505,000	160,000	160,000	2.1	3,300	41	1.0	8,600	3,500	2.0	10,000
Boulder Perseverance Ltd.	387,000										
		Kalgurli Ore Treatment Company Ltd.									
Kalgoorlie Enterprise Mines Ltd.	278,000	340,000	360,000	2.8	9,500	37.5	1.0	9,400	3,500	2.0	13,000
North Kalgurli (1912) Ltd.	2,133,000*	Croesus Proprietary Treatment Company Ltd.									
		270,000	270,000	2.9	7,800	35	0.6	13,600	4,800	3.0	12,000
South Kalgurli Consolidated Ltd.	353,000										
Paringa Mining & Exploration Ltd.	88,000	80,000	100,000	3.1	2,500	36	0.7	7,200	2,600	2.5	9,000
TOTALS		1,720,000			50,200	36.2	1.7	105,800	36,700		115,000

*North Kalgurli (1912) Ltd. sends ore to both Kalgurli Ore Treatment Coy. Ltd. and Croesus Pty. Treatment Coy. Ltd.

(b) *Mount Charlotte.*—This mine, situated alongside the business centre of Kalgoorlie, has a large orebody containing 3.56 dwt. of gold per ton. Data supplied by Wiluna Gold Mines Ltd., which had an option over the mine until the end of 1950, show that the sulphur content of the ore is about 3 per cent, and that concentration and roasting of the pyrite is not necessary for good extraction of gold. A pyrite concentrate could therefore be recovered from the residue after gold recovery. If the mine were worked it would be on a large scale, and it is estimated that 25,000 to 50,000 tons of pyrite concentrate having a sulphur content of 46 per cent could be recovered annually. It has recently been announced that the option has been abandoned.

Big Bell.—Big Bell Mines Ltd. is working a large low-grade gold mine, fourteen miles from Cue. The sulphur content of the ore is increasing with depth. It was 2.2 per cent on the 433 feet level and is 4 per cent on the 1000 feet level. About one-sixth of the sulphur is contained in pyrrhotite and the rest in pyrite, with a little arsenopyrite and stibnite. In 1948 the company planned to make pyrite concentrate and roast it at an acid works as a means of improving gold recovery, but other small improvements to the process in use produced the same result. The amount and grade of concentrate consistent with maximum gold recovery was estimated to be 11,800 tons—containing 39 per cent sulphur—which could be increased to 15,400 tons of the same grade if throughput of ore were increased by adding closed circuit crushing to the present process.

Hill 50.—This gold mine is situated at Boogardie, two miles from Mount Magnet. The orebody is siliceous, but contains 5.1 per cent sulphur, mostly in pyrrhotite, the calculated mineral analysis of the ore being pyrite 2.6 per cent and pyrrhotite 9.8 per cent. Tests showed that 85 per cent of the sulphur in the ore could be recovered in a concentrate assaying 30 per cent sulphur, but only 60 per cent could be recovered in a concentrate assaying 33 per cent sulphur. The concentrate would therefore be too low in sulphur to be economically suitable for transport to an acid works.

PAPUA-NEW GUINEA.

Laloki.—The following extract is taken from B.M.R. Summary Report No. 31 (Dimmick, 1948) :—

> "Heavily pyritic orebodies on the Astrolabe Mineral Field, near Port Moresby, have been mined for the recovery of copper and gold. The principal ore reserves exist in the Laloki Mine, which is situated nineteen miles by road from Port Moresby in an east-south-easterly direction. The orebody is a large irregular lens of massive sulphide with the following maximum known dimensions: Length 450 feet, width 90 feet, depth 160 feet. The proved ore is estimated at 265,000 tons, assaying approximately 40 per cent sulphur, 37.5 per cent iron, 4.5 per cent copper, and 4 dwt. gold per ton. Of this some 60,000 tons could be mined by open cut.

Smaller bodies of sulphide ore are known to exist in the Moresby King-Sapphire Mine, two miles north of Laloki, and in the Dubuna Mine, three miles south-east of Laloki. The oxidized portions of the Moresby King-Sapphire Mine were worked prior to December 1941, for their gold content, but the Dubuna Mine has not been worked since 1925, and is now collapsed."

PYRITE CONCENTRATE FROM MIXED SULPHIDE OREBODIES.

Large orebodies of mixed sulphides containing pyrite are being mined and treated in Queensland, New South Wales, and Tasmania. At Mount Morgan in Queensland, and at Mount Lyell in Tasmania, orebodies are being mined for their copper-gold and copper contents, respectively, but they contain a considerable amount of pyrite. At Mount Isa in Queensland, Captain's Flat in New South Wales, and Read-Rosebery in Tasmania, orebodies are being mined for their lead, zinc and silver contents, but they also contain considerable amounts of pyrite.

Pyrite concentrates are recovered at Mount Lyell and Captain's Flat, and, to a small extent, at Mount Morgan. The possibilities of recovery at these and other mines are discussed below.

In addition to giving the published reserves of ore and their pyrite content, an attempt has been made to give the actual amounts of pyritic concentrates that are, or would be, obtainable by normal methods of treatment (ore-dressing) after the other valuable minerals had been removed as concentrates. Some of the pyrite, etc., would enter the concentrates of the other metals or minerals, and some would remain in the residues after the pyritic minerals were removed. For some orebodies, therefore, the actual recoverable amounts of pyrite are much less than the reserves.

The figures represent the recoverable amounts of pyritic concentrates, but it does not follow that all the recoverable pyritic minerals will be used to make sulphuric acid. A considerable proportion of the pyritic concentrates obtainable from some treatment plants, e.g., Mount Isa, Captain's Flat and Mt. Lyell, would be too fine in grain for use in existing sulphuric acid plants. The fine pyritic concentrates might be used if supplementary plant were added to the existing acid plants, but this has not yet been done at any plant operating commercially in Australia. The fine concentrates are not included in the figures of reserves given, except for Mount Morgan.

QUEENSLAND.

Mount Isa.—(See also "Pyrite and Pyrrhotite Orebodies," page 24; "Zinc Concentrates from Mixed Sulphide Orebodies," page 42; "Lead Concentrates from Mixed Sulphide Orebodies," page 46.) The field contains lead-zinc orebodies in which the main sulphides are pyrite, sphalerite and galena. The reserves of lead-zinc sulphide ore at 30th June, 1950, were 9,169,698 tons, containing 1,110,000 tons of pyrite and 250,000 tons of pyrrhotite, the pyrite content of the ore being 12 per cent and the pyrrhotite content 2.7 per cent.

The ore is very complex, the sulphide minerals having been replaced and intergrown to an extraordinary degree, and, although milling methods are very efficient and grinding is carried to an extreme degree of fineness, the recovery of zinc in the year ended 30th June, 1950, was only 55.6 per cent, and recovery of lead 84.7 per cent. The lead concentrate contains large amounts of sphalerite, pyrite and pyrrhotite. The recovery of lead had improved considerably since 1948, when it was only 73.2 per cent.

Sulphide ore treated in the year ended 30th June, 1948 (a typical year), was 558,460 tons, containing 76,914 tons of sulphur, the amounts of mill products and distribution of sulphur among them being as follows:—

Lead concentrate—82,308 tons, containing 20,539 tons sulphur.
Zinc concentrate—45,702 tons, containing 14,158 tons sulphur.
Tailing—430,450 tons, containing 42,227 tons sulphur.

Much of the pyrite enters the lead, and to a less extent the zinc, concentrate. Of the 69,000 tons of pyrite and 14,800 tons of pyrrhotite in the ore (558,400 tons), only 52,000 tons of pyrite and 8000 tons of pyrrhotite are left in the tailings, i.e., about 71.8 per cent of the total pyrite and pyrrhotite. It is estimated by the company that 50 per cent of the pyrite and pyrrhotite in the tailings (or about 35 per cent of that in the ore) might be recoverable as a pyritic concentrate, but this would contain much very fine pyrite at present unacceptable to manufacturers of acid. It is possible also that the content of lead and zinc might render it unsuitable for use in the manufacture of sulphuric acid.

The recovery of a pyritic concentrate has not been undertaken, and is not contemplated, by the company. However, the company has considered the making of a scavenger concentrate before sending the tailing underground for mine-filling. It is estimated that 40 per cent of the pyrite in the tailing could be recovered in the concentrate, and the lead and zinc recovered from the concentrate in a fuming plant. This would release about 15,000 tons of sulphur in the form of sulphur dioxide, which might be used for sulphuric acid manufacture if a market were available and if the possible presence of lead in the acid were not objectionable. Alternatively, the fuming could be done in conjunction with an existing acid works, but the complications necessary to recover lead and zinc oxide would make this unattractive to manufacturers of acid.

The lead concentrate is sintered (roasted) and smelted at Mount Isa, and the sulphur-dioxide gas passes to air and is wasted. The zinc concentrate is roasted at oversea zinc works and the sulphur dioxide is believed to be used in the manufacture of sulphuric acid, but this does not benefit Australia.

At Mount Isa there are also copper sulphide orebodies containing pyrite and pyrrhotite. In 1943, because of the shortage of copper in Australia, the company transferred its attention to copper production and mined a copper orebody at depth and adjacent to the Black Star lead-zinc orebody, but in 1946 copper production was suspended and mining of the lead-zinc orebodies was resumed. A new concentrator and smelter for copper ore are being erected, and copper production will be resumed when they are completed.

Reserves of sulphide copper ore at 30th June, 1950, were 2,951,664 tons, assaying 4.1 per cent copper, and containing 340,000 tons of chalcopyrite, 160,000 tons of pyrite, and 99,000 tons of pyrrhotite. As copper is the only valuable metal present in commercial quantity in this orebody, the ore, although ground very fine by ordinary standards, does not have to be ground as fine as the lead-zinc ore.

It is proposed to treat 400,000 tons of copper ore, and produce 18,000 tons of copper, annually. Copper concentrate will be roasted to reduce the sulphur content prior to smelting in a reverberatory furnace. The roaster gas will contain annually the equivalent of about 5000 tons of sulphur in a form suitable for manufacture of sulphuric acid because of its richness in sulphur dioxide. The remainder of the sulphur present will eventually form sulphur dioxide in the converters, but their intermittent cycle of working makes the use of the gas uneconomic for making acid.

From the copper concentrator tailing 7800 tons of pyritic concentrate, assaying 50 per cent sulphur, could readily be produced annually. The high cost of freight to acid works could prohibit its use for this purpose.

Dugald River.—At this locality, 35 miles north-west of Cloncurry, a zone of mineralization extends over a length of 8000 feet. A limited amount of testing by costeaning and diamond drilling by the Enterprise Exploration Co. Pty. Ltd. indicated the existence of two shoots, Main and Northern, the Main shoot being 1130 feet and the Northern shoot 670 feet long.

The dimensions of the Main shoot at the surface indicate about 3000 tons of ore per vertical foot. The dimensions of the Northern shoot at the surface indicate about 1000 tons per vertical foot. The sulphide ore (water level is at about 110 feet) includes the following minerals in the proportions shown:—Sphalerite, 25 per cent; pyrrhotite, 20 per cent; pyrite, 15 per cent; and galena, 3 per cent.

The orebodies will probably not be worked for a long time to come. If they were worked, a pyrite concentrate could be produced, but the distance it would have to be transported would make its cost at an acid plant too high. Reserves that would be recoverable from zinc concentrate are given on page 42.

Mount Morgan.—The Mount Morgan Mine is 32 miles by rail south-west of Rockhampton. The orebody was very rich in gold in the oxidized zone, where it was worked by open-cut. The sulphide ore, consisting of quartz and pyrite, with some chalcopyrite and gold, was worked by the old company by filled square set stopes, but the present company, Mount Morgan Ltd., has used only large-scale open-cut methods to mine the parts of the sulphide orebody left by the old company. The methods used necessitate removal of large quantities of overburden, some of which contains enough gold to be worth treating. For this reason the average grade of material treated is usually much below that of the declared ore reserves.

In the year ended 24th June, 1950, 2,048,806 wet tons of material were dug, of which 885,804 wet tons were delivered to the mills for treatment and 7928 tons for direct smelting, the rest being dumped. The sources of the material treated in the mills for the same period were as shown below (all in dry tons):—

Sulphide ore	349,687 tons
Low-grade ore	304,794 tons
Treatable overburden	101,821 tons
Old stope-filling	81,493 tons
Total	837,795 tons

There are two mills; No. 1 treats the sulphide ore and some other material, and No. 2 is run when suitable material is available—for the financial years 1949 and 1950 it was run continuously. The combined capacity of the two mills is 2900 tons daily, or about 1,000,000 tons annually.

Ore reserves as at 25th June, 1950, are declared by the company as follow:—

	Tons	Copper per cent	Gold dwt./ton
Sulphide ore	4,830,200	2.01	3.97
Low-grade ore	2,650,600	0.50	1.36
Total	7,480,800	1.34	3.05

Since the 25th June, 1950, it has been announced that diamond drilling in the Sugarloaf area, adjacent to the mine workings, has disclosed a low-grade orebody containing at least 10,000 tons of ore—possibly 25,000,000 tons.

The sulphide ore contains about 40 per cent and the low-grade ore about 25 per cent pyrite. The sulphur content of the current mill residues is about 12 per cent, and may be 15 per cent. At the present mill capacity, assuming a pyrite recovery of 75 per cent, the potential capacity of pyrite concentrate from current mill tailings is 180,000 tons annually, assuming that the whole of the pyrite would be acceptable to manufacturers of acid. If the pyrite were to be used in existing acid plants, the finest sizes would have to be discarded or dust-catching methods at the plants improved.

Large amounts of pyrite also occur in the mill-tailing dumps, which have accumulated since 1929. The older dump—about 4,000,000 tons—contains a large quantity of semi-oxidized material, and the company has not enough data to estimate its pyrite content. The other dump—about 4,500,000 tons—is estimated to contain about 25 per cent of pyrite, that is, about 1,125,000 tons. The pyrite in both dumps is subject to deterioration by weathering.

