

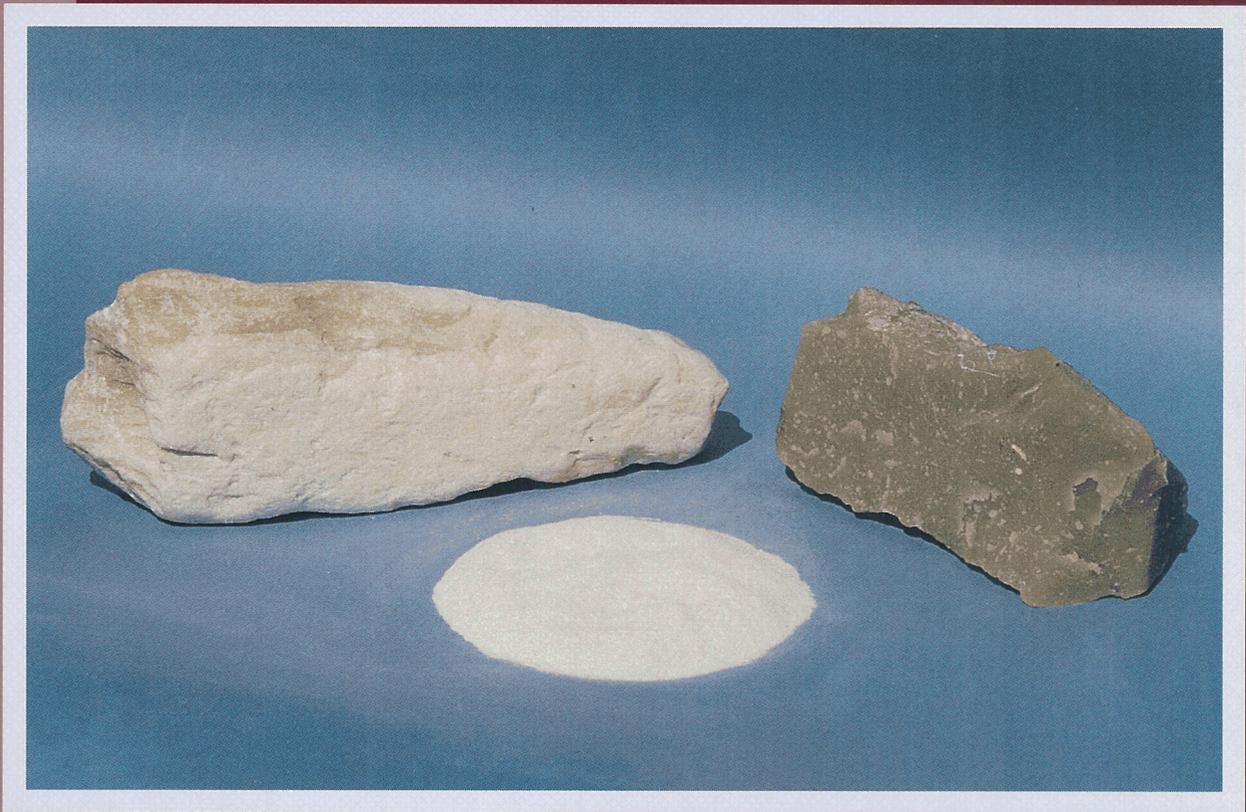
**MINERAL
RESOURCES
BULLETIN
16**



**GOVERNMENT OF
WESTERN AUSTRALIA**

TALC, PYROPHYLLITE AND MAGNESITE IN WESTERN AUSTRALIA

by P. B. Abeysinghe



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY



**TALC, PYROPHYLLITE
AND MAGNESITE IN
WESTERN AUSTRALIA**



COVER:

Talc powder flanked by Mount Seabrook talc (left) and Three Springs talc (right)

FRONTISPIECE:

The talc mine at Three Springs sits comfortably amongst recently planted wheat paddocks.
Photo: courtesy of WMC Talc Asia Pacific



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by
P. B. Abeysinghe

Perth 1996

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Talc, pyrophyllite and magnesite in Western Australia

by

P. B. Abeyasinghe

Abstract

Talc

Talc is currently produced from two mines in Western Australia — at Three Springs and Mount Seabrook. Production from Three Springs in 1994 was 72 896 t, valued at \$AUS 5.4 million, and that from Mount Seabrook was 27 942 t valued at \$AUS 2 million. The total identified talc resource in Western Australia is approximately 12 Mt. At Three Springs, the talc mineralization is in flat-lying to gently dipping Proterozoic dolomite of the Coomberdale Subgroup of the Moora Group. There is a proven, probable, and indicated resource of 9.2 Mt in deposits at the mine. The rock types at Mount Seabrook consist of a mixed schist–quartzite unit that grades upward into a dolomite–chert–quartzite–talc unit. The talc is thought to be formed by alteration of sandy dolomitic rocks. Reserves and resources at the Mount Seabrook deposit are estimated at 1.55 Mt. The most prospective areas for exploration in Western Australia are the regions of Proterozoic dolomite intruded by mafic dykes, such as those found in the Moora belt.

Pyrophyllite

The only deposit of pyrophyllite of possible commercial interest is located at Pinnacle Well, near Leonora, and has an inferred resource of 10 Mt.

Magnesite

Magnesite was last produced in Western Australia in 1984 — 16 729 t valued at \$AUS 215 936 — and came from deposits at Bandalup near Ravensthorpe. These are also the largest magnesite deposits in the State. Western Australia's magnesite occurs as residual deposits on Archaean ultramafic and mafic rocks, or is found within the Tertiary Pallinup Siltstone. The Pallinup Siltstone deposits have an estimated recoverable resource of 1.3 Mt, and residual deposits related to ultramafic and mafic rocks have an inferred resource of 300 000 t. Another important magnesite deposit is found at Bulong. It comprises veins in serpentinized ultramafic rocks and the largest zone occurs within a northerly trending basin, parallel to Lake Yindarigooda, that extends for nearly 3.7 km. Other notable magnesite occurrences are those at Lawlers, Eulaminna, Comet Vale, Coolgardie and Mount Burges, all associated with ultramafic rocks.

KEYWORDS: Coomberdale Subgroup, dolomite, magnesite, Moora Group, Mount Burges, Mount Seabrook, Pinnacle Well, pyrophyllite, Ravensthorpe, talc, Tertiary Pallinup Siltstone, Three Springs, ultramafic rocks, Western Australia

Summary

Talc

The mineral talc is a hydrated silicate of magnesium, theoretically containing 63.36% SiO₂, 31.89% MgO and 4.75% H₂O. It is the softest common mineral, having a hardness of 1, and its specific gravity is 2.58 to 2.83. Minerals associated with talc are tremolite, dolomite, mica, quartz, chlorite and magnesite. Steatite is an especially pure type of industrial talc with less than 1.5% CaO and Fe₂O₃ and less than 4% Al₂O₃. Soapstone is a massive, soft, grey to bluish talcose rock that may be sawed into various shapes, and is also used as a medium for sculpture and carving.

The main uses of talc are in the paint, paper, plastics, ceramics, cosmetics and rubber industries. Of the many uses, some have a declining trend, whereas others are growing. The use of talc by the plastics industry is growing in Europe and the USA. In Europe, paper continues to be a leading consumer, paints remain a staple consumer, and talc usage in the cosmetics industry has declined over the last ten years. Prices have generally remained flat for most varieties of talc during the past seven years, except for Chinese ground talc, which increased in price to \$AUS420 in 1994.

More than 40 countries in the world produce talc, for a total annual production of around 6 to 8 Mt. The major producing countries are China, USA, South Korea, CIS, Brazil, India, Finland, France and Australia. China contributed approximately 32% of the world production in 1994, whereas that of USA was 11% and that of Australia was 1%. The global trend between 1974 and 1994 indicates that output of talc generally increased from 5.8 Mt in 1974 to a peak of 9.0 Mt in 1992 followed by a slight decrease to 8.6 Mt in 1994. A noticeable feature is that production from China has increased substantially, from around 150 000 t in 1979 to more than 2.5 Mt in 1994. Some countries have a reputation for certain types of talc: France, Italy, China and Australia are known for cosmetic talc; and New York is the best-known source of ceramic talc.

Australian production increased from approximately 64 000 t in 1974 to more than 115 000 t in 1994. Western Australia contributed 100 838 t valued at \$7 million, 87% of the Australian production. The total production from Western Australia, South Australia and New South Wales, between 1940 and 1994, was more than 3 704 000 t, of which the Western Australian contribution was 3 052 000 t or about 82%. Production from the remainder of Australia was insignificant.

Western Australian production has increased substantially since 1968 and the State is presently the largest producer in Australia. There are two producing centres: the Three Springs mine, 330 km north of Perth, is owned by Western Mining Corporation Limited; and the Mount Seabrook mine, approximately 174 km northwest of Meekatharra, is owned by Gwalia Consolidated Limited. Production from Three Springs in 1994 was 72 896 t valued at \$5.4 million, whereas Mount Seabrook produced 27 942 t valued at \$2 million. However, the production from Three Springs during 1993 was 140 411 t valued at \$10.3 million. The total identified talc resource in Western Australia is approximately 12 Mt.

The most common hosts for talc include the following: sedimentary rocks, mainly dolomite altered by regional or contact metamorphism; serpentized ultramafic rocks located in tectonically active areas; and, less commonly, mafic rocks. Of the known talc occurrences in Western Australia the commercially exploitable deposits such as Three Springs and Mount Seabrook are associated with Proterozoic sedimentary rocks intruded by dolerite and the rest occur in Precambrian greenstones, mainly within ultramafic associations.

At Three Springs, the talc mineralization is in flat-lying to gently dipping Proterozoic dolomite of the Coomberdale Subgroup of the Moora Group. Talc lies beneath about a metre of loamy soil that at depth grades into stromatolitic talc, compact massive talc and then into sedimentary rocks. The formation of the talc is most likely due to the intrusion of dolerite that resulted in silica from the host sedimentary rocks reacting with magnesium of the dolomite. A number of localities such as Coorow, Marchagee, Carnamah and Moora in the Proterozoic dolomite belt of the Moora Group are prospective for talc. The deposit at Three Springs is divided into four pits, of which pits A and B were in operation before April 1984, and pits C and D are currently being mined. Proven and probable resources total 6.4 Mt in pits C and D and adjoining leases.

The high-grade talc at Three Springs is massive, cryptocrystalline, waxy, grey-green to white steatite. The common impurities in fresh talc are chlorite, apatite, and rare pyrite, and quartz veinlets. The talc is fibrous but does not contain asbestiform minerals, and its brightness generally varies between 80 and 90%. The important commercial applications of Three Springs talc are for paper and pulp, electroceramics, paint, plastics and rubber, with its main customers in Japan, South Korea, USA, Europe, New Zealand and Australia.

At Mount Seabrook the rock types consist of a mixed schist–quartzite unit that grades upward into a dolomite–chert–quartzite–talc unit. The rocks in the mine area are folded around an axis parallel to the northwesterly regional trend and are intruded by granitoid, with a northerly trending contact at the eastern side of the mine area. Some exposures in the mine area demonstrate alteration of dolomite to talc and quartz and the traditional view is that the talc has formed by alteration of sandy dolomitic rocks. Talc mineralization is also common at a number of other localities within the Mount Seabrook belt such as at Livingstone, Trillbar and Beduburra Pool. The talc reserves and resources at the Mount Seabrook deposit are estimated at 1.55 Mt. The talc is massive, white, fine grained, opaque (in places translucent), micaceous, and contains quartz inclusions. The talc is marketed mainly for cosmetic uses in Europe, and for various industrial uses in the USA.

The most prospective areas for future exploration in Western Australia are areas of Proterozoic dolomite intruded by mafic dykes, such as those in the Moora belt. One such locality is southwest of Kundip where preliminary exploration activities have produced encouraging results. Preliminary investigations of dolomitic rocks of the Irregularly Formation in the Bangemall Group east of Maroonah and close to the Henry River indicate that they contain talc mineralization of unknown quality.

Talc associated with ultramafic rocks is quite common in the Eastern Goldfields, but large deposits of commercial significance are unknown. A deposit at Mount Monger has been mined, but its true potential is unknown. Bolgart and Glen Lynn, with recorded production, are also small deposits and are related to locally altered ultramafic rocks. Trace element determinations indicate that talc hosted by ultramafic associations contains appreciably higher chromium and nickel than that associated with Proterozoic dolomite.

Pyrophyllite

Pyrophyllite is a hydrous aluminium silicate similar to talc in physical properties and uses, but different in its composition and mode of occurrence. Pyrophyllite may occur in spherulitic aggregates of small crystals, radiating needle-like crystals, or fine-grained foliated lamellae with platy cleavage. The colour varies from white to pale green, pale yellow, buff, or light to dark grey. Deposits of economic significance are formed by hydrothermal alteration of acid volcanic rocks such as rhyolite or, less commonly, in schist derived by metamorphism of volcanic ash. Pyrophyllite is not produced commercially in Western Australia, but the Pinnacle Well deposit, 22 km north-northwest of Leonora, is prospective.

Magnesite

Pure magnesite has a theoretical composition of 47.8% MgO and 52.2% CO₂, but is rarely found. Naturally occurring magnesite consists of varying proportions of calcium and magnesium carbonates in an isomorphous

series. The cryptocrystalline variety is massive, with conchoidal fracture, a hardness of 3.5 to 5.0, and a specific gravity of 2.9 to 3.0. Crystalline magnesite has a hardness of 3.5 to 4.0 and a specific gravity of 3.02, which increases with iron content.

Most of the world magnesite output is dead burned by calcining at 1500°C to 2000°C to produce refractory magnesia, which is widely used in the steel industry to line basic open-hearth furnaces and converters, copper smelters and cement kilns. The refractory industry requires rigid specifications for raw magnesite, which should typically contain more than 95% MgO, less than 1% Fe₂O₃, a lime–silica ratio of 2:1, and have a bulk density of 3.4 g/cm³. Caustic magnesia, produced by calcining magnesite to temperatures of 700° to 1000°C, has a number of uses in agriculture, animal feeds, construction, rubber, abrasives, chemicals, pharmaceuticals, and also has environmental applications. In terms of the dollar value of the day, the prices of dead-burned and calcined varieties increased from about \$275 and \$250 in 1984, to about \$540 and \$420 respectively in 1994, whereas that of crude or raw magnesite dropped from approximately \$90 in 1984 to \$65 in 1994.

The principal countries producing natural magnesite are China, North Korea, CIS, Turkey, Australia, Czech Republic, Austria, and Greece. Of these, the first three contributed approximately 64% of world production during 1994. The output from Australia in 1994 amounted to 5% of global production, due to increased output from the Kunwarara and related deposits in Queensland. Global trends in the production of natural magnesite between 1981 and 1994 indicated a general increase between 1981 and 1989, with a peak of 20 Mt in 1989 decreasing to 16.3 Mt in 1994.

Total Australian production between 1940 and 1994 was 2.8 Mt, with Western Australia producing 0.08 Mt. However, in 1994, Queensland had an output of 278 622 t compared to 15 553 t from New South Wales and 1228 t from South Australia. Magnesite is not being mined in Western Australia, the last recorded production being 16 729 t in 1984 valued at \$215 936, from deposits at Bandalup near Ravensthorpe.

Magnesite occurs as a replacement mineral in carbonate rocks, as an alteration product in ultramafic rocks, as a vein filling, and as a sedimentary rock. The recently developed Kunwarara deposit in Queensland has geochemical characteristics common to ultramafic associations as well as chemical replacement type ore bodies.

The largest deposits in Western Australia are at Bandalup, approximately 30 km east of Ravensthorpe. Some of the deposits are residual on Archaean ultramafic and mafic rocks, whereas others occur within the Tertiary Pallinup Siltstone, but have probably derived their magnesium from the serpentinitous rocks of the region. The Pallinup Siltstone deposits are more massive, of more uniform quality, and lower in trace elements like chromium and nickel than the magnesite associated with the mafic and ultramafic rocks, and have an indicated resource of

1.3 Mt. The residual deposits have an inferred resource of 300 000 t.

Another important deposit of magnesite occurs at Bulong, approximately 37 km east of Kalgoorlie. It comprises veins in serpentinized ultramafic rocks, and the largest deposit occurs within a northerly trending basin that extends for nearly 3.7 km, parallel to Lake Yindarlgooda. Common impurities of magnesite in the area are chalcedonic and opaline silica derived from the host serpentinites, and appreciably higher chromium and nickel than in comparable material from Bandalup. The resources available in the area are some few million tonnes. Other notable magnesite occurrences in Western Australia are those at Lawlers, Eulamina, Comet Vale, Coolgardie and Mount Burges, all of which are associated with ultramafic rocks.

Chapter 1

Introduction

Object and scope

1. The main objective of the Bulletin is to compile all the available published and unpublished information on talc and magnesite into one publication.
2. Western Australia, with an annual production of some 120 000 t, is at present the largest producer of talc in Australia.
3. Pyrophyllite is included with the talc section because of its physical similarities to talc, although it is not currently being mined.
4. Magnesite has been exploited in the past, although it is not commercial at present.
5. Although a significant amount of information on all these minerals is already available within the Geological Survey of Western Australia, there is no single source of such information — the current publication addresses this problem. The bulletin is not intended to be an exhaustive study of all the known occurrences, but is a comprehensive summary pointing the reader to sources of further data.

Sources of information

The sources of information are from both published and unpublished data, supplemented by field inspections. Of the published information, *Minerals of Western Australia* (Simpson, 1952), has been referred to extensively, and most other published data are from Geological Survey of Western Australia (GSWA) publications. Unpublished information is derived from GSWA internal records, annual reports, technical files, and also the reports submitted to the Department by various companies. Some of the major deposits, and others thought to be significant, were visited by the author during three field trips between March and May 1993, when approximately 80 samples were collected for chemical analysis. Eleven of these samples were studied for mineral identification, by X-Ray Powder Diffractometry (XRPD) and Scanning Electron Microscope (SEM) methods, in the Western Australian Government Chemical Laboratories now Chemistry Centre (WA). All chemical analyses were done by the Chemistry Centre (WA).

Numerous locations given by Simpson (1952) are not precise and often lack geological information. These

localities have been included in the bulletin for completeness, and to assist with further searches.

Bulletin layout

The Bulletin is divided into two parts: Part One deals with talc and pyrophyllite, and Part Two with magnesite. Most of the Bulletin is devoted to talc and magnesite — important industrial minerals in Western Australia — with a small section allocated to pyrophyllite at the end of part 1.

The economic viability of projects involving industrial minerals is strongly dependent on the location of the deposit in relation to infrastructure, to the availability of other competitive minerals, and to global production and usage trends. Such trends for both talc and magnesite are discussed at length.

In accordance with the recent style of GSWA Mineral Resources Bulletins, the mineral occurrences are grouped by tectonic provinces, with major deposits being discussed first. The tectonic provinces are based on the Survey's Memoir 3 (Geological Survey of Western Australia, 1990) with modification by Myers (in press). A brief account of the geology of each tectonic province is given. However, for a more detailed description of the geology of these tectonic units the reader should refer to Memoir 3.

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
CANMET	Energy, Mines and Resources, Ottawa, Canada
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CC	Chemistry Centre (WA)
\$AUS	Australian Dollars
DME	Department of Minerals and Energy
E	Exploration Licence
EDXRA	Energy Dispersive X-Ray Analysis
FIMISCO	Financial Mining Industrial & Shipping Co
GCL	Western Australian Government Chemical Laboratories (now CC)
GML	Gold Mining Lease
GSWA	Geological Survey of Western Australia
M	Million
MC	Mineral Claim

ML	Mineral Lease
PP	Private Property
P	Prospecting Licence
PA	Prospecting Area
Qmag	Queensland Magnesia Project Joint Venture
SEM	Scanning Electron Microscope, Scanning Electron Micrograph
SG	Specific Gravity
t	Tonnes
USA	United States of America
USBM	United States Bureau of Mines
WMC	Western Mining Corporation Limited
XRPD	X-Ray Powder Diffractometry
XRD	X-Ray Diffraction

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Part 1

Talc

Chapter 2

Mineralogy, mode of occurrence and uses of talc

Mineralogy

Talc is the softest common mineral. It has a hardness of one on the Mohs' scale and a density of 2.58 to 2.83 g/cm³. Apart from its softness, it is well-known for its greasy feel, pearly lustre, and white to greenish colour. It has perfect basal cleavage and is found in compact, foliated, or massive aggregates. Talc is a hydrated silicate of magnesium — $3\text{MgO}\cdot 4\text{SiO}_2\cdot \text{H}_2\text{O}$ — theoretically containing 63.36% SiO₂, 31.89% MgO and 4.75% H₂O. However, it rarely approaches theoretical purity, and is broadly defined as all gradations from pure mineral to impure, massive, talcose rocks containing as little as 50% of the mineral talc. Minerals commonly associated with talc are tremolite, dolomite, mica, quartz, chlorite and magnesite, depending on the rocks from which the talc is derived.

Steatite is an especially pure type of industrial talc containing less than 1.5% of each of CaO and Fe₂O₃, and less than 4% Al₂O₃ (Harben and Bates, 1990a). Steatite was originally an alternative mineralogical name for talc, often restricted to grey-green or brown massive talc or talcose rock (Wells, 1965). Block steatite is block talc that meets specifications for electronic insulators. Block talc is any massive talc or soapstone from which products can be obtained by machining. Steatite, on firing at 1800°F (980°C) for six hours, converts to interlocking crystals of clinostatite (MgSiO₃) that is then called 'lava' (Roe and Olson, 1983). 'Lava' is also a term used in the trade to designate block talc or the finished product made from block talc.

Soapstone is a soft, massive, grey to bluish or greenish talcose rock with a smooth, unctuous feel that may be sawed into various shapes such as boards and benchtops, and is used for other types of special-purpose dimension stone.

'French chalk' is a soft, massive variety of talc used for marking cloth.

Roe and Olson (1983) classified talc into four categories:

1. Steatite — an especially pure type of industrial talc;
2. Soft, platy talc — an alteration product of sedimentary magnesium-carbonate rock having chlorite as a common accessory mineral;

3. Tremolite talc, sometimes called 'hard' talc — a massive or laminated rock composed of varying percentages of tremolite, anthophyllite, calcite, dolomite and serpentine, together with soft talc. It is characterized by calcium oxide contents of between 6 and 10%.
4. Mixed talc ores — contain a mixture of soft talc, platy talc, dolomite, calcite, serpentine and many other trace minerals.

Substitute minerals

Pyrophyllite has similar properties to talc and has similar applications. It is a hydrous aluminium silicate $\text{Al}_2\text{O}_3\cdot 4\text{SiO}_2\cdot \text{H}_2\text{O}$, with a theoretical composition of 66.7% SiO₂, 28.3% Al₂O₃ and 5% H₂O. 'Wonderstone' is a term applied to massive block pyrophyllite from South Africa. Agalmatolite and pagodite are terms applied to massive pyrophyllite from China and Korea that is used to produce carved ornaments and pagodas!

Mode of occurrence

Chidester et al. (1964) stated that the most common host rocks of talc are those with the following associations:

- (a) Sedimentary associations — especially dolomitic rocks altered by regional or contact metamorphism, e.g. California-Nevada, Montana, and New York in USA, Three Springs in Western Australia;
- (b) Ultramafic associations — e.g. Vermont district in USA, Eastern Goldfields in Western Australia;
- (c) Mafic associations — e.g. Central Appalachian Mountains in USA.

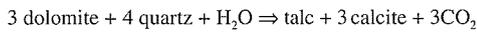
Most of the known talc ore bodies in the world occur in Precambrian rocks (Roe and Olson, 1983), with the talc forming as a secondary mineral, also during the Precambrian.

The reason for this restriction of talc to Precambrian rocks is unclear. In the case of ultramafic rocks it could be said that these rocks are more abundant in the Precambrian than in younger geologic systems, and therefore give rise to more talc deposits. The same thing cannot apply to sedimentary-dolomitic associations because these rocks are more common in the Cambrian

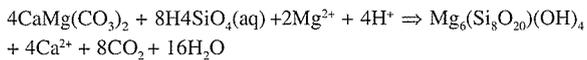
and younger geologic systems. Roe and Olson (1983) suggested that deep burial and consequent dynamic metamorphism could have attained sufficient intensities to produce talc only during Precambrian times. However, they stated that although such a theory might apply to some deposits such as those in Montana and New York, there are other deposits which do not show extreme dynamic metamorphism even though they have undergone deep burial.

Sedimentary associations

Talc in sedimentary associations is most common in dolomitic rock that has been intruded by igneous rocks. The intrusive contact, faults and shears are favourable zones for talc mineralization, and most of the known deposits in the USA occur in such a situation. The simplest method of forming talc from dolomite, suggested by Winkler (1974), is as follows:



Blount and Parkinson (1991) suggested the following volume-for-volume replacement of dolomitic marble for the deposits in South West Montana:



They postulated that hydrothermal fluids migrated through a large volume of rock surrounding the site of actual massive talc formation. Harben and Bates (1990a) suggested that in general dolomitic strata are selectively tremolitized when granitic rocks are emplaced, and subsequent retrograde metamorphism results in talc schist.

Commercial talc deposits are typically tabular and concordant with the parent rock and have commonly undergone regional metamorphism.

Ultramafic associations

Talc deposits are commonly associated with dunite, peridotite and serpentinite and in these rocks talc mineralization generally involves an intermediate stage of serpentinization. Talc can form from serpentine either by a metasomatic reaction with carbon dioxide or by a metamorphic reaction with siliceous country rock, depending upon the prevailing geochemical conditions, to produce deposits that contain dominantly talc-carbonate rock or dominantly talc rocks respectively (Brown, 1973).

Mafic associations

Talc mineralization in mafic rocks is less common than in the other two associations and is less important as a source of commercial talc. One example is the talc mineralization (mainly soapstone) associated with mafic igneous rocks in the Central Appalachian Mountains where hydrothermal alteration of gabbroic rocks is thought to be the cause.

Properties and uses

In spite of the relatively low purity of the naturally occurring mineral, talc is a very useful material because of its extreme versatility. The quality or grade of the talc is very important in its end use. The main properties that determine grade are softness, smoothness, extreme whiteness, lustre, high slip tendency (or lubricity), low moisture content, oil and grease absorption, chemical inertness, a high fusion point, low thermal and electrical conductivity, and high dielectric strength (Cooper and Hartwell, 1970). The following industries are major consumers of talc:

Paint	Roofing
Paper	Cosmetics
Plastics	Rubber
Ceramics	

Table 1 lists the important properties required of talc for the above industries — paint and paper industries are the main users. As with many other industrial minerals, there is an increasing demand for talc of higher purity and consistency.

Paint

The important properties of talc for use in paint are whiteness, fineness, oil absorption, chemical inertness and optimum viscosity. The oil absorption is measured by ASTM method D281-31, which determines the number of parts of acid-refined linseed oil required to produce a coherent paste with 100 parts of talc pigment (Roe and Olson, 1983). A Hegman gauge is used to test the fineness and degree of dispersion of paint.

Talc helps reinforce paint films and prevents sagging. It also prevents settling of solids to the bottom of the paint container. The softness of talc contributes minimal abrasion to process and application equipment. Talc is also used for gloss control in paints where an exact degree of sheen or lustre is required.

Paper

There is a growing demand for talc for coating and filling paper. The main reason for growth is the availability of high-quality micronized talc manufactured to required specifications. Talc, when used as a filler, should not contain more than 2 to 5% CaCO₃ or similar contaminants that react with the alum used in paper formulations. Particle size should range from 5 μ to less than 0.5 μ (Table 1) with surface areas from 4 to 25 m²/g. Talc products of high purity find a good market in competition with titanium oxide fillers. The ability of talc to preferentially coat oily materials in the presence of water makes it extremely effective in 'pitch control'. The efficiency of this application depends on the mineralogy and the particle size distribution of the talc. For example the specific surface of the micronized talc and the extent of lamellar, platy talc are essential parameters (Schober, 1987). Pitch and other oleoresinous components of paper pulps cause serious

Table 1. Talc properties important to specific industries

Paint industry

Colour (whiteness)
 Particle shape
 Packing quality
 Oil absorption
 Fine particle size (Hegman gauge rating)
 Opacity

Paper industry

Free of grit (low Valley Abrasion value)
 Colour (with MgO as 100, 90 or higher is preferred)
 Opacity
 Particle size (less than 5 μ)
 Low alkali content
 Effective in controlling pitch, oil, or other oleoresinous substances
 Talc pigment gives lower wax pick values than clay pigments
 Talc gives lower ink receptivity than clay

Ceramic industry

Uniform chemical composition
 Constant amount of shrinkage on firing
 Fired colour
 Particle size distribution

Cosmetic industry

Contains only traces of dolomite, tremolite, quartz, or other harsh minerals
 Some chlorite may be acceptable
 No colour change after heating
 Odourless; has good fragrance retention when compounded
 100% through 100 mesh and 98% minimum through 200 mesh; finer grades as specified by buyer
 Neutral to litmus paper
 Water-soluble substances: 0.1% maximum
 Acid-soluble substances: 2.0% maximum
 Loss on ignition: 5.0% maximum
 Arsenic (as As): 3 ppm maximum
 Lead (as Pb): 20 ppm maximum
 Total aerobic plate count including yeast and mould, 100 per g maximum
 Gram-negative bacterial plate count, less than 10 per g
 Good 'slip' and 'unctuosity' when applied to human body, also the white colour should disappear as the talc is rubbed into the skin
 Good deodorizing ability

Plastics industry

Low iron content
 Particle shape
 Reinforcing ability
 Compatibility with resins and other components (talc is inert)
 Superfine particles
 Resistivity

Roofing industry — asphalt backing and surfacing

Minimum oil absorption
 Colour
 Particle size consistency
 Brightness
 Particle shape

Petroleum and automotive industries – lubricants, body putty, asphalt undercoating

Free from grit (pure platy talc for lubricants)
 Chemically inert
 Nonwicking (undercoating)

Rubber industry

Good lubricity
 Free of grit
 Colour (only in white rubber and latex)
 Resistivity
 Must be chemically compatible when used as latex filler

NOTE: after Roe and Olson (1983)

manufacturing problems if they are not controlled. Materials such as diatomaceous earth and clay can be used instead of talc, but are either abrasive or much less effective in the presence of water.

Plastics

Talc is used in the plastics industry as a filler to improve chemical and heat resistance, impact strength, dimensional stability, stiffness, hardness, thermal conductivity, tensile strength, creep resistance and electrical insulation properties. Talc can be used in both thermoplastics and thermosets. The use of talc decreases the overall cost of the plastic product. Talc is also used as a reinforcing extender filler in many thermoplastics, where it controls melt flow, reduces creep in moulded parts, increases moulding cycles, and increases heat-deflection temperature and dimension stability (Roe and Olson, 1983).

Ceramics

The uniform chemical and physical properties of talc are utilized in the ceramics industry, where talc has beneficial effects relating to the control of thermal expansion of ceramic bodies. Talc is used in semi-vitreous whiteware such as wall tiles and dinner ware. It is also used as a glaze ingredient, where it provides a low-cost source of MgO. Steatite-grade talc is used for the manufacture of high-frequency insulators, which requires upper limits of 1.5% CaO, 4% Al₂O₃ and 1.5% iron oxides. There are numerous competing raw materials such as wollastonite, kyanite, alumina, and clays for some talc uses in the ceramics industry.

Roofing products

Talc is sprinkled on the surface of roofing products such as asphalt shingles or roll roofing to prevent sticking during manufacture and storage. Typical size specifications for such uses are:

Tyler Mesh Range	%wt talc
+35 mesh	none
+65 mesh	10–20
-65 +100 mesh	15–30
-100 +200 mesh	25–35
-200 mesh	20–25

Other important properties of talc required for the roofing industry are given in Table 1.

Rubber

Ground talc is used as a filler in many synthetic rubbers. Stress-strain relationship of the product is affected by the volume changes, amount of filler and the particle size of talc used (Cooper and Hartwell, 1970). Talc is required to be free of grit, and to have good lubricity and resistivity. Chemical compatibility is needed when used as a latex filler. Talc is also used as a dusting agent to prevent sticking.

Cosmetics and pharmaceuticals

The quality of talc required for the cosmetics industry is increasing steadily: both in purity and in stringent quality requirements. For example, prior to the end of 1960 talc was considered to be of suitable grade for cosmetics if it had good slip, was reasonably light coloured, free of gritty hard mineral particles, and measured up to required fragrance retention standards. The requirements at present set by the industry and by government agencies are now much more stringent, as shown in Table 1. The main concerns are health and safety aspects, especially in connection with asbestiform minerals associated with talc.

Other uses

Talc is also used in other industries (see Table 1) and for other uses such as:

- Insecticides
- Textiles
- Upholstery (for fabric making)
- Corrosion-proofing compounds (such as automotive undercoating)
- Dry fire-extinguishing powders
- Cereal polishing (rice, corn, barley)
- Bleaching agents
- Odour absorption from foods
- Floor wax
- Water filtration
- Leather treatment
- Joint fillers and grouts
- Shoe polishes
- Welding rod coatings
- Printing inks
- Encapsulant for acceleration testing of artillery shells up to 50 000 g
- Coating for iron pellets in direct-reduction processes
- Source of magnesium in plant foods
- Refractories
- Animal feedstuffs

Methods of mining

Talc is obtained from both openpit and underground mines. In the USA it is estimated that more than 75% of talc production is from openpit mines. In Western Australia both operating talc mines are openpits.

Underground operations usually require timbering for support (Cooper and Hartwell, 1970) and these must be placed carefully because of the slippery nature of the talc ore. Equipment currently used in underground mines is typically unsophisticated and capable of producing only a few tons per hour (Roe and Olson, 1983). Mining methods range from conventional shrinkage stoping operations to room-and-pillar mine workings. Some underground operations have vertical shafts over 300 m in depth.

In openpit mines extraction is based on traditional methods utilizing commercial stripping, loading and

Table 2. Summary of talc beneficiation studies undertaken by CANMET in Canada

Sample location	Feed analysis % acid insoluble	Mineralogy	Process methods	Process performance
Adams, Ont (1)	nd	talc, chlorite, carbonates, pyrrhotite	flotation	Brighter talc could not be produced by flotation alone because of the presence of pyrrhotite and chlorite
			flotation, magnetic separation	Magnetic separation was successful in removing the magnetic fraction, but even with subsequent flotation, brightness values above 85% could not be obtained
Bakertalc, Que (2)	nd	nd	roll crushing	A high recovery could be expected with a very tight rolls setting with moderate dust loss and a satisfactory product
Brome Cnty, Que (3)	82.9	talc, ferruginous chlorite	magnetic separation	Magnetic separation was not successful in improving grade of final product
			flotation	80% of the acid iron was removed by flotation and the colour of the concentrate was distinctly lighter than the feed
Deloro, Ont (4)	23.0	magnesite, talc, quartz, oxides, sulfides	flotation	Good flotation separation was obtained, producing a talc concentrate which, after magnetic separation, analysed 96.6% acid insolubles for a 66.8% recovery
Grimsthorpe, Ont (5)	56.3	talc, carbonates, iron minerals	flotation	A flotation concentrate analysing 92.4% acid insolubles was obtained but with only a 38% recovery
Madoc, Ont (6)	nd	talc, carbonates, iron minerals	flotation	Flotation from high-grade samples produced a suitable product (0.35% CaO) but with a low recovery of 51.8%
			flotation	Flotation from low-grade samples produced a suitable product (0.62% CaO) but with a very poor recovery of 23.0%
Broughton, Que (6)		talc, carbonates, iron minerals	flotation	Flotation reduced CaO to <1%, but was unable to reduce iron oxides to acceptable levels
Madoc, Ont (7)	51.8	talc, dolomite, iron minerals	grinding	Selective grinding was not effective
			air classification	Air classification (Gayco) was about 50% effective in reducing the CaO level
			wet tabling	Wet tabling was about 60% effective in the -150 µm range in reducing the CaO level
			flotation	Flotation was very successful in reducing the CaO level by 90%
Madoc Talc, Ont (8)	50.0	talc, dolomite	flotation	A high-grade 97.2% talc concentrate was obtained after regrinding to 70% -44 µm. Recovery was fair at 64.1%
Madoc Talc, Ont (9)	nd	talc, dolomite	sorting	Separation of dolomite by photometric sorting appeared to be encouraging
Matheson, Ont (10)	50-60	talc, magnesite, magnetite	flotation, magnetic separation	The brightness of the flotation product was 86%; this was improved to 88.2% by magnetic separation. Talc recovery was estimated at 75-80%
Pacific Talc, B.C. (11)	70.8	talc, magnesite, dolomite	flotation	Flotation of a high-grade, 97.8% acid insoluble concentrate was obtained but at a poor recovery of 48.5%

NOTES: after Andrews (1986)
Numbers in bracket not explained in Andrews (1986)
nd = not determined;

haulage equipment. The amounts of drilling and blasting depend on the nature of the ore mined. For example, in the case of block, relatively soft, talc, a minimum of explosive is used to avoid shattering the ore, but in the case of massive, blocky, and hard talc ores, extensive drilling and blasting are employed.

Since many talc products are sold on the basis of a good white colour and a minimum of abrasive material, it is important to carry out mining in a systematic manner. When mining ore of different grades within the same deposit, selective mining and hand sorting may be used. Cooper and Hartwell (1970) commented on an efficient electronic classifier developed in England to eliminate hand sorting. This equipment photo-electrically scans falling streams of 6 mm to 20 mm crushed rock and ore, and determines whether the colour of each particle is within predetermined limits; any material outside these limits is blown into a waste chute by blasts of air.

