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ATLAS OF AUSTRALIAN RESOURCES - MINERAL DEPOSITS (Second Edition) COMMENTARY

by

I.R. McLeod & Y.Miezitis

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INTRODUCTION

Australia is well endowed with minerals and rocks of economic importance. Coal mining began in 1799 at Newcastle, and metalliferous mining (silver-lead) in 1841 at Glen Osmond, now an Adelaide suburb. The discoveries of gold in the eastern States in 1851 and later years brought many experienced miners and prospectors to Australia, and created a public interest in the search for mineral deposits. Many important deposits and fields were discovered in the last third of the nineteenth century, including Broken Hill, Mount Lyell, Mount Morgan, Kalgoorlie, and north Queensland and northern New South Wales tinfields. From 1893 to 1948, the only significant mineral deposits discovered were the King Island tungsten deposit, the Aberfoyle tin-tungsten vein systems near Rossarden, the Tennant Creek gold deposits, and the Mount Isa silver-lead-zinc and copper orebodies.

This scarcity of new discoveries led to claims that all major deposits visible at the surface had been found. However, from 1949 onwards, several notable discoveries have been made; all of these (except those of petroleum and natural gas) were deposits well exposed at the surface:

> Uranium at Rum Jungle, South Alligator River and Mary Kathleen; bauxite at Gove and Weipa; iron ore at Constance Range in Queensland, and the Hamersley Range and other parts of Western Australia; manganese at Groote Eylandt; and petroleum and natural gas at a number of widely scattered places.

During this period too, it was recognised that certain deposits in areas already known to be mineralized were much larger than had been assumed. These included the Darling Range bauxite, Savage River iron ore, Western Australian and some east Australian beach sands, and several tin deposits, including those at Ardlethan, Greenbushes, and Renison Bell. These discoveries, and the increasing application of specialized techniques such as geophysics, geochemistry, geomorphology and palaeogeography, have given a new impetus to mineral exploration in the last decade or so, and give hope that discoveries of major deposits will continue.

The search for minerals in Australia is predominantly by companies, syndicates and individuals - only rarely do Governments themselves carry out mineral exploration as such, and then usually because of exceptional circumstances. On the other hand, both Federal and State Governments assist mineral exploration in many ways, both direct and indirect. These include: regional geological mapping (mostly at a scale of 1:250,000 or, in more detail, at 1:63,360) and detailed surveys of selected areas; geochemical and geophysical surveys; testing prospects by drilling; technical advice; and laboratory investigations, including assay, petrographic, and mineragraphic services.

More indirect assistance is given in certain cases in the form of taxation concessions, subsidies, and incentives such as rewards for the discovery of deposits of a particular commodity. The provision of capital works such as ports, railways, and roads may also indirectly encourage mineral exploration.

METALLIFEROUS PROVINCES

The rocks forming the Australian continent can be broadly divided into two types, which are distinguished by different background tints on the map-sheet.

Metalliferous deposits and many non-metallic deposits occur mainly in rocks which have been folded and metamorphosed to a greater or lesser degree. Most deposits are related to igneous intrusions which accompany the folding and metamorphism; but some are produced by the metamorphism itself. The few commodities found in sedimentary basins are chiefly of organic origin, such as coal, petroleum, and natural gas, and limestone formed from the remains of calcareous organisms. Alluvial deposits and some other types of sedimentary deposits, deposits formed by weathering of the rocks, and superficial chemical deposits (such as salt and gypsum) can occur in regions of either type of rock.

Within the regions not occupied by sedimentary basins, deposits of certain metals or associations of metals tend to predominate in particular areas, which are referred to as metalliferous provinces. An understanding of the cause of the association and of the origin of the deposits in a particular province may give a clue to the discovery of additional deposits. The more important Australian metalliferous provinces are briefly noted below.

The provinces are distributed in two broad geological regions. Ancient rocks, from 600 million to more than 3,000 million years old, constitute the stable Precambrian shield which forms the basement of the western and central part of the continent. Younger (Palaeozoic) rocks, less than 600 million years old, extend around the eastern portion of the continent from northern Queensland to western Victoria, and form much of Tasmania (See "Geology" map sheet).

Most of the production of gold, copper, iron, and silver-lead-zinc in Australia comes from metalliferous provinces of the Precambrian shield. A province within some of the earliest Precambrian (Archaean) metamorphosed sediments and volcanic rocks in the south-west quarter of Western Australia includes the major gold-mining area in Australia today, between Meekatharra, Southern Cross, Norseman and Wiluna. Other minerals in this province are iron, tin, pegmatitic minerals (beryl, feldspar, tantalo-columbite, lithium, mica), copper, and manganese, but of these only iron and tin are of more than minor importance at present. Farther north, in the Pilbara region, another province of comparable or slightly younger age includes deposits of iron, manganese, pegmatitic minerals, tin and copper. Most of the deposits in these provinces are in the older Archaean rocks, but manganese and the vast iron ore deposits occur in younger sediments of Proterozoic age.

An Archaean province in Eyre Peninsula in South Australia contains the large iron deposits of the Middleback Ranges, and minor gold and base metal mineralization.

In the eastern part of the Precambrian region, the rocks and mineral deposits are less ancient. A province centred on Broken Hill includes the Broken Hill silver-lead-zinc deposit, which is dated at 1,600 million years, and small deposits of uranium and pegmatitic minerals. In north-western Queensland, the Mount Isa silver-lead-zinc and copper orebodies, the uranium deposits at Mary Kathleen, and numerous smaller copper, copper-gold, and cobalt deposits form another highly mineralized province of about the same age.

Most of the economic deposits in a province between Maranboy and Darwin in the Northern Territory are associated with Proterozoic rocks and, probably excepting the uranium are related to pegmatite and granite intrusions. Mining in this province was active for a brief period at the turn of the century; the uranium discoveries in 1949 stimulated further prospecting and mining. Uranium, iron, gold, copper, tin, and pegmatitic minerals are the more important deposits. Another Proterozoic province farther south contains copper and gold deposits, including those at Tennant Creek, and minor occurrences of pegmatitic minerals.