The company estimated in 1948 and confirmed in 1950 that, if the requisite machinery and buildings were immediately obtainable, a plant with an output of 45,000 tons of pyrite a year could be erected within six months and could be expanded in stages as demand arose. By giving up the treatment of low-grade ore and overburden, no new plant or buildings would be necessary, and about 120,000 tons of pyrite could be produced annually. These figures are based on the assumption that no discarding of fine pyrite would be necessary.

Table 16 shows the only pyrite production from Mount Morgan. This is from a small pilot plant with daily production capacity of 20 tons of pyrite.

TABLE 16

PRODUCTION OF PYRITE CONCENTRATE—MOUNT MORGAN.

Year Ended	Pyrite Tons	Sulphur Per cent	Gold dwt./ton	Copper Per cent
27/6/48	5,565	48.48		
26/6/49	790	48,27		
24/6/50	8,875	48.5	1.9	0.147
TOTAL	15,230			

Towards the end of the financial year ended 24th June, 1950, the company installed another bank of twelve flotation cells in the pyrite concentrate section. These should result in a large increase in production of pyrite concentrate provided the concentrate can be economically transported to market. Production has so far been limited by demand.

The use of Mount Morgan pyrite is restricted by various difficulties:—

(a) The geographical location, near the central part of the Queensland coast, would not be a serious obstacle if good transport were available, but it necessitates transport over long distances to market, and therefore high transport costs.

(b) Land and sea transport present difficulties.

The 32-mile railway from Rockhampton to Mount Morgan includes 1 mile 36 chains of Abt rack railway, on which the gross load going toward Rockhampton is 100 tons. This stretch would have to be relocated and regraded to take ordinary trains if a large quantity of pyrite were to be handled. The alternative, road transport, is equally difficult, as the road is narrow and has sharp curves and gradients of 1 in 14. The road would have to be widened and straightened and gradients eased if it were to be used for large-scale transport.

The port of Rockhampton is shallow, and could not accommodate ships to load more than 2000 to 3000 tons of pyrite. Loading facilities are not adequate for rapid and cheap loading of pyrite. The alternative ports are Gladstone and Port Alma, each of which can take large ships, but the use of either port would necessitate a considerably longer road or rail haul, and therefore a larger number of motor trucks or railway rolling stock. Loading facilities would also have to be improved.

(c) The pyrite concentrate contains about 1.8 dwt. of gold per ton, of which the company has estimated that two-thirds could be extracted by cyanidation after flash-roasting. At the present price of gold this recoverable gold would be worth 18/6d. and, after allowing for treatment costs and amortisation of the capital cost of one or more cyanide plants, the gold content represents a large potential profit that the company is reluctant to lose.

Apart from these considerations, the company feels that more profitable use could be made of the sulphur content of the ore than selling low-priced pyrite concentrate. The company has therefore done much research into the economics of using the sulphur content of the ore—including production of elemental sulphur by the Orkla process—and into the manufacture of ammonium sulphate.

The following extracts are taken from the Chairman's address to shareholders on the 26th October, 1950:—

> "It is clear that elemental sulphur is a much more readily marketable commodity than pyrite, and therefore careful consideration is being given also to the production of elemental sulphur from the Mount Morgan ore.
>
> "As advised previously, Mr. H. R. Potts, formerly chief metallurgist for the Rio Tinto Company, visited the mine and furnished a report on the possibilities of using the Orkla process. Following this, Mr. J. Malcolm Newman visited Europe and the North American continent. Consultations were had with Mr. Stanley Robson, a world authority on sulphuric acid, as well as with others whose views were most helpful. Visits were paid to a number of plants, and particularly the works of the Orkla Company in Norway and the Noranda Mine in Canada.
>
> "It has been suggested that a considerable tonnage of our pyrite may be recovered for making sulphuric acid to be used in manufacturing ammonium sulphate in Central Queensland for the Queensland sugar industry. The Queensland Government is awaiting the reports of American and English experts who have been in Queensland investigating the problem."

No announcement has been made about the results of the Orkla process investigation.

The amount of ammonium sulphate suggested—50,000 tons annually—would need 25,000 tons of pyrite concentrate if made by the process indicated. This would still leave a large amount of pyrite available for other uses. If the process used at Trail, B.C., by the Consolidated Mining and Smelting Co. of Canada Ltd. (Kirkpatrick, 1949) were adopted, 75,000 tons of pyrite concentrate would be used to produce 50,000 tons of ammonium sulphate, but two-thirds of the sulphur content of the pyrite would be recovered in the form of concentrated (100 per cent) sulphur-dioxide gas suitable for recovery of by-product brimstone by passing the gas through incandescent coke. As recovery by this method is high, provided correct conditions are maintained, about 24,000 tons of brimstone could be recovered annually.

NEW SOUTH WALES.

Captain's Flat.—Lake George Mines Pty. Ltd. works a group of leases at Captain's Flat, 30 miles from Canberra. Pyrite, accompanied by a little copper, occurs extensively in the leases, being most common in the most intensely sheared rocks, and extending beyond them in small quantities for some hundreds of feet. In the most intensely sheared rocks there are also lead and zinc, which in several places occur in sufficient quantity to form payable lodes. (See also "Zinc Concentrates from Mixed Sulphide Orebodies," page 44; "Lead Concentrates from Mixed Sulphide Orebodies," page 47.) Four of these lodes—forming a line which is worked by Lake George Mines Pty. Ltd.—are, from north to south, Elliott's, Central North, Central and Keating's. At the bottom working level (1230 feet horizon) Central North lode has joined Elliott's, Central lode has cut out, and Keating's lode is considerably shorter than it was on the higher levels. A lower level (1390 feet horizon) is now being driven.

Only the footwall portion of these lodes is mined, the ore containing approximately 6 per cent galena, 14 per cent sphalerite, 1.8 per cent chalcopyrite, and 32 to 36 per cent pyrite, with quartz as the most abundant gangue mineral. The hangingwall portions of the lodes contain very small amounts of lead or zinc minerals, but large amounts of pyrite; the pyrite content is highest (up to 50 per cent) adjacent to the hangingwall of the lead-zinc stopes, and bands of pyritic material are present as far as 75 feet from the hangingwall of the stopes. Some of this hangingwall pyrite is mined with the lead-zinc ore from the open stopes in Keating's lode.

Lead-zinc ore reserves at 30th June, 1949, were 1,600,000 tons, including measured and indicated ore, with a small quantity inferred below the bottom working level. The Bureau of Mineral Resources has estimated that, taking an average of 40 per cent pyrite as desirable, Keating's and Elliott's lode could produce per vertical foot 1600 tons of extra pyritic ore from which 320 tons of pyrite concentrate could be produced. Mining the hangingwall portions of the lead-zinc lode would increase the difficulty and add to the cost of mining the lead-zinc ore and, at current pyrite prices, would be uneconomical. It would also have to be done in conjunction with current mining of the lead-zinc ore—to try to mine in the walls of worked stopes would be difficult and dangerous because movements have taken place.

There are also 500,000 tons of pyritic material of undetermined grade between the Central tunnel and No. 6 level. This could be mined for pyrite, but the mining would be expensive because the Central lode is narrow, and in this particular area low in lead and zinc.

The ore treated and the amount of pyrite concentrate obtained for the years 1940-50 are shown in Table 17, compiled from information supplied by the Lake George Mines Pty. Ltd.

TABLE 17

PRODUCTION OF ORE AND PYRITE CONCENTRATE AT CAPTAIN'S FLAT.

Year Ended 30th June	Ore Treated Tons	Pyrite Concentrate Tons
1940	164,675	5,267
1941	187,308	13,683
1942	185,708	26,453
1943	233,787	35,264
1944	232,899	34,193
1945	164,549	23,766
1946	135,244	29,850
1947	162,810	22,000
1948	142,265	16,260
1949	37,808	2,650
1950	141,317	20,244
TOTAL	1,788,370	229,630

Of the pyrite in the ore, about one-seventh goes into the copper, lead and zinc concentrates, about one-third into pyrite concentrate, and the remainder goes to waste—as slime before the pyrite concentrate is floated, and in the plant tailing. Australian Fertilizers Ltd. specify that pyrite supplied should contain not more than 25 per cent of particles smaller than 32 microns, because fine pyrite dust causes trouble in the acid chambers. If efficient dust-collecting apparatus were installed, the finer pyrite could be used and a larger quantity of pyrite concentrate supplied by the mine.

TABLE 18

SHIPMENTS OF PYRITE CONCENTRATE BY LAKE GEORGE MINES PTY. LTD.

Year Ended 30th June	Australian Fertilizers Ltd. Tons	Phosphate Co-operative Co. Pty. Ltd. Tons
1940	1,798	—
1941	14,514	28
1942	13,250	10,840
1943	12,857	20,817
1944	12,964	20,531
1945	8,946	19,782
1946	15,520	14,301
1947	17,512	800
1948	872	—
1949	5,025	—
1950	10,546	—
TOTAL	113,804	87,099

Pyrite concentrate has been sold to two companies—the Australian Fertilizers Ltd. at Port Kembla and Phosphate Co-operative Co. Pty. Ltd. at Geelong—in the quantities shown in Table 18. No pyrite has been supplied to the Phosphate Co-operative Co. since 1947, as the mine has not been able to supply the other company with all its needs.

TASMANIA.

Mount Lyell.—(For sulphur reserves in pyrite and pyrrhotite orebodies, see page 25.) The copper orebodies consist of disseminated sulphides (chalcopyrite and pyrite) in schist. The field contains numerous orebodies, several of which have been mined; those now being mined include West Lyell and Prince Lyell; and, on a smaller scale, Royal Tharsis, North Lyell and Crown Lyell. The West and Prince Lyell orebodies are being mined in the West Lyell open-cut. The ore reserves at 30th September, 1950, were 31,685,000 tons which, with an estimated pyrite content of 7 per cent, would contain 2,220,000 tons of pyrite. At an assumed recovery of 70 per cent, the total recoverable pyrite is about 1,550,000 tons, but, if the very fine material be excluded, only 1,330,000 tons. The ore is concentrated by flotation, and separate concentrates of chalcopyrite and pyrite are obtained. At present the pyrite concentrate recovered is about 55,000 tons per year, but part has to be stored because of lack of shipping. Production could be increased to 60,000 tons per year if extra ships were available to transport the stored and the additional concentrate to the mainland, and to 70,000 tons if the acid makers could use the finest pyrite economically.

TABLE 19

PRODUCTION AND CONSUMPTION OF MOUNT LYELL PYRITE CONCENTRATE (1940-1950).

Year Ended 30th Sept.	Ore Treated Tons	Pyrite Concentrate Production Tons	Pyrite Concentrate Consumption Year Ended 30th June		
			Yarraville Tons	Port Kembla Tons	Total Tons
1940	1,165,347	50,649	35,918	13,211	49,129
1941	1,290,200	46,151	28,858	726	29,584
1942	1,491,733	48,663	26,899	579	27,478
1943	1,531,343	45,393	31,549	168	31,717
1944	1,487,858	50,081	29,640	—	29,640
1945	1,477,862	55,325	35,938	6,754	42,692
1946	1,468,825	54,627	44,181	4,295	48,476
1947	1,462,461	51,524	32,582	3,152	35,734
1948	1,319,429	52,131	36,287	700*	37,000
1949	1,426,114	52,966	42,286	4,000*	46,300
1950	1,516,832	56,800	41,900	2,200*	44,100
TOTAL . .	15,638,004	564,310	386,038	35,800	411,800

*Shipments to Port Kembla.

Table 19 gives details, since 1940, of the ore treated, pyrite concentrate produced, and pyrite concentrate consumed, the figures being supplied by the companies concerned.

From 1940 to 1948 the production was regulated generally in accordance with requirements. In recent years, however, because of shipping shortage, it has not been possible to transport from Tasmania all the pyrite produced, and at 31st October, 1949, about 170,000 tons of pyrite concentrate were stored at the mine.

Another possible source of pyrite is the waste rock that has to be broken and discarded at the West Lyell open-cut in order to mine the copper ore. This waste rock contains 10.7 per cent pyrite, and the mining programme necessitates the removal of 750,000 tons of it annually. Allowing for the same recovery factors as for copper ore, 45,000 tons of pyrite concentrate could be recovered annually if the price of pyrite concentrate were sufficiently high to repay the cost of extra milling plant.

Read-Rosebery.—The Electrolytic Zinc Co. of Australasia Ltd. owns two mines on the west coast of Tasmania, 71 miles south of Burnie—the Rosebery Mine at Rosebery, and the Hercules Mine at Mount Read, five miles away. These are worked principally for their zinc content, but also produce lead and copper concentrates in smaller quantities. (See also "Zinc Concentrates from Mixed Sulphide Orebodies," page 45; "Lead Concentrates from Mixed Sulphide Orebodies," page 47.) The ore contains 30 per cent pyrite, most of which goes into the mill tailing (which assays 21 per cent sulphur), but could be collected into a pyrite concentrate if markets and transport were available.

The Company supplied the following estimate in 1948, and confirmed it early in 1950:—

> "About 82 per cent of the pyrite in the ore appears in the residue; of this, 50 per cent might be recoverable in a concentrate assaying 48 per cent sulphur. On this basis, the weight of pyrite in the concentrate would amount to $30 \times 0.82 \times 0.5 = 12.3$ per cent of the ore treated.
>
> (a) Current production of ore is about 160,000 tons per annum = 19,680 tons of pyrite.
>
> (b) Ore production when planned increase has been completed is expected to be about 240,000 tons per annum = 29,520 tons of pyrite."

Ore treated for the twelve months ended 30th June, 1950, was 150,583 tons, assaying 19.80 per cent zinc, 5.96 per cent lead, and 0.47 per cent copper.

Ore reserves at the same date were announced as "approximately 1,500,000 tons of average grade."

