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RECORD

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MINERAL RESOURCES OF AUSTRALIA

1985

by

MINERALS BRANCH

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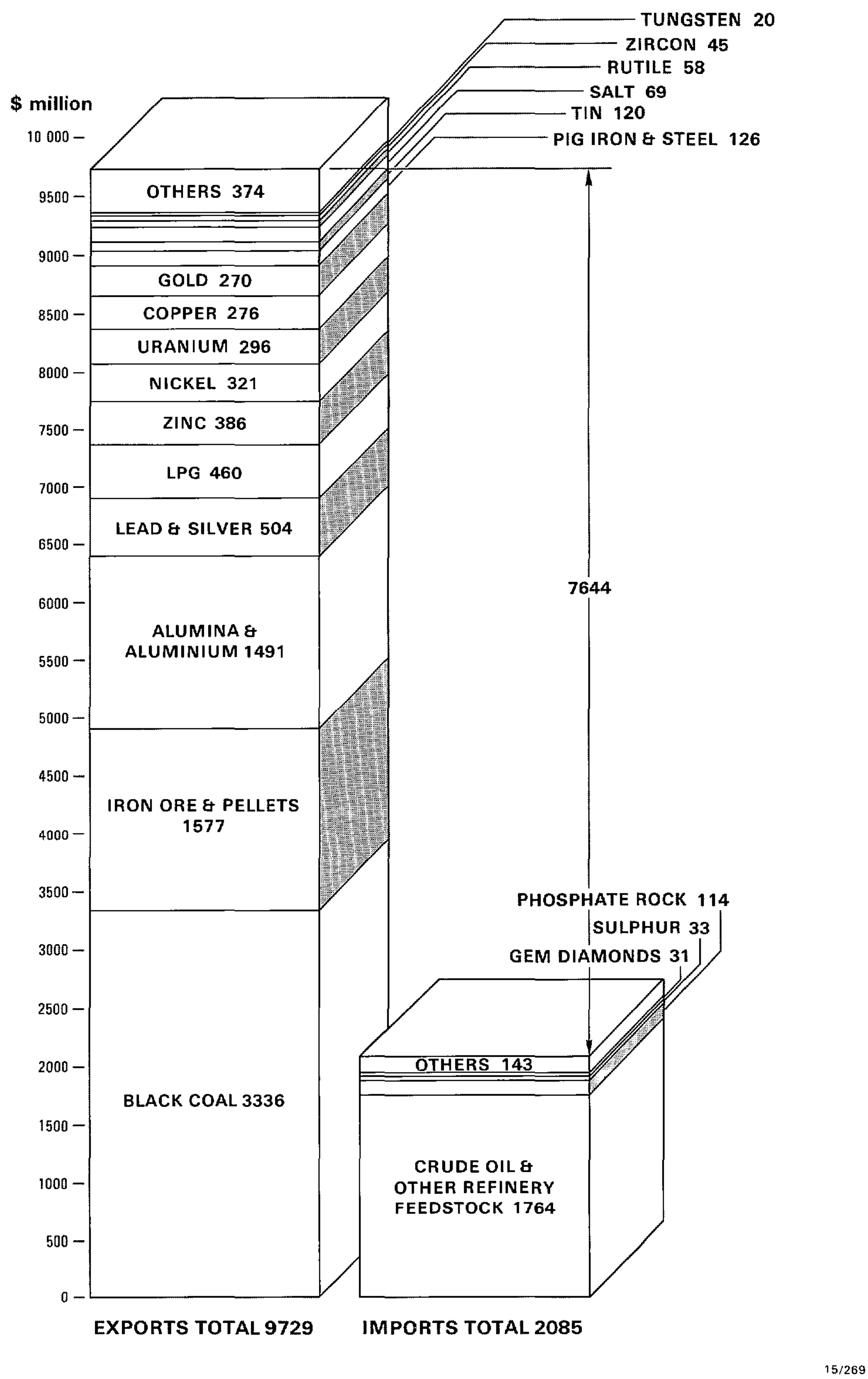
ABSTRACT

The minerals industry has made an important contribution to the Australian economy since the mid 1800s, and in the last 20 years it has expanded severalfold. It now plays a fundamental role in the Australian economy and has become an equal partner with the agricultural-pastoral industries as a mainstay of our economy and export trade. The annual value of mine production is now more than $10.2 billion and Australia's favourable annual balance in mineral trade is about $7.6 billion.

This paper first summarises the development of the Australian mineral industry, which is divided into four stages - early settlement and exploration from 1788 to 1851, establishment of the mineral industry from 1851 to about 1910, the lean years of exploration and development from 1910 to about 1950, and the large and varied developments leading from discoveries made in the last three decades. The broad spectrum of minerals mined in Australia is then described, under the general headings: energy minerals, iron and ferroalloys, base metals, other metals, and non-metallic minerals.

Australia is now a leading world producer and exporter of many minerals, and in most cases this is based on extensive resources. Before World War II Australia had a long list of mineral deficiencies. As late as 1965 the value of mineral trade was barely in balance, but now the value of exports is more than four times as great as that of imports. Coal, iron ore, and the products of bauxite mining account for about 66% of the value of mineral exports; oil continues to be our most costly mineral import and accounts for about 85% of the value of mineral imports. At this stage, elemental sulphur seems to be our only true 'geological' mineral deficiency. Other major mineral imports (asbestos, phosphate rock, and ferroalloys) reflect 'economic' rather than 'geological' deficiencies.

Government has assisted the development of the mineral industry by providing topographic, bathymetric, geological, and geophysical maps; through bounties, subsidies, and taxation concessions; and by stockpiling. However, notwithstanding Government assistance and a rich natural mineral endowment, vigorous exploration and development programs must be maintained if the industry is to continue as a major industrial sector of the economy, and a major source of supply of minerals, processed and unprocessed, to world markets.



Australian Balance of Trade, Mineral Products, 1983

INTRODUCTION

This paper attempts to give a broad picture of Australia's mineral industry, and of the varied and widespread resources on which it is founded. It includes a quick glance at the history of the industry and the domestic requirement for the principal minerals and ores, some notes on the chief deposits and centres of production, reference to some of the industrial activities dependent on minerals, remarks about recent important events in mineral exploration, and an attempt to foresee what lies ahead. We should like to acknowledge the assistance of officers of the Petroleum Branch, the Uranium Resources Evaluation Unit, the Division of Continental Geology, and particularly Mr A.G.L. Paine of the Publications and Information Section for his editorial assistance.

The topic of mineral resources is a large one. Australia's known mineral wealth has increased with every decade since the first major discoveries more than a century ago. Our growth as a nation has owed much in the past to the flow of population and capital which followed the early mineral discoveries. This flow reached a peak towards the end of the last century, then slackened for almost fifty years; it began again in the last three decades in the wake of exciting discoveries from which great new sources of wealth have emerged.

This new era in mineral development in Australia, with its rash of discoveries and subsequent exploitation, stemmed from many related factors - new exploration tools and concepts, the introduction to Australia of foreign capital and expertise, the rise of Japanese markets, and the advent of bulk carriers, to name a few - and has resulted, in recent years, in the mining industry rivalling the rural industry as a mainstay of our economy and export trade.

Statistics available do not indicate the real contribution of the mineral industry to G.D.P. but the value of exports of industrial groups within Australia, given in Table 1, shows the rising impact of the mineral industry on overseas funds as the largest single export earner in recent years. The contribution of mines and quarries in 1983-84, given as 27.3% of all exports, is in fact higher because the industrial classification used in Table 1 allocates some exports by the smelting and refining sections of the industry to 'manufactures'. For example, if the value of alumina is added to mineral exports the contribution rises to 32.0%.

However, the mineral industry cannot be seen in perspective without identifying problems as well as achievements. If the current high level of self-sufficiency in crude oil is to be maintained, additional reserves must be

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delineated; this will require large amounts of capital for exploration and development; restricted domestic markets for processed products, amongst other factors, continue to place restraints on mineral processing; domestic cost increases, relative to those overseas, have eroded our competitiveness and discouraged some new developments; and the prosperity of the industry, inevitably based on exports although benefiting from long-term contracts, remains heavily dependent on the Japanese economy, which currently provides markets for 42% by value of our mineral exports. Indeed the temporary slowing down of the Australian mineral industry from 1975 to 1978, as a result of lower world metal prices and of checks to the economy of both USA and Japan in particular, as well as the current world economic recession, serve as a salutary reminder of our vital concern with world economies and of our need to diversify our mineral trade as much as possible.

Reactions from Australian and foreign stock exchanges, the inevitable failure of some ill-equipped small mining companies, and other regrettable but spectacular events following the boom years of the late 1960s and early 1970s tended to exaggerate the situation and to obscure the fact that in terms of development and production the industry has continued to progress. The ex-mine value of production and value of exports continued to rise. The level of exploration expenditure, in real terms, has increased every year from 1976 to 1981; this trend was reversed in 1982 for non-petroleum exploration expenditure which declined in both money and real terms, and has continued to decline to December 1984, the last date for which expenditure statistics are available. A high rate of exploration is important if Australia is to be provided with the additional ore deposits required for continued development of the mineral industry in the 1980s, and is to be able to make proper assessments of its resources.

Another factor affecting the industry is the concern about environmental matters accompanied by delays and additional costs in some mining developments, and likely permanent loss of identified resources particularly those of mineral sands along the east coast. Moreover, new emphasis on aboriginal land rights has been claimed to be slowing down mineral exploration and development in some areas.

Attached is a summary of ore reserves and of mineral processing in Australia as an indication of both resources and processing facilities. Overseas trade in minerals and mineral sufficiency, showing values of imports and exports of minerals in 1983, are illustrated in a diagram facing page 1.

The minerals discussed are grouped under the following headings -

(a) Energy minerals: petroleum, uranium, coal, and oil shale
(b) Iron, manganese, nickel, chromium, and other metals commonly used in the manufacture of steel
(c) Base metals: copper, lead, zinc, tin
(d) Other metals
(e) Non-metallic minerals

Mineral statistics given are those for 1983, the latest calendar year for which complete figures are available.

DEVELOPMENT OF THE MINERAL INDUSTRY

The Australian mineral industry started with the first quarrying and shaping of Hawkesbury Sandstone for early buildings at Sydney Cove and when the first settlers dug clay for brickmaking. Its development can be conveniently divided into four stages - early settlement and exploration, from 1788 to 1851; establishment of the industry, from 1851 to about 1910; the lean years, from 1910 to about 1950; and the large and varied developments leading from discoveries made in the last three decades.

It is significant that these are not only local stages; they can be broadly identified in other countries with a sufficiently long history of the mineral industry, like USA and Canada. Indeed, episodic discovery and development within mineral industries relate to a number of basic controls including the level of technology in exploration, mining and treatment and such matters as government policies and the emergence of markets.

Early settlement and exploration, 1788-1851

The first recognition of mineral wealth followed soon after settlement and inevitably concerned coal, as the settlement of Sydney lay toward the centre of a coal basin that contained coal at depth and cropping out along the coast to both north and south. Coal was first discovered in the Newcastle area by escaped convicts in 1791; discovery of coal on the south coast followed a few years later and mining started near Newcastle in 1799. Coal provided the first mineral export from Australia, in 1800.

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However, this first stage of development lacked emphasis on mineral resources, apart from coal, for a number of reasons. At that time, Britain was not seeking mineral supplies overseas and did not encourage the young colony to explore for minerals. Moreover, the colony, first established as a penal settlement, was preoccupied in early years in learning how to feed itself, with little interest in mineral deposits; partly for this reason scientific contributions resulting from geographical exploration during this period were largely in the field of botany rather than geology. And, following British law, deposits of gold and silver were regarded as belonging to the Sovereign and thus prospecting for these metals was unattractive in early years.

However, traces of gold were reported from 1823 onwards and the occurrence of other metallic minerals was recorded from time to time in the early decades of the 19th century.

The first metal mines did not open until the 1840s. Silver-lead ores were mined in 1841 near Adelaide, and copper ore at Kapunda in the same general area in 1842. In the same decade the first pig iron was produced from a small deposit of iron ore at Mittagong near Sydney, although the enterprise found great difficulty in competing with imported material and eventually ceased operation in 1877.

Establishment of the industry, 1851-1910

It was the discovery of payable alluvial gold near Bathurst, NSW, in 1851 that gave impetus to the mineral industry in Australia and, as search and discovery quickly spread to other parts of eastern Australia, the migrants which the gold attracted, the new communities and new access which resulted, and new emphasis on the mineral potential of the young country all profoundly influenced the development of Australia from the 1850s onwards.

It was not long before new interest and expertise in prospecting, arising from the succession of gold discoveries, led to the finding and exploitation of other metals. The start of tin mining in 1872 almost simultaneously at Inverell (NSW), Stanthorpe(Qld), and Mount Bischoff (Tas.) heralded very considerable tin production in eastern Australia, which became the major world source of tin for nearly a decade in the late 1870s and early 1880s. Copper mining was rejuvenated by discoveries at Cobar, NSW, in the early 1870s and the finding of Mount Morgan, Qld in 1882 and of Mount Lyell, Tas., in 1885; although Mount Morgan and Mount Lyell were first mined for gold, by the close of the century they had been shown to contain large reserves of copper ore too. The mineral industry was further diversified with the discovery of the rich lead-zinc-silver lodes at Broken Hill, NSW, in 1883, which, to the credit of the pioneers of that field, were developed to the stage of local smelting by 1885 and as feed to larger smelters at Port Pirie by 1889.

Up to this time successful mining had been restricted to eastern and southern Australia, despite attempts to discover payable gold in the Kimberley and Pilbara divisions of Western Australia and in areas east of Perth. However, discovery of payable alluvial gold near Coolgardie in 1892 and subsequently of the gold lodes of Kalgoorlie extended profitable mining to the western portion of the continent at a time when the economy in the east badly needed new outlets.

The lean years of exploration and discovery, 1910-1950

The mining industry continued to prosper in the early years of the twentieth century, but fortunes began to change and a general decline in both production and ore reserves of copper, gold, and tin continued at least until the 1950s, although gold production temporarily revived in the 1930s. During these lean years, significant new mineral discoveries were restricted to lead-zinc-silver and copper at Mount Isa, Qld in 1923 and 1930 respectively and scheelite (an ore of tungsten) on King Island, Tas. in 1925. Only lead, zinc, and silver production and exports, based on Broken Hill and Mount Isa, showed a general increase in this period; they continued as a solid base for the mineral industry for most of the first half of this century, in which problems of falling domestic production and lack of new major discoveries became more obvious and challenging as time elapsed.

However, mineral processing in Australia continued and expanded during this period; production of lead bullion and copper continued, and output of refined pig lead substantially increased in the second decade and was joined by refined tin and by significant increases in output of refined zinc after 1917. Mineral discoveries made in the 19th century offered challenges to the mineral industry in terms of mining and treatment problems, from mining methods and underground water removal to more efficient smelting, and mineral separation and recovery. Some of these challenges were answered by technological improvements and innovation during the lean years for exploration, and perhaps the most outstanding examples were the development of differential flotation for the separation of lead and zinc sulphides from Broken Hill ores and, later, the electrolytic refining of zinc sulphides to pure metal, in the early part of the 20th century. Basically the same flotation process has been used in the treatment of sulphide ores around the world ever since. //

The early years of the twentieth century were noteworthy for the establishment of the Australian steel industry, which made its way stubbornly against competing imports. Pig iron production, beginning at Lithgow, NSW, in 1875 and based on local coal supplies, provided the basis for the first production of steel by open hearth in 1900, but although some production of steel continued at Lithgow until 1932, distance from iron ore supplies and from ports prevented Lithgow from becoming the centre for expanded steel production. Detailed planning eventually led to the establishment by The Broken Hill Pty Co. Ltd of steelworks on the coast at Newcastle, NSW, in 1915 and, although faced with problems in both the 1920s and the 1930s, steelmaking was firmly established and began to expand. Another enterprise, G. & C. Hoskins, eventually transferred steel-making from Lithgow to the coast near Wollongong in 1928, but subsequent trouble in the depression in the early 1930s led to this project being taken over by The Broken Hill Pty Co. Ltd in 1932. In 1919 the Victorian Government passed legislation to establish the brown coal industry in the Latrobe Valley, based on large deposits discovered 30 years earlier.

In the late 1930s the mineral industry, although well established, played a minor role in the Australian economy. It had been particularly successful in opening up the country, had provided coal as fuel in all States, had bolstered the economy about the turn of the century, and continued to provide steel, lead, zinc, copper, and tin for Australian secondary industry.

The need for new ore reserves of many minerals was the major concern of the industry in the late 1930s and early 1940s, and the embargo placed on the export of iron ore in 1938, when reserves of high-grade ore were believed to be no more than 260 Mt tonnes, was a reaction of the Commonwealth Government to this concern.

The industry in modern times

It is therefore all the more remarkable that within the next decade, starting with the discovery of uranium at Rum Jungle in 1949, there began a series of ore discoveries that is still continuing and that has far exceeded any previous mining boom in Australian history.

There were many reasons for this spectacular upsurge in exploration and development, but most are concerned either with incentives for exploration and development, including higher metal prices, or with the tools by which they can be accomplished. The combination of mineral potential in Australia (particularly in the extensive areas of Precambrian rocks which have provided the bulk of the world's metals), political stability, and Government assistance for exploration

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and mining attracted both domestic and foreign companies to Australian fields. The general policy of Government of providing basic scientific information and an encouraging climate for mineral exploration, but leaving private enterprise comparatively free to search, discover, and develop, paid off handsomely.

It is interesting to note how technological progress has changed the pattern of mineral discovery in Australia since the 1930s. Before the Second World War the discovery of most mineral deposits owed little to science but much to the keen eye, the luck, or the curiosity of prospectors, boundary riders, and other amateurs. Since the war, although prospectors and others still make discoveries, the emphasis has shifted to the scientific exploration team.

The mineral industry has resumed its old role of opening up the country with railway lines, roads, ports, and towns, has added oil and natural gas to Australian fuel supplies, and has provided processed aluminium and nickel for Australian industry. The long list of significant mineral insufficiencies of the late 1930s has been reduced to sulphur; economic considerations have either limited or deferred development of known resources of some minerals such as asbestos, chromite, phosphate rock and potash. Production of diamonds, hitherto on the mineral deficiency list, began in the Kimberleys in 1983.

But perhaps the most notable changes brought about by the upsurge of the mineral industry concern overseas funds and the Australian economy as a whole. The value of exports of mineral primary products has risen from $69 million in 1950 to $9728 million in 1983, to provide currently about 39% of Australia's overseas earnings and to rival the combined agricultural and pastoral industries as Australia's largest export earner. The mineral industry produced in 1965 what was probably the first favourable balance of overseas mineral trade this century; this favourable balance has grown from $5 million in 1965 to $7642 million in 1983 and will undoubtedly continue to increase in the decade ahead.

The rise of the mineral industry was timely, happening when wool and most other rural industries were in difficulties, and doubtless saved Australia from currency devaluation and import restrictions in the late 1960s. Reserves of iron ore, coal, and bauxite, which now account for about 66% of Australian mineral exports, are very large and, combined with long term contracts and rising demand for minerals throughout the world, promise continued major production and export. Added to this, exports of uranium have begun and export of natural gas is in prospect within the next few years.

