CHAPTER 5

RAW MATERIALS: NON-FERROUS METALS

THE task of winning metals from the earth's crust can be divided into a number of well-defined steps: first there is the discovery and estimation of the size of the ore bodies in which the metals occur; then comes the mining of the ore and its treatment whereby the minerals it contains are concentrated so that they are ready for the last stage—extraction of the metals. These stages had been fully developed in Australia for all of the "big five" metals except aluminium; in the metallurgy of zinc, lead and copper—especially in the concentration and separation of their minerals by methods of flotation—Australia had made valuable and well-recognised contributions.[1] For other scarcer, but vitally-important metals, all degrees of exploitation, from practically zero to full utilisation, could be found in 1939.

Notwithstanding the fact that mining ranked high among Australia's primary industries, there was before the war of 1939-45 no national geological survey. Practically nothing had been done to collate the findings of the State geological surveys, with the result that the Commonwealth's geological staff, consisting of only two officers (the Geological Adviser and the Palaeontologist), was completely inadequate for the task of determining the country's total resources of the various minerals of wartime interest. The war saw two general developments of fundamental importance in the minerals industry: rapid growth of a Commonwealth-wide survey of mineral resources, and the initiation by the Division of Industrial Chemistry (of the C.S.I.R.) of a program of research directed towards more efficient and extensive use of indigenous minerals.

Few countries, if any, are self-sufficient in all the minerals essential to industry. Even one so well endowed by nature as the United States is without worthwhile deposits of quite a number of minerals. Australia is no exception, lacking commercially useful sources of chromium, nickel, and mercury. Metals in this group, important to industry and defence, but used in relatively small amounts, were often referred to as strategic metals. Their procurement and stockpiling was the responsibility of the Department of Supply and Development. Counterbalancing these deficiencies in Australian mineral resources were several metals (lead and zinc) and minerals (wolfram, scheelite, rutile, zircon, tantalite and beryl) whose output was greater than the country's needs, thus enabling Australia to make a valuable contribution to the material resources of the Allied Nations.

The Department of Supply and Development was entrusted not only with the importation of strategic minerals but also with initiating or increasing the local production of minerals and metals. Before dealing with its

[1] An account of the foundation work done by G. D. Delprat and L. Bradford at Broken Hill is to be found in *Principles of Flotation* by K. L. Sutherland and I. W. Wark, Australasian Institute of Mining and Metallurgy (Inc.), (1955).

more notable efforts in the latter direction it will be necessary, if a balanced picture is to be given of the production of non-ferrous metals, to refer briefly to the well-established metal industries.

Zinc. The beginning of the electrolytic zinc industry at Risdon (Tasmania) was closely associated with the first world war. In the early years of the present century Australia was second only to the United States as a producer of zinc ore, practically all of which was sent in the form of concentrates to Germany and Belgium for the extraction of the metal. When, after the outbreak of war in 1914, zinc concentrates from Broken Hill began to accumulate owing to the diminution of exports, and at the same time Britain began to look for increased supplies of high-quality zinc for her munitions program, Lieutenant Gepp[2] (an outstanding mining engineer, then an officer in the engineers of the Australian Military Forces) was sent to the United States in 1915 to investigate the extraction of zinc from its ores. While there he made an intensive study of the Anaconda Company's plant at Great Falls, Montana, where zinc was being recovered by the electrolysis of aqueous zinc sulphate solution, and gained practical experience in the operation of this process that was later to be of great value in Tasmania. He was present at the first experimental testings in California on the suitability of Broken Hill zinc concentrates for electrolytic extraction. About the time of Gepp's return to Australia the Electrolytic Zinc Company of Australasia Ltd was formed, and on his advice took an option over an offer of cheap hydro-electric power made by the Tasmanian Government. The Great Lake Scheme, then under the management of Mr Butters,[3] had reached a stage where there was power to spare for the encouragement of new industries.[4] The offer was accepted and work on the construction of the Risdon plant began. Production of zinc in 1917 came too late to be of much value in the first world war.

From then on, except during the years of the economic depression, the industry prospered and expanded and by 1939 it was a highly efficient industry and the third largest of its kind, with an annual output of approximately 70,000 tons. This being nearly twice Australian requirements for zinc, the industry was able to make a very substantial contribution to the needs of the Allied nations. At the beginning of the war the Electrolytic Zinc Company of Australasia Ltd entered into a contract, renewed from year to year until 1945, to sell specified quantities of zinc to the British Ministry of Supply. The metal, which was supplied at a price (£22 per ton) substantially below the price ruling in markets overseas (£32 per ton), represented a monetary advantage to Britain. Zinc was also exported

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[2] Sir Herbert Gepp. Gen Manager, Electrolytic Zinc Co of Australasia, 1916-26; Chairman, Development and Migration Commn, 1926-30; Director, North Aust Aerial Geological and Geophysical Survey; Managing Director Aust Paper Manufacturers Ltd 1936-50. B. Adelaide, 27 Sep 1877. Died 14 Apr 1954. Gepp, in collaboration with de Bavay, supervised the construction at Broken Hill of the first large-scale flotation plant ever built.

[3] Sir John Butters, CMG, MBE, VD. Hon Consulting Military Engineer HQ Staff AMF 1927-43; Chairman Associated Newspapers Ltd, Sydney, since 1940. B. Alverstock, Eng, 23 Dec 1885.

[4] The Great Lake Hydro-Electric Scheme was begun by a private company and later taken over by the Tasmanian Government.

to the United States and to India. In order to make sure of meeting the greater demands likely to be made on it, the Electrolytic Zinc Company, at the request of the British Ministry of Supply, undertook to extend its plant. Consequently production rose to a maximum in 1944 of 80,635 tons, of which 40,000 went to Britain. The accompanying table shows how the output of refined zinc varied over the war years.

Year	Production of zinc (in tons)	Sold to Aust consumers (in tons)	Percentage of zinc consumed in Aust
1940	75,957	40,552	53.4
1941	76,698	46,082	59.3
1942	74,282	54,526	73.4
1943	75,756	32,958	43.5
1944	78,716	19,828	25.2
1945	83,773	26,639	31.8
1946	76,316	35,984	47.2
1947	69,421	47,442	68.4

Australian production of refined zinc and the proportion allocated for domestic use.

Source: *Extractive Metallurgy in Australia: Non-ferrous Metallurgy* (1953). Ed. F. A. Green, p. 251.

Zinc found its most important use in galvanising (coating steel to reduce corrosion); next in importance was its use for making brass, one of the most useful of all alloys and extensively used in war time for cartridges and shell cases. Zinc was also an important component of alloys suitable for die-casting either by gravity or under pressure. Such castings could be made so reproducibly accurate (to within one thousandth of an inch or better) that their use avoided a great deal of the machine finishing ordinarily necessary on articles cast by older methods. During the war the technique of die-casting was extended considerably to enable the mass production of many accurately-dimensioned, small items of military equipment at speeds that would otherwise have been impossible. This development could not have taken place had there not been available supplies of zinc of a degree of purity exceeding that of the purest zinc generally available for commercial purposes. Unless the zinc used in making alloys for die-casting was specially free from traces of lead, castings made from the alloys would fail mechanically.