ZINC CONCENTRATE FROM MIXED SULPHIDE OREBODIES.

Large orebodies of mixed sulphides of lead, zinc, etc., are being mined at Mount Isa, Captain's Flat, Broken Hill and Read-Rosebery.

QUEENSLAND.

Mount Isa.—The orebodies and mineralized zones of this area contain large amounts of pyrite, and have been described above (pp. 32-34). (See also "Pyrite and Pyrrhotite Orebodies" at Mount Isa, page 24; "Lead Concentrates from Mixed Sulphide Orebodies," page 46.) The published figures for reserves of lead-zinc sulphide ore at 30th June, 1950, were 9,169,698 tons, having a zinc content of 7.4 per cent and a lead content of 8.8 per cent.

The zinc concentrate contains some galena, pyrite and pyrrhotite, and the sulphur content averages about 31.3 per cent. The production of zinc concentrate for the year ended 30th June, 1950, was 41,743 tons derived from 531,810 tons milled, but, as the mill was closed for 45 days on account of a strike of coal miners, the production of zinc concentrate was less than normal, which may be taken as 46,100 tons (average for 1947-1948 and 1948-1949 was 46,116 tons). From these figures, the sulphur content of the zinc concentrate produced annually is 14,400 tons, all of which is exported. The destination of Mount Isa zinc concentrate has varied from time to time, but in 1949 it is believed that most of it went to Belgium.

Dugald River.—The ore shoots in this deposit have been described on page 34.

The average assay of the sampling of the Main shoot by costeaning was 2.6 per cent lead, 2.6 per cent zinc, and 2.5 oz. silver per ton. Ten diamond drill holes tested the sulphide ore at vertical depths from 174 to 304 feet, the average assay being 2.2 per cent lead, 12.7 per cent zinc and 2.2 oz. silver per ton. In an eleventh diamond drill hole, which intersected the shoot at a maximum vertical depth of 564 feet, the lode material assayed only 0.2 per cent lead, 8.5 per cent zinc and 0.5 oz. silver per ton.

The average assay of the outcrop of the Northern shoot, sampled by costeaning, was 1.7 per cent lead, 2.4 per cent zinc and 2.1 oz. silver per ton.

The amount of lead in the orebodies is so low that they are not likely to be worked in the near future. If they were worked a zinc concentrate would also be produced, having a sulphur content equal to 6 per cent of the ore mined. On this basis, the ore shoots between the 100 feet and 500 feet horizons contain 112,000 tons of sulphur associated with zinc, and 96,000 tons would be recoverable in a zinc concentrate.

NEW SOUTH WALES.

Broken Hill.—The city of Broken Hill is 699 miles by rail west of Sydney and 256 miles by rail from Port Pirie, South Australia. The productive part of the mining field is immediately alongside the town, and is worked by four companies—North Broken Hill Ltd., Broken Hill South Ltd., Zinc Corporation Ltd., and New Broken Hill Consolidated Ltd.

The field is worked for lead, silver and zinc, but small quantities of copper, cadmium, antimony, cobalt and gold are also recovered. The field has been described by Andrews (1922—with appendix by Stillwell), Woodward (1940) and others. A very extensive bibliography is given in Woodward's paper.

In 1948, the Bureau of Mineral Resources and the New South Wales Mines Department estimated that the total reserves of ore (measured, indicated and inferred) in the principal Broken Hill mines are:—Lead lode, 53,000,000 tons, and zinc lode 5,000,000 tons. These estimates were based on an examination of all available data and discussion with technical officers of the various companies at Broken Hill. As some of the information supplied is confidential, detailed figures for individual mines cannot be given. It is estimated that these reserves, which are sufficient to sustain operations for 38 years, contain 5,065,000 tons of recoverable sulphur, of which 3,535,000 tons will be recovered in zinc concentrates, and 1,530,000 tons in lead concentrates.

From 1938 to 1948 the quantity of ore mined yearly at the principal mines at Broken Hill varied between 1,059,563 tons and 1,468,402 tons. The ore yields about 22.5 per cent zinc concentrates containing about 31.5 per cent sulphur.

With expansion of operations by Zinc Corporation Limited and New Broken Hill Consolidated Ltd. it is expected that production of zinc concentrates at Broken Hill will increase. The expected annual production of ore from 1949 onwards, and the estimated sulphur content of zinc concentrates expected to be obtained therefrom, are given in Table 20. The estimates for 1949 and 1950 were closely fulfilled.

TABLE 20

BROKEN HILL MINES—ESTIMATED PRODUCTION OF ORE AND SULPHUR CONTENT—1949 ONWARDS.

Year	Ore Tons	Estimated Sulphur Content of Zinc Concentrates Tons
1949	1,298,000	79,180
1950	1,373,000	83,750
1951	1,448,000	88,330
1952	1,503,000	91,680
1953	1,528,000	93,200
1954	1,555,000	94,850

From 1954 onwards production is expected to remain stationary.

The zinc concentrates produced at Broken Hill are railed to Port Pirie and are distributed to three sulphuric acid plants in South Australia, one in New South Wales, and one in Tasmania. The amounts of Broken Hill concentrates thus used in the manufacture of sulphuric acid since the 30th June, 1937, are given in Table 21.

TABLE 21

USAGE OF BROKEN HILL ZINC CONCENTRATES IN AUSTRALIA.

Year Ended 30th June	South Australia			N.S.W.	Tasmania	Total
	Birkenhead Tons	Wallaroo Tons	Port Pirie Tons	Cockle Creek Tons	Risdon Tons	Tons
1938	21,269	11,919	37,516	—	5,356	76,060
1939	22,478	14,366	33,510	1,610	1,310	73,274
1940	23,617	13,750	35,137	1,690	953	75,147
1941	24,025	15,246	34,611	6,570	—	80,452
1942	27,904	12,578	23,049	22,351	—	85,882
1943	24,007	7,240	17,902	20,343	—	69,492
1944	25,544	9,980	16,223	26,114	413	78,274
1945	26,027	14,096	31,019	31,423	2,593	105,158
1946	25,540	13,475	26,291	27,626	2,401	95,333
1947	27,571	13,381	31,740	29,971	4,363	107,026
1948	26,338	17,290	39,950	30,328	2,958*	116,864
1949	25,643	14,980	38,641	26,239	16,909*	122,412
TOTAL	299,963	158,301	365,589	224,265	37,256	1,085,374

*Calendar year.

The roasted concentrates (calcine) are sent to Risdon, Tasmania, for electrolytic extraction of the zinc; the remainder of the concentrates is exported. Exports of zinc concentrates in the year ended 30th June, 1949, were 101,740 tons of a total of 214,569 tons delivered to the seaboard.

Destination and usage of Broken Hill zinc concentrates may therefore be summarized thus: 47.5 per cent. was exported in 1948-49, the remainder being calcined in Australia. Very little of the sulphur content of the concentrates roasted on the mainland is wasted, but large amounts are wasted at Risdon in the form of "Risdon" concentrates, which originate in part from Broken Hill concentrates; this will all be utilized when the programme of building sulphuric acid plants at Risdon is complete.

Consolidated Zinc Corporation has announced that, by 1954, it will be treating 81,000 tons of zinc concentrate, producing 60,000 tons of acid, at Cockle Creek, N.S.W. In the meantime the company is investigating the possibility of increasing acid production at Cockle Creek, using pyrite as the raw material. (For information on lead concentrates see "Lead Concentrates from Mixed Sulphide Orebodies," page 47.)

Captain's Flat.—The orebodies in this locality have been described on page 38. (See page 47 for reserves in lead concentrate.) Production of zinc concentrate in the year ended 30th September, 1950, was 24,719 tons, assaying 33 per cent—the sulphur content was therefore 8200 tons.

The zinc concentrate is exported without roasting, and the sulphur content is therefore not used here.

TASMANIA.

Read-Rosebery.—The Read-Rosebery orebodies have been described on page 41. The ore treated contains 29.75 per cent of sphalerite; if the ore reserves are of similar grade, they contain 145,000 tons of sulphur associated with zinc minerals. Reserves of sulphur in lead minerals are given on page 47.

A zinc concentrate of tonnage equal to 30.8 per cent of the ore treated is obtained by selective flotation. Production of zinc concentrate in the year ended 30th June, 1950, was 46,299 tons, with an average sulphur assay of 33.1 per cent, that is, 15,300 tons of sulphur.

Before 1949 much of the zinc concentrate from Read-Rosebery was roasted to atmosphere at Zeehan—in 1948 20,946 tons were roasted at Zeehan and 16,485 tons at Risdon—but in 1948 the roasting works at Zeehan were closed, and all roasting is now done at Risdon.

Between 1937 and 1941 Read-Rosebery zinc concentrate was also shipped to Cockle Creek, where it was roasted by the Sulphide Corporation Ltd. and used for making acid.

The amount of Read-Rosebery zinc concentrate used since 1937 for making acid is shown in Table 22.

TABLE 22

ROSEBERY ZINC CONCENTRATE USED IN MANUFACTURE OF SULPHURIC ACID.

Year Ended 30th June	Where Used		Total
	Risdon Tons	Cockle Creek Tons	Tons
1938	6,614	22,448	29,062
1939	11,783	21,349	33,132
1940	10,641	20,017	30,658
1941	1,824	15,546	17,370
1942	6,320	—	6,320
1943	5,475	—	5,475
1944	9,610	—	9,610
1945	2,231	—	2,231
1946	3,480	—	3,480
1947	3,556	—	3,556
1947*	2,551	—	2,551
1948†	3,635	—	3,635
1949†	4,860	—	4,860
1950†	30,872	—	30,872
TOTAL	103,452	79,360	182,812

*Six months ended 31st December.

†Calendar year.

In addition, a large amount of "Risdon" concentrate has been roasted at Risdon each year since 1941 and used in part for making acid. "Risdon" concentrate is a product consisting of particles of zinc sulphide—derived from the Rosebery and Broken Hill concentrates—that have escaped oxidization and solution in the Risdon plant. It has not been possible to determine the amounts from Rosebery and Broken Hill respectively.

It is estimated that the sulphur content of Read-Rosebery and "Risdon" zinc concentrates roasted to air at Risdon, and therefore wasted, amounted in 1949 to 20,500 tons, from which 56,000 tons of acid could have been made. When the programme of building sulphuric acid plants at Risdon is complete, no concentrates will be roasted to air, but all sulphur in them will be used to make sulphuric acid or ammonium sulphate.

LEAD CONCENTRATE FROM MIXED SULPHIDE OREBODIES.

The mixed sulphide ores being mined at Mount Isa, Captain's Flat, Broken Hill and Read-Rosebery contain large quantities of galena; lead concentrate is the most important product of each of these mines except Read-Rosebery. The lead concentrates from Captain's Flat and Read-Rosebery are shipped unroasted, and smelted overseas; Mount Isa lead concentrate is smelted at Mount Isa, and Broken Hill lead concentrates are smelted and refined at Port Pirie.

Prior to smelting in the blast furnace, the sulphur content of the lead concentrates is reduced to a low percentage by sintering—a process in which the lead concentrates, mixed with fluxes, are burned to form a porous cake. Sulphur-dioxide gas is given off, and is at present discharged into the air at Mount Isa and Port Pirie. Under present arrangements the percentage of sulphur dioxide in these gases is rather low for making sulphuric acid, but alterations could be made so that the percentage of sulphur dioxide would be sufficiently high for this purpose.

In order to eliminate the nuisance caused by the discharge of sulphur dioxide to the air, the Broken Hill Associated Smelters Pty. Ltd. announced their intention of building extra acid plant in which the lead roaster gases would be used. The programme, announced in 1947, called for the completion of one quarter of the extra acid-making plant by 1950, but progress has been slow because of scarcity of materials, high costs and technical difficulties.

QUEENSLAND.

Mount Isa.—It has been estimated that, at Mount Isa, sulphur in recoverable galena above the 2000 feet level amounts to 80,000 tons and that sulphur in other sulphides in the lead concentrate will amount to a further 270,000 tons, all of which will be discharged to atmosphere under present arrangements. Sulphur content of gases discharged to atmosphere in 1949 was 28,300 tons. Sulphur reserves in pyrite and pyrrhotite orebodies are given on page 24, and reserves from pyrite and zinc concentrates from mixed sulphide orebodies on pages 32 and 42.

NEW SOUTH WALES.

Broken Hill.—The total ore reserves of 58,000,000 tons at Broken Hill contain 1,557,000 tons of sulphur in lead minerals. (For reserves in zinc minerals see page 42.) It was estimated that the sulphur content of the expected production of lead concentrates from Broken Hill during 1949-1954 would be 34,890 tons in 1949 and would increase to 42,000 tons in 1954. The sulphur content of gases from lead sintering and smelting in 1949 was estimated at 32,300 tons.

Captain's Flat. The declared ore reserves of 1,600,000 tons contain 16,000 tons of sulphur in lead minerals. (See pages 38 and 44 for reserves in pyrite and zinc concentrates.) Sulphur in recoverable galena in lead concentrate amounts to 13,000 tons, with a further 23,000 tons associated with other minerals in the lead concentrate. Declared ore reserves are sufficient for seven years' operations. All current production of lead concentrate is sent overseas without roasting.

TASMANIA.

Read-Rosebery.—The declared ore reserves of 1,500,000 tons contain 14,400 tons of sulphur in lead minerals. Reserves in pyrite and zinc concentrates are given on pages 41 and 44. Sulphur in recoverable galena in lead concentrate amounts to 10,000 tons together with a further 12,000 tons associated with other minerals in the lead concentrate. Declared ore reserves are sufficient for ten years' operations. The lead concentrate is shipped overseas without roasting.

SULPHATES.

The sulphate mineral that occurs most plentifully in Australia is hydrated calcium sulphate—gypsum. Alunite—hydrated potassium aluminium sulphate—also occurs in considerable quantities. Anhydrite (calcium sulphate) is important, but deposits are not known in Australia.