Processing and beneficiation

The main gangue minerals in talc ore are dolomite, magnesite, calcite, chlorite, tremolite, clay minerals, sulfides, iron minerals and quartz. Traditional talc milling techniques involving simple grinding and dry processing to remove the gangue minerals are now becoming more sophisticated because of increasing demand for higher purity and grade. New talc mills include complex froth flotation, sedimentation, hydro-cycloning, dry and wet magnetic separation, centrifugal sizing, spray drying and new grinding techniques (Roe and Olson, 1983). The non-metallic section of the minerals processing laboratory at CANMET in Canada is conducting research on evaluation and beneficiation of diverse talc deposits (Andrews, 1986). The research, which

has had varying degrees of success, is summarized in Table 2.

Flotation is the main beneficiation technique and its principal parameters are summarized in Table 3, and the consumption of reagents in Table 4. Magnesite and dolomite are not efficiently removed by flotation unless there is successive cleaning, which in turn results in reduced talc recovery. Magnetic iron minerals are not difficult to remove. The need to retain colour during grinding typically rules out conventional milling with steel rods and balls because they cause discolouration. However, good grinding rates can be achieved for soft talc with ceramic grinding media. The fine grinding required for some uses such as for paper filler is achieved with vertical-shaft pulverizing mills (3500 rpm) and jet milling equipment (Roe and Olson, 1983). There is very little information available on wet grinding. Windsor Minerals Inc., a totally owned subsidiary of Johnson & Johnson Co., has a plant at West Windsor in USA that uses wet process technology and has contributed to a better understanding of the basic problems involved in the beneficiation of talc ores. Roe and Olson (1983) provided a flow sheet for wet processing in the Windsor Minerals Inc. plant in Vermont. The Baker talc plant at the Van Reet mine in Potton township, 128 km southeast of Montreal, utilizes froth flotation and high-intensity magnetic separation to produce quality talc products. This ore could not be sufficiently beneficiated by froth flotation alone because of the presence of iron-bearing minerals that caused discolouration.

Information is scarce on commercial application of the froth-flotation process to tremolitic talc ore. The available information suggests that clean separation of soft platy talc from tremolite is difficult by froth-flotation processing (Roe and Olson, 1983).

Table 3. Principal flotation parameters (from CANMET in Canada)

Sample location	Rougher			Cleaner	
	Ground size (μm)	Pulp density (% solids)	Float time (mins)	No. of cleaning stages	Float time (mins/stage)
Adams, Ont (1)	100% -75	15	6	3	4
	99% -300	14	5	3	4
Brome Cnty, Que (3)	65% -75	nm	nm	2	nm
Deloro, Ont (4)	100% -300	17	nm	2	nm
Grimsthorpe, Ont (5)	65% -75	nm	nm	1	nm
Madoc, Ont (6)	nm	nm	(a) 8	1	(a) 6
	nm	nm	(a) 11	2	(a) 8
Broughton, Que (6)	nm	nm	nm	—	—
Madoc, Ont (7)	nm	nm	5	1	5
Madoc, Ont (8)	90% -210	8	nm	(b) 1	nm
Matheson, Ont (10)	100% -75	11	15	2	10
Pacific Talc, B.C. (11)	(a) 94% -600	(a) 15	6	3	4

NOTES: after Andrews (1986)

(a) Estimated

(b) Ground to 70% -44 μm prior to cleaning

nm = not measured

Table 4. Flotation reagent quantities

Sample identification	Collectors (g/t)			Modifiers (g/t)			Quebracho (tanning extract)
	Pine Oil (terpineol)	Armac 12D (amine collector)	Potassium Xanthate	Na ₂ CO ₃	Na ₂ SiO ₃	Calgon	
Rougher flotation							
Adams Ont (1)	56	-	-	-	-	-	-
	60	-	-	-	-	-	-
Brome Cnty, Que (3)	50	-	-	375	-	-	-
Deloro, Ont (4)	50	-	-	-	-	-	-
Grimsthorpe, Ont (5)	50	-	-	350	-	-	-
Madoc Talc, Ont (6)	75	-	-	375	-	-	-
	75	-	-	750	-	-	250
Broughton (6)	nm	-	-	nm	-	-	nm
Madoc Talc, Ont (7)	-	-	200	500	nm	-	-
Madoc Talc, Ont (8)	-	300	-	-	-	400	-
Matheson, Ont (10)	168	-	-	-	-	-	-
Pacific Talc, B.C. (11)	110	-	-	-	-	-	-
Cleaner flotation							
Brome City, Que (3)	25	-	-	-	250	-	-
Madoc Talc, Ont (8)	-	400	-	-	-	1 000	-
Grimsthorpe, Ont (5)	25	-	-	-	200	-	-

NOTE: after Andrews (1986)
nm — not measured

Chapter 3

Production and market trends of talc

World production

World-wide production of talc is around 8.6 Mt per annum (Table 5). More than 40 countries contribute to the production of talc because the diversity of grades required for the many end uses cannot be satisfied by a single source. Some countries have gained a reputation for supplying certain types of talc. For example, French, Italian, Chinese and Australian talc is best for cosmetics, and New York talc is preferred for ceramics (Harben and Bates, 1990a). Of total world production in 1994, China supplied approximately 32% and USA approximately 11%, with China producing more than 2.5 Mt, and USA nearly 1 Mt (Fig. 1). Other countries with substantial production were South Korea, CIS (former USSR), Brazil, India, Finland, France and Australia (Roe and Olson, 1983; O'Driscoll, 1992). Australia contributed approximately 1% of world production in 1994. The global trend between 1974 and 1994 (Fig. 2) indicates that output of talc increased from 5.8 Mt in 1974 to a peak of 9.0 Mt

in 1992, followed by a slight decrease to 8.6 Mt in 1994. A noticeable feature of the trend is that production from China has increased substantially from around 150 000 t in 1979 to more than 2.5 Mt in 1994.

USA

Talc production in the USA is concentrated in five states, namely Montana, Vermont, New York, Texas and California.

In Montana, large deposits of talc are found in the southwestern region, where most of the mining is in the Ruby Range. Talc deposits are restricted to the dolomitic marble of the pre-Beltian sequence, which includes highly metamorphosed mica schist, quartzite and gneiss in addition to dolomite (Roe and Olson, 1983). The talc is high in chlorite and is noted for its chemical purity, brightness, and absence of tremolite. The paper and pulp,

Table 5. World production of talc, and some major producing countries (tonnes)

Year	USA	South Korea	China	CIS	Brazil	India	Australia	Rest of world	World
1974	1 169 817	442 091	299 371	408 233	201 184	308 562	63 992	2 917 773	5 811 023
1975	875 079	415 874	272 156	417 305	220 671	200 474	67 242	2 433 059	4 901 859
1976	991 039	496 468	149 686	439 985	213 848	254 080	77 447	2 650 661	5 273 212
1977	1 093 008	615 229	149 686	453 593	253 882	281 618	112 920	3 133 805	6 093 741
1978	1 255 319	665 083	149 686	471 736	260 520	336 882	137 553	3 120 163	6 396 942
1979	1 317 898	778 206	149 686	480 808	365 478	386 708	138 226	3 258 950	6 875 959
1980	1 125 297	719 173	916 257	489 880	413 056	369 556	159 962	3 336 047	7 529 227
1981	1 218 273	564 617	898 113	498 952	454 500	367 569	74 840	3 139 784	7 216 647
1982	1 030 031	598 742	898 113	508 024	383 739	350 173	143 325	2 977 615	6 889 763
1983	967 422	632 136	952 544	508 024	396 463	353 042	167 009	3 082 340	7 058 979
1984	1 022 779	848 649	952 544	517 095	413 347	417 734	179 009	3 180 865	7 532 023
1985	1 078 000	932 478	1 000 000	520 000	438 243	329 192	132 074	3 398 336	7 828 323
1986	1 106 000	797 680	1 000 000	520 000	436 778	378 683	179 467	3 336 572	7 755 180
1987	1 080 000	851 871	1 000 000	530 000	476 627	359 448	206 865	3 294 036	7 798 847
1988	1 136 347	820 254	1 000 000	530 000	438 533	417 493	201 740	3 412 042	7 956 409
1989	1 171 871	932 396	1 000 000	530 000	595 000	414 268	208 998	3 418 770	8 271 303
1990	1 185 142	910 000	1 000 000	500 000	600 000	416 000	234 579	3 405 075	8 250 796
1991	1 037 000	840 000	2 300 000	500 000	570 000	480 000	177 456	3 527 544	8 932 000
1992(e)	1 071 000	840 000	2 300 000	500 000	570 000	480 000	177 484	3 522 516	8 961 000
1993	968 000	750 000	2 700 000	(e)500 000	440 000	472 000	178 794	2 691 206	8 700 000
1994(e)	972 000	750 000	2 700 000	500 000	440 000	470 000	115 875	2 652 125	8 600 000

SOURCES : US Bureau of Mines (1977-1993)
ABARE (1992)

NOTES: South Korea and Brazil include pyrophyllite; China unspecified
World production includes pyrophyllite
(e) Estimates only

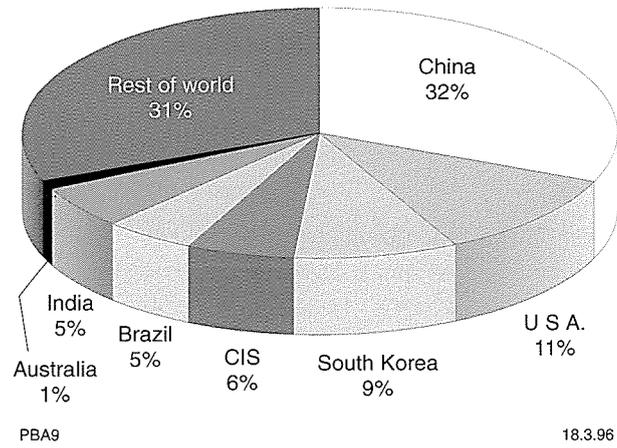
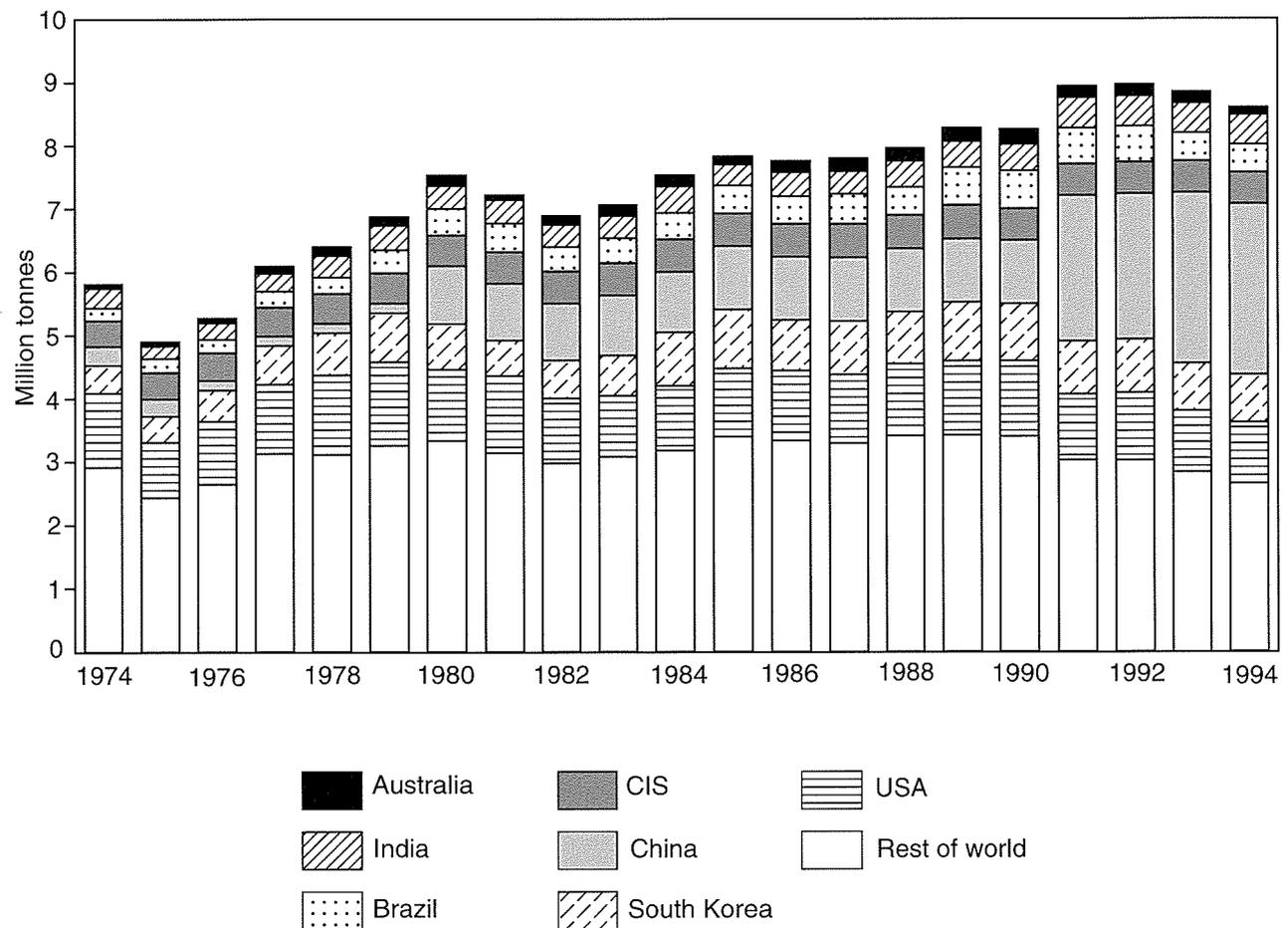


Figure 1. Global production of talc, 1994. Values are estimates only. Source: US Bureau of Mines (1995)

paint, and ceramics industries are the most important applications (Dickson, 1982).

In Vermont, deposits of talc occur in a sinuous belt of ultramafic rocks that extends from Massachusetts to Quebec. The ultramafic rocks intrude a sequence of metamorphic rocks and are extensively serpentinized. Talc occurs as large bodies of talc-carbonate and talc rock surrounding cores of serpentinite. Tremolite is absent, but the talc is typically contaminated with carbonate that has to be removed by flotation. The grade of Vermont talc is commonly lower than that from other districts in USA, but there are a few masses of pure talc in the Vermont district that are large enough to mine (Harben and Bates, 1990a; Roe and Olson, 1983). A major mine is located at Wyndham in the southern part of the state.

In New York State, all the known commercial talc occurs within the Balmat-Edwards or Gouverneur mining districts, on the northwest side of the Adirondack Mountains (Roe and Olson, 1983; Harben and Bates,



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Figure 2. Global production of talc, 1974-1994. Sources: US Bureau of Mines (1977-1993, 1993, 1995)

1990a). The talc-bearing rock lies within a 13 km-long belt of gneiss and marble forming part of the Precambrian Grenville Series. Brown and Engel (1956) subdivided the marble sequence into 15 units, of which only unit 13, with an average width of 150 m, is the 'talc unit' containing commercial deposits of talc. The talc is considered to be a retrograde product of tremolite. New York talc commonly contains more than 50% tremolite, although in the northeastern part of the district, anthophyllite is a major constituent. The main uses of New York talc are in ceramics and paint.

In Texas there is extensive talc mineralization in the Llano district in the central part of the state and the Allamoore district in the west. The Allamoore district is the more important, and the talc-bearing rocks occur in a belt about 48 km long extending westwards from near Van Horn, Culberson County to the Steeruwitz Hills near Sierra Blanca, Hudspeth County. The ore occurs in the Precambrian Allamoore Formation that consists of carbonate and volcanic rocks, and phyllite. The talc ore is typically strongly foliated, with the individual foliae ranging from paper thin to as thick as 19 mm. Colour ranges from greyish white to dark grey or black. The origin of the talc is controversial and the traditional view is that it was formed by regional metamorphism of either siliceous dolostone or magnesium-rich tuff, although Bourbon (1982) suggested an origin by hydrothermal alteration of sedimentary magnesite, probably during the Precambrian.

In the eastern sector of California, close to the border with Nevada, commercial talc is associated with sedimentary rocks. Three areas contain talc in geologically similar conditions in a 320 km-long, north-trending belt. At the northern end of the belt, in the Inyo Mountains–Panamint Range, the talc deposits occur along fracture and shear zones, in steeply dipping metadolerite and quartzite of Ordovician and Silurian age. Talc is particularly common along dolomite–quartzite contacts where it has replaced both rock types. To the south in Death Valley–Kingston Range, Inyo and San Bernardino counties, talc occurs near the middle of the Precambrian Crystal Spring Formation (Harben and Bates, 1990a).

There has been a significant consolidation of the North American talc business in recent times (Burger, 1991). Cyprus Minerals used to be the dominant force, with 40% of the market through its ownership of Vermont Talc Company and Winds Minerals Inc. However, RTZ's North American talc arm (under Luzenac Inc.) has expanded significantly with the purchase of Cyprus Minerals. Other major producers in USA are Pfizer Inc., R.T. Vanderbilt Co. Inc. and Montana Talc Co.

China

The main talc-mining provinces are Liaoning, Shandong, and Guangxi, with proven reserves of some 160 Mt. One of the most famous deposits is at Haicheng in Liaoning Province in northeastern China where production has been

known to exceed 500 000 t per annum. The talc occurs in association with dolomite, magnesite and marble, and is considered to result from hydrothermal replacement (Harben and Bates, 1990a). The talc is white, pinkish, apple green or light grey and is associated with quartz, apatite and chlorite.

China dominates the far-eastern paper-filling markets, exporting around 500 000 t per annum in addition to feeding its substantial local markets. Chinese talc also supplies the cosmetics, plastics, paint, and ceramics industries in Southeast Asia.

CIS (former USSR)

The Shabrovsk, Miasek, Gruzta and Irkutskliuda plants are reported to be active. Of these, Shabrovsk obtains its ore from the Shabrovskoje deposit in Sverdlovsk region, and the Irkutskliuda plant from the Ontskoje deposit at Irkutsk (O'Driscoll, 1992). The local demand for talc has been forecast to exceed 1.1 Mt by the year 2000.

Brazil

More than 70% of talc production in Brazil is concentrated in the state of Parana, with other production centres in Bahia (12%), Sao Paulo (10%), and Minas Gerais (5%). Much of the production in Parana is an off-white to yellow grade, and is mostly used in the ceramics industry. The talc is associated with dolerite, carbonate rocks and quartzite, and has chlorite, montmorillonite, tremolite, serpentine and amphibole impurities. The production from Bahia State is mainly of high-purity white grades used in cosmetics and pharmaceuticals, as fillers and extenders in paint, paper and plastics, and as pitch-control agents for the pulp industry. The talc occurs as fine-grained compact steatite in veins of magnesite that replace the dolomite of the Precambrian Complexo Fundamental. Production in Parana is dominated by Costalco–Mineracao, Industria & Comercio Ltda and in Bahia State by Magnesita SA.

India

Approximately 85% of talc production in India is from Rajasthan. Other production centres are Andhra Pradesh, Bihar and Madhya Pradesh (Harben and Bates, 1990a; O'Driscoll, 1992). Most of the deposits in Rajasthan occur at contact zones between basic dykes and dolomitic marble, but economic deposits are also known within the Aravalli Quartzites and quartz schist. The estimated reserves in India amount to approximately 15 Mt, with 55% in Maharashtra and 42% in Rajasthan. The leading producer is the Golcha Group.

Finland

Finnish talc is typically a mixture of talc and magnesite. In 1990 there were two main operations: Suomen Talkki

Oy's Lahnaslampi mine in Sotkamo in central Finland, and the Polvijarvi mine belonging to Finnminerals Oy in eastern Finland, with a combined production of 380 000 t per year. Central and eastern Finland have numerous serpentinitized ophiolites with widespread carbonatization and steatitization. Deposits of soapstone are fairly common, especially in north Karelia and further north in Kainuu in the Karelian Schist area. At the Lahnaslampi mine, talc material occurs in a vertical lenticular body conformable with the foliation of the surrounding micaceous gneiss. This body is estimated to contain 300 Mt of ore, 50% of which is talc with the balance containing breunnerite, and 1 to 2% opaque minerals. The orebody at Polvijarvi is similar, and contains 60% talc and 40% magnesite (Harben and Bates, 1990a). In 1992, by company takeover, Finnminerals Oy became the country's sole producer of talc (O'Driscoll, 1992).

France

France produces more than 300 000 t per year, centred on the Trimouns deposit, 85 km south of Toulouse, held by SA Talc de Luzenac. The deposit occurs in an overthrust zone between Saint Barthelemy metamorphic rocks below, and an overlying chlorite-graphite metamorphic series including an Ordovician dolomite. The ore is mainly a mixture of talc and chlorite occurring in veins, the principal vein forming a complex lenticular body with moderate to steep dips. The main impurities are calcite, quartz, tremolite, various sulfides and, less commonly, phosphates, cassiterite and rare earth carbonates (Harben and Bates, 1990a). SA Talc de Luzenac is the main operator in France.

Australia

Production of talc in Australia between 1940 and 1994 is shown in Figure 3. The total production from Western Australia, South Australia and New South Wales was 3 704 503 t, of which Western Australia produced 3 052 758 t, South Australia 594 293 t, and New South Wales 57 453 t. Production from other states was insignificant (Australian Mineral Industry Annual Review, 1967–1989; Kalix et al., 1966; ABARE, 1992).

Western Australia

Production from Western Australia has increased substantially since 1968 and at present the state is the largest producer in Australia, with operating mines at Three Springs and Mount Seabrook. The Three Springs deposit, owned by Western Mining Corporation Limited, is located approximately 330 km north of Perth, and had a peak production in 1987 of 166 154 t valued at \$AUS 11.6 million. However, the output from Three Springs dropped to 72 896 t valued at \$5.4 million during 1994. The Mount Seabrook mine is located approximately 174 km northwest of Meekatharra. Production in 1994 was 27 942 t valued at \$2.0 million (Tables 6 and 7). Details

of these deposits and other Western Australian deposits and occurrences are discussed in the following chapters.

South Australia

South Australia has supplied Australian requirements for many years, although high-grade block steatite is now scarce (Hiern, 1976). Recorded production of talc and soapstone in 1994 amounted to 15 037 t. The deposits in South Australia are found in several stratigraphic units of the Cambrian and Precambrian sequences in the Adelaide Geosyncline and on the Eyre Peninsula.

Large deposits, 130 km east of Lyndhurst in the Flinders Ranges, lie in fault zones in a large lens of massive dolomitic marble, equated with the Balcoona Formation of the Adelaidean Umberatana Group. A significant amount of this material is of high quality, used mainly in cosmetics. The talc associated with altered dolomites of the Wywyana Formation in the Flinders Ranges is low grade and contains actinolite and iron-oxide impurities. In the Mount Lofty Ranges, bodies of coarse-grained, green, foliated talc containing fine- and coarse-grained albite and local quartz veining, occur within the Undalya Quartzite in a zone extending from Gumeracha (40 km east of Adelaide) to near Lyndoch (35 km to the north). The talc is low to medium grade and contains an appreciable amount of iron. Talc is found in a diopside-actinolite zone associated with vermiculite in the Woolshed Flat Shale about 3 km north of Lyndoch. The material has been extracted as 'asbestine'. At Tumby Bay, approximately 13 km north of Port Lincoln on the Eyre Peninsula, lenticular bodies of high-grade talc occur around the margins of a narrow elongate body of dolomite, equated with the Cleve Metamorphics, in a poorly exposed zone of Lower Proterozoic quartz-talc schist and other metasedimentary rocks. The main areas of past production of talc and talcose schist are along the eastern flank of a synclinal fold and are associated with dolomite. Talc also occurs as pale, fine-grained material associated with serpentinitous dolomitic marble, chrysotile asbestos and nephritic jade in the Cleve Metamorphics at two localities north of Cowell on the Eyre Peninsula.

New South Wales

The talc deposits mined fall into two categories: those derived from the hydrothermal alteration of ultramafic and associated metamorphic rocks, and those occurring in thermally metamorphosed dolomitic rocks. Most deposits are of the former type — located at South Gundagai, Muttama, and Wallendbeen. The ultramafic rocks at South Gundagai are represented by sheared talc-chlorite schists; the Muttama talc deposits are developed on a northerly extension of the Coolac Serpentine; and the geological setting of Wallendbeen is similar to both Muttama and South Gundagai. Deposits in thermally metamorphosed dolomitic rocks occur mainly at Cow Flat and are associated with Silurian schists, calcareous shales and dolomites intruded by the Bathurst Granite (Lishmund, 1976a). Talc has been mined from all four localities. Production from New South Wales in recent years has been insignificant.

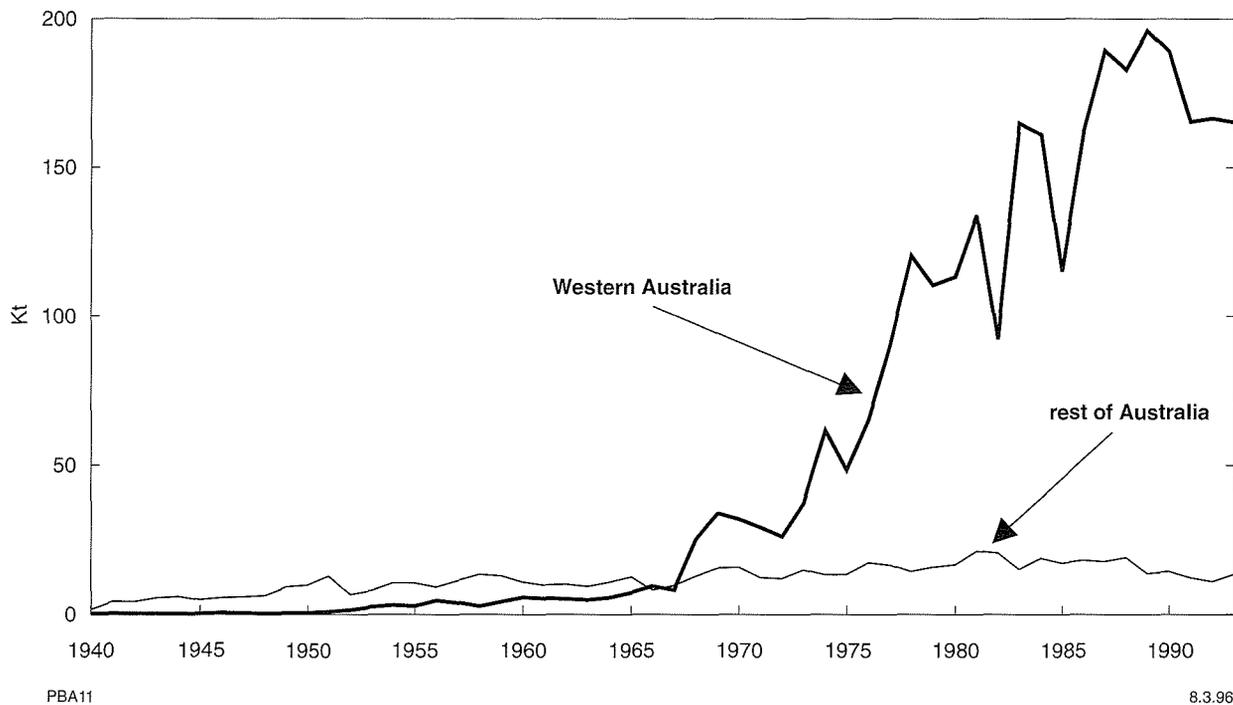


Figure 3. Production of talc in Australia between 1940 and 1994. Sources: Kalix et al. (1966); Australian Mineral Industry Annual Review (various years between 1967 and 1989); verbal advice from Mines and Energy, South Australia and New South Wales Department of Mineral Resources

Market and outlook

Market

Talc usage is declining in some fields, growing in others, but has a general upward trend globally. The decline is due to many factors such as availability of cheaper alternative raw materials, health and safety limitations, and the recessionary economic trends that have prevailed since the late 1980s.

In terms of dollar value of the day, the price of most talc generally increased between 1984 and 1987, followed by noticeable decline, for certain varieties, in 1989 and 1992 (Fig. 4). For example, the price of Chinese (-200 mesh) talc increased from around \$190 in 1984 to \$330 in 1987, dropped to around \$300 in 1989, and then picked up to about \$420 in 1994. Italian cosmetic talc increased from around \$250 in 1984 to \$410 in 1987, followed by a decrease to around \$360 in 1989, an increase to \$420 in 1992 and then a drop again to about \$370 in 1994. The price of ground talc has continued to increase: from \$100 in 1981, to \$230 in 1991, followed by a significant rise to about \$350 in 1992, and then a slight drop to about \$310 in 1994. The prices indicated on Figure 4 are extracted from various editions of the journal *Industrial Minerals*, but prices can vary depending on individual trade contracts. A number of authors have discussed the market trends of talc (Dickson, 1982; Robbins, 1985; Schober, 1987; Mulryan, 1990; Burger, 1991; O'Driscoll, 1992), and the following description is based on their discussions.

Plastics

Talc usage in the plastics industry is increasing in Europe (by 7% per annum) and USA (6% per annum), particularly its use as a filler in polypropylene. One of the most exciting aspects of polypropylene is its potential recyclability. Amongst related industries, polyester, containing at least 50% talc, and used in autobody patch compounds, has a slow but growing market, and polyolefin compounds, used in a variety of automotive appliance, electronic and household furniture components, also have a growing market.

Paper

In Europe, paper continues to be the leading consumer of talc, consuming about 500 000 t per annum. However, its use as a paper filler in Europe and North America has declined over the last two decades because of the industry's move to the alkaline paper-making process, which uses calcium carbonate. Japan, by contrast, with a consumption of more than 500 000 t per annum, has generally not moved towards the alkaline process. The market for talc used for pitch control in the USA has doubled over the last few years, although it is flat at present. There is a very large market for paper in the Southeast Asian region and, of the 1.6 Mt per annum of talc produced in the region, more than two-thirds is consumed as a mineral filler for paper. More than half the filling talc is used in Japan and South Korea, and most of the rest is used by the domestic industry in China. China dominates the Far Eastern paper-filling market, and exported 528 000 t to Japan in 1990,

Table 6. Production of talc from Western Australian deposits (tonnes)

Year	Three Springs	Mount Seabrook	Mount Monger	Bolgart	Bridgetown (Glen Lynn)	Total
1942	—	—	39	—	269	308
1943	—	—	74	—	—	74
1944	—	—	—	—	266	266
1945	—	—	—	—	—	—
1946	—	—	396	—	—	396
1947	—	—	216	—	—	216
1948	—	—	73	—	—	73
1949	184	—	—	—	—	184
1950	203	—	57	—	—	260
1951	606	—	56	—	39	701
1952	900	—	69	274	—	1 243
1953	2 153	—	110	—	—	2 263
1954	2 929	—	38	—	—	2 967
1955	2 601	—	27	—	—	2 628
1956	4 449	—	78	—	—	4 527
1957	3 534	—	178	—	—	3 712
1958	2 541	—	—	—	—	2 541
1959	4 113	—	—	—	—	4 113
1960	5 558	—	—	—	—	5 558
1961	5 232	—	—	—	—	5 232
1962	5 061	—	—	—	—	5 061
1963	4 744	—	—	—	—	4 744
1964	5 519	—	—	—	—	5 519
1965	7 202	—	—	—	—	7 202
1966	9 302	—	—	—	—	9 302
1967	8 028	—	—	—	—	8 028
1968	25 121	—	—	—	—	25 121
1969	33 741	—	—	—	—	33 741
1970	31 796	—	—	—	—	31 796
1971	29 076	—	—	—	—	29 076
1972	26 013	—	—	—	—	26 013
1973	36 788	400	—	—	—	37 188
1974	56 985	4 668	—	—	—	61 653
1975	39 604	8 732	—	—	—	48 336
1976	56 748	8 522	—	—	—	65 270
1977	60 734	29 732	—	—	—	90 466
1978	80 756	39 596	—	—	—	120 352
1979	70 059	40 300	—	—	—	110 359
1980	91 205	22 006	—	—	—	113 211
1981	119 814	14 182	—	—	—	133 996
1982	72 519	19 663	—	—	—	92 182
1983	141 136	23 723	—	—	—	164 859
1984	141 658	19 318	—	—	—	160 976
1985	115 031	—	—	—	—	115 031
1986	161 368	—	—	—	—	161 368
1987	166 154	23 120	—	—	—	189 274
1988	158 000	24 774	—	—	—	182 774
1989	164 185	31 915	—	—	—	196 100
1990	143 321	45 765	—	—	—	189 086
1991	165 263	—	—	—	—	165 263
1992	137 335	29 239	—	—	—	166 574
1993	140 411	24 899	—	—	—	165 310
1994	72 896	27 942	—	—	—	100 838

NOTES:

Mount Monger — production from GML 5961^E until 1948 and from MC 15^E between 1950 and 1957

Bolgart — production from private property of J. Butterley

Bridgetown (Glen Lynn) — 1942 production includes 10 t from PA1 PP; production during 1944 came from MC438^H and during 1951 from MC 428^H

Table 7. Total value of talc from Western Australian deposits (\$AUS)

Year	Three Springs	Mount Seabrook	Mount Monger	Bolgart	Bridgetown (Glen Lynn)	Total \$Aus value of the day
1942	—	—	114.00	—	1 950.00	2 064.00
1943	—	—	339.70	—	—	339.70
1944	—	—	—	—	1 656.00	1 656.00
1945	—	—	—	—	—	—
1946	—	—	2 997.80	—	—	2 997.80
1947	—	—	1 626.00	—	—	1 626.00
1948	—	—	1 464.00	—	—	1 464.00
1949	4 750.00	—	—	—	—	4 750.00
1950	4 980.00	—	420.00	—	—	5 400.00
1951	14 861.70	—	465.10	—	250.00	15 576.80
1952	26 131.50	—	546.00	2 688.00	—	29 365.50
1953	60 890.12	—	974.00	—	—	61 864.12
1954	91 369.02	—	333.00	—	—	91 702.02
1955	75 293.30	—	240.00	—	—	75 533.30
1956	108 100.32	—	775.20	—	—	108 875.52
1957	98 058.00	—	1 754.50	—	—	99 812.50
1958	70 608.60	—	—	—	—	70 608.60
1959	116 169.60	—	—	—	—	116 169.60
1960	138 227.70	—	—	—	—	138 227.70
1961	129 162.00	—	—	—	—	129 162.00
1962	143 620.10	—	—	—	—	143 620.10
1963	142 425.60	—	—	—	—	142 425.60
1964	150 004.00	—	—	—	—	150 004.00
1965	205 410.00	—	—	—	—	205 410.00
1966	231 625.24	—	—	—	—	231 625.24
1967	227 037.44	—	—	—	—	227 037.44
1968	467 705.70	—	—	—	—	467 705.70
1969	708 746.28	—	—	—	—	708 746.28
1970	742 256.63	—	—	—	—	742 256.63
1971	747 281.00	—	—	—	—	747 281.00
1972	627 355.00	—	—	—	—	627 355.00
1973	955 410.00	15 760.00	—	—	—	971 170.00
1974	1 557 296.00	182 371.00	—	—	—	1 739 667.00
1975	744 282.00	344 700.00	—	—	—	1 088 982.00
1976	1 057 379.00	345 725.00	—	—	—	1 403 104.00
1977	1 144 217.00	1 275 819.00	—	—	—	2 420 036.00
1978	1 729 574.00	1 791 800.00	—	—	—	3 521 374.00
1979	1 557 617.00	2 015 000.00	—	—	—	3 572 617.00
1980	1 715 749.00	1 100 300.00	—	—	—	2 816 049.00
1981	6 024 528.00	352 520.00	—	—	—	6 377 048.00
1982	4 401 997.00	983 150.00	—	—	—	5 385 147.00
1983	7 984 229.00	1 186 150.00	—	—	—	9 170 379.00
1984	1 103 359.00	642 710.00	—	—	—	1 746 069.00
1985	1 069 424.00	—	—	—	—	1 069 424.00
1986	1 928 741.00	—	—	—	—	1 928 741.00
1987	11 630 761.00	2 305 455.00	—	—	—	13 936 216.00
1988	11 060 029.00	2 201 497.00	—	—	—	13 261 526.00
1989	9 857 064.00	3 801 150.00	—	—	—	13 658 214.00
1990	10 032 470.00	4 447 793.00	—	—	—	14 480 263.00
1991	11 568 410.00	—	—	—	—	11 568 410.00
1992	9 665 720.00	2 046 730.00	—	—	—	11 712 500.00
1993	10 307 770.00	1 746 800.00	—	—	—	12 054 570.00
1994	5 351 170.00	1 955 940.00	—	—	—	7 307 110.00

NOTE: For Mount Monger, Bolgart and Bridgetown (Glen Lynn), production comes from those tenements noted in Table 6

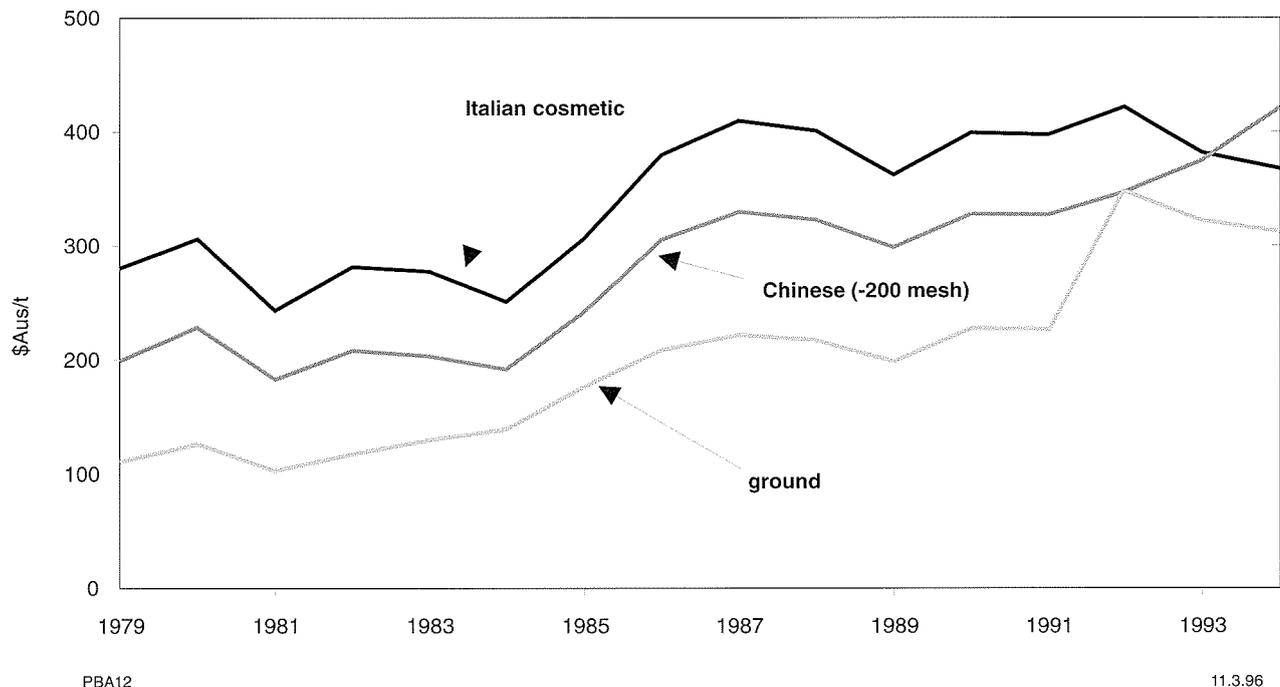


Figure 4. Trends in world talc prices between 1979 and 1994 in \$AUS value of the day. Source: Industrial Minerals (1979–1994)

compared to 107 000 t exported to Japan by Australia in the same year.