In 1935 Mr Williams,[5] Superintendent of the company's Research Department, began directing experiments to test the usefulness of ordinary electrolytic zinc, which had an average purity of 99.983 per cent, for making die-casting alloys. It was found that, although it was suitable for alloys used in making such everyday items as door handles, ordinary electrolytic zinc did not measure up to the more stringent requirements of military equipment. Specifications called for a zinc of better than 99.99 per cent purity and containing less than 0.007 per cent of lead, the most deleterious of all impurities so far as die-casting was concerned. Attempts made at Risdon over several years failed to reduce the lead content of the zinc below 0.01 per cent. The best results were achieved by carrying

[5] R. T. D. Williams. Research Superintendent, Electrolytic Zinc Co of Australasia for 30 years. Of New Town, Tas; b. Williamstown, Vic, 28 Jan 1885.

out the electro-deposition with lead anodes alloyed with 1 per cent of silver. After the Munitions Department had failed to reach an agreement with the New Jersey Zinc Corporation to secure details of its method for preparing zinc of 99.99 per cent purity by distillation, the Electrolytic Zinc Company resumed work on the problem.

Mr Hannay,[6] of the Consolidated Mining and Smelting Company of Canada, suggested the simple expedient of carrying out the electro-deposition at a lower temperature than was customary (28 instead of 35 degrees centigrade), as a possible means of further reducing the contamination of zinc with lead.[7] This proved to be the solution to the problem. In a small unit built for the purpose, 10,000 tons of zinc of 99.99 per cent purity, containing less than 0.005 per cent of lead, were produced. Most of it was used in the manufacture of an alloy known by the trade name "EZDA", which contained approximately 96 per cent zinc, 4 per cent aluminium and 0.05 per cent magnesium.

Lead. Australia, being second on the list of lead-producing countries, was also able to make a substantial contribution to the Allied war resources of this metal. The 1939 output of lead concentrates, sustained and even increased in the early years of the war, fell off later owing to the diversion of manpower at Mount Isa, Queensland, from lead to copper mining. The lead industry, which like the zinc industry had been greatly stimulated by the first world war, was well established by 1939 at two main centres: at Port Pirie, South Australia, where concentrates from the Broken Hill mines were smelted in the works of Broken Hill Associated Smelters Pty Ltd (which had the distinction of producing more lead in a year than any other and of being the first continuous refinery in the world); and at Mount Isa, where the Mount Isa Company smelted its lead concentrates to produce a lead bullion but did not remove silver from the bullion to form pure lead. The trends of activity in the lead industry and the extent of its contribution to the resources of the Allied nations during the war may be seen from the accompanying table.

Year	Production of lead (in tons)	Australian consumption (in tons)	Percentage of refined lead consumed in Australia
1940	189,150	28,797	15.2
1941	213,476	43,872	20.5
1942	206,929	48,122	23.3
1943	180,629	40,583	22.5
1944	154,547	29,853	19.3
1945	155,852	30,198	19.4
1946	137,459	42,040	30.6
1947	158,548	33,242	21.0

Source: *Extractive Metallurgy in Australia*, p. 256.

[6] W. H. Hannay. Member of Research Board Consolidated Mining & Smelting Co of Canada. B. Belfast, Ireland, 16 Jan 1882.

[7] D. H. Johnstone, "Production of Electrolytic Zinc at the Works of the Electrolytic Zinc Co of A/sia Ltd, Risdon, Tasmania", from *Extractive Metallurgy in Australia: Non-ferrous Metallurgy* (1953), p. 96.

Magnesium. On account of its lightness, magnesium, usually alloyed with aluminium, figured prominently among the metal components of aircraft. The technology of magnesium, the lightest of all metals in use for constructional purposes, had been most highly developed in Germany, with the result that that country was the world's leading producer. Magnesium was in fact the only metal of which Germany had an exportable surplus. Its uses had been more thoroughly exploited there than in any other country, but other highly-industrialised nations were not far behind. Britain and the United States had set up plants in the late nineteen-thirties for the recovery of magnesium from sea water, but owing to the unprecedented demand for magnesium for aircraft construction and for other defence purposes, the output of these plants was insufficient to prevent a widespread shortage of the metal in the early part of the war. The seriousness of the situation was underlined about the middle of 1940 by Britain's intimation that she would no longer be able to supply Australia with magnesium.

Fortunately the B.H.P., foreseeing the country's need for this metal, had taken the initiative, and after preliminary negotiations with the British firm of Murex Ltd of Rainham, Essex, had sent two of its technical officers, Messrs Henderson[8] and Norgard,[9] to England to study the metallurgy of magnesium. They arrived on 27th July 1940. Almost exactly one year later the plant at Newcastle began to operate.

Basically the process used was the then novel one of thermal reduction carried out in gas-fired, heat-resistant, steel retorts: magnesium oxide, mixed with finely ground calcium carbide,[1] was heated *in vacuo* to a temperature of 1,150 degrees centigrade and the magnesium was distilled off. Remelting and alloying were carried out under a suitable flux, since at temperatures above its melting point magnesium readily takes fire. Finely powdered magnesium, which burns with an extremely brilliant white flame, was used in flares, star shells, ignition mixtures and photographic flash foils and filaments. Pure magnesium has relatively little strength and in this form its uses were limited to those just mentioned and to certain metallurgical practices; for instance, it was used as a deoxidiser in casting aluminium, brass and bronze. Light alloys of considerable strength and usefulness, especially in the aircraft industry, could be made with magnesium and small quantities of several other metals.

During the war the B.H.P. produced 2,582,000 pounds of magnesium, of which 2,019,375 pounds were used for making special alloys and the remainder for pyrotechnical preparations. The accompanying table shows

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[8] E. T. Henderson. Officer in charge of Magnesium Plant, BHP, Newcastle, from its inception; helped establish tungsten-carbide and ferro-alloy plants at BHP, Newcastle. Metallurgist; b. Glen Osmond, SA, 26 Mar 1877. Died 15 Jan 1950.

[9] F-Lt J. D. Norgard, BEMet. Metallurgist, B.H.P. Co Ltd; served RAAF 1942-45. Manager, BHP Steelworks, Newcastle, NSW, since 1952. Of Adelaide; b. Adelaide, 3 Feb 1914.

[1] Calcium carbide from Electrona, Tasmania, was used in the early stages, but later the B.H.P. made its own.

the composition of magnesium alloys belonging to the Elektron series produced by B.H.P. for making castings of aircraft parts.

Designation of alloy	Aluminium %	Zinc %	Manganese %	Magnesium %
Y	6	3	0.3	90.7
X	7.8	0.4	0.3	91.5
W	9.5	0.4	0.3	89.8

Magnesium alloys containing over 6 per cent of aluminium could be greatly improved in mechanical and other physical properties by heat treatment, which involved maintaining the metal at predetermined temperatures for specified periods of time (23 hours at 420 degrees centigrade, followed by 9 hours at 200 degrees centigrade). Temperatures had to be maintained within quite narrow limits if batches of material were not to be spoiled. In checking the accuracy of commercial temperature-measuring instruments, the Physics Sections of the National Standards Laboratory and the Munitions Supply Laboratories gave indispensable help to the metal industry. The manufacture of these alloys exemplified a new general trend brought about by the demands of war. Manufacturers of munitions were required to adhere rigidly to specifications relating to the composition and heat treatment of alloys far more exacting than those to which they had formerly been accustomed.

Because of the great falling off in demand for magnesium after the war the industry was abandoned.

Copper and Bauxite Committee. As supplies of strategic minerals became short, hurried searches revealed wide gaps in the knowledge of Australia's mineral resources. There is little doubt that Australia was caught at a disadvantage compared with countries, such as the United States, Canada and India, which had national geological surveys and, as was the case with the first two, bureaux of mines. The situation was aggravated by the slump that occurred in many branches of the mining industry early in the war as a result of the drift of men away from the mines. Local production of minerals had fallen well below pre-war levels and it was clear that some decisive action was needed to prevent a major collapse in the industry. Copper and aluminium were the two metals that caused most concern.