A metalliferous province extends from south of Adelaide northwards through the Flinders Ranges, with an easterly projection towards Broken Hill. The province includes deposits of copper, uranium, lead, silver, manganese, and other minerals, in rocks ranging in age from Archaean to Cambrian. Most of the deposits exposed in these provinces have been formed at a shallower depth than those of the older Precambrian provinces in the west.

The mineral deposits of the younger, Palaeozoic, region of eastern Australia are distributed in meridional belts in the Eastern Highlands. In north Queensland an important province extending from Cooktown to south of Charters Towers and west to Croydon contains a great variety of ores - principally tin, tungsten, molybdenum, copper, lead, zinc, silver, and gold - associated with Carboniferous to Permian granite intrusions. In a slightly younger province, between Townsville and Brisbane, late Permian to Triassic granites introduced ores of copper, gold, silver, mercury and other metals; this province includes the Mount Morgan copper-gold orebodies. A small Cretaceous province around Maryborough contains gold and antimony deposits.

The province embracing the New England area in north-eastern New South Wales and extending north to Stanthorpe in Queensland includes a diversity of ores - tin, tungsten, molybdenum, gold, copper, antimony, and mercury - related to late Permian to Triassic granites. Chromite deposits resulted from the injection of earlier serpentinites.

In south-eastern Australia a mineral province extends from Western Victoria northwards to Dubbo in New South Wales. The region has a complex geological history and was mineralized several times during the Palaeozoic. Periods of intense folding and intrusion of igneous rocks were accompanied by mineralization in Ordovician, Silurian, Devonian and Carboniferous times, when deposits of gold, copper, tin, silver-lead-zinc, tungsten, and other metals were introduced. The Victorian part of the province was once the most important gold-producing area in Australia. The principal goldfields were north and north-west of Melbourne, in a series of meridional belts. An extension of the province to Bourke contains the important copper deposits at Cobar.

Two mineral provinces can be distinguished in Tasmania. Most of the deposits on the richly mineralized west coast (lead, zinc, copper, silver, gold, tin, iron, and other metals) were probably formed in the middle Palaeozoic, although some occur in much older rocks. This province includes the Mount Lyell, Read-Rosebery, Zeehan-Dundas and Renison Bell mining fields. Minor copper-nickel and platinoid metal deposits are of Cambrian age. North-eastern Tasmania is predominantly a region of tin-tungsten mineralization related to middle Palaeozoic granites, with gold and other minerals of lesser importance.

MINERAL SUFFICIENCY

A qualitative summary of the known reserves of the commodities shown on the map is given below. The commodities are classified below according to life expectancy on the basis of current and foreseeable production. Very small or very low-grade deposits which could be exploited when costs are not a prime consideration have not been taken into account.

Known reserves very large

Aluminium
Asbestos (crocidolite)
Cadmium
Coal, black
Coal, brown
Dolomite
Gypsum
Ilmenite
Iron
Lead
Limestone
Magnesite
Manganese
Salt
Silver
Zinc

Known reserves adequate

Alunite
Antimony
Barytes
Copper
Diatomite
Dimension stone
Feldspar
Fire-clay
Gold
Lithium
Opals
Perlite
Pottery clay
Pyrite
Rutile
Silica
Siliceous abrasives
Talc
Tin
Tungsten
Uranium
Zircon

Known reserves small or negligible

Arsenic
Asbestos (amphibole)
Asbestos (chrysotile)
Bentonite
Beryl
Bismuth
Chromite
Cobalt
Corundum
Diamonds
Emery
Fluorspar
Fuller's earth
Gemstones

Known reserves small or negligible

Glauconite
Graphite
Kyanite
Mercury
Mica
Molybdenum
Natural gas
Nickel
Oil shale
Osmiridium
Petroleum
Phosphate rock
Pigment minerals
Platinum
Pyrophyllite
Rare earth minerals
Sillimanite
Tantalum and columbium
Vermiculite

Considerable amounts of elemental sulphur, potassium salts, cryolite, and boron salts are used in Australia each year. These commodities are not listed (except the potassium compound alunite) because no deposits of them are known in Australia.

MAJOR METALS

Lead and Zinc

Australia is one of the world's principal producers of both lead and zinc. Most of the output has come from a few large lead-zinc deposits in the eastern part of the continent, especially at Broken Hill and Mount Isa, and the smaller orebodies on the west coast of Tasmania and at Captain's Flat in New South Wales.

The Broken Hill lode, discovered in 1883, has been one of the world's most important sources of lead and zinc. By the end of 1964, approximately 92,000,000 tons of ore had been raised, and the lead and zinc concentrates produced contained approximately 12,400,000 tons of lead and 8,600,000 tons of zinc respectively, and 672,000,000 ounces of silver. The lodes are disposed along the east limb of a major syncline in intensely folded Archaean metasediments. The lode is mineable almost continuously over a length of 20,000 feet with a vertical extent of up to 2,000 feet, and further mineralization has been found at or near the surface over a distance of 13 miles. The principal ore minerals are galena and sphalerite.

Another large producer of lead and zinc is Mount Isa in Queensland. Ore mined to the end of 1964 contained 1,163,000 tons of lead, 563,000 tons of zinc, and 92,085,000 ounces of silver. In 1964 silver-lead-zinc ore reserves were 27,100,000 tons containing 7.8 percent lead, 5.9 percent zinc, and 5.6 oz silver per ton. The base metal mineralization occurs within a meridional belt of Proterozoic shale over a total length of at least 17 miles and the main sulphide ore minerals are galena, sphalerite, and tetrahedrite.

The third important producer of lead and zinc in Australia is Read-Rosebery, in western Tasmania, where the orebodies occur in lower Palaeozoic tuffaceous shale. Ore reserves in 1964 were 4,000,000 tons. The Mount Farrell mine, near Read-Rosebery, produces a few hundred tons of lead annually.

In the Northern Territory a very large low-grade zinc-lead orebody has been located in pyritic shales at McArthur River, but the deposit has not yet been worked.

In the past, lead-zinc deposits of considerable importance were mined at Captain's Flat in New South Wales, but all the known reserves were worked out by 1962. Other lead-mining centres of note, mostly of past importance, are Chillagoe in Queensland, Northampton in Western Australia, and Yerranderie in New South Wales. Production from these has been far less than from the deposits described above.