Paints

Paints remain a staple consumer of talc in Europe, using around 90 000 t per annum, with growth areas perceived in certain new formulations. The future in Europe appears to be good for water-based paints that are environmentally friendly and have high solids content. Paint manufacturers have been attempting to use lower density fillers because paint is sold by volume rather than by weight. The paint market for talc in the USA has contracted by some 6 to 9% over the last ten years. Paint markets now tend to be regional and it is quite likely that both China and Australia will become significant suppliers to South East Asia in the near future.

Cosmetics

Talc sales to the cosmetic industry in Europe are reported to have declined over the last ten years — the increasing use of disposable nappies has had an adverse effect on talcum powder consumption. The health and safety standards imposed on various products containing non-asbestiform minerals has also had an adverse effect on demand for cosmetic talc, although recent research has shown that there is no conclusive evidence to link health risks with minerals such as tremolite, actinolite, and anthophyllite (Industrial Minerals, 1993a). Southeast Asia and Australia supply about half the cosmetic talc requirements of the world, produced in approximately equal volumes from China, Australia (Mount Seabrook) and Korea. Although cosmetic applications consume much less talc than used by the paper industry, they are an

important factor in the total value of Asian and Australian production. Italian talc has been the world standard for decades and this is still the case, but the best Chinese, Korean, and Australian grades approach the Italian product in quality, and at much more attractive prices.

Ceramics

Talc for ceramics tends to be obtained from regional suppliers. The contraction of the construction industry caused by the world-wide recession in the late 1980s has caused the ceramic talc market to founder in Europe and the USA. However, with rapid economic growth in Southeast Asia, Australia and China will become important suppliers to that region.

De-inking

De-inking of recycled newsprint and graphic papers has a growing market in Europe and USA because of the vast increase in recycling such materials.

Outlook

Australia and Southeast Asia contain some of the largest talc reserves in the world and are in a good geographical position to serve fast-growing Pacific Rim economies. These factors have enabled the Australasian countries to compete with other world producers in recent years. It is also very likely that, because of the proximity of Australia and China to the fast-growing economies of the region, production and sales of high-quality talc from these countries will continue to grow faster than the world economy.

Talc in Western Australia

Introduction

The known talc occurrences in Western Australia (Fig. 5) can be broadly grouped into two categories according to their geological associations:

- (i) Talc in Proterozoic dolomite intruded by mafic dykes at the western, southern and northwestern margins of the Yilgarn Craton, e.g. Three Springs talc mine in the Moora Group;
- (ii) Talc in structurally deformed Archaean ultramafic rocks, e.g. Mount Monger.

Commercially exploitable talc deposits have been discovered in both geological associations, but the best deposits have so far come from the first category. For the purposes of description, the talc occurrences are grouped according to the Western Australian tectonic provinces as set out in Memoir 3 of the Geological Survey of Western Australia (1990) and updated by Myers (in prep.) (Fig. 5). This allows easy reference to Memoir 3 where the geology of each tectonic province is described in some detail. The tectonic provinces are listed below:

Moora Group
Narryer Terrane
Eastern Goldfields, Yilgarn Craton
South Western terranes, Yilgarn Craton
Albany–Fraser Orogen
Southern Cross, Yilgarn Craton
Murchison terrane, Yilgarn Craton
Gascoyne Complex
North Pilbara granite–greenstone terrane
Marymia Inlier
Ashburton Basin

Moora Group

Regional geology

The Proterozoic Moora Group outcrops at the western edge of the Yilgarn Craton (Fig. 6), which is truncated at its western margin by the Darling Fault. The rocks in the Moora Group, divided into the Billeranga and Coomberdale Subgroups, have been described by Logan and Chase (1961), Playford et al. (1976), Carter and Lipple (1982) and Baxter and Lipple (1985). The Billeranga Subgroup comprises a ‘weakly deformed, immature fluvial–alluvial fan to basin margin’ sequence, which unconformably overlies the Archaean basement. The

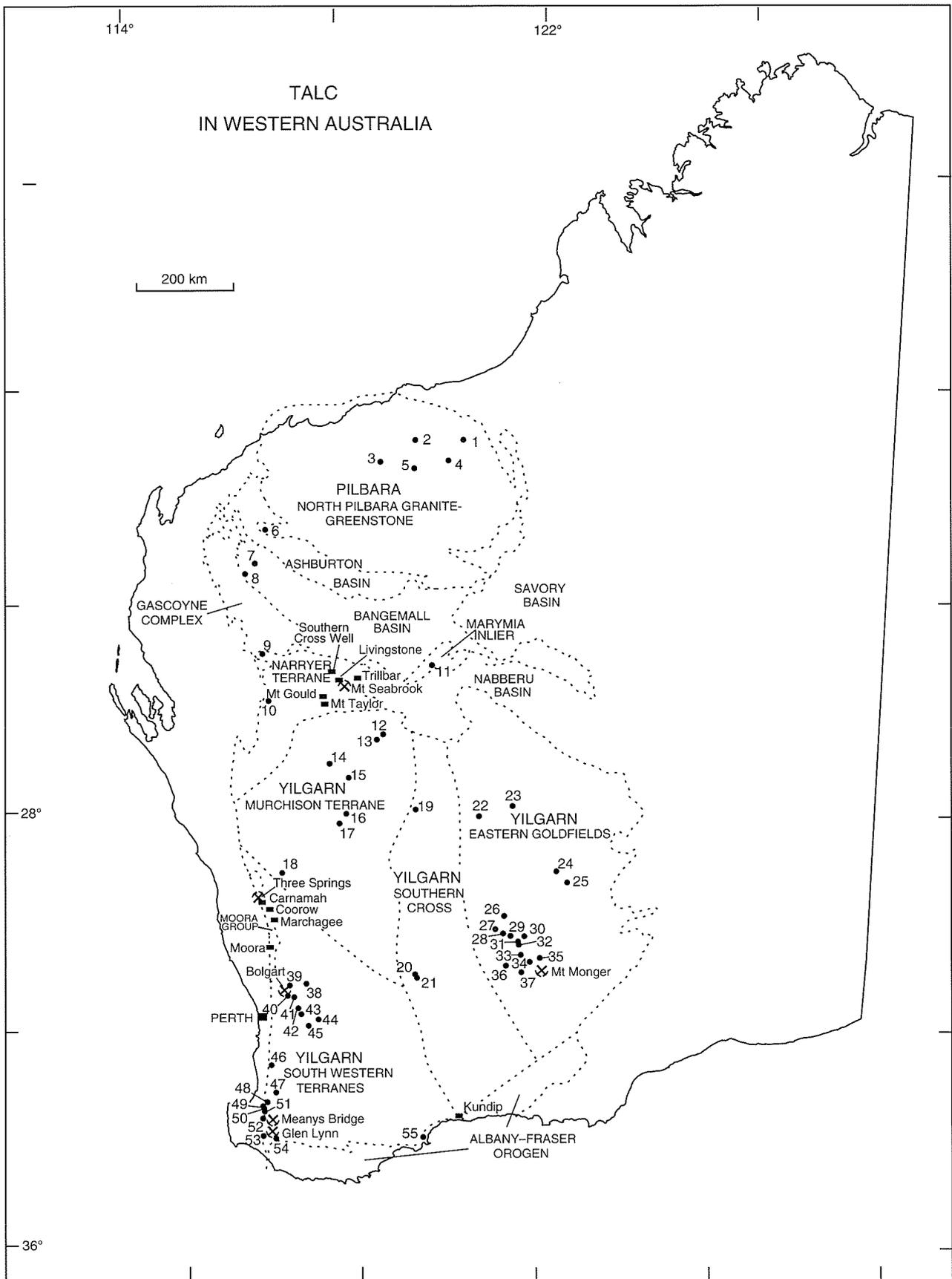
Coomberdale Subgroup, disconformably overlying the Billeranga Subgroup, is an undeformed ‘mature, upward-fining, siliciclastic–dolomitic paralic sequence’ (Baxter and Lipple, 1985). Myers (1990a) included the Moora Group in his description of the Pinjarra Orogen. Stratigraphic units within the Moora Group are given in Table 8.

The known talc mineralization within the Moora Group is confined to the Coomberdale Subgroup and extends in a belt from Marchagee to Three Springs. The belt is intersected by a number of northerly trending dolerite dykes of ?Precambrian age (Fig. 7). The Coomberdale Subgroup has a width of 4 to 15 km, and extends northward for more than 200 km from Mount Lamb nearly to Jacobs Ladder. The units within the Coomberdale Subgroup are the basal Mokadine Formation, the Winemaya Quartzite and Campbell Sandstone, and the overlying Noingara Siltstone, Noondine Chert and Jingemia Dolomite. The talc mineralization is predominantly developed within the Noondine Chert (generally regarded as a silicified carbonate unit) and its associated sedimentary rocks. In areas of talc mineralization, outcrops are mainly restricted to sparse chert, dolomite and arenite. Dolomite intruded by dolerite dykes appears the most favourable loci for talc.

The Coomberdale Subgroup has not undergone significant deformation and metamorphism, except for contact metamorphism adjacent to dolerite dykes. Weak to moderate cleavage, and minor concentric folding have developed in shale and siltstone. Close to the Darling Fault the folds are increasingly compressed, with steep bedding dips of approximately 80° being recorded. However, approximately 2 km further to the east dips are almost flat.

Exploration for talc in the Moora Group

The Three Springs talc mine, located in the northern part of the Moora Group (Fig. 7), is at present the biggest talc producer in Australia. It was discovered in the early 1940s, and its owner, Western Mining Corporation Limited, subsequently expanded exploration activities in the early 1970s, covering the area from just north of Three Springs to south of Marchagee by geological mapping and exploration drilling. In the late 1980s, other companies such as Amte Pty Ltd., Imdex NL, Wakefield Holdings Pty Ltd and Commercial Minerals Limited, also carried out exploration, and a number of new localities with high



✕ OPERATING TALC MINE

Three Springs
Mount Seabrook

✕ NON-OPERATING TALC MINE

Mount Monger
Meanys Bridge
Glen Lynn
Bolgart

■ SIGNIFICANT OCCURRENCE

Livingstone
Mount Taylor
Mount Gould
Carnamah
Coorow
Marchagee
Moora
Kundip

● MINOR OCCURRENCE

1 Bamboo	28 Ora Banda
2 McPhees Range	29 Windanya
3 Mount Francisco	30 Mulgarrie
4 Warrawoona	31 Paddington
5 Soanesville	32 Kanowna
6 Peake Station	33 Kalgoorlie
7 Henry River	34 Golden Ridge
8 Sheela Bore	35 Bulong
9 Mooloo Downs	36 Coolgardie
10 Yarra Yarra Creek	37 Feysville
11 Plutonic	38 Goomalling
12 Meekatharra	39 Culham
13 Yaloginda	40 Coondle
14 Poona	41 Wongamine
15 Cue	42 Hamersley Siding
16 Mount Magnet	43 York
17 Yowergabbie	44 Balkuling
18 Ninghanboun Hills	45 Beverley
19 Sandstone	46 Wagerup
20 Bullfinch	47 Collie
21 Southern Cross	48 Wellington Mill
22 Lawlers	49 Donnybrook
23 Darlot	50 Kirup
24 Pykes Hollow	51 Mullalyup
25 Linden	52 St Johns Brook
26 Comet Vale	53 Donnelly River
27 Siberia	54 Manjimup
	55 Bremer Bay

PBA30A

20 12.95

Figure 5. Occurrences of talc in Western Australia

potential for talc were identified near Coorow, Marchagee and Carnamah.

Three Springs talc mine

Location: Lat. 29°30'30"S, Long. 115°51'30"E; PERENJORI*

Historical background

A talc deposit located at Coodawa, 11.5 km east-northeast of Three Springs, was inspected by Matheson in 1944 (Matheson, 1946). The deposit was on a farm owned by Mr. C. B. Barrett, and an ML was held by the Midland Railway Company, but was leased to Universal Milling Company Limited for mining on a royalty basis (Berliat, 1955a). It is known that up to September 1944, 28 t of talc had been mined from three wells on the farm with depths of 21 m, 16 m and 19 m. The Universal Milling Company Limited (UMC) produced 29 771 t of talc during the period 1949 to 1960 by underground mining, which was valued at \$809 440 (Tables 6 and 7). In 1959–1960 UMC sold 50 percent of its interest to Western Mining Corporation (WMC), and in 1978 sold its remaining 50 percent to Kalgoorlie Southern Gold Mines NL (KSGM). In the mid-1970s, the joint venture operation was named Three Springs Talc Pty Ltd. Western Mining Corporation acquired total ownership of the Three Springs deposit in 1987. With the part change of ownership in 1959–1960, opencut mining methods were introduced (Fig. 8), and production progressively increased. Total production between 1961 and 1994 was 2.6 Mt valued at approximately \$ 117 million.

Geology

Talc mineralization occurs within flat-lying to gently dipping Proterozoic dolomitic sedimentary rocks of the Noonidine Chert within the Coomberdale Subgroup. A section from the surface downwards in the area known as Pit A/B shows (Read, 1971; Baker, 1976):

1. red-brown soils, talc rubble and discontinuous chert bands, with a maximum thickness of 6 m;
2. stromatolitic talc (0–6 m thick);
3. compact massive talc (0–12 m thick);
4. thin, crossbedded quartzite, medium grained, pebbly, with thin talc horizons.

In the mine area the dolomitic rocks are intruded by a number of northerly trending dolerite dykes. The dolerite intrusions have caused hydrothermal alteration of the dolomite with the development of talc and chlorite and pyrite in the underlying sedimentary rocks. The talc units in the mine area get thinner to the north and grade into talc arenite and orthoquartzite (Figs 9 and 10).

The talc orebody is lenticular, trends northerly, and dips gently west. It has a maximum width of 200 m as mined,

* Names of 1:250 000 geological sheets are capitalized.

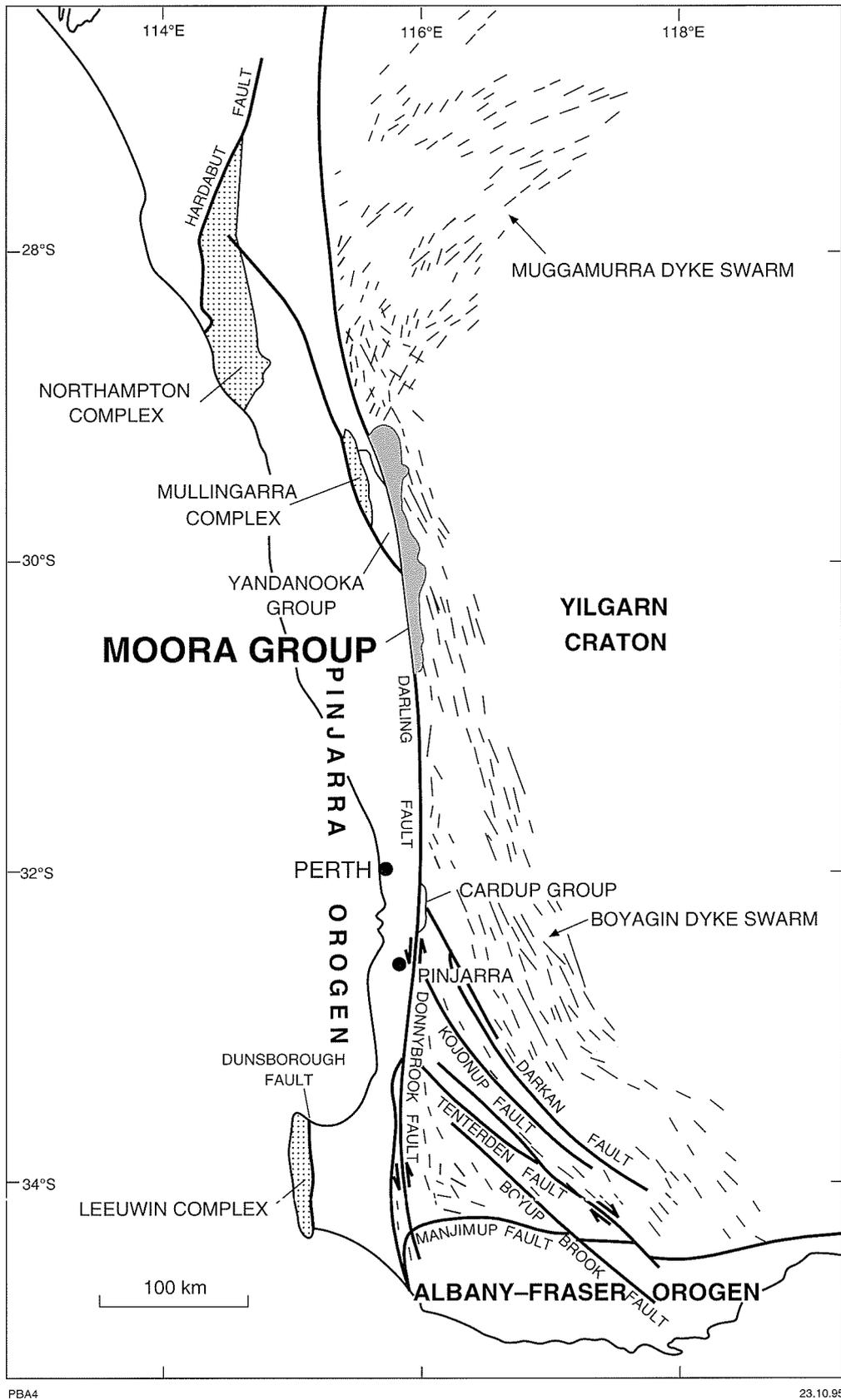


Figure 6. Map of the southwest portion of the State showing the position of the Moora Group. Proterozoic gneissic and sedimentary rocks in the Pinjarra Orogen west of the Darling Fault are also highlighted

Table 8. Stratigraphy of the Moora Group

<i>Subgroup</i>	<i>Formation</i>		<i>Previous nomenclature</i>
	<i>Moora 1:250 000 sheet</i>	<i>Perenjori 1:250 000 sheet</i>	
Coomberdale		Coomberdale Chert	Dudawa Beds
		Jingemia Dolomite	
	Noondine Chert	Noondine Chert	
	Noingara Siltstone	Noingara Siltstone	
	Winemaya Quartzite	Campbell Sandstone	
	Mokadine Formation	Mokadine Formation	
~~~~~ unconformity or disconformity ~~~~~			
<b>Billeranga</b>			Billeranga Beds
			Billeranga Group
		Oxley Chert	
		Morawa Lavas	
	Dalaroo Siltstone	Dalaroo Siltstone	
	Capalcarra Sandstone	Neereno Sandstone	
~~~~~ unconformity ~~~~~			
ARCHAEOAN BASEMENT			

NOTE: after Baxter and Lipple (1985)

and a thickness varying from a few metres to more than 30 m (Aoukar, 1991). The ore is underlain by a clastic unit that is a few metres thick (Figs 9 and 10). Above the clastic unit is massive talc with abundant chlorite grading into an upper zone of massive talc of mineable quality. Above this zone, low-quality talc, a bluish to black colour, is interbedded with dolomite, and is mined as substandard talc. The upper part of the orebody exhibits stromatolitic textures within both talc and massive dolomite.

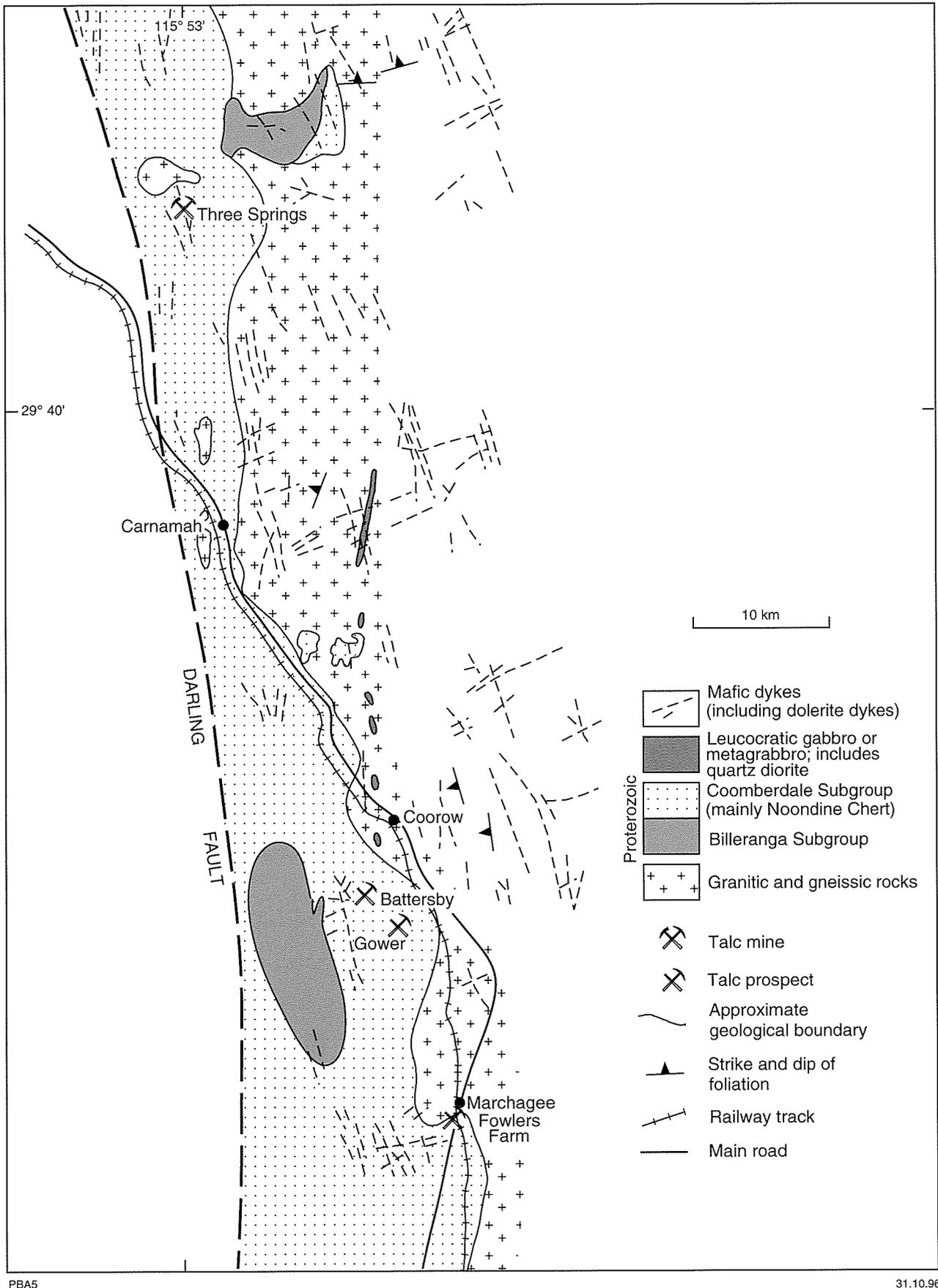
Resources

At present the Coodawa deposit has been exploited in four pits A, B, C and D (Fig. 11). Interdigitating lenses and bands of talc arenite caused mining to be suspended at pit A in April 1984 and in pit B in November 1983, when it became uneconomic to obtain high-grade talc from those pits. Some unmined tonnage is still available. Current mining is from pits C and D. The shallow northern end of pit C has been mined down to a chloritic clastic unit, and all available talc has been extracted. Production from pit C has also been difficult due to the presence of lenses of talc-dolomite rock. It is estimated that there is a proven and probable reserve of 6.0 Mt (proven 2.4 Mt, probable 3.6 Mt) in pits C/D and adjoining leases, in addition to an indicated resource of 3.2 Mt (Western Mining Corporation, 1995, pers. comm.).

Grade of ore

The high-grade talc at Coodawa is a massive, cryptocrystalline, waxy, grey-green to white steatite. The common impurities in fresh talc are chlorite, scattered quartz veinlets and rare pyrite. Impurities such as iron and manganese oxides are present in joints and shears and in weathered talc. Impurities affect the brightness, but have no significant effect on the chemical composition. The brightness generally varies between 80 and 90%. The cryptocrystalline nature of the Three Springs talc gives it a number of advantages, such as ease of grinding, good opacity, low abrasiveness and consistently high brightness. The talc is not fibrous and does not contain asbestiform minerals. Chemical analyses of samples collected by GSWA indicate that they are close to steatite in composition (Table 9). The Al₂O₃, Fe₂O₃ and FeO contents of these are slightly higher than those of Mount Seabrook talc (Table 10). Sample 117377, with relatively low silica, is from the mixed ore before crushing. The chromium content of all the samples analysed was <4 ppm and nickel content was also low.

Two samples of talc taken by GSWA from pit D were studied by XRPD to identify minerals present in the ore. Sample 117374 (washed second-grade ore) comprised one dark- and one light-grey to green fist-sized fragments of talc with minor iron-oxide staining in the darker fragment. They contained >85% talc, approximately 5%



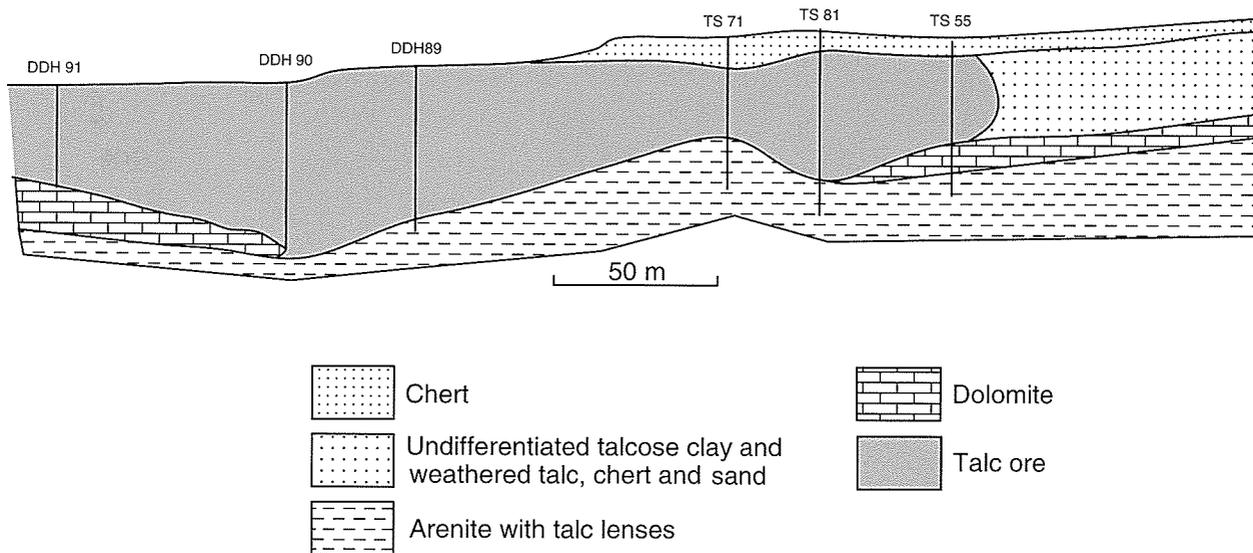
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Figure 7. Regional geology of the Three Springs–Marchagee belt (modified from Aoukar, 1991, 1992; Baxter and Lipple, 1985)



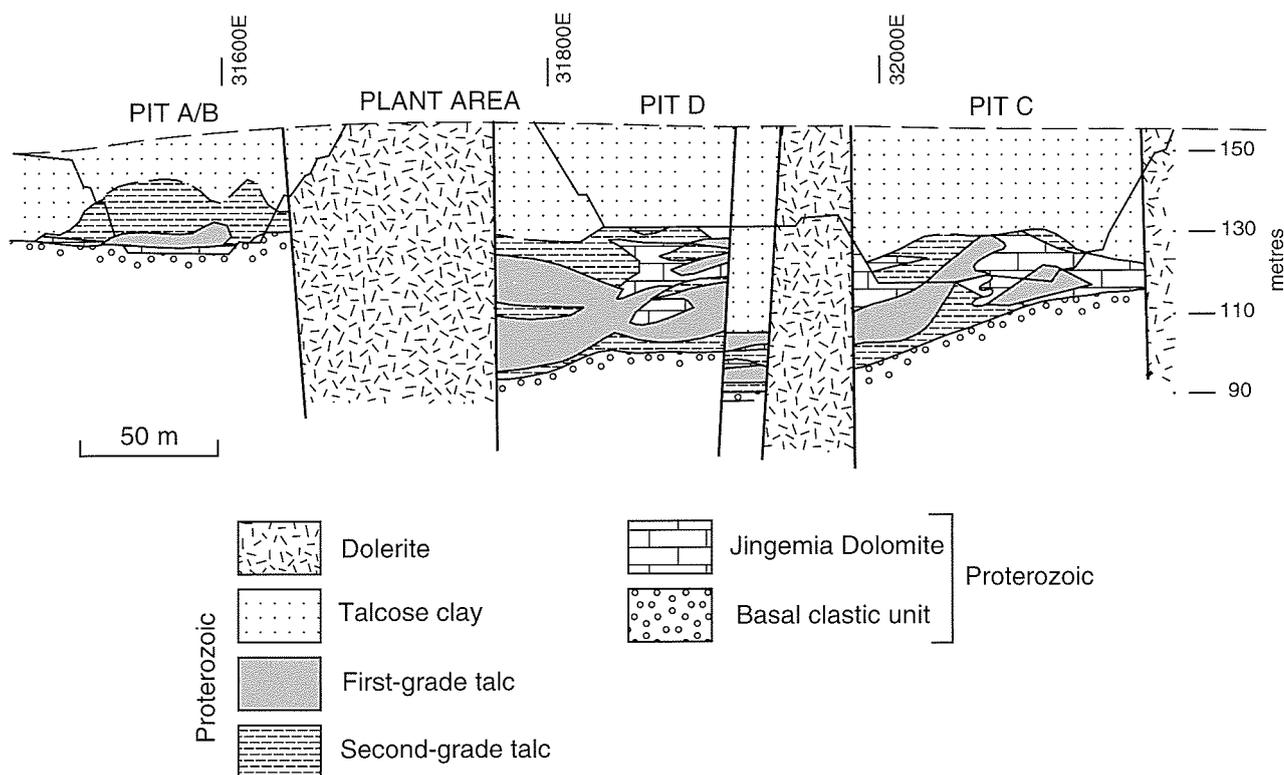
Figure 8. Photograph of openpit D at Three Springs talc mine showing zone of talc mineralization with lenses of dolomite



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Figure 9. North-south cross section at the Three Springs talc mine. N is to the right



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Figure 10. East-west cross section at the Three Springs talc mine. Pit D is currently in operation

clinochlore, 2–5% apatite, and 2% rhodochrosite. Sample 117376 was collected from the stockpiles of fine ore of mixed grade and comprised two dark- and two light-grey to green fragments (~3 cm) with no visible impurities. The sample contained approximately 90% talc, 5% dolomite, 2% clinochlore, 1% quartz, and <1% apatite. SEM photographs of the same samples milled to -53 µm indicate that the ore is fine grained with individual particles consisting of aggregates (Fig. 12). The physical properties of the samples are given in Table 11.

Selection of ore to be mined is based on both drilling results and visual inspection. Ore grading is done at the various stages between ore found in situ and the crushed and washed ore. Lump ore is further controlled by inspection on a slow-moving conveyor belt where lumps that do not meet stringent visual quality criteria are removed by hand — generally less than 5% need to be removed at this final stage. The company produces two grades of talc, having brightnesses of 89% and 85%, and a third grade of washed fines. Mined ore is regularly sampled and laboratory tested for chemical quality, brightness and other characteristics.

Commercial applications

Three Springs talc is mainly used by the paper and pulp industry, the electroceramics industry and the paint, plastics, and rubber industries.

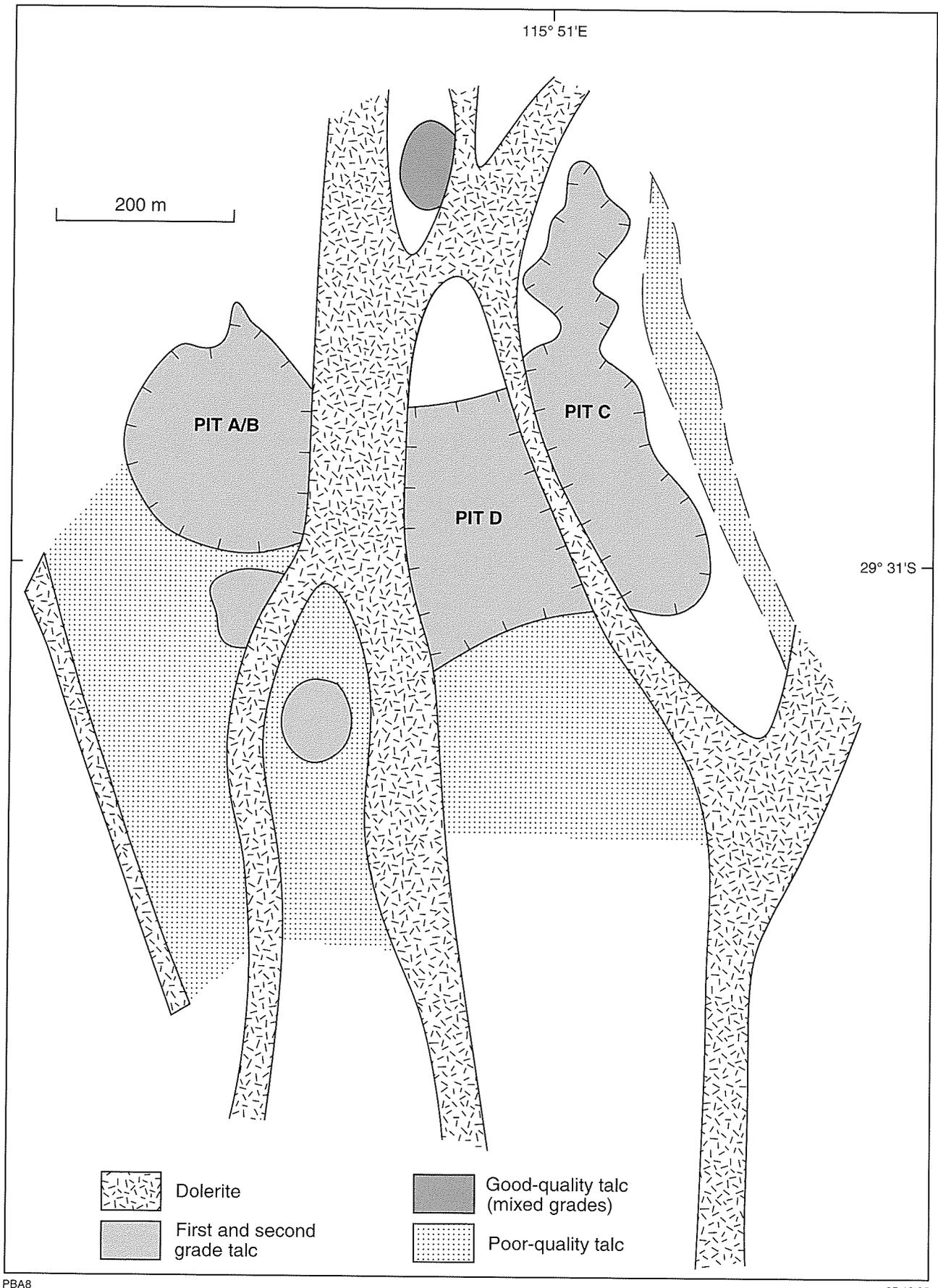
The main customers for Three Spring talc are in Japan, Europe, New Zealand and Australia, but it is also supplied to a number of other countries. More than 50% of the talc mined at Three Springs is currently exported to Japan. In May 1991, Three Springs Talc Pty Ltd took a significant interest in Westmin Talc BV, a leading mineral processor based in the Netherlands, and subsequently upgraded and expanded that facility to increase its European market (Griffiths, 1992).

Origin

The talc commonly exhibits well-preserved sedimentary structures inherited from the parent carbonates of the Noondine Chert (Read, 1971), including stromatolite regrowth on stromatolite fragments, which suggests a shallow water subtidal environment at the time of deposition. Because of the close spatial relationship between the talc deposits and the dolerite dykes it is tempting to propose that the intrusion of dykes into the carbonates and sandy sediments resulted in redistribution of silica, some of which reacted with magnesium in the dolomite to form talc, while some remained as chert associated with talc.