It was for the purpose of advising the Government on the most suitable ways of stepping up local production of copper and of beginning an aluminium ingot industry that the Commonwealth Copper and Bauxite Committee was set up in May 1941 within the Department of Supply and Development, under the chairmanship of Sir Colin Fraser.[2] For many years

[2] Other members of the committee were: Dr H. G. Raggatt (C'wealth Geological Adviser, Deputy Chairman), A. J. Keast (Zinc Corp Ltd), J. M. Newman (independent mining engineer), M. J. Martin (Sulphates Pty Ltd), J. Horsburgh (Mt Morgan Co) and A. C. Smith (Dept of Supply and Development), who was Secretary to the Committee.

This committee was later increased in size and called the Minerals Committee. It ceased to function in 1942 when the Minerals Production Directorate in charge of Mr J. M. Newman was formed.

Fraser had exerted a powerful influence on the metals industry in Australia, and the standards of efficiency to which it had attained contributed in no small measure to the success of the munitions program. As Adviser to the Government on Non-ferrous Metals he had already given valuable service to the country.

Copper. From being a large producer and an exporter of copper, Australia was reduced in the decade before the war to a level where she was barely able to supply her own needs. When the munitions program called for greatly increased supplies of copper to make the brasses, bronzes and other copper alloys used in cartridges, shell cases and similar components, a serious shortage was threatened. Copper was smelted at four main centres in the Commonwealth: at Port Kembla by the Electrolytic Refining and Smelting Company of Australia; at Queenstown, Tasmania, by the Mount Lyell Mining and Railway Company Ltd; and at Mount Morgan Ltd and Mount Isa Mines Ltd in Queensland. The Mount Lyell Company, operating on an extremely low-grade copper ore (the lowest exploited on a large scale anywhere in the world), was unable in spite of the high efficiency of its metallurgical processes, to increase its output. Neither could the output of Mount Morgan be increased. Consequently it became imperative to look for other sources of copper. It was due mainly to the efforts of the Copper and Bauxite Committee that attention was drawn to the possibility that Mount Isa, previously a producer of zinc and lead, might be exploited for copper.

In normal times, when much proving and testing of ore bodies and metallurgical processes is done before large sums of money are committed, mining is generally regarded as a financially hazardous undertaking. Under war conditions the hazards are even greater, especially when attempts are made to bring back into production mines which have been closed down because they were unprofitable, or to open up new ventures in a great hurry. In war, when a metal was urgently needed for the manufacture of arms and the cost of producing it was a matter of secondary importance only, the Government often provided financial assistance to mining industries, as it did with Mount Isa. In this way Mount Isa came into production towards the end of 1943 with an annual output of about 6,000 tons of copper. A fortunate circumstance in which a large copper-ore body was found close to the main lead-zinc body made it possible for the two to be developed from the main set of workings. Copper from Mount Isa was obtained at the expense of a reduction in the output of zinc and lead, but as already mentioned these two metals were being produced in amounts far beyond Australia's requirements. Most of the copper smelted at the various centres was subsequently refined electrolytically at Port Kembla and Queenstown. The accompanying table, which sets out the quantities of metal so treated, also gives some idea of the output of copper over the war years. The table does not show all the copper produced. There was, for example, a carry-over of 9,910 tons of Mount Isa blister copper not shown in the figures for 1944.

Blister Copper Electrolytically Refined

	1940	1941	1942	1943	1944
Port Kembla					
E.R. and S. Co.	3,205	3,593	3,147	6,656	5,258
Chillagoe	2,352	1,901	1,652	1,437	—
Mt Morgan	3,592	5,775	4,174	4,054	3,088
African	2,124	4,836	—	—	—
Mt Isa	—	—	—	1,897	6,691
Queenstown					
Mt Lyell	12,022	8,507	12,630	10,760	8,556
TOTAL	23,295	24,612	21,603	24,804	23,593

Much credit is due to the mining engineers and metallurgists who, under the leadership of Mr Kruttschnitt,[6] brought Mount Isa into production of copper in so short a time. Mines such as the Lake George mine at Captain's Flat, New South Wales, were brought back into production, and the total annual output of copper was raised to about 30,000 tons—almost double that of the years immediately preceding the war. Although still below wartime requirements, which at the peak rose to 75,000 tons a year, this represented a substantial contribution, and together with 131,000 tons of copper that had been imported from Africa by the Commonwealth Government and stock-piled, coupled with the savings brought about by severe restrictions in the use of copper for civilian purposes, tided the country over the war years, with some to spare.

One lesson that emerged from the attempts to increase mineral supplies during the war was that it was seldom, if ever, practicable to open up entirely new large-scale developments. In war it is almost always a case of making the most of the existing mines and at best extending their working, as was done at Mount Isa.

Aluminium. The second task of the Copper and Bauxite Committee was to investigate the local supply of bauxite, the raw material required for the extraction of aluminium. In spite of the fact that there had been announcements on the part of big metallurgical companies, dating as far back as the first world war, that they were about to begin the extraction of aluminium, no detailed survey had ever been made of the sources of bauxite in Australia. These companies appear to have been deterred from launching the industry because of fear of competition from powerful world aluminium combines. But as no country could develop an aircraft industry without an assured supply of aluminium, government intervention seemed to be the only way of starting an aluminium industry. Surveys initiated by the Copper and Bauxite Committee revealed the existence of sufficient medium-grade bauxite in Queensland, New South Wales, Victoria and

[6] J. Kruttschnitt, PhB. Gen Mgr Mount Isa Mine 1930-37; Chairman, Bd of Directors, Mount Isa Mines Ltd, 1930-52. B. New Orleans, U.S.A., 7 May 1885.

Tasmania to support an annual production of 6,000 tons of the metal a year; the highest grade deposits were found in Victoria, and proved to be considerably larger than was at first estimated.[7] Commercially useful bauxite was unknown in Tasmania until late in 1941 when an ore-body estimated to contain 500,000 tons of 41.2 per cent alumina was discovered in the Ouse Valley. Later exploration on Wessel Island, north-east of Arnhem Land, revealed the presence of 10,000,000 tons of better-grade bauxite than any previously discovered on the mainland.

Two metallurgists, Messrs Keast[8] and Hey,[1] were sent by the Government to examine the aluminium industries of Great Britain, Canada and the United States. They found, as they had expected, that throughout these countries the only processes used for producing aluminium were the Bayer process for purifying the bauxite and the Hall electrolytic process for the extraction of the metal. Although during the early part of the war large sums of money were spent by the United States War Production Board and Bureau of Mines in efforts to increase the production of aluminium, no new process reached the commercial stage. Alternative methods of purifying bauxite which did not require the large quantities of caustic soda used in the Bayer process and then in short supply, were worked out by White Metals Pty Ltd and Sulphates Pty Ltd, Victoria. Despite the fact that they seemed quite promising, they were not followed up, for the reason that caustic soda once more became plentiful.

An essential requirement for the economic extraction of aluminium from its ores was an ample supply of cheap hydro-electric power. Experience had shown that there was a minimum size for a metal extraction industry below which it became uneconomic. The number of electrolytic cells needed for most efficient operation was smaller for aluminium than for most other metals. It so happened that this minimum coincided roughly with the size of the plant contemplated for Australia: one capable of an annual output of 6,000 tons of aluminium. The quantity imported before the war was much less than this, amounting to a little over 1,300 tons a year, but it rose considerably after 1939, reaching an average of about 9,000 tons in the war years. However these plans were baulked by the refusal of the United States to supply under Lend-Lease the necessary plant and technical information.