However, the upsurge of the mineral industry since the Second World War brought problems as well as achievements. The cost of exploration and development far exceeded the funds available in a country with a small population. Moreover, since ore reserves are wasting assets, a continued flow of risk capital is required in the future to replace depleted reserves, particularly of crude oil, if Australia's high level of self-sufficiency in oil is to last. Australia was shielded to a large extent from the world crude oil crisis in the 1970's by the level and prices of domestic supplies.

Inflation in Australia has increased the cost of exploration, development, and production, reduced profitability, increased cut-off grades, and discouraged new developments, particularly where world metal prices, such as those for copper, have not increased in real terms. The world economic recession has added to the industry's problems because of its dependence on exports.

The late 1960s brought growing awareness in Australia, as elsewhere, of environmental problems which inevitably questioned the disturbance of landscape and levels of pollution which accompanied in varying degrees the operations of the mining and some other industries; as a result the mining industry no longer operates with the degree of isolation from the rest of the community that was evident in previous years.

ENERGY MINERALS

Petroleum*

Australia's main mineral deficiency has long been that of indigenous petroleum, particularly crude oil, the lack of which has compelled it to import significant amounts of crude oil and refined products to meet domestic consumption. In 1983 the value of imports of refinery feedstock and refined products fell to $2226 million (crude oil $1211 million) from $3301 million (crude oil $2140 million) in 1982, mainly reflecting a decrease in domestic consumption; indigenous crude oil supplied 73% of demand in 1983. Consumption of marketable petroleum products decreased by 3.7% in 1983. The average annual rate of decrease in consumption of the same range of products for the five years ended 31 December 1983 was 1.6%.

Since the mid-1950s an Australia-wide search for oil has been going on. In 1965,156 exploratory wells were drilled in Australia, compared with only 14 in 1959; in succeeding years the number has ranged from a low of 19 in 1976 to a record 221 in 1982 and 209 in 1983. Based on announcements of future programs, the estimated number of exploratory wells to be drilled in 1984 is 242.

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*Prepared by Petroleum Branch, BMR

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Part of the reason for the increased tempo of petroleum exploration in Australia in the 1960s undoubtedly resulted from the Commonwealth's policy of subsidising private companies' expenditure under a scheme first introduced in 1958, extended to June 1969, and further extended until its termination in June 1974. Under this scheme selected operations were at first reimbursed by 50 percent (later reduced to 30 percent) of the cost. The then Commonwealth Government did not renew this subsidy scheme after June 1974, but established a Petroleum & Minerals Authority with powers and responsibilities in fields of petroleum and minerals exploration and development. However, the High Court in July 1975 ruled that the Act establishing the Petroleum & Minerals Authority was invalid.

Incentive was, of course, increased by the commercially viable oil and gas discoveries made in the early 1960s and before the decline in drilling activity in the mid 1970s. These include the gas fields in the Roma area in Queensland and the Kincora and Boxleigh-Silver Springs gas fields now supplying Brisbane with natural gas; the Gidgealpa-Moomba-Big Lake - Della and Namur gas and condensate fields (Cooper Basin) in South Australia, now supplying Adelaide and Sydney with natural gas; the Gippsland Shelf major gas/oilfields, Barracouta and Marlin, supplying gas to Melbourne; the Dongara area fields in WA now supplying Perth; and the Palm Valley field in NT now supplying Alice Springs power station. Other gas fields still to be developed are on the Northwest Shelf off Western Australia where development drilling commenced in November 1983. Gas has also been discovered in the Wilcox well, 130 km northwest of Dampier. Several major discoveries of natural gas on the Northwest Shelf, including those at North Gorgon and Central Gorgon are being appraised and production plans assessed.

In September 1975 the incentive to explore was further increased by the introduction of the Government's "new oil" pricing policy with the introduction of world parity price for "new oil" discovered after 14 September 1975. This policy was amended in 1976 so that "new oil" received the full import parity price free of any excise and this arrangement is still in force in early 1984.

Oil was discovered at Moonie and Alton, Qld, in 1961 and these fields have been producing since 1964. The Barrow Island oilfield, WA, began commercial production in December 1966. The most prolific oil discoveries were the Kingfish and Halibut fields in the Gippsland Basin in Bass Strait; significant discoveries were made in the Barracouta, Marlin, Mackerel, Tuna, Flounder and Cobia fields and more recently at Fortescue in the same basin. The installation of a production platform at West Kingfish was completed in August 1981 and at the end of 1983 development drilling was in progress; the Cobia and Fortescue platforms had also been installed and drilling commenced in March 1983 and June 1983 respectively. Commercial production of gas began from Barracouta in late 1969 and was followed by oil from Halibut in 1970, Kingfish in 1971, and Mackerel in 1977. The Tuna oil field was brought into production in 1979.

At present, companies hold exploration permits over selected areas in most sedimentary basins. Interest has been maintained in offshore localities although several permits in the deeper waters of the Exmouth Plateau off Western Australia have been relinquished because no encouraging results were obtained. The most significant discovery in 1983 was Jabiru 1A, an oil find in the Timor Sea, 600 km west of Darwin. Early indications suggest the field might be as large as the Fortescue field in the Gippsland Basin, however, further appraisal drilling is required to accurately estimate its size and reserves. Drilling offshore is much more expensive than drilling on land, but the prospects for large discoveries are considered to be better offshore.

The first offshore rig, the Glomar III drill ship, was brought to Australia in 1964. With its first well, Barracouta No. 1, it discovered gas and what is now known as the Barracouta field, some 50 km from the Gippsland coast of Victoria. More offshore drilling units arrived in Australia, and by mid-1969 six mobile units were operating in Australian coastal waters. Three of these units were drill ships, two were semi-submersible platforms, and one was a jack-up unit. Only two units, 'Ocean Digger' and 'Ocean Endeavour', both Australian-flag units, were in operation by the end of 1976. At the end of 1983 eight mobile offshore units were active in Australian waters and four platform rigs were also active - one each on the Cobia, Fortescue and West Kingfish platforms, and one drilling the first of seven wells on the North Rankin 'A' platform, Northwest Shelf.

The year 1969 saw the completion of three major natural gas pipelines. The 170-km, (760 mm diameter) pipeline from Longford to Dandenong first delivered gas to Melbourne and its environs in early 1969, and in 1983 was delivering gas at a rate of about 14.0 million m^3/day. Brisbane received its first delivery of natural gas from the Roma area in March 1969 through a 270 mm diameter, 410-km pipeline. Production during 1983 from this area, together with that from the Kincora and Boxleigh-Silver Springs fields, was being delivered at a rate of 1.1 million m^3/day. In late 1969, Adelaide received natural gas through a 560 mm 778-km pipeline from the Gidgealpa-Moomba field.

The natural gas line to Sydney from the Cooper Basin fields in South Australia was brought into service in December 1976. The average rate of gas production from the Cooper Basin fields (for Adelaide and Sydney) during 1983 was 12.2 million m^3/day. At the end of 1982 a liquids pipeline had also been built from the Cooper Basin fields to Port Bonython on Spencers Gulf, from where LPG will be exported to Japan, beginning mid 1984. Other liquids were despatched from this port to Australian and New Zealand refineries with shipments having commenced February 1983.

A new 780 km (323 mm diameter) Jackson to Moonie pipeline, was completed in 1984. This pipeline will initially service the Jackson and Jackson South fields in southwest Queensland; recent discoveries at Gunna, Chookoo, Naccowlah South, and Wilson are also expected to be connected with the line after these fields have been thoroughly assessed.

Natural gas was first delivered to the Perth area from the Dongara field in October 1971 deliveries from this field as well as the Woodada field in 1983 averaged 2.9 million m^3/day.

In 1983, indigenous oil production supplied 73% of Australia's requirements. However, the crude oils discovered so far have been deficient in the heavier distillation fractions required by heavy industry as well as for road and paving construction, and as lubricants; thus, import of crudes rich in these fractions must continue, at a rate of about 30% of total consumption, until an adequate source is found in Australia.

Should Australia fail to find more petroleum, then it would become necessary for it to rely on other and less convenient source materials for fuel, and other sources of energy such as uranium, coal, and oil shale. A petroleum substitute can be extracted from oil shale, and attention is now being directed to such deposits, particularly in Queensland; Australia's very extensive resources of coal could also provide a possible alternative source if economic methods of conversion are developed. Research into coal conversion is now active in Australia and abroad, especially USA and West Germany.

The Commonwealth contributes to the exploration process in Australia by carrying out, through BMR, regional geophysical surveys and geological research related to Australia's sedimentary basins and the origin of petroleum.

Uranium

Australia is not a consumer of uranium, although small quantities of enriched uranium are imported for use in research and production of radioisotopes in the atomic reactor at Lucas Heights, near Sydney. In Australia there have been two periods of uranium production, the first between 1954 and

1971 and the second from 1976 onwards. Since 1976, Australia has progressively become an important producer and exporter of uranium oxide.

The national search for uranium deposits began in 1944 and resulted in the discovery of Rum Jungle in 1949 and of Mary Kathleen in 1954. Small deposits were also known in South Australia as early as 1906, and others, which were to become useful but minor contributors to the output, were found in the South Alligator area, NT, in the early 1950s.

During the first period of uranium production, treatment plants were erected at Port Pirie, SA, where for several years high-cost material was produced from ores mined at Radium Hill; in the Northern Territory at Rum Jungle, where the plant remained in operation treating stockpiled ores until 1971 and at Moline and Rockhole; and at Mary Kathleen, Qld, which began operating in 1956, was placed on care-and-maintenance in 1963, resumed production in 1976, but was closed down permanently in 1982.

These early discoveries were made at a time when uranium was in strong demand for military purposes, and when world supplies were still so uncertain that prices were arbitrarily established by Government agreement. In retrospect, the prices secured by Australia in several of its long-term contracts turned out to be very favourable. However, dwindling defence needs and the lack of any comparable requirement for peaceful purposes led to a situation in which no market existed for the Australian product once contracts were fulfilled.

In 1967 the Commonwealth Government relaxed its embargo on uranium exports and the growing need for uranium for nuclear power purposes stimulated exploration, which met with notable succcess. Large deposits were discovered at Ranger, Nabarlek, Koongarra and Jabiluka, about 230 km east of Darwin, confirming the existence of a major uranium province in the Alligator Rivers area. New discoveries were also made in the Frome Embayment, SA; at Yeelirrie and Mulga Rock in Western Australia; and several small deposits in the Ngalia and Amadeus Basins in the Northern Territory. In Queensland, new discoveries were made at Maureen and Ben Lomond and in the Westmoreland-Pandanus Creek area near the Qld-NT border.

In South Australia the Olympic Dam copper/uranium deposit was discovered by Western Mining Corporation on Roxby Downs Station in 1975. A significant intersection of uranium at the Acropolis prospect, 25 km southwest of Olympic Dam, further enhanced the potential of the Stuart shelf region west of the main Adelaide Geosyncline.

As at 31 December 1983, BMR assessed Australian resources of uranium in the reasonably assured category, and extractable at costs up to $US80/kg - to be 474 000 t U, about 30% of the world's uranium resources in that category.

Uranium oxide is currently being produced from two mining/milling operations. Queensland Mines Ltd mined the entire orebody at Nabarlek in 1979; the stockpiled ore is being treated on-site (capacity of the treatment plant is 1080 t/year U_3O_8). Energy Resources of Australia Ltd commenced production from the Ranger deposit in 1981. Mining is by open-cut methods and the treatment plant has a rated capacity of 3000 t/year U_3O_8. The mine has sufficient reserves to last approximately 30 years at current production rates.

At the Olympic Dam deposit, exploratory drilling continued from both the surface and underground. Western Mining Corporation announced that drilling had defined probable reserves of 450 Mt averaging 2.5% Cu, 0.8 kg/t U_3O_8, 0.6 g/t Au and 6.0 g/t Ag. In December 1984, the company reported that a technical study would be carried out and the results of this study would be used in the overall feasibility study of the project. For this technical study the company considers that the first stage of the project will treat ore averaging 3.0% Cu, 1.3 kg/t U_3O_8 and 0.4 g/t Au, with additional production of gold from a discrete ore zone containing approximately 2000 t U_3O_8, and approximately 55 000 t Cu per annum, commencing in 1988, and approximately 100 000 ounces Au per annum commencing in 1987.

Feasibility studies and Environmental Impact Statements have also been completed for several uranium deposits including Jabiluka and Koongarra in the Northern Territory, Yeelirrie and Lake Way in Western Australia, Beverley and Honeymoon in South Australia, and Ben Lomond in Queensland.

World demand for uranium increased sharply between 1974 and 1976, with spot prices increasing from $US7.70/lb U_3O_8 in early 1974 to a maximum of $US43.40/lb in mid-1978. The spot price remained above $US40 until the end of 1979, but has since fallen to a low of $US15.25/lb (December 1984).

Black coal

The last two decades have seen a spectacular increase in the growth of the Australian black coal industry. The main catalyst for this growth was orignally the coking-coal export market but in recent years growing demand for thermal coal, as a result of the oil crisis, has also contributed to increased coal exports. As a result of increased world demand for Australian coal, new mines have been developed in both Queensland and New South Wales; however this development phase has now been completed and there is little prospect of further new mines in the next few years.

Australia's largest, and economically most important, deposits of black coal are concentrated in two main areas: the Bowen Basin in eastern Queensland and the Sydney Basin in New South Wales. More than 85% of Australia's demonstrated economic resources of black coal are in these two areas.

In 1983 Australia was the eighth-largest black coal-producing nation, accounting for about 3% of world production of saleable coal; raw coal production increased to 120.5 Mt for a saleable coal output of 98.7 Mt.

The State producing the largest amount of coal is New South Wales, accounting for 55% of raw coal production. The growth of production of raw coal in Queensland slowed in 1983 but the State again produced 41% of the national output of raw coal. Growth in Queensland production has been based on the development of large-scale open-cut mines mainly for coking coal; almost 90% of Queensland's raw coal output now comes from open-cut mines. The bulk of production comes from the Bowen Basin in eastern Queensland; most of the coal produced is low to medium volatile coking coal for export. Approximately 42 000 t of coking coal from the Bowen Basin was also shipped to BHP's steelworks at Whyalla, SA, in 1983, a substantial reduction on previous years. Smaller quantities of non-coking coal are mined at or near Blair Athol, Callide, Ipswich, Toowoomba and Maryborough for use by electric power stations or local industry. Thermal coal mined in the Bowen Basin in small quantities is used in domestic industries and some is exported. In addition, some semi-anthracite is produced at the Yarrabee open cut mine near Blackwater.

Coal mined in New South Wales is bituminous and nearly all is mined in the Sydney Basin. In 1983, underground mines accounted for 66% of raw coal production. About 60% of total New South Wales production is high-volatile soft-coking coal and steaming coal, most of which is mined in the Singleton-North West and Newcastle Districts; smaller quantities are mined in the South Maitland District and in the Western District near Lithgow. The soft-coking coal is used to produce coke for the Newcastle steel-works or is exported. At the present time most of the steaming coal is consumed locally for electric power generation and local industry, but in recent years the quantity of steaming coal being exported has increased substantially.

Low-volatile and medium-volatile hard-coking coals (i.e. premium grades), are mined in the South Coast and in the Burragorang Valley Districts. About one-fifth of this coal is used at the Port Kembla steelworks and for the manufacture of coke at other plants, a small amount is shipped to the Newcastle steelworks, and the rest is exported. In 1983, 0.8 Mt of coking coal from the Port Kembla and Newcastle steelworks was shipped to Whyalla.

Minor quantities of coal are mined at Gunnedah and at Ashford in northern New South Wales.

Comparatively small amounts of non-coking coal are mined in other States for use by electric power stations or local industry. Non-coking coal is obtained from the open-cut mine at Leigh Creek (SA) and from underground and open-cut mines at Collie (WA), and from underground mines near Fingal in Tasmania.

In 1983, consumption fell by 0.5 Mt to 36.9 Mt; an increase of 1.5 Mt for electricity generation was insufficient to offset a fall of just over 2 Mt in the iron and steel industry. Consumption in electricity generation accounted for 74% of total consumption, and in the iron and steel industry for 16%, a fall of 5% on the previous year.

Australia is a major exporter of black coal. In 1983 it was ranked second largest in the world; the 60.5 Mt exported accounted for about 23% of world trade and was valued at about $3329 million, making coal Australia's largest single export earner. Exports were made up of 18.3 Mt of thermal coal and 42.2 Mt of coking coal.

Exports to Japan rose by 12% to 36.1 Mt in 1983 consisting of 28.4 Mt of coking coal and 7.7 Mt of thermal coal. The remaining coal, comprising about 13.8 Mt of coking coal and approximately 10.6 Mt of thermal coal, was exported mainly to Europe and Southeast Asia.

The substantial improvement in outlook for world crude oil supplies and prices has tempered forecasts of growth in demand for thermal coal. Growth in demand for coking coal continues but its magnitude will depend on continued world economic recovery. Only a limited number of countries had the potential to substantially increase their coal export capacities in 1984 to meet the projected growth in requirements. For coking coal Australia, USA, and Canada had the greatest potential, whilst for thermal coal Australia, USA, South Africa, and possibly China had the greatest potential. As much of the additional capacity had been committed in anticipation of an increased demand, the slowdown in demand has led to an excess of capacities in these countries. Thus until demand improves the Australian industry will experience difficulties maintaining export tonnages and prices. Australia's known resources are sufficient to allow it to continue as a major exporting country for many decades to come.

Brown coal

Australia's major economic deposits of brown coal (more than 98% of demonstrated economic resources) occur in Victoria. Deposits are also known at many places along the southern margin of the continent and as far north as

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central Queensland. However, except for the brown coal deposits in Gippsland, and at Bacchus Marsh, Altona, and Anglesea in Victoria, the deposit at Kingston, and other deposits in South Australia and the deposit near Esperance, WA, other known deposits are either too small, too deeply buried, contain too much salt, or are otherwise unattractive as sources of energy.

Because brown coal has a relatively low specific-energy value and high water content, its utilisation depends on large-scale, low-cost mining, and negligible transportation costs in its raw state.

Victoria is the only State which produces brown coal; the industry has reached a high degree of sophistication in mining, on-site development for power generation, briquetting, and char manufacture. Production of raw brown coal in 1983 totalled 34.2 Mt 10% less than in 1982; more than 96% was produced by the State Electricity Commission at Yallourn and Morwell and the rest by privately-owned mines at Anglesea and Bacchus Marsh. Because brown coal deteriorates rapidly and may ignite spontaneously when stockpiled, producers and consumers do not accumulate large stocks; consumption is roughly equivalent to output.

Apart from the markets linked with solvent-refined coal, activated carbon and char production, the major markets available to brown coal are power generation and, potentially, liquefaction. Investigations are presently being undertaken by Victoria's Brown Coal Research & Development Committee to determine the liquefaction potential of various Victorian brown coal deposits.

Australia's known reserves of brown coal are very large and greatly expanded production of brown coal would be possible in Victoria, subject only to environmental, manpower, and capital limitations.