Gypsum is potentially important as a source of sulphur, but is being used to only a small extent. Anhydrite is preferred to gypsum because it contains no water. The process involving their use is one of calcining the calcium sulphate with shale, clay, etc. The resulting products would be clinker—which could be ground and used as cement—and sulphur-dioxide gas from which sulphuric acid or ammonium sulphate could be made. Sulphuric acid and/or ammonium sulphate are produced from anhydrite in United Kingdom, France, Holland, Belgium and Austria. In Holland and Belgium a process has been worked out for using gypsum, but it is not in use. Gypsum is being used in India for production of ammonium sulphate, but there is no reference to the making of sulphuric acid. U.S.A. is not using gypsum or anhydrite.

In 1950, 3 per cent of sulphur used in the world was from anhydrite and other sulphates.

Alunite is not used primarily as a source of sulphur. When used as a source of potash it is calcined and part of the sulphur content (theoretically three-quarters) is released as sulphur dioxide, which could be used for making acid.

GYPSUM.

Gypsum occurs at many localities, which may be grouped into four distinct regions all of which lie between latitudes 30° S. and 36° S. (Croll, 1950). These regions are:—(1) From Griffith to the neighbourhood of Broken Hill, N.S.W., a distance of 380 miles with a width of approximately 80 miles; (2) that enclosed in a rectangle about 250 miles long (east-west) and 100 miles wide, with the south-east corner at Kerang, in Victoria; (3) a triangular area—with the base along the west coast of Gulf St. Vincent (South Australia) and the apex at Australian Bight—including eight or nine isolated deposits; (4) a roughly triangular region, the reserves of which have not been estimated, with the base through Cunderdin and the apex north-east of Southern Cross, Western Australia.

Reserves in the first two regions have not been measured, but amount to many millions of tons of medium to good quality gypsum, and the fourth region supplies sufficient gypsum to satisfy the Western Australian market. However, these three regions are relatively unimportant compared with the one in South Australia; more than 70 per cent of the gypsum produced in Australia to date has come from this region, which includes the largest and most important deposit of Lake MacDonnell. Reserves of gypsum at this locality have recently been measured, and amount to 765,000,000 tons of first grade gypsum, of which 607,500,000 tons are available without appreciable overburden. Average workable thickness is 15 feet (maximum 27 feet) over an area of 34 square miles. The material available contains more than 94 per cent gypsum with 1 to 5 per cent calcium carbonate, and 0.2 to 1 per cent common salt. The gypsum will be hauled by rail to Ceduna, where calcining works are established and mechanical shiploading gear will be installed (Dickinson and King, 1949).

The total gypsum resources of Australia are, therefore, very large, and will meet demand for a long period. The Lake MacDonnell deposit alone contains a reserve of 134,000,000 tons of sulphur.

Australian production of gypsum in 1948 was 276,000 tons. Australian consumption is estimated at 235,000 tons. Gypsum is not used in Australia as a source of sulphur or sulphate.

ALUNITE.

Alunite occurs in Western Australia, South Australia and New South Wales. The largest deposits are the lake muds at Lake Campion, in Western Australia, and similar deposits have recently been found in South Australia. Small deposits occur in the form of veins in New South Wales and South Australia, but these need not be considered in this bulletin.

SOUTH AUSTRALIA.

Pidinga.—Lake muds containing alunite were discovered in 1948 near Pidinga, 40 miles south of Ooldea; the Department of Mines of South Australia has arranged to test the deposits.

TABLE 23

SULPHUR IN RECOVERABLE ORE OR CONCENTRATES FROM IMPORTANT SULPHIDE DEPOSITS.

(All figures in thousands of tons)

State	Locality	Ore Reserves		Pyrite Concentrates Recoverable from Ore Reserves		Zinc Concentrates Recoverable from Ore Reserves		Lead Concentrates Recoverable from Ore Reserves		Sulphur in Recoverable Concentrates.					
										Pyrite Concentrates		Zinc Concentrates		Lead Concentrates	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
Q'land	Mount Isa—														
	(a) Lead-zinc ore	9,170	—	472	—	828	—	1,700	—	217	—	260	—	425	—
	(b) Copper ore	2,952	3,000	126	128	—	—	—	—	58	59	—	—	—	—
	Mount Morgan—														
	(a) Reserve ore	4,830	—	1,449		—	—	—	—	724		—	—	—	—
	(b) Low-grade ore	2,650	10,000†	497	1,875†	—	—	—	—	248	937†	—	—	—	—
	(c) Tailings	4,500	—	750	—	—	—	—	—	375	—	—	—	—	—
N.S.W.	Broken Hill	58,000*	—	—	—	11,100	—	10,300		—	—	3,535	—	1,530	—
	Captain's Flat	1,600	400	218	54	275	69	200	50	102	25	91	21	46	11
	Leadville	60		60		—	—	—	—	26		—	—	—	—
Tasmania	Chester	2,800		840		—	—	—	—	420		—	—	—	—
	Mt. Lyell	1,650		1,650		—	—	—	—	725		—	—	—	—
	Mt. Lyell & Jukes-Darwin	31,685	30,000	1,330	1,280	—	—	—	—	665	640	—	—	—	—
	Read-Rosebery	1,500	1,500	192	192	460	460	100	100	92	92	153	153	20	20
	Renison Bell	746	264†	522	185†	—	—	—	—	209	74	—	—	—	—
Sth. Aust.	Gibraltar (Nairne)	9,500	50,000†	1,835	9,680†	—	—	—	—	845	4,450†	—	—	—	—
W. Aust.	Big Bell	1,600	2,200	51	69	—	—	—	—	20	27	—	—	—	—
	Kalgoorlie	9,500	12,800	580	784	—	—	—	—	210	282	—	—	—	—
	Iron King (Norseman)	1,070	2,000	478	900	—	—	—	—	220	413	—	—	—	—
TOTALS		143,813	112,164	11,050	15,148	12,663	529	12,300	150	5,156	6,999	4,039	174	2,021	31
BRIMSTONE EQUIVALENT—										4,718	6,404	3,635	157	1,617	25

TOTAL OF BRIMSTONE EQUIVALENTS OF SULPHIDE MINERALS, 16,556,000 Tons.

A Measured and indicated ore. B Inferred ore. * Includes both A and B † Signifies that there is certainly more ore present than has been stated under A and B.

WESTERN AUSTRALIA.

Chandler. As a war-time measure a potash industry at Chandler, near Southern Cross and Merredin, was started by a private syndicate and later taken over by the State (W.A.) Alunite Industry.

Alunite mud was dug from the bed of Lake Campion. In the calcining of the muds, sulphur-dioxide gas equivalent to 1200-1500 tons of sulphur annually was given off. This was very much below the theoretical amount because of the inefficiency of the calcining process, and the formation of sodium sulphate and magnesium sulphate from sodium chloride and magnesium chloride, respectively, in the alunite mud.

The industry was not a technical or a commercial success, and has not operated since December, 1949, but, even if the plan to supply all of Australia's potash needs had succeeded, any production of sulphuric acid from the furnace gases would have been of only minor importance. Reserves are about 7,500,000 tons of mud, containing approximately 25 per cent sulphur trioxide.

RESERVES.

Information concerning those important deposits of sulphide minerals about which sufficient is known to make estimates is given in the following tables:—

Table 23.—Summary of tonnages of ore reserves, recoverable concentrates and sulphur contents.

Table 24—Pyrite and pyrrhotite bodies.

Table 25—Pyrite concentrates from mixed sulphide bodies.

Table 26—Zinc concentrates.

Table 27—Lead concentrates.

It is not claimed that these reserves represent all sulphide minerals that could be used as a source of sulphur. In the Mount Morgan, Renison Bell and Nairne deposits there is more sulphide ore than is shown in Tables 23 to 25 [these are marked (†) in the above tables], but insufficient information is available to state the additional amounts. Other deposits have been omitted because insufficient information is known about them to make estimates of their sulphur content. The total known reserves of sulphur in sulphide minerals and the brimstone equivalent, that is, the tonnage of brimstone from which an equal quantity of acid could be produced, are shown below:

	Sulphur Content Tons	Brimstone Equivalent Tons
Pyrite and pyrrhotite bodies	7,921,000	7,248,000
Pyrite concentrates from mixed sulphide bodies	4,234,000	3,874,000
Zinc concentrates	4,213,000	3,792,000
Lead concentrates	2,052,000	1,642,000
Totals	18,420,000	16,556,000

TABLE 24

PYRITE AND PYRRHOTITE OREBODIES.

State	Mine or Field	Ore Reserves		Pyrite and Pyrrhotite Content per cent	Assumed Recovery per cent	Recoverable Pyrite Concentrates		Sulphur Content of Pyritic Products Per cent	Sulphides Present in Product	Sulphur in Products (Ore or Concentrates)	
		A Tons	B Tons			A Tons	B Tons			A Tons	B Tons
N.S.W.	Leadville	60,000		83	100	60,000 (ore)		44	Py.	26,000	
Tasmania	Chester	2,800,000		38	75	840,000		50	Py.	420,000	
	Mt. Lyell	1,650,000		83	100	1,650,000 (ore)		44	Py.	725,000	
	Renison Bell	746,000	246,000†	88	80	522,000	185,000†	40	Pyrr., Py.	209,000	74,000
Sth. Aust.	Gibraltar	9,500,000	50,000,000†	23	85	1,835,000	9,680,000†	46	Py., Pyrr.	845,000	4,450,000†
W. Aust.	Big Bell	1,600,000	2,200,000	6.6	50	51,000	69,000	39	Py., Pyrr.	20,000	27,000
	Kalgoorlie	9,500,000	12,800,000	5.8	73	580,000	784,000	36	Py.	210,000	282,000
	Iron King	1,070,000	2,000,000	50	82½	478,000	900,000	46	Py.	220,000	413,000
TOTAL ..										2,675,000	5,246,000†

A Measured and indicated ore.

B Inferred ore.

Py. = pyrite.

Pyrr. = pyrrhotite.

†Signifies that there is certainly more ore present than has been stated under A and B.

TABLE 25

PYRITE CONCENTRATES FROM MIXED SULPHIDE OREBODIES.

State	Mine or Field	Ore Reserves		Pyrite and Pyrrhotite Content	Assumed Recovery	Recoverable Pyrite Concentrates		Sulphur Content of Pyrite Concentrates	Sulphides Present in Concentrates	Sulphur in Recoverable Pyrite Concentrates.	
		A Tons	B Tons	Per cent	Per cent	A Tons	B Tons	Per cent		A Tons	B Tons
Q'land	Mt. Isa—										
	(a) Lead-zinc ore	9,170,000		14.7	32	472,000		46	Py., Pyrr.	217,000	
	(b) Copper ore	2,952,000	3,000,000	8.6	50	126,000	128,000	46	Py., Pyrr.	58,000	59,000
	Mt. Morgan—										
	(a) Reserve ore	4,830,000		40	75	1,449,000		50	Py.	724,000	
	(b) Low-grade ore	2,650,000	10,000,000†	25	75	497,000	1,875,000	50	Py.	248,000	937,000†
	(c) Tailings	4,500,000		25	66	750,000		50	Py.	375,000	
N.S.W.	Captain's Flat	1,600,000	400,000	35	39	218,000	54,000	47	Py.	102,000	25,000
Tasmania	Mt. Lyell & Jukes-Darwin .	31,685,000	30,000,000	7	60	1,330,000	1,280,000	50	Py.	665,000	640,000
	Read-Rosebery	1,500,000	1,500,000	30	41	192,000	192,000	48	Py.	92,000	92,000
TOTAL										2,481,000	1,753,000

A Measured and indicated ore.

B Inferred ore.

Py. = pyrite.

Pyrr. = pyrrhotite.

†Signifies that there is certainly more ore present than has been stated under A and B.

TABLE 26

ZINC CONCENTRATES FROM MIXED SULPHIDE OREBODIES.

State	Mine or Field	Ore Reserves A Tons	Ore Reserves B Tons	Sphalerite or Marmatite Content Per cent	Assumed Recovery Per cent	Recoverable Zinc Concentrates A Tons	Recoverable Zinc Concentrates B Tons	Sulphur Content of Zinc Concentrates Per cent	Sulphides Present in Concentrates	Sulphur in Recoverable Zinc Concentrates A Tons	Sulphur in Recoverable Zinc Concentrates B Tons
Q'land	Mt. Isa	9,170,000		11.0	50	828,000		31.3	Sp., Py.	260,000	
N.S.W.	Broken Hill	58,000,000*		20	88	11,100,000		32	Ma.	3,535,000	
	Captain's Flat	1,600,000	400,000	14.5	70	275,000	69,000	33	Sp., Py.	91,000	21,000
Tasmania	Read-Rosebery	1,500,000	1,500,000	29.4	88	460,000	460,000	33	Sp.,Ga.,Py.	153,000	153,000
TOTAL										4,039,000	174,000

A Measured and indicated ore. B Inferred ore. * Total of A and B Py. = pyrite. Sp. = sphalerite. Ma. = marmatite. Ga. = galena.

TABLE 27

LEAD CONCENTRATES FROM MIXED SULPHIDE OREBODIES.

State	Mine or Field	Ore Reserves A Tons	Ore Reserves B Tons	Galena Content Per cent	Assumed Recovery Per cent	Recoverable Lead Concentrates A Tons	Recoverable Lead Concentrates B Tons	Sulphur Content of Lead Concentrates Per cent	Sulphides Present in Concentrates	Sulphur in Recoverable Lead Concentrates. A Tons	Sulphur in Recoverable Lead Concentrates. B Tons
Q'land	Mt. Isa	9,170,000		11.0	84	1,700,000		25	Ga.,Sp.,Py.	425,000	
N.S.W.	Broken Hill										
	(a) Lead lode	53,000,000*		17.3	97	10,300,000		14.8	Ga., Ma.	1,530,000	
	(b) Zinc lode	5,000,000*		4.6							
	Captain's Flat	1,600,000	400,000	6.5	70	200,000	50,000	23	Ga.,Sp.,Py.	46,000	11,000
Tasmania	Read-Rosebery	1,500,000	1,500,000	6.9	65	100,000	100,000	20	Ga.,Sp.,Py.	20,000	20,000
TOTAL										2,021,000	31,000

A Measured and indicated ore. B Inferred ore. * Total of A and B Py. = pyrite. Sp. = sphalerite. Ma. = marmatite. Ga. = galena.