Coorow (Battersby's farm)

Location: Lat. 29°55'15"S, Long. 116°00'15"E; PERENJORI



PBA8

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Figure 11. Distribution of dolerite dykes and talc ore, and the locations of pits A/B, C and D at Three Springs mine (based on Hopkins, 1991)

Table 9. Chemical analyses of Three Springs talc (major and trace elements)

Element	GSWA no. Lab. no. Field no.	2/2989 4020 A	2/2987 4021 B	2/2988 4022 C	2/2996 4023 D	117374 1	117375 2	117376 3	117377 4	117378 5
		percentage								
SiO ₂		62.08	62.47	62.07	60.52	61.70	61.80	61.50	59.10	62.20
TiO ₂		0.01	0.02	0.01	0.03	<0.05	<0.05	<0.05	0.05	<0.05
Al ₂ O ₃		0.46	0.58	0.72	1.23	0.56	0.49	0.52	1.96	0.13
Fe ₂ O ₃		0.08	0.2	0.15	0.25	0.25	0.30	0.37	0.37	0.24
FeO		0.77	0.76	0.71	0.85	0.86	0.94	0.80	1.06	0.79
MnO		trace	trace	trace	0.01	<0.05	<0.05	<0.05	<0.05	<0.05
MgO		31.33	30.55	31.13	30.81	30.08	30.70	30.50	30.60	30.80
CaO		0.04	0.07	0.01	0.16	0.33	0.06	0.45	0.10	<0.05
Na ₂ O		0.31	0.08	0.08	0.02	0.27	0.26	0.25	0.27	0.23
K ₂ O		0.01	nil	nil	0.02	<0.05	<0.05	<0.05	<0.05	<0.05
P ₂ O ₅		nil	0.03	0.15	0.04	0.25	<0.05	0.15	<0.05	<0.05
CO ₂		0.06	0.06	0.02	0.02	0.13	<0.1	0.49	0.13	<0.1
S		nd	nd	nd	nd	<0.01	<0.01	<0.01	<0.01	<0.01
H ₂ O ⁺		4.68	4.8	4.92	5.19	4.87	4.92	4.66	5.49	4.82
H ₂ O ⁻		0.33	0.44	0.25	0.55	0.20	0.10	<0.1	<0.1	<0.1
Cr ₂ O ₃		nil	trace	nil	trace	nd	nd	nd	nd	nd
Cl		nil	nil	nil	trace	nd	nd	nd	nd	nd
SO ₃		nil	nil	nil	0.01	nd	nd	nd	nd	nd
Rest (calc)%		nd	nd	nd	nd	0.01	0.01	0.01	0.02	0.01
Total		100.16	100.06	100.22	99.71	99.51	99.58	99.7	99.5	99.22
		parts per million								
Mn		nd	nd	nd	nd	24	23	41	30	24
Ni		nd	nd	nd	nd	8	11	9	14	6
Cr		nd	nd	nd	nd	<4	<4	<4	<4	<4
As		nd	nd	nd	nd	<4	<4	<4	<4	<4
Pb		nd	nd	nd	nd	<4	<4	<4	<4	<4
Th		nd	nd	nd	nd	2	<2	<2	3	<2
U		nd	nd	nd	nd	<2	<2	<2	<2	<2
V		nd	nd	nd	nd	8	8	9	20	<3
Zn		nd	nd	nd	nd	22	22	19	34	19
Zr		nd	nd	nd	nd	20	19	20	26	20

NOTES: Samples 2/2987 to 2/2989 and 2/2996 — after Matheson (1945) (Analysts C. E. S. Davies and C. R. LeMesurier)
 Samples 117374 to 117378 from stockpiles at Three Springs mine (analyses by CC)
 117374 and 117375 are first- to second-grade lump ore from stockpiles
 117376 is first- to second-grade fine ore from stockpile
 117377 and 117378 are from the mixed ore before crushing
 nd — not determined

Battersby is approximately 5 km south-southwest of Coorow and approximately 50 km southeast of Three Springs (Fig. 7). The area contains predominantly Proterozoic Coomberdale Subgroup sedimentary rocks intruded by northerly and northwesterly trending mafic dykes. Initial interest in the area resulted from the reported presence of talc in a borehole and in samples of road metal (Western Mining Corporation Limited, 1980). WMC tested the area in the 1970s with 49 vertical diamond drillholes, drilled to depths of 40 to 50 m, but did not locate commercial grade talc (Hopkins, 1991).

Massive talc identified by Imdex NL (Imdex, 1990) on a property called Gower, approximately 3 km east of Battersby (Fig. 7), is considered to be structurally related to the deposit at Battersby.

Marchagee (Fowler's farm)

Location: Lat. 30°03'40"S, Long. 116°04'00"E; MOORA

The Fowler's farm prospect is located south of Marchagee (Fig. 7), largely within the Coomberdale

Subgroup. A number of holes drilled by Imdex NL (Imdex, 1990) and WMC intersected talc at varying depths to 35 m, with an indicated/inferred resource of approximately 1 Mt of massive talc. The top of the orebody lies within a few metres of the surface and there is a positive increase in brightness of talc with depth, from 83 at the surface, increasing to 93 at 21 m. The talc is considered to be of inferior quality due to undesirable iron-oxide levels.

Carnamah (Niven's property)

Location: Lat. 29°40'50"S, Long. 115°53'00"E; PERENJORI

Niven's property is located approximately 10 km south of Coodawa (Fig. 7), just north of Carnamah. Exploratory drilling carried out by WMC in the 1970s, Wakefield Holdings Pty Ltd between December 1988 and December 1989, and Commercial Minerals Ltd between February and June 1990 and March to May 1991 (Marshall, 1990; Thynne, 1991, 1992) indicated that there is a zone of talc mineralization in altered dolomitic sedimentary rocks of the Coomberdale Subgroup close to mafic dykes. Wakefield Pty Ltd outlined a significant talc unit

Table 10. Chemical analyses of Mount Seabrook talc (major and trace elements)

Sample no.	29627A	29627B	29627C	29627D	29627A-D	117379	117380	117381	117382	117383	Cosmetic grade (a)	Industrial grade (a)	Washed fines (a)
	percentage												
SiO ₂	63.60	64.30	63.40	64.30	63.90	62.00	61.30	65.30	62.70	61.10	62	61	63
TiO ₂	<0.01	<0.01	0.02	0.02	<0.02	<0.05	<0.05	<0.05	<0.05	<0.05	—	—	—
Al ₂ O ₃	0.24	0.25	0.22	0.28	0.25	<0.05	0.47	0.35	<0.05	<0.05	0.2	0.6	0.3
Fe ₂ O ₃	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.28	0.14	0.13	0.7	0.7	0.7
FeO	0.46	0.46	0.57	0.57	0.51	0.51	0.57	0.36	0.43	0.54	—	—	—
MnO	—	—	—	—	—	<0.05	<0.05	<0.05	<0.05	<0.05	—	—	—
MgO	30.50	30.10	31.30	30.60	30.60	30.50	30.30	27.60	31.10	30.00	31	31	30
CaO	0.36	0.26	0.09	0.02	0.18	1.07	1.05	0.56	0.11	1.70	0.5	0.9	0.8
Na ₂ O	<0.01	0.02	<0.01	<0.01	<0.01	0.21	0.31	0.20	0.21	0.22	—	—	—
K ₂ O	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.05	<0.05	<0.05	<0.05	0.01	0.01	0.01
P ₂ O ₅	0.01	0.05	0.02	0.02	0.03	0.82	0.78	0.36	0.06	1.32	0.3	0.6	0.6
CO ₂	<0.01	<0.01	<0.01	<0.01	<0.01	0.12	0.13	0.25	0.15	0.10	—	—	—
S	—	—	—	—	—	<0.01	<0.01	<0.01	<0.01	<0.01	—	—	—
H ₂ O ⁺	4.81	4.58	4.50	4.50	4.59	4.39	4.88	4.29	4.54	4.25	—	—	—
H ₂ O ⁻	0.07	0.07	0.26	0.22	0.15	<0.01	<0.01	0.15	<0.01	<0.1	—	—	—
LOI	—	—	—	—	—	—	—	—	—	—	4.7	4.9	5.1
Rest	—	—	—	—	—	0.01	0.01	0.01	0.01	0.01	—	—	—
Total	100.05	100.09	100.38	100.53	100.21	99.63	99.80	99.71	99.45	99.37	—	—	—
	parts per million												
Cr	28	20	54	35	34	<4	<4	<4	<4	<4	—	—	—
V	<10	<10	<10	<10	<10	6	6	9	3	5	—	—	—
Zn	13	5	10	7	9	<3	<3	<3	<3	3	—	—	—
Pb	11	14	37	19	20	<4	<4	<4	<4	<4	>10	>10	>10
Cu	16	6	18	11	12	<4	<4	<4	<4	<4	—	—	—
Co	3	3	14	14	8	—	—	—	—	—	—	—	—
Ba	90	110	120	110	107	<11	<11	12	<11	<11	—	—	—
Zr	<5	<5	<5	<5	<5	19	19	19	20	18	—	—	—
Rb	<5	<5	<1	<1	<3	<2	<2	<2	<2	<2	—	—	—
Sr	4	5	<1	9	<5	3	3	2	<2	3	—	—	—
Li	<1	3	<1	<1	<1	—	—	—	—	—	—	—	—
Ga	1	0	0	0	0	<3	<3	<3	<3	<3	—	—	—
B	2	9	7	7	6	—	—	—	—	—	—	—	—
As	—	—	—	—	—	<4	<4	<4	<4	<4	>3	>3	>3
Mn	14	18	15	14	15	<5	13	23	<5	<5	—	—	—
Ni	19	24	13	21	19	9	8	13	10	10	—	—	—

NOTES: Samples 29627A-D — after Lipple (1975); Samples 117379 to 117383 — Mount Seabrook (analyses by CC); Sample 117379 — first-grade cosmetic talc; 117380 — industrial grade from stockpiles; 117381 — talc <4 mm from stockpiles; 117382 — from pit 4 ore zone, 117383 — pit 1 ore zone
(a) Monks, T., 1995 (pers. comm.)

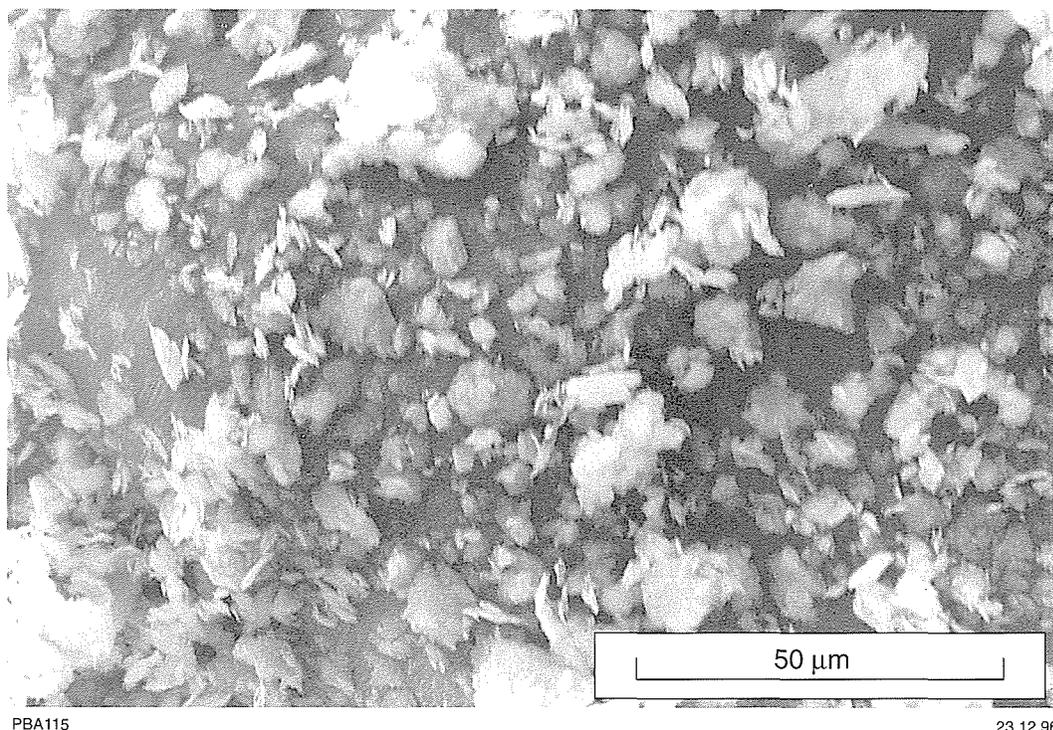


Figure 12. GSWA 117376 (Lab. no 92M0613 (002). Scanning electron micrograph of Three Springs talc milled to -53 µm showing fine-grained particles consisting of aggregates (EHT = 20.0 KV)

approximately 30 m wide with a northeasterly trend, a strike length of 200 m and a thickness of between 1 and 10 m. Samples from five drillholes confirmed high-quality talc, with percentages of MgO and SiO₂ equivalent to pure talc. However, Commercial Minerals concluded that the prospect was unlikely to contain commercial grade talc at depths less than 40 m.

Moora

Location: Lat. 30°42'40"S, Long. 116°04'00"E; MOORA

Approximately 11 km east-southeast of Moora soapstone is exposed in an old quarry (Fig. 5) on the western side of a low hill (Matheson, 1945). The deposit is lenticular, with a length of 76 m and a maximum width of 8 m, and is sheared and veined with quartz. The ore and its host rocks, mainly granitic gneisses with a few thin bands of hornblende gneiss, trend north with a westerly dip of 75°. The gneisses are intruded by quartz, pegmatite and dolerite. The fresh soapstone is fine grained, pale green and foliated, with some magnetite disseminations and thin seams of anthophyllite, chlorite and sericite. The deposit is not considered to be commercially viable because of its high levels of impurities and its schistosity.

The presence of magnetite and thin seams of anthophyllite and chlorite in fresh soapstone, suggest the derivation of talc from localized hydrothermal alteration of lenses of mafic rock rich in ferromagnesian minerals, as opposed to derivation from dolomitic rocks, as observed elsewhere in the area.

Narryer Terrane

Regional geology

The Narryer Terrane forms the northwestern part of the Yilgarn Craton and is one of the largest intact fragments of early Archaean (>3.3 Ga) crust on earth. The terrane consists of high-grade gneiss derived from granitoid and minor amounts of granodiorite, tonalite, layered basic intrusions and metasedimentary rocks (Myers, 1988).

Metasedimentary rocks are widespread as discontinuous layers within the Meeberrie and Dugel Gneisses, and the most abundant and distinctive are quartzites and banded iron-formation. The talc mineralization in the Mount Seabrook–Livingstone–Trillbar belt occurs within a Proterozoic metasedimentary and metavolcanic sequence (Fig. 13) along the margin of the Archaean Yilgarn Craton. A sequence of dolomite, shale, muscovite–quartz siltstone, sandstone, and conglomerate and associated metavolcanic rocks, minor gabbro and ultramafic intrusions has generally undergone greenschist facies metamorphism. There is a decrease in metamorphic grade toward the central dolomitic unit, and talc mineralization is commonly associated with dolomitic marble–chert horizons and talc schists. Lipple (1975) suggested that the metasedimentary sequence is either a continuation of the Archaean volcanic and sedimentary rocks at Mount Maitland, and Mount Taylor–Mount Gould in the Yilgarn Craton, or relics of the Proterozoic rocks of pre-Bangemall age. The sequence in the Trillbar belt is interpreted to be younging progressively from south to north and is correlated with the shelf facies

Table 11. Physical properties of two samples of talc from Three Springs

Sample no. (GSWA no.) Lab no. 92M0613	117374 1	117376 2
Average particle density (g/cm ³)	2.89	2.9
Pigment vehicle demand: grams (linseed oil) per 100 grams	42.7	40.6
Reflectivity at 457 nm: relative to MgO 100% (a)	80.7	82.9
Hardness (Mohs' scale)	1	1
Refractive Index	1.58	1.58
pH	9.4	9.5

NOTE: (a) Elrepho brightness determined on a reference sample of Premier Grade Georgia kaolin was found to be 82.1

of the Glengarry Group and the related Morrissey Metamorphic Suite (Norris, 1990). A number of workers in the area consider that the mafic and ultramafic schists of the sequence may be correlated with the Narracoota Formation. However, Myers (1989) stated that no sedimentary or volcanic structures were identified in those parts of the Trillbar Complex considered to correlate with the Narracoota Formation, and that the primary structures observed were igneous textures in metagabbro and metaperidotite. Furthermore, he commented that rocks previously mapped as siliceous metasedimentary rocks were either quartz–muscovite schist and mylonite formed from intensely deformed Dugel Gneiss, or weathered and bleached schistose ultramafic rocks occurring as lenses in the gneiss. He suggested that the metamorphosed dolomite at Mount Seabrook talc mine might be an integral part of the Trillbar metagabbroic and ultramafic Complex, and that the Trillbar Complex could represent the lower part of an ophiolite sequence or the crustal underplate obducted along a major thrust onto the Yilgarn Craton.

The basement rocks of the Trillbar belt consist of Archaean gneissic and granitic rocks of the Yilgarn Craton and the Yarlalweelor gneiss belt. The basement rocks grade northward into a sequence of schistose rocks, sandstone, grit, conglomerate, and a prominent banded iron-formation unit.

Mount Seabrook–Livingstone Belt

The Mount Seabrook talc mine is located approximately 174 km northwest of Meekatharra, in the Mount Seabrook–Livingstone belt (Fig. 13). It is the second largest operating talc mine in Australia, and is owned by Gwalia Consolidated Ltd (see editor's note below). Although this is the only operating mine in the belt at present, intensive exploration in the 1980s by WMC, Thames Mining NL and Gwalia Minerals NL has shown significant potential for other large talc deposits. Talc has been known for some time at Mount Gould, Mount Taylor and south of Livingstone Find (Fig. 13), and

exploration activities at present are concentrated in an area extending from east of Winja Well to north and west of Southern Cross Well. WMC holds most of this ground in a joint venture agreement with Gwalia Minerals. Thames Mining has identified significant talc mineralization at its Livingstone prospect, and WMC has identified potential talc mineralization at the Southern Cross Well prospect. Gwalia Minerals has also proved substantial resources for its future operations in leases close to the mine area.

Mount Seabrook talc mine

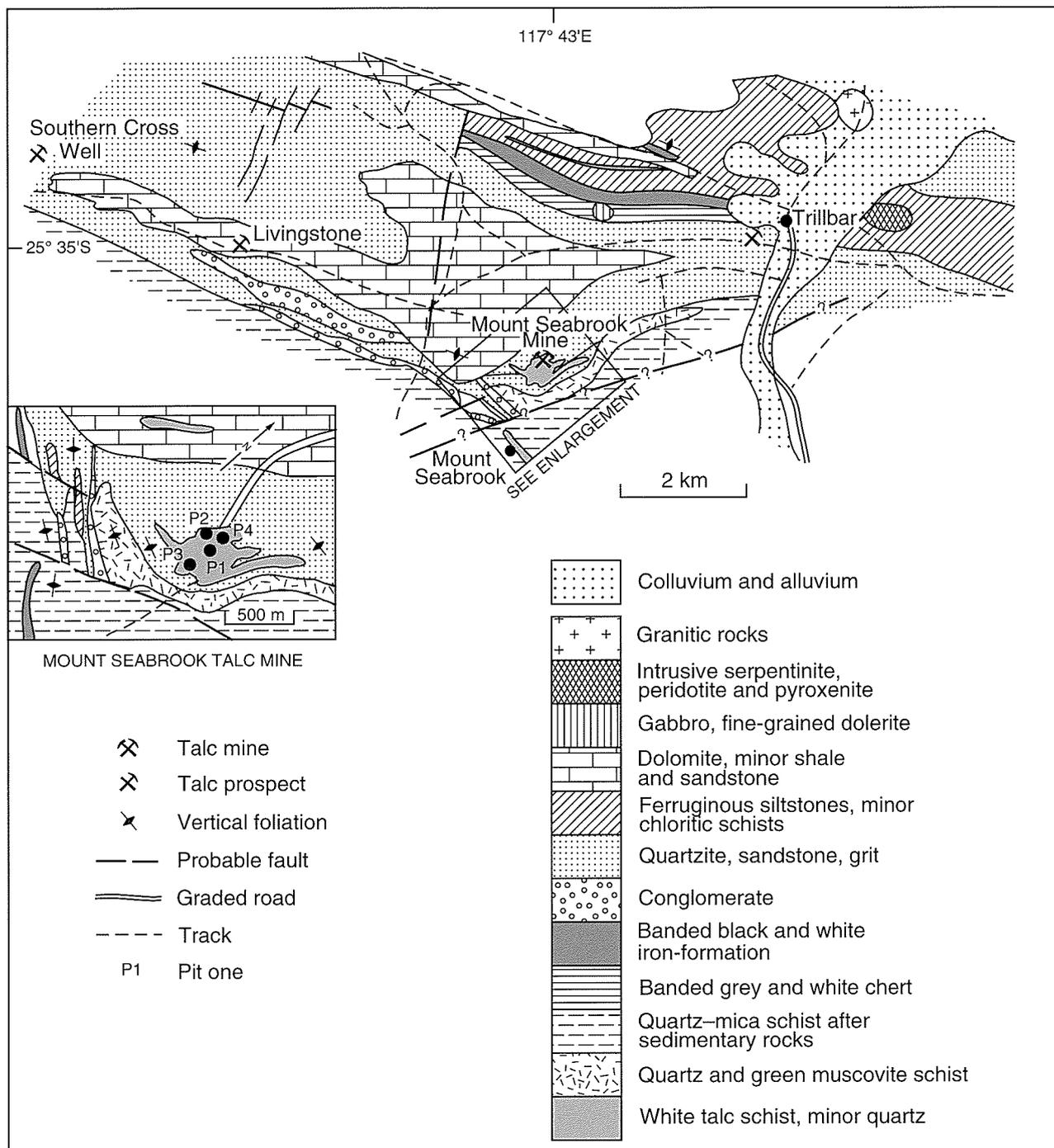
Location: Lat. 25°35'25"S, Long. 117°43'00"E; ROBINSON RANGE

Historical background

Talc at Mount Seabrook (Fig. 13) was first discovered in 1965 by prospector Mr. M. Lalor in company with an Aboriginal. The deposit was pegged in May 1969 by Mr. A. Doust under the mineral claim MC 190P, and later purchased by Lalor Prospectors Syndicate, which also pegged an adjacent lease in June 1969 (Lipple, 1975). Subsequently, Westside Mines NL acquired the whole area and carried out exploration from October 1969 to May 1972 (Hodges and Lalor, 1985), including geological mapping, percussion drilling, core drilling, shaft sinking and costeaning. During this period Westside Mines NL also developed an exploratory openpit, and lump talc was shipped to eastern Australia and to Japan, USA and New Zealand. The quality of the talc was acceptable to the buyers, particularly to Japan, so production continued, with a reported yield of 230 842 t between 1973 and 1984 valued at approximately \$10 million. Ownership changed in 1986–1987 to Thames Mining NL, a subsidiary of the Gwalia Group, and the name was later changed to Gwalia Minerals NL, a subsidiary of Gwalia Consolidated Ltd. (Editor's note: early in 1996 Gwalia Consolidated Ltd sold 50% of the mine to Industrial Mineraria Italiana Fabi Sri (IMI Fabi)). Production from the Mount Seabrook mine between 1987 and 1994 totalled 207 654 t valued at \$18.5 million (Tables 6 and 7).

Mine geology

The rock types within the mine and adjoining area consist of metamorphosed sandstone, dolomite, quartzite, pebble conglomerate, and quartz–muscovite schist, and biotite- and chlorite-bearing lenses of white to light-green, contorted talc schist (Fig. 13). The relationship between the talc schist and the enclosing metasedimentary rocks is complicated by local folding, and the talc has a lenticular interfingering relationship with the surrounding quartzose sedimentary rocks (Lipple, 1975). The talc rock is described as fine grained, massive to weakly foliated, with minor rounded and anhedral quartz, and veinlets of fine opal. The talc has also been partially replaced by quartz (Lipple, 1975). Monks (1992a) described the sequence in the mine area as a mixed schist–quartzite unit grading upwards into a dolomite–chert–quartzite–talc unit, with talc developed as steeply dipping lenses within dolomite.



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Figure 13. Geology around the Mount Seabrook mine (based on Lipple, 1975)

The dolomite-quartzite-talc unit and schist are intruded by granite at the eastern side of the mine area (Monks, 1992b).

Small lenses and grains of quartz, and oxides of iron and manganese, filling fractures, are common within the talc unit. With increasing depth, there is a tendency for less

iron-oxide staining. Quartz is commonly associated with large talc bodies within the dolomitic unit and talc schists. Petrological studies of some samples from the deposit (Libby, 1988) indicate that apatite and chlorite are common accessory minerals in the talc schists. Muscovite, sericite and hematite are also present in some schistose rocks in accessory amounts.

Mine operation

The mine area has four pits, numbered 1, 2, 3 and 4, and at present only pit 1 is in operation. The pit operates seasonally. It is approximately 150 m × 100 m, about 30 m deep, and has high-quality talc exposed at the bottom. Pit 4 is approximately 65 m deep and 250 m × 100 m in area. Within this pit, the talc orebody is approximately 50 m wide and 250 m long, and is open at both ends. The talc mineralization is associated with lenses of dolomite and quartz.

Grade of ore

In general, the talc from Mount Seabrook is massive, white, fine grained, opaque to locally translucent, and contains quartz inclusions. Hardness varies between 1.0 and 1.5, and the ore consists of approximately 75% talc, with the remainder containing iron-stained talc, quartz, clays and opaline silica above the water table, and mainly dolomite and quartz below. The mineralogy of ore-grade talc from Mount Seabrook is given in Table 12. The amount of saleable talc depends on the efficiency of selective mining and ore beneficiation. The yield of cosmetic-grade talc from the deposit is 40% and typical specifications are a lump size of 80% minus 200 mm; maximum moisture 3%; and brightness

89–91% (Industrial Minerals, 1993b; Monks, T., 1995, pers. comm.).

Two samples of talc from stockpiles at Mount Seabrook were studied by XRPD to identify minerals present in the ore. Sample 117379, comprising lumps of washed first-grade cosmetic-grade ore, consists of grey-green talc with occasional inclusions of quartz, and traces of thin black streaks of (possibly) manganese oxide. XRPD studies revealed that this sample contained approximately 98–100% talc, 1–2% apatite, and traces of quartz, albite, a barium–manganese oxide mineral (probably hollandite), and an unidentified manganese oxide mineral. Sample 117380 is from the stockpiles of industrial grade product and is a grey-green talc with traces of manganese oxide. XRPD studies revealed that it contained approximately 99% talc and less than 1% clinocllore with traces of an unidentified manganese oxide mineral. The distribution of impurities within the talc is notably inhomogeneous.

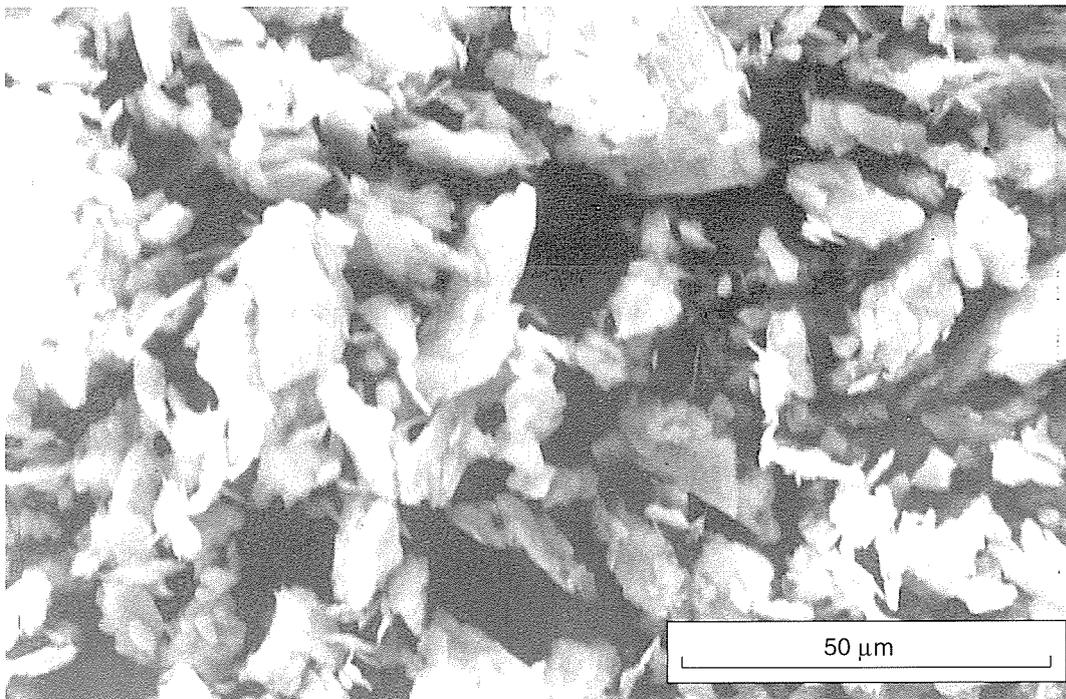
Previous XRD studies of a number of samples of talc from Mount Seabrook (Blount, 1987, 1988) indicated that the ore generally consists of talc with corrensite (mixed layers of 50:50 chlorite–vermiculite) and minor chlorite and smectite. Samples thought to be chlorite schist contained corrensite with very little or no chlorite. The only carbonate in the ore was dolomite and the insoluble residue from the dolomite consisted of talc, corrensite,

Table 12. Physical properties and mineral composition of Mount Seabrook talc

Properties tested	(a)117379 (b)3	(a)117380 (b)4	Cosmetic grade	Industrial grade	Washed fines
Average particle density (g/cm ³)	2.85	2.85	–	–	–
Pigment vehicle demand: grams (linseed oil)/100 grams	35.6	37.7	–	–	–
Reflectivity at 457 nm: relative to MgO 100%	85.6	86.4	–	–	–
Hardness (Mohs' scale)	1	1	–	–	–
Refractive Index	1.59	1.59	–	–	–
pH	9.1	9.0	–	–	–
Physical properties					
Brightness (Hunterlab)	–	–	89–91	84–86	80–84
Lump size	–	–	<200 mm	<200 mm	<25 mm
Free moisture	–	–	<3%	<3%	<3%
Acid insolubles	–	–	0.8%	1.2%	1.8%
Mineral content					
Talc	–	–	98%	98%	93–97%
Dolomite and apatite	–	–	<1.5%	<1.5%	2–4%
Quartz	–	–	<1.0%	<1.0%	1–2%
Asbestos	–	–	bld	bld	bld

SOURCE: GSWA and Monks, T., 1995 (pers. comm.)

NOTES: bld below level of detection
– not determined
(a) GSWA sample no.
(b) Subcomponent of Laboratory no. 92M0613



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Figure 14. GSWA 117380 (Lab. no 92MO613(004). Scanning electron micrograph of Mount Seabrook talc milled to -53 µm showing the plate-like character of the talc (EHT = 20.0 KV)

chlorite, feldspar and quartz. The talc in tightly folded and contorted rock samples lacked a preferred orientation. According to Blount (1988) commercial talc in the USA and elsewhere does not contain corrensite. She further commented that white ore at Mount Seabrook resembles the talc of Alabama and the green variety resembles that in the Yellowstone mine in Montana.

SEM photographs of the milled talc reveal that individual crystals are uniform, and do not exhibit intergrowths or distortions. SEM photographs of sample 117380 milled to -53 µm indicates that the ore is coarser than that from Three Springs, and individual particles are more clearly plate-like in character (Fig. 14). Under milling conditions, the crystals separate into discrete platelets, which impart good overall slip, good coverage, high reflectivity, and acceptable oil absorption. Other physical properties of these two samples are given in Table 12. Hodges and Lalor (1985) gave the following physical properties for Mount Seabrook talc.

Typical physical properties of Mount Seabrook talc (99.6% passing through 350 mesh BSS)

Colour	pure white
Whiteness	90 to 93 (MgO = 100) GE scale
Specific gravity	2.8
pH value	9.0
Oil absorption	33 to 36/100 g (spatula rub out)
Density	0.46 g/cm ³
Particle shape	platy

There are some differences between those properties given above and those in Table 12, which may be due to the differences in the types of samples collected.

The available chemical analyses of the ore (Table 10) indicate that the composition is atypical of talc, with slightly lower Al₂O₃, Fe₂O₃ and FeO than the Three Springs talc. The average chemical composition is approximately 63.19% SiO₂ and 30.26% MgO. Industrial grade has a minimum of 57% SiO₂ and 26% MgO. Typical analyses are given in Table 10. Impurities, such as CaO, Al₂O₃ and Fe₂O₃ are appreciably lower than the upper limits accepted for many commercial-grade talcs. The Cr, Ni and V contents are low, suggesting that the source rocks of the talc are unlikely to be related to the Archaean ultramafic rocks in the region.

Commercial applications

Mount Seabrook talc has been marketed for cosmetic uses in Europe and to various industrial markets in the USA. However, talc is now sold mainly to Commercial Minerals Ltd of New South Wales, for blending and further processing in Australasia and Malaysia (Industrial Minerals, 1993b; Monks, T., 1995, pers. comm.).

Resources

Lipple (1975) inferred a total resource of 6.8 Mt to a depth of 35 m for the whole deposit. The estimates by Westside Mines NL at the commencement of mining amounted to 1 074 000 t, comprising a measured resource of 508 000 t and an indicated resource of 566 000 t (Hodges and Lalor, 1985). The latest ore reserve estimates by Gwalia Minerals indicate a total of 1.55 Mt of resources and reserves comprising 200 000 t proven reserves,

500 000 t measured resources, and 800 000 t indicated resources. However, the deposit is considered to have much greater potential as the talc zone is geologically open ended, but has not been explored because at current production rates the mine life is already more than ten years (Industrial Minerals, 1993b).

Origin

The traditional view is that the talc has formed by alteration of sandy dolomitic rocks. Lipple (1975) suggested that hydrous metamorphism resulted in the formation of talc at low to moderate temperatures, with the excess quartz thus liberated being recrystallized as lenses and granules within the talc schist. The low levels of Ni, V and Cr (Table 10) suggest that derivation of talc from a mafic or an ultramafic source is very unlikely. Monks (1992b) suggested that talc mineralization is due to low temperature (200–230°C) hydrothermal alteration of dolomite by silica-rich fluids derived from the granite intrusion to the east of the mine. The presence of corrensite indicates that the talc formed at temperatures of 200 to 250°C under hydrothermal conditions. This is a lower temperature of formation than any carbonate-hosted talc deposit in the USA (Blount, 1988).

Livingstone talc prospect

Location: Lat. 25°35'00"S, Long. 117°39'00"E; ROBINSON RANGE

In 1983, Thames Mining NL discovered a small talc outcrop northwest of Three Corners Bore, south of the Livingstone Find gold workings (Fig. 13). It is now referred to as the Livingstone talc prospect. The prospect was explored by a trench and two percussion drillholes, one vertical hole to 41 m, the other to 41 m at -60° (Graindorge, 1985). Both holes intersected talc over their entire length. The area was further investigated in October 1985 with reconnaissance mapping, a total of 753 m of reverse circulation and 125 m of core drilling. Subsequent mapping located more talc occurrences further to the west. Between November 1985 and February 1986, more mapping and 74 RAB holes totalling 945 m and 3 diamond holes totalling 99 m were completed in a gridded area of 3000 m × 7200 m. At the end of these programs Thames Mining NL had identified two high-grade talc deposits, and twelve other talc occurrences, six of which have been tested so far. A number of other areas with potential for high-grade talc mineralization have yet to be tested by drilling.

Geology

The Livingstone talc prospect consists of a sequence of metasedimentary rocks intruded by granitic rocks (Fig. 15).

The metasedimentary rocks extend along strike from the dolomite–chert–quartzite–talc unit described earlier in the Mount Seabrook area. The schistosity is generally subparallel to the regional foliation of 300°, with steep

southwesterly dips. The rocks are deeply weathered and poorly exposed. The metasedimentary rocks consist of quartzite, sandstone, dolomite, marble and talc schist. Quartzite is massive, fine to medium grained, and strongly and irregularly jointed. Sandstone is poorly exposed, but has been recognized in a number of drillholes, and is generally very weathered. Dolomitic marble that outcrops throughout the area is white to purple, massive, medium to coarse grained, and well crystallized. Talc schist is mainly exposed in the northwest quadrant of the area.

Boulder conglomerates described by Graindorge (1985) are probably the result of silcrete forming in the laterite weathering profile over a thick horizon of interbedded talc and altered quartzites (Monks, T., 1995, pers. comm.).

Talc occurrences

Fourteen talc occurrences recognized in the Livingstone area were classified into three categories based on their associated host rocks:

- (a) Massive high-grade talc and high-grade disseminated talc in dolomitic rock at the contact zones of altered quartzite;
- (b) Talc schist in quartzite;
- (c) Talc schist in altered quartzite in contact with dolomite.

Talc occurrences 1, 2 and 9 (Fig. 15) belong to category (a), with occurrence 1 being the largest deposit of high-quality talc so far identified at the prospect. All three occurrences have been tested by drilling.

Talc occurrences 3 to 7 and 10 to 13 belong to category (b), and have been outlined by outcrop and scree mapping. RAB drilling of some of these occurrences indicates that the talc is generally very soft below the silicified zone in comparison with occurrences 1 and 2. It is also highly weathered, altered and contains impurities such as quartz, quartzite, sandstone, clay and chalcedonic silica. Graindorge (1986) suggested that these occurrences are similar to category (c).