Oil shale

Triggered by the first major increase in the world crude oil price in 1973, interest was revived in oil shale as a potential source of liquid fuels. However, this interest waned a little because of weakening oil prices and rapidly increasing capital costs of processing plants. Exploration in the last few years, especially in Queensland, has resulted in the discovery of extensive resources.

Oil shale is a fine-grained sedimentary rock containing organic matter that yields substantial amounts of oil when heated in a closed retort. Intermittent production took place from some Australian deposits in New South Wales (e.g. at Glen Davis and Joadja) from 1865 until 1952. The most intensified production was during a period of oil shortage and rationing during and after World War II; total production during this period amounted to about 230 000 m^3 (1.4 million bbl) of shale oil. W

Australia's inferred subeconomic resources of oil shale are estimated to be capable of yielding 40 350 million m^3 (250 000 million bbl) of oil. This huge inferred resource is contained mainly in the thin Toolebuc Formation which is thought to underlie 400 000 km^2 of inland Australia, extending south from the Gulf of Carpentaria to southern Queensland. Formidable technical and other problems would need to be overcome to enable this resource to be upgraded to 'economic' status.

However, certain oil-shale deposits in Queensland are much thicker, richer, and in geographically favourable locations, and therefore offer more potential for development in the forseable future. The Rundle deposit near Gladstone, with stated resources of 421 million m^3 (2650 million bbl) of oil and the Condor deposit near Proserpine, with resources of 1340 million m^3 (8450 million bbl) of oil, were the subject of comprehensive feasibility studies by Esso Exploration & Production Australia Ltd and the Japan Australia Oil Shale Corporation respectively. The results of the studies are being assessed with a view to making decisions in early 1985 about how the two projects should proceed. An independent audit of identified resources at Yaamba, which was completed during 1983, confirmed an in situ resource of about 420 GL (2640 million barrels) in an area of about 32 km^2. A technical feasibility study of the prospect is underway.

Australia's demonstrated resources of oil obtainable from oil shale presently stand at 4093 million m^3 (about 25 750 million bbl), but all of this is still classified as subeconomic; most of the demonstrated resources are in Queensland. Rundle, Julia Creek, Condor, Stuart, Yaamba, Nagoorin (including Nagoorin South), Lowmead, and Duaringa are the most important resource localities.

There are two major options for development of oil shale deposits: (1) mining, followed by surface processing of shale to extract the oil, and (2) in-situ processing. So far, only the first has been used in commercial oil-shale exploitation. Some in-situ processing methods have been investigated but their developers are awaiting more favourable economic circumstances before committing their processes to commercial application.

IRON AND FERROALLOYS

Australia has long been largely self-sufficient in the production of iron and steel, and exports have acted chiefly as a buffer between domestic production and demand. Some special steels and shapes and some 30% of ferroalloys are still imported.

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Iron and steel

Production of iron ore for iron and steelmaking in 1983 decreased to 71.0 Mt, 19% less than output in 1982. The decrease reflected planned cutbacks by producers in accordance with depressed domestic and export demand as well as the effects of industrial disputes, including a dispute which interrupted production at Newman in the September quarter for 10 weeks. Output at Newman fell by 35% to 18.6 Mt. Stockpiling and stockpile replenishment enabled production to be maintained at Tom Price and Paraburdoo early in 1983 but combined output fell by 10% to 30 Mt (Mount Tom Price down 7% to 19.8 Mt and Paraburdoo down 11% to 11.0 Mt). Output at Pannawonica decreased by 16% to 13.2 Mt. Output also fell substantially from the Middleback Range deposits at Iron Knob and Iron Baron in accordance with depressed domestic steel output but production increased at Yampi Sound after increased export orders were obtained. Production at the Koolyanobbing mine in Western Australia decreased by more than 60% reflecting its closure in August, closure having been deferred since April 1982 when the Kwinana blast furnace which it mainly supplied was shut down. Production at Shay Gap decreased only slightly.

Production of pig iron decreased by 15% in 1983, to 5.0 Mt, reflecting reduced steelmaking requirements as well as closure of the Kwinana blast furnace in 1982.

Production of steel decreased by 12% to 5.6 Mt in 1983. After a low level early in the year production sales increased in the June and September quarters as domestic sales increased but then fell slightly in the December quarter. Steel production fell by 12% to 3.18 Mt at Port Kembla and by 16% to 1.56 Mt of Newcastle, but rose by 2% to 872 000 t at Whyalla partly to meet export orders.

Exports of crude steel, including ingots, blocks, lumps, blooms, billets, and slabs, increased by 20% to 384 000 t valued at $72 million in 1983. Exports of crude steel plus rolled and shaped iron and steel products were valued at $477 million in 1983 and imports at $402 million. Pig iron exports increased 9-fold in 1983 to 469 000 t valued at $376 million following a recovery in exports to Japan and Singapore.

Iron and steelmaking absorbed 8.9 Mt of iron ore in 1983. The main sources were the Middleback Ranges, SA, and Newman, Koolyanobbing, and Cockatoo Island, WA. Newman supplies more than 50% of domestic blast furnace requirements. In 1983, 46 757 t of iron ore (mainly magnetite) was imported, principally from Canada, for use as a heavy medium in the coal washing industry.

In addition to the iron ore consumed in Australia, about 74.3 Mt of ore, including 2.3 Mt of pellets, was exported, 2% more than in 1982. The increase reflected increased exports to Europe, Taiwan Province and South Korea, which offset reduced shipments to Japan. Iron ore exports were principally from Western Australia; Tasmania continued to export iron ore pellets. The f.o.b. value of exports in 1983 was $1577 million, 11% more than in 1982, and reflected increase shipments, depreciation of the Australian dollar relative to the US dollar, in which contract prices are mostly expressed and increases in contract prices in 1982 which were still operative in 1983.

Even in the 1940s and 1950s reserves of iron ore in Australia were regarded as too low for safety in comparison with our long-term industrial needs, and few foresaw the possibility of major new discoveries. Because of this a complete embargo on the export of iron ore had been maintained for more than twenty years. Since the embargo was eased in 1960 new discoveries have confirmed that Australia has one of the most important iron provinces in the world, and a major export trade has been established.

To illustrate the spectacular change in Australia's reserves of iron ore it may be noted that in 1959 the official estimate of demonstrated reserves amounted to only 359 Mt. At that time exploratory drilling in several States had raised hopes that intensified search could reveal some worthwhile new deposits. Among the principal prospects at that time were: Savage River in western Tasmania, where airborne magnetic surveys by BMR had shown a belt of intense anomalies extending over a length of several kilometres; Constance Range in northwest Queensland, where preliminary testing beneath silica-rich ironstone outcrops had shown a marked improvement in quality at depth and some prospect of large tonnages of ore suitable for deep mining methods; and Mount Goldsworthy, near Port Hedland, WA, where drilling had shown a more substantial body than was indicated by outcrop and surface sampling.

Encouraged by these hopes the Commonwealth Government eased the export embargo in 1960, and soon afterwards a series of discoveries in the Pilbara district, east of Onslow, WA, focused attention on an area hardly touched by modern large-scale mineral prospecting. In little more than a year important deposits were reported from such localities as Deepdale, Robe Rive, Mount Tom Price, and Mount Newman, all lying in this neglected northwestern part of the State. The discoveries included deposits of hematite (iron oxide, Fe_2O_3) and of limonite (a mixture of hydrated iron oxides); early development at Mount Tom Price, Mount Whaleback, Paraburdoo and Mount Goldsworthy, and Koolanooka east of Geraldton, was based on hematite deposits, but limonite deposits at Robe River and hematite-goethite (goethite is an hydrated iron oxide, FeO.OH) deposits near Mount Whaleback particularly are now also worked.

Deposits in Western Australia have since been vigorously tested and very large tonnages of high-grade ore have been demonstrated. Though the full extent is not yet known, BMR assesses economic resources in the Hamersley Iron Province alone at around 20 270 Mt within total economic resources for Australia of 21 700 Mt. In other words, since 1959, Australia's known resources have increased some 60-fold at least and any anxiety for the adequacy of domestic supplies has been removed.

However, not all the increase in reserves has come from the discovery of new deposits. Metallurgical research aimed at making possible the use of low-grade ores, of which there is an abundance in several States, has also contributed to the changed picture and may have a greater long-range effect than is presently realised. Major expansion projects by the Mount Newman Joint Venture and by Hamersley Iron Pty Ltd, designed to enable low-grade ore to be upgraded, were completed in mid-1979. Robe River also completed an expansion program during 1979 to substantially lift production and has extended mining to East Deepdale.

When the export policy was altered in 1960, the change was expected to lead to an increase in prospecting with reasonable chances of proving new reserves. The result exceeded the most optimistic expectations, and led to a situation in which the development of an export trade in ore, which plays an increasing part in the national balance of payments, became the paramount consideration. The first small-scale export began in March 1966 from Geraldton; and after extraordinarily vigorous construction schedules, large-scale exports began from new ports at Dampier and Port Hedland in the later part of that year.

Integrated iron and steel plants now exist at Port Kembla, Newcastle, Whyalla, and there is a rolling plant at Kwinana. Investment in iron and steel plant is now running at more than $200 million annually. Since the mid 1970 s investment has included some important new facilities, particularly at Newcastle, Port Kembla, Whyalla, and Laverton, although it was mainly directed towards upgrading existing facilities. Some less efficient plant has been closed.

In 1983 a $144 million expansion of basic oxygen steelmaking facilities at Port Kembla was completed and a new plant to produce billets from scrap was commissioned at Laverton North, Vic., by Smorgon Consolidated Industries Pty Ltd.

Depressed demand and surplus steel production capacity since the mid 1970s has caused a major restructuring of the world steel industry in the early 1980s. The Australian steel industry has also been forced to adjust to lower

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production levels and details of a plan aimed at restoring the industry's competitive position internationally were announced by the government in 1983. The plan covers all three primary steelmaking centres at Newcastle, Port Kembla and Whyalla and involves capital investment of up to $800 million over four years. Financial assistance is to be provided by the government as bounty payments on domestic sales of particular high alloy and flat steel products at a rate of up to $70 million/year for five years from 1984.

World consumption of steel in 1983, at 669.0 Mt, was 14% below peak consumption of 774.2 Mt in 1979. World production increased to 663.7 Mt, 3% above output in 1982 but was 11% below record output in 1979.

Manganese (Mn)

Manganese is one of the key metals in the manufacture of steel, its chief use being as a de-oxidiser and de-sulphuriser in the plant process; adequate supplies of its ores (principally pyrolusite, MnO_2) are essential for the long-range security of the steel industry. Current usage requires about 9.5 kg of manganese dioxide for every tonne of steel produced. It is also a hardening constituent in many grades of steel; and high-quality manganese dioxide is used in the manufacture of dry-cell batteries. In 1983, 276 000 t of manganese ore was required by our industries.

Although Australia's known resources of manganese were for many years small, its self sufficiency in this mineral is more established. Until the late 1940s the steel industry drew upon deposits in Queensland, New South Wales and South Australia; subsequently Western Australia became the main source of supply.

As with iron ore, manganese was subject to a long-standing embargo on exports, but this was partly relaxed in 1956 to allow for shipments of a portion of any new discoveries made. This change was designed to encourage exploration, and resulted in a burst of prospecting activity in northwestern Western Australia, during which many new small deposits were discovered amounting, in all, to several million tonnes. In 1960 a discovery of much greater importance was made by BMR officers at Groote Eylandt, in the Gulf of Carpentaria, where BHP have now established an open-cut mine and treatment plant. Shipments of ore from Groote Eylandt have increased to supply most of Bell Bay's ferromanganese requirements, plus an export surplus. This deposit can supply all of Australia's requirements for metallurgical-grade ore for a long period to come; however, Australia has no production of battery-grade ore and continues to import this at the rate of about 1300 t/year. In addition, electrolytic manganese dioxide is imported from Japan and USA (1208 t in 1983) for battery manufacture.

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Australian production of manganese ore in 1983 increased to 1.4 Mt. Exports totalled 1.0 Mt, mainly for Japanese and European markets. Imports other than battery-grade ores have shown a marked decline from 1965 and were 182 t in 1983. Australia's production of high-carbon ferromanganese now satisfies local demand, but imports of other grades including ferromanganese powder and manganese metal, powder and flakes, totalled 2400 t in 1983. Since the end of production in the Port Hedland district of Western Australia in 1973, Groote Eylandt is now the only large-scale producer of manganese ore.

Nickel (Ni)

Nickel is used mainly as an alloy in stainless steel (about 40%) and other alloy steel, nickel rich 'superalloys' used in high temperature applications such as gas turbine engines, cast-iron, nickel-copper and copper-nickel alloys, and with chromium or molybdenum and iron in corrosion resistant alloys. The main other users of nickel, chiefly in the form of alloys, are manufacturers of chemicals and allied products and petroleum refiners. Nickel is used in electroplating and with some of its salts as catalysts. It is also used in batteries and fuel cells, in carbides and hard facing materials and in ceramics.

The main nickel mineral mined in Australia (and worldwide) is the iron-nickel sulphide pentlandite ($(Fe,Ni)_9S_8$), although most of the world's known resources are contained as oxides and silicates in laterite, a tropical-weathering product of certain rocks.

Following the initial discovery, by Western Mining Corporation Ltd, of sulphide nickel ore at Kambalda in 1966, other companies made important finds and by the end of 1974 fourteen nickel mines were in production. Fluctuating nickel prices and depletion of reserves have since caused some mine closures but several new mines have started up, and one large mine has been reopened. WMC remains the largest producer of nickel ore from its group of nine mines at Kambalda, where measured and indicated reserves at December 1984 were estimated to be 26 Mt of ore averaging 3.3% Ni. In 1983 WMC produced a total of 44 595 t of nickel in concentrates (nickel contained in ore produced at the Nepean mine, owned by Metals Exploration Limited, is included in the WMC figure).

The Greenvale lateritic mine (Metals Exploration Queensland Pty Ltd/ Freeport Queensland Nickel Inc.) in northern Queensland produced 1.75 Mt of ore from which about 13 200 t of nickel was recovered in sintered nickel oxide and nickel-cobalt sulphide. Measured ore reserves at this mine are 13.8 Mt averaging 1.45% Ni.

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Production of concentrates by the Windarra Nickel joint venture at Mount Windarra resumed mid-1981. Plant for the production of concentrates was recommissioned in conjunction with modified facilities to treat gold ore from the nearby Lancefield mine, and production capacity of nickel in concentrates 8000 t/year; production in 1983 was 3820 t nickel in concentrates. Demonstrated reserves at Mount Windarra and South Windarra together totalled 8.5 Mt of ore averaging 1.7% Ni.

The Agnew mine, operated by Agnew Mining Co. Pty Ltd (60 percent Seltrust Mining Corp Pty Ltd, 40 percent MIM Holdings) started producing nickel concentrates in mid-1978. Original studies called for the production of 30 000 t/year of nickel. However, because of a recession in the nickel industry, initial production began at the rate of 10 000 t/year of nickel in concentrate. A program announced in 1979 to increase production to 15 000 t/year by 1984 is behind schedule because difficulties have been encountered in mining the required ore grades. Output of nickel in concentrates totalled 10 637 t in 1983. Demonstrated ore reserves at the mine are 36.7 Mt averaging 1.92% Ni.

In addition to the projects already mentioned, whose output is more than sufficient for Australian requirements, there are several large but low-grade deposits which at the present time are not economically viable. A large lateritic deposit occurs at Wingellina in Western Australia near the northern end of the South Australian border. Large low grade sulphide deposits occur north of Agnew at Mount Keith, Yakabindie and Honeymoon Well, and at Sherlock Bay southeast of Port Hedland. Several higher-grade but smaller deposits also occur at Widgiemooltha, Forrestania, and Mount Keith.

Production of nickel concentrates began in June 1967 at Kambalda and output for that year was 2060 t of contained nickel. In 1983 Australian mine production of nickel was 76 625 t. In 1983, Australia was the third-largest world producer of nickel behind USSR and Canada. In 1983 virtually all of the nickel mined was processed in Australia to either metallic nickel, high-grade nickel matte, or sintered nickel oxide. The nickel refinery at Kwinana near Fremantle started production in 1970 with an output of 15 000 t/year of nickel metal. Output in 1983 was 29 461 t of refined nickel but the plant has the capacity to produce 30 000 t/year. WMC commissioned a nickel smelter at Hampton near Kalgoorlie in 1972 with a capacity of about 200 000 t/year of concentrate, but this has since been increased to more than 450 000 t/ year with potential for substantial further expansion.

Tungsten (W):

Tungsten is used in certain ferroalloys to produce high-speed tungsten steels, and metallic tungsten filaments which are used in electric light bulbs. Tungsten carbide approaches diamond in hardness and is used as cutting tips or inserts in cutting tools and in other applications where resistance to extremely abrasive conditions is necessary. Since tungsten became commercially important in about 1900, Australia has been an important producer of its ores - wolframite ($(Fe,Mn)WO_4$) and scheelite ($CaWO_4$) - but the scale of production has varied with widely fluctuating overseas prices. The greater part of production has always been exported. Domestic consumption is small and there should be little difficulty in meeting Australian requirements for ore from known resources; Australia does not presently produce metal or alloys.

The principal deposits are in Tasmania and Queensland. Wolframite comes mainly from Mount Carbine in northern Queensland where Queensland Wolfram Pty Ltd also produces minor amounts of scheelite. A major deposit of scheelite has been mined for many years on King Island, Bass Strait, where known reserves are 7.21 Mt, averaging 0.92% tungstic oxide (WO_3).

Natural scheelite concentrate is produced at King Island by both gravity and flotation methods and contains about 2% molybdenum (Mo) in powellite, which is physically inseparable from the scheelite. Its presence in the coarse gravity concentrate is not regarded as a disadvantage because of the uses of this particular product. However, its presence in the fine flotation concentrate imposes limitations on the marketing of this material, and attracts a price penalty. To overcome this problem, the company has constructed an artificial scheelite plant which chemically treats the fine concentrate, producing a high-grade calcium tungstate or "artificial scheelite" and molybdenum trisulphide. Australian production in 1983 of tungsten-bearing raw materials (expressed in t of W content) was 2013 t.

Australian consumption of WO_3 is about 200 t/year; its main use is in the manufacture of tungsten-carbide-tipped tools.

Molybdenum (Mo)

Molybdenum is being used increasingly in high-strength low-alloy (HSLA) steels for oil and gas pipelines, because of the superior resistance of such steels to corrosion. Some steels in which molybdenum is alloyed with chromium and nickel are being used increasingly where extreme hardness is required. Molybdenum is also used in lubricants, pigments, corrosion inhibitors, flame 30 retardants, and as a catalyst. Before 1920 substantial quantities of molybdenite were produced in Australia, but for many years production has been small. In 1983 domestic production of molybdenum concentrates was about 26 t. Imports of molybdenum ore and concentrates decreased in 1983 to 63 t and imports of ferromolybdenum decreased to 115 t; imports of molybdenum oxide and hydroxide decreased from 31 t in 1974 to less than 1 t in 1975; figures for later years are not available.