By 1944 all danger of an aluminium famine had passed; importation of 10,000 tons from Canada during that year removed the immediate need to produce aluminium locally. However the basic importance of aluminium to Australian industry was not forgotten; in April 1944 an agreement was reached between the Commonwealth and Tasmanian Governments under the Aluminium Industry Act to establish the industry in Tasmania and in May of the following year the Australian Aluminium

[7] Development of this field was carried out by Sulphates Pty Ltd, Vic.

[8] A. J. Keast, CBE, MM. (Served 1st AIF and RAF.) General Manager, Broken Hill Assoc Smelters, 1947-50; General Manager, Aust Aluminium Production Commission, 1951-55. B. Kiata, Vic, 21 Jun 1892.

[1] H. Hey. Chief Metallurgist, Electrolytic Zinc Co, 1927-43, Technical Superintendent 1943-44, Chairman and Mg Dir since 1952. B. Horbury, Eng, 20 Jun 1892.

Production Commission was constituted. At its inaugural meeting in Hobart on 12th May 1945 the scope of its activities was outlined by Mr Makin, the Minister for Munitions. The guiding motives were now dictated by a desire to establish an economically sound industry instead of one improvised under war conditions, and a less hurried approach was made to the whole question. The sequel will be described in the final chapter of this volume.

Non-ferrous metal fabricating industries. The growth in Australia of factories where copper, zinc, lead and other non-ferrous metals and their alloys were wrought to basic shapes such as plate, sheet, strip, rod, sections, wire and tubes,[2] for subsequent use by the numerous units of the finishing industry, was a feature of the inter-war period.

With capital provided to a large extent by Australian mining companies, and technical assistance and machinery provided by established oversea firms, especially by British wire and cable interests, a large manufacturing centre was built up by Metal Manufactures Ltd at Port Kembla to produce an almost complete range of rolled, extruded and drawn shapes in copper. All the high-conductivity copper wire, as well as much other non-ferrous metal wire (aluminium and steel-cored aluminium) used in the electrical industry was made by this company. Austral Bronze Company Ltd of Alexandria, a subsidiary of Metal Manufactures, produced most of the copper and copper-alloy plate, sheet and strip, extruded rods, bars and sections and alloy wire used in Australia.

To be near the main government munitions factories, both companies established branch factories at Maribyrnong, where a similar but more limited range of products was made. About the same time the Austral Bronze Company built an annexe at Derwent Park, Tasmania, for rolling copper and copper alloys. Early in the war great extensions in the facilities for metal manufacturing were made by the government munitions factories themselves; here, especially in the ammunition factories at Footscray and at Hendon, South Australia, were made practically all the requirements of copper, lead and tin alloy sheet and strip for use in the manufacture of cases and detonator caps for small-arms ammunition, cases for gun ammunition and for many other purposes. All these were key industries, for in the manufacture of munitions copper and its alloys were exceeded in importance only by iron and steel.

By far the greater part of the fabrication of zinc in this country was in the hands of two companies: the Century Storage Battery Company Ltd and Metals and Ores Pty Ltd, both of Alexandria, New South Wales. The former, operating since 1935, produced a considerable proportion of the sheet zinc used in lithographic and photo-engraving work. In a factory designed with technical assistance from the United States but operated by an Australian staff, Metals and Ores Pty Ltd, a subsidiary of Eveready (Australia) Pty Ltd, began a new venture in 1942: the rolling of sheet zinc for the rapidly expanding dry battery industry.

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[2] The operations involved are referred to collectively as metal manufacturing.

Perhaps the most noteworthy development of the metal manufacturing industry in Australia during the second world war was the fabrication of aluminium, a development closely linked with the decision to manufacture aircraft. In the late thirties a group consisting of the British Aluminium Company Ltd, the Aluminium Company of Canada Ltd, Electrolytic Zinc Company of Australasia Ltd, and Metal Manufactures Ltd, formed the Australian Aluminium Company Pty Ltd. Rolling mills and a 3,000-ton horizontal hydraulic press for the extrusion of rods, bars and sections ordered by the company from Britain in 1939 were never delivered in Australia. Soon after the plant was completed it was transferred to the British Government, whose needs for aircraft at that time were urgent. A duplicate set of equipment ordered in the United States was ready to be delivered to Australia when Lord Beaverbrook intervened to have it transferred to Britain. Only after the intercession of the Australian Prime Minister, Mr Menzies, was the transfer cancelled and the equipment finally shipped to Australia; it was installed in the newly-completed works of the Australian Aluminium Company Ltd at Granville, New South Wales.

Provision was also made for casting and forging aluminium and its alloys; a special annexe operated on behalf of the Commonwealth Government was equipped with a drop hammer of 35,000 pounds' capacity for making large aluminium alloy forgings—propeller blades, crank cases, and tail wheel forks for aircraft.

The second largest fabricator of aluminium was G. E. Crane and Sons, whose factory at Concord, New South Wales, equipped with modern rolling mills and a first-class engineering workshop, was in point of fact the first to produce light alloy (aluminium base) aircraft sheet.[3] This company had fortunately just completed the installation of new and improved mills and ancillary plant intended for copper and brass sheet when the government aircraft program first began. Conversion to the processing of aluminium and its alloys was soon accomplished and the company took its place as an important supplier of material to aircraft factories. All the ingot aluminium used in these factories came from the Canadian Aluminium Company, which not only supplied large quantities of the metal (20,000 tons) but did so according to the promised schedules.

In the early thirties Professor Laby[4,5] had directed a team of geophysicists in the application, under the auspices of the Imperial Geophysical Experimental Survey, of the then-known methods of geophysical prospecting, to the testing of known ore bodies, and in the search for new ones. Expansion of this work was hampered to some extent by the fact that in no Australian university was there a department of geophysics (or, for that matter, of geochemistry), but in spite of this a small group of geophysicists was built up during 1934-41 by the Aerial, Geological and Geophysical Survey of

[3] A third factory for fabricating aluminium was built at Wangaratta, Vic, but it was completed too late to warrant its being put into operation.

[4] With the cooperation of Messrs Broughton and Edge.

[5] T. H. Laby, FRS, MA, ScD. Professor of Natural Philosophy, Univ of Melbourne, 1915-44; first President, Institute of Physics of Aust. B. Creswick, Vic, 3 May 1880. Died 21 Jun 1946.

Northern Australia. Its geophysicists were drawn largely from Australians who took part in the Imperial Geophysical Experimental Survey.

The small geological organisation in the Department of the Interior, known as the Geological Branch, was transferred to the Department of Supply and Development at the end of 1941. Early in 1942, at the request of this department, a committee of geologists appointed by the Australian National Research Council, with Professor Cotton[6] as Chairman, prepared a comprehensive report covering existing knowledge of the mineral resources of the Commonwealth.

As a result of the presentation of this report, the Geological Branch was increased in size by the addition of the geophysicists from the Aerial, Geological and Geophysical Survey, and the appointment of additional geologists, and renamed the Commonwealth Mineral Resources Survey. Dr Raggatt,[7] then Commonwealth Geological Adviser, was made Director of the Survey with Mr Nye[8] as Assistant Director. Thus began the first comprehensive and systematic attempt to coordinate the knowledge of the Commonwealth's mineral resources. It was restricted at first to minerals of importance to the war effort, but was later extended to include all minerals and to result in the formation of the first national geological survey.[9]

The State Mines Departments had a very good knowledge of the mineral resources within their own borders, but something more than that was required for planning a mineral industry and for meeting the calls made upon Australia by the Allied Nations. The great need was for coordinating information concerning the resources, production and consumption of minerals and for surveys on an Australia-wide basis.