Talc occurrences 8 and 14, classified as category (c), have been drilled. The talc in occurrence 8 is weathered, soft and multicoloured, whereas talc in 14 contains a significant proportion of kaolinitic clay.

Drilling of a further 15 RAB holes during 1988 delineated the main talc occurrence in the area (Monks, T., 1995, pers. comm.).

Grade of ore

Analyses of six core samples from a diamond drillhole in occurrence 1 (Table 13) indicated that four analyses had compositions similar to high-grade talc at Mount Seabrook but with higher percentages of Fe₂O₃ and FeO. The four samples were light green and had an average brightness (GE) of 88.5%, pH 8.96, and bulk density 2.84 g/cm³. The other two samples were of lower

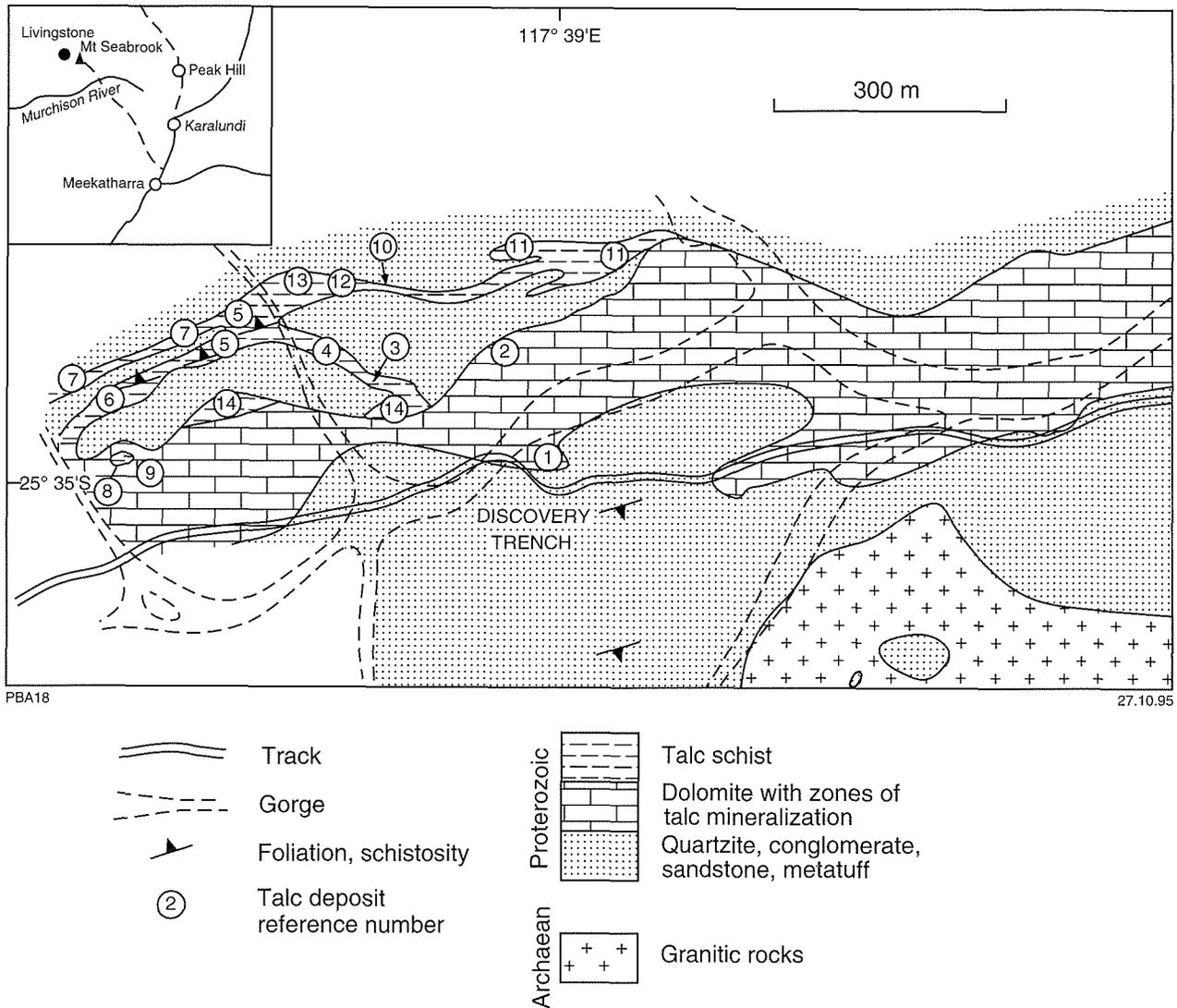


Figure 15. Interpreted geology of the Livingstone talc prospect (after Graindorge, 1985)

quality and were dark green with an average brightness (GE) of 84.05%, pH 8.89 and bulk density of 2.76 g/cm³. A further fifteen analyses of core samples of very soft talc indicated that only three had the composition of high-grade talc. A large number of these samples contained a significant amount of kaolin and a few had significant smectite, suggesting that the samples were very weathered (Graindorge, 1985).

Petrological and SEM studies of a high-grade sample from diamond drillcore indicate that it contains 98% talc, and traces of apatite, quartz, xenotime, iron oxide and an unknown Ca-Na silicate. Two samples of dark-green talc contained significant concentrations of chlorite.

Resources

The Livingstone talc prospect has an indicated resource of 190 000 t of premium-grade talc (Louthean, 1993).

Trillbar–Southern Cross Well prospects

Since 1970 WMC has been exploring for talc in the Mount Seabrook–Livingstone–Trillbar belt and has identified a number of areas with potential. The Trillbar and Southern Cross Well areas in particular (Fig. 13) have been explored in more detail, with encouraging results.

Geology

The main lithologic units in the area between Winja Well and Southern Cross Well have been described earlier (Fig. 13), and consist of Proterozoic quartz–chlorite schist, marble, chert and quartz–sericite schist, equivalent to the ‘shelf facies’ of the Glengarry Group, and mafic and ultramafic rocks correlated with the Narracoota Formation. The sequence has been intruded by granitic rocks.

Table 13. Chemical analyses of Livingstone talc (major and trace elements)

Sample no.	A	B	C	D	E	F
	percentage					
SiO ₂	61.00	61.60	61.60	60.50	58.60	56.00
MgO	30.80	30.60	30.90	30.80	32.20	31.40
Fe ₂ O ₃	1.50	1.59	1.62	1.47	1.71	1.79
FeO	1.23	1.25	1.21	1.14	1.27	1.15
K ₂ O	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Al ₂ O ₃	0.25	0.09	0.15	0.07	1.92	2.53
CaO	0.21	0.13	0.28	0.35	0.04	1.49
TiO ₂	0.05	0.01	0.01	0.03	0.10	0.23
P ₂ O ₅	0.04	0.11	1.11	0.07	0.03	0.81
LOI	4.82	4.56	4.49	4.90	4.53	5.99
Total	99.90	99.94	101.37	99.33	100.40	101.39
	parts per million					
Pb	35	<10	27	10	18	160
Cu	<2	<2	<2	<2	<2	3
Co	<5	<5	<5	<5	<5	<5
Mn	35	18	13	18	138	44
As	<5	<5	<5	<5	<5	<5

NOTES: Sample A from drillhole DDL Lt 1, depth 10.70–10.95 m
 Sample B — DDL Lt 1, depth 22.70–22.95 m
 Sample C — DDL Lt 1, depth 37.40–37.60 m
 Sample D — DDL Lt 1, depth 44.60–44.90 m
 Sample E — DDL Lt 1, depth 22.30–22.50 m
 Sample F — DDL Lt 1, depth 32.50–32.75 m
 SOURCE: after Graindorge (1985)

Trillbar prospect

Location: Lat. 25°34'20"S, Long. 117°44'45"E; ROBINSON RANGE

More than 2300 m of reverse circulation and 280 m of diamond drilling was completed on the Trillbar prospect between 1987 and 1989, and intersected marble with talc lenses and minor chert units (Norris, 1990). The talc was of very high quality, equivalent to that at Mount Seabrook. Cosmetic-grade talc was intersected in several reverse circulation drillholes and in most of the diamond holes. The talc occurs as subvertical lenses up to 8 m in true thickness (more generally 2 to 5 m), which are separated by marble. A further 1010 m drilled in 1990 considerably increased the known strike extent of cosmetic-grade talc to the northeast and west (Mazzoni, 1990). The western boundary of the prospect adjoins Gwalia Consolidated Ltd's boundary.

Southern Cross Well prospect

Location: Lat. 25°34'00"S, Long. 117°38'00"E; ROBINSON RANGE

More than 1160 m of reverse circulation drilling was carried out at this prospect (Fig. 13) between 1987 and 1989, but results were not very encouraging (Norris, 1990). Only minor talc zones were intersected within marble and chert units and the quality ranged from substandard to industrial grade. A further 1406 m of

reverse circulation drilling carried out between October 1989 and October 1990 to follow up possible westerly extensions of mineralization, intersected massive but substandard talc (Mazzoni, 1990). Significant intersections, with thicknesses varying between 8 and 16 m, were obtained in three holes. The talc-bearing stratigraphy is open to the west, and passes into a zone where fold- and fault-thickening of the footwall meta-arenite suggests a structural target.

Mount Taylor

Location: Lat. 25°55'20"S and Long. 117°21'45"E; ROBINSON RANGE

A significant body of talc (soapstone) of fine scaly texture, is known near Mount Taylor, approximately 50 km southwest of Mount Seabrook (Campbell, 1909; Simpson, 1912). Johnson (1950) stated that according to local residents a parcel of talc was dug out and despatched to Perth for testing around the year 1910. The talc from this location had a composition close to pure talc (Table 14), but was slightly foliated and cracked badly on heating. However, the material showed no sign of fusion when heated to 1500°C for some hours (Simpson, 1912).

Johnson (1950) examined a lens of foliated, sheared talc 60 m long and 3 m wide, 3 km northeast of Mount Taylor. This talc is in the nose of a large dragfold in metasedimentary rocks that are here intruded by pegmatite. The axis of the drag fold pitches 40° due west, and schistosity in the talc strikes 255°. The meta-sedimentary rocks have a regional strike of 110° with a

Table 14. Chemical analysis of talc from Mount Taylor

	%
SiO ₂	61.00
MgO	27.88
FeO	6.14
MnO	0.20
Al ₂ O ₃	0.80
H ₂ O ⁺	4.72
H ₂ O ⁻	0.12
Total	100.86

NOTE: after Simpson (1952)

50° southwesterly dip. Simpson (1952) described the talc from Mount Taylor as light greenish grey, micaceous, schistose and too strongly foliated for slab or block making. Selected samples gave a white, gritless powder. A representative sample collected by Johnson (1950), described by the then GCL (now CC), consisted of a number of pieces of talc heavily stained with limonite and, to a lesser extent, manganese oxides. The talc was foliated, and split readily, and small amounts of fine quartz and opal, and traces of chlorite and apatite were present. The powder, although white, was too coloured to be of value except for uses where off-white colour is not objectionable.

In recent times, between 1988 and 1990, the Mount Taylor area was held by Mr Reindler under Exploration Licence 51/203, an area of 16 km². The area consists of an elongated ultramafic sequence of possible Archaean age with a northeasterly trend and westerly dips. The dominant rock types are massive, medium- to coarse-grained serpentine–actinolite–tremolite-bearing rocks representing metamorphosed ultramafic rocks, and a suite of talc–carbonate–chlorite–serpentine schist (Middleton, 1989). Talc-rich units are well developed and often form large pods of pure talc. At this stage the continuity of the deposits is not clear, but they are considered to have good potential. Chemical analyses of samples have indicated that the ore is close to typical talc and contains insignificant impurities such as oxides of iron. Grinding tests indicate that the talc would be acceptable for chemical, paint and cosmetic applications.

Mount Gould

Location: Lat. 25°47'40"S, Long. 117°20'30"E; ROBINSON RANGE

Massive talc of very high quality, suitable for the paper and rubber industries and for application in cosmetics, has been obtained from Mount Gould, which is located approximately 15 km north-northwest of Mount Taylor (Simpson, 1952). The main rock types in the area are north-northeasterly trending mafic and ultramafic Archaean rocks with some granitoid. Talc schists striking east-northeast outcrop at the foot of the northern slope of Mount Gould (Ellis, 1963).

Minor occurrences

Mooloo Downs

Location: Lat. 25°03'00"S, Long. 116°03'20"E (approximately); GLENBURGH

Talc from approximately 6.5 km east of Mooloo Downs Station is somewhat iron stained but is considered to yield good powder (Simpson, 1952). No other details are available.

Yarra Yarra Creek

Location: Lat. 25°57'20"S, Long. 115°56'30"E (approximately); GLENBURGH

Outcrops of greenish, massive talc are found in Yarra Yarra Creek, close to Yarra Yarra Station (Simpson, 1952). The talc is reported to yield a good white powder suitable for the rubber and pottery industries, but cracks badly when heated to 1150°C.

Eastern Goldfields, Yilgarn Craton

Regional geology

The Eastern Goldfields Province is a typical Archaean granite–greenstone province that occupies the eastern sector of the Yilgarn Craton. It consists of large areas of granitic rocks and linear to arcuate belts of greenstone, mainly with a north-northwest trend. The greenstones exhibit various degrees of deformation, and have undergone greenschist facies metamorphism (Griffin, 1990a). The province is overlain unconformably by sedimentary rocks of the Naberu Basin in the north and northeast; and by sedimentary rocks of the Officer Basin in the east. It has become incorporated into the Albany–Fraser Orogen to the south. Basement rocks are unknown. The north-northwest trending Mount Ida Fault forms the boundary between the Eastern Goldfields Province and the Southern Cross Province to the west. In general, granitoid rocks are more poorly exposed than the greenstone, and the main types are granitic gneiss, foliated and unfoliated granitoids and small discordant granitoid stocks. In the greenstone belts the lowest parts are mostly mafic to ultramafic volcanic rocks, overlain by felsic volcanic rocks and clastic sedimentary rocks. The age of the granite–greenstone rocks in the province is between 2600 Ma and 2800 Ma (McCulloch et al., 1983).

The Eastern Goldfields Province, as the name implies, is better known for gold and for nickel than talc, although talc alteration may be closely associated with gold. Large deposits of commercial grade talc are unknown within the province, and the known occurrences are mainly confined to greenstone belts bounded by Ravensthorpe in the south, Coolgardie in the west, Comet Vale in the north and Bulong in the east. The only locality where there has been commercial production in the past is at Mount Monger,

but it is possible that other areas of talc mineralization of commercial interest may exist within the greenstone belts.

Mount Monger

Location: Lat. 31°01'20"S, Long. 121°55'20"E; WIDGIE-MOOLTHA

Talc has been produced at Mount Monger, 59.5 km southeast of Kalgoorlie (Clarke, 1925a; Ellis, 1944) where talc and soapstone were mined from hangingwall, footwall and matrix material of gold-bearing shears. The mining took place on a lease named Loganberry (Fig. 16), a few kilometres northwest of Mount Monger, within the Lass O'Gowrie mining centre. The total production between 1942 and 1957 was 1411 t valued at \$12 050 (Tables 6 and 7).

Geology

The Mount Monger deposit is located within the southerly extension of a north-northwest trending Archaean sequence consisting of mafic and ultramafic rocks with conglomeratic beds, intruded by late dykes. Gray and Low (1950) recognized serpentinites containing soapstone and talc, with porphyries, metasedimentary rocks with thin jaspilites, and gabbro intrusions in the area. The serpentinites form a continuous belt that trends northwest. A more detailed description of the geology of the Mount Monger area is given by Hickman (1986). The sheared auriferous quartz veins trend northwest, with westerly to southwesterly dips of 30° to 60°, and are cut by minor easterly trending shears with moderate dips. The talc occurrences are foliated lenses that pitch steeply to south. Other talc occurrences have been found approximately 2 km southeast of the old workings, within former MC 14E, but there is insufficient information to estimate the extent of these discoveries. Ellis (1951) described a 9 m-deep shaft sunk in good-quality talc with a foliation striking 325° and a 60° southwesterly dip. The talc is pitted and brownish at shallow depth, but changes to pale-green, less pitted material at depth. The thickness of the talc in this shaft would be about 3 m, with the hangingwall not exposed. There are other parallel occurrences of foliated talc in nearby trenches.

Mining

Soapstone was produced in the form of blocks of coarse- and medium-grained talc-tremolite rock, with dimensions of 0.3 m × 0.3 m × 0.15 m and 0.15 m × 0.15 m × 0.15 m, obtained from workings from the surface to 30 m vertical depth. The maximum width available was 0.5 m, and the longest exposure in a drive was 6 m of soapstone. There is minor high-grade talc in veins.

Grade and resources

The talc and soapstone from Loganberry Lease were considered to be superior in quality to that from Glen Lynn (discussed later) in having more talc and fewer relict

minerals (Ellis, 1944). However, no pure talc suitable for cosmetic grade has been produced from this deposit. The best quality talc in the area southwest of Loganberry is pale apple-green with a small proportion of relict minerals (Ellis, 1951). It yields an off-white, grit-free, smooth powder, and would be suitable for the paper, paint and rubber industries. The high-grade, but foliated, talc is unlikely to be suitable for surface linings, which would crack under high pressure. The GCL (*in* Gray and Low, 1950) described two samples collected from this locality as follows:

Lab No. 6958/49. Mark No. 2

Greenish, foliated talc with flakes of chlorite and scattered crystals of rutile and dark-green spots that consist of chlorite with remnant cores of iron ore. The rock is readily crushed to a very slightly greenish white powder; the slight grittiness evident on crushing is not detectable in the fine powder, which is unctuous and adheres well to the skin. This material is suitable for industries requiring a high-grade, gritless talc powder such as for paint, rubber and industrial dust manufacture. One specification for talc for use in manufacture of vulcanized battery cases provides that the amount of manganese (Mn) present shall not exceed .005%. The slight greenish tinge may be detrimental to its use as a high-grade paper filler.

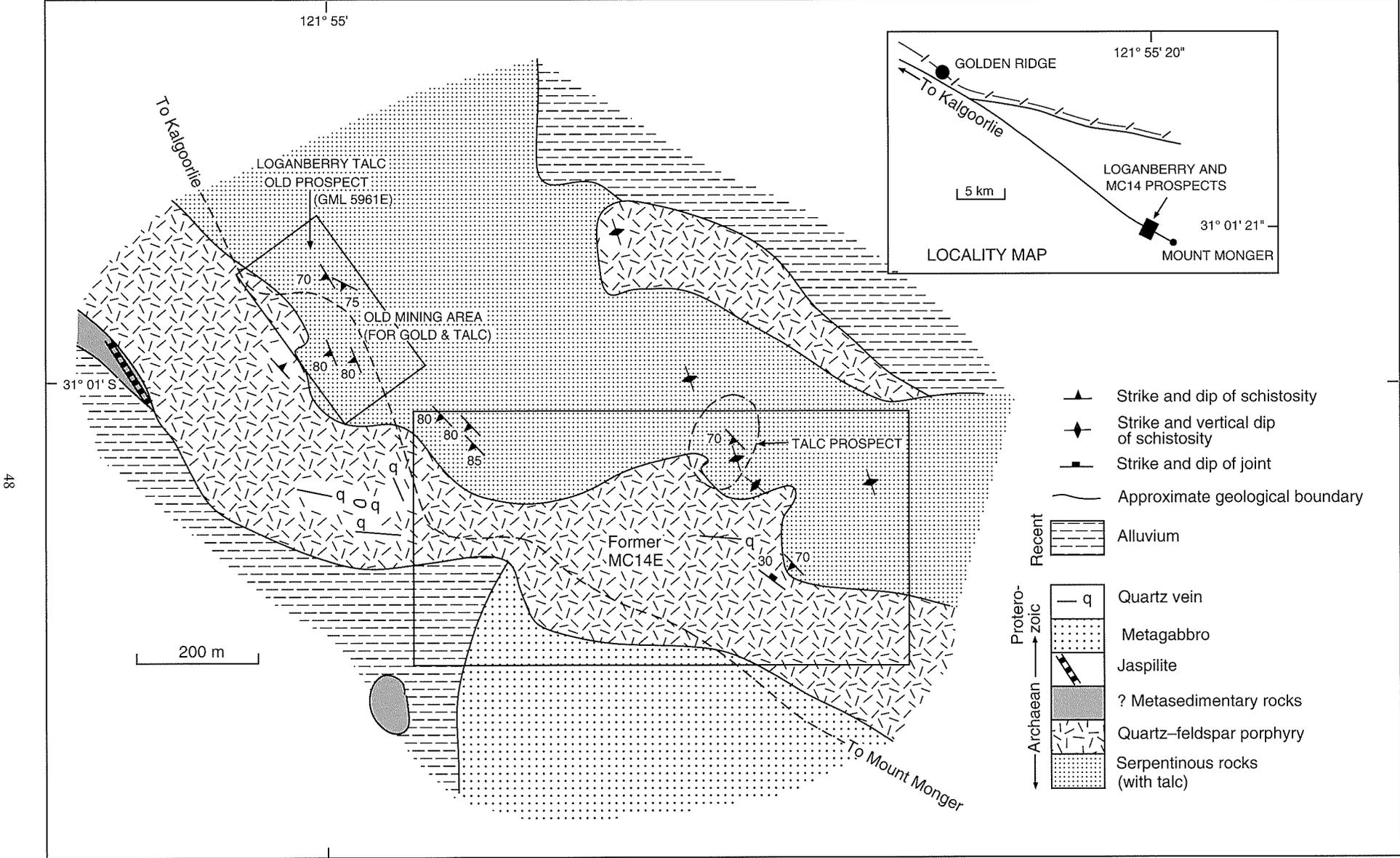
Lab No. 6959/49. Mark No. 3

Greenish, foliated, almost identical with 6958/49 above, but with no rutile present. A sawn block when heated slowly in a muffle furnace disintegrated along foliation planes at a temperature of approximately 600°C. This appeared to be due to segregations of chlorite in the block. The talc is quite unsuitable for the manufacture of furnace blocks.

A pale-green sample (117357) collected from a dump at an old mine shaft, at Lat. 31°02'30"S and Long. 121°56'36"E, analysed using XRPD, contained 50–60% talc, 5–10% dolomite, 30–40% corrensite and traces of chromium and nickel. Corrensite is a multilayer mineral consisting of regular interstratification of alternate chlorite and smectite or chlorite and vermiculite layers. This sample also contains traces of visible secondary gold, mainly in goethite-lined, oxidized sulfide casts. SEM/EDXRA studies indicate that the gold is of high purity with no detectable silver but has possible traces of magnesium and iron.

Exploratory work carried out so far is insufficient to assess the quality and quantity of the resources available. However, Ellis (1951) was of the view that the potential of the deposit was very good, and there were good indications of being able to extract considerable quantities of foliated, massive, high-grade, grit-free, off-white talc. He also anticipated that talc suitable for cosmetic grade would be available.

Chemical analysis of three samples of pale-green, foliated talc average 59.71% SiO₂ and 29.94% MgO, close to the chemical composition of pure talc (Table 15). These samples contained flakes of chlorite, scattered crystals of



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Figure 16. Geology around Loganberry, former Gold Mining Lease 5961E and Mineral Claim 14E, west of Mount Monger (after Gray and Low, 1950)

Table 15. Chemical analyses of talc from Mount Monger (major and trace elements)

Sample no.	A	117357	117358
	percentage		
SiO ₂	59.52	60.10	59.50
Al ₂ O ₃	1.48	1.45	1.53
Fe ₂ O ₃	0.39	0.75	0.44
FeO	2.20	1.67	1.68
MnO	0.02	<0.05	<0.05
MgO	30.61	29.30	29.90
CaO	0.18	0.07	<0.05
Na ₂ O	0.05	0.21	0.19
K ₂ O	–	<0.05	<0.05
H ₂ O ⁻	0.08	0.21	<0.1
H ₂ O ⁺	4.98	5.49	5.34
TiO ₂	0.05	<0.05	0.05
CO ₂	0.03	0.29	0.22
P ₂ O ₅	0.03	<0.05	<0.05
Cr ₂ O ₃	0.26	–	–
V ₂ O ₃	–	–	–
S	–	<0.01	<0.01
Rest	–	0.39	0.59
Total	99.88	99.83	99.44
	Trace elements in parts per million		
Cr	–	958	1 616
Ni	–	1 868	2 654
Pb	–	<4	<4
As	–	<4	<4
Cu	–	6	4
Ga	–	3	4
Mn	–	224	324
Zn	–	28	41
Zr	–	15	16

NOTES:

Sample A, after Ellis (1951)

Sample 117357 Lat. 31°02'30"S, Long. 121°56'36"E (from dumps of an old mine shaft)

Sample 117358 Lat. 31°02'37"S, Long. 121°56'42"E (from dumps of an old mine shaft)

rutile and spots of iron oxide. The Cr and Ni contents of these samples are much higher than those from Three Springs and Mount Seabrook, consistent with their derivation from an ultramafic source rock.

Minor occurrences

Talc-bearing rocks are a common feature in any deformed greenstone terrane such as the Eastern Goldfields Province. Many such occurrences have been described by previous workers, but with scant information on their precise locations and extent. These occurrences are summarized in Table 16.

South Western terranes, Yilgarn Craton

Regional geology

The South Western terranes tectonic unit of the Yilgarn Craton (Myers, in prep., Myers, 1990b), is bounded by the

Albany–Fraser Orogen to the south, Southern Cross Province to the east and northeast, the Murchison terrane to the north, and the Darling Fault and Moora Group to the west. The main geologic units within the South Western terranes are granitoid, the Jimperding Gneiss Complex and the Balingup Gneiss Complex. The granitic rocks that intrude the Jimperding and Balingup Gneiss Complexes are the most widespread rock type in the province. The granitic rocks are less deformed and younger than granitoids of the Narryer Terrane and are partly recrystallized in greenschist facies, and have been mapped as even-grained, seriate, or porphyritic granitoids. The Saddleback Greenstone Belt lies within these granitoids and consists of metamorphosed siltstone, felsic lava, pyroclastic rocks and basalt (Wilde and Pidgeon, 1986). The Jimperding Gneiss Complex consists of metasedimentary and ultramafic rocks and banded quartzofeldspathic orthogneiss. The metasedimentary rocks are mainly fuchsite-bearing quartzite, quartz–feldspar–biotite–garnet gneiss, andalusite and sillimanite schist, banded iron-formation and minor calc-silicate rocks. The Balingup Gneiss Complex consists mainly of metasedimentary rock, quartzofeldspathic gneiss, amphibolite, calc-silicate gneiss and ultramafic rock (Wilde, 1980). Metasedimentary rocks are mainly interlayered quartzite, quartz–mica schist, quartz–feldspar–biotite–garnet gneiss and banded iron-formation. The Balingup Gneiss Complex is affected by amphibolite-facies metamorphism, although localized assemblages of granulite-facies metamorphism are present.

Talc mineralization occurs at the western margin of the Jimperding Gneiss Complex, at the contact zone between granitic rocks and probable greenstones, and also within the Balingup Gneiss Complex. The occurrences are generally not extensive and large deposits of commercial-grade talc are unknown. Deposits in a few localities have been commercially exploited in the past, but on a very small scale.

Glen Lynn and Bridgetown

Location:

Glen Lynn Lat. 34°01'29"S, Long. 116°09'33"E;

PEMBERTON

Bridgetown Lat. 33°58'20"S, Long. 16°08'00"E (approximately); COLLIE

The first recorded production of 259 t of talc from Glen Lynn was in 1942 (production listed in Table 6 includes 10 t from PA1 PP in Balingup area). The deposit produced a total of 564 t between 1942 and 1951, valued at \$3806 (Tables 6 and 7). The talc was mined from an area 2.4 km south of Glen Lynn. Talc has been seen from several small shallow costeans at various times (Forman, 1944; Simpson, 1952; Ellis, 1963; Wenham, 1976). The talc is a massive, greenish-grey soapstone containing chlorite, rutile and actinolite. Testing indicated that the material was suitable for block making, but there were difficulties in locating massive talc bodies large enough to produce 30 cm³ blocks on a continuous basis. The powdered ore is gritty and multicoloured. The country rock is not exposed, but appears to be weathered biotite schist, gneissic granitoid,

Table 16. Minor occurrences of talc in the Eastern Goldfields Province of the Yilgarn Craton

<i>Locality</i>	<i>Lat. (S)</i> <i>(approximate)</i>	<i>Long. (E)</i> <i>(approximate)</i>	<i>Remarks</i>	<i>References</i>
Bulong	30°45'00"	121°50'00"	Carbonated talcose rocks are known west of Bulong	Feldtmann (1918, 1919)
Comet Vale	29°57'30"	121°07'30"	White and pale-green pure talc occurs in talcose schists west of Comet Vale, at the old Sand Queen mine and in other areas in the district	Jutson (1921) Farquharson (1921) Ellis (1963)
Coolgardie	30°56'40"	121°10'30"	Widespread hornblende talcose rocks occur east of the granitoids in the Coolgardie region. A vein of pure talc was reported from drilling at the old Phoenix GML. Talc-carbonate rock, with tremolite and chlorite, is developed by wall-rock alteration of serpentinites around the gold lodes at Bayleys mine	Blatchford (1899) Maitland (1900) Simpson (1952) Blockley (1956)
Darlot	27°53'30"	121°16'30"	Talc is associated with quartz on old GML 648 known as Monte Christo	Gibson (1907) Ellis (1963)
Feysville	30°57'00"	121°36'00"	Talc carbonate rocks are known south of Hannans Lake. Location is described as 0.6 km north of quartz blow on GML 3945E	Honman (1916) Ellis (1963)
Golden Ridge	30°51'00"	121°40'00"	A typical talc schist is exposed at the eastern area of the abandoned Golden Ridge mine	Honman (1916) Ellis (1963)
Kalgoorlie	30°44'00"	121°28'00"	Minor occurrences in the district. Boulders of talc schist were reported 3 km south of Boulder and 1 km west of the Cemetery Reserve	Feldtmann and Farquharson (1913) Ellis (1963)
Kanowna	30°36'00"	121° 36'00"	Talc-chlorite-calcite rocks occur at the old Robinson mine and Last Chance mine	Blatchford (1912) Feldtmann (1916) Ellis (1963)
Lawlers	28°05'00"	120°31'00"	Talc was encountered in the Emu Bore No. 1	Blatchford (1912) Feldtmann (1916) Simpson (1952)
Linden	29°18'00"	122°25'00"	A prominent talc schist is known to occur northwest of the Bore Well on the Linden-Edjudina road	Honman (1917) Ellis (1963)
Mulgarrrie	30°23'00"	121°30'00"	At the old GML 1326, approximately 1 km east of the reserve, is known to contain highly talcose greenstone	Ellis (1963)
Ora Banda	30°22'00"	121°04'00"	Talc occurs as a constituent mineral in some altered country rocks in the vicinity of lode channels	Jutson (1914) Ellis (1963)
Paddington	30°28'40"	121°20'20"	Talc schist is known in a tunnel at the west side of a hill of quartz reef, located between the 41 Milepeg (66 km) and 42 Milepeg (67.5 km) on the railway line	Ellis (1963)
Pykes Hollow	29°07'00"	122°10'40"	Talc is known a few hundred metres east of old GML 3461	Honman (1917) Ellis (1963)
Siberia	30°14'00"	120°57'00"	Talc schist is a major rock unit in the mineral belt at Siberia and the outcrops occur near the cemetery	Ellis (1963)
Windanya	30°23'00"	121°15'00"	The auriferous quartz veins in the area are often associated with serpentinous talcose rocks containing veins of talc	Simpson (1905, 1952)

Table 17. Description of talc samples from Glen Lynn and Bridgetown

Locality	Lab. no.	Sample	Mineral composition	Chemical composition (approx. %)					Powder	Ashley Test	Block form	Remarks
				Al ₂ O ₃ (a)	Fe ₂ O ₃	Cr ₂ O ₃	CaO	K ₂ O				
Loc. 503, Glen Lynn, from costean at northeast end of deposit	CC2278/40	(a) Sawn slab 65 mm thick <i>Greenish-grey massive soapstone</i>	Talc, chlorite, rutile, minor actinolite	5.0	7.0	0.7	tr	nil	Pale olive-grey to pearl-grey, slightly gritty	28/100	Free from faults, but small cracks developed at 1250°C. No shrinkage	All three samples do not yield a good white powder. However, the blocks are suitable for marketing
		(b) Sawn slab 50 mm thick <i>As for (a) but iron stained</i>	Talc, chlorite, actinolite, 12% rutile, limonite	4.9	7.8	pr	1.2	nil	Cartridge-buff to ivory-yellow, harsher than (a)	—	Strong and free from flaws, small cracks at 1250°C. Shrinkage 0.7%	
		(c) Sawn slab 50 mm thick <i>Similar to (a) and (b)</i>	Talc, chlorite, actinolite, rutile, limonite	—	—	—	—	—	Pale olive-buff to pale olive-grey, slightly gritty	—	As for (a) and (b)	
Loc. 504, Glen Lynn, from costean at south-western end of deposit	2279/40	(a) Sawn slab 50–65 mm thick <i>Weathered massive soapstone</i>	Talc with some chlorite and a little actinolite and limonite	—	—	—	—	—	Buff pink	—	Strong, no shrinkage at 1250°C. Badly cracked	Iron staining restricts use as powder (a) cracked badly in block form
		(b) Sawn slab 50 mm thick <i>Mottled brown to greenish-grey, massive soapstone</i>	Talc with a little chlorite and a few grains of rutile	4.4	7.7	pr	nil	nil	Light pinkish, cinnamon, slightly gritty	—	Strong, shrinkage at 1250°C — 0.8%. Small cracks developed and also soft patches	(b) developed soft patches
Loc. 564, Bridgetown	2280/40	Irregular boulder of talc rock 100–125 mm thick <i>Foliated scaly talc rock</i>	Talc, chlorite with small amounts of actinolite, limonite, chromite	8.2	5.6	pr	nil	nil	Pale ochreous-salmon to light buff. Slightly gritty	24/100	Foliated, but small blocks were free from flaws. Shrinkage at 1250°C was 1.2%. No cracks developed	Suitable for use in blocks after burning. Powder rather highly coloured

NOTES: after Simpson (1952)
Analyst: H. P. Rowledge
(a) Al₂O₃ includes TiO₂ and Cr₂O₃
pr = present
tr = trace

gneissic granitoid, pegmatite and quartz veins intruded by granitoid and coarse-grained greenstone. The physical and chemical properties of a sample from this location, and another from one km south of Bridgetown, are given in Table 17.

The talc was formed by local alteration of lenses of ultramafic rocks within the metamorphic complex.

Bolgart

Location: Lat. 31°20'30"S, Long. 116°28'20"E; PERTH

There is a record of 274 t of talc valued at \$2688 (Table 6) being mined in 1952 from a property owned by Mr J. Butterley, located 9 km south-southwest of Bolgart. The output came from a number of shallow pits and opencuts between 1 and 3 m deep, within an area of about 45 m × 75 m. There are no outcrops in the area, but there are altered ultramafic rocks in the general region that contain talc and asbestos (Wilde and Low, 1978; Wenham, 1976).

Berliat (1955b) was of the view that the talc was not of uniform grade although some specimens of a pale-green, fine-grained compact variety produced a greyish white powder of probable cosmetic grade. Other specimens scattered throughout the Bolgart area were darker, coarse grained and seemed to be of inferior quality, with only partial alteration to talc. Simpson (1952) described samples of greenish massive talc yielding a very pale-green powder that were probably collected from Bolgart. The talc included minor tremolite or anthophyllite and was sufficiently free from cracks to be used for insulating blocks, but proved to be unsuitable for furnace linings, cracking badly when heated to 1150°C.

Meanys Bridge and Balingup

Location: Lat. 33°45'00"S, 116°03'20"E; COLLIE

A soapstone deposit lies in a complex of quartz-mica gneiss, quartz veins and quartz dolerite dykes at Meanys Bridge, approximately 8 km north of Greenbushes (Matheson, 1944; Wilde and Walker, 1982). The deposit consists of 17 lenses of soapstone. However, these lenses are discontinuous at depth and therefore are of no commercial value. The recorded production of 10 t in 1942 from PA1 PP (included in production figures of Glen Lynn in Table 6) is possibly from this location. The exact location is unknown, but PA1 PP was reported to be a few kilometres east of Balingup.

Simpson (1952) noted the occurrence of massive talc at a location approximately 8 km east of Balingup, which is possibly the area around Meanys Bridge described earlier. The talc is pale greenish grey, scaly and has no prominent foliation. Other talc occurrences are also known near the ballast pit at the 101 milepeg (162.5 km) on the old railway line. An analysis of talc from the latter location gave 57.26% SiO₂, 27.57% MgO and 6.77% FeO (Table 18).

Table 18. Chemical analyses of talc from Balingup, Mullalyup and Mount Hardy

	<i>Balingup</i> (a)	<i>Mullalyup</i> (a)	<i>Mount Hardy</i> (b)
	percentage		
SiO ₂	57.26	61.75	60.80
TiO ₂	—	—	0.04
Al ₂ O ₃	3.87	0.71	0.70
Fe ₂ O ₃	0.73	0.67	1.43
FeO	—	1.24	3.09
CaO	tr	0.05	—
MnO	6.77	—	0.02
MgO	27.57	31.11	28.00
Na ₂ O	—	—	<0.05
K ₂ O	—	—	0.03
P ₂ O ₅	—	—	0.01
NiO	—	—	—
H ₂ O ⁻	0.45	0.16	—
H ₂ O ⁺	3.73	4.85	—
VOL	—	—	5.32
Total	100.38	100.54	99.44

NOTES: (a) after Simpson (1952)
(b) after Morris and Jones (1990)
tr — trace

York (Mount Hardy, Mount Bakewell)

Location: Lat. 31°53'20"S, Long. 116°46'30"E; PERTH

Talc occurs near York at two localities, Mount Hardy and Mount Bakewell, as follows:

Mount Hardy: Soapstone at Mount Hardy (Lat. 31°55'30"S, Long. 116°46'30"E) approximately 6 km south-southeast of the York–Beverley road, was inspected by Morris and Jones (1990). They found that the soapstone was limited to a small area less than 2 m wide and 5 m long, striking at approximately 060°. Talc has possibly formed by metamorphism of a lens of ultramafic rock within banded garnetiferous quartz-feldspar-muscovite gneiss. A chemical analysis of a sample of soapstone indicates that it is very similar to typical talc and contains appreciable Ni and Cr (Table 18), suggesting its derivation from an ultramafic source.