Copper

The earliest record of copper production in Australia was in 1844 from the Kapunda mine in South Australia. Soon afterwards important copper mines were established in the Wallaroo-Moonta area and later other deposits were opened for production at Cobar, Mount Lyell, Mount Morgan, and many other places. In recent years the focus of copper mining has shifted to Mount Isa, while the other major producers are Mount Morgan, Mount Lyell, a group of mines near Tennant Creek, and Cobar, where production has recently recommenced.

The largest known copper deposit in Australia is at Mount Isa. Outcrops of silver-lead-zinc orebodies were discovered in 1923 but the hidden copper ores were not found for several years, and not exploited until 1943. Copper mining ceased in 1946, but recommenced in 1953. The orebodies occur in

Lower Proterozoic shale. The silver-lead-zinc and copper orebodies are closely related, but are separate bodies. Economic copper mineralization, which occurs in large silica-dolomite masses, has been proved to a depth of more than 2,500 feet. Production to the end of 1964 amounted to 571,400 tons of copper. In 1964 published ore reserves were 34,000,000 tons, containing 3.5 percent copper. Copper has been mined at many other places in the north-west Queensland mineral province.

The Mount Morgan deposit, discovered in 1882, is the other major source of copper in Queensland. It was first worked for gold; copper mining did not start until 1902, when workings reached the copper-bearing ore in the lower part of the deposit. The orebodies occur in a roof pendant of Devonian volcanic and sedimentary rocks which crop out as a long narrow belt flanked by granite to the east and west. Large scale open-cut mining was begun in 1932 and to the end of 1964 production amounted to 268,900 tons of copper. In 1964 ore reserves were 10,155,000 tons, containing 1.10 percent copper and 2.34 pennyweights (dwt) gold per ton.

Before 1953, the chief source of copper in Australia was Mount Lyell in Tasmania, where mining began in 1883. The rich copper ores have been mostly worked out and mining has been transferred to the large, low-grade orebodies which are mined by open-cut. The mineralization is concentrated along a major north-south shear at intersections of cross-cutting faults. Most of the sulphide ore occurs within Cambrian volcanic rocks at or near their contact with overlying younger conglomerate. In 1964 the ore reserves amounted to 22,874,000 tons containing 0.93 percent copper with small amounts of gold and silver.

The deposits near Tennant Creek were originally worked for gold. Large-scale copper-mining began in 1952. Several smaller deposits were discovered in later years with grades ranging from 1.0 to 4.62 percent copper and 2.9 to 9 dwt. gold per ton.

Copper was discovered at Cobar in 1869. The field was an important source of copper for some time, but production ceased in 1921. Copper mining recommenced in 1935, but again ceased in 1952. Later, intensive exploration revealed an estimated total of 18,000,000 tons of ore and large-scale mining was begun in 1965. The lodes are massive sulphide bodies in shear zones.

Small deposits of rich oxidised copper ore are widely distributed throughout Australia but few have produced more than 50 tons of copper, mostly from the rich surface ore. The grade of underlying primary ore has generally been too low for economic exploitation.

Iron

Iron ores were known to be widely distributed throughout Australia, but the vast magnitude of the ore reserves has only been realized in recent years. In 1959, measured and indicated reserves* were only 369 million tons. The large-scale mining of iron-ore has been virtually confined to the Middleback Ranges and Yampi Sound, which, with the small production from Koolyanobbing, supply the demands of the Australian iron and steel industry. Smaller deposits in Queensland, New South Wales, Tasmania, Victoria, and South Australia have been worked for iron oxides for cement manufacture, gas purification, coal washing, fluxing, and pigments.

The Middleback Ranges iron ores were first used as a flux in the Port Pirie lead smelter. Production began in 1903 from the Iron Knob orebody and ore has since been mined intermittently from this and the Iron Monarch (the most important), Iron Prince, and Iron Baron orebodies. Total production to the end of 1964 amounted to about 90,200,000 tons of iron ore. The deposits crop out over a distance of nearly 40 miles. Generally they occur in synclinal structures and in association with aluminous schist, banded hematite quartzite, and amphibolite. In all deposits the ore consists essentially of bedded hematite and has an iron content of 60 to 68 percent. Phosphorus and sulphur is usually less than 0.1 percent. The manganese content is generally below 0.5 percent, but locally may be as much as 30 percent. Measured and indicated reserves in the Middleback Ranges amount to 169 million tons of ore with 60 to 64 percent iron, plus 14,000,000 tons of lower-grade scree ore.

The other major source of iron ore is the Yampi Sound area, in the north of Western Australia. Production from the deposit on Cockatoo Island began in 1951 and 9,962,000 tons of ore averaging 63.3 percent iron had been mined by the end of 1964. Production from Koolan Island began at the end of 1964. Smaller deposits occur on three other islands in the same area. The dominant rocks are bedded quartzite, schist, and hematite quartzite. The orebodies on Koolan and Cockatoo Islands are overturned hematite beds. In 1965 total measured and indicated reserves in Yampi Sound amounted to 71,000,000 tons of ore of 64 to 66 percent iron and 14,000,000 tons of 55 to 60 percent iron.

* The terms "measured", "indicated", and "inferred" are used in describing reserves in mineral deposits to signify how well the size and grade of the deposit is known. There is no unanimity on the use and scope of the terms. Briefly, measured reserves are those in which the tonnage and grade of the ore are very well known by sampling and measurements by drill-holes and mine openings; estimation of indicated reserves involves some extrapolation or interpolation from parts where the size and grade are known; inferred reserves are those for which quantitative estimates are based on few, if any, samples or measurements.

The Koolyanobbing deposits have been worked for iron ore on a small scale; production to the end of 1964 was 593,300 tons of ore. They consist of five lenses of high-grade limonite-hematite ore which gives way to magnetite at depth. Reserves are 53,000,000 tons averaging 62 percent iron.

Recently, vast deposits of iron ore have been discovered within and around the Hamersley and Ophthalmia Ranges in the north-west of Western Australia. High-grade deposits are associated with thick Proterozoic jaspilite formations and consist of hematite-goethite with a little limonite. The ore is a product of surface enrichment of the jaspilite close to a well-preserved Tertiary land surface and is commonly found in limbs and troughs of synclinal folds. The grade of these deposits is above 60 percent iron and the phosphorus content is about 0.1 percent. Numerous large deposits of high-grade ore are known, including those at Mount Tom Price, Mount Newman, and Mount Goldsworthy. Inferred reserves of iron ore exceeding 60 percent iron in the Hamersley Range Iron Province amount to about 8,000 million tons.