Most of the molybdenite deposits in Australia are pipe-like in form and development to any appreciable depth is costly. One exception is at Yetholme, NSW, where a disseminated contact deposit aggregating some 800 t of molybdenite lies at shallow depth beneath comparatively thin overburden. A discovery of extensive disseminated low-grade molybdenite at Mount Pleasant, 30 km southeast of Mudgee, was announced by CSR Ltd in September 1979, and a deposit at Mount Mulgine, WA, is under investigation. Total Exploration Australia Pty Ltd is presently evaluating a uranium - molybdenum deposit at Ben Lomond, Qld. During World War II the Commonwealth sponsored exploration for new deposits, but results were generally not encouraging.

Recovery of molybdenum as a by-product from treatment of scheelite at King Island began in 1978. This could supply part of Australia's demand in times of emergency, supplemented by imports from USA or Chile.

Chromium (Cr)

Chromite ($(Fe,Mg)(Cr,Al,Fe)_2O_4$), the ore which yields the metal chromium, has two uses in the steel industry; as an ingredient in the production of alloy steel (especially stainless steel), and as a chemically inert furnace lining. Its other main use is in the manufacture of chemicals. Australian annual consumption of chromite, all of which is imported, has averaged about 7500 t in recent years. In 1983, 970 t of chromite was imported, mainly from South Africa. Imports of ferrochromium, mainly from South Africa, increased to 5438 t in 1983. Production of chromite at Barnes Hill, Tasmania ceased in 1980 when reserves were depleted.

The largest known Australian deposit of chromite of economic interest is at Coobina, in the Ophthalmia Range, WA. The only recorded production from this location was between 1952 and 1957 when 14 500 t of ore was produced. The chromite is suitable for metallurgical and chemical use; processing facilities are not available domestically at the present time to warrant development of the deposit.

In general, because of cheaper overseas sources, Australia has been an importer of chromium and its alloys and compounds. Chromium metal is not manufactured locally, and although small quantities of high-carbon ferrochromium were produced at Newcastle until the closure of that plant at the end of 1974, all requirements are now imported. In time of emergency Australia could almost certainly revive its domestic ore production to meet local demand.

Vanadium (V)

This metal, used in both ferrous and non-ferrous alloys, and in the chemical industry, is a common constituent of minerals, though there are relatively few deposits mined.

Substantial resources of vanadium have been recognised in Australia in recent years and several vanadium-bearing deposits have also been investigated and evaluated. Agnew Clough Ltd commissioned a vanadium pentoxide extraction plant at Wundowie in June 1980. The plant had a capacity to produce 1620 t/year of vanadium pentoxide flake (98% V_2O_5) from ore mined at a rate of 200 000 t/year from the nearby Coates deposit. Mechanical problems, rising costs and lower prices caused production to be suspended in late 1981.

Australian imports are not recorded as a separate item in overseas trade statistics because only small quantities are involved. Consumption, principally in the steel industy, is estimated as only a few tonnes/year.

The possibility of economic development of vanadiferous titaniferous magnetite at Barrambie, 470 km east-northeast of Geraldton, WA, is under investigation. Oil shale deposits at Julia Creek in northwestern Queensland also have potential to produce large quantities of byproduct vanadium. In addition, up to 1000 t/year of vanadium pentoxide could also be produced as by-product from any uranium mining at Yeelirrie in Western Australia.

Overseas sources of supply are mainly USA, South Africa, Finland, and Southwest Africa. World production in 1983 was about 29 710 t.

BASE METALS

Copper (Cu):

The first recorded production of copper was in the Kapunda field, SA, in 1842 and at Burra in 1846. In these early years, Australia was one of the world's leading producers, but during the first half of this century known deposits were gradually depleted so that it appeared that Australia would soon become largely dependent upon imports. However, this possibility was dispelled by the confirmation of large reserves of copper ore, first discovered in 1931, adjacent to the lead-zinc lodes at Mount Isa. Since then other deposits have been found in other parts of the continent.

Important discoveries of copper mineralisation have been made in recent years in South Australia, Victoria, New South Wales and Western Australia. Exploration is proceeding at these and other prospects, and Australia can be expected to continue, for some time, to provide not only for its own needs, but for a significant export trade as well.

The full potential of the Mount Isa deposits was not realised until the early 1950s, although copper was mined for emergency purposes from some minor lodes during World War 2. After the discovery by drilling of high-grade copper lodes, a major new enterprise got under way in 1953 and output has since grown steadily. The Mount Isa mine is now the most important source of copper in Australia; of the 6 Mt of copper produced in Australia since 1884, most has come from it.

Australian mine production increased steadily for many years also because of expanded output from Mount Lyell and the commissioning of several new mines in the late 1960s and during the 1970s. Copper production reached a record level in 1983 (261 000 t).

Mount Isa produced about 64% of total Australian production in 1983 and has reserves sufficient to support a high rate of production for over 25 years. Other important centres are Mount Lyell, Tas; Cobar, NSW; Woodlawn, NSW; and Tennant Creek, NT. Mining at Mount Gunson is expected to end during 1985 and production from the Teutonic Bore copper-zinc mine in Western Australia, which commenced in mid-1981, is expected to cease by early 1986 because of depleted reserves.

Exploration for copper deposits continued in 1983 and 1984. Diamond drilling continued on Western Mining Corporation's large Olympic Dam prospect at Roxby Downs, SA, where an extensive zone of copper-uranium-gold mineralisation from 8 to 248 m thick, with probable economic grades, has been intersected about 350 m below the surface. WMC announced in November 1983 that work had established within the mineralised area a probable 450 Mt of material averaging 2.5% copper, 0.8 kg/t U_3O_8, 0.6 g/t gold and 6 g/t silver. A technical study to be used in the project feasibility study is to be completed in March 1985 and involves plans for a staged production rate of 55 000 t/year Cu and about 2000 t/year U_3O_8 rising later to 150 000 t/year Cu and 4000 t/year U_3O_8 when market conditions permit; the study also involves additional gold to be produced from a discrete ore zone containing about 6 g/t Au. In September 1983, WMC announced the discovery of economically significant secondary and primary copper mineralisation at their Nifty prospect in the Throssell Ranges, about 200 km ESE of Marble Bar, WA. The secondary copper mineralisation is described as being amenable to open-cut mining and the announcement suggests that on present indications the average grade should be in the economic range. WMC announced that a great deal more drilling is required to evaluate the primary mineralisation.

In October 1983, EZ Industries Ltd (EZI) announced plans for a feasibility study of the Scuddles copper-zinc deposit at the Golden Grove prospect near Yalgoo, WA. The program is planned for completion in 1986 and will provide the basis for a determination of the viability of the deposit for commercial development. In a joint venture with Chevron Exploration Corporation, Peko Wallsend Ltd continues to investigate the Goonumbla porphyry copper-gold deposits near Parkes. Exploration elsewhere in the district continues to reveal mineralisation of a similar nature with potential to add to the known resources.

Details of copper in all mine products in 1983 are as follows:

		Tonnes (metal)
Queensland		
Mount Isa	164 607	
Others	809	165 416
New South Wales		
Cobar	10 097	
Broken Hill lead-zinc-silver mines (by-products)	3 531	
Woodlawn	12 603	
		26 231
Tasmania		
Mount Lyell	23 847	
Others	3 675	27 522
Western Australia		
Teutonic Bore	11 347	
Nickel mines (by-product)	3 485	14 832
South Australia		
Burra	679	
Mount Gunson	12 617	13 296
Northern Territory		
Tennant Creek mines	10 735	
		10 735
Total		(a)258 312

(a) This total may differ from figures quoted in the text because they come from different sources of information.

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Australia has two copper refineries - at Port Kembla and at Townsville. The refinery at Townsville (operated by Copper Refineries Pty Ltd, a wholly owned subsidiary of MIM Holdings Ltd), with an annual capacity recently expanded to 175 000 t, is by far the larger. It was commissioned in 1959 and refines the whole of the Mount Isa output. In 1983, 74% of the copper in copper concentrates produced in Australia was processed in Australia to blister or refined metal. The Tennant Creek flash smelter, re-opened by Peko-Wallsend in 1980, was closed down again in October 1981 because of continuing technical and economic problems. The Mount Morgan smelter continued to treat concentrates from Tennant Creek during the year and nearly all blister output was exported.

Lead (Pb)

Lead and zinc are usually discussed together because nearly all Australia's production is obtained from orebodies containing the sulphides of both metals (generally galena (PbS) and sphalerite ($(Zn,Fe)S$)); the lead and zinc are separated by crushing and flotation. Galena also almost always contains silver; it is the most important ore of lead and one of the most important sources of silver.

Since the discovery, in 1883, and development of the Broken Hill lead-zinc-silver orebody, perhaps the richest in the world, Australia has been a major producer of lead and zinc ores and, in the years following 1923, its position was reinforced by the discovery and exploitation of the Mount Isa deposit. Australian metal mining began with silver-lead in South Australia in 1841. Australia has been amongst the world's leading producers of lead for many years and in 1983, with production of 480 626 t, it ranked as the second-largest producer in the world behind USSR. Australia's known resources are sufficient to sustain exports for several decades.

Mine production has run uniformly high in recent years and reached a record level in 1983. Large increases in output occurred at Mount Isa. Elura, which came on stream in the early part of 1983, gradually phased in production throughout 1983.

Australia's demonstrated economic resources of lead and zinc constitute about 10% of the world's demonstrated economic resources. Nearly all are in lead and zinc sulphide deposits and the bulk of demonstrated economic resources are contained in the Mount Isa, Broken Hill and Cobar regions. Demonstrated economic resources of lead, zinc and silver have declined slightly over the last five years, although total identified resources over the same period have increased slightly. Australia has substantial resources in the inferred and subeconomic categories that could be reclassified into the demonstrated economic category with some upturn in price levels. A number of prospects are at present the subject of intensive exploration and development. These include Hilton, Lady Loretta and Thalanga in Qld; Scuddles deposit/Golden Grove and Sorby Hills in WA; and Hellyer in Tas.

Details of lead in all mine products from the States in 1983 are as follows:

		t Pb
New South Wales		
All Broken Hill mines	196 938	
Woodlawn	20 311	
Cobar	3 523	
Elura	22 268	
Other	253	243 293
Queensland		
Mount Isa	200 117	
Others	2 137	202 254
Tasmania		
Read-Rosebery - Que River		34 777
Other States		302

Most of Australia's lead concentrates are smelted in Australia, at smelters at Mount Isa, Qld, and Cockle Creek, NSW, which together produced 187 536 t of lead in lead bullion in 1983, and a smelter and refinery at Port Pirie, SA, which produced 208 529 t of refined lead (196 335 t from primary sources and 12 194 t from secondary sources. Output of refined lead from other secondary producers totalled 15 000 t. Domestic consumption decreased to 55 600 t.

Lead acid batteries continue to be the most important lead market and account for 45-50% of all lead consumed. Growth in the domestic and world lead markets appears to be closely linked with future developments in the automotive industry, which is the largest single consumer of batteries. The industry is under pressure to manufacture smaller and lighter vehicles which in turn may result in a reduced demand for lead. However, expansion in other applications, including off-road vehicles and standby power plants, will help to offset any decrease. In addition, the future possible introduction of battery-powered electric vehicles could result in a substantial increase in demand.

The implementation of increasingly stringent regulations controlling vehicle exhaust emissions in some countries has resulted in a decrease in consumption of lead (as tetra-ethyl lead) in petrol. In view of the introduction of similar regulations in other countries it is now inevitable that the amount of lead so consumed will have fallen considerably by the late 1980s and this end-use, which presently ranks second to batteries, may well disappear altogether by the 1990s. There appears to be little fluctuation in demand for most other uses of lead.

Zinc (Zn)

For a number of years Australia has ranked third behind Canada and USSR as the world's leading producers of zinc ores except in 1981 when it slipped into fourth place behind Peru. In 1983, mine production was a new record of 696 071 t.

Details of 1983 production are as follows:

		t Zn
New South Wales		
Broken Hill mines	267 911	
Woodlawn	62 946	
Cobar	10 840	
Elura	39 896	
Other	28	381 621
Queensland		
Mount Isa		201 075
Tasmania		
Read-Rosebery-Que River		82 285
Western Australia		
Teutonic Bore		31 090
		696 071

There are three zinc refineries in Australia - a large electrolytic plant (capacity 210 000 t/year) at Risdon, Tas. based on hydroelectric power; an Imperial Smelting Process plant (capacity 75 000 t/year) at Cockle Creek, NSW; and at Port Pirie, SA, an electrolytic refinery (capacity 45 000 t/year), which recovers zinc from accumulated lead smelter slag dumps as well as granulated smelter slag from current operations. About 50% of Australia's total zinc concentrates (representing all of Tasmania's output, the bulk of Woodlawn's and Cobar's production, and some of Broken Hill's and Mount Isa's output) was treated at these plants in 1983. The remainder of concentrates from Broken Hill and Mount Isa was exported. In 1983, production of refined zinc was 302 951 t (including 4500 t from secondary sources). Domestic consumption in 1983 increased slightly to 83 471 t of refined zinc, of which 78 971 t was of primary origin.

Growth of the zinc market appears to be closely linked with future developments in galvanising, by far the largest end-use for zinc. In Australia, with continued erosion of the galvanised sheet-steel market by 'zincalume' and the importation of one-sided coated steel products, both of which use less zinc (and the zinc-aluminium surface of 'zincalume' is claimed to also have twice the life of ordinary galvanised surfaces), prospects for growth appear limited. However, the use of painted zinc coatings on steel surfaces, as well as the introduction of new product lines such as 'galtan' which uses more zinc, may arrest this decline.

Zinc die-castings, the second-largest end use for zinc in Australia, have also met considerable competition from substitute materials. The trend to conservation of energy and weight reduction in automobiles has led to manufacture of thinner, lighter zinc castings and partial substitution by plastics and aluminium, reducing the amount of zinc used in vehicles. The introduction of thin coatings of zinc on car panels and other consumer durables may offset this decline.

Other applications, notably zinc oxide (used as an activator in the rubber industry and as a trace element in fertilisers), zinc dust (consumed mainly in the manufacture of zinc-rich primer paints), and rolled zinc (for dry-cell batteries), appear to be areas where future growth seems assured.

Tin (Sn)

Commercially the most important ore mineral of tin is the oxide, cassiterite (SnO_2). From being a country with a considerable tin export surplus (Australia led the world in tin production for nearly a decade around 1883), Australia became partly dependent on imports about 1947. The revival of several old mining centres radically changed this position and Australia became a net exporter of tin again in 1966.

Production of tin in concentrates reached a record 12 571 tonnes in 1979. It fell to 9275 t in 1983 because of export quotas imposed by the International Tin Council on its producer members. World production has exceeded consumption for several years, and the quotas were imposed in an effort to bring the two into balance. Production of primary refined tin, after reaching a peak in 1972 of 7027 tonnes, decreased in later years partly because of changes in the type of concentrate available to the larger smelter. It was only 2913 t in 1983.

Imports in 1983 were 103 t of refined tin and 186 t of tin concentrates; exports were 473 t of refined tin and 17 729 t of concentrates containing 6202 t of tin. Estimated consumption of primary refined tin in the same year was 2500 t. Consumption in 1984 probably will be about the same.

Tin alloys have many uses - soft solder (tin and lead), bronze, bearing metal, gun metal, die-casting, and pewter. Tin salts are used in ceramic enamels, plastics, fungicides, and pesticides.

Tinplate, produced at Port Kembla, accounts for about two thirds of the domestic consumption of tin.

Technological advances have resulted in a progressive decrease in the amount of tin consumed per unit area of tinplate produced. Tinplate is susceptible to substitution by other packaging materials, but has advantages, particularly in food packaging, that have enabled it to retain much of its share of this sector at least.

Associated Tin Smelters Pty Ltd, operating at Alexandria, NSW, is the main domestic producer of primary refined tin. Annual smelter capacity is rated at about 7000 t of tin metal. The smelter can more than meet Australia's requirements of refined tin. Greenbushes Tin Ltd has an electric smelter, with a capacity of 1500 t/year of concentrate, at Greenbushes and produces a tin suitable mainly for alloys because of its antimony content.

Traditional treatment methods are not suitable for ores in which the cassiterite is very fine grained, especially if other metal sulphide minerals are also common in the ore. A process known as matte fuming gives promise that such ores can be economically treated. Although Aberfoyle Limited has developed the process to the pilot plant scale, the process has not yet been commercially applied.

In the past much Australian tin production was from alluvial deposits, particularly those inland from Cairns in north Queensland, in the New England and central west regions of New South Wales, and in northeast Tasmania. However, with the discovery of new orebodies in some old lode mining areas, the emphasis swung in the late 1960's from alluvial to lode mining, both underground and open cut. The major producers, at Renison Bell and Luina in northwest Tasmania, Ardlethan in central western New South Wales, and Greenbushes in Western Australia, are all lode mines. The major alluvial producer is inland from Cairns in north Queensland.

Exploration for tin deposits greatly increased in the late 1970s, and several promising new discoveries have been reported. Decisions on development have been deferred because of the uncertain world market. Published ore reserves in most mines are sufficient for only a few years, but further exploration could result in reserves being increased, especially if prices were higher. However, the Renison mine contains more than three-quarters of the total Australian demostrated economic resources, its annual production is more than Australian consumption, and this mine alone has the potential to supply Australia's requirements of tin to the turn of the century at least.

Some of the greatest tin-producing countries in the world, Malaysia, Thailand, and Indonesia, lie immediately to the north of Australia, but it is very unlikely that Australia would be unable to supply its own needs in any emergency in the foreseeable future.

OTHER METALS

Aluminium (Al)

Over the past two decades the production of aluminium and its ore, bauxite (mainly a mixture of hydrous aluminium oxides and aluminium hydroxides) and alumina (Al_2O_3), a partly processed product, has been one of the most rapidly expanding sectors of Australia's mineral industry. Three decades ago Australia appeared to be seriously deficient in bauxite resources. Although exploration during the war years had shown that there were small domestic reserves, and the decision was reached to establish an aluminium smelting industry at Bell Bay, Tas., it was nevertheless believed that the industry would, at most times, be dependent upon imported ores with local ores held in reserve.

A series of discoveries was to change this picture completely. The discoveries began in 1949 when BMR found relatively small deposits of bauxite at Marchinbar Island off the coast of Arnhem Land; this was followed by a more substantial discovery on the mainland near Gove. Later, in 1956, very large deposits of bauxite were found at Weipa on Cape York Peninsula by an exploration company; and in 1958 important new sources were recognised at Jarrahdale in the Darling Ranges close to Perth, where the bauxites had previously been regarded as too low-grade for commercial exploitation. In 1965, an announcement was made of the discovery of further large deposits inland from Admiralty Gulf in the Kimberley district of Western Australia, and in 1973 it was announced that extensive, lower-grade deposits lay to the north of these, on Cape Bougainville. Exploration during the early 1970s south of the Weipa deposits indicated several hundred million tonnes of bauxite.