Mount Bakewell: This locality (Lat. 31°50'00"S, Long. 116°46'30"E) lies approximately 5 km north of York and approximately 3.5 km northeast of Mount Bakewell (Simpson, 1952). The talc is brownish grey, and a powdered sample contained fine scaly and fibrous aggregates of talc with scales of pale yellowish-green chlorite, and traces of limonite and chromite. The powder on fine grinding is drab grey and slightly harsh, owing to the presence of traces of iron oxide. Slabs developed cracks when they were burned. Chemical analysis shows 4.3% Al₂O₃, 9.6% Fe₂O₃ and 1.0% Cr₂O₃.

Minor occurrences

Minor occurrences of talc in the South Western terranes of the Yilgarn are summarized in Table 19.

Albany–Fraser Orogen

Regional geology

The Albany–Fraser Orogen adjoins the southern and southeastern margins of the Yilgarn Craton. The area of interest for talc mineralization is its northern boundary with the Yilgarn Craton, where Mount Barren Group rocks are exposed. The Mount Barren Group consists of three formations, namely the Steere Formation, the Kundip Quartzite and the Kybulup Schist (Thom and Chin, 1984). The Steere Formation consists of quartzite, conglomerate and dolomite, whereas the Kybulup Schist is derived from pelitic and semipelitic rocks. A notable feature of the Kundip Quartzite is that it is intruded by dolerite sills.

Significant talc mineralization is known within the Mount Barren Group in the Kundip area.

Kundip

Location: Lat. 33°42'00"S, Long. 120°08'20"E; RAVENSTHORPE

Marymia Exploration NL holds ground southwest of Kundip, where it commenced exploration for talc in 1991. The project area is located approximately midway between Hopetoun and Ravensthorpe. The company's aim is to look for talc mineralization in altered Proterozoic dolomitic rocks in settings similar to those at Three Springs. Work carried out so far includes geological mapping, RAB drilling and assessment of talc quality.

Simpson (1952) and Ellis (1963) noted an occurrence of high-grade, coarsely crystalline talc at a locality 6.5 to 8 km from Kundip (direction not given), on the east side of Ravensthorpe Range. The talc is pale sea-green and yields a white powder. The material was considered to be unsuitable for production of slabs or blocks because of its strongly foliated nature. A chemical analysis of a sample showed a typical talc composition (Table 20), with SiO₂ 63.39% and MgO 30.22%. The nickel content of 0.29% suggests derivation from ultramafic rocks.

Geology

The project area is mainly within the Mount Barren Group in the northern part of the Albany–Fraser Orogen (Fig. 17). Rock types present include stromatolitic dolomite, phyllite, quartzite and minor conglomerate. According to Parks (1991) the dolomitic units in the area are more widespread than those described by earlier workers. She stated that dolomite grades laterally into dololite, siltstone and metasedimentary rocks, and recognized two dolomitic units, one at the base of the succession and

another possibly overlying the phyllites. The dolomite is typically massive and has a distinct karst-like appearance. It is capped by pink to red jasper up to 2 m thick. The lower dolomitic unit is richer in iron, and has a thicker jasper capping than the upper unit. Chert and secondary silica are also present as cappings. Quartzite in the area is well bedded and generally dips gently to the south, but dips become steeper near the boundary of the migmatite–gneiss belt of the Albany–Fraser Orogen. Regionally, the quartzite varies in composition from orthoquartzite to more schistose and pelitic varieties containing up to 50% andalusite (Thom et al., 1977). Phyllite and schist are commonly chevron folded due to mild thrusting (Sofoulis, 1958), and in places they appear to be graphitic and manganeseiferous. At East Mount Barren the phyllite has been metamorphosed to kyanite–staurolite–garnet schist.

Ms J. Parks discovered talc mineralization within the areas held by Marymia Exploration NL during systematic geological mapping at a scale of 1:25 000 (Evans, J., 1995, pers. comm.). Within the tenements the phyllites are deformed and altered to white and pale-green kaolin–sericite–quartz assemblages that contain talc-rich horizons. Minor ultramafic rocks, deformed and altered to talc–carbonate–chlorite–saussurite assemblages were also noted within the Mount Barren Group. They seem to occupy the central part of the Proterozoic sequence, and have been correlated with the Cowerdup Sill (Parks, 1991). Witt (1992) has suggested that these ultramafic horizons and the talc-rich schist may be thin slices of Archaean ultramafic rocks caught up and interleaved with the Proterozoic sedimentary rocks during thrusting of the Archaean Yilgarn Craton. The area is structurally complex. There is a prominent axial planar cleavage in a direction of 200° to 240° with a moderate to steep southeasterly dip. A second cleavage with a northwesterly trend is less commonly developed. Small-scale folds with southwesterly trending fold axes have been noted in the upper dolomitic unit.

Talc mineralization

A number of holes drilled in the area have intersected talc at varying depths from the surface to approximately 45 m (Fig. 18). Talc layers occur within kaolinitic, sericitic and other metasedimentary rocks such as phyllite, and talc may be associated with thin dolomitic horizons.

Quality

Talc is white to pale brown with a trace of very fine-grained quartz, tourmaline and opaques. Chemical analyses and XRD studies indicate that some samples are close to typical talc composition (Table 20) with quartz, kaolin and oxides of iron as impurities. The Cr, Ni and V contents are low, suggesting that derivation of talc from an ultramafic source is unlikely. Preliminary tests indicate that Kundip talc meets the requirements of the ceramic, paper filling and plastic industries (Parks, 1991).

Table 19. Minor occurrences of talc in the Yilgarn — South Western terranes

Locality	Lat. (S) (approximate)	Long. (E)	Remarks	References
Balkuling	31°59'00"	117°30'00"	Angular boulders of massive talc associated with serpentinous rocks occur approximately 1 km north of a ballast pit, 36 km west of Balkuling Siding. Fibrous talc also occurs near the ballast pit	Ellis (1963)
Beverley	32°07'00"	116°55'00"	A fine, granular, grey to greenish rock composed largely of talc is found on the north side of the road on Fisher's Farm	Simpson (1952)
Collie	33°22'00"	116°09'00"	Soapstone containing anthophyllite as an impurity occurs near Collie. Exact location is unknown. It is unfit for cosmetics, possibly suitable for insulating blocks, but cracks badly at about 1100°C. Another occurrence is at Lyalls Hill, 11 km from Collie	Simpson (1952)
Coondle	31°29'00"	116°26'00"	A talc-rich rock occurs approximately 5 km from Coondle along the Clackline-Miling line. Talc is stained with oxides of iron	
Culham	31°23'00"	116°26'45"	A talc specimen from Culham (6.5 km NNW) contained 60.02% SiO ₂ , 27.24% MgO, 5.45% iron oxide. Anthophyllite, tremolite and actinolite were present. Another specimen from the same locality is classified as commercial quality	Simpson (1952)
Donnelly River	34°05'00"	116°05'00"	Steeply dipping beds of steatite interbedded with Precambrian rocks occur between the abandoned graphite mine at Donnelly River and Wilgarup. Also white talc of reasonable quality is reported from E70/174 in the Donnelly River area	Simpson (1952) Astro Mining (1987)
Donnybrook	33°34'00"	115°49'00"	Steatite occurs on the footwall of an auriferous quartz reef in Bourke and Hunter's old claim at the south end of Block 268	Simpson (1952)
Goomalling	31°18'00"	116°50'00"	A narrow belt of talc at Goomalling contains some asbestos and is derived from serpentinite	Simpson (1952)
Hamersley Siding	31°46'00"	116°43'00"	Massive, soft, greenish-grey talc contains specks of a black mineral, possibly magnetite or chromite	Ellis (1963)
Kirup	33°43'00"	115°54'00"	A talc rock contains some magnetite and actinolite, 16 km from Kirup. There are no more precise directions	Simpson (1952)
Manjimup	34°15'00"	116°09'00"	A sample of impure and iron-stained talc collected from this district appeared to have no commercial value	Simpson (1952)
Mullalyup	33°45'20"	115°57'00"	Creamy white, finely micaceous talc occurs in weathered biotite schist. It is considered to be suitable for rubber and other industries, and is free from grit and yields white, fine, scaly powder	Simpson (1952) Ellis (1963)
St Johns Brook	33°50'00"	115°54'00"	Massive and micaceous foliated talc occurs at the head of St Johns Brook, 29 km south of Donnybrook. The massive talc is fine, scaly and brownish, whereas micaceous talc is colourless to pale-green and yields a white powder	Simpson (1952)
Wagerup	32°57'00"	115°54'00"	Impure talc is reported from the vicinity of Wagerup	Simpson (1952)
Wellington Mill	33°29'00"	115°54'00"	Granular actinolitic talc is found with vermiculite in a small pit 1.5 m deep, approximately 3 km south of Wellington Mill. Float of foliated, iron-stained and scaly talc spreads over approximately 300 m ² overlying biotite granitoid	Ellis (1963)
Wongamine	31°31'20"	116°40'00"	Talc with minor chlorite, magnetite and ilmenite occurs in the Wongamine area. Samples could be ground to a fine powder containing minor grit. When heated to 800°C the sample broke up	Simpson (1952)

Minor occurrence

Bremer Bay

Location: Lat. 34°12'20"S, Long. 119°19'00"E (approximately); BREMER BAY

Massive, foliated talc of a whitish green colour has been reported from approximately 20 km northwest of Bremer Bay. It is said to be very pure and to somewhat resemble the talc from Kundip (Simpson, 1952). The general area is underlain by lateritized sedimentary rocks of the Eocene Plantagenet Group, with a few inliers of granitic basement. The location given by Simpson (1952) must be considered dubious.

Minor occurrences in other tectonic units

Southern Cross Province

The Southern Cross Province of the Yilgarn Craton is unconformably overlain by the Nabberu Basin to the north and is in tectonic contact with the Albany–Fraser Orogen to the south. It is bounded to the east by the Eastern Goldfields and to the west by the South Western terranes and the Murchison terrane (Myers, in prep.). Boundaries between these provinces are not well defined. Both greenstone and granitic rocks are strongly deformed, with evidence of polyphase deformation. Ages range between 2.5 and 3.1 Ga (Griffin, 1990b). All the rocks have a dominant north-northwesterly trend similar to that of the Eastern Goldfields rocks. The greenstones consist of an upper and a lower sequence separated by a major unconformity. The lower sequence consists of a quartzite unit at the base overlain by dominantly mafic and ultramafic volcanic rocks, with clastic sedimentary rocks and minor felsic volcanic rocks at the top of the sequence.

Only three talc occurrences are known in the Southern Cross Province — two are within the greenstone belt at Southern Cross and Bullfinch, and the third is northwest of Dandarga (south of Sandstone).

Bullfinch

Location: Lat. 31°06'40"S, Long. 119°12'20"E (approximately); SOUTHERN CROSS

Talcosed material is known from the west side of the road, approximately halfway between Southern Cross and Bullfinch. No other information is available (Blatchford, 1917; Ellis, 1963).

Sandstone

Location: Lat. 27°59'S, Long. 119°18'00"E (approximately); SANDSTONE

A sample of massive talc of commercial quality has been obtained from a location approximately 27 km

Table 20. Chemical analyses of Kundip talc (major and trace elements)

Sample no.	655613	655621	655622	832E/17	117309
	Percentage				
SiO ₂	63.40	63.60	65.40	63.39	62.50
Al ₂ O ₃	1.79	0.50	4.13	nil	2.22
Fe ₂ O ₃	0.47	1.83	1.20	0.08	0.25
FeO	—	—	—	1.24	<0.1
TiO ₂	0.02	0.04	0.29	—	<0.05
MnO	<0.01	0.02	0.01	nil	<0.05
MgO	28.14	28.50	22.80	30.22	28.00
CaO	0.02	0.03	0.01	nil	<0.05
Na ₂ O	—	—	—	—	0.35
K ₂ O	0.14	0.04	0.11	—	0.06
P ₂ O ₅	—	—	—	—	<0.05
CO ₂	—	—	—	—	0.51
S	—	—	—	—	<0.01
NiO	—	—	—	0.29	—
H ₂ O ⁻	—	—	—	0.20	0.22
H ₂ O ⁺	—	—	—	4.56	4.91
LOI	5.77	—	—	—	—
Rest	—	—	—	—	0.06
Total	99.75	94.56	93.95	99.98	99.08
	parts per million				
Cr	—	—	—	—	16
Ni	—	—	—	—	16
Pb	—	—	—	—	15
As	—	—	—	—	<4
Cu	—	—	—	—	21
Ga	—	—	—	—	<3
Mn	—	—	—	—	<5
Zn	—	—	—	—	212
Zr	—	—	—	—	20
V	—	—	—	—	19

NOTES: Samples 655613 and 655621 after Parks (1991)
Sample 832E/17 after Simpson (1952)
Sample 117309 Lat. 33°06'28"S, Long. 120°05'0"E (Analyses: C C)

southwest of Dandarga homestead, 17 km south of Sandstone. The sample was ground to a fine powder free of grit (Ellis, 1963).

Southern Cross

Location: Lat. 31°10'40"S, Long. 119°16'15"E; SOUTHERN CROSS

Talc specimens, presumably collected from a talc-schist band adjacent to a jaspilite between Southern Cross and Hopes Hill (approximately 7 km northwest of Southern Cross) were impure and considered to be of low quality. At Turkey Hill (approximately 13 km north of Southern Cross), a scaly granular talc rock is said to be abundant (Saint-Smith and Farquharson, 1913; Ellis, 1963).

Murchison terrane, Yilgarn Craton

Regional geology

The Murchison terrane lies in the northwestern part of the granite–greenstone terrane of the Yilgarn Craton (Watkins, 1990). To the east it is in contact with the Southern Cross Province and to the south with the South Western terranes

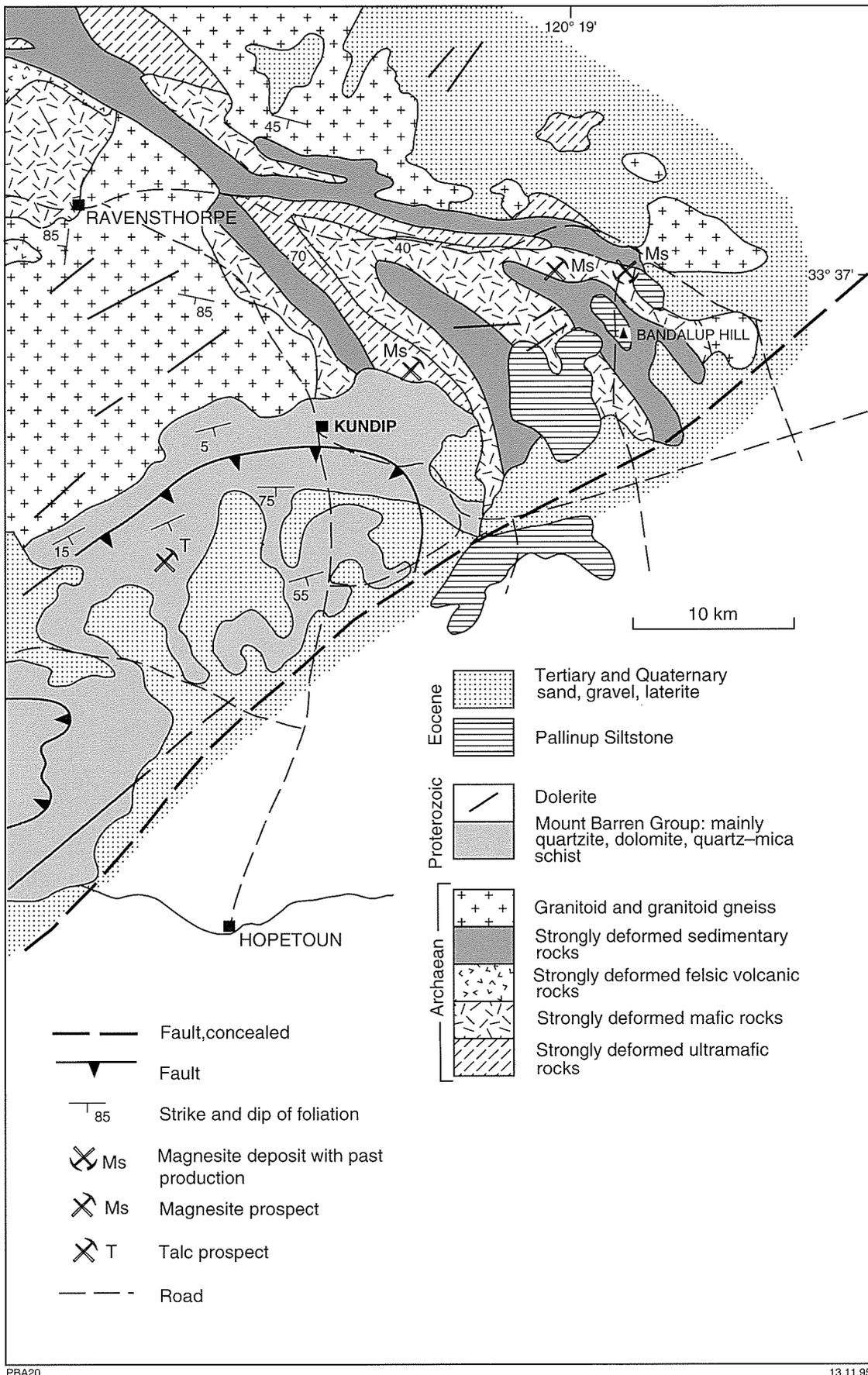
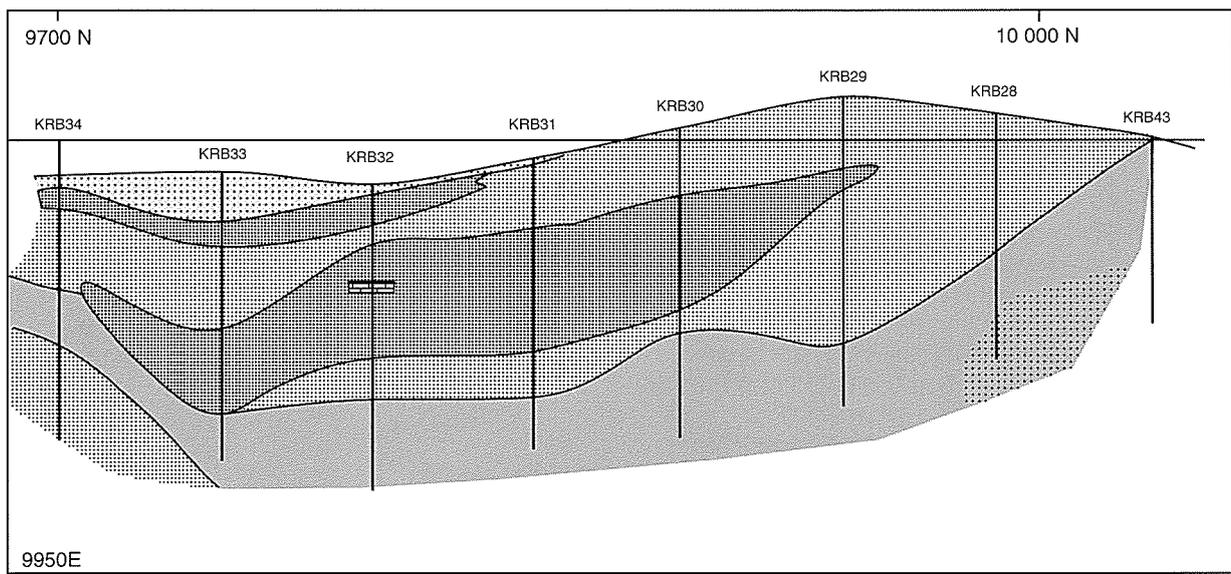
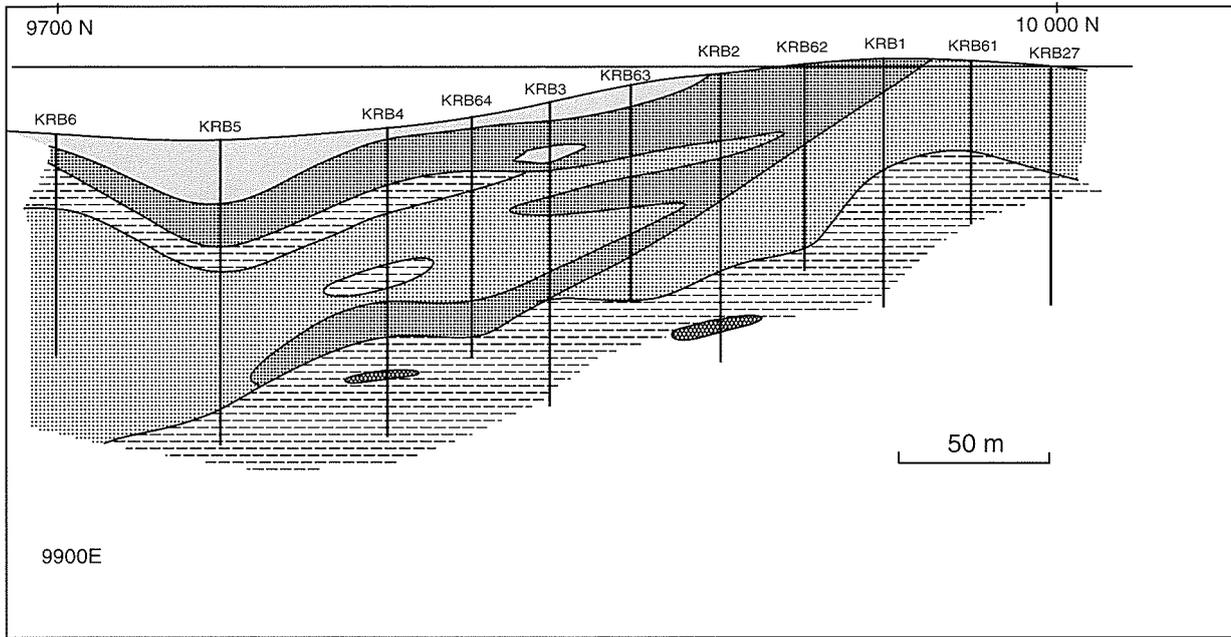


Figure 17. Regional geology of the Bandalup, Ravensthorpe and Kundip areas (modified from Myers, 1995)



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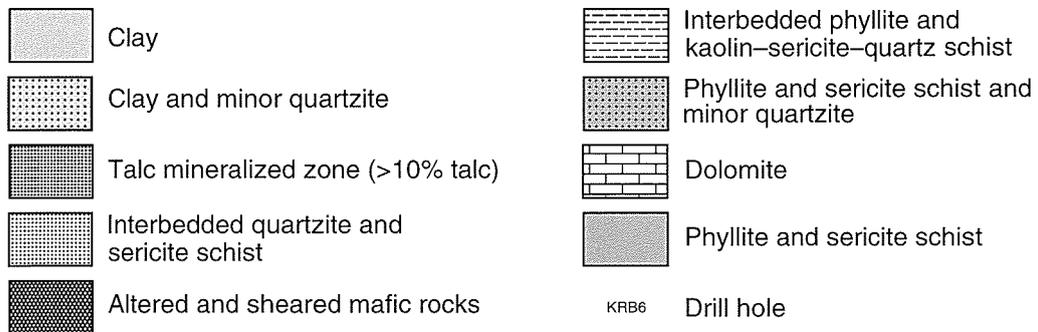


Figure 18. Cross sections along 9900E (top) and 9950E (lower) at the Kundip talc prospect (after Parks, 1991)

(Myers, in prep.); none of these boundaries is well defined. To the west it is in tectonic contact with the Moora Group and Phanerozoic rocks of the Perth Basin. The terrane is bordered to the north and northwest by the Narryer Terrane, and the northeast boundary is unconformably overlain by the Nabberu Basin.

The main rock types of the Murchison terrane are:

- (a) Supracrustal rocks of the greenstone belts;
- (b) Granitoid and granitoid gneiss;
- (c) Mafic and ultramafic intrusive rocks.

The supracrustal rocks make up the Murchison Supergroup, which is divided into the Luke Creek Group and the overlying Mount Farmer Group (Watkins and Hickman, 1990). Luke Creek Group rocks are continuous throughout most greenstone belts in the province, and form a layered stratigraphy about 10 km thick. The age of the Luke Creek Group is around 3000 Ma. The Mount Farmer Group has a limited lateral distribution and comprises the remnants of nine contemporaneous volcanic centres and one epiclastic sedimentary basin. This group has an age of about 2818 ± 57 Ma.

The Murchison Supergroup is intruded by four suites of siliceous plutonic rocks, and two of these have been folded and metamorphosed to pegmatite-banded gneiss and recrystallized monzogranite. Two monzogranite intrusions have ages of 2690 Ma and 2681 Ma. The other two suites of plutonic rocks retain igneous mineralogy and texture, and two plutons of this type have ages of 2641 Ma and 2617 Ma.

Mafic and ultramafic intrusions in the Murchison terrane are of two types: concordant sills in greenstone belts; and cross-cutting dykes, sills and plugs in both granitic rocks and greenstones. Cross-cutting intrusions of dolerite and gabbro have an age of 2400 Ma and represent the last phase of igneous activity in the Murchison terrane. The geological history of the Murchison terrane is summarized in Table 21.

The known talc occurrences in the Murchison terrane are associated with greenstones. However, very little information is available on these occurrences and they all appear to be small.

Cue

Location: Reedys Maranoa Leases, Lat. $27^{\circ}25'00''$ S, Long. $117^{\circ}46'30''$ E and Shamrock GML, Lat. $27^{\circ}33'00''$ S, Long. $118^{\circ}01'30''$ E (approximately); CUE

Pale, fibrous talc is found approximately 13 km west of Cue. It is presumably an alteration product of the amphiboles that occur in biotite schist at Reedys Maranoa leases. At this locality talc is laminated with hornblende, resulting in dark-green and white bands.

Talc-bearing schists are also known on the old Shamrock GML 540D at Jasper Hill, approximately 19 km southeast of Cue (Clarke, 1916; Simpson, 1952; Ellis, 1963).

Table 21. Geological history of the Murchison terrane

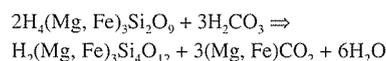
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- (l) D₅: development of east- to southeast-trending shear zones and faults in the northwestern part of the province
 - (k) Intrusion of a west- to west-southwest trending mafic dyke suite
 - (j) D₄: development of northwest- to northeast-trending shear zones and faults; there was much overlap between (i) and (g)
 - (i) Intrusion of post-folding granitoid plutons into greenstone belts and contacts between greenstone belts and earlier granitoids
 - (h) Regional metamorphism of granitoids and greenstones, mainly in greenschist facies
 - (g) D₃: tight to isoclinal, north- to northeast-trending upright folding of granitoids and greenstones; D₃ more intensely developed than D₂
 - (f) D₂: tight, east-trending, upright folding of granitoids and greenstones
 - (e) Intrusion of voluminous monzogranite as thick sheets into the base of the Murchison Supergroup; development of amphibolite-facies contact metamorphic aureoles
 - (d) Deposition of Mount Farmer Group greenstones, probably unconformably on Luke Creek Group greenstones and pegmatite-banded gneiss
 - (c) D₁: development of major recumbent folds, and possibly thrusts, in the Luke Creek Group; development of pegmatite-banded gneiss by deformation of granitoid sheets; (b) and (c) could have been contemporaneous
 - (b) Intrusion of monzogranite and granodiorite sheets
 - (a) Deposition of Luke Creek Group greenstones on inferred, unidentified basement at about 3.0 Ga
-

NOTE: after Watkins (1990)

Meekatharra

Location: Lat. $26^{\circ}35'40''$ S, Long. $118^{\circ}31'15''$ E; GLENGARRY

Clarke (1916) stated that talc is a very common rock-forming mineral at Meekatharra, and small quantities were detected in all the auriferous concentrates examined. Talc forms in altered peridotites and dolerites through an intermediate-stage serpentine, derived from olivine in peridotite and pyroxene–amphibole in dolerite. Mesitite (magnesite) is also commonly associated with talc as an alteration product of serpentine, as suggested by the following reaction:



Local removal of carbonate by underground waters leaves behind bodies of massive talc. A specimen from such a body was collected from a depth of 52 m in the State Battery Well. This specimen was slightly foliated, and a pale greenish colour. A more strongly foliated specimen, a green to buff colour, was collected along a small fault plane at 91 m in the Ingliston Extended gold

Table 22. Minor occurrences of talc in the Murchison terrane of the Yilgarn Craton

Locality	Lat. (S) Long. (E) (approximate)	Remarks	References
Mount Magnet	28°09'00" 118°20'00"	Talcoses rocks occur near Mount Magnet. A talc specimen from Boogardie (10 km west of Mount Magnet) is pale and foliated, with gritty partings	Simpson (1952)
Ninghanboun Hills	29°12'00" 116°25'00"	Talc, thought to be derived from amphibolite, occurs at the eastern end of the Ninghanboun Hills	Simpson (1952)
Poona	27°08'00" 117°27'30"	Massive and crystallized talc was obtained from a vein (10–15 cm wide and 1.8 m deep) in the Poona District. Blocks produced had too many flaws, but yielded a powder suitable for commercial grades	Simpson (1952)
Yaloginda	26°40'00" 118°25'30"	Talc rocks are known in the vicinity of Yaloginda, and talc–carbonate rocks are known at the northern end of Karanghaki workings	Clarke (1916) Simpson (1952) Ellis (1963)
Yoweragabbie	28°14'00" 117°39'00"	A large broadly laminated block of talc obtained from Yoweragabbie contained grey bands of soft, pure, fine-grained talc, and white bands of gritty and harsh talc	Simpson (1952)

mine. Clarke (1916) gave petrological descriptions of black talc–chlorite–carbonate rocks found in many mines in the northern parts of the Paddys Flat belt. They are generally sheared, greenish to black, soft, brittle talcoses rocks containing small euhedral magnesium carbonate crystals. Some specimens consisted of numerous small white rounded bodies of talc surrounded by yellowish green chloritic scales and scaly aggregates (Farquharson, 1912; Simpson, 1952; Ellis, 1963).

Other occurrences

Other occurrences of talc in the Murchison terrane are summarized in Table 22.

Marymia Inlier

Plutonic gold mine

Location: Lat. 25°13'40"S, Long. 119°33'15"E; PEAK HILL

A number of bands of talc schist are interbanded with mafic and ultramafic rocks that host the gold mineralization at the Plutonic gold mine. Talc schist generally occurs away from the main area of gold mineralization.

Outcrops of light-brown to yellowish, foliated talc schist are fairly well exposed approximately 2 km east of the tailings dam. Drilling at the locality of Kingston, approximately 500 m east of the above outcrops, intersected a band of talc schist more than 20 m thick, but its potential has not been investigated.

North Pilbara granite–greenstone terrane

Regional geology

The north Pilbara granite–greenstone terrane forms the northern third of the exposed area of the Pilbara Craton. The greenstones consist of metamorphosed basalt, felsic volcanic rocks, mafic and ultramafic sills, sandstone, shale, siltstone, chert, banded iron-formation, amphibolite and pelite, and psammitic and ultramafic schists (Griffin, 1990c). Granitic rocks constitute approximately 60% of the terrane, occupying anticlinal culminations or domes, and consist of monzogranite, syenogranite, granodiorite and migmatite. The greenstones have been dated between 3.6 Ga and 2.8 Ga (Blake and McNaughton, 1984). Hickman (1983) grouped all the Archaean greenstones of the north Pilbara Craton into the Pilbara Supergroup (Table 23).

Only minor talc occurrences are known in the granite–greenstone terrane; talc is commonly a constituent mineral in schistose rocks within greenstone. Most of these occurrences (summarized in Table 24) are in the Warrawoona Group of the Pilbara Supergroup.

Bangemall Basin

Regional geology

The Bangemall Basin contains a thick sequence of Proterozoic clastic sedimentary rocks known as the

Table 23. Stratigraphy of the Pilbara Supergroup

Formation	Main lithology	Thickness (km)
Mount Negri Volcanics	Basalt and andesite	0.2
Louden Volcanics	Basalt and ultramafic rocks	1.0
~~~~~ Unconformity ~~~~~		
<b>WHIM CREEK GROUP</b>		
Rushall Slate	Slate, minor tuff	0.2
Mons Cupri Volcanics	Felsic volcanic rocks	0.5
Warambie Basalt	Vesicular basalt	0.2
~~~~~ Tectonic contact ~~~~~		
DE GREY GROUP		
Mosquito Creek Formation	Psammitic-pelitic schist	5.0
Lalla Rookh Sandstone	Sandstone and conglomerate	3.0
~~~~~ Unconformity ~~~~~		
<b>GORGE CREEK GROUP</b>		
Honeyeater Basalt	Basalt (pillowed)	1.0
Cleaverville Formation	Banded iron-formation	1.0
Charteris Basalt	Basalt and dolerite (locally developed)	1.0
Corboy Formation	Metasedimentary rocks	1.5
~~~~~ Local unconformity ~~~~~		
Wyman Formation	Rhyolite	1.0
~~~~~ Unconformity ~~~~~		
<b>WARRAWOONA GROUP</b>		
Salgash Subgroup		
Euro Basalt	Basalt (and komatiite)	2.0
Panorama Formation	Felsic volcanic rocks and sandstone	1.0
Apex Basalt	Basalt (and high-Mg basalt and komatiite)	2.0
Towers Formation	Chert and basalt	0.5
Duffer Formation	Felsic volcanic rocks	5.0
~~~~~ Local unconformity ~~~~~		
Talga Talga Subgroup		
Mount Ada Basalt	Basalt	2.0
McPhee Formation	Ultramafic rock (maybe carbonated), schist and chert	0.1
North Star Basalt	Basalt	2.0

NOTE: after Hickman et al. (1990)

Bangemall Group. The group was initially subdivided into nine formations (Daniels, 1975), but was later modified to six subgroups and one major formation (Muhling and Brakel, 1985). Subsequent work in the area by Williams (1987) led to the proposed subdivision of the Bangemall Group given in Figure 19.

The known talc occurrences in the Bangemall Basin are confined to two localities.

Henry River (east of Maroonah)

Locations:

A: Lat. 23°25'30"S, Long. 115°44'30"E

B: Lat. 23°29'20"S, Long. 115°48'40"E; EDMUND

Kalgoorlie Southern Gold Mines NL and Unimil Pty Ltd explored for talc in an area east of Maroonah homestead and west of Henry River (Fig. 20) between 1981 and 1983. Areas of dolomitic rock of the Irregularly Formation are intruded by Proterozoic dolerite, and

were considered to be prospective for talc mineralization similar to that in the Three Springs region. Three Springs talc is thought to be formed by the metasomatic alteration of dolomite resulting from the intrusion of dolerite. Dolomite varieties include microcrystalline, massive, and finely laminated lithologies. They contain stromatolitic horizons. Associated rocks include quartzite and shale. Initial exploration by Kalgoorlie Southern Gold Mines NL identified three areas prospective for talc, including the two areas, A and B above, and shown in Figure 20.

The talc samples were of good quality, with high brightness, good slip and 5 to 10% clay. Further exploration work in the area by Unimil Pty Ltd indicated that talc zones occur in grey siliceous rock; and drilling in one of the prospective areas indicated that there is widespread serpentine but only minor talc development (Monks, 1983; Unimil Pty Ltd, 1984). Index NL (1988) conducted more exploration work in area B, where high-grade talc is scattered over an area of approximately 6 ha, and concluded that it is prospective for commercial talc deposits.