In the same region lower-grade ores are developed in the valleys of Robe River, Duck Creek, and Turner River, as cappings on mesas and as terrace deposits along the valley sides. The ore consists of pisolitic goethite-limonite with minor hematite. It is thought to have formed mainly by desilicification of accumulated jaspilite detritus in the drainage channels during a protracted erosion cycle. The general grade of these deposits is 50 to 60 percent iron. Reserves are incompletely tested, but are likely to amount to 6,000 million tons or more.

In Tasmania magnetite-rich zones have been found within intrusive amphibolite on the upper reaches of the Savage River. The total of inferred and indicated reserves is 460,000,000 tons.

Sedimentary iron-rich beds are widespread in the Constance Range area in north-west Queensland. Material of ore grade occurs in several zones, as separate deposits. Total reserves are 257,000,000 tons averaging 51.5 percent iron. The ore is oolitic in part; the iron minerals are hematite, siderite, chamosite and minor pyrite.

Many other Australian deposits have been tested but, with the exception of Koolanooka and Scott River in Western Australia, and Frances Creek and Mount Bundey in the Northern Territory, their development is not envisaged at present.

Aluminium

The great potential of the bauxite deposits around the Gulf of Carpentaria and in the Darling Range of Western Australia has only been realized in the past decade, although the existence of bauxite at these places has been known or suspected for many years.

The Weipa deposits are probably the largest single occurrence of bauxite in the world - economic-grade bauxite covers at least 200 square miles between Vrilya Point and Archer Bay, and reserves of bauxite probably exceed 2,000 million tons. The bauxite forms a flat-lying surface deposit ranging in thickness from a few feet to 30 feet. The bauxite is strongly pisolitic, with an alumina content of more than 50 percent.

Bauxite deposits at Gove and Marchinbar Island, on the west side of the Gulf of Carpentaria, are similar to, but not as extensive as, the Weipa deposits. Reserves at Gove are probably about 200 million tons; measured and indicated reserves at Marchinbar are 9,800,000 tons.

Bauxite forms many separate deposits within an area 200 miles long and 25 miles wide in the Darling Ranges in south-western Western Australia. The deposits are mined at Jarrahdale. The average thickness of bauxite is 10½ feet with a maximum of 50 feet, under an average overburden of 2½ feet. Proved reserves amount to nearly 80 million tons, with a reasonable indication of a further 100 million tons. Reserves in similar deposits near Boddington, provisionally estimated as 1,200,000 tons per vertical foot, could total 18,000,000 tons.

Small deposits in Queensland, New South Wales and Victoria have been worked for many years for bauxite for water softening, flux in steel making, and chemical manufacture.

Tin

For a period in the 1880's, Australia was the world's major tin producer, her production representing 25 percent of the world's total. Output declined greatly in the 20th century, and Australia became only a minor producer. Production has increased in recent years with the discovery of several large, low-grade deposits. Total reserves (mostly measured and indicated) in the major deposits exceed 150,000 tons of metallic tin.

At least half Australia's production of 683,800 tons of tin concentrates (averaging 70 percent Sn) has come from alluvial deposits. Many of these were small and quickly worked out, but extensive deposits at places such as Mount Garnet in north Queensland, the Ringarooma River and its tributaries near Gladstone and Derby in Tasmania, and Greenbushes in Western Australia, have been important sources of production. The overall grade of these large alluvial deposits is low, normally less than 1 lb of tin oxide per cubic yard.

The Aberfoyle and Storeys Creek mines near Rossarden in north-east Tasmania produce tin and tungsten from systems of quartz veins in tightly folded Silurian sediments. The veins, which dip moderately steeply, are related to a Devonian granite cropping out near the mines. In 1964, ore reserves in the two mines totalled 781,000 tons.

Reserves at Renison Bell in western Tasmania total 11,000,000 tons averaging 0.72 percent tin, plus 330,000 tons assaying 1.26 percent tin. The tin occurs in narrow quartz veins and, associated with iron and other sulphides, in flat-lying lodes.

A recently discovered deposit at Mount Cleveland, 10 miles west of the old tin mining district of Mount Bischoff, in northern Tasmania, contains 2,000,000 tons of ore averaging about 1 percent tin. The tin occurs as particles of cassiterite in pyrite-pyrrhotite replacement lodes.

For many years, tin was produced on a minor scale from both alluvial and primary deposits near Ardlethan, in New South Wales. In 1964, large-scale mining began on orebodies formed by disseminated cassiterite in altered granite. Reserves then were 3,000,000 tons of ore averaging 0.4 percent tin.

PRECIOUS METALS

Gold

Although many earlier finds were made, the first officially recognized discovery of gold in Australia was in 1851 near Bathurst, New South Wales. Many other fields were discovered in the same year, in both New South Wales and Victoria, and recorded gold production in 1852 was almost 3,000,000 ounces. Total recorded Australian production is more than 180,000,000 ounces.

Except in Western Australia, where detrital deposits are unimportant, mining on most fields was begun on alluvial deposits. In Victoria especially, these were a major source of gold - three-quarters of the 20,000,000 ounces produced at Ballarat came from surface alluvial deposits and deep leads. Production from many fields ceased with exhaustion of the alluvial deposits, but on others mining was extended to the primary orebodies. Production from most of these fields, including many once famous and important, has since ceased or become negligible. The bulk of current Australian production is from a few relatively large gold-mines, or as a by-product of base metal mining.

Most of the primary deposits in eastern Australia are in Palaeozoic rocks; the gold is almost invariably associated with quartz. The majority of the Western Australian deposits occur in Precambrian basic or ultrabasic igneous rocks.