Production of ore from Weipa, Jarrahdale, and Gove has mounted rapidly and in 1983 was 24.5 Mt. Australian reserves are now known to be very large, at least 6000 Mt, and the largest of any country in the world except Guinea. Bauxite mining and shipping facilities at Weipa are currently capable of handling over 11 Mt/year. Facilities in the Darling Range have a total mining and treatment capacity of over 13 Mt/year, while those at Gove, NT can handle 5 Mt/year.

Developments in the field of processing have also been rapid. From 1963, when Alcoa of Australia Ltd commissioned its Kwinana, WA, alumina refinery (present capacity 1.4 Mt/year of alumina), other refineries were commissioned by: Queensland Alumina Ltd at Gladstone, Qld, in 1967 (capacity now 2.7 Mt/year) by Nabalco Pty Ltd at Gove, NT, in 1972 (present capacity 1.2 Mt/year); by Alcoa again, at Pinjarra, WA in 1972 (present capacity 2.4 Mt/year) and at Wagerup, WA, in 1982 (initial capacity 0.5 Mt/year). In addition, Worsley Alumina Pty Ltd (a partnership of Reynolds, Shell, Dampier, and Kobe) has constructed an alumina plant at Worsley WA; the 1 Mt/year stage of this refinery was commissioned early in 1984.

Total aluminium smelting capacity of Australia's four smelters is presently 798 000 t/year of metal and new construction presently being undertaken is expected to increase this to 843 000 t/year by 1985. Australia's smelting capacity is located at Tomago, NSW (Gove Aluminium Ltd/Pechiney Ugine Kuhlmann - 220 000 t/year) Kurri Kurri, NSW (Alcan Australia Ltd - 90 000 t/year), Point Henry, Vic (Alcoa - 165 000 t/year aluminium), Bell Bay, Tas., (Comalco - 117 000 t/year, and Boyne Island, near Gladstone (Comalco - 206 000 t/year). Capacity at Kurri Kurri is being increased to 150 000 t/year.

Alcoa commenced construction of a new 132 000 t/year (initial capacity) smelter at Portland but work on this project was deferred in the latter part of 1982 because of increased costs (particularly of electricity for smelting), and depressed markets. However early in 1984 the company announced development would go ahead.

Other smelter projects have been mooted in recent years but escalating costs and the current widespread recession have made these much less certain.

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Titanium (Ti)

Australia's resources of the titanium minerals, rutile (TiO_2) and ilmenite ($FeTiO_3$), are adequate. Domestic recoverable economic resources are put at about 9 Mt of rutile and 42 Mt of ilmenite, although almost half of the resources of rutile on the east coast are currently unavailable for mining because of environmental considerations.

In 1983 Australia supplied about 58% of world output of rutile concentrates and about 25% of the world's ilmenite concentrates.

The original uses of rutile were for the manufacture of welding rods and the production of titanium metal; since the early 1960s, by virtue of the chloride method of processing, rutile has been used in the manufacture of pigment for high-gloss white paint, an outlet which now accounts for about 70% of total rutile consumption. The use of ilmenite is virtually confined to pigment manufacture. However, the commercial application of processes by which ilmenite is upgraded to approach rutile in TiO_2 content (beneficiated ilmenite or synthetic rutile) provides a feed for either metal or pigment via the chloride process; beneficiated ilmenite now complements and competes with supplies of natural rutile. Although installed world capacity for beneficiated ilmenite was rated at about 300 000 t/year in 1983, only about 70% of this capacity was actually used because of reduced demand for TiO_2 feed.

The principal source of Australian production of rutile is sands on and adjacent to the beaches of its eastern coast. The discovery in 1971 of old shoreline deposits of rutile, zircon, and ilmenite near Eneabba, 270 km north of Perth, constituted a major additional supply of rutile. Commercial production of rutile from this source began in 1975 and installed capacity for rutile production in the area is now about 150 000 t/year. In 1983, production from this source accounted for about 30% of total Australian output of rutile concentrates. On the eastern coast much of the ilmenite which accompanies the rutile and zircon has too high a chromium content to be saleable for pigment and for the most part has been discarded or stockpiled; however, ilmenite from the mid-Queensland coast tends to have a more acceptable chromium content and eventually could provide a suitable base for the production of synthetic rutile. The main operators on the east coast are Mineral Deposits Ltd at Myall Lakes, NSW, Rutile & Zircon Mines (Newcastle) Ltd at Tomago, NSW, and Consolidated Rutile Ltd and Associated Minerals Consolidated, both at North Stradbroke Island, Qld.

The ilmenite industry has been built up mainly along the south-western coast of Western Australia. The quality of the ilmenite from this source is most satisfactory for the manufacture of titanium white and, as ilmenite is the main heavy-mineral constituent of the sands, its recovery forms the basis of the industry, together with the production of zircon, rutile, and monazite. In mid-1971 Western Titanium Ltd, now a wholly-owned subsidiary of Associated Minerals Consolidated Ltd, commissioned a commercial beneficiation plant at Capel, WA, and an annual production rate of 45 000 t of beneficiated ilmenite was achieved. The plant is now based mainly on ilmenite from the company's operation at Eneabba, supplemented with secondary ilmenite produced at Capel. However it was closed temporarily in 1983. A semi-commercial plant with an annual capacity of about 15 000 t/year of synthetic rutile, closed down in 1975, was reactivated at the end of 1979. Both rutile and anatase pigments are produced in Australia; both pigments are produced at Bunbury, WA, but only rutile pigment is produced at Burnie, Tas. Both plants are based on the sulphate process and use ilmenite concentrates produced from the Capel deposits. Australian production capacity for TiO_2 pigments is 55 000 - 60 000 t/year about 95% of which was utilised in 1983. Ilmenite concentrates are exported from Bunbury and Geraldton, where substantial bulk loading facilities are available.

Australia will be self-sufficient in most beach-sand minerals, particularly in ilmenite, at least to the turn of the century. Current resources of rutile available for mining could be exhausted in the 1990's.

Zirconium (Zr)

Australian resources of zircon ($ZrSiO_4$), are considerable and are almost twice those of rutile. Again, however, almost half of east-coast resources are unavailable to mining because of environmental considerations. Zircon is produced as a co-product of rutile mining along the east coast and in the Eneabba area, and as a by-product of ilmenite mining in the southwest corner of Western Australia. Western Australia became the leading State producer of zircon concentrates in late 1976, and in 1983 produced 68% of domestic output.

The market for zircon, principally required by foundries for moulds, facings, and cores, and for refractories and ceramics, faced oversupply in 1970 but became firm in 1973; as temporary assistance to the industry, the Commonwealth Government, early in 1971, supported a stockpiling scheme initiated by industry, by controlling the minimum price of zircon in export contracts. When world demand recovered the position of oversupply was quickly reversed, and in 1973 Australia exported 431 000 t of zircon concentrates. However, a position of potential oversupply again developed in 1975 and the Government re-introduced a minimum price for zircon exports, albeit almost five times as high as that in 1971. In 1983, Australia exported 382 000 t of zircon concentrates.

In July 1983, Nilcra Ceramics, a joint venture between CRA Ltd and Oliver J. Nilsen (Aust.) Ltd, was established to develop, manufacture, and market an advanced ceramic product known as partially stabilised zirconia (psz). This material has three times the compression strength of steel but is 20% lighter. In October 1983, CSIRO was reported to be seeking a commercial partner to develop the capability to manufacture zirconia in Australia.

Thorium (Th) and cerium (Ce)

The main commercial source of thorium, which has been of interest because of its possible nuclear uses, is the mineral monazite ((Ce,La,Nd,Th)(PO_4,SiO_4)), a by-product of beach-sand operations on both the east and west coasts of Australia. Notwithstanding the use of thorium in several US experimental reactors, large-scale nuclear use of this material in fast-breeder reactors is said to be many years off. Although research on the nuclear application of thorium continues, commercial introduction of the thorium-uranium fuel cycle in the high-temperature gas-cooled reactor (HTGR) as an industrial source of high temperature heat is not seen before the 1990s although a commercial thorium- fuelled HTGR of 330 MW capacity is operating (at about 35% capacity) in USA.

The increasing interest in monazite results from its rare-earth content, particularly of cerium and yttrium. World demand for rare earths increased sharply in 1973, particularly for high-strength low-alloy steels used in oil and gas pipelines. In recent years, the pattern of rare-earth applications has changed from one based on the use of rare earths as catalysts to one more strongly oriented to metallurgical applications. Estimated percentage end-use applications in 1983 were: catalysts 55%; metallurgy 30%; glass and ceramics 13%; TV electronics, nuclear, and miscellaneous 2%. Cerium is also present in the mineral allanite ($(Ce,Ca,Y)(Al,Fe)_3(SiO_4)_3(OH)$), large quantities of which occurred in the Mary Kathleen uranium deposit.

High-grade monazite concentrates are recovered from beach sands in Western Australia, Queensland, and New South Wales. The monazite recovered in the southwest corner of Western Australia is a by-product of ilmenite production, but elsewhere it is a by-product of rutile and zircon production. Small

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tonnages of xenotime (yttrium phosphate) are also produced as a by-product of ilmenite production in the Capel area of Western Australia. Development of extensive mineral sands deposits commenced at Eneabba about 270 km north of Perth in 1975, and the area is now a major world source of monazite.

In 1983 Australian production was 15 305 t of concentrates containing 14 040 t of monazite, 96% of which came from Western Australia; Australia supplies about 60% of non-Communist world output of monazite concentrates. Before 1969 all sales were to export markets, but an old uranium plant at Port Pirie, purchased from the South Australian Government, was commissioned in May 1969 to process monazite. In early 1972 an annual throughput rate of 1300 t of monazite concentrates was achieved at the plant for the production of cerium and lanthanum hydrates, yttrium oxide, thorium sulphate, and tri-sodium phosphate. However, financial and marketing difficulties forced closure of the plant in mid-1972.

Australia is undoubtedly self-sufficient in these minerals for any foreseeable requirement; alternative sources of supply would be South Africa, Malaysia, India, Brazil, and USA.

Antimony (Sb)

The main end use of antimony is as the compound antimony trioxide, used exclusively in fire retardants. However it is also still used to impart hardness and stiffness to lead alloys e.g. in vehicle batteries, as an ingredient in type metal, Babbitt (a soft alloy of tin, antimony, copper, and lead), Britannia metal (alloy of tin, antimony, and copper), pewter, and in the plastics industry.

Mine production of antimony in 1983 was 538 t, of which 71 t was produced as antimony concentrates and 467 t was recovered at Port Pirie from Broken Hill Pb-Zn concentrates. In addition, 484 t of antimony was recovered from scrap. All antimony recovered at Port Pirie is recycled to produced antimonial lead (28 638 t in 1983).

Exports of antimony in 1983 included 1695 t of ores and concentrates and 4318 t of antimonal lead alloy. Some 26 t of antimony metal was imported. In early 1977 Quelar Chemicals established a small electrolytic antimony refinery in Brisbane. Production in 1977 was reported to be about 3 t of metal, but the high energy costs involved made it uneconomic and the operation was placed on care-and-maintenance in early 1978.

Antimony ores have been produced in Australia since the middle of the last century, but most deposits have been worked out. Recently, the only production has come from mines in the Hillgrove area in northeastern New South Wales.

Australia is self-sufficient in antimonial lead, but requires minor imports of high-purity antimony metal and antimony trioxide.

Beryllium (Be)

Beryllium is a lightweight metal processed mainly from the mineral bertrandite ($Be_4Si_2O_7(OH)_2$) but also from beryl ($Be_3Al_2Si_6O_{18}$), good specimens of which may also be marketed as gemstones (e.g. aquamarine and emerald are varieties of beryl). The metal has become of particular interest since the development of nuclear technology, but its main use is still in alloys of copper, nickel, and aluminium, which it toughens for industrial uses. Domestic demand, if any, is small.

Australian production of beryl began in 1939 and reached a peak in the war years. It fell away soon afterwards and mine production in 1967 was only 55 t, containing some 6.9 t of beryllium oxide. Production in 1974 was 9 t of contained BeO; there has been no production since 1974.

Most Australian production has come from open-cuts at the Triple Chance mine near Broken Hill, with some production coming also from Olary, SA, across the border, and from the Goldfields district of Western Australia. In times of emergency, particularly if production costs were not to be the principal consideration, the small scattered deposits already known could most probably produce sufficient for Australia's foreseeable requirements. Main overseas sources are Brazil and USA.

Lithium (Li)

The main uses of lithium are in the glass, ceramics, and pharmaceutical industries, and in the preparation of greases, and welding and brazing fluxes; as lithium seems particularly suitable as a battery anode material, and much interest in battery research has been generated in recent years, a significant market could develop in the future. Consumption of lithium products in Australia is not known in detail, but is quite small; requirements, except for occasional purchases from local production, are met by imports. USA dominates the world production scene, but Canada and Chile are also large producers.

Lithium ores have been produced intermittently in Australia since 1905. In 1974 small amounts totalling 1.0 t were produced in Western Australia, but no production has been recorded since 1974. However, considerable resources of high-grade lithium have been discovered at Greenbushes, WA, adjacent to the tantalum deposits which also occur there. Greenbushes Tin Ltd has begun marketing small parcels of high-grade lithium concentrates and began regular production of about 5000 t/year of lithium concentrate in 1984. In addition, several years ago, a company was reported to have drilled various lithium prospects near Kalgoorlie and Ravensthorpe, WA, and extensive resources are said to have been indicated.

Tantalum (Ta)-columbium (niobium)(Nb)

Tantalum and columbium are metals that occur together in nature and are used in alloying, in high-temperature corrosion-resistant chemical ware, in tipped cutting tools, and in anodes and grids for electronic equipment. Tantalum is used also in semiconductor devices. Australia is an important producer of the ore (tantalite-columbite) which is produced mainly as a co-product of tin mining at Greenbushes and Moolyella, and also from Wodgina in Western Australia. Greenbushes Tin Ltd, the main producer, announced in late 1980, the discovery of a major tantalum resource below its present open-cut. On present indications it would appear to be one of the largest-known tantalite deposits of its kind in the world. The company is developing a new mine to begin production in 1986. In addition to concentrates the company produces tantalum and columbium oxides from concentrates, and tantalum glass from tantalum-rich tin smelter slag.

Total Australian production of combined concentrates in 1983 was 117 t, which was nearly all exported. Presently, there is no domestic demand but should this ever be generated, such could adequately be met from available resources.

Selenium (Se) and tellurium (Te)

Selenium is used in small quantities in the electronic, chemical, glass, and metallurgical industries, but is being replaced in some of its uses by the cheaper materials silicon and germanium. There is some production from tankhouse slimes at the electrolytic copper refinery at Port Kembla and a small quantity of selenium-bearing residue is also produced by Sulphide Corporation at

Cockle Creek; statistics of production are not available for publication. Peko-Wallsend Ltd produces concentrates containing gold, bismuth, copper, silver, and selenium at Tennant Creek. No payment is received for selenium in concentrates and it is therefore not recorded as production. Domestic consumption is not large. Leading overseas producers are USA, Canada, and Japan.

No Australian production of tellurium has been recorded since 1964, when output was 1.6 t. The metal was then mainly produced as a by-product of copper and lead refining. Small quantities were also recovered from flue gases and dusts generated from the smelting of copper, lead, and bismuth ores, as well as from the roasting of tellurium-rich gold ores, and from the roasting of some pyrite ores for production of sulphuric acid.

Tellurium is mainly used as an additive to cast iron, to improve its machining properties, and in copper alloy springs to increase their life in electrical apparatus.

Bismuth (Bi)

Post World War II production of bismuth in Australia has come almost entirely from the Northern Territory - initially on a small scale as a by-product of tin and tungsten mining and, since 1967, on a much larger scale as a by-product of copper/gold mining at Tennant Creek, by Peko Mines Ltd. Production statistics have, since 1979, not been available for publication; production in 1978 was 1054 t. Imports of bismuth metal in 1983 totalled 7 t.

Bismuth is used mainly as a constituent of fusible alloys and low-smelting-point solders, as well as in the production of various salts for use by the pharmaceutical and chemical industries. The use of bismuth as a metallurgical additive to aid the casting of iron and improve the machinability of aluminium and steel has increased in recent years.

Calcium (Ca) and Magnesium (Mg)

Calcium and magnesium occur in abundance in nature as limestone (essentially $Ca\ CO_3$) and dolomite $(Mg, Ca)\ CO_3$).

Calcium is a soft metal which, because it corrodes rapidly in air, has little use on its own. However, it has found a use as an alloy of lead, to which it imparts hardness. In more recent years it has also found use in a process which recovers uranium metal from uranium hexafluoride.

Magnesium has been called the lightweight champion of metals, being only two-thirds the weight of aluminium. It is used mainly in alloys, particularly with aluminium, to which it imparts strength, and which is used extensively in the aircraft and allied industries.

Neither metal is presently produced in Australia, although magnesium was smelted from magnesite ($Mg\ CO_3$) in limited amounts at Newcastle during the war. Elsewhere in the world magnesium is produced mainly from seawater; world production in 1983 was 266 000 t. Australia imports magnesium mainly as unwrought metal; imports in 1983 of 2602 t were valued at $6.4 million.

Mercury (Hg)

Australian resources of mercury are negligible. Until 1945, when Australian production ceased, about two-thirds of its total output of 23.6 t had come from various small cinnabar deposits in the Kilkivan area of Queensland. Production resumed in 1967, but solely on a by-product basis - by The Electrolytic Zinc Company of Australasia at Risdon - from roaster gases produced from the calcining of zinc concentrates. No production has been recorded since 1977; production from 1967 to 1977 totalled 8.6 t.

Mercury is used mainly in batteries and other electrical products, in the electrolytic production of chlorine and caustic soda, in paints; in industrial and control instruments, and various other uses.

Imports of mercury in 1983 were 40 045 kg; the bulk of imports were from China (42%), UK (30%) and Spain (17%). World production in 1983 was estimated by USBM as 192 000 flasks, down slightly from the 192 160 flasks produced in 1982 (1 flask = 34.5 kg). World consumption of mercury declined in 1983 mainly because of continuing environmental restrictions.

Silver (Ag)

The main uses of silver are in photography and in electrical and electronic products. Early in 1980 speculation caused prices to rise to an all-time high of more than $1000/kg before quickly retreating to about $400-$500/kg. Most of the silver produced in Australia is a by-product of lead mining, but some is also a by-product of zinc, copper, and gold mining. Mine production in 1983 was a record 1 032 895 kg, most of which was recovered from lead-zinc ore. Refined silver is produced mainly by The Broken Hill Associated Smelters at Port Pirie, The Electrolytic Refining & Smelting Company of Australia at Port Kembla, and the Perth Mint (from gold bullion), but also by several small refiners recovering silver from primary and secondary material (Johnson Matthey Ltd, Harringtons Metallurgists and Englehard Industries). Production of refined silver in 1983 totalled 332 317 kg; mine production not recovered at refineries is exported as a component of base metal concentrates or lead and gold bullion.

Indium (In)

Indium is another alloy metal not commonly found in economic deposits, but derived mainly from flue dust at lead and zinc smelters. Australia's consumption is negligible and there is no production. The Baal Gammon copper-silver-tin deposit at Herberton, North Queensland, contains indium but recent feasibility studies indicate there is little likelihood of the deposit being worked at present. Indium can be obtained from Canada, USA, Belgium, West Germany, or Japan.

Cobalt (Co)

Cobalt is a by-product of the Australian nickel industry and also of the production of zinc. It has a variety of uses which include high-temperature alloys, high-speed steels, and magnetic materials.

In 1983, mine production of cobalt totalled 2196 t, of which 1634 t were contained in lateritic nickel ore mined at Greenvale in Queensland, 477 t in nickel concentrates produced in Western Australia, and 85 t in zinc concentrates from Broken Hill. However, only a small proportion of cobalt produced in mine products is recovered in Australia. The zinc refinery at Risdon, Tas., which continues to be the major supplier of cobalt for Australian industry, produced 20 t of cobalt in cobalt oxide from zinc concentrates in 1983. Nickel-cobalt sulphide products are produced at the nickel refinery at Kwinana and the Yabulu refinery near Townsville. In 1983 the cobalt content of materials from both these sources was 1041 t, but these products are exported rather than further refined in Australia. These by-products, if suitably refined, would make Australia self-sufficient in cobalt; otherwise Australia's relatively small requirement is imported in the form of metal and compounds, mainly from Zaire (the world's principal producer), Canada, Morocco, and Zambia. The USA is an alternative source from which imports could also be obtained.

Cadmium (Cd)

Cadmium is an important metal in alloys for high-pressure bearings required to have a low expansion co-efficient, and has other uses in cadmium plating of steel, nickel-cadmium batteries, in pigments and chemicals, and in fusible alloys for electric fuses and automatic fire extinguishers.

In Australia, cadmium is produced solely as a by-product of lead-zinc-silver mining. Production of refined cadmium in 1983 was 1076 t of metal; 601 t came from Risdon, 476 t from Cockle Creek, and in addition 44 t of crude cadmium was produced at Port Pirie. Mount Isa has produced minor quantities of cadmium-thallium sponge in past years, which was exported, but these was no production in 1983. Estimated domestic sales in 1983 were about 82 t of refined cadmium and the rest was exported, including cadmium contained in lead-zinc-silver concentrates. Australia is more than self-sufficient in this metal, but USA, Canada, and Japan are alternative sources.

Gold (Au)

For the past four years annual production of gold has increased steadily and projections indicate that output will continue to increase for the next five years. in 1972, after two years of rising gold prices, gold production in Australia rose to 23 500 kg but by the mid-1970s production rates had declined to about 15 000 kg annually. Higher prices in 1979 and 1980 sparked renewed interest in gold - exploration activity increased and some new mines were established, old mines were rehabilitated and numerous dumps were retreated to recover gold left behind by earlier treatment methods. As a result of these developments, production increased in 1983 to 30 567 kg. In Western Australia, Northern Territory, and Victoria most of the gold produced is won from gold mines; in the other States nearly all the gold produced is a by-product of the mining and refining of other metals, principally copper, lead, and zinc. Gold won from gold mines accounts for about 87% of Australian production, 86% of such mine production in 1983 coming from Western Australia. In terms of total 1983 production, however, 78% came from Western Australia, 9% from the Northern Territory, 6% from Tasmania, 3% from Queensland, 2% each from New South Wales, with small contributions from Victoria and South Australia.

Australia imported 3091 kg of gold in 1983, mostly as unrefined bullion, and exported 17 742 kg of refined gold in the same year.

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The price of gold was only US$103/oz in August 1976. From this low point it recovered to an average US$606.11 in 1980, and US$424.52 in 1983. Although the price has fallen since 1980, it appears to have moved into a phase of greater stability, in a range US$300-400/oz.

Platinum-group metals

The main uses of the metals of this group (iridium, osmium, palladium, platinum, rhodium, ruthenium) are in chemical ware, in jewellery, in alloys used for electrical purposes, and in the petroleum, glass and automotive industries. There has been a small erratic production of platinum and osmiridium (a natural alloy of osmium and iridium) for over 70 years, but known resources have never amounted to much. Small deposits have been worked in Tasmania and New South Wales, but very little production from platinum deposits has been recorded since 1968.

Platinum-group metals (mainly palladium and platinum) are contained in nickel concentrates produced at Kambalda, WA; production in 1982-83 of recoverable palladium in nickel concentrates was 461 kg and of recoverable platinum 55 kg. Palladium and platinum are recovered at Port Kembla, by ER&S, from by-product copper sulphide residue from WMC's Kwinana nickel refinery. Production in 1983 was 257 kg of palladium (virtually all from the treatment of copper sulphide residue). The balance of palladium and platinum mine production is exported in nickel matte.

Imports in 1983 were valued at $2.94 million and exports were valued at $1.36 million. The pattern of world production is stable, with South Africa, USSR, and Canada together accounting for over 99% of world primary production. As sources of supply, however, Canada and USSR are not as consistent as South Africa, because the quantity of platinum-group metals produced in Canada and USSR is dependent on the quantity of nickel produced, and decreases whenever the nickel industry is depressed. In South Africa, on the other hand, platinum is won from mines where it is the primary product, and copper and nickel are by-products.

Many countries deal extensively in the secondary trade of the platinum-group metals; in 1983, for instance, Australia imported 1904 kg of platinum-group metals and alloys, mostly from USA, and re-exported 296 kg, mainly to UK, Hong Kong, and New Zealand.

Platinum group metals have potential for substantially increased use in chemical, petroleum refining, electronics and jewellery applications. Further growth in the use of palladium and platinum as a catalytic converter in automobile exhaust systems is possible in the medium term and the use of platinum in fuel cell technology for electricity generation has potential for growth in the longer term.

GEMSTONES

Diamonds

Diamonds were mined on a small scale in New South Wales as far back as the 1870's and sporadic production continued until 1961; total production until then was 211 188 carats. In the late 1960's an upsurge of diamond exploration led to the discovery of diamonds at numerous places throughout Australia and over a hundred kimberlitic pipes, the usual host rock for diamonds. Diamonds discovered in alluvial deposits at Smoke Creek, in the Kimberley region, WA, led to the discovery of the nearby kimberlitic pipe AK-1 at Argyle, WA, which has proved to be the richest pipe in the world with a grade about eight times richer in diamonds than the highest grade kimberlite pipe in Southern Africa. However, by world standards the Argyle diamonds have a low gemstone content. Reserves are estimated to be 60 Mt of ore grading at 6.8 ct/t, of which 55 percent are industrial, 45 percent cheap gem and 5 percent gem quality diamonds. Investigation of the diamond occurrences in New South Wales has continued but their source has never been identified.

Commercial mining commenced on the Smoke Creek alluvials in January 1983 and production for the year amounted to 6.3 million carats, estimated to be about 13 percent of world production. A decision was made to mine the kimberlitic pipe AK-1 from 1985 onwards; the planned production rate is 25 million carats a year.

Until 1983 Australia was a net importer of diamonds but will in future be an important exporter of industrial and gem diamonds.

Sapphires

Sapphires were first discovered in the New England district, NSW, and production from Queensland started in the 1890's. They occur mainly in Tertiary gravels, economic concentrations being found in the Anakie district, Qld, and in the Inverell-Glen Innes-Glenco region, NSW.

Australia's sapphire production in 1983 was estimated to be worth more than $23.8M. Australia produces 70-80% of the world's uncut sapphires including most of the highly prized golden sapphires and the characteristic ink blue sapphire.

It is difficult to estimate Australia's sapphire resources but the widespread distribution of sapphires in parts of New South Wales and Queensland indicates that resources are adequate to maintain production for many years.

Opal

Opal occurs in a variety of highly weathered rocks in Australia. It is mined in South Australia at Andamooka, Coober Pedy and Mintabie, in New South Wales at Lightning Ridge and on a smaller scale at a number of small localities in a zone between Opalton and Yowan in Qld.

Australia produces over 80 percent of the world's opals and all of the world's black opals. The value of production of opal in 1983 is estimated to be $42 million. Accurate figures of production are not known because of the nature of the industry; estimates are made on the basis of mining activity on the opal fields. Australia's undiscovered resources of opal have not been fully assessed but are assumed to be very large.

Other gemstones

Australia produces rhodonite, nephrite (jade), chrysoprase, garnet, zircon, amethyst and small quantitities of other gemstones. A small emerald mine, the Aga Khan, WA, was placed on care and maintenance early in 1983.

NON-METALS

Abrasives

Australia's resources of natural abrasives are restricted to diamonds, garnet, and flint pebble; it has no economic resources of natural corundum (Al_2O_3) and emery (an impure variety of corundum containing varying amounts of iron oxides). Production of industrial (and gem) quality diamonds by Argyle Diamond Mines Joint Venture (led by CRA) from alluvial material began in January 1983 at a rate of about 2 million carats/year; mining of the AK-1 kimberlite pipe is scheduled to start in 1985, at a rate of about 20 millions carats/year comprising about 5% gem quality stone, 45% cheap gem, and the remainder industrial grade stone. Production of such quantities would increase the volume of world production of natural stones by about 50%, and would have an estimated value of about US$250 million. The success of the Joint Venture has spurred intense exploration activity by other companies, both in the Kimberly region as well as other parts of Australia.

Australian imports of industrial diamonds in 1982-83 totalled 852 381 carats (value $2.7 million); exports totalled 564 333 carats (value $7.6 million). Zaire is the world's major producer, followed by USSR and other African countries.

Corundum and emery have been mined on a small scale in Western Australia but there is now no domestic production, and imports of artificial corundum commonly amount to 3000-4500 t/year. Zimbabwe is the world's leading producer of corundum followed by USSR and South Africa. Turkey is easily the largest producer of emery.

Part of Australia's requirement of garnet is obtained as a by-product of mining mineral sands; production in 1983 of 2657 t was all from Port Gregory, WA. The bulk of domestic requirements is met by imports, mainly from USA.

Soft abrasives such as diatomite and ground feldspar are produced in Australia in the quantities required.

Arsenic (As)

Arsenic is mainly recovered as a by-product of copper and gold mining and the principal world producers are France, USSR, Mexico, Sweden, and Peru. Arsenic is generally used in industrial chemicals (wood preservatives and mineral flotation reagents), agricultural chemicals (herbicides and plant desiccants), glass and ceramics, non-ferrous alloys, and other uses (mainly pharmaceuticals).

In 1975, Copper Refineries Pty Ltd at Townsville commenced production of copper arsenite, for wood preservative, at the rate of 100-200 t/year. This was the first recorded production of arsenic on a commercial scale in Australia since 1952. The company produced 143 t of tetracupric arsenate in 1983. Broken Hill Associated Smelters Pty Ltd produces and stores about 200 t of arsenic annually in calcium arsenite, a residue of lead refining at Port Pirie. To date no satisfactory method has been found for treatment of the residue to recover arsenic in a saleable product. Most arsenic required in Australia is imported. A total of 1225 t of arsenic trioxide was imported in 1981; later statistics are not available for publication.

A considerable amount of arsenic was at one time also obtained as a by-product from gold mining at Wiluna, WA, and a number of other Australian sources are also known but these are not economically exploitable under present conditions.

Asbestos

Asbestos is the commercial name for a group of six fibrous minerals. Commercially, the most important variety is chrysotile (white asbestos) because of its fineness, strength, flexibility, and suitability for spinning fibre. Other important varieties are amosite, and crocidolite (blue asbestos). Blue asbestos lacks many of the desirable properties of white asbestos, but is stronger and more resistant to chemical action. No detailed statistics on the use of asbestos are collected in Australia, but consumption is mostly for the manufacture of asbestos cement products.

Australia has some resources of blue asbestos (crocidolite) in the Hamersley Range, WA. Deposits of crocidolite near Wittenoom were worked, mainly for export, until 1966 when production stopped because of rising costs.

Australian production of asbestos decreased markedly in 1983 because Australia's sole producer, Chrysotile Corporation of Australia Pty Ltd (a wholly owned subsidiary of Woodsreef Mines Ltd), operated its plant for only one month of the year; the company, which operates at Woodsreef, NSW, 15 km east of Barraba, permanently closed its dry-milling plant on 28 January, 1983 because decreasing fibre recovery rates and dust control obligations associated with the dry-milling plant had increased production costs. Chrysotile Corporation has, for some years, been studying the commercial viability of a wet-milling process; in 1981 the company constructed a 1.5 t/day fibre prototype wet-process mill. Company reports indicate that technical and economic aspects of the wet-milling process are encouraging and during 1983 some 2100 t of cement grade fibre was produced from ore as well as from dry-milled tailings.

Asbestos imports in 1983 comprised 9413 t chrysotile, 90 t amosite, and 611 t other varieties (mainly chrysotile fines); shipments were mainly from Canada and South Africa. Demonstrated economic resources of fibre-bearing rock at Woodsreef total some 19 Mt (BMR estimates the recoverable fibre content as about 2-3%); an additional 16 Mt of material is classified as inferred.

A small quantity of asbestos has also been produced at Baryulgil, NSW, also by Chrysotile Corporation; production from here ceased in 1979.

Barite ($BaSO_4$)

Barite, also known as barytes, is naturally occurring barium sulphate. It is one of the heaviest of the non-metallic minerals and is used extensively as a weighting agent in oil-well drilling muds to control gas pressures.

Australian production of barite in 1983 was 11 752 t; production was nearly all from South Australia, by Commercial Minerals Ltd. Production from Western Australia, by Dresser Australia, stopped in 1981 when the company put its North Pole mine, 110 km east of Port Hedland, WA, on care-and-maintenance.

Production from South Australia was mainly from the Oraparinna region in the Flinders Ranges but also from Olary and Truro; production comprises both industrial-grade material (which, apart from minor amounts imported from China, meets all of Australia's industrial-grade requirements) as well as drilling-grade material.

Minor occurrences of barite are known in every State of Australia but of all such occurrences only one, at Trunkey Creek, NSW, has, in recent years, produced small amounts consistently.

Although about 75% of barite production worldwide (5.0 Mt in 1983) is used in drilling muds, barite has various other industrial applications: it is used in the manufacture of glass, as a flux and to impart brilliance and clarity; as an extender in paints and as a filler in rubber and linoleum; for making heavy printing paper and in brake linings, clutch facings, and plastics; and because of its high density, inertness, and ability to absorb X-ray and gamma radiation, it is also used in special concretes in hospitals and nuclear reactors for shielding purposes and in barium "meals" for X-rays. Barite is also used for manufacturing a variety of barium chemicals but Australia has no such industry; requirements are met by imports. Imports in 1983 were: precipitated barium carbonate (418 t), precipitated barium sulphate (blanc fixe, 274 t), lithopone (barium sulphate and zinc sulphate, 13 t) and barium chloride (1312 t). Consumption of barite in Australia in 1983 was estimated by BMR as 24 000 t, including 19 300 t of drilling-grade material.

Australia has adequate resources of barite which could be brought to production to meet strategic requirements. However, most are in remote localities mainly in Western Australia and South Australia, and as the commercial viability of deposits of minerals of low unit value is mainly influenced by transport costs, domestic requirements will continue to be partly met by imports.

Clays (bentonite, fuller's earth, kaolin, and other clays)

The term 'clay' is used in a variety of ways; over its long history as an industrial mineral it has come to acquire different meanings related to mineralogy, particle size, and rock type. In this summary clays are grouped as follows:

i. bentonite and fuller's earth;
ii. kaolin, ball clay, halloysite and refractory clays; and
iii. miscellaneous clay and shale.

Bentonite is composed mainly of the mineral montmorillonite, a hydrous aluminium silicate. Bentonitic material may be broadly categorised as either swelling or non-swelling. Swelling types have a capacity for absorbing water, which causes them to swell; when added to water such bentonites form a gel-like mass. Swelling-type bentonites are sometimes referred to as sodium bentonites or sodium montmorillonites. Non-swelling bentonites swell little more than common clays and most crumble in water. However their swelling capacities may be improved by treatment with sodium carbonate. Bentonite is used in a wide range of end uses but particularly as a bonding agent in moulding sand for foundry use, as a sealant to minimise fluid loss by seepage - as in dams, earthworks and in drilling muds, and in stockfeeds.

Australian production of bentonite in 1983 was 30 026 t; output was mainly from two quarries in the Miles area of southern Queensland (24 765 t), both operated by Cudgen RZ Ltd, but also from near Scone, NSW (4261 t, Commercial Minerals Ltd). A small amount (1000 t) was also produced by Goldbent Holdings Pty Ltd from Greenwald, Vic., 45 km south of Casterton.

On the basis of production and imports (17 767 t, nearly all from USA), apparent consumption of bentonite in 1983 was about 48 000 t; exports cannot be separately identified because they are included with other clays in a single item, exports of which in 1983 totalled 7918 t.

The term fuller's earth has become a collective term for clay and fine-grained earthy material characterised mainly by its sorptive properties; the principal constituent clay minerals are attapulgite and sepiolite. The term's origin dates back to antiquity when, by virtue of its ability to remove lanolin and dirt, if was used for cleaning and 'fulling' wool. In the latter part of the last century it was found that some such materials could also be used for de-colourising and purifying mineral, vegetable and animal oils. Since then the term 'fuller's earth' has been further broadened to include not only 'naturally-active clays', but also 'activated clays' - clays which have had useful properties imparted by treatment with acid. Together, naturally-active and activated clays are sometimes referred to as bleaching clays.

In Australia, attapulgite is produced only by Mallina Holdings Ltd, from Lake Nerramyne, WA, about 95 km northeast of Geraldton. Production in 1982 was 14 769 t of solar-dried product; data for 1983 are not available. The company constructed a pilot acid-activation plant at Geraldton to carry out trials on producing a beneficiated product for export to Malaysia for refining palm oil. Apparent consumption of fuller's earth group clays cannot be determined as neither import nor export statistics can be separately identified.

Kaolin is a clay consisting principally of the mineral kaolinite and differing from other clays in its superior qualities of softness, whiteness, and water dispersion characteristics.

Ball clay is defined by the American Society for Testing and Materials as a secondary clay commonly charactrised by the presence of some organic matter, high plasticity, high dry strength, long vitrification range, and a light colour when fired. The principal clay mineral is kaolinite. Halloysite is a mineral very similar to kaolinite. Clays containing halloysite are, like ball clay, considered as a variety of kaolin.

Generally speaking Australian production statistics of kaolin, ball clay, and halloysite are grouped in a single item 'kaolin', production of which, in 1983, was 115 526 t. Production of paper-coating grade kaolin is restricted to Pittong, Victoria. Filler and other grades of kaolin are produced mainly at Rowsley and Axedale in Victoria; Gulgong, Home Rule, Mudgee, and Albury in New South Wales; Mount Crawford and Birdwood in South Australia; and Mount Kokeby and Mukinbudin in Western Australia.

Kaolin, ball clay and halloysite have widespread applications as a paper and general purpose filler such as in paints, caulking compounds, adhesives and plastics, and for manufacturing vitreous china sanitary ware, tableware china, electrical porcelain, and floor and wall tiles. On the basis of production and imports, (exports cannot be separately identified), apparent consumption of kaolin in 1983 was 120 000 t.

Australian production statistics for ball clay are not available separately; they are included in an item 'other clays' production of which in 1982 (the last year for which complete statistics are available) totalled 1 640 907 t. Ball clay imports in 1983 totalled 428 t, and were nearly all from the UK.

Refractory clays are used in the manufacture of refractory products such as fire bricks and various other shapes, refractory mortars and mixes, ramming and air gun mixes, monolithic and castable materials, retorts, crucibles and various other products. The principal types of clay included in refractory clay are kaolin, some ball clays, and fire clay. The term 'fire clay' is used for refractory clays which do not burn white. It therefore excludes kaolin and, terminology-wise, overlaps with non-white buring refractory-grade ball clays. Fireclays can also have a wider range of silica and alumina content and therefore also include some shales.

Although specifications for refractory clays vary depending on end-use, the main one is obviously heat resistance. The fusion point of refractory clay (including fire clay) is generally in the range 1490-1835°C. Other very important specifications cover resistance to shrinkage, warping, cracking and abrasion.

Production of fire clay in Australia in 1983 totalled 57 163 t; the principal centres of production were the industrial districts of Ipswich, Queensland and Newcastle, Sydney and Wollongong (all NSW) and in addition Marulan, Mudgee, Wingin, and Coorabin in New South Wales; Bacchus Marsh, Axedale, Hallam, Rowsley, and Stawell in Victoria; Mount Crawford, Birdwood and Cromer in South Australia; and Clackline, Byford, and Bullsbrook in Western Australia. Imports of fire clay and 'chamotte' (a calcined semi processed fire clay) in 1983 totalled 3327 t and were mainly from South Africa.

The category miscellaneous clay and shale includes a wide variety of clay and other fine-grained rocks which are used in a variety of ways. Most products made from them are fired, and include structural and face bricks, pavers, vitrified pipe, roofing tile, quarry tile and other building products. Large quantities of such materials are also 'bloated' by firing, to form lightweight aggregate, and large quantities are also used in making Portland cement. Applications not requiring firing of a finished product include use as a filler, for packing explosives in blast holes as impermeable membrances in water storages and for plugging oil and gas wells.

Diatomite

There are many small deposits of diatomite in Australia and small-scale production has been almost continuous since 1896; production in 1983 was 7921 t and came mainly from Barraba, NSW.

Apparent consumption of diatomite in Australia in 1983 was 17 800 t most of which was imported, mainly from USA. Diatomite ('diatomaceous earth') is a siliceous rock composed mainly of opaline skeletal remains of aquatic organisms called diatoms. Diatomite is used extensively as a filter medium to clarify and purify liquids in breweries, wineries, sugar refineries, food processing plants, dry cleaning plants, chemical and petroleum plants and swimming pools. Diatomite for this use is nearly all imported; Australian diatomite is generally used mainly as a thermal and acoustic insulator in wallboards, as a thermal insulator in kilns, as a filler in paints, varnishes, synthetic plastics, and rubber, as a mild abrasive in various polishes, and as an ingredient in lightweight ceramics.

Felspar

Felspar (known mineralogically as feldspar) is the commercial name for, collectively, the most abundant group of rock-forming minerals. However, rocks consisting almost entirely of felspar, and which would thus be of greatest commercial interest, are rather rare. Felspar is used mainly in the glass and ceramics industries and as an abrasive. Australian resources are large and more than enough for any likely requirement. Present centres of production are Mukinbudin and Rothsay, WA, and Broken Hill, NSW. In recent years consumption has been declining because of substitution by nepheline syenite rock in glass manufacture, and the use of recycled glass. Production in 1983 was 4244 t, and imports (including nepheline syenite) were 1385 t.

Fluorite

The mineral fluorite, also known as fluorspar, is naturally occurring calcium fluoride (CaF_2). There has not been any production of this mineral in Australia since 1974 when Leighton Mining NL closed its small mine near Walwa, Vic., for economic reasons. Historically, fluorspar production in Australia has been on a small scale; in the previous fifty years only about 50 000 tonnes has been mined, mainly from the Chillagoe district in Queensland.

Commercial requirements have determined three grades of fluorspar as follows: acid grade - to contain not less than 98% CaF_2; ceramic grade - to contain not less than 95% CaF_2; and metallurgical grade - to contain not less than 80% CaF_2.

Apparent consumption of fluorspar (all grades) in Australia in 1983 was 12 700 t. The steel industry is the largest consumer of fluorspar and The Broken Hill Pty Co. Ltd used about 7 000 t of metallurgical-grade material in 1983, as a metallurgical flux for removing impurities in manufacturing steel. The balance represents mostly acid-grade material used mainly in production of anhydrous hydrofluoric acid (HF). There are two HF plants in Australia, at Newcastle and Camellia, NSW. Hydrofluoric acid is an intermediate stage in the manufacture of fluorocarbons, which are used mainly as propellants in aerosol sprays, as refrigerants, and in urethane foam. The use of fluorocarbons by the aerosol industry declined markedly in 1977 because the continuing controversy about the affect of fluorocarbons on the earth's ozone layer encouraged the use of alternative propellants. Small amounts of HF are also used for pickling stainless steel, in petroleum refining, and by the glass industry. Minor quantities of acid-grade and ceramic-grade fluorspar are also used in aluminium smelting, in glass and fibreglass manufacture, in enamels for coating metal ware, and in coatings for welding-rod electrodes.

As well as importing all the fluorspar it requires, Australia also imports various fluorochemicals of which aluminium fluoride and synthetic cryolite (Na_3AlF_6), both used in aluminium smelting, are the most important. In 1982-83 the total f.o.b. value of imports of fluorochemicals was $17.1 million. Because fluorspar is the major source of fluorine, resources are measured in tonnes of contained fluorine. Of total Australian identified resources of fluorine of 67 Mt, only 3.3 Mt occurs in fluorite deposits; by far the greatest portion of identified resources is contained in the fluorapatite ($Ca_5(PO_4)_3F$) which is the essential component of Australia's resources of phosphate rock. All known fluorite deposits are classified economically as submarginal and none are likely to be developed in the foreseeable future.

Graphite (C)

Graphite has extensive uses as a lubricant, and is also employed in many manufacturing processes, for moulding, for graphite crucibles, and in lead pencils. Local production was last recorded in 1963 and so far no high-grade deposits have been discovered in Australia, although possible resources have not been fully investigated. All Australia's requirements are met by imports, which amounted to 795 t in 1983 (mainly from China, Korea, and Sri Lanka), plus 1772 t of artificial graphite, mainly from Japan, USA, India, China and UK.

Limestone, dolomite, and magnesite

Australian resources of these materials - the carbonates of calcium ($Ca\ CO_3$, limestone), magnesium ($Mg\ CO_3$, magnesite), and calcium and magnesium ($(Mg,Ca)\ CO_3$, dolomite) - are adequate, particularly for limestone and dolomite.

Australian production of limestone in 1983 totalled about 10.0 Mt. About 70% is used to manufacture Portland cement (production of this in 1983 amounted to 4.8 Mt). Apart from this major use, limestone is also used as a flux in metallurgical smelting processes (about 20% of production), for the production of calcium carbide (used mainly in the production of acetylene gas) and other chemicals and, after fine-grinding, as an industrial product (sometimes referred to as whiting) used as a filler and extender in paints, plastics, and rubber compounds.

Dolomite is used mainly (about 90%) by the iron and steel industry, as a flux in basic-oxygen furnaces, as fettling to protect the hearth of open-hearth furnaces, and in the manufacture of tar-bonded refractory bricks (also for basic-oxygen furnaces). Australian production in 1983 totalled 585 171 t, most of which (about 418 000 t) was produced by BHP at Ardrossan, SA.

Magnesite is consumed mainly after calcining, either as chemically active caustic-calcined magnesite (calcined to 700-1000°C) or as inert, dead-burned magnesite (calcined to 1600-1900°C) which is used as a refractory material. Magnesite too is used mainly by the steel industry as a refractory lining in basic-oxygen furnaces, but also as a refractory lining in other types of furnaces and kilns; lesser amounts are also used in the manufacture of oxychloride cement, insulating materials, in agriculture and in chemicals.

Australian mine production of magnesite in 1983 totalled 20 539 t, nearly all of it from New South Wales (Young and Fifield). BMR estimates that consumption of magnesite in Australia in 1983, which is partly met from imports, was 49 600 t; this includes the raw magnesite equivalent of imports of magnesium oxide and manufactured refractory products.

Mica

Although Australia's resources are probably large, production has been minor because cheaper material has generally been available from overseas. In 1983, mica production amounted to 266 t, about 65% from Pippingarra, WA. While the Commonwealth Mica Pool was operating during and after World War II, a series of small mines in the Harts Range in the Northern Territory met most of Australia's requirement. With the winding up of the Mica Pool in 1960, most mining activity stopped.

Imports in 1983 amounted to 335 t, mainly from China, India, USA and South Africa. In the event of an emergency, mine production could probably be revived to meet requirements. Alternative sources of supply include Argentina, Brazil, and the Malagasy Republic.

Quartz crystal and silica (both SiO_2)

Australia is self-sufficient in various forms of silica used in glassmaking, foundry sands, refractory bricks, etc., but there has always been an acute shortage in Australia of high-quality quartz crystal, the piezo-electric properties of which make it so very useful for stabilising frequencies in radio communications. Quartz crystal is also used in optical instruments. A wide search made by Government agencies during World War II failed to discover any substantial deposits, and an intermittent search by industry in subsequent years has met with little success. Since 1952, when production was recorded from near Glen Innes, the only recorded production of quartz crystal has been from Mukinbudin, WA - 70 t in 1974. Recent developments overseas in synthesising quartz crystals have eased pressure on the need to discover natural sources.

Imports of quartzite and natural quartz amounted to 355 t in 1983. Some 817 000 t of high-grade silica sand was exported in 1983, mainly to Japan, from deposits near Cape Flattery, north Queensland, and also from deposits near Perth, WA.

Sillimanite and kyanite (both Al_2SiO_5)

These related minerals are consumed mainly in the manufacture of high-alumina refractory linings used in furnaces. Deposits of sillimanite are known in several parts of Australia; presently the only production is from Mount Crawford, SA. Mineral sands in the Eneabba-Jurien Bay area of Western Australia contain large resources of kyanite. Allied Eneabba Pty Ltd commissioned the first stage of a kyanite separation circuit in its mineral sands operation about mid-1982, and in 1983 produced 445 t of by-product kyanite concentrate. Australian production of sillimanite peaked at 3500 t in 1963 but has since steadily declined; production was 121 t in 1983. Imports in 1983, under an item which included kyanite, sillimanite, andalusite, mullite, and dinas earth, totalled 212 t.

South Africa, USA, France and India are major producers. It is likely that Australia could meet its own requirements in any emergency, as the main consideration of exploitation continues to be the cost of transport. The presence of markets in Japan, particularly for kyanite, continues to encourage some exploration.

Talc and pyrophyllite

Although talc and pyrophyllite are chemically different (talc is a hydrous silicate of magnesium whereas pyrophyllite is a hydrous aluminium silicate), the two minerals are often discussed together because they have similar physical properties.

Australian production of talc in 1983 totalled 167 009 t; production was mostly from Western Australia (152 033 t), by two producers - Three Springs Talc at Three Springs, and Mount Seabrook Talc from its mine northeast of Meekatharra. Mount Fitton, SA, in the northern Flinders Ranges is also an important centre of production, especially for Australian industry. Lower grade and lesser amounts of talc were also mined in South Australia at Gumeracha and Tweedie Gully; total production from South Australia in 1983 was 14 913 t.

Australia is by far a net exporter of talc; exports in 1983 totalled 131 914 t and imports 147 t.

Talc is a very versatile industrial mineral which, after milling, is used in ceramics, paints, rubber, plastics, insecticides, agricultural dusts and, of course, cosmetics. The average level of Australian consumption of talc is about 33 000 t/year.

Pyrophyllite is used mainly as a refractory. Australian production (9569 t) was, in 1983, restricted to 2 locations - Pambula and Mudgee, both in New South Wales. Exports of pyrophyllite in 1983, unlike talc, were negligible - less than 200 t.

As well as its use as a contact refractory, pyrophyllite, because of its high fusion point, it also used in vitreous china, crockery, electrical porcelain, sanitary ware, wall and floor tiles, and whiteware ceramics generally. Pyrophyllite can substitute for talc in many applications and, with its high anti-skid property, is also used in road-surfacing aggregate.

Major producers of talc and pyrophyllite are Japan, USA, China, South Korea, USSR, and India.

Vermiculite

This mineral has the ability to expand to many times its original volume when heated to high temperatures. It is used in fire and rot-proof building panels, as an insulator in electrical and heating equipment, in the manufacture of building plaster, and as a light-weight aggregate in concrete. Western Australia is the only State in which vermiculite is produced; production in 1983 was 56 t. Requirements are met mainly by imports (3133 t in 1983), South Africa being the main supplier (88%). USA and South Africa account for over 90% of total western world production.

Salt & other sodium compounds

Salt (NaCl) production in Australia is all by solar evaporation, mainly of sea water but also of underground brines. Most of Australia's production is from four large operations in Western Australia;this is nearly all exported, most of it to Japan. Australia's own salt requirements are supplied by various smaller operations situated mainly in South Australia, Victoria, and Queensland.

Australia's salt industry expanded rapidly in the late 1960s and early 1970s to meet increased demand for salt from Japan's chemical industry; the expansion was confined to Western Australia where about 4.5 Mt/year of new salt production capacity was commissioned. In the mid-1970's export demand slackened and the industry was plagued by excess capacity. The Australian government than set a minimum f.o.b. price of US$8.13/tonne for salt exports but this control was lifted a year later, in March 1977. World demand and salt prices have since improved.

Australian salt production in 1983 was 5.17 Mt; production from Western Australia accounted for about 80% of this. The large export-oriented operations in Western Australia are located at Dampier and Lake MacLeod (Dampier Salt),Port Hedland (Leslie Salt Co.), and Shark Bay (Shark Bay Salt Pty Ltd); requirements of Western Australia's local markets are supplied by WA Salt Supply (1977) from Lake Deborah near Koolyanobbing and Western Salt Refinery Pty Ltd from Pink Lake near Esperance.

ICI Australia Limited is the largest of Australia's salt producers producing for Australian markets. The company produces about 500 000-600 000 t/year of salt from Dry Creek, SA, for manufacturing sodium carbonate and sodium hydroxide at its nearby alkali plant at Osborne; ICI also produces about

150 000 t/year of salt from underground brine and sea water at Bajool, Qld, about 30 km south of Rockhampton, which the company uses for manufacturing sodium hydroxide at Botany, NSW, and Yarraville, Vic. Other important salt producers (and the location of their operations) are Cheetham Salt Ltd (Port Phillip Bay, Corio Bay, and Lake Tyrrell, all in Victoria), The Broken Hill Pty Co. Ltd (Whyalla, SA), Waratah Gypsum Pty Ltd (Lake MacDonnell, SA), Australian Salt Co. Ltd (Lake Bumbunga, SA), Ocean Salt Pty Ltd (Price, SA), and Queensland Salt Pty Ltd (Bajool and Bowen, both in Queensland).

Although consumption of salt is more evident in households and in food processing industries, the greater part is used by the chemical industry for producing sodium carbonate (soda ash), and sodium hydroxide and co-product chlorine. Sodium carbonate is used mainly in manufacturing glass but also in many other industrial applications, and sodium hydroxide is used mainly in the Bayer process for processing bauxite to alumina. Despite Australia's position as one of the world's main exporters of crude salt, domestic requirements of salt-derived sodium compounds, particularly sodium hydroxide, are largely met by imports because Australia's capacity to process salt to sodium compounds is limited by its capacity to also consume by-product chlorine. Chlorine is used in a variety of chemicals and in many applications; its more important uses are as a bleaching agent, particularly in the paper industry, and in the petrochemical industry for manufacturing vinyl chloride which is a basic building block of many plastics.

Resources of seawater-derived salt are practically limitless; brine resources have not been adequately assessed but appear to be substantial. In recent years, as a result of exploration drilling for oil and gas, extensive subterranean beds of rock salt have been identified, particularly in central and northern Australia, further adding to total resources. However, there seems little likelihood of rock salt deposits being commercially developed in the foreseeable future, particularly as investigations to date have not indicated the presence of potash, an important associated mineral of some salt deposits in other parts of the world.

Gypsum ($CaSO_4 \cdot 2H_2O$)

The formation of gypsum usually requires semi-arid conditions. Although Australian occurrences are widespread, they are still within the region where annual rainfall is less than 500 mm. In 1983 Australia produced about 1.51 Mt of gypsum, about 60% of it from South Australia, where the main production centres are Lake MacDonnell and Kangaroo Island. Other important areas of production are Shark Bay, Lake Brown, Lake Seabrook, Lake Cowcowing and Lake Hillman in Western Australia, Cowangie and Nowingi in Victoria, and a smaller amount is produced from the Cobar Mining Division in New South Wales.

Australian exports of gypsum in 1983 totalled 799 957 t and were valued at $11.14 million; imports are negligible.

Calcined gypsum, or plaster of Paris, is widely used in the building industry for plaster board and related products, and also in the manufacture of special plasters for use in pottery, in orthopaedic and dental applications, and as statuary plaster. Gypsum is also an important ingredient in cement and is often also used as a fertiliser and soil conditioner.

Australia's gypsum resources are very large; demonstrated resources total more than 760 Mt.

Pigments and ochres

The terms as used here denote natural earth pigments such as the iron oxides, stained clays, and slate powder which are used to give colour or body to paints, plaster, cement, linoleum, and rubber. A number of small deposits have been worked over the years and Australia undoubtedly has large resources of the iron oxide variety. In recent years, red and yellow ochres have been mined in the Ulverstone-Penguin area of northwest Tasmania and red ochre has been produced in the Weld Range area of Western Australia. However, there was no production in 1983. Domestic consumption is small. Some 10 700 t of natural and synthetic iron oxides was imported in 1983.

Sulphur-bearing materials

Commercial deposits of elemental sulphur ('brimstone') and sulphur-bearing ('sour') natural gas are not known in Australia and in recent years 70-80% of demand has been met by imports, mainly from Canada. Imports in 1983 of 392 581 t were valued at $32.93 million f.o.b. Four oil companies recover sulphur from the refining of imported crude oil; 12 897 t of sulphur was recovered from such refining operations in 1983. Although combined capacity of their six recovery plants is about 50 000 t/year of elemental sulphur, actual production depends on the sulphur content of the refinery feedstock. However, Australia has large reserves and resources of sulphurous materials such as iron sulphide (pyrite), zinc sulphide (sphalerite), and lead sulphide (galena).

Sulphur is nearly all consumed in the form of sulphuric acid, and in 1983, 32% of Australian sulphuric acid production of 1.78 Mt was from indigenous material, as by-product acid of metal-smelting operations. The metal smelters at which sulphuric acid is recovered (and the material from which it is recovered) are located at Cockle Creek, NSW (lead and zinc concentrates from Broken Hill, Woodlawn and Cobar, NSW), Port Pirie, SA, (lead concentrate from Broken Hill), and Risdon, Tas. (zinc concentrates from Broken Hill, Elura, NSW, Rosebery and Que River, Tas., and Mount Isa, Qld). Western Mining Corporation Ltd recovers sulphur as ammonium sulphate at the company's nickel refinery at Kwinana, WA. A pyrite-based acid plant, at Burnie, Tasmania, which used by-product pyrite from Mount Lyell and Rosebery in Tasmania, ceased production in August 1979, for economic reasons.

The recovery of sulphur as sulphuric acid from sinter gases of indigenous sulphide minerals dates back mainly to the early 1950s when brimstone was in short supply and the Federal Government introduced incentives, by way of bounty payments, to promote self-sufficiency. Later, when changing circumstances abroad increased the supply situation, the Government announced that bounty payments would not be renewed after June 1965 but, on reconsideration, the Sulphuric Acid Bounty Act was first extended to 1969, and then to 1972, when it lapsed.

Imported sulphur is used mainly for manufacturing sulphuric acid which, together with most of the acid recovered from indigenous materials, is used for manufacturing phosphatic fertilisers, particularly single superphosphate. Of total Australian acid consumption in 1983 (1.90 Mt), 68% was in fertilisers; 20% was in metallurgical applications and 12% was in general chemicals.

In the chemical industry sulphuric acid is used mainly for manufacturing hydrofluoric acid. As a general chemical itself, the use of sulphuric acid extends to many diverse industries and industrial activities including wool scouring, the production of drugs, explosives, glue, leather, paper, soap, glycerine, and detergents, and in lead-acid batteries. In the mineral industry sulphuric acid is used for processing ilmenite to titanium dioxide and for extracting uranium oxide (yellowcake) from its ore. It is also widely used in metallurgical applications, especially for galvanising, tin plating and other electroplating processes, copper and zinc refining, and cleaning metal surfaces for soldering and welding. About 21 000 t/year of elemental sulphur was consumed in 1983 for other-than-acid uses, of which the main ones are in insecticides, fungicides, gunpowder, as a vulcanising agent in rubber, and for manufacturing carbon disulphide.

Fertiliser minerals

In Australia, single superphosphate, despite its higher transport costs per unit of phosphorus (P) compared with double and triple superphosphate, remains the most widely used fertiliser because of Australian soils' widespread need for sulphur (S) as well as phosphorus. Other major elements added to soil as fertiliser are nitrogen (N) and potassium (K). Most of the fertilisers are chemically manufactured from mineral raw materials.

Besides the major nutrients, N, P, and K, some soils also require calcium or magnesium which is generally added as ground gypsum, limestone, or dolomite, but details of consumption are not available. Minute quantities of other elements, notably copper, zinc, manganese and iron, also play an important part in plant nutrition. Such "trace elements" are normally applied mixed with the main fertilisers.

Phosphate rock: Phosphate rock is used almost entirely for manufacturing superphosphate, production of which in 1983, in terms of single-superphosphate equivalent (9.6% P basis), was 2.69 Mt. Consumption of superphosphate in Australia has traditionally been subsidised by the Federal Government; presently the phosphate subsidy is $138/tonne of available P, equivalent to $12/tonne for single superphosphate.

Australian fertiliser manufacturers have been entirely dependent on rock imports; these have come mainly from Nauru, Christmas Island and, up to 1979 when reserves were depleted, Kiribati (previously known as Ocean Island).

Very large resources of phosphate rock were discovered in 1966, in northwest Queensland, by BH South Ltd; these now belong to Western Mining Corp Holdings Ltd (WMC). BH South brought its Duchess deposit to production in 1975 but due to flagging export markets and a reluctance of Australian fertiliser manufacturers to modify existing plant to accommodate a new product, failed to achieve anticipated sales and the operation was put on care-and-maintenance in 1978. Operations were resumed in the latter part of 1981, but the mine was again closed down at the end of 1982.

A small quantity of phosphate rock (4868 t in 1983) is produced each year in South Australia; this material, because of its high iron and aluminium content, is not suitable for manufacturing superphosphate and is used locally in horticultural applications.

Before mid-1981 the distribution in Australia and New Zealand of phosphate rock from all sources had been controlled by the British Phosphate Commissioners, an inter-government agency representing the governments of Australia, New Zealand and UK. Similarly, the Christmas Island Phosphate

Commission, representative of the Australian and New Zealand governments, controlled mining operations on Christmas Island. As the result of a government enquiry into the phosphate industry, the main recommendations of which were implemented from 1 July, 1981, both the BPC and CIPC were phased out. The BPC's role of distributing rock has been taken over by the fertiliser manufactures themselves, as the Australian Phosphate Corporation Ltd, while all operations on Christmas Island are now carried out by a wholly Australian government-owned company called The Phosphate Mining Company of Christmas Island Ltd.

Imports of phosphate rock in 1983 totalled 2.20 Mt and were valued at $113.6 million, f.o.b.

Australia's identified resources of phosphate rock are substantial: 2800 Mt of near-economic (paramarginal) resources (average grade 7.4% P), and 2480 Mt of subeconomic resources.

Potash: Potassium, together with nitrogen, phosphorus, and sulphur, is one of the four main nutrients essential for plant life. Potassium deficiencies in soil are generally rectified by applying potassium chloride or potassium sulphate. Australia has no known deposits of either of these salts and its requirements are met by imports mainly from Canada and USA. In 1983 Australia imported 181 303 t of potassium chloride and 8 647 t of potassium sulphate; the total value of imports including 6 t of other potassic fertilisers, was $20.1 million, f.o.b.

Potassium also occurs as a constituent of the mineral alunite ($KAl_3(SO_4)_2(OH)_6$), deposits of which occur in various parts of Australia Although these deposits are not regarded as economic sources of potassium, they have, as a wartime measure, been exploited as a source of potassic fertiliser. At the end of World War II, the Western Australian Government sponsored attempts to produce commercial-grade potash from an estimated 12 Mt of alunitic red mud in Lake Campion, WA, about 50 km north of Merredin. The deposit was worked to 1949, when operations ceased for economic reasons; the venture produced about 13 000 t of potassic fertiliser from about 175 000 t of alunite. Small amounts of alunite have also been produced from Bulahdelah, NSW; production from here stopped in 1952 after about 71 000 t had been produced in the previous 60 years.

In November 1973 Texada Mines Pty Ltd commissioned plant to produce langbeinite ($K_2Mg_2(SO_4)_3$) from the residual brine liquor of its salt (sodium chloride)- producing operation at Lake MacLeod, WA. The project was beset by technical problems, declining export markets and ultimately by flooding. The langbeinite operation was then put on care-and-maintenance, pending further feasibility studies. About 10 000 t of material, produced and stockpiled during progressive commissioning of the plant, was sold overseas in 1976 after BHP bought a controlling interest in the company. The controlling interest of the Lake MacLeod operation has since passed to Dampier Salt (Operations) Pty Ltd, a subsidiary of CRA Ltd.

Nitrates: Australia has no known deposits of nitrates. However, many important nitrogenous compounds are manufactured in Australia, mainly from indigenous material; minor imports supplement local production. The starting point for manufacturing nitrogenous compounds is ammonia (NH_3), which can be produced from various raw materials including natural gas, refinery gas, (imported) naphtha, and water (all for their hydrogen component), and air (for its nitrogen component). The Broken Hill Pty Co. Ltd produces about 65 000 t/year of ammonium sulphate from ammonia recovered from coke-oven gas at the company's steelworks at Newcastle and Port Kembla, NSW and Whyalla, SA. Consolidated Fertilizers Ltd (at Gibson Island, Qld), WMC (at Kwinana, WA), and Eastern Nitrogen Ltd (at Newcastle, NSW) manufacture ammonia from natural gas; Kwinana Nitrogen Co. Pty Ltd (at Kwinana, WA) makes ammonia from refinery gas; Queensland Nickel Pty Ltd (at Yabulu, Qld) manufactures ammonia from imported naphtha; and Electrolytic Zinc Co. of Australasia Ltd (at Risdon, Tas.) synthesises ammonia from nitrogen and hydrogen, obtained respectively from fractional distillation of air and electrolysis of water.

The main nitrogenous fertilisers are ammonia, ammonium sulphate, urea, ammonium phosphate, and ammonium nitrate. Compounds of nitrogen are also used in industry; ammonium nitrate is used in some types of explosives and the ammonia produced by WMC and Queensland Nickel is used in metallurgical processes to recover nickel metal from its ore. Australian production statistics for individual nitrogenous compounds are not available for publication, but BMR estimates the N content of nitrogenous fertiliser produced in Australia in 1982-83 as 194 600 t; the nitrogen content of imports of various nitrogenous fertilisers in the same period is estimated by BMR as 81 500 t.

Consumption of nitrogenous fertilisers has increased markedly since 1966 when the Commonwealth Government introduced the Nitrogenous Fertiliser Subsidy Act which provided a benefit of $78.74/t of contained N to consumers of nitrogenous fertiliser; the steady increase of consumption is partly due to the use of nitrogen in new applications, especially wheat, other cereals, and pasture. However, the Industries Assistance Commission (IAC) recommended in 1975 that the subsidy be phased out over a period of three years. After deferring its decision in 1976, the Government reduced the subsidy to $60/t of contained N from 1 January 1977. A further reduction in 1978 was also deferred, but from 1 January 1979 the subsidy was reduced to $40/tonne of contained N, and from 1 January 1980 to $20/t contained N, at which level it has remained.

SUMMARY OF MINERAL RESOURCES AND MINERAL PROCESSING

A broad summary of mineral resources (which are not necessarily economic at present) and capacities for mineral processing in Australia, directed particularly toward the performance of the mineral industry in times of emergency, has been attempted in Table 2. Discussions of the magnitude of resources present problems because no realistic estimate of identified resources in Australia is yet available for many of the minerals concerned. BMR each year prepares and publishes estimates of Australia's identified resources of the major minerals, using information available to it (which is not always complete). In Table 2 identified resources have been classified under general categories based on the expected life of known resources at current rates of production, as follows:

Very large	-	sufficient for more than 100 years
Large	-	sufficient for 30-100 years
Adequate	-	sufficient for 15-30 years
Small	-	sufficient for 5-15 years
Very small	-	less than 5 years

In some cases, the uncertainty of reserves is indicated.

The table draws attention to a number of cases where mineral resources are available but where there is no associated capacity to produce the metal or processed material needed by the manufacturing industry.

TABLE 1: VALUE OF EXPORTS BY AUSTRALIAN STANDARD INDUSTRIAL CLASSIFICATION ($'m)

ASIC Divisions/Sub-divisions	1980-81	%	1981-82	%	1982-83	%	1983-84	%
Agriculture, forestry, fishing and hunting								
Agriculture	3942		4016		3491		4506	
Forestry and logging	3		4		7		3	
Fishing and hunting	22		17		13		12	
Total	3966	20.7	4038	20.7	3511	15.9	4522	18.2
Mining								
Metallic	1729		1943		2366		2585	
Coal	1975		2292		3075		3315	
Other (a)	102		411		458		876	
Total	3806	19.9	4646	23.7	5899	26.7	6776	27.3
Manufacturing								
Food, beverages and tobacco	4064		3687		3823		3748	
Chemical, petroleum and coal products	853		903		1558		1641	
Basic metal products	2862		2890		3247		3768	
Other manufactures	2558		2659		2804		3158	
Total	10337	53.9	10146	51.8	11432	51.8	12315	49.6
Other industries (b)	(c)832	4.3	471	2.4	550	2.5	446	1.8
Non merchandise	228	1.2	281	1.4	668	3.0	747	3.0
Total	19169	100.0	19576	100.0	22060	100.0	24805	100.0

(a) Construction materials, other non-metallic minerals, and oil and gas.

(b) Wholesale and retail trade, business services, waste and scrap n.e.c., secondhand goods.

(c) Includes oil and gas.

TABLE 2: MINERALS IN AUSTRALIA, 1983: ORIGIN, SUPPLY, PROCESSING, ETC.

	Availability			Processing			
	Distribution	Identified resources	Current raw material imports	Level of processing	Distribution	Current imports	Possible disadvantages in emergency
Energy minerals							
Petroleum (a) Crude Oil	Wide but known economic resources mainly in Bass Strait	Medium	About 30% of requirement - crude and refined products	Full range of refinery products and petrochemicals	Well distributed	Some refinery products, heavy crudes	Major supplies offshore. Import of heavy crudes
(b) Natural gas	Wide, but some with long distances to markets	Large	-	Sales gas. LPG for export and home market. ethylene for petrochemicals.	Expanding. LNG export to commence 1989.	-	Considerable production offshore.
Uranium	Northern Australia, WA, SA	Large	-	U_3O_8 (yellow cake) radio-isotopes	Northern Australia, Sydney	Radio-isotopes	Reserves spread but current plant only in NT.
Coal	Mainly Eastern Australia	Very large	Some high-quality anthracite	Coke, coal gas, char, briquettes	Coke-Qld, NSW, SA, Char - Vic. WA	Petroleum coke	No chemical plants
Oil Shale	Eastern Australia	Very large	-	-	-	-	-
Ferrous							
Iron ore	Well distributed but largest resources in WA	Very large	-	Ores, concentrates, pellets, and sinter to steels and fabrications	Steel - well distributed	Ferroalloys, special steels	-
Nickel	WA, Qld	Very large	-	Concentrates, matte, metal, oxide, sulphide by-product	WA, Qld	Metal and alloys	Metal available but remote from most industrial centres
Chromium	WA, small NSW, Qld	Large metallurgical and chemical	All requirements	-	-	Ferrochromium	Largely dependent on imports.

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	Availability			Processing			
	Distribution	Identified resources	Current raw material imports	Level of processing	Distribution	Current imports	Possible disadvantages in emergency
Ferrous (continued)							
Manganese	Groote Eylandt, NT	Large (metallurgical)	Battery-grade	Concentrates, ferromanganese and silico-manganese sinter and alloys	NT, Tasmania	Some ferro-manganese and metal	Main reserves in NT. No metal capacity.
Tungsten	King Island, Tas., and Qld. Minor-NSW, WA.	Adequate	-	Concentrates including artificial scheelite	-	Tungsten	Small tungsten carbide capacity (but could be increased)
Molybdenum	Minor-NSW, Qld, Tas.	Very small	Bulk of requirements	-	-	Ferromolybdenum, molybdic trioxide	No domestic capacity of acid and ferro-molybdenum in emergency.
Non-ferrous							
Tin	Well distributed - mainly Tas.	Adequate	-	Concentrates and metal	Metal - Sydney; lower quality metal at Greenbushes	Minor	Major deposits not on mainland. Only one refinery of highgrade tin.
Lead	Well distributed - mainly eastern Australia	Large	-	Concentrates, bullion, and metal	Metal - SA, Bullion NSW, Qld.	-	-
Silver	Well distributed - mainly eastern Australia	Large	-	Metal	SA; some metal from scrap - NSW Vic., WA.	-	-
Zinc	Well distributed - mainly eastern Australia	Large	-	Concentrates, metal	Metal - Tas., NSW, SA	-	-
Copper	Well distributed - mainly eastern Australia	Adequate	Small amounts	Concentrates, blister, metal	Metal - Qld, NSW	-	-
Gold	Mostly in WA but also NT, Tas.	Adequate	Some unrefined bullion and scrap.	Refined bullion.	Mostly WA (Perth); also SA, NSW, Qld	-	-

	Availability			Processing			
	Distribution	Identified resources	Current raw material imports	Level of processing	Distribution	Current imports	Possible disadvantages in emergency
Mineral sands							
Titanium	E and SW coasts	Adequate	-	Concentrates, upgraded ilmenite, pigments	Pigment - WA, Tas.	Metal and small tonnages of special-type pigment.	No metal capacity
Zirconium	E and SW coasts	Adequate	-	Concentrates	-	-	No metal or oxide capacity
Monazite	E and SW coasts	Adequate	-	Concentrates	-	-	-
Light metals							
Aluminium	Northern and SW Australia	Very large	-	Alumina, metal	Metal - NSW, Vic., Tas., Qld.	Minor shapes	Major resources N. Aust. WA, remote from smelters
Magnesium	Well distributed (magnesite)	Adequate	About 60% magnesite equivalent	Calcining and dead-burning	-	All metal	No metal capacity
Fertiliser/industrial minerals							
Phosphorus (phosphate rock)	NW Qld, NT	Very large	All requirements	Fertiliser	All States	Some mixed fertilisers	Domestic resources mainly in NW Qld, NT.
Potassium	WA	Appear adequate	All requirements	Fertiliser	All States	Some mixed fertilisers	Deposits remote from factories.
Sulphur	(Sulphides) well distributed	Elemental nil, sulphide large	70-80% of requirements	Acid	All States	Small amounts of acid	-
Salt	Well distributed	Unlimited	-	Salt, sodium hydroxide, chlorine, sodium carbonate	NSW, Vic., SA	Some chlorine, 70% caustic soda requirements.	-
Diamonds	WA	Large		Gem and industrial diamond separation	-	Some gem and industrial diamonds	Only source in NW Aust.

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	Availability			Processing			
	Distribution	Identified resources	Current raw material imports	Level of processing	Distribution	Current imports	Possible disadvantages in emergency
Fertiliser/industrial minerals (continued)							
Asbestos	NSW, WA	Chrysotile (short fibre) adequate;	Small	Fibre grades	NSW	Fibre grades	Not all grades produced.
		Crocidolite (long fibre) very small	All requirements	-	-	-	-
Fluorspar	WA, Qld	Adequate	All requirements	Hydrofluoric acid	NSW	-	Deposits low grade and in remote areas
Minor metals							
Vanadium	WA, Qld (including oil shale and uranium)	Large	-	Vanadium pentoxide (production suspended)	WA	All vanadium & composites	-
Bismuth	Mainly NT	Adequate	-	Bismuth concentrates containing gold & copper	-	All metal	Small metal capacity
Cobalt	Eastern Australia, WA	Adequate (from nickel ores)	-	Oxide and sulphide by-products	Qld, WA, Tas.	Cobalt, cobalt alloys, oxides and hydroxides.	No metal or alloy capacity
Mercury	Eastern Australia	Small but uncertain	-	-	Tas.	All requirements	No production - could be commissioned
Mica	Central and Western Australia	Adequate	-	-	-	All grades	No current operation but could be produced
Cadmium	NSW, Tas, Qld	Adequate	-	Metal (by-product)	NSW, SA, Tas.	-	-
Antimony	NSW, Victoria	Adequate	Very small	Metal (by-product) contained in antimonial lead	SA	Metal plus oxides	-

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	Availability			Processing			
	Distribution	Identified resources	Current raw material imports	Level of processing	Distribution	Current imports	Possible disadvantages in emergency
<u>Minor metals</u> (continued)							
Beryllium	NSW, WA	Small but uncertain	-	-	-	Any metal required	No metal capacity
Tantalum	WA	Large	Bulk of requirements	Upgraded Ta_2O_5.	WA	All metal	No metal capacity
Columbium	WA	Large	Bulk of requirements	Upgraded Cb_2O_5.	WA	All metal	No metal capacity
Lithium	WA	Large	Bulk of requirements	Concentrates	-	All metal	No metal capacity