Table 24. Minor occurrences of talc in the north Pilbara granite-greenstone terrane

Locality	Lat. (S) (approximate)	Long. (E) (approximate)	Remarks	References
Bamboo	20°56'00"	120°12'00"	Talcosed serpentinitic rocks occur in No. 1 Bore of Kitchener mine	Simpson (1952); Ellis (1963)
McPhees Range	21°04'00"	118°59'00"	Talc-chlorite-carbonate schists are abundant at McPhees Patch, approximately 97 km southeast of Port Hedland	Simpson (1952)
Mount Francisco	21°22'00"	118°33'00"	Talc occurs in a narrow belt of greenstone at Mount Francisco, associated with chlorite, biotite, olivine, hypersthene, magnetite, ilmenite, apatite and spinel	Simpson (1952)
Peake Station (Wylloo)	22°30'00"	116°20'00"	A band of talc schist occurs 8 km northwest of Peake Station homestead, associated with greenstones that are thought to be part of the Pilbara Supergroup	Talbot and Simpson (1926) Simpson (1952); Ellis (1963)
Soanesville	21°20'00"	119°00'00"	Light-grey massive talc has been collected from Soanesville	Simpson (1952)
Warrawoona	21°19'00"	119°53'30"	A soft, green talc-chlorite schist containing long crystals is known in the country rock of the old Golden Gate Reef	Maitland and Montgomery (1908) Simpson (1952)

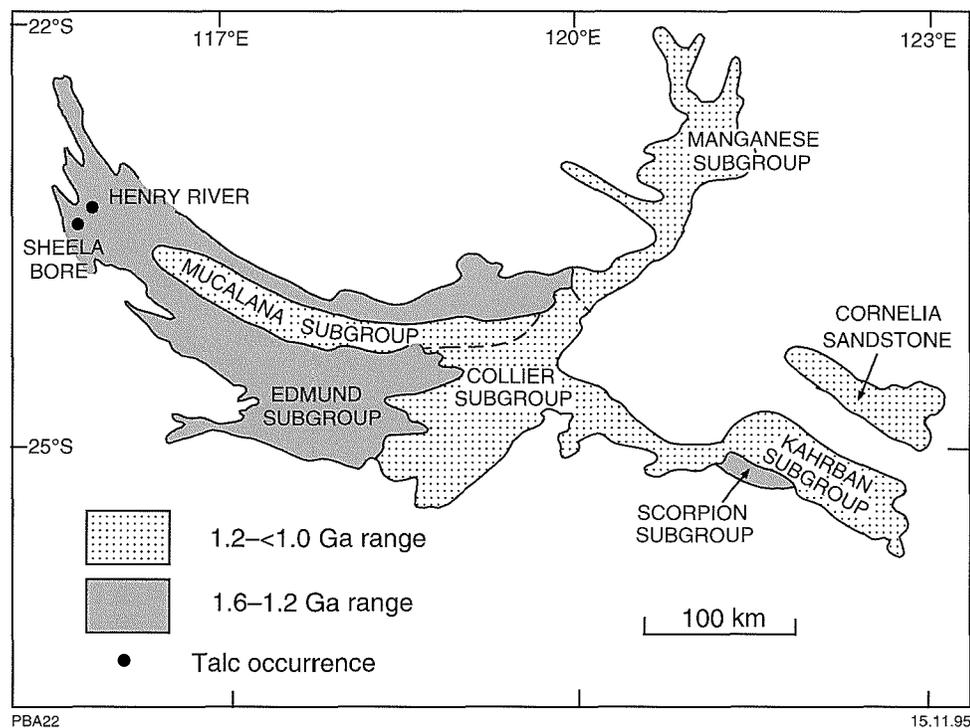
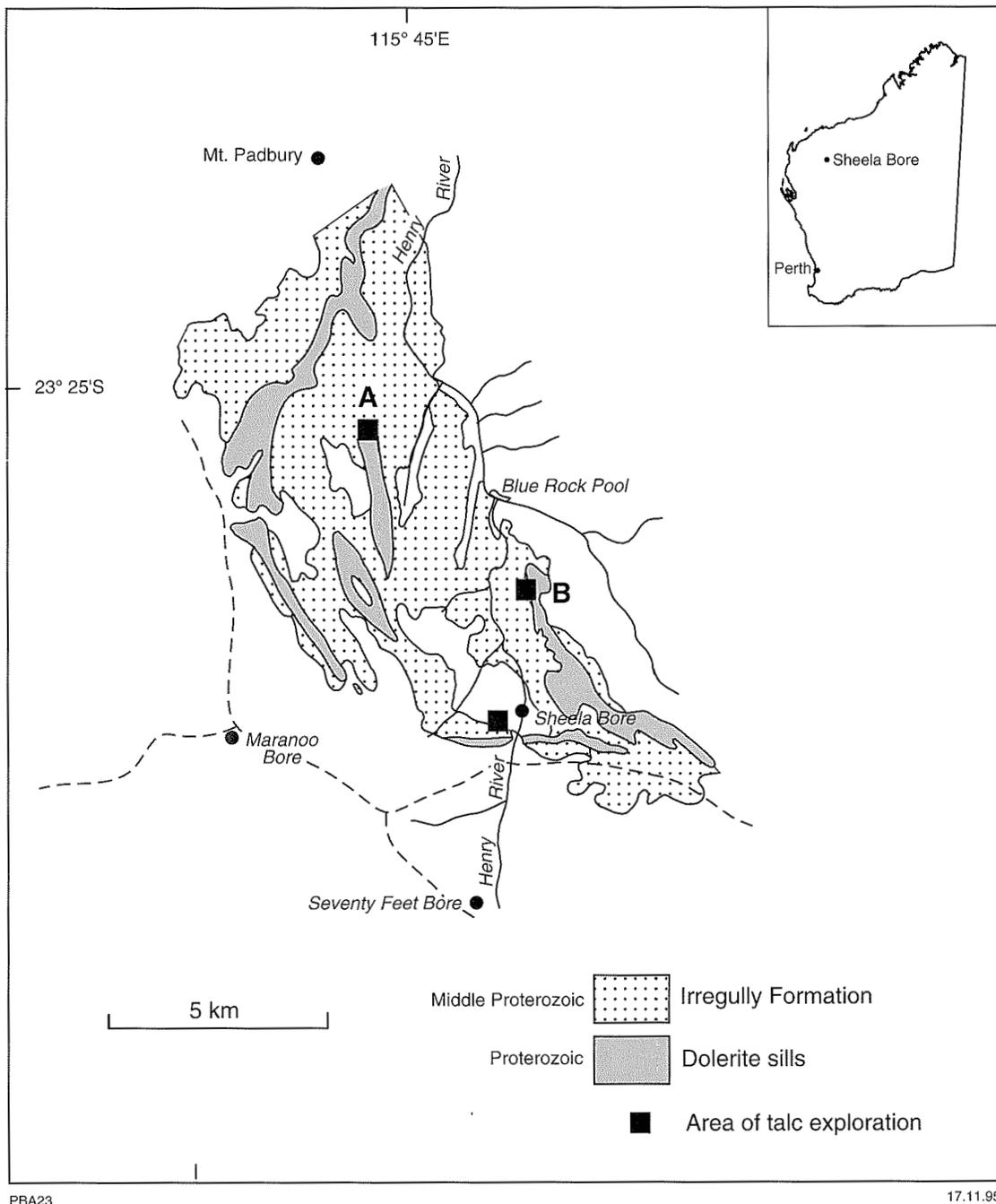


Figure 19. Subdivision of the Bangemall Group (after Williams, 1990)



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Figure 20. General geology and location of talc prospects at Sheela Bore, and west and east of Henry River

Sheela Bore

Location: Lat. 23°32'00"S, Long. 115°47'30"E; EDMUND

This prospect is located west of the Henry River and south of the locations described above. Reconnaissance exploration work by Imdex NL (1988) west of Sheela Bore (Fig. 20) located talc float between two flat dolerite sills approximately 500 m apart. Imdex concluded that the area is highly prospective for commercial talc. However, more exploratory work is needed.

Mount Palgrave (Henry River)

Location: Lat. 23°28'00"S, Long. 115°49'00"E; EDMUND

A sample of pure-white, foliated talc–talc schist was collected from a location 19 km southwest of Mount Palgrave, west of the Henry River (Simpson, 1952). This occurrence may be close to the Sheela Bore and Henry River locations described earlier.

Pyrophyllite in Western Australia

Pyrophyllite is a hydrous aluminium silicate, $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$, which usually occurs in spherulitic aggregates of small crystals, radiating needle-like crystals, or fine-grained foliated lamellae with platy cleavage. The colour can vary from white to pale-green, pale yellow, buff, or light- to dark-grey. Pyrophyllite may be used as a substitute for talc. It has similar physical properties and end uses, but has different composition and mode of occurrence to talc. Furthermore, unlike talc, pyrophyllite is markedly refractory (Harben and Bates, 1990a). Deposits of economic importance occur as hydrothermal alteration products of acidic volcanic rocks such as rhyolite and, less commonly, in schist derived from metamorphism of volcanic ash.

Pyrophyllite is not mined in Western Australia. Only a few occurrences are known. The only deposit of possible commercial interest is at Pinnacle Well, and that at Kangaroo Bore appears to be significant. There is very little information available on other occurrences.

Pinnacle Well

Location: Lat. 28°41'00"S, Long. 121°22'00"E; LEONORA

Pinnacle Well is located 22 km north-northeast of Leonora, in the Eastern Goldfields of the Yilgarn Craton. A report by Southern Ventures NL (Ward, 1990) indicated that the area was explored for pyrophyllite and gold between 1989 and 1990. Seven rock-chip samples of pyrophyllite collected from a prominent ridge in the vicinity of Pinnacle Well (Fig. 21) had chemical compositions similar to material at Pambula in New South Wales, where pyrophyllite is produced. Average assays for silica, alumina and iron oxide of the rock chip samples are as follows:

	<i>Pinnacle Well</i> (Average %)	<i>Pambula</i> (Average %)
SiO_2	76.9	75.7
Al_2O_3	17.5	18.8
Fe_2O_3	0.73	0.38

The area was further explored by 396 m of drilling across the pyrophyllite ridge. Assay results from the drilling indicate that the Al_2O_3 content of this pyrophyllite is marginally higher than that published for the Pambula pyrophyllite, and has specifications suitable for refractory applications. The colour of the pyrophyllite may be grey, white, red or brown. Brightness and opacity have not been tested.

The inferred resource is approximately 10 Mt, but more drilling is necessary to confirm this figure. According to Ward (1990) there is potential for reserves further afield.

Kangaroo Bore

Location: Lat. 29°26'40"S, Long. 122°27'25"E; EDJUDINA

Kangaroo Bore is about 6 km northwest of Mount Celia, approximately 210 km by road northeast of Kalgoorlie.

Exploration drilling for gold by Union Development Corporation in 1987 at Kangaroo Bore intersected pyrophyllite (Graindorge, 1988) in quartz-sericite-muscovite schists of Archaean age. Petrographic studies indicated that these schists contain assemblages of quartz-sericite-muscovite-pyrophyllite(-paragonite-kaolinite-chlorite). The underlying rock is a quartz-muscovite-dolomite-chlorite-calcite schist.

The thickness of pyrophyllite-bearing rock is variable and extends from the surface to a depth of about 170 m. Qualitative estimates indicate approximately 40% pyrophyllite at certain intervals, and the presence of this mineral has been confirmed by XRD. Associated minerals are calcite, dolomite, chlorite, andalusite and pyrite, with some arsenopyrite. Native gold is present in some samples associated with pyrophyllite alteration.

Marble Bar

Location: Lat. 21°15'00"S, Long. 119°44'00"E; MARBLE BAR

Pyrophyllite is known from the Archaean Mount Roe Basalt, approximately 2 km south of the Comet gold mine (also referred to as south of Starrs Find) and some 100 m south of the Marble Bar-Wittenoom road. Carbonate rock with a chalk-like matrix and nodules of pyrophyllite is known at this locality (Hickman A. H., 1993, pers. comm.). An analysed sample of this material (Lab No. 15594/72) comprises an aggregate of fine-grained illite and pyrophyllite, with a small amount of a fine-grained pale-brown material (GSWA, 1972).

Pyrophyllite is also known from the Mount Roe Basalt, 10 km north of Paraburdoo (Blight, D. F., 1995, pers. comm.).

Mount Leopold

Location: Lat. 20°58'00"S, Long. 116°30'00"E; DAMPIER

Pyrophyllite occurs with diaspore at Mount Leopold, southwest of Dampier. It is associated with the Mount Roe Basalt near the base of the Fortescue Group in a stratigraphic position similar to that of the Marble Bar occurrence. One sample examined from the locality contained 60.7% diaspore and 35.7% pyrophyllite, but further details are unknown (GSWA, 1970).

Browning Well

Location: Lat. 21°12'00"S, Long. 118°21'00"E; PYRAMID

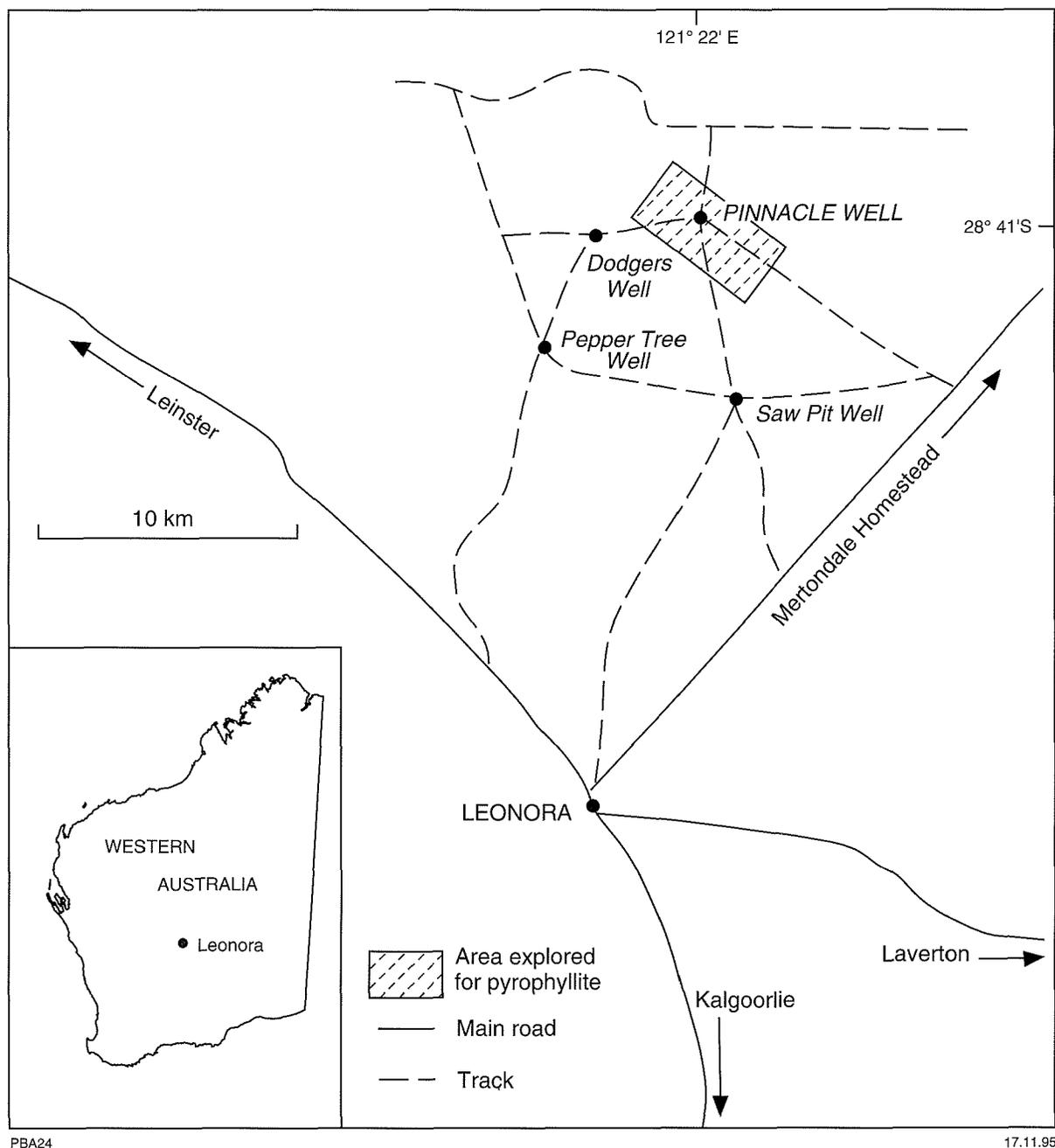


Figure 21. Location map of Pinnacle Well pyrophyllite deposit

Pyrophyllite was reported 75 m south of MC 1187, approximately 6 km northeast of Browning Well on Sandy Creek. The claim datum peg is 1.5 km south of the northwest corner of Yandearra Reserve 24490. The pyrophyllite is assumed to have come from drill core, but no other geological information is available (GSWA, 1970). However, the associated geology, as seen from the published maps, appears to be felsic volcanic and basaltic rocks of the Archaean Warrawoona Group.

Tabba Tabba

Location: Lat. 20°50'00"S, Long. 118°54'00"E (approximately); PORT HEDLAND

A sample of pyrophyllite held at the CC in Perth is recorded from 3 km south of Tank Pool (this appears to be a local name). No other information is available (GSWA, 1970).

Part 2

Magnesite

Mineralogy, mode of occurrence and uses of magnesite

Mineralogy

Magnesite, MgCO_3 , is the magnesium end member of an isomorphous series of carbonate minerals having calcite (CaCO_3) and siderite (FeCO_3) as the Ca and Fe end members. With increase in calcium, the magnesite becomes dolomite, and with iron, becomes breunnerite. Pure magnesite has a theoretical composition of 47.8% MgO and 52.2% CO_2 but is rarely found in nature, the natural mineral being almost always an isomorphous mixture of the series.

Natural magnesite occurs as crystalline (or bone) and cryptocrystalline (or amorphous) varieties. The two types differ in crystal structure, as well as in their mode of formation. The cryptocrystalline variety is massive and has a conchoidal fracture, a hardness of 3.5 to 5.0 and S.G. of 2.9 to 3.0. Crystalline magnesite is softer, of hardness 3.5 to 4.0, and with a higher S.G. of 3.02 (increasing with iron content). Both varieties show a range of colours from white to buff to black, commonly with tinges of red, blue, yellow and grey. The colour of magnesite does not usually indicate its quality.

Mode of occurrence

Magnesite occurs as a replacement mineral in carbonate rocks, as an alteration product of ultramafic rocks, as a vein-filling material, and as a sedimentary rock (Bain, 1924). Magnesite deposits are classified in three ways: on the basis of type localities (Pohl and Siegel, 1986); crystal size (Schmid, 1987); or geological setting (Bain, 1924). According to Abu-Jaber and Kimberley (1992), the classification based on type localities is unsatisfactory because type names are not self-explanatory and the classification is not adaptable. Neither do these authors recommend crystal size as a basis for classification because it does not indicate overlapping ranges among vein and sedimentary deposits. They, instead, proposed two methods of classification, based on geological setting (Table 25), or genetic interpretation.

Geologic setting classification

The first classification of Abu-Jaber and Kimberley (1992) is based on the fact that magnesite deposits occur mainly in two geologic settings, namely sedimentary-hosted, and ultramafic-associated deposits. They named the former

Table 25. Classification of magnesite deposits by geologic setting

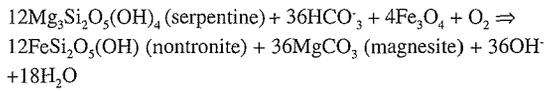
<i>Present classification</i>	
Stratabound	
<i>Chemical</i>	
	Marine authigenic
	Lacustrine authigenic
	Marine replacement
	Lacustrine replacement
<i>Clastic</i>	
Ultramafic	
	<i>Vein</i>
	<i>Massive</i>

NOTES: after Abu-Jaber and Kimberley (1992)

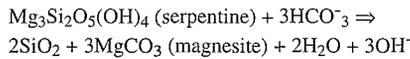
type as stratabound deposits in chemical sedimentary rocks and the latter as ultramafic-associated deposits (Table 25). The following notes summarize the two geological settings. Detailed descriptions are available from Abu-Jaber and Kimberley (1992).

Ultramafic-associated deposits

In comparison with the stratabound deposits, the ultramafic-associated type does not form large deposits. The average magnesite content of these deposits is generally between 10 and 20%, although economically recoverable content is between 3 and 10%. The deposits appear in rocks with ages varying from Archaean to Phanerozoic, occurring as either veins or massive bodies formed by metasomatic replacement of large volumes of ultramafic rocks by CO_2 of magmatic origin (Wellman, 1942; Griffis, 1972). The depth of metasomatism can be greater than one kilometre, and Takasawa and Kuroda (1974) interpreted some such massive bodies as carbonatites. Vein-type magnesite deposits are more widespread, and their mode of formation — the source of the carbon, the pressure-temperature conditions, and the volatiles required to precipitate magnesite — is controversial. Abu-Jaber and Kimberley (1992) are of the view that magnesite veins form in near-surface environments at low temperatures and pressures and that magnesium is derived from the alteration of serpentine. They proposed the following generalized reactions of serpentine alteration:

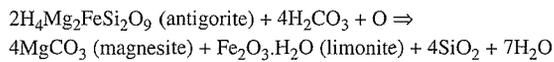


or

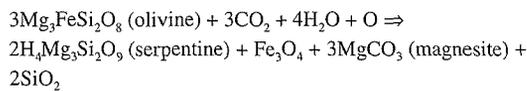


The source of carbon is from metamorphic alteration of carbonaceous sedimentary rocks deep within the crust, and the precipitation of magnesite is caused by an increase in pH resulting from a combination of wallrock alteration and degassing of rising water.

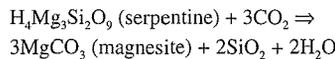
Magnesite is also commonly formed by weathering of serpentine- and olivine-rich rocks, and the chemical reactions involved can be written as follows:



or



or



Stratabound deposits

Stratabound deposits are mostly chemical sedimentary rocks ranging from stratiform-authigenic beds to irregular replacements of limestone and dolostone (Abu-Jaber and Kimberley, 1992). Large deposits of this type are known in the southern Ural Mountains in Siberia, north and east China, Rum Jungle in northern Australia, and in Nepal. Replacement-type magnesite deposits described by Bain (1924) and Harben and Bates (1990b) might possibly be assigned to this category. Both stratiform-authigenic and replacement-type deposits have more commercial value than ultramafic-associated deposits, because they are more extensive and of higher quality. In replacement-type deposits, the magnesite is possibly formed by replacement of country rock by magnesium-rich fluids that enter the system through fissures, cleavage planes and capillary openings. Replacement is selective and the minerals formed depend largely on the country rocks. For example, carbonate-rich country rocks may produce magnesite and dolomite, but alteration of carbonates associated with quartzose country rocks may produce predominantly diopside, talc and serpentine, and negligible quantities of dolomite. Replacement can be arrested at any stage, according to the porosity and the permeability of the host rocks. Replacement-type deposits are found in USA, Brazil, Spain, Austria and Czech Republic.

Genetic classification

The genetic classification is based on three factors: the source of the fluid; the mode of fluid supply; and the cause

of precipitation. There are diverse views on these matters (Pohl, 1989); this classification seems to be of more theoretical interest and will not be discussed in this Bulletin.

Other deposit types

The newly discovered Kunwarara and other associated magnesite deposits of the Queensland Magnesia Project Joint Venture (Qmag) in Australia, and Salda Lake magnesite deposit in Turkey, have geological characteristics common to ultramafic-associated as well as chemical replacement-type ore bodies and are therefore discussed separately. The Kunwarara deposit, which is owned by Queensland Metals Corporation Ltd (60%) and Pancontinental Mining Ltd (40%), contains more than 400 Mt of high-grade magnesite. The deposit averages 40 to 45% by volume (ranging from 20 to 95%) of cryptocrystalline magnesite nodules and lumps, ranging from several millimetres to a metre in diameter, in a matrix of soft mudstone-sandstone-earthy magnesite, and is underlain by dolomitic mudstone, sandstone or gravel. The Salda Lake and Kunwarara deposits consist of cryptocrystalline magnesite containing a small amount of iron. Both are presumed to have been derived from magnesite stockwork veins in serpentinite that are weathered, eroded and subsequently transported and deposited in lacustrine environments. Schmid (1987) considered that the present-day geology of Turkey's Salda Lake deposit shows the different stages of magnesite development that have taken place at the Kunwarara deposit. On this basis, he proposed the following sequence of events for the formation of secondary magnesite in such deposits:

1. Deep weathering and erosion of primary serpentine rocks with magnesite stockworks caused by heavy rainfall;
2. Fluvial transport of the eroded magnesite-serpentine material to basins or lagoons, followed by decomposition, then sedimentation as mud with a high magnesium carbonate and hydrated magnesium carbonate content;
3. Waterlevel fluctuations causing cycles of drying and overflow of magnesite mud along the edges of the basins. Additional intake of carbon dioxide from the atmosphere caused crystallization of the half-dry mud matrix into cryptocrystalline magnesite nodules and lumps;
4. Periodic wave movements or water flow during the crystallization phase wash and remove non-crystallized impurities of SiO_2 , Fe_2O_3 , Al_2O_3 and CaO from the newly formed magnesite nodules and lumps;
5. In deep lakes, e.g. Salda Lake (190 m), washed, non-crystallized impurities settle in deeper parts of the lakes, and large storms form onshore gravel dunes (up to 10 m high) of highly concentrated clean magnesite;
6. In shallow lakes (e.g. the Kunwarara deposits, which formed in basins between 10 and 20 m deep)

Table 26. Synthetic magnesites from seawater or brine

Producer or magnesite product, by country	Kiln (a)	Lime/silica	MgO	CaO	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	B ₂ O ₃	Density (g/cm ³)	Other
USA										
H W Ludington 96A	S	3.0	96.6	2.3	0.7	0.20	0.20	0.02	3.42	
Ludington 98	S	1.0	98	0.7	0.6	0.2	0.2	0.08	3.42	
Martin Marietta 98	S	3.0	97	2.2	0.7	0.20	0.20	0.02	3.42	
Mexico										
Penoles-Quimica del Rey										
RY-99-AD	S	7.0	99.01	0.7	0.10	0.10	0.09	0.003	3.40	
RT-99-SAD	S	7.0	98.94	0.7	1.10	0.10	0.09	0.003	3.40	0.07 Cr ₂ O ₃
Ireland										
Premier Periclase	R	4.0	96.8	2.3	0.6	0.2	0.2	0.04	3.44	
UK										
Steeley Pelletised 31PHO	R	5.0	97	1.9	0.4	0.2	0.2	0.05	3.43	
Netherlands										
Magnesia International	S	3.8	98.5	0.65	0.17	0.45	0.07	0.01	3.44	
Italy										
Sardamag	R	4.0	96.8	2.3	0.55	0.15	0.20	0.05	3.42	
Cogema	R	4.0	97.0	2.2	0.5	0.15	0.15	0.04	3.40	
Japan										
Ube 98	R		98.3	0.8	0.8	0.05	0.05	0.05	3.40	
Shin Nihon SSS	R	3.0	98.6	1.0	0.3	0.06	0.06	0.08	3.41	
Israel										
Dead Sea Periclase	S	3.0	99.4	0.3	0.08	0.14	0.06	0.01	3.45	
Yugoslavia										
Magnohrom YU5										
Chemical grade	R	2.9	99.3	0.4	0.15	0.06	0.05	0.01	3.37	

NOTES: after Duncan (1986)
(a) S — shaft kiln; R — rotary kiln

deposition of the washed non-crystallized impurities took place around the magnesite nodules or in hollows and pores within the lumps, to form a sand-clay matrix with interbedded magnesite nodules and lumps, and dolomitic magnesite and sandstone layers;

- The newly formed magnesite horizons in the shallow lake basins are buried and compacted by soil cover. There is part encrustation of silica-rich impurities as a skin around the magnesite nodules, the lumps, and in pores. Finally, the action of circulating subsurface groundwaters with high bicarbonate content causes crystallization and an increase in the density of the magnesite.

Magnesia from seawater and brine

Seawater and brine are important sources of magnesia, especially in countries where natural magnesite is scarce (e.g. Japan). Production of magnesia from seawater is based on the removal of carbon dioxide from the water by the addition of sulfuric acid, or slaked lime to precipitate CaCO₃. The decarbonated water is then mixed with a slurry of calcined dolomite or lime to precipitate

magnesium hydroxide, which is concentrated in settling tanks, washed and filtered. The filter cake is then calcined in a Herreschoff multiple-hearth furnace, briquetted in high-pressure rolls and sintered in a rotary or pressurized shaft kiln to produce high-density magnesia (Harben and Bates, 1990b). In the case of brine, magnesium hydroxide is produced by reaction with dolomitic lime in stirred reactors. The magnesium hydroxide thus formed is thickened, filtered and calcined to produce magnesia (Coope, 1987).

Magnesia produced from seawater and brine has a uniform composition, and has advantages because it can be produced to required specifications (Table 26). This is especially important in the case of refractory grades where industry demands so-called first-grade magnesia with very high purity and density, and a high lime:silica ratio (Harben and Bates, 1990b; Schmid, 1984). Natural magnesite is virtually excluded from this market. Most producers of magnesia from seawater and brines produce some caustic magnesia for sale. However, such production tends to be a small sideline to the output of refractory magnesia (Industrial Minerals, 1987a). Prior to the early 1970s, about 85% of magnesia requirements of industrialized countries were from synthetic magnesia, but this was severely curtailed by the sharp increase in energy costs in the 1970s. Synthetic magnesia is produced in USA, Japan,

UK, Italy, Mexico, Netherlands, Israel, France, Norway, and Germany.

Uses

Dead-burned magnesia

Approximately 90% of the magnesite output is dead burned to produce refractory magnesia either in the form of loose grains or shaped bricks (Bates, 1969). Dead-burned magnesia, also known as magnesia clinker, sintered magnesia, or periclase (Harben and Bates, 1990b) resists chemical attack and is highly refractory. It is prepared by calcining magnesite or magnesium hydroxide at 1500° to 2000°C. The dead-burned magnesite presently available on the market can generally be subdivided into three categories according to raw material source (as given in Table 27). Magnesite refractory bricks are widely used in the steel industry to line basic open-hearth furnaces and converters, and are also used in copper smelters, cement kilns, and other high-temperature installations. Refractory bricks may be made of magnesia alone or magnesia mixed with chromite, silica or olivine. Magnesite refractories in use a few decades ago contained 4 or 5% iron oxide, a comparable percentage of silica, and minor amounts of alumina and lime. The present-day refractory industry requires much more rigid specifications. For example, the raw material should contain more than 95% MgO, less than 1% Fe₂O₃, a lime:silica ratio of 2:1, and a bulk density of 3.4 g/cm³. New and developing steelmaking procedures have also increased the demand for high-quality magnesia-based refractories at the expense of other refractory types (Coope, 1990), e.g. magnesia-carbon bricks, based on high-grade sintered magnesia and graphite, are now used widely in both primary and secondary steelmaking. The specifications for magnesia-carbon refractories are even more stringent, and synthetic magnesia from seawater dominates usage because only a few natural magnesites can meet such requirements (Coope, 1987). Magnesite producers are now trying to improve the quality of refractory magnesite by increasing its bulk density and crystal size.

Caustic magnesia

Most magnesia-consuming industries require an active magnesium compound known as caustic magnesia (also known as caustic calcined magnesia or light-burned magnesia), produced by calcining magnesite to temperatures of 700° to 1000°C to drive off carbon dioxide. The main uses of caustic magnesia prepared from natural magnesia are as follows.

Agriculture — animal feeds, fertilizer

Products containing 80 to 85% MgO are used in the agricultural sector for animal feedstuffs and fertilizers. Magnesium is vital for nutritional metabolism and in the nervous system, and its deficiency can lead to an animal disease known as grass staggers. Calcined magnesite

containing 85% MgO is used for pasture dusting, free-access mineral mixes and in food supplements to overcome magnesium deficiency (Industrial Minerals, 1987a). The levels of common impurities CaO, SiO₂, Al₂O₃ and Fe₂O₃ are not critical, but the product must be free from toxic elements (Coope, 1983).

Magnesia is used as a fertilizer to correct soil deficiencies but has to compete with kieserite, a hydrous magnesium sulfate mineral, which is more soluble and considered to be better for the purpose. However, there is some evidence to show that kieserite is too soluble and can be too easily leached from the soil. Calcined magnesite contains 48% Mg compared to 16% Mg in kieserite and the price of both is about the same.

Construction

Magnesia is used in the construction sector for making special cements and insulating boards. For example, oxychloride (or Sorel) cement prepared by mixing finely ground magnesia with a solution of magnesium chloride, is a tough, dense cement suited for heavy-duty interior flooring such as those in railway cars and stations, schools, hospitals and other public places (Bates, 1969). The magnesia should have low iron (for reason of colour) and low calcium (which affects the cement setting) (Industrial Minerals, 1987a). The 'Heraklith' insulating boards, produced by subsidiaries of the Radex Group in Australia, Austria and Greece, use magnesia, magnesium sulfate, woodchips and polystyrene.

Other industrial applications

- Pulp and paper — for the preparation of magnesium sulfite lye used in the 'magnefite' paper-making process (Industrial Minerals, 1987a)
- Rubber — used to control vulcanization and curing in neoprene rubbers and other elastomers
- Abrasives — used as a binder in grinding wheels
- Lubricating oils — used as an additive to neutralize acids
- Plastics, paints and adhesives — used as a flame-retardant filler
- Flux in steelmaking — normally used when magnesia is more readily available than dolomite or olivine
- Chemicals — magnesia is a starting point for the production of other magnesium salts such as magnesium sulfate and magnesium nitrate
- Pharmaceuticals — special grades of oxide, hydroxide and carbonate are used in antacids, cosmetics, toothpaste, ointments and Milk of Magnesia
- Steel coatings — used to coat grain-oriented silicon steel for electrical transformer cores
- Fused magnesia — caustic magnesia is used as a raw material for fused magnesia products.

Table 27. Analyses and bulk densities of typical dead-burned magnesite

Dead-burned qualities by raw material source		MgO	CaO	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	B ₂ O ₃	LOI	Bulk density (g/cm ³)
Percentage									
Seawater and brine magnesia									
Dead Sea Periclase	Israel	99.40	0.30	0.08	0.14	0.06	0.01	0.15	3.45
Cogema 31	Italy	97.00	2.20	0.50	0.12	0.15	0.04	0.10	3.40
Ludington Exhibit A	USA	96.60	2.30	0.70	0.20	0.20	0.02	0.15	3.40
UBE 98	Japan	98.30	0.80	0.80	0.05	0.05	0.05	0.15	3.40
British High Quality	England	97.00	2.00	0.60	0.10	0.20	0.03	0.15	3.40
Sardamag 31	Italy	96.80	2.30	0.55	0.15	0.20	0.05	0.15	3.42
Billiton	Holland	98.50	0.65	0.17	0.45	0.07	0.01	0.10	3.44
Cryptocrystalline low-iron natural magnesite									
Euboea E 21 A	Greece	95.70	2.20	1.30	0.64	0.06	0.01	0.10	3.45
Euboea Magflot A	Greece	96.00	2.30	0.80	0.75	0.04	0.01	0.10	3.40
Yerakini Periclase A	Greece	95.50	1.60	2.60	0.08	0.12	0.01	0.10	3.35
Yerakini Periclase D	Greece	91.50	2.00	5.50	0.15	0.25	0.01	0.12	3.30
Kumas	Turkey	96.50	1.50	1.25	0.35	0.04	0.01	0.15	3.40
Magnohrom MK-1	Yugoslavia	95.50	2.00	1.70	0.60	0.20	0.01	0.20	3.35
Macrocrystalline low-iron and iron-rich natural magnesite									
Typ 9090	China	92.40	1.25	3.50	1.00	1.50	0.01	0.15	3.20
Typ 8790	China	90.00	1.30	5.80	1.10	1.60	0.01	0.15	3.15
Flotation Grade	North Korea	95.10	1.60	1.20	1.28	0.56	0.01	0.20	3.25
Normal Grade	North Korea	91.90	1.80	4.00	1.10	0.70	0.01	0.40	3.15
Dimag N	Spain	92.90	2.95	0.80	3.20	0.15	0.01	0.10	3.25
Breitenau B 91	Austria	91.00	2.40	0.50	5.70	0.20	0.01	0.12	3.30
Sinter L Radex	Austria	90.00	3.00	1.00	5.00	1.00	0.01	0.15	3.35
Lubenik	Czech Republic	87.00	3.10	1.60	8.00	1.00	0.01	0.20	3.25
Jelsava S	Czech Republic	88.00	2.70	0.90	7.50	0.50	0.10	0.16	3.25
Magnesitas M 20	Brazil	94.50	0.80	1.30	2.70	0.80	0.01	0.15	3.35
China 98 (foreseen)	China	98.00	0.80	0.60	0.40	0.20	0.01	0.10	3.40
China 97 C:S (foreseen)	China	97.20	1.40	0.70	0.45	0.15	0.01	0.10	3.40
China 96 (foreseen)	China	96.50	1.20	1.50	0.50	0.30	0.01	0.10	3.35
China 95 C:S (foreseen)	China	95.50	2.50	1.30	0.50	0.30	0.01	0.15	3.35

NOTE: after Schmid (1984)

Environmental applications

A very strong interest is emerging in the use of magnesia and magnesium hydroxide in environmental applications for water treatment, flue-gas desulfurization and as a boiler fuel additive (Coope, 1990; Industrial Minerals, 1987a). Calcined magnesia is one of the most powerful yet environmentally friendly alkali agents which can be used in the fields of effluent treatment and toxic-waste disposal. Magnesia and magnesium hydroxide have so far been used selectively because of their high cost and the availability of other alkalis such as lime, caustic soda and soda ash, but significant advantages of magnesia over other alkalis have been recognized recently. Magnesia is better for neutralizing acids, for example, because less material is required and it is more easily transported and handled.

CSIRO of Australia in collaboration with Qmag is engaged in a major research program to evaluate the commercial application of calcined MgO in the following areas:

neutralizing acids; stabilizing tailings dumps and sludge pits; removing metals

from solutions; removing solids from suspension; removing algae and other organic material; removing dyes; treating paper and pulp effluents; removing phosphorus and ammonia from effluents; removing oil from water; scrubbing waste gases.

Fused magnesia

Fused magnesia is one of the most useful end products of calcined magnesia. Most production of this grade is from high-purity natural magnesite, but more specialized products are based on high-purity synthetic magnesia. Fusion is achieved in electric arc furnaces at temperatures of about 2850°C. Fused magnesia is mainly used for electrical insulation in water-heating elements, cookers, irons, washing machines, and coffee machines (Industrial Minerals, 1987a).

Natural magnesite containing more than 95% MgO and lime to silica ratios favouring silica is also used for insulation applications.

Source of magnesium metal

Recent trends indicate that natural magnesite is gaining recognition as a major source of magnesium metal. The traditional raw materials for magnesium metal production have been mainly seawater and brine using the electrolytic process, or dolomite using the silicothermic process (Coope, 1990). In 1990, two plants in Canada began commercial production of magnesium metal from natural magnesite using a process involving chlorination followed by electrolysis. Qmag has plans to produce magnesium metal from the Kunwarara natural magnesite. The Mineral Processing Licencing Company (MPLC) has developed a process to produce magnesium metal by mixing raw magnesite with chlorine and carbon monoxide in a single stage reactor at 1000° to 1050°C (Harben and Bates, 1990b). The molten material thus produced contains anhydrous magnesium chloride, from which magnesium metal is won in an electrolytic cell.