About 80 percent of the current Australian production is from Western Australia: the principal centres are Kalgoorlie, Norseman, and Mount Magnet. Most of the major discoveries in this State were made in the last decade of the nineteenth century, and the State soon became the pre-eminent Australian producer. Much of the output has come from the "Golden Mile", an area of rich mineralization about 2 miles long and 1 mile wide near Boulder, 4 miles south of Kalgoorlie. This area is part of a north-trending auriferous belt.The rocks are Precambrian basic lavas and tuffs with some sediments, intruded by dolerite and gabbro. The basic rocks were altered to greenstone by low-grade regional metamorphism, and tightly folded. The lodes occur along shears and fractures and range generally from 5 to 20 feet in width. The gold content of the lodes as a whole tends to decrease with depth.

Most of the gold won at Norseman has come from quartz veins in metamorphosed basic rocks; the veins are very persistent - one was traced over a distance of 11,000 feet. Minor amounts of gold have come from quartz-pyrite lodes in metamorphosed siliceous sediments; some of the lodes have been worked as a source of sulphur.

The main producer at Mount Magnet has been the Hill 50 mine, where the gold is associated with fault zones in siliceous sediments.

Gold is won at Tennant Creek in the Northern Territory from both gold and gold-copper ores. Most of the orebodies are associated with quartz-hematite or quartz-magnetite lodes, the richest shoots occurring in shear zones in or adjacent to the lodes. In the most important mine on the field, the Peko, the central part of a massive quartz-magnetite pipe has been replaced by pyrite, pyrrhotite, and chalcopyrite.

Mount Morgan in Queensland, now better known as a copper producer, was originally worked as a gold mine, and is still an important Australian source of gold. The average gold content of the ore reserves is about 2.3 dwt. per ton.

Other large base-metal mines which contribute small but significant quantities of gold to the Australian total are the Read-Rosebery and Broken Hill silver-lead-zinc mines, and the Mount Lyell copper mine. A small amount of gold has been produced as a by-product of uranium mining in the South Alligator River valley.

Silver

Australia is one of the principal world producers of silver; total output to the end of 1964 is estimated to have been about 963,000,000 ounces. Almost all current production is a co-product of base-metal mining, mainly from the lead-zinc deposits at Broken Hill, Mount Isa, and Read-Rosebery. Smaller amounts are extracted from copper ore mined at Mount Isa, Cobar, Mount Morgan, and Mount Lyell.

A small amount of silver is recovered during gold refining. The silver content of gold ores is normally not high, but gold from some of the Western Australian fields contained 40 percent silver.

OTHER METALS

Beach Sands

For the last 20 years Australia has been the principal world supplier of rutile and zircon. Most of the output has been from the coast of southern Queensland and northern and central New South Wales. Total production in Queensland to the end of 1964 amounted to 461,000 tons of rutile and 408,000 tons of zircon. New South Wales has produced 887,000 tons of rutile and 971,000 tons of zircon.

Much of the total production has come from the coastal strip between North Stradbroke Island and Byron Bay. The deposits are of two kinds, those on present-day beaches, and those in coastal sand dunes or under low-lying sandy areas behind the dunes. The richer deposits on the beaches have been largely worked out and mining operations have been transferred to the lower grade but larger deposits behind the beaches. Minerals of economic importance are zircon, rutile, and monazite. The deposits also contain large amounts of ilmenite, but, because of its high chromium content, most is discarded. Other heavy minerals such as garnet constitute less than 5 percent of the total heavy mineral content. Generally the variation in the proportion of heavy minerals in any particular deposit is small.

An important area of ilmenite production is the south-west of Western Australia, which also produces small amountsof zircon, rutile, and monazite. The heavy mineral deposits are disposed along the present beach of Geographe Bay from Bunbury to Cape Naturaliste and along five fossil shore-lines farther inland. Ilmenite is the predominant heavy mineral and the ilmenite-leucoxene series generally exceeds 75 percent of the heavy mineral fraction. The ilmenite has a low chromium and vanadium content and is suitable for pigment manufacture.

The richest and the most extensive deposits are near Capel. In 1964 reserves of heavy minerals were estimated as a minimum of 12,000,000 tons at a grade better than 20 percent. The heavy mineral content ranges up to 90 percent and the average grade mined is 30 to 40 percent. Production of ilmenite concentrates began in 1956 and, to the end of 1964, the content of concentrates dispatched amounted to 1,151,000 tons of ilmenite, 3,700 tons of rutile and 55,800 tons of zircon.

Heavy minerals are also worked on a higher shoreline north and south of Yoganup, which is south-east of Capel, and on the recent beaches of Koombana Bay, north of Bunbury, and Wonnerup, east of Busselton. The average grades mined are lower than those of the Capel deposits.

It has been estimated that reserves of ilmenite in the Geographe Bay area amount to 15,000,000 tons along with 1,000,000 tons of zircon, 100,000 tons of monazite, and up to 500,000 tons of rutile and leucoxene. These reserves have a lower average grade than the deposits currently mined.

Uranium

The demand for uranium for atomic energy stimulated the exploration for uranium ores in Australia. Following the discovery of new deposits, the uranium industry developed rapidly between 1954 and 1959. Most uranium oxide won in Australia has come from the well-known areas of Mary Kathleen , Rum Jungle, Radium Hill, and South Alligator River.

Uranium mineralization was discovered at Mary Kathleen in 1954. The orebody occurs in Precambrian calcareous metasediments near the axis of a pitching syncline. Uraninite is the principal ore mineral but secondary uranium minerals have been developed in oxidized zones. At the end of 1963 indicated reserves amounted to 3,171,600 tons of ore averaging 3.2 lb of U_3O_8 per ton and a further 1,235,700 tons of possible ore reserves averaging 4.17 lb per ton. Because of world over-supply, the mine closed in October 1963, after 9,021,000 lb of uranium oxide had been produced.

The first record of mineral discoveries in the Rum Jungle area was in 1869 when a green slaty mineral was reported, probably the uranium mineral torbernite in association with malachite. However, the uranium mineralization was only positively identified 80 years later, in 1949. The original orebodies, White's and Dyson's deposits, were worked out by the end of 1960, and mining of the Rum Jungle Creek South deposit ceased early in 1963. The deposits occur in and near sheared carbonaceous sediments of Lower Proterozoic age. Pitchblende, the main primary ore mineral, and secondary uranium minerals were associated with sulphides of copper, lead, and cobalt. Pitchblende was the only ore mineral present at Rum Jungle Creek South. At the completion of the 10 year contract early in 1963, 3,249,000 lb of uranium oxide had been sold. Additional ore was stockpiled to keep the local treatment plant operating for several years.

In 1953, uranium mineralization was found in the South Alligator River valley in Proterozoic sediments. Individual deposits are small but rich. The total production of uranium oxide to the end of 1964 amounted to 1,420,000 lb..

The radio-active deposit at Radium Hill, discovered in 1906, was worked sporadically for radium until 1931; production of uranium oxide began in 1954. Uranium mineralization occurs in fractures in folded gneiss and schist of the Archaean basement, and the predominant ore mineral is davidite. Mining ceased in 1961 and the remaining reserves are reported to be small. About £17,500,000 worth of uranium oxide was produced.

Smaller scattered radio-active deposits and prospects have been noted in the Precambrian rocks of Queensland, South Australia and the Northern Territory. Aggregate production from these deposits has been small and most are of little or no significance.

Tungsten

Australia was once a major world producer of tungsten, but since 1920 has occupied only a minor position. Nearly all the current tungsten output comes from three mines. The main producing deposit, on King Island, consists of scheelite disseminated through metasomatised limestone. Ore reserves are 1,485,400 tons containing 0.525 percent tungsten oxide (WO_3). The other two deposits, the Aberfoyle and Storeys Creek mines in Tasmania, are described briefly under Tin.

Much of the past output was from small pipe and reef deposits in eastern Australia, especially in the Cairns hinterland in north Queensland and the New England Tableland in north-east New South Wales. Aggregate production from these deposits, though large in the past, is now negligible.

Manganese

The main manganese producing areas in Australia consist of groups of relatively small deposits. Most of the deposits are the result of enrichment of manganese-bearing sediments by weathering processes (some of the Western Australian deposits formed by deposition in cavities) and not many of the high-grade deposits contain more than a few thousand tons of ore. Reserves in the Western Australian deposits were estimated in 1959 to be 3,800,000 tons of ore containing more than 40 percent Mn with an additional 3,200,000 tons containing 30 to 40 percent Mn. Reserves in other States are not known.

Several manganese deposits have recently been discovered on Groote Eylandt, in the Gulf of Carpentaria. They are of considerable extent and occur as flat-lying or gently dipping seams of pisolitic ore, associated with lower-grade manganiferous material. The thickness of the deposits varies considerably. Drill holes have penetrated up to 50 feet of manganiferous material, but much of this is not classed as ore at present. Total reserves are not yet known, but are thought to be large.

FUELS

Black Coal

Australia is well endowed with deposits of good quality black coal, although measured and indicated reserves are not large by world standards. Measured and indicated reserves were estimated for the Coal Utilization Research Advisory Committee (1962) to be 4,420 million tons(including 3,050 million tons in New South Wales, and 950 million tons in Queensland): inferred reserves are many times this amount. Coal of bituminous rank is predominant in the black coal deposits in Queensland, New South Wales, Victoria and Tasmania. The only commercial deposits in South Australia (Leigh Creek) and Western Australia (Collie), with measured and indicated reserves of 404 million tons, are sub-bituminous in rank. Anthracitic and semi-anthracitic coals are relatively rare in Australia; only semi-anthracite is mined, at Baralaba in Queensland. Total Australian production of black coal was about 967,000,000 tons to the end of 1964.

The greatest deposits of coal are in the Sydney Basin in New South Wales, north, west, and south of Sydney, and in the Bowen Basin in Queensland between Collinsville and Kianga-Moura; they are of Permian age. Seams in the Sydney Basin are worked mainly in the Hunter Valley (especially around Muswellbrook, Maitland, Cessnock, and Newcastle), on the Illawarra coast (Bulli and Wollongong), and at Lithgow and Burragorang in the west. The Bowen Basin seams are worked mainly at Collinsville, Bluff, Baralaba, and Kianga-Moura, but large deposits of good-quality coal are known to occur elsewhere, and have been worked to some extent at several other places, such as Blackwater.

Calorific values (air dried basis) of the Sydney Basin coals as mined are mostly about 12,500 to 13,500 B.Th.U. per lb; calorific values of the Bowen Basin coals are rather more variable, but are generally comparable.

Outside these two basins, fields with known measured and indicated reserves of more than 50 million tons are Ipswich and Callide (Triassic), and Blair Athol (Permian), in Queensland; Leigh Creek (Triassic) in South Australia; and Collie (Permian) in Western Australia. In Victoria the most important field is Wonthaggi (Jurassic), and in Tasmania, Fingal (Triassic). Deposits are or have been worked at many other places, but the seams of many of these fields are thin, vary laterally in thickness and/or quality, or are folded or faulted. Seams of considerable thickness have been intersected in water or oil bores in some of the sedimentary basins, but have not been tested further because of their depth or remoteness from markets.

The seams of the Ashford, Callide, Blair Athol, and Leigh Creek fields are at a shallow depth and are worked by open-cut mining. The coal is won by both open-cut and underground mining on the Muswellbrook, Kianga-Moura, Collinsville, and Collie fields.

Coking coal for domestic iron and steel production is obtained mainly from certain seams of the Hunter Valley, Illawarra coast, and Burragorang fields in New South Wales. In Queensland, coal suitable for metallurgical coke occurs at Collinsville, Kianga-Moura, Blackwater, and Ipswich.

In the Sydney Basin, premium-quality gas-making coal is mined only at Cessnock; because of local availability and/or price considerations, coal mined on some of the other fields is used for gas-making, though less well-suited. The Jurassic coals of Rosewood, Oakey, Tannymorel, and Mulgildie in Queensland are suitable for gas-making, and are mined mainly at Rosewood for this purpose, as is Cretaceous coal at Burrum. In Tasmania, the Permian coals of Spreyton (Mersey field) are high volatile types suitable for gas manufacture. The Collie coal is used for gas making to some extent, although not well suited to this application.

Brown Coal

Brown coal has been found in bores at many places in Australia, but the only known occurrences of thick seams at shallow depth are in Victoria and South Australia. Utilization of the South Australian deposits has been negligible. Victorian reserves were estimated for the Coal Utilization Research Advisory Committee (1962) as 54,700 million tons measured and indicated, and 43,000 million tons inferred. South Australian reserves in the same year were quoted as 530 million tons, measured and indicated. The deposits are all of Tertiary age.

Enormous reserves of brown coal exist in the Latrobe Valley in eastern Victoria. They have been extensively mined at Yallourn and Morwell; the deposits of the Loy Yang and Coolungoolun districts are as yet little developed. Altogether, a combined thickness of 1,000 feet of coal is available in the three major seams of the Yallourn - Morwell field; the depth of overburden in the four open-cuts ranges from 50 to 100 feet. The ash content of the coal is low (generally less than 4 percent on a dry basis); the gross calorific value (dry basis) is about 11,000 B.Th.U. per lb. The moisture content of the coal as mined is about 60 percent. In 1962, total reserves in the Latrobe Valley were quoted as about 45,000 million tons measured and 42,000 million tons inferred; about 17,500 million tons of this could be won by present open-cut methods.

The brown coal deposits at Anglesea are estimated to contain 300 million tons measured and 400 million tons indicated. An upper seam averaging 100 feet in thickness is underlain by several seams 25 to 50 feet thick. The ash content of the coal is low, and the calorific value (dry basis) is about 11,500 B.Th.U./lb.

The main seam at Bacchus Marsh has a maximum thickness of 140 feet. The ash content is about 7 percent and the calorific value almost 11,000 B.T.U./lb. Available reserves are estimated to be about 50 million tons. The seams of the Altona district are thick, but relatively deeply buried, and have not been worked for many years.

In the Gelliondale district, an area of 10 square miles contains reserves of at least 1,000 million tons with an overburden of less than 100 feet; the ash content is about 2.5 percent, and calorific value (dry basis) 10,600 B.Th.U./lb. Relatively small deposits were worked for many years in the Dean Marsh district, but production ceased in 1959.

Brown coal seams have been found in South Australia at several places in the sedimentary basins on the east and west sides of the Mount Lofty Ranges, but most of the seams are thin, and the overburden relatively thick. At Moorlands, an average of 21 feet of coal is covered by an average of 86 feet of overburden; proved reserves are 31.8 million tons. Reserves in the Inkermann-Balaclava district are 400 million tons, but the main seam is only 20 feet thick, under 240 feet of overburden.

Petroleum and natural gas

The search for oil and natural gas in Australia has gone on intermittently since the turn of the century, but little intensive, systematic exploration was done before the mid-1950's, and commercial oil was not found until 1961. The principal structural feature on the known fields is generally an anticline. In the Roma area, permeability variations influence the distribution of the oil pools within the structures.

The only producing oilfield is at Moonie in south Queensland, discovered in 1961. The oil is of high quality, and occurs in Jurassic rocks. Recoverable reserves in early 1965 were estimated to be 38,000,000 barrels (1 barrel equals 35 imperial gallons). The Alton field, west of Moonie, has not yet been fully tested; recoverable reserves in early 1965 were estimated to be 5,000,000 barrels; the oil occurs in Jurassic rocks. Both oil and gas have been encountered in Jurassic and Cretaceous rocks in wells on Barrow Island, off the north-west coast of Western Australia.

Many wells drilled around Roma, in southern Queensland, have encountered commercial quantities of natural gas in Triassic and Jurassic rocks. Individual flows are mostly less than 5,000,000 cubic feet per day, but aggregate recoverable reserves were quoted in early 1965 as possibly 70 to 100 billion* cubic feet. Farther north, in the Rolleston area, several wells have produced gas from Permian sands. At Mereenie, in the Northern Territory, gas and some oil have been encountered in Ordovician rocks; recoverable gas reserves are possibly 1,000 billion cubic feet. Recoverable gas reserves at Gidgealpa, in South Australia, are possibly 500 billion cubic feet; the gas occurs in Permian rocks.

Substantial flows of gas or oil have been met in several wells in addition to those on the fields described above, such as Gin Gin in Western Australia, Gippsland Shelf off Victoria, and Palm Valley in the Northern Territory.

* In the petroleum industry, "billion" means 10^9, following American usage.

NON-METALLIC AND OTHER MINERALS

Limestone

Deposits of good-quality limestone are common, especially in the Palaeozoic rocks of eastern Australia. The reserves and grade of many deposits have never been established because of their distance from industrial centres. Large quantities for cement making and iron smelting are mined at Marulan, Kandos, and Portland in New South Wales. Large Palaeozoic deposits are known in eastern Victoria and have been exploited to some extent, but most of the limestone used for cement making in Victoria, at Geelong, is Tertiary in age. Dead coral dredged from Moreton Bay is the main source of limestone in southern Queensland, while Palaeozoic deposits are exploited in the centre and north of the coastal part of the State. Lower Proterozoic limestones near Cloncurry, some of which contain small amounts of copper, are used for flux at the Mount Isa smelters. The main sources of limestone in South Australia are Proterozoic to Cambrian (Rapid Bay, Angaston) and Miocene (Klein Point)beds, and Pleistocene and Recent dunes built of shell remains (Wardang Island, Coffin Bay). Almost all the Western Australian production is of rather low-grade material from Tertiary dunes along the coast. Vast tonnages of shell fragments are known around the shores of Hamelin Pool. Enormous quantities of Tertiary limestone underlie the Nullabor Plain, but have not yet been utilized.

Asbestos

Most of the asbestos produced in Australia has been the crocidolite or "blue asbestos" variety. Crocidolite deposits occur at several places in the Hamersley Ranges of Western Australia, and have been mined on a large scale at Wittenoom Gorge and nearby Colonial Gorge. Here the deposits consist of three groups of narrow seams in ferruginous quartzite associated with dolomite and calcareous shale. The seams are gently dipping and range up to two inches in thickness. Only the upper two groups of seams are worked. Similar deposits occur in the vicinity of Yampire Gorge and Marra Mamba.

Chrysotile or "white asbestos" has been produced principally from Baryulgil in New South Wales and Lionel and Nunyerri in Western Australia. The output of amphibole asbestos has been small.

Pyrite

Many metalliferous ore deposits, especially those of copper, lead, and zinc, contain pyrite in addition to the ore minerals. The only Australian base-metal ore deposits from which the pyrite is recovered for making sulphuric acid are at Mount Morgan in Queensland and Mount Lyell in Tasmania. Gases evolved during roasting of base-metal sulphides from the Broken Hill and Read-

Rosebery mines are also used for sulphuric acid manufacture. Pyrite is mined at Nairne in South Australia, where thin bands of pyrite and pyrrhotite in Cambrian sediments form up to 15 percent of the rock; and at Norseman in Western Australia, where the orebodies are massive lenticular lodes. Auriferous pyrite concentrates from some Kalgoorlie gold mines are also used as a source of sulphur.

Gypsum

Gypsum deposits are widespread in the semi-arid parts of southern Australia. The gypsum occurs on the floors of dry or intermittently flooded lakes and as dunes around the larger ones. The largest deposit known in Australia is at Lake Macdonnell in South Australia, where reserves of high-grade material (more than 94 percent gypsum) exceed 600,000,000 tons. Several other large, high-grade deposits are known in the State. Other important sources of gypsum in Australia are north-west Victoria, central western New South Wales, and the interior of the south-west of Western Australia. Many of these deposits are not high-grade, and washing is necessary to produce an acceptable product.

Magnesite

The main Australian sources of magnesite have been Fifield and Thuddungra in New South Wales. The magnesite occurs as veins in ultrabasic igneous rocks - hornblendite at Fifield and serpentinite at Thuddungra. Several large deposits at and near Bandalup Creek in Western Australia consist of massive cappings overlying serpentinite; reserves in these deposits are thought to exceed 10,000,000 tons. Magnesite of sedimentary origin forms thin but extensive beds in the Precambrian rocks of the southern Flinders Ranges in South Australia.

Dolomite

Dolomitic rocks are associated with many Australian limestone deposits, but, for want of adequate testing, their full extent is known in only a few cases. Nearly all the current Australian production is from Ardrossan, on Yorke Peninsula in South Australia, where a flat-lying bed of Lower Cambrian dolomite, up to 370 feet thick, is quarried. Many other large dolomite deposits are known, but most of those worked have been quarried on only a relatively small scale.

REFERENCES AND FURTHER READING

This survey of Australian mineral deposits is necessarily brief and incomplete. The reader seeking more information is referred to the following publications, which contain numerous references to earlier publications:

Australasian Institute of Mining and Metallurgy (1953). - Coal in Australia. Fifth Empire Mining and Metallurgical Congress: Publications: Volume 6. Australasian Institute of Mining and Metallurgy, Melbourne.
A State-by-State account of the then producing coal-fields.

Blainey G. (1963). - The Rush that Never Ended. Melbourne University Press: Melbourne.
A history of Australian mining.

Edwards A.B. ed. (1953). - Geology of Australian ore deposits. Fifth Empire Mining and Metallurgical Congress: Publications: Volume 1. Australasian Institute of Mining and Metallurgy, Melbourne.
Contains detailed accounts of the more important then current and past metalliferous deposits and fields.

Lawrence L.J. ed. (1965). - Exploration and mining geology with particular reference to the Commonwealth of Australia. Eighth Commonwealth Mining and Metallurgical Congress: Volume 2. Australasian Institute of Mining and Metallurgy, Melbourne.
An account of current practice in mineral exploration and mining geology.

McAndrew J. ed. (1965) . - Geology of Australian ore deposits. 2nd edn. Eighth Commonwealth Mining and Metallurgical Congress: Volume 1. Australasian Institute of Mining and Metallurgy, Melbourne.
A revision of Edwards (1953) with general papers on each of the base metals and other major commodities, and accounts of some non-metallic mineral deposits.

McLeod I.R. ed.(1965). - The Australian mineral industry: The mineral deposits. Bur.Min.Resour.Aust.Bull.72.
A comprehensive survey, with leading references, of metallic and non-metallic mineral deposits with descriptions of the geology of the larger deposits.

Woodcock J.T. (1965) . - The Australian mining, metallurgical and mineral industry. Eighth Commonwealth Mining and Metallurgical Congress: Volume 3. Australasian Institute of Mining and Metallurgy, Melbourne.
A comprehensive commodity-by-commodity account of the industry, including brief surveys of Australian resources.

Descriptions of mineral deposits and mining fields are contained in publications of the State Mines Departments and their Geological Surveys, and of the Bureau of Mineral Resources, Geology and Geophysics of the Department of National Development. Each organisation issues lists of its publications.

Note on Map-sheet

The commodities shown on the map-sheet are those which have been produced in Australia. Exceptions are construction materials such as heavy clays, sand, gravel, and crushed rock, although their annual value of production is about £30,000,000. Deposits of these commodities are widespread, but their exploitation depends on proximity to sources of demand rather than size and quality. Quartz crystal, jarosite and strontium, which have been produced in small quantities in the past, also are not shown: the occurrence of usable quartz crystal is largely fortuitous and the known deposits of jarosite and strontium are unlikely to be economic. Whiting is also not shown, because all current production is finely ground limestone. Of all the commodities listed on the map, only kyanite, mercury, and nickel were not produced in the twelve-year period 1952 to 1963.

The map does not show every locality at which a commodity has been produced or at which a possibly economic deposit exists, except in some cases, such as mercury and nickel, for which few localities are known in Australia. Some measure of judgment was used in selecting deposits, against a background of current and forseeable economic conditions. Generally, deposits which have been omitted are those of minor importance when the number and aggregate productivity of all Australian deposits of that commodity are taken into account.

At many localities one symbol may represent several scattered deposits or a field made up of many small deposits. The absence of a symbol in one or two of the columns of the alphabetical list denotes that deposits of that size are not known in Australia.

The division of the deposits into three sizes in qualitative - a distinction using quoted reserve figures is not practicable because such figures may not be available (or not known), the bases used for estimating reserves differ widely and, for industrial minerals especially, the quality of the material is an important factor in the exploitation of a deposit. For the classification published and some unpublished information was used. Different points of division were adopted for each commodity, because modes of occurrence and rates of consumption differ so much. Thus a deposit containing 10,000 tons of tin metal has been classed as a major deposit, while a deposit containing the same amount of iron is too insignificant in terms of annual world production to be shown on the map.