There are also 134,000,000 tons of sulphur in the Lake MacDonnell gypsum deposits. No estimate of the brimstone equivalent of this sulphur can be given at present because the sulphur content can be made into acid only in conjunction with cement-making, and it is not yet certain that this could be done economically. No sulphur would be recovered from making plaster of paris from the gypsum.

The most important reserves of sulphide minerals occur at Broken Hill, Mount Morgan, Nairne and Mount Lyell. Broken Hill is not only the largest proved source of sulphide minerals, but is predominant among Australian lead-zinc mines, having 3,535,000 tons of sulphur recoverable in zinc concentrates out of a total of 4,213,000 tons, and 1,530,000 tons of sulphur recoverable in lead concentrates out of a total of 2,052,000 tons. Mount Morgan has 2,284,000 tons, Nairne 5,295,000 tons, Mount Lyell (including the adjacent Jukes-Darwin district) 2,030,000 tons, and Iron King 633,000 tons out of a total of 12,155,000 tons of sulphur recoverable in pyrite ore or concentrates.

Certain items included in the totals mentioned must be excluded from immediate practical consideration:—

(1) Mount Isa lead and pyrite concentrates. The lead concentrate contains only about 40 per cent lead and 25 per cent sulphur, and transport to an existing acid works for roasting would be quite uneconomical. The alternative—to build an acid works in North Queensland—is not likely to eventuate because the demand in that area for acid or for fertilizer requiring acid in its manufacture will not be large within the life of the mine.

(2) Part of Broken Hill zinc concentrates is exported unroasted to the United Kingdom, where it is roasted and used for acid manufacture and zinc recovery. It is likely that the United Kingdom requirements for zinc concentrates will become more urgent because of U.S.A. restrictions on export of sulphur and increased purchases of zinc by the U.S.A. for stockpiling. Although this position may ameliorate considerably during the life of the Broken Hill mines, it assumed that the amount of Broken Hill zinc concentrates exported unroasted will increase to 50 per cent of the concentrates produced.

(3) For the same reason as in (2), Mount Isa and Captain's Flat zinc concentrates are more likely to be diverted to the United Kingdom, or to continue to be exported to hard currency areas, than to be roasted and treated in Australia. Roasting and zinc recovery works of the Electrolytic Zinc Co. of Australasia Ltd. are working to full capacity and extra capacity being installed is fully committed to treat increased production from Broken Hill and Read-Rosebery.

(4) Captain's Flat and Read-Rosebery lead concentrates are lower in lead content and higher in zinc content than Broken Hill lead concentrates, and it is claimed that they are not acceptable in large quantities to the Port Pirie smelters. These smelters are fully committed to smelt the projected increase in Broken Hill lead concentrates.

(5) Technical and financial difficulties (page 30), as well as heavy transport charges, nullify the use of Kalgoorlie gold-pyrite concentrates for making acid.

Omitting the above, the sulphide reserves available for use are:

READILY AVAILABLE SULPHIDE RESERVES.

(Expressed in terms of sulphur content and brimstone equivalent in thousands of long tons.)

State	Locality	Sulphur in Recoverable Concentrates				Total
		Pyrite & Pyrrhotite Orebodies	Pyrite Concs. Mixed Sulphide Orebodies	Zinc Concentrates	Lead Concentrates	
Q'land	Mt. Morgan		2,284			2,284
N.S.W.	Broken Hill			1,767	1,530	3,297
	Captain's Flat		127			127
	Leadville	26				26
Tas.	Chester	420				420
	Mt. Lyell Mine	725				725
	Mt. Lyell & Jukes Darwin Fields		1,305			1,305
	Read-Rosebery		184	306		490
	Renison Bell	283				283
S.A.	Nairne (Gibraltar)	5,295				5,295
W.A.	Big Bell	47				47
	Iron King (Norseman)	633				633
	Sulphur content	7,429	3,900	2,073	1,530	14,932
	Brimstone Equiv.	6,798	3,568	1,866	1,224	13,456

CONCLUSIONS.

The Interdepartmental Sulphuric Acid Committee (1950) estimated that the demand for sulphuric acid would be 732,850 tons in 1952-53 and 886,850 tons in 1957-58. This would require 240,000 tons of brimstone in 1952-53 and 290,000 tons in 1957-58 (using a factor of 3.05 tons of monohydrate sulphuric acid per ton of brimstone), that is, an increase in demand of 10,000 tons of brimstone annually. It is assumed that sulphur needed for purposes other than sulphuric acid will be 8,500 tons in 1952-53, increasing by 1500 tons annually, and that imports of brimstone will be diminished at the annual rate of 20 per cent of the present consumption. On this basis, the amount of sulphur in readily available sulphide reserves (equivalent to 13,456,000 tons of brimstone) would be sufficient for 33 years.

It is not claimed that this is an accurate figure, as estimates become increasingly hazardous at more than a few years' range. Demand for sulphuric acid or for brimstone may increase at a faster rate than estimated because of the use of superphosphate for pasture improvement, new chemical industries, synthetic fibres, etc., or demand may not increase as rapidly as estimated because of the use of fertilizers requiring no sulphuric acid in their manufacture. (Appendix 6).

The figure does show, however, that there is sufficient sulphur available in sulphide minerals for all immediate purposes. Within the estimated life of the orebodies listed in the tables, other orebodies may be found, others known but not tested will be examined and resources estimated, and advances in technology may completely revolutionize the demand for sulphur and sulphuric acid.

Melbourne. 21st March, 1952.

REFERENCES.

In addition to the references listed below, information on Australian resources of sulphur-bearing minerals has been drawn from unpublished reports by officers of the Bureau of Mineral Resources and information supplied by mining companies and the State Mines Departments, whose help is gratefully acknowledged.

ANDREWS, E. C., 1922—The Geology of the Broken Hill District; *Mem. Geol. Surv. N.S.W., No. 8.*

————, 1928—Mineral Resources of New South Wales, 384: Sulphur, *Geol. Surv. N.S.W.*

BLANCHARD, R., and HALL, G., 1942—Rock Deformation and Mineralisation at Mount Isa; *Proc. Aust. Inst. Min. and Metall.,* n.s. 125, 5 and table 9.

BLATCHFORD, T., 1915—The Geology and Mineral Resources of Yilgarn Goldfield, Part II: Gold Belt South of Southern Cross; *Bull. W. Aust. Geol. Surv.,* No. 63, 72-89.

BRADSHAW, A. V., 1949—Contribution to Discussion on Paper by Potts and Lawford (1949); *Bull. Inst. Min. and Metall.,* No. 512.

BRUCE, J. L., 1948—Cyprus Mines Copper Again; *Amer. Inst. Min. & Metall. Engrs.* T.P. No. 2459.

CROLL, I. C. H., 1949—Mineral Resources of Australia: Gypsum; *Comwlth. of Aust. Bur. Miner. Res. Geol. & Geophys., Summ. Rep.* No. 36, 9.

————, 1950—Mineral Resources of Australia: Gypsum in Australia: *Comwlth. of Aust. Bur. Miner. Res. Geol. & Geophys., Econ. Notes and Statistics,* 3, 42.

DICKINSON, S. B., and KING, D., 1949—The Lake Macdonnell Gypsum Deposit; *S. Aust. Min. Rev.,* No. 87, 109.

DIMMICK, T. D., 1948—Mineral Resources of Australia: Sulphur; *Comwlth. of Aust. Bur. Miner. Res. Geol. & Geophys., Summ. Rep.* No. 31.

EDWARDS, A. K. M., 1950—Report of Investigations of Sulphur Deposits at Ismelele; *Comwlth. of Aust. Bur. Miner. Res. Geol. & Geophys. Rep.* 1950/29.

FISHER, N. H., and NOAKES, L. C., 1942—Geological Reports on New Britain. *Geol. Bull. Terr. N. Guinea,* No. 3.

FISHER, N. H., 1950—Sulphur Deposits at Lolobau, Pangalu and Kasololi, New Britain; *Comwlth. of Aust. Bur. Miner. Res. Geol. & Geophys. Rep.* 1950/20.

HILL, L. C., 1950—The Cupriferous Pyrites Industry; *Bull. Inst. Min. & Metall.,* No. 523, 9.

JOSEPHSON, G .W., and DOWNEY, M. G., 1942—Sulphur and Pyrites; *Reprint U.S. Bur. Min. Miner. Yearb.,* 4.

KENNY, E. J., and MULHOLLAND, C. ST. J., 1941—The Ore Deposits of Captain's Flat, N.S.W.; *Proc. Aust. Inst. Min. & Metall.*, n.s. No. 122, 58.

KIRKPATRICK, W. S., 1949—The Economic Utilisation of Waste Gases of the Integration of Base Metal and Chemical Fertiliser Operations at Trail, B.C.; *Fourth Empire Min. & Metall. Congr. Paper* No. H.I.9.

LUNDY, W. T., 1949—Sulphur and Pyrite; INDUSTRIAL MINERALS AND ROCKS, *Amer. Inst. & Metall. Engs.*, Chapter 47.

M.C.J., 1948—*Mining Congress Journal*, 36 (2), 114.

MONTGOMERY, A., 1914—Report on the Development of the Philips River Auriferous Copper Mines; *W. Aust. Min. Dep. Rep.*, 9.

NYE, P. B., and BLAKE, F., 1938—The Geology and Mineral Resources of Tasmania; *Bull. Geol. Surv. Tas.* No. 44, 68.

ORKLA METAL-AKTIESELSKOP (Technical Staff), 1950—Contribution to Discussion of Paper by Potts and Lawford (1949); *Bull. Inst. Min. & Metall.*, No. 515.

POTTS, H. R., and LAWFORD, E. G., 1949—Recovery of Sulphur from Smelter Gases by the Orkla Process at Rio Tinto; *ibid.*, No. 509.

REID, A. MCINTOSH, 1918—The North Pieman and Huskisson and Sterling Mining Fields; *Bull. Geol. Surv. Tas.* No. 28, 71.

RICH, E., 1949—Contribution to Discussion of Paper by Potts and Lawford (1949); *Bull. Inst. Min. & Metall.*, No. 511.

S.A.M.D., 1918—Government Diamond Drilling Operations; *S. Aust. Min. Rev.*, No. 27, 24.

S.C.A.P., 1946—Sulphur Resources of Japan; *G.H.Q., Supreme Commander for the Allied Powers, National Res. Sec. Rep.* No. 66.

STILLWELL, F. L., 1922—The Geology of the Broken Hill District, *Mem. Geol. Surv. N.S.W.*, No. 8, Appendix 11.

TURNBULL, R. C., HARDIEK, W., and LAWFORD, E. G., 1948—Notes on the Treatment of Pyrites Cinders at the Plant of the Pyrites Co., Inc., Wilmington, Deleware; *Bull. Inst. Min. & Metall.*, No. 505.

TYLER, PAUL M., 1945—Taggart's HANDBOOK OF MINERAL DRESSING, *Wiley, New York*, Sec. 3, 3-120.

WEBER, GEORGE, 1947—Sulphur from Sour Gas; *Oil & Gas Jour.*, 45 (44), 58.

WILLAN, T. R., 1925—Geology and Ore Deposits of Mt. Stewart, Leadville, N.S.W.; *Proc. Aust. Inst. Min. & Metall.*, n.s. No. 57.

WOODWARD, O. H., 1940—A Review of the Broken Hill Lead-Silver-Zinc Industry; *ibid.*, n.s. No. 119 (1).

APPENDIX 1.

SULPHUR BOUNTY.

Under the provisions of the Sulphur Bounty Act of 1923, a bounty on the sulphur content of domestic sulphide minerals used for making sulphuric acid was paid until the 23rd October, 1939. The authorized rate of payment was £2/15/- per ton of equivalent sulphur, but this rate was reduced by the Financial Emergency Act of 1931 to £1/16/- per ton for production between the dates 20th July, 1931, and 1st January, 1938. It is known that the bounty was paid on some gasworks' spent oxide, the remainder being on pyrite and zinc concentrates. Table 28 shows the amounts paid and the estimated amounts of equivalent sulphur.

TABLE 28

SULPHUR BOUNTY PAID.

Fiscal Year Ended 30th June	Amount of Bounty £A.	Amount of Equivalent Sulphur Tons
1924	9,382	3,753
1925	47,140	18,856
1926	38,549	15,420
1927	34,339	13,736
1928	57,377	22,951
1929	52,009	20,803
1930	55,108	22,007
1931	48,520	19,000
1932	30,962	17,201
1933	46,245	25,692
1934	47,955	26,642
1935	50,831	28,239
1936	74,282	41,268
1937	68,011	37,784
1938	83,144	40,000
1939	87,575	35,030
1940	55,036	22,014
TOTAL	£886,375	410,396

On the expiry of the Sulphur Bounty Act of 1923, another Sulphur Bounty Act, No. 36 of 1939, was passed, and was amended by the Sulphur Bounty Amendment Act No. 38 of 1944. The essential provisions of these two acts are as follow:—

(1) The maximum amount of bounty payable is £180,000.

(2) The bounty is payable to the manufacturer of sulphur or sulphuric acid.

(3) The bounty is payable in respect of—
   (a) Sulphur produced from Australian material.
   (b) The sulphur-equivalent of sulphuric acid produced from any material of Australian origin.

(4) When the price of imported sulphur is £6 per ton, the bounty is £1/7/- per ton of sulphur, rising or falling by one shilling for each shilling fall or rise in the price of imported sulphur. The maximum rate of bounty is £1/16/- per ton.