Japan's entry into the war in December 1941, resulting as it did in the loss of important world sources of tungsten and tin in South-East Asia, greatly intensified interest in Australian resources of these metals. After the scope of the surveys of mineral resources had been widened, a corresponding expansion in the organisation for producing minerals took place, in March 1942, with the formation within the Department of Supply and Development of a Directorate of Minerals Production under Mr Newman,[10] a leading mining engineer. The National Security (Minerals) Regulations gazetted on 6th March 1942 gave Newman wide powers of operating, controlling and directing the production and supply of minerals throughout the Commonwealth, and authorised him to take any measures he thought necessary or expedient to those ends. From the outset it was planned that the Commonwealth Mineral Resources Survey should co-

[6] L. A. Cotton, MA, DSc. Prof of Geology and Physical Geography, Univ of Sydney, 1925-48; Prof Emeritus since 1948. B. Nymagee, NSW, 11 Nov 1883.

[7] H. G. Raggatt, CBE; DSc. C'wealth Geological Adviser 1940-51; Dir, Bureau of Mineral Resources, 1942-51; Sec, Dept of National Development, since 1951. B. North Sydney, 25 Jan 1900.

[8] P. B. Nye, OBE; MSc. (Served 1st AIF.) Govt Geologist, Tas, 1923-34; Asst Dir, C'wealth Bureau of Min Resources, 1942-51, Dir since 1951. B. Collingwood, Vic, 21 Mar 1893.

[9] An account of the formation of the Bureau of Mineral Resources is given in the last chapter.

[10] J. M. Newman, CBE; BE. C'wealth Controller of Minerals Prodn 1942; Director of mining companies in Aust, New Zealand and Malaya. B. Caboolture, Qld, 20 Jun 1880.

operate closely with the Controller of Minerals Production. The two organisations, in fact, used common files although they functioned separately.

Newman made full use of the facilities and experience of private mining companies, which cooperated in the development of undertakings and also provided much expert technical advice. This was particularly true of the Zinc Corporation, North Broken Hill, Broken Hill South, Mount Isa Mines and Lake George Mines. With the aim of enlisting the aid of all government mining administrations, Newman appointed as his delegates heads of Departments of Mines in all States—an arrangement which, operating smoothly, enabled the fullest use to be made of the resources of State departments. In carrying out his work as controller, Newman was constantly hampered by the fact that it was impossible at any time during the war to determine with any degree of accuracy Australian requirements of metals and minerals. There was of course no novelty in this; the same could be said about the supply of almost any material in almost any country at war. He was, however, aware of the main metals and minerals whose local output should be increased—copper, aluminium, tungsten, tin, beryllium, mica, molybdenum, tantalum, antimony and arsenic, quartz crystals, and asbestos—and control of production and distribution was concentrated mainly on these.

Tungsten. When the Japanese overran China, Thailand, Burma and Malaya they cut the Allied nations off from the source of roughly 60 per cent of the world's tungsten. Without tungsten, which was indispensable for making special steels, radio valves, electric lamps and tungsten carbide, the manufacture of munitions would have been seriously impeded. Australian production of tungsten concentrates, in the neighbourhood of 1,000 tons a year before the war, had dropped to 800 tons by the end of 1941, owing partly to the drift of labour from the mines. In answer to an urgent appeal from the British Government early in 1942, the Controller of Minerals took steps designed to stimulate the production of tungsten concentrates (wolfram and scheelite), in some instances by establishing government enterprises and in others by providing financial assistance to companies and individuals; and in general by ensuring the highest priorities for manpower, plant and equipment. The major enterprise operated by the Government was a failure. Some 600 Chinese workers evacuated from Nauru and Ocean Islands where they had been working for the British Phosphate Commissioners, were sent to the Hatches Creek and Wauchope tungsten mines in the Northern Territory. Unfortunately these workers proved uncooperative and ill-fitted for the work. At the end of 1943 they were taken over by the United States Army and arrangements were made to replace them by Italian workers. The replacement was never made, because by that time the urgent need for tungsten had passed.

The prospects of producing large quantities of tungsten concentrates from the different private ventures were not good because they were as a rule small and widely dispersed. Much effort was spent on exploiting them, with disproportionately small returns. The outlook changed early in 1943 when, as a result of surveys made by Mineral Resources Surveys in the previous year, the true extent of the scheelite deposit on King Island (in Bass Strait) was ascertained. The deposit appeared to be the largest of its kind anywhere in the world. Its existence had been known for many years and it had been worked from 1916 to 1920.[8] In 1938 the mine was re-opened, but its output rapidly declined—from 275 tons in 1940 to 32 tons in 1944—owing mainly to shortage of labour and more particularly to the reorganisation of the plant which took place towards the end of that period. By then the Allies had all the tungsten they needed, but notwithstanding this, reorganisation of the mine and treatment plant was continued.

In spite of the vicissitudes of the different ventures, and in the face of difficulties arising from fierce competition for machinery and manpower, Australia was able to fulfil her own needs for tungsten as well as to supply 2,000 tons of concentrates (valued at £1,000,000) to the British Government at a time when they were urgently needed. The B.H.P. extracted approximately 500,000 pounds of the powdered metal, besides consuming a good deal of tungsten concentrates in the manufacture of ferro-tungsten. Much of the powdered tungsten was used for making tungsten-carbide tool tips; some was used for making wire. The Metallurgy School of the University of Melbourne designed and constructed a plant for the fabrication of tungsten rod and wire at the rate of about half a ton a year. It was in operation between 1943 and 1944 but thereafter was completely abandoned, presumably because tungsten wire could be imported more cheaply. Having developed the specialised techniques of powder metallurgy required to fabricate tungsten, it might seem a mistake that the whole thing was abandoned, since in the event of another war it would have to be built up again. As with most apparently lost opportunities of this kind, the reasons were mainly economic: the needs of the whole of the Australian electrical industry (lighting and radio) were insufficient to make it worth while to continue manufacturing tungsten wire locally.

Tin. From being the world's leading producer of tin (between 1873 and 1882), contributing 25 per cent of the world's supplies, Australia had by 1939 fallen to ninth on the list with a contribution only 2 per cent of the world total. Even this reduced output was more than ample for the country's peacetime needs. Tin was one of the essential metals, both for munitions and peacetime industry, for which it was often impossible to find an adequate substitute. About 35 to 40 per cent of the world's tin was used in the manufacture of tinplate, without which the food-canning industry would be at a serious disadvantage. Owing largely to the opposition of oversea interests, Australia at this period had no tinplate industry and was thus entirely dependent on outside supplies.

[8] It was discovered by Mr T. Farrell, and in 1916 was reported on by Mr L. Waterhouse, at that time Assistant Govt Geologist in the Tasmanian Mines Dept. The later assessment was made principally by P. B. Nye and M. A. E. Mawby.

Tin was an essential component of many alloys—bronzes, gun metals and solders—and it was mainly for these purposes that tin was used in the munitions program. Greatly increased consumption was expected during the war (it actually rose from about 2,100 tons in 1939 to 3,000 tons in 1942). After the loss of the Malayan tin mines, the principal source of world supplies, the Australian Government was informed by the Raw Materials Board in Washington that it would have to rely on its own tin resources to supply its needs and that it should also make itself responsible for satisfying the needs of New Zealand. Before the war a substantial proportion of locally-produced tin came from small producers, and in the early years of the war many of these men left the industry, with the result that the increased Australian needs could not be met. The Minerals Production Directorate promptly took over the Mount Bischoff tin mine in north-west Tasmania and operated it for several years. This mine, once among the great tin producers of the world, had gradually fallen off in its output until, just before the war, it was producing no more than 126 tons a year and was in danger of being closed down. Its revival did not long outlast the war since reserves were practically exhausted and the mine was no longer capable of economic operation. The directorate also took over the alluvial tin deposits of the Dorset flats in north-eastern Tasmania and installed a dredge, a project which was still being operated by the Commonwealth Government ten years after the war. By giving extensive financial and technical help to many small producers and by rigid control over the uses of tin for purposes other than making munitions, the Government ensured that wartime needs of tin were met.

Cobalt. No attempt had been made to extract metallic cobalt in Australia before the war. The problem of satisfactorily disposing of cobalt nitroso-β-naphthalate, the form in which the metal was removed in the course of purifying zinc sulphate solutions before electrolysis, had occupied the research department of the Electrolytic Zinc Company for many years. It was the demand which sprang up during the war for metallic cobalt to make cemented tungsten carbide tool tips and special magnetic alloys (such as the alnico alloys), that first provided a useful outlet for the small amounts of cobalt recovered at Risdon, Tasmania.

About this time New Zealand and Australian scientists working on problems of animal nutrition discovered that sheep grazing on pastures deficient in cobalt became subject to serious malnutrition, from which they often died; further, that the disease could be cured by the simple expedient of adding cobalt salts to the deficient soils. Cobalt in the form of cobalt sulphate, also made at Risdon, was supplied to agriculturalists for incorporation in fertilisers, so providing another outlet for this useful by-product.

Antimony and arsenic. When supplies from Wiluna, Western Australia, the largest producer of antimony in Australia, began to show signs of falling off, the Directorate of Minerals Production arranged to bring into operation, as government enterprises, several areas in Victoria (including

Coimadai and Costerfield), in order to guarantee adequate supplies of this metal, which found extensive use in the munitions industry for hardening the lead used in bullets and storage batteries. O. T. Lempriere and Co Pty Ltd, Sydney, furnished the whole of the Australian requirements of antimony, antimony oxide, and sodium antimonate. Large amounts of the oxide were used during the war in making up flame-proofing mixtures for treating canvas. Australia was also able to supply her own needs of the closely related element arsenic and to send 3,000 tons of arsenic to the British Government in response to an urgent order after the fall of France.

It has been said that the extent to which unprocessed minerals are exported from a country may be taken as a rough index of its lack of industrial development.[9] In applying this criterion it must be remembered that in 1939 there were some metals that were extracted from their ores only in the most highly industrialised countries. Australia had a number of ore deposits in this category, such as those containing the metals tantalum, beryllium and titanium.

Tantalite. Western Australia and the Northern Territory were notable for their deposits of rare metals; the former possessed at Wodgina a deposit of tantalite, source of the metal tantalum, which for its size and the high ratio of tantalum to columbium in its ores was unique.[1] The first tantalite mined anywhere on a commercial scale came from this field in 1905, and up to 1939 Australia enjoyed a world monopoly in the production of high-grade tantalite. Until that time nothing had been done to process tantalite locally. In 1942 Professor Greenwood[2] and Mr Myers[3] of the Department of Metallurgy in the University of Melbourne, following methods worked out in Europe and the United States and working on a laboratory scale only, separated Australian tantalite ores into the complex fluorides of tantalum and columbium.[4] They made the carbides of each of these metals and later isolated the metals themselves. Before any commercial use could be made of this laboratory work,[5] the Commonwealth received an urgent request from the United States Government for as much tantalite as could be supplied. A contract was made with the Metal Reserve Corporation of the United States by which the Commonwealth would supply 165 tons of concentrates assaying 60 per cent tantalum oxide. Small as this amount may sound, it was a tall order, for

[9] R. Grenfell Thomas, "Chemical Processing in the Australian Mineral Industry", *Journal of the Society of Chemical Industry of Victoria,* Vol. 43 (1943), p. 483.

[1] These two metals always occur together. At the time there was greater interest in the use of tantalum.

[2] J. N. Greenwood, DSc. Professor of Metallurgy, Univ of Melbourne, 1924-45, Research Professor of Metallurgy since 1946. B. St Helens, Eng, 12 Dec 1894.

[3] R. H. Myers, MSc, PhD. Commonwealth Research Fellow, Univ of Melbourne, 1941-47; Research Officer Atomic Energy Research Estab, Harwell, Eng, 1948-52; Prof of Metallurgy, NSW Univ of Technology, since 1952. Of Melbourne; b. Melbourne, 21 Feb 1921.

[4] R. H. Myers and J. N. Greenwood, "The Processing of Tantalite Ore and the Preparation of the Carbides of Tantalum and Columbium", *Proceedings of the Aust Institute of Mining and Metallurgy,* New Series, No. 129 (1943), p. 41.

[5] The experimental work on the carbides found application in the manufacture of sintered carbide cutting tools.

tantalum is an exceedingly rare metal. In an attempt to meet it quickly the Controller of Minerals bought up parcels of concentrates from scattered small producers, and at the same time took over the Wodgina tantalite mines.

At one stage of the war the need for tantalum was so acute that 18 tons of tantalite concentrates were actually flown from Australia to the United States. It was there that the entire requirements of the Allied nations for refined tantalum metal were produced. Although more equipment was installed at Wodgina in order to treat an increased output of ore, the results proved disappointing. After about 3,500 tons of crude ore had been mined, the deposit gave out; the total quantity of tantalum concentrates exported to the United States did not amount to more than 24 tons assaying 65 per cent tantalum oxide. This, while far short of the contracted amount, did make up a substantial proportion of the requirements and was therefore a most useful contribution. The project, which involved the Directorate of Minerals Production in a loss of more than £100,000, was written off as a direct contribution to the Allied war effort.

Most of the numerous uses to which tantalum metal was put depended on its extraordinary resistance to corrosion. It is outstanding in its suitability for implantation in the human body, and much of the metal was used in the manufacture of thousands of surgical plates, wires, tubes and ligatures. Another important wartime use for tantalum was in the form of alloys with tungsten and nickel in the manufacture of radio and radar valves. Compounds of tantalum found two important applications. Firstly, potassium tantalum fluoride was widely used as a catalyst in the making of butadiene, starting material for one of the most important of the synthetic rubbers (Buna S). Secondly, small amounts of tantalum carbide were mixed with tungsten carbide in making cemented tips for machine tools; during 1943 and 1944 Hard Metals Pty Ltd of Sydney, a subsidiary of Australian General Electric Pty Ltd, consumed 1,389 pounds of tantalite in the manufacture of tool tips. This was the only instance of the commercial use of processed tantalum concentrates in Australia during the war years. For some years after the war the output of tantalite in Australia slowly declined, reaching 1 or 2 tons a year in the period 1947-48. Deposits of the ore in sight had been practically exhausted, and ruling prices offered little incentive to further exploitation.

Beryl. When, towards the end of 1942, the United States advised the Commonwealth Government that it urgently needed large supplies of beryl (the only mineral so far used commercially for the extraction of beryllium), a hurried search had to be made for possible sources of supply. The delay that occurred in locating sources was inevitable in the absence of a national survey of mineral resources. It so happened that the demand could have been met from one mine in Western Australia, but this information was not revealed until every State in the Commonwealth had been written to and until the replies had been examined and compared.[6] In any well-organised survey of mineral resources it would have been available instantly.

Beryllium is a very light, extremely hard, and somewhat brittle metal with a lustre resembling that of a freshly-cut surface of lead. It is difficult to machine and is highly resistant to corrosion. At this time the metal itself was not widely used but its alloys were highly prized, for reasons which make wartime demands for it clear. Beryllium-copper, for example, possessed to an unusual degree resistance to fatigue combined with great strength, hardness and resistance to corrosion and wear. The electrical conductivity of this alloy was not appreciably less than that of pure copper. These properties made beryllium-copper and similar alloys useful for the construction of springs for the moving parts of aero-engines and aircraft instruments, and in the manufacture of parts for tanks, guns, electric motors and shells. Owing to its non-sparking character beryllium-copper was used in making tools for work in explosives factories. Most of the beryllium consumed during the war went to the aircraft industry, much of it in the form beral, an alloy of beryllium and aluminium.

Most of the beryl mined in 1943-44 was obtained as a by-product of the mining of tantalite, with which it is closely associated. A considerable stock of beryl built up by the former owner of the mine at Wodgina, together with some produced by operations on behalf of the Commonwealth Government, amounting in all to about 925 tons, was exported to the United States. Beryl from this source also contained small but none the less important amounts of the extremely rare metal caesium.[7] At the conclusion of mining operations in 1944 all easily won beryl and tantalite in sight had been exhausted.[8]

Beryl was one of the first minerals to be studied at the Division of Industrial Chemistry, where small amounts of beryllium oxide were smelted with carbon and copper to make beryllium bronze.

Rutile. The stimulus of war not only hastened the establishment of a national survey of mineral resources, it also did much to spur on scientific investigation of methods for the more efficient use of known resources, especially those minerals for which Australian industry had so far found little or no use and of which there was a plentiful supply.

In the beach sands of the eastern coast of Australia are some of the world's richest deposits of rutile and zircon, minerals containing the metals titanium and zirconium. When these sands were first exploited, in the early thirties, little more was done than recover the minerals in the form of a crude mixed concentrate, which was then exported to the United States at the rate of many thousand tons a year.

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[6] H. G. Raggatt, "Australia's Mineral Industry in the Present War". Clarke Memorial Lecture delivered before the Royal Society of NSW, 23 Jun 1943.

[7] About 1 per cent.

[8] C. J. Sullivan, *Beryllium Summary Report No. 18*; Bureau of Mineral Resources; reprinted 1948. At this date geologists held the view that similar bodies of beryl might well be found at greater depths.

By 1939 one section of the industry had evolved methods based on the principles of flotation and differential magnetic separations, for the production of clean zircon concentrates of exceptional purity, and rutile of only a slightly lower grade.[9] In spite of this success, most of the minerals shipped overseas during the war continued to take the form of crude mixed concentrates.[10] A growing concern at the failure of the mining and chemical industries to take a more practical interest in exploiting these and other minerals resulted in the formation, within the Division of Industrial Chemistry, of the Minerals Utilisation Section.[1] This was a significant step towards a greater development of the country's internal resources. A few examples will illustrate the usefulness of the section's work during the war.

One of the principal uses of rutile was for coating rods for arc welding, where its function was to shield the electric arc from oxidation during welding and to produce a brittle slag which protected the cooling weld deposit. Most of the 400 tons of rutile consumed locally was used for this purpose.

Rutile, however, was a valuable raw material for chemical industry. It was the source of one of the best smoke-producing substances known—titanium tetrachloride. The Minerals Utilisation Section, by means of a pilot-scale plant, worked out details of a process for manufacturing the tetrachloride using locally mined rutile in place of imported, chemically prepared, titanium dioxide.[2] This process formed the basis of its subsequent large-scale production for the Commonwealth Government by I.C.I.A.N.Z. Once the demand for large quantities of titanium tetrachloride as a smoke producer diminished, the problem arose of finding other uses for reserve stocks. At least two interesting developments followed.

Firstly, the tetrachloride was used as a raw material for the extraction of the metal. The metallurgy of pure ductile titanium metal was not well developed anywhere until some years after the war; the manufacture of titanium powder of reasonably high purity was a fairly difficult operation.[3] The Physical Metallurgy Section in the Division of Industrial Chemistry, using a method based on the reduction of titanium tetrachloride with magnesium, made small quantities of the powder of 98 per cent purity, and showed that it was entirely satisfactory for removing the last traces of oxygen and nitrogen from already highly evacuated radio valves. At least one Australian valve manufacturing company (Amalgamated Wireless

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[9] W. R. Poole, "Zircon and Rutile from Beach Sands", Part I, *Chemical and Engineering Mining Review,* Vol 31 (1939), p. 365.

[10] The position changed after 1944 when the Department of Trade and Customs prohibited the export of mined crude concentrates.

[1] The section was put in charge of Mr R. Grenfell Thomas. See R. Grenfell Thomas, "Chemical Processing in the Australian Mineral Industry", *Society of the Chemical Industry of Victoria,* Vol 43 (1943), p. 483.

[2] F. K. McTaggart, "Production of Titanium Tetrachloride from Australian Rutile Sand", *Journal of the Council for Scientific and Industrial Research,* Vol 18 (1945), p. 5.

[3] Owing to its great affinity for oxygen and nitrogen, titanium metal at high temperatures must be handled in an inert atmosphere, preferably of helium or *in vacuo.* This, together with its high melting point, makes its production both difficult and costly.

Valve Co Pty Ltd) adopted this method for supplying its requirements of titanium powder.

This was the first important work done in Australia on the metallurgy of a metal which, on account of its lightness, strength and resistance to corrosion, seemed likely to become an important material of construction.

A discovery made by the Minerals Utilisation Section was the use of butyl titanate as a vehicle for various inorganic pigments such as zinc and aluminium powder in the formulation of heat-resisting paints. While striking results were obtained with the use of such paints, commercial development of these products was slow during the war. Subsequently the formulations were greatly improved by the Paints Section of the Munitions Supply Laboratories and industrial interest in the manufacture of butyl titanate abroad was initiated as a result of this work. The possibility of using synthetic titanium nitride as a bonded material for tipping cutting tools was also explored by the Minerals Utilisation Section. Somewhat inferior to tungsten carbide in hardness, the bonded titanium nitride was much cheaper to produce; its use in the war period did not go beyond the experimental stage.

Sulphur. No organised searches were made for new sources of sulphur. However, many deposits of pyrites were examined by officers of mines departments and the Mineral Resources Survey in the course of other investigations. When all the information from these sources was collated it became evident that Australia's resources were very large indeed and that they could meet all her sulphur requirements for a very long time.

Mica. Some minerals are valued not for any metals they may contain but for themselves. Mica, graphite, asbestos and quartz belong to this class. Though not consumed in large amounts, their uses were such as to render them of some importance, especially in war. Mica was unequalled as an electrical insulator, and had no substitute: no other mineral combined ready cleavage, flexibility, elasticity and optical transparency with high dielectric strength, electrical resistance and low thermal conductivity. During the war it was in greatest demand by the electrical industry, for making condensers. Efforts in various parts of the world before the war to make synthetic mica failed to yield the large single crystalline sheets found in nature.[4] In the electrical industry it was even more important than copper.

Of the commonly-occurring varieties of mica, muscovite was quite the most important. It occurs as crystalline plates which can be readily split into extremely thin, clear, practically colourless transparent sheets, some 60 square inches or more in area. In peacetime many different grades of mica, colour-spotted and stained as well as the highest grade, are used; in war the same was true except that the relative proportions of the

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[4] Siemens in Germany successfully synthesised crystalline mica sheets by the end of the war, but only on an experimental scale.

grades used were reversed so that the highest grade was the one for which demand was greatest.

The most important deposits of mica were found in regions not easily accessible—in the Harts Ranges and along the Plenty River, 150 and 250 miles north-east of Alice Springs. Smaller deposits at Yinnietharra, Western Australia, and the Barker River were in similar out-of-the-way places. As happened in other branches of the mining industry, and for substantially the same reason—drift of labour from the mines—the output of mica fell seriously during the early part of the war—from about 30 tons a year to less than 10 tons in 1942. A Commonwealth Mica Pool formed in 1942 was at first unable to do more than attempt to stockpile and to conserve supplies by controlling distribution. Since large amounts were needed for the rapidly growing aircraft and electrical industries, it was imperative that it should not be diverted to less essential uses.[5] Manufacture of radiators, toasters and electric irons was therefore forbidden. This had the effect of increasing the cost of producing high-grade mica by taking away the outlet for inferior sheet.

Production of mica became the close concern of the Controller of Minerals, who in order to attract workers to the fields in the Harts Ranges and neighbouring country, arranged with the Director-General of the Allied Works Council to have reasonably good roads constructed and water supplies put down. Every encouragement was given to miners to return to the mines: motor compressors, jack hammers and other mining equipments were brought into the area and hired out by the Government on a rental basis; weekly transport was arranged to convey stores and mail, and wireless transmitting and receiving sets were installed at suitable mines. These conditions, together with a guaranteed price for mica, induced miners to return. Production climbed steeply, output rising to 50 tons a year of mica, principally muscovite of high quality. All these efforts were not sufficient to keep pace with the sevenfold increase in consumption of mica and it was fortunate that it was possible to bridge the gap by imports from India.

Quartz crystals. Quartz, though easily the most abundant mineral in the earth's crust, is seldom found in large deposits of well-formed crystals of any size. Only after the advent of radio-communication did quartz crystals possess sufficient technical applications to warrant an intensive search for them. They then assumed considerable importance because of their piezo-electric properties.[6] When distorted by mechanical pressure, differences of electrical potential are created on their surface. The reverse is also true: if a potential difference is applied to the opposite faces of a crystal a small change in shape, or distortion, will result.

The great demand for quartz crystals in war depended on their use to maintain constancy in the frequency of radio waves employed in communi-

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[5] Fifty per cent of high-grade mica was used in the radio industry, 10 per cent in making spark plugs for internal combustion engines.

[6] Other crystals are known to be piezo-electric, but none is so durable and robust as quartz.

cation. Another but less common use depended on the fact that vibrating quartz crystals set in motion by high-frequency currents were the source of ultrasonic waves used in the underwater detection of submarines, and in depth recorders. The consequent greatly-increased demand early in the war exceeded the output of Brazil and Madagascar, the world's principal sources of supply. Anxious searches were made at the instigation of the Controller of Minerals for supplies in Australia. For a brief period, owing to the unprecedented demands of the Services, there was a possibility that ships, tanks and aircraft might not be adequately equipped with radio, so meagre were supplies of quartz crystals. Responsibility for investigating all known deposits and reported occurrences of quartz crystals was undertaken by North Broken Hill Ltd, which arranged for its consulting geologist, Mr Garretty,[7] to carry out surveys. Crystals were found in many localities but in only one was there a sufficient quantity of the high quality needed to warrant commercial exploitation. This was at Kingsgate, New South Wales, where the first efforts were concentrated on turning over old "dumps" left from mining operations for molybdenum begun during the 1914-18 war. Later, operations were transferred to the mines themselves—shafts that had been sunk into the pipes of an old volcano.[8] The yield of high-quality crystals from this source was not high. Nevertheless it was, for a time, Australia's sole source of supply.

Asbestos. Australia had always relied on oversea sources—principally Canada and Africa—for supplies of asbestos. For this reason the Mineral Resources Survey made a detailed assessment early in its history of the rather widespread but small Australian deposits of chrysotile. Efforts were first made to work deposits in Western Australia of chrysotile of a grade suitable for spinning the textiles used in heat insulation and fire proofing. From 1942 onwards small amounts of chrysotile mined in New South Wales were used in making asbestos cement products: plain and corrugated sheets and pipes for the building industry. In Tasmania an attempt was made to work a small deposit of chrysotile near Zeehan, but it proved to be uneconomic and was soon abandoned. Attention was then given to the very large deposits of crocidolite (another variety of asbestos) in the Hammersley Ranges in Western Australia, and the industry was begun at Wittenoon in 1943. Before much progress had been made with this mine African and Canadian producers, finding their European markets closed, began to offer increasing quantities to Australia. Nothing much came of this venture until some years after the war.

Graphite. Graphite, one of the naturally-occurring crystalline forms of carbon, was an essential component of dry batteries, foundry facings, crucibles and some types of refractory. It owed its use in these ways to its

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[7] M. D. Garretty, DSc. Chief Geologist, North Broken Hill Ltd, 1939-46. B. Sydney, 23 Feb 1914.

[8] M. D. Garretty, "Notes on the Occurrence of Piezoelectric Quartz in Australia with Special Reference to the Kingsgate Field", Bulletin No. 13, Geological Series No. 4, Bureau of Mineral Resources, Dept of Supply and Shipping. See also: F. Canavan, "Piezo-electric Quartz", Bulletin No. 10, Misc. Series No. 4; and F. N. Hanlon, "The Etch Figures of Basal Sections of Quartz", *Journal and Proceedings of the Royal Society of NSW*, Vol 77 (1943), p. 40.

chemical stability and inertness. Over the years 1940-44 the proportion of Australia's requirements of graphite obtained from local sources rose from 3 to 40 per cent. Most local graphite came from mines at Uley and Koppio in South Australia and from Collinville in Queensland. Owing to the stringent requirements for the graphite used in batteries—only minute amounts of impurities could be tolerated—none of the Australian graphite could be used alone for this purpose. By blending with superior imported graphite it was possible to use a substantial amount of Queensland graphite in the battery industry. Attempts were made to improve the grade of Australian graphite, both by chemical and by physical methods.

One of the long-range problems undertaken by the Division of Industrial Chemistry was a study of the fundamental processes underlying flotation. Although Australian mining companies had done much pioneering work in the early part of the century on the large-scale application of flotation, there was still a great deal to learn about its scientific basis; but before going ahead with this it was natural that the division's attention should have been directed to *ad hoc* problems brought up by the war. One of these was the purification of graphite. Treatment by flotation enabled the purity of graphite to be raised to somewhere in the vicinity of 90 per cent, but though the carbon content was high enough the nature of the impurities that remained precluded its use in batteries. Chemical methods for removing impurities inaccessible to the flotation process of separation, were then pressed into service. Combination of the two methods of purification resulted in a graphite whose performance in dry cells was equal to that of the high-grade material imported from Ceylon. Owing to the inertia of the battery companies the application of this work came too late to have any direct influence on the use of Australian graphite during the war, but it was of permanent value in later years.

Monazite. Monazite, a minor component of the black sands of the East Australian beaches, is recoverable during the separation of zircon and rutile. Notable for the variety of products obtainable from it by chemical processes, monazite is a valuable source not only of thorium and cerium but also of a number of metals belonging to the rare earth family. When treated by a process worked out in the Minerals Utilisation Section, monazite proved a source of the rare earth fluorides used in the cores of searchlight carbons to give the arc its great brilliance, and also of mixed cerium group oxides for polishing optical components. The Division of Industrial Chemistry made substantial quantities of a special grade of rare earth oxide, mainly cerium dioxide, which it supplied to the Scientific Instrument and Optical Panel of the Department of Munitions. This material, the speediest and most effective of all polishing powders, played a useful part in the production of optical munitions.