Mining methods

Large, massive, replacement-type deposits such as those in China, North Korea, CIS, Spain, USA and Canada are mined by opencut methods. Some of the deeper ore bodies in Greece, Turkey, and India are also mined by opencut methods, where the ore to waste ratio is high (Coope, 1987). The Kunwarara deposit in Queensland is mined by opencut methods.

Several Austrian and Czech Republic deposits located in mountainous terrain are mined by underground methods. Some of these operations use room and pillar mining, involving chambers up to 60 m high, made using machinery such as electric shovels and 50 t underground haulage trucks.

Processing and beneficiation

The traditional processing of magnesite begins with crushing, screening and washing. In countries such as Greece, Turkey and India, where labour costs are comparatively low, hand sorting is also common, depending on the nature of the ore (e.g. white magnesite associated with dark serpentine). However, companies such as Grecian Magnesite Co. in Greece, use optical sorting by photometric ore sorters, particularly for finer fractions (Coope, 1987). Further processing is generally not required for agricultural grades of caustic magnesia and for lower quality brickmaking grades of dead-burned magnesia. If the quality of the ore is high enough, further processing may not be needed even for industrial grades of caustic magnesia and regular quality brick-making grades of dead-burned magnesia, but magnetic

separation, heavy media separation, flotation and partial calcination (Duncan, 1986) are generally used to remove impurities from magnesite ore. The impurities are commonly a combination of dolomite, quartz, talc, chlorite, serpentine, phlogopite, pyrite, magnetite and graphite.

Beneficiation techniques may differ, depending on the nature of the ore. For example, operations in the USA, Austria, Spain (Navarras), Czech Republic, and North Korea tend to grade magnesite ore into three fractions (Coope, 1987):

1. Graded lump material for direct charging into a furnace shaft kiln for either calcining or sintering.
2. A medium-sized fraction from which principal impurities are removed by heavy media separation, using drums for the 10–60 mm fraction and cyclones for -10 mm material.
3. A fine fraction, which may or may not need further grinding before beneficiation by flotation.

The beneficiation plant at Kunwarara deposit consists of three main sections, namely primary scrubbing, heavy-medium separation, and product handling (Keane, 1992). In the primary scrubbing section the ore is attritioned and washed with log washers and vibrating screens. The scrubbed and sized (>16 mm) product then proceeds to the heavy-medium drum circuit for separation of light gangue material including clay and sandstone, where it is crushed, sized to <20 mm and rescrubbed. The heavy-media cyclone circuit then separates the magnesite into two quality streams, of S.G. 2.55 to 2.75, and S.G. +2.75.

Chemical beneficiation

Chemical beneficiation techniques are used to upgrade natural magnesite or to process brines to high-quality magnesia (Coope, 1989). The Sulzer process involves leaching calcined magnesia with calcium chloride and carbon dioxide to produce a magnesium leach liquor which is then converted to nesquehonite ($MgCO_3 \cdot 3H_2O$) by reacting with ammonia and carbon dioxide. Refractory magnesia of reasonably high density can then be obtained from nesquehonite by means of a calcining /pelletising/ sintering route. The Ruthner process involves a spray roasting process to convert magnesium chloride to magnesia. Magnesium chloride is obtained from natural magnesite by treating waste flue dust with hydrochloric acid.

Production and market trends

World production

The world production of natural magnesite in 1994 was 16 Mt (Table 28). The principal producing countries of natural magnesite are China, North Korea, CIS, Turkey, Australia, Czech Republic, Austria and Greece, and of these, China, North Korea and CIS contributed 64% of world production in 1994 (Fig. 22). The output from Australia in 1994 was 5% of global production due to increased output from the Kunwarara and related deposits in Queensland. Global trends in the production of natural magnesite between 1981 and 1994 indicate an increase between 1981 and 1989, peaking at 20 Mt in 1989, then dropping to 16.3 Mt in 1994 (Fig. 23).

Market and demand for magnesite

Clarke (1992) reported that toward the end of 1989 it was considered that the magnesia markets would gain momentum, leading to an increase in price. However, in terms of the dollar value of the day the prices of dead-burned and calcined varieties increased from around \$275 and \$250 in 1984 to around \$470 and \$460 in 1987, and decreased to around \$415 and \$410 respectively in 1989. Subsequently the price of the dead-burned variety increased to around \$580 in 1992 and then dropped to around \$540 in 1994, whereas that of calcined material increased to around \$420 in 1994. The price of crude or raw magnesite marginally increased from around \$90 in 1984 to around \$135 in 1987, but dropped to a consistent \$65 in 1994 (Fig. 24). The industry has been forced to slim down, restructure, save costs and, at the same time, produce higher quality products. Permanent or temporary closures of plants were common after 1990.

Changing demand for dead-burned magnesite by refractory producers have resulted in magnesia becoming essentially a 'two grade' industry (Mining Journal, 1992). The best grade has a higher MgO content, a controlled lime:silica ratio, a higher density, and a low boron content. Density and MgO content are not so important for the lower grade product. The market for the best grade is dominated by synthetic magnesite producers such as Japan and USA, and the market for the lower grade product is dominated by the natural magnesite producers, notably China and North Korea. Although the demand for high-

performance refractories has benefited the synthetic magnesite producers, oversupply of lower grades has resulted in lower prices. The main threat to European magnesite producers is the cheap supply from China, and the European Commission has brought in anti-dumping duties on imports of dead-burned and caustic-calcined magnesite from China (Industrial Minerals, 1992). Some major producers, such as FIMISCO in Greece, have gone into liquidation because of cheap Chinese supplies. The entry of Queensland magnesia from Qmag into the market has been welcomed by some producers of refractories. This operation is expected to become the world's largest supplier of refractory-grade magnesia and its effect on the world market is yet to be seen. Kunwarara was expected to produce 15 000 t per year of dead-burned product and 25 000 t per year of electrofused magnesia by the year 1995 (Mining Journal, 1992; The Miner, 1992). It is believed that Kunwarara may reduce many manufacturers' reliance on Chinese magnesite, which might become more expensive due to both Chinese exporting policies and increasing domestic demand. It is apparent that a combination of high quality and production-cost advantages will determine the market trends for magnesia products.

China

China is the largest supplier of natural magnesite, with an annual production of approximately 5.0 Mt a year. The largest deposits are located approximately 60 to 70 km south and southeast of Anshan in Liaoning Province, approximately 650 km northeast of Beijing. The magnesite mineralization is known to extend for more than 200 km and is thought to contain around 3000 Mt. The deposits are in an upper Precambrian sequence of quartzite, sandstone, dolomite, schist and marble striking at 60° to 80° (Schmid, 1984). The schists contain tourmaline, staurolite, andalusite, sericite, biotite and talc. Minor intrusions of 'porphyritic greenstones' and quartz porphyries are known.

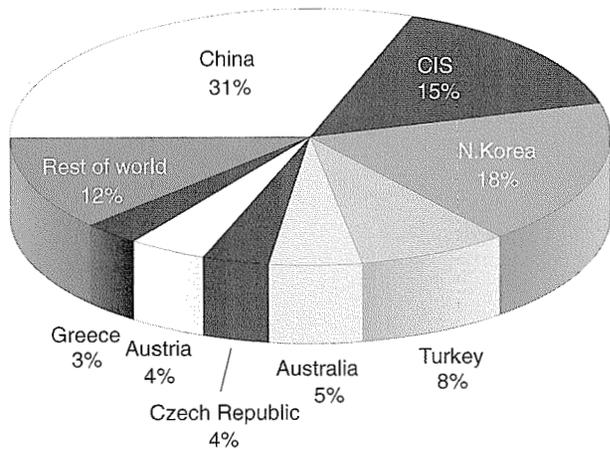
The magnesite is medium grained to coarsely crystalline, ranging from white or pale pink to shades of grey. It occurs as conformable beds 40 to 500 m thick within dolomite and minor schist. The contact between the magnesite and dolomite is not always clear and at times talc is present.

Operations in the early 1980s mined approximately 50 Mt per year of ore and waste to produce about 70 000 t

Table 28. World production of natural magnesite

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994(e)
	('000 tonnes of crude ore)													
Australia	26	30	21	67	58	41	54	63	65	65	365	250	800	800
Austria	1 159	1 031	1 006	1 183	1 255	1 084	947	1 122	1 199	1 179	1 100	995	627	684
Brazil	790	750	745	724	623	649	650	680	700	700	700	880	880	900
Canada	50	35	100	112	136	144	150	200	200	200	220	200	180	200
China	2 000	2 000	2 000	2 400	3 400	3 400	3 400	3 400	3 500	3 500	3 500	2 600	5 000	5 000
Czech Republic	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 700	2 700	2 400	1 400	1 200	600
Greece	962	967	891	1 064	846	944	842	848	850	697	550	471	450	500
India	463	418	435	418	421	460	420	508	480	500	500	550	450	400
Nepal	(a)	(a)	15	44	20	63	50	45	28	25	25	(a)	(a)	(a)
North Korea	1 900	1 900	2 500	2 500	2 500	2 500	2 500	2 500	3 000	3 000	3 000	3 000	3 000	3 000
Poland	11	17	16	21	19	21	22	24	24	23	23	(a)	(a)	(a)
South Africa	57	32	23	33	29	61	75	74	76	114	120	(a)	(a)	(a)
Spain	476	534	597	692	682	588	396	473	470	460	420	400	400	400
Turkey	784	910	725	723	1 137	1 307	1 190	1 126	1 199	850	900	1 200	1 300	1 300
USA	250	200	200	150	100	100	100	100	100	100	100	(a)	(a)	(a)
USSR (CIS)	4 200	4 500	4 500	5 000	5 000	5 000	5 000	5 000	5 000	5 000	4 640	3 800	3 000	2 500
Yugoslavia	300	328	304	374	419	423	403	382	364	268	250	195	55	15
Zimbabwe	60	61	24	22	19	28	29	30	33	33	33	(a)	(a)	(a)
Total	15 988	16 213	16 602	18 027	19 164	19 313	18 728	19 075	19 988	19 414	18 846	15 941	17 342	16 299

NOTES: after Coope (1989, 1991 to 1995)
(a) not available
(e) 1994 figures are preliminary or estimated



PBA13

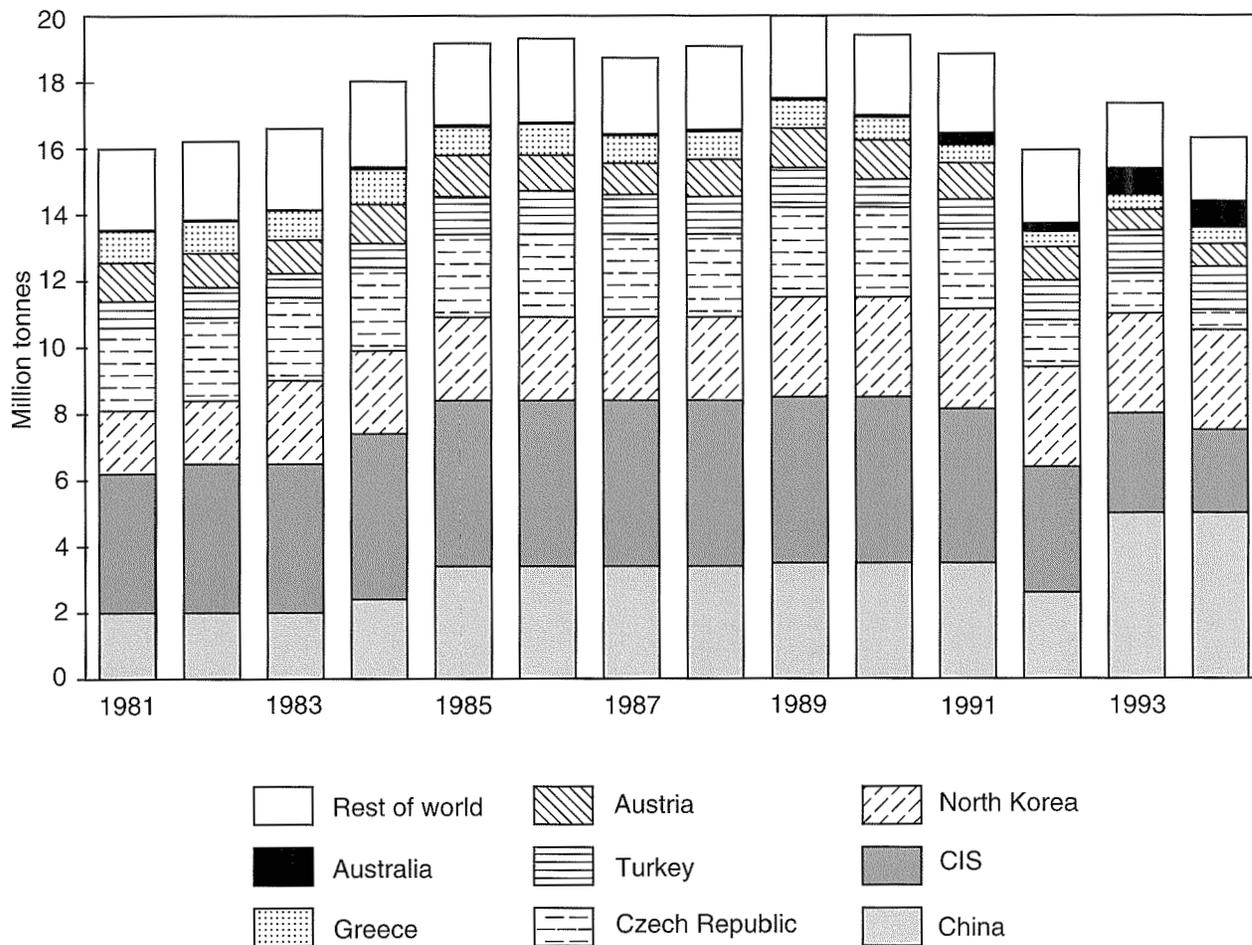
8.3.96

Figure 22. Global production of natural magnesite, 1994. Source of data: Coope (1995)

of dead-burned magnesite, 80 000 t of caustic-calcined magnesite and 300 000 t of dead-burned dolomite (Lebauer, 1982). The main operator is the Liaoning Magnesite Company.

CIS (Commonwealth of Independent States)

The CIS (former USSR) is a large producer of natural magnesite, with an annual output of approximately 2.5 Mt. A large proportion of the magnesite is produced from the area around Satka, Ufa Province, in the southern Ural Mountains. The magnesite is in upper Precambrian to Cambrian dolomite, marl, conglomerate, sandstone, slate and phyllite. It occurs mainly in two parallel series of lenses within a belt 8 km long. Recent discoveries in the mountains of Eastern Siberia are said to contain more than 2000 Mt of magnesite, although the grade is



PBA14

31.10.96

Figure 23. Global production of natural magnesite, 1981 to 1994. Source of data: Coope (1989, 1991 to 1995)

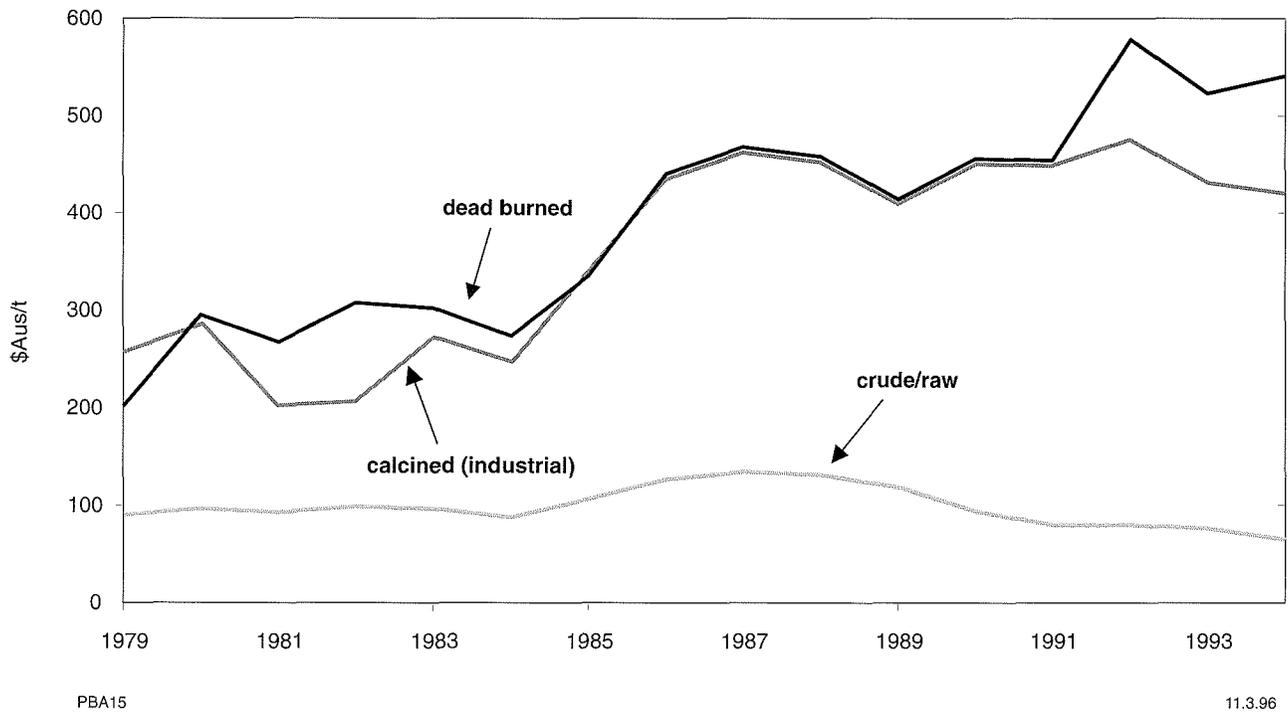


Figure 24. Trends in prices of magnesite — for dead burned, calcined, and crude/raw varieties, 1979 to 1994. Sources of data: Industrial Minerals (1979 to 1994)

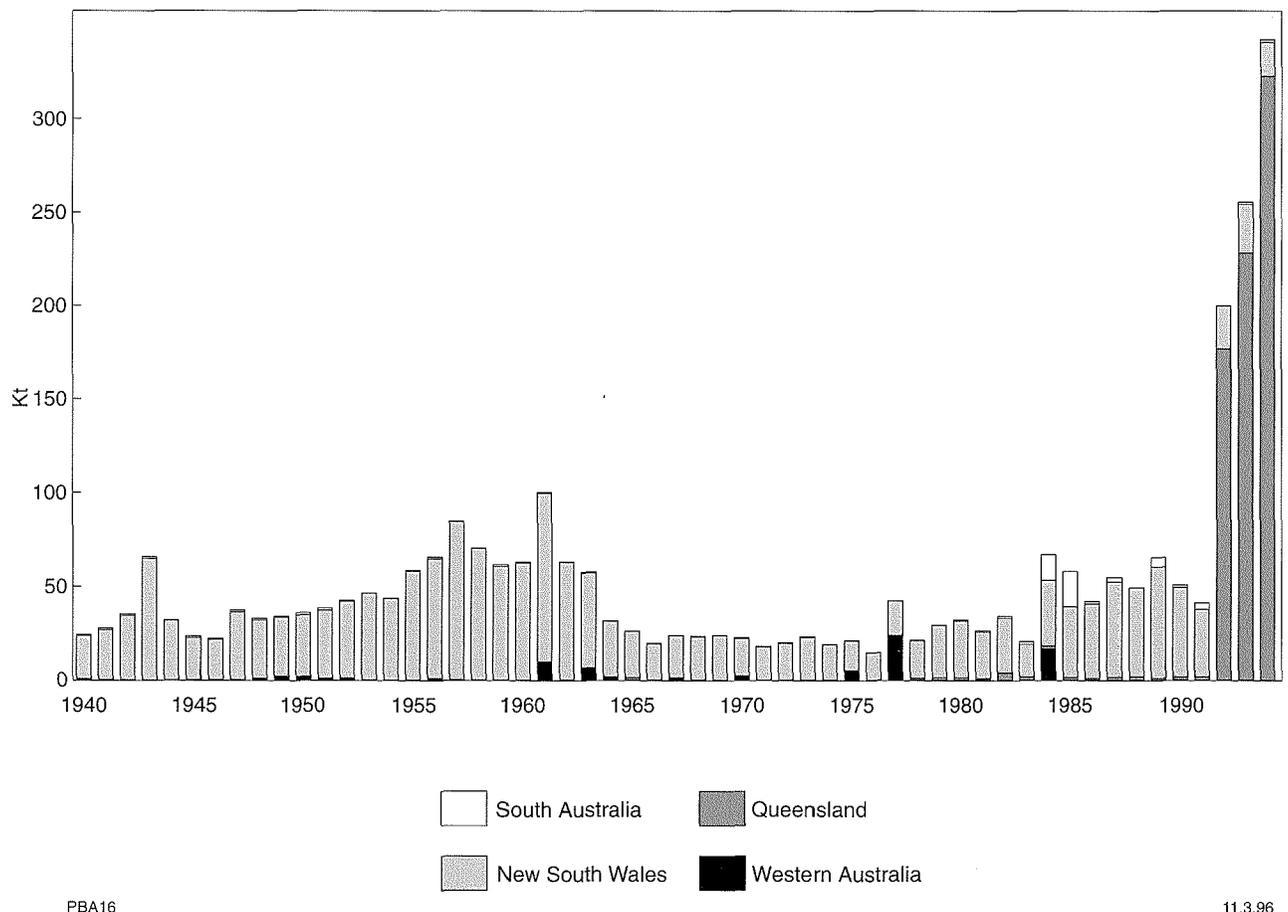


Figure 25. Production of magnesite in Australia, 1940–1994. Sources: Kalix et al. (1966); Australian Mineral Industry Annual Review (1967 to 1989); ABARE (1993, 1994, 1995); verbal advice from Mines and Energy, South Australia and New South Wales Department of Mineral Resources

low and there is a high talc content (Harben and Bates, 1990b). Despite its large production, the former Soviet Union was a major importer of natural magnesite products from North Korea. The major operators in CIS are Magnesite Refractory Works (MRW), Vnukovsky Refractory Works (VRW) and Bogdanovichsky Refractory Works (BRW), all located in Russia.

North Korea

The deposits in China continue along strike into North Korea, and include the enormous deposits at Tansengun, South Kankyo Province, and Gosui in North Kankyo Province (Comstock, 1963), with a production of natural magnesite of around 3 Mt per year.

Austria

The production of magnesite in Austria is concentrated in the southern part of the country in a belt of metamorphosed sedimentary rocks known as the greywacke zone (Harben and Bates, 1990b). Annual production of natural magnesite from Austria is approximately 0.7 Mt. The main producing companies are Radex, Tiroler (a subsidiary of Radex), and Veitscher.

Greece

The production of natural magnesite from Greece is approximately 0.5 Mt per year, with major contributions from mines in the Chalkidiki Peninsula in the north, and from the island of Euboea in the Aegean Sea. The associated rock types include shelf carbonates, shale, greywacke, volcanoclastic rocks and a discontinuous belt of mafic-ultramafic rocks. The ultramafic complex contains veins up to 2 m wide consisting of magnesite with minor dolomite, quartz, chalcedony and calcite (Harben and Bates, 1990b). The main producers are the Grecian Magnesite Company, Magnomin General Mining Co., and Mining Trading and Manufacturing Ltd. FIMISCO, which was a leading natural magnesite producer, announced its liquidation in February 1992.

Turkey

Turkey produces more than 1 Mt of natural magnesite per year. Most comes from the provinces of Eskisehir and Kutahya. Magnesite is also produced at Konya, 240 km south of Ankara, from stockwork deposits, with magnesite infilling web-like cracks in serpentine. The main producers are Kutahya Manyezit Isletmeleri AS and Sumerbank.

Czech Republic

The Czech Republic produces approximately 0.8 Mt of natural magnesite per year from a series of deposits between the towns of Kosice and Lucenec, in the extreme east of the country near the border with Poland, Hungary and CIS (Kuzvart, 1981). The magnesite is considered

to have been formed by hydrothermal replacement of fine-grained dolomite during the Cretaceous. The main producing company is Slovenske Magnezitove Zavody.

Brazil

Mining of magnesite in Brazil is almost exclusively from deposits around Brumado in Southwestern Bahia, approximately 1000 km from Belo Horizonte. The annual production of natural magnesite is around 0.9 Mt, and approximately 340 000 t of dead-burned magnesia and 20 000 t of caustic-calcined magnesia is also produced. Magnesite is associated with upper Precambrian dolomite and quartzite overlying Precambrian gneiss and schist, and is intruded by small amphibolite and rhyolite dykes. The dolomite, together with talc, quartz and magnesite, tends to be in lenticular deposits up to 900 m long. The major deposit of crystalline magnesite of commercial interest is in an isolated mountain chain in the area of Serra das Eguas. Magnesite occurs in blade-like aggregates, euhedral crystals, and massive aggregates, in a range of colours from white to light-grey to an orange-red variety that contains disseminated hematite (Harben and Bates, 1990b). The main producer is Magnesite SA.

India

An annual production of nearly 0.4 Mt of natural magnesite comes mainly from two centres in India. The larger deposits are at Salem, approximately 280 km southwest of Madras in Tamil Nadu Province in southern India. White cryptocrystalline magnesite occurs as veins associated with dunite, peridotite and pyroxenite (Harben and Bates, 1990b), and output from this area is approximately 460 000 t per year. The second centre is Almora in Uttar Pradesh Province, where coarsely crystalline magnesite is associated with dolomite, talc, siliceous limestone, and pyrite-bearing shale. Production from this area is approximately 24 000 t per year (Coope, 1983). The main producers are Dalmia Magnesite Corporation, Tamil Nadu Magnesite Ltd, Burn Standard Co. Ltd, Belpahar Refractories Ltd, and the Steel Authority of India.

Australia

Australian magnesite production is shown in Figure 25. The total Australian output from 1940 to 1994 is approximately 2.8 Mt, of which New South Wales produced 1.99 Mt, Queensland 0.71 Mt, Western Australia 0.08 Mt, and South Australia 0.07 Mt. However, Queensland produced 278 622 t during 1994 compared to 15 553 t from New South Wales and 1228 t from South Australia, and is emerging as a major new source following the discovery of the Kunwarara deposits in the Rockhampton area in 1985. Western Australia has been a moderate producer in the past, but no magnesite has been mined since 1984. There is no mining currently in Victoria, Tasmania or Northern Territory, and past production has been insignificant.

Table 29. Magnesite production from Western Australia, 1915 to 1994 (tonnes)

Year	Bandalup	Coolgardie	Bulong	Mount Hunt	Northam	Westonia	Total (tonnes)
1915	—	—	611	—	—	—	611
1916	—	—	99	—	—	—	99
1917	—	—	21	—	—	—	21
1918	—	—	107	—	—	—	107
1938	—	10	—	—	—	—	10
1940	—	261	—	—	—	—	261
1941	—	—	102	—	—	—	102
1942	—	25	—	—	—	—	25
1946	—	—	11	—	—	—	11
1947	—	—	74	—	—	—	74
1948	—	474	—	—	503	—	977
1949	—	21	27	—	2 018	—	2 066
1950	—	41	—	—	1 817	—	1 858
1951	—	350	425	—	—	—	775
1952	—	1 072	—	—	—	—	1 072
1953	—	20	—	—	—	—	20
1954	—	93	—	—	—	—	93
1956	—	467	97	287	—	—	851
1959	19	—	—	—	—	—	19
1961	9 779	—	—	—	—	—	9 779
1962	228	—	—	—	—	—	228
1963	6 576	—	—	—	—	22	6 598
1964	1 600	—	—	—	—	—	1 600
1965	202	—	—	—	—	—	202
1966	137	—	—	—	—	—	137
1967	1 184	95	—	—	—	—	1 279
1968	169	—	—	—	—	—	169
1970	2 215	—	—	—	—	—	2 215
1971	61	—	—	—	—	—	61
1972	30	—	—	—	—	—	30
1975	5 119	—	—	—	—	—	5 119
1977	23 897	—	9	—	—	—	23 906
1984	16 729	—	—	—	—	—	16 729
1985–94	—	—	—	—	—	—	0
Total	67 945	2 929	1 583	287	4 338	22	77 104

NOTES: **Bandalup** Production from MC76, 77 — Basic Raw Materials Co. Ltd. (1959–1963); Magnesite (WA) Pty Ltd (1964–1967); Norseman Gold Mines NL (1968 and 1970); Magnesite (WA) Pty Ltd. (1971, 1972 and 1975); M74/76, 77, 9, 10 — Norseman Gold Mines NL (1977 and 1984)

Coolgardie Production from MC116–119 — Austin Glass Mfrs Co.; ML87, 91, 92, PA6600 — Scahill and Gibbons; ML94 — Swan Portland Ltd

Bulong Production from MC10Y — Broken Hill Pty Ltd; ML3Y (1946 only) — Jones, R. L. C.; PA1409Y (1956 only) — Frank, C. B.; 59H — Sheppard, W.; MC25/1109 (1977 only) — Seurico Nominees Pty Ltd

Mount Hunt Production from MC17E — Jones, R. L. C.

Northam Production from private land

Westonia Production from MC60 — Read, J. E.; Nell, L. R.; Fletcher, R. F.

Queensland

Continuous production of magnesite began in Queensland as late as 1978, but will undoubtedly increase in the future. The most important deposit in Queensland is that owned by Qmag at Kunwarara, approximately 60 km northwest of Rockhampton. This deposit, centred at latitude 22°55'S and longitude 150°13'E, is reported to contain a measured resource of 1200 Mt ore covering 63 km² and is considered to be the largest cryptocrystalline magnesite deposit in the world (Queensland Metals Corporation Ltd, 1992). Production from this deposit in the December quarter of 1994 was 691 595 t of ore, 56 202 t of beneficiated magnesite, 13 650 t of dead-burned magnesia and 4260 t of electrofused magnesia. A brief description of the geology of the deposit is given in Chapter 5.

Kunwarara forms part of the Hillview project area, which also includes magnesite deposits at Oldman, located 5 km southeast (more than 124 Mt with 58 Mt of raw magnesite, at an inferred grade of 93.7% MgO). The Triple Four deposit, 28 km west of Kunwarara, contains 35 Mt of raw magnesite at an indicated grade of 92.3% MgO in a total resource of 77 Mt (Industrial Minerals, 1987b). Other deposits in the Rockhampton area are at Marlborough, Merimal and Yaamba. Yaamba, 35 km north of Rockhampton, has reserves of approximately 188 Mt. The magnesite occurs as nodules within alluvial clay and Cainozoic sand and gravel overlying serpentinite basement (Harben and Bates, 1990b).

Other magnesite occurrences in Queensland include Mount Pring, 16 km west-southwest of Bowen, where the

Table 30. Total value of magnesite from Western Australia, 1915 to 1994 (\$AUS)

Year	Bandalup	Coolgardie	Bulong	Mount Hunt	Northam	Westonia	Total (\$AUS) \$ value of day
1915	-	-	1 202.00	-	-	-	1 202.00
1916	-	-	194.00	-	-	-	194.00
1917	-	-	42.00	-	-	-	42.00
1918	-	-	668.00	-	-	-	668.00
1938	-	24.00	-	-	-	-	24.00
1940	-	460.00	-	-	-	-	460.00
1941	-	-	175.00	-	-	-	175.00
1942	-	200.00	-	-	-	-	200.00
1946	-	-	52.50	-	-	-	52.50
1947	-	-	146.00	-	-	-	146.00
1948	-	3 382.00	-	-	2 970.42	-	6 352.42
1949	-	114.00	148.00	-	9 166.36	-	9 428.36
1950	-	350.00	-	-	7 300.16	-	7 650.16
1951	-	1 740.14	2 198.00	-	-	-	3 938.14
1952	-	5 685.00	-	-	-	-	5 685.00
1953	-	146.00	-	-	-	-	146.00
1954	-	515.00	-	-	-	-	515.00
1956	-	2 452.60	384.00	1 326.00	-	-	4 162.60
1959	148.00	-	-	-	-	-	148.00
1961	129 954.20	-	-	-	-	-	129 954.20
1962	3 186.40	-	-	-	-	-	3 186.40
1963	88 155.90	-	-	-	-	177.20	88 333.10
1964	20 039.70	-	-	-	-	-	20 039.70
1965	3 176.40	-	-	-	-	-	3 176.40
1966	1 958.52	-	-	-	-	-	1 958.52
1967	10 755.96	1 468.00	-	-	-	-	12 223.96
1968	2 411.50	-	-	-	-	-	2 411.50
1970	31 600.00	-	-	-	-	-	31 600.00
1971	900.00	-	-	-	-	-	900.00
1972	450.00	-	-	-	-	-	450.00
1975	102 244.00	-	-	-	-	-	102 244.00
1977	637 315.00	-	134.00	-	-	-	637 449.00
1984	215 936.00	-	-	-	-	-	215 936.00
1985-94	-	-	-	-	-	-	0.00
Total	1 248 231.58	16 536.74	5 343.50	1 326.00	19 436.94	177.20	1 291 051.96

NOTES: **Bandalup** — MC76, 77 and M74/76, 77, 9, 10
Coolgardie — MC116-119; ML87, 91, 92; PA6600 and ML 94
Bulong — Value of production from PA1409Y; MC10Y; MC3Y; 59H and MC25/1109
Mount Hunt — MC17E
Northam — Private land
Westonia — MC60

mineral forms veins (mostly less than 30 cm wide) associated with weathered serpentinite (Brooks, 1976). Other deposits are known near Forsayth, Herberton, and Bowen in north Queensland, the Clermont-Capella District in central Queensland, Degilbo, Kilkivan, Toowoomba and Ipswich in southeast Queensland (McLeod, 1965), Upper Widee and west-southwest of Gympie (Brooks, 1976).

New South Wales

Current production in New South Wales is from the Thuddungra deposits, approximately 35 km by road northwest of Young. Magnesite occurs as small irregular veins and nodules within the weathering zone of intrusive Silurian serpentinites and adjacent metasedimentary rocks (Lishmund, 1976b). A reserve of about 12.4 Mt is reported for the Thuddungra deposits, which include Baileys, Noakes and Young (Louthean, 1993). Devex Ltd has

recently signed a Heads of Agreement with Toyota Tsusho Corporation and Mitsubishi Materials Corporation for further development of its magnesite operations at Thuddungra (Industrial Minerals, 1992).

The Fifield deposits are located approximately 30 km northeast of Condobolin in the Western Division. Magnesite occurs as veins and nodules up to 60 cm in diameter within the zone of weathering of intrusive Alaskan mafic-ultramafic bodies, typically beneath soil cover about 2 m thick. This area has been explored and, although reserves are extensive, figures are not available. The area produced 925 000 t of magnesite up until 1975.

Other deposits of magnesite in New South Wales are at Crow Mountain near Barraba, Attunga, and Woodsreef, where the magnesite occurs in weathered serpentinite as irregular veins and pods up to a few metres wide and as extensive stockworks. At Warialda west of Cargelligo,

magnesite is probably derived from nepheline-bearing olivine basalt. At Mineral Hill, magnesite is associated with chlorite schists.

South Australia

Magnesite has been produced from a number of localities in South Australia with some of the main deposits being associated with upper Proterozoic rocks at Port Germein Gorge, Mundallio, Copley, Witchelina, Balcanoona, Eyre Peninsula and the Mount Lofty Ranges.

The Port Germein deposits are approximately 24 km north of Port Pirie. The highest grade magnesite is confined to a belt of massive pale-grey brecciated magnesite. The associated rocks are dolomite, dolomitic shale, sandstone and chert. In the Mundallio area, approximately 19 km northeast of Port Augusta, magnesite is interbedded with dolomite, shale, chert and thin bands of quartzite. In the Copley and Witchelina areas, magnesite beds occur in a belt from approximately 5 km southwest of Copley and extending for 27 km in a northwesterly direction. In this belt magnesite is interbedded with steeply dipping calcareous shale, dolomitic limestone and subordinate quartzite and grit. At Balcanoona, white coarsely crystalline magnesite forms in a number of

irregular pods metasomatically replacing the Balcanoona Dolomite. Magnesite is commonly intimately associated with graphite in the Eyre Peninsula. Weathering and subsequent reaggregation of deposits associated with graphite have resulted in high-grade cryptocrystalline masses, such as the one at Tumby Bay. There has been minor production of magnesite from the vicinity of Torrens Gorge in the Mount Lofty Ranges (Johns, 1976; McLeod, 1965).

Western Australia

Although magnesite is known from many places in Western Australia, total production between 1915 and 1984 was only 77 104 t valued at \$1.3 million. The last officially recorded mining was by Norseman Gold Mines NL in 1984 from the Bandalup deposit close to Ravensthorpe (16 729 t valued at \$215 936). Magnesite has also been mined at Coolgardie, Bulong and Northam (Tables 29 and 30). The geology of the magnesite deposits in Western Australia is discussed in Chapter 7.

Magnesite in Western Australia

The known magnesite occurrences in Western Australia (Fig. 26) can be broadly grouped into two categories based on their geologic associations:

- (a) magnesite in altered serpentinous ultramafic rocks of Archaean age, e.g. Bulong, Coolgardie and some deposits in the Ravensthorpe area;
- (b) magnesite in Tertiary sedimentary rocks, e.g. some deposits at Bandalup near Ravensthorpe.

Deposits of association (a) are widespread in the State, and are discussed by tectonic province below. Deposits of association (b) are so far known only from the Ravensthorpe district (at Bandalup) and are described with the other magnesite deposits in the Southern Cross Province. Deposits of commercial grade are known from both association types, but none is being exploited at present. The last recorded production was in 1984 from the Bandalup deposit, then owned by Norseman Gold Mines NL.

For this discussion the magnesite occurrences in Western Australia are grouped by tectonic units as shown in Figure 26, and are described under the following headings:

1. Southern Cross Province of the Yilgarn Craton
Ravensthorpe district
Munglinup