(5) The bounty will be reduced by any amount by which customs duty on sulphur is increased.

(6) Bounty payable to any manufacturer, plus profit made on the sale of sulphuric acid, may not exceed 10 per cent of the capital actually used by him in making sulphuric acid.

The provisions of these two acts are still (1950) in force, but no bounty has been paid because the Australian price of imported sulphur has not fallen below £7/7/- per ton since 1939.

APPENDIX 2.

CUSTOMS TARIFFS ON SULPHUR AND PYRITE.

Both brimstone and pyrite are subject to import duty, but no duty is charged on brimstone while the Sulphur Bounty Act is in force.

The relevant part of the schedule is reproduced below:—

	British Preferential Tariff	Intermediate Tariff	General Tariff
Item 275.			
(A) (1) Sulphur n.e.i. per ton Provided that, so long as a bounty is payable on sulphur, under any law of the Commonwealth, the importation of sulphur to which this by-law applies shall be free of duty.	15/-		50/-
(2) Sulphur, volcanic, for manufacturing purposes for which purposes sulphuric acid produced from pyrite or other sulphide ores is not suitable as prescribed by Departmental By-laws	Free		Free
(B) Pyrites per ton	11/3	25/-	25/-
(C) Pyrites, the produce of Papua or of any island or territory belonging to or administered under mandate by the Commonwealth, 5/- per ton.			
(D) Pyrites, as prescribed by Departmental By-laws	Free		Free

No departmental by-laws have been issued under sub-sections (A) (2) or (D).

Both brimstone and pyrite are exempt from primage duty.

APPENDIX 4.

MINING AND REFINING OF SULPHUR.

(Lundy, 1949; S.C.A.P. 66, 1946).

The origin of elemental sulphur deposits is a matter of controversy, but on the basis of manner of occurrence they can be divided into several classes. In order of commercial importance these are:—

(1) Sulphur-bearing limestone interbedded with barren limestone, anhydrite and gypsum, occurring as cap rock of salt domes and overlain by unconsolidated sediments. The sulphur content of the sulphur-bearing formations is not high—20 to 40 per cent—as the sulphur has filled the pores of the limestone. More than a hundred of these salt domes have been tested in the Gulf of Mexico region of the U.S.A., but only a dozen of them have produced important amounts of sulphur. These important domes vary from less than a hundred to several hundred acres in area.

(2) Sulphur-bearing limestone interbedded with bituminous shales occurring in large basins and overlain by gypsum, sandstone, limestone and clays. This type of deposit includes most of the producing mines of Sicily, of which there were 99 in 1939, and some important mines in north-eastern Italy. Sulphur-rock as mined is 12 to 50 per cent pure, the estimated average in 1941 and 1942 being 15 per cent.

(3) Complex deposits—sedimentary deposits that have been subjected to impregnation and replacement. The largest mines in Japan are of this type. Average purity of the sulphur-rock mined is 30 per cent.

(4) Impregnation and replacement deposits within zones of shearing and fracture or porous sedimentary or clastic beds. Numerous deposits of this type exist in the Andes Mountains and in Japan, where the rock as mined averages 21 to 32 per cent sulphur.

(5) Deposits consisting of interbedded sulphur and clastic sediments, chiefly in Japan. The sulphur-rock as mined averages about 40 per cent sulphur.

(6) Sublimation deposits. These are usually small but high grade—from 45 per cent, or more, sulphur. Large numbers of these deposits exist in the Andes Mountains, Japan and elsewhere, but sulphur production from them is small.

(7) Sedimentary deposits formed by washing down of sublimed sulphur into crater lakes or other depresssions. Most of the Indonesian production came from deposits of this type.

(8) Sulphur-flows from volcanoes. These are 60 to 80 per cent pure sulphur. Several have been known, all in Japan, but none is being worked at present.

In classes (2), (3), (4) and (5) black iron sulphide (pyrite and marcasite) also exists disseminated throughout the sulphur and interbedded rocks, or in beds and masses. In class (3) iron sulphide exists in considerable quantity and, at the largest sulphur mine in Japan, a pyrite concentrate is also made from the ore.

APPENDIX 3.

PARTICIPATION OF MINING COMPANIES IN ACID-MANUFACTURE IN AUSTRALIA

TABLE 29

PAID-UP VALUE OF SHAREHOLDINGS BY MINING COMPANIES IN COMPANIES PRODUCING SULPHURIC ACID AND SUPERPHOSPHATE.

Fertilizer Companies.	Shareholding Companies.		
	Mt. Lyell Mining & Railway Co. Ltd. £	Electrolytic Zinc Co. of Australasia Ltd. £	Consolidated Zinc Corporation Ltd. £
Australian Fertilizers Ltd.	93,750	93.750	
Sulphide Corporation Pty. Ltd.			Wholly owned
Commonwealth Fertilisers and Chemicals Ltd.	907,431		
Wallaroo-Mt. Lyell Fertilisers Ltd.	27,150		
Cuming Smith and Mt. Lyell Farmers' Fertilisers Ltd.	450,000		

Notes:

(1) Electrolytic Zinc Co. of Australasia Ltd. and the North Broken Hill Ltd. have indirect interests in the Sulphide Corporation Pty. Ltd. through their shareholdings in the Consolidated Zinc Corporation Ltd.

(2) North Broken Hill Ltd. and Broken Hill South Ltd. have large shareholdings in the Electrolytic Zinc Co. of Australasia Ltd.

(3) The Consolidated Zinc Corporation also owns acid and fertilizer works in the United Kingdom through the wholly owned subsidiary, Imperial Smelting Corporation Ltd.

High purity sulphur is produced from salt-dome deposits of the U.S.A. by the Frasch process, a typical installation consisting of numerous boreholes to the bottom of the sulphur-containing rock and three concentric pipes—an eight-inch line down which water heated to 300° F. is pumped, a one-inch line down which compressed air is passed, and an intermediate-sized line up which molten sulphur, air and water ascend. The molten sulphur is run into large vats holding up to 500,000 tons for solidification. The success of the process is due to the high purity of the product and to the fact that costs are low on account of cheap fuel, copious supplies of pure water, good transport facilities and, in most places, a moderate depth of overburden—although sulphur has been produced from a depth of 2300 feet.

Lundy describes operations of a typical deposit as follows:—

"The Bryanmound sulphur deposit, except for two short suspension periods, was in operation from 1912 to 1935. At one period in its history, Bryanmound, with an installed plant capacity of 23,000 boiler horsepower, delivered daily about 9,000,000 gallons of water for mining purposes. The cap-rock area comprises approximately 800 acres, but the major part of the production was secured from 296 acres. During the life of Bryanmound 1897 wells were drilled. The average production was 2635 tons per well."

Sulphur deposits elsewhere are mined by ordinary surface or underground mining methods. Some larger mines are mechanized, but all small mines and many larger ones use hand mining only, with a little blasting in harder rocks.

The sulphur-rock is usually merely broken to lump-size for refining, but some mines make a flotation concentrate 60 to 80 per cent pure.

Several methods of refining the crude sulphur-rock are used—excluding the Frasch process, which is a combined mining and refining process yielding a product 99.5 to 99.9 per cent pure. These refining methods are:—

(i) Self-combustion, in which part of the sulphur is burnt to furnish heat to melt the remaining sulphur out of the crude rock at a temperature of 140° C. to 180° C. The refining is done either in heaps (calcaroni) or in small hearths (Gill furnaces). About 30% of the total sulphur is burnt to supply heat, and the sulphur recovered is 40 to 55 per cent of the total, the remainder being irrecoverable. The product contains 90 to 95 per cent sulphur.

(ii) Retort distillation, in which the sulphur-rock is heated to about 700° C. in a closed retort. The sulphur vaporizes and is condensed in a separate vessel. Recovery is about 70 per cent of the sulphur charged, and the sulphur content of the product is 99.5 per cent or higher.

(iii) Autoclave refining, in which superheated steam at 50 lb. pressure is passed through sulphur held in steel cylinders, the molten sulphur settling to the bottom of the cylinders. The method is used on fine sulphur-rock or flotation concentrates. The product contains 99.5 per cent sulphur, and recovery is about 55 per cent.

APPENDIX 5.

BY-PRODUCT ELEMENTAL SULPHUR.

In recent years much attention has been given to recovery of elemental sulphur from sulphide minerals and natural and smelter gases. Hundreds of patents have been taken out and a large number of processes designed, of which only a few have been proved technically and commercially successful, the one most widely used being the "Lenander," or "Orkla," process. Table 3 gives estimates of production of by-product sulphur.

The principles used in the most promising technical process are listed below—some have been used in commercially successful processes:—

- (1) Direct recovery of sulphur—
  - (a) By volatilization ("Noranda" process).
  - (b) By electrolysis of fused sulphides.
- (2) Recovery of sulphur by reduction of sulphur-dioxide gas—
  - (a) With previous concentration of gas (Trail, I.C.I., Lurgi, A.S.R. processes).
  - (b) Without concentration of gas ("Orkla" process).
- (3) Recovery of sulphur by oxidization of hydrogen sulphide and organic natural and industrial gases.

(1) DIRECT RECOVERY OF SULPHUR.

(a) *Volatilization.* Part of the sulphur content of pyrite (roughly two-fifths) is in loose chemical combination, and some of it may be dissociated by heat and recovered by condensation and electrostatic precipitation. Experiments quoted by Rich (1949) indicate that all the labile sulphur is volatilized by heating to 650° C. for eight hours, or to 750° C. for six hours.

A process devised by Noranda Mines Ltd. in conjunction with the National Research Council, and put into operation at a pilot plant at Noranda in Western Quebec, consists of pelletising pyrite concentrate to $\frac{1}{4}$-$\frac{1}{2}$ inch pellets in a revolving furnace, then sintering on Dwight-Lloyd machines in such a way that labile sulphur is driven off and recovered as brimstone, while the rest of the sulphur content is burned to sulphur dioxide.

The process was designed to make profitable the working of a very large pyritic body containing small amounts of copper and zinc which, without the extra revenue from sulphur, was unpayable at the time. The mine is too far from potential consumers to enable pyrite to be marketed profitably.

This process, or one using the principle of volatilization of the labile sulphur, appears to have possibilities at Kalgoorlie, provided that recovery of gold from the calcined pyrite would not be adversely affected. Some sulphur could also be recovered by this means at any large acid works, where the sulphur dioxide could be used for making acid at the works and the elemental sulphur transported elsewhere.

No information is available about the efficiency of recovery of the labile sulphur, but it is not likely to be high at the temperature attained and in the time of roasting possible on the pallets of a sintering machine.

If sulphuric acid can be made from the sulphur-dioxide gas, and the elemental sulphur considered as a by-product, the overall efficiency could be very high.

The "Orkla" process, details of which are given on page 70, uses the volatilization principle in part.

(b) *Electrolysis of Fused Sulphides.* The idea of producing metals by direct electrolysis of fused sulphides is not new, but no process using it has been operated commercially. The "Halkyn" process for producing metallic lead and sulphur electrolytically from fused lead concentrate has been actively investigated by the Broken Hill Associated Smelters Pty. Ltd. for several years, but its commercial application in Australia seems remote.

(2) RECOVERY OF SULPHUR BY REDUCTION OF SULPHUR-DIOXIDE GAS.

In the recovery of elemental sulphur from sulphur dioxide, two chemical reactions are important, the first being the reduction of sulphur-dioxide gas by incandescent carbon, and the other the reduction of sulphur-dioxide gas by gaseous carbon monoxide. Consumption of carbon for reducing purposes is, for the first reaction, 0.375 ton per ton of sulphur produced, and for the second reaction 0.75 ton per ton of sulphur produced. It is therefore important to use a process which, as far as possible, uses the first reaction. The patent literature is conflicting on this point, but, from private information received, the first reaction is substantially predominant at temperatures in excess of 1200° C.

The heat necessary for efficient reduction is usually supplied by extra carbon, and, to keep consumption of carbon within economical limits, it is usually necessary to limit the amount of oxygen present and to have a large percentage of sulphur dioxide in the gas.

(a) *With Previous Concentration of Gas.* Most smelter and industrial gases do not fulfil these conditions, and some form of concentration is usually necessary.

This may be done either by using oxygen instead of air in smelting operations (the oxygen-enrichment process), or by passing the smelter gas through a solvent from which concentrated sulphur-dioxide gas may be recovered. The oxygen-enrichment process has been used chiefly for increasing furnace capacity, but the resultant gas could be used for sulphur recovery.

Several processes using different solvents have been devised, including the I.C.I. which uses basic aluminium sulphate, the Lurgi which uses xylidine, the A.S. and R. which uses dimethylaniline, and the "Trail" using aqueous ammonia solution. The "Trail" process, details of which are given on page 72, recovered ammonium sulphate as a by-product of the concentration method used.

(b) *Without Concentration of Gas.* A process devised by N. E. Lenander, and usually known as the "Orkla" process, recovers sulphur from smelter gas without concentration by having sulphur dioxide reduced by carbon in the furnace. It has been applied only to blast furnace smelting of pyritic copper ores which would normally require no carbon for fuel, but coke is added to the furnace charge to reduce sulphur-dioxide gas to elemental sulphur and to raise the smelting temperature. Details of the process are given on page 70.

(3) OXIDIZATION OF HYDROGEN SULPHIDE AND GASEOUS ORGANIC SULPHUR COMPOUNDS.

The most economical means of oxidizing hydrogen sulphide and gaseous organic sulphur compounds is by means of sulphur-dioxide gas, by which the oxidizing agent contributes a part of the sulphur recovered. The writers have not been able to ascertain whether a process using any other oxidizing agent is in commercial operation.

The amount of hydrogen sulphide in natural or industrial gas is too low for economical sulphur recovery, and it must be concentrated. Josephson and Downey (1948) mention three processes for concentrating hydrogen sulphide—the Phenolate, Phosphate and Girbotol processes. As described by Weber (1947), the Girbotol process uses monoethanolamine as a solvent from which pure hydrogen-sulphide gas may be recovered.

Part of the concentrated hydrogen-sulphide gas may be burned to form sulphur-dioxide gas, which then reacts in a catalysing chamber with the remainder of the hydrogen sulphide to form elemental sulphur. The article by Weber describes a plant producing 70 tons of sulphur daily from natural gas containing 4250 grains of hydrogen sulphide per 100 cubic feet.

A plant operating at Boliden, Sweden, and recovering about 10,000 tons of sulphur annually, used the principle of reduction of hydrogen sulphide and organic sulphur compounds. Hill (1950) says: "At Boliden, in Sweden, sulphur was produced for some time by a method in which part of the furnace gas was passed through red hot coke in a plant very similar to the ordinary producer-gas plant. The gas was first mixed with a certain amount of air and preheated. The resulting gas, which contained hydrogen, hydrogen sulphide, carbon disulphide and carbonyl sulphide, in addition to carbon monoxide and sulphur vapour; was then mixed with the rest of the furnace gas and passed over a catalyst consisting of mixed ferric and aluminium oxides in two chambers in series."

The catalytic reduction of hydrogen sulphide and gaseous organic sulphur compounds is also used in the "Orkla" copper smelter at Thamshavn, in Norway. The hydrogen sulphide is derived from volatile hydrocarbons in the coke used, and the gaseous organic sulphur compounds—chiefly carbon bisulphide and carbonyl sulphide—are derived from the interaction of sulphur vapour with carbon and carbon compounds.

THE "LENANDER" OR "ORKLA" PROCESS.

The first plant built to use the process devised by Mr. N. E. Lenander was erected at Lokken, in Norway, in 1928. The success of this plant led to the construction, by the Orkla Metal-Aktieselskap at Thamshavn, in Norway, of four blast furnaces which, using this process, were capable of a total production of 100,000 tons of sulphur annually. The plant was kept in operation by the Germans after the invasion of Norway in 1940, and, except in 1945, has worked at full scale since then. In the fiscal year ended 30th June, 1950, Australia imported from Norway 13,225 tons of sulphur, all of which was produced by the Orkla process.

The first unit of an Orkla process plant in Spain was installed at Rio Tinto in 1930. The plant was subsequently expanded to a capacity of 27,000 tons of sulphur annually. It has been described in detail by Potts and Lawford (1949).

A plant was built at the San Domingos Mine, in Portugal, in 1934, and later expanded to a capacity of 11,000 tons of sulphur annually. Information about the plant was given by Bradshaw (1949) in the discussion on the paper by Potts and Lawford.

It is significant that no installations other than these three have been made. This is because the cost of copper smelting is increased owing to the low grade of matte produced.

The very low ratio of concentration in the original blast furnace is caused by superimposing, in the same furnace, a reduction process for sulphur recovery upon a smelting process, which is essentially oxidizing. The result is necessarily a compromise, resulting in higher cost of production of copper—because of the necessity of resmelting the low-grade matte—though not affecting the overall efficiency of copper recovery.

At the three installations mentioned the net revenue from sulphur is apparently greater than the extra cost of copper production. Mount Morgan Ltd. has investigated the possibility of applying the process to its mine, but, although no public announcement has been made, it is believed that the process will not be installed there.

Direct smelting of pyritic copper ore in blast furnaces is very little used now, having been replaced by smelting of copper concentrates mostly in reverberatory furnaces. In most cases it would be uneconomical to scrap these installations and instal blast furnaces, and, when the higher cost of producing copper is considered, it is not surprising that so few installations of the Orkla process have been made. If, however, a copper mine is already using blast furnaces or considering their installation, it may be profitable to modify the furnaces and recover elemental sulphur by the Orkla process.

The modifications to the furnace consist of enclosing the top and adding double charging bells so that the released sulphur will not burn in air. Additional equipment required consists of an electrostatic precipitation unit for cleaning dust from the furnace gases; condensers for the sulphur; and, in the absence of arsenic, antimony or large quantities of lead and zinc, one or two catalysing units for the oxidization of hydrogen sulphide derived from the volatile hydrocarbons in the coke, from the interaction of sulphur vapour and steam, and from the oxidization of organic sulphur compounds (carbon bisulphide, carbonyl sulphide) derived from the interaction of sulphur vapour and incandescent carbon. Small quantities of lead and zinc may be slagged without harmful effect.

The process as used at Thamshavn is more elaborate than at Rio Tinto or San Domingos, and has a much better overall recovery of sulphur—due partly to the absence of arsenic and partly to the sulphur in the gas from the resmelting of the low-grade matte being recovered at Thamshavn and wasted at Rio Tinto and San Domingos. Table 30 shows the composition of the ores smelted at the three places.

TABLE 30

COMPOSITION OF PYRITE ORES SMELTED AT THAMSHAVN, RIO TINTO AND SAN DOMINGOS.

	Thamshavn Per cent	Rio Tinto Per cent	San Domingos Per cent
Sulphur	41.0	46.75	46.0
Copper	1.87	1.9	1.5
Zinc	1.92	1.8	3.0
Lead		1.0	0.7
Arsenic		0.7	0.5

The presence of arsenic causes losses: (a) it makes catalysis impossible because it condenses on the catalyst mass and rapidly makes it useless; (b) it is condensed with the crude sulphur, from which it has to be removed by treatment with milk of lime, forming calcium thioarsenate; (c) a further loss, caused by the necessity for removal of arsenic, results from the formation of calcium polysulphides in the refining process.

In the absence of arsenic, catalysis may be carried out in two stages—hot catalysis (at 450° C.), which recovers sulphur from carbon bisulphide and carbonyl sulphide, and cold catalysis (at 140° C.), which recovers sulphur from carbonyl sulphide and hydrogen sulphide. Both hot and cold catalysis use sulphur dioxide as the oxidizing agent.

The furnace charge in all three installations consists of pyrite ore, limestone and quartz—or siliceous gossan—for flux, and coke for reducing sulphur-dioxide gas. Rio Tinto also adds converter slag and sulphur residues. The ratio of concentration of the copper is quite low—6.1 : 1 at Thamshavn, 3.5 : 1 at Rio Tinto, and 2.9 : 1 at San Domingos—as compared with ratios attainable in straightout pyritic smelting (up to 17 : 1). The overall percentage recovery of sulphur is high at Thamshavn, 83.1 per cent, and fairly low at Rio Tinto, 51.2 per cent, and San Domingos 53.5 per cent, but, because of the absence of arsenic in the ore, the Thamshavn smelter uses hot and cold catalysis, which recover about half the sulphur in sulphur compounds in the gas, which would otherwise be wasted. For the same reason sulphur refining loss is low.

In addition, the Thamshavn smelter recovers the sulphur from the resmelting of the low-grade matte. Sulphur refining loss at Rio Tinto amounts to about 6 per cent of the sulphur in the ore, this high figure being due to the very low arsenic content in the refined sulphur (ten parts of arsenic per million) demanded by the Spanish market. The gas discharged from the Rio Tinto condensers contains 20 per cent of the sulphur in the ore; the low-grade matte, which is resmelted in a separate furnace and the sulphur discharged to air, contains 13 per cent. If half the sulphur in the exit gases could be recovered (as at Thamshavn) and half of the sulphur in low-grade matte, the recovery of sulphur in crude brimstone would be about 72 per cent, but the refining loss could not be avoided unless the upper limit for arsenic in the refined sulphur could be raised.

Table 31 gives some figures for the operation of the three installations.

TABLE 31

ORKLA PROCESS. OPERATING FIGURES.

	Thamshavn	Rio Tinto	San Domingos
Carbon (from coke) per ton pyrite	0.101 ton	0.090 ton	0.072*
Sulphur recovered. Per cent of sulphur in ore	83.1	51.2†	53.5
Sulphur recovered. Tons per ton of pyrite	0.341	0.239	0.246
Sulphur recovered. Tons per ton of carbon in coke	3.4	2.66 (refined) 2.95 (crude)	3.4

*Charcoal has been used, when recovery of sulphur rose to 59.8 per cent.

†From 1934-39 overall recovery of sulphur was 53 per cent.

The figures for recovery of sulphur per ton of carbon are better than the best theoretical figure for reduction of sulphur dioxide by carbon. This shows definitely that part of the sulphur recovered has been volatilized and recovered without reduction. In the absence of any excess oxygen it is probable that the whole of the labile sulphur (42 per cent of the sulphur content of pyrite) would be recovered in this way. Calculations based on the paper by Potts and Lawford, and the discussion, show that about 25 per cent of the sulphur in the pyrite is recovered by volatilization at Thamshavn and Rio Tinto. The ratio *sulphur reduced by carbon* to *sulphur reduced by carbon monoxide* is given by the staff of the Orkla Metal-Aktieselskap (1950) as 88 to 12 and, on the assumption that half the sulphur recovered at Rio Tinto has been volatilized, the ratio *sulphur reduced by carbon* to *sulphur reduced by carbon monoxide* is approximately 3 to 4.

THE "TRAIL" PROCESS.

This process, named after the smelter in British Columbia where it was installed by the Consolidated Mining and Smelting Company of Canada, used a method of concentrating sulphur dioxide in roaster gas by absorption in aqueous ammonia solution, thereby forming ammonium sulphite and, with further absorption of sulphur dioxide, ammonium bisulphite. Tyler (1945) describes the process as follows:—

"Dust-free roaster gas is absorbed in wood-slat trickle towers in aqueous ammonium sulphite, thereby changing the sulphite to bisulphite, temperature being held below 40° C. Absorbing capacity is kept up by bleeding off bisulphite solution at a concentration of 5 to 6 lb. sulphur dioxide per gallon and adding aqua ammonia. Solution is filtered through plate presses and then acidified with concentrated sulphuric acid, which, with steam, drives off sulphur-dioxide gas and forms ammonium sulphate. The sulphur-dioxide gas is dried with concentrated sulphuric acid and reduced with coke."

An examination of the chemical equations describing these reactions shows that, except for plant losses, all the sulphur-dioxide gas absorbed by the aqueous ammonia solution is recovered as concentrated sulphur-dioxide gas. Half the recovered gas may be used to make the sulphuric acid necessary for the process, and the other half as a source of elemental sulphur. In this case, from 100 tons of sulphur dioxide in roaster gas 50 tons of sulphur-dioxide gas is recovered in concentrated form and 103 tons of ammonium sulphate is made. If the roaster gas has a high enough concentration to enable sulphuric acid to be made directly from it, then from every 100 tons of sulphur dioxide in roaster gas, 66 tons of sulphur dioxide could be recovered in concentrated form and 69 tons of ammonium sulphate made.

The process was installed at Trail because sulphur dioxide from the base-metal smelter there has for many years been a nuisance to near-by landowners, many of them in the U.S.A., as Trail is within a few miles of the international border. The most economical method of disposing of the sulphur-dioxide gas would have been to make sulphuric acid and use that for the manufacture of phosphate fertilizers. Markets for fertilizers and sulphuric acid within a convenient distance were limited at the time, and the company decided to recover elemental sulphur from part of the gases. The process was first operated commercially in 1936, and produced about 40,000 tons of sulphur annually for some years, but was discontinued in 1943, when the demand for fertilizers was sufficiently large to enable sulphuric acid to be made from all of the roaster gases and used for fertilizers.

The source of the gases from which elemental sulphur was recovered was the lead concentrate roasters. These gases contained only 0.5 to 1 per cent sulphur dioxide, very much below the usual strength for making sulphuric acid (5 to 14 per cent). The elemental sulphur recovered was 99.9 per cent pure.

GENERAL.

The recovery of elemental sulphur from smelter gases is very attractive at first sight because of the marked superiority of brimstone over sulphide minerals in sulphuric acid manufacture. A sulphur burner is a very simple and compact piece of apparatus; there is no ash-disposal problem and the resulting gases have a high sulphur dioxide content. On the other hand, sulphide minerals need a large roasting furnace but cannot economically be completely roasted and, if finely ground concentrates are used, the dust-removal apparatus must be both large and efficient. The extra plant and larger ground space and buildings required for an acid plant using sulphide minerals make the capital cost about twice that of an equivalent plant using brimstone.

Apart from this, the advantages of using brimstone are not great. Damp pyrite is fairly corrosive; dry sulphur is not, but is very easily inflammable. The specific gravity of brimstone is less than one-half of pyrite (2.1 against 5.0), therefore the brimstone is bulkier than the equivalent amount of pyrite even though it weighs only half as much, with the result that there is no saving on sea freight. In addition, brimstone is much more valuable than pyrite, and in Australia rail freight rates are higher for more valuable goods.

When the extra cost of recovering elemental sulphur from sulphide minerals is taken into account, it may be stated as a general rule that, if it is to be used for making sulphuric acid, it is not economical to recover elemental sulphur from sulphide minerals, but preferable to use the roaster gases direct for acid manufacture.

APPENDIX 6.

PHOSPHATE FERTILIZERS WITHOUT SULPHURIC ACID.

The largest use for sulphuric acid is in superphosphate fertilizer manufacture, the role of sulphuric acid being to convert the phosphorus in the rock phosphate (present in the form of tri-calcium phosphate) to a soluble form. The sulphuric acid combines with the calcium present as carbonate and with part of the calcium present in the tri-calcium phosphate forming calcium acid phosphate and free orthophosphoric acid, which are water soluble, and gypsum, which makes up about half of the commercial superphosphate. Gypsum is helpful to many soils, particularly to heavy clay or "black alkali" in irrigation areas, or soils containing potassium silicates, but where necessary it could be cheaply obtained from the numerous gypsum deposits in Australia (Croll, 1949).

Superphosphate is carried by the Australian railways at uneconomic rates, and there is therefore no inducement for fertilizer manufacturers to eliminate some of the diluting gypsum or to produce a material higher in soluble phosphates. This has been attempted elsewhere, as the following quotation from the report of the Interdepartmental Committee (1950) shows:—

"The problem of sulphur supplies has been and is being examined from another angle, namely, by investigating the feasibility of converting phosphate rock into forms assimilable by plants using methods which eliminate or reduce the quantity of sulphuric acid normally employed. The United Kingdom Department of Scientific and Industrial Research towards the end of 1949 commenced such an investigation at its Chemical Research Laboratories.

"Pre-war, Germany carried out developmental work on processes for the production of phosphate fertilizers by heating to the sintering temperature (1400-1500° C.) phosphate rock with sodium or calcium salts or silica. Only one such process was operated commercially pre-war, namely, the manufacture of Rhenania phosphate by Kali-Chemi A.G. in Holstein in a plant which was originally a Portland cement works. The process is similar to cement making.

"The output was about 90,000 tons yearly, and the product contained 23-30 per cent of phosphorus pentoxide soluble in neutral ammonium citrate solution depending on the grade of phosphate rock. It was made by heating phosphate rock, soda ash and silica in rotary kilns, the approximate proportions being 10 : $2\frac{1}{2}$: 1 respectively. The cost per kilogram was said to be about 0.30 R.m. compared with about 0.23 R.m. per kilogram in basic slag.

"It is believed that other similar processes are in various stages of development in post-war Germany. One of these involves the sintering of rock phosphate with sand and limestone. Such phosphate fertilizers contain citrate-soluble phosphorus pentoxide and are thought to be suitable for pasture treatment in higher rainfall areas. Ordinary superphosphate is distinguished from such products by its much higher content of water-soluble phosphorus pentoxide. It is feasible to produce concentrated superphosphate or double phosphate* by treating phosphate rock with phosphoric acid previously obtained from phosphate rock. Double superphosphate is very similar to the product obtained by the treatment of phosphate rock with sulphuric acid, although it is not diluted with gypsum, and hence contains a much higher percentage of phosphorus pentoxide, about 45 per cent, as contrasted with the phosphorus pentoxide content of 22 per cent in calcium superphosphate. The Tennessee Valley Authority (U.S.A.) has developed the manufacture of double superphosphate by the use of electric furnace phosphoric acid. Such a process presupposes that cheap electric power is available. Its interest lies in the fact that sulphuric acid is not required."

Double superphosphate may also be produced by a wet method in which the phosphoric acid is produced by the action of excess sulphuric acid on phosphate rock. This is the method used at Trail, in British Columbia, where phosphoric acid produced in the same way is also used for the production of ammonium phosphate. These concentrated phosphate fertilizers were made because of the long distances from Trail to market.

Concentrated phosphate fertilizers are dearer per unit of phosphorus pentoxide than superphosphate, and are a little more difficult to apply. The other fertilizers mentioned have the disadvantage of having a lower water-soluble phosphorus pentoxide content, although the total of the water-soluble and citrate-soluble phosphorus pentoxide content may be as high as in superphosphate. For these reasons the use of phosphate fertilizers other than superphosphate is comparatively small, but a large increase in the cost of sulphuric acid might make it economical to make more use of them.

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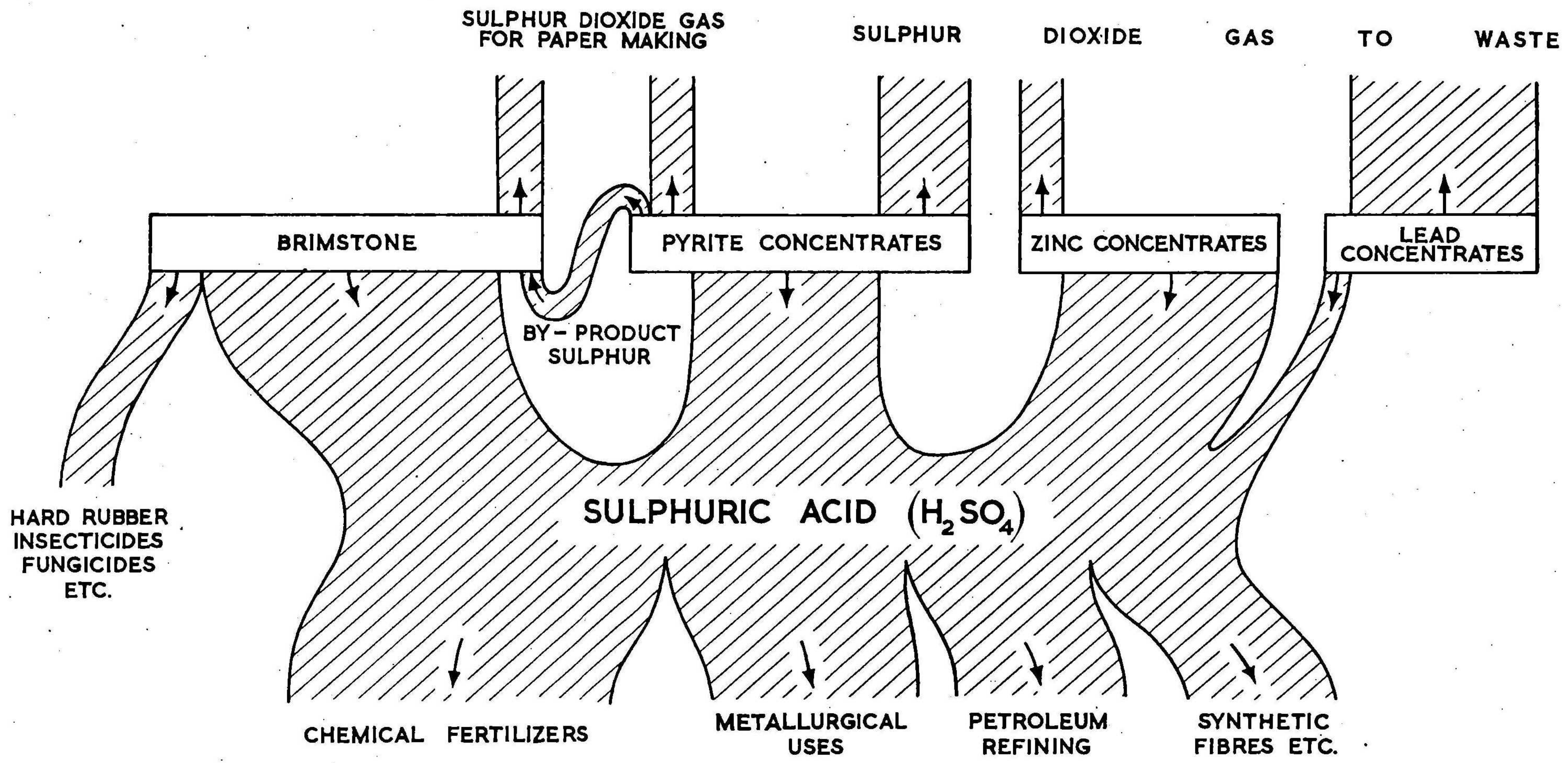
*Also called triple superphosphate.

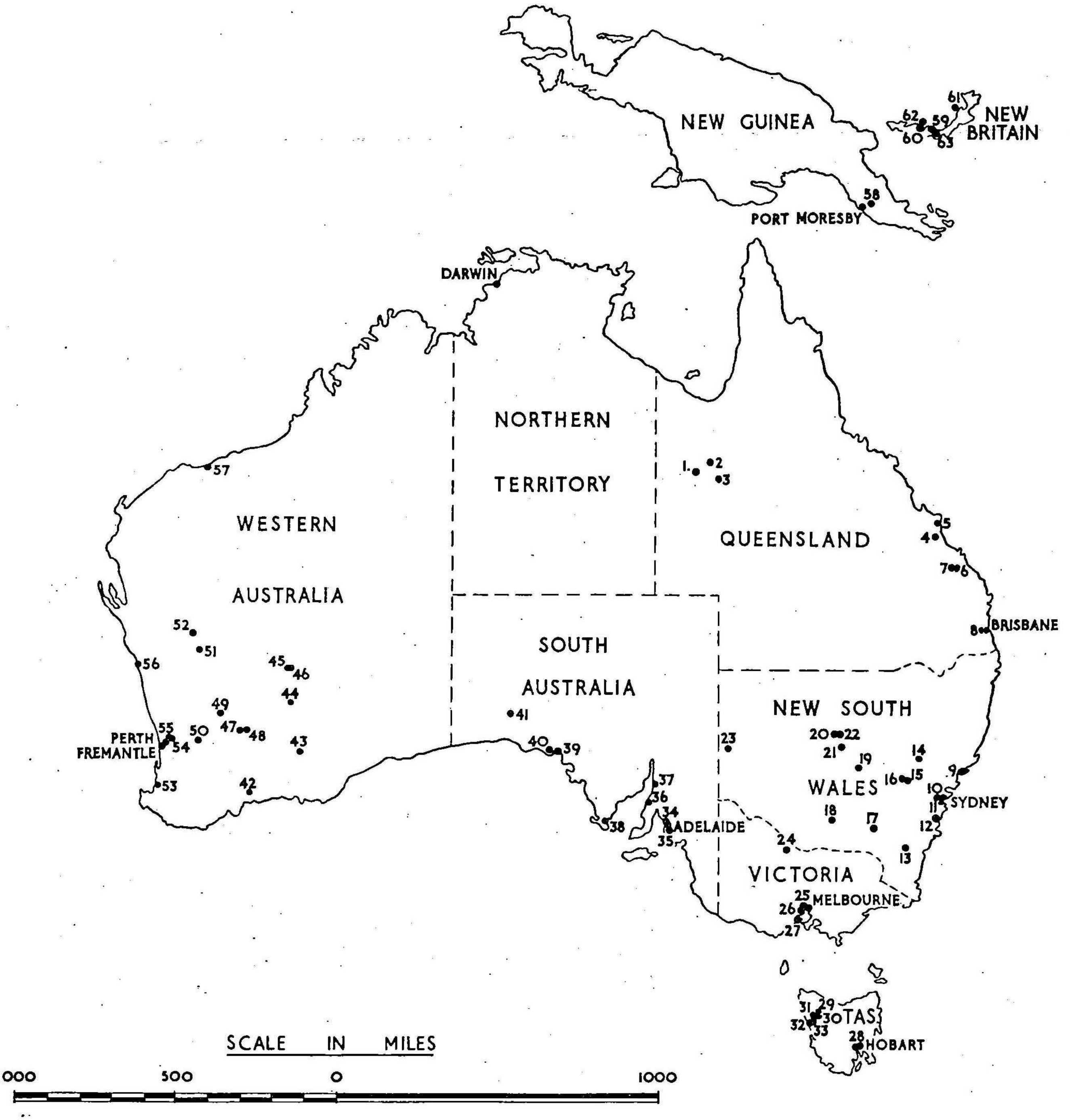
SOURCES AND USES OF SULPHUR AND SULPHURIC ACID

(NOT TO SCALE)



Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics.

PLATE 2



REFERENCE

1. MT. ISA (S)
2. DUGALD RIVER (S)
3. HAMPDEN (S)
4. MT. MORGAN (S)
5. MT. CHALMERS (S)
6. MANY PEAKS (S)
7. MT. CANNINDAH (S)
8. PINKENBA (O)
9. COCKLE CREEK (O)
10. VILLAWOOD (O)
11. ROZELLE (O)
12. PORT KEMBLA (O)
13. CAPTAIN'S FLAT (S)
14. LEADVILLE (S)
15. LEWIS PONDS (S)
16. CALEULA (S)
17. TUMUT (S)
18. GRIFFITH (G)
19. TOTTENHAM (S)
20. COBAR (S)
21. NYMAGEE (S)
22. MT. HOPE (S)
23. BROKEN HILL (S)
24. KERANG (G)
25. DEER PARK (O)
26. YARRAVILLE (O)
27. GEELONG (O)
28. RISDON (O)
29. CHESTER (S)
30. RENISON (S)
31. ROSEBERY (S)
32. ZEEHAN (S)
33. MT. LYELL (S)
34. BIRKENHEAD (O)
35. NAIRNE (S)
36. WALLAROO (O)
37. PORT PIRIE (O)
38. PORT LINCOLN (O)
39. CEDUNA (G)
40. LAKE MACDONNELL (G)
41. PIDINGA (A)
42. MT. MACMAHON (S)
43. NORSEMAN (S)
44. KALGOORLIE (S)
45. EULAMINNA (S)
46. MURRIN MURRIN (S)
47. MT. CAUDAN (S)
48. NEVORIA (S)
49. CHANDLER (A)
50. CUNDERDIN (G)
51. MT. MAGNET (S)
52. BIG BELL (S)
53. PICTON JUNCTION (O)
54. BASSENDEAN (O)
55. BAYSWATER (O)
56. GERALDTON (O)
57. WHIM CREEK (S)
58. LALOKI (S)
59. MT. PAGO (B)
60. MT. GARBUNA (B)
61. LOLOBAU (B)
62. PANGALU (B)
63. KASOLALI (B)

LEGEND

S SULPHIDE DEPOSITS
B NATIVE SULPHUR
A ALUNITE DEPOSITS
G GYPSUM DEPOSITS
O SULPHURIC ACID PLANTS

		TYPE OF DEPOSIT		
		PYRITIC DEPOSIT	LEAD-ZINC DEPOSIT	COPPER DEPOSIT
SULPHUR-BEARING PRODUCT PRODUCED AND USED FOR SULPHURIC ACID	LUMP PYRITIC ORE	NORSEMAN		
	PYRITIC CONCENTRATE	NORSEMAN	CAPTAIN'S FLAT	MT. LYELL MT. MORGAN
	ZINC CONCENTRATE		BROKEN HILL READ-ROSEBERY	

LOCALITY MAP SHOWING

DEPOSITS OF SULPHIDE ORES NATIVE SULPHUR ALUNITE AND GYPSUM AND SULPHURIC ACID PLANTS

Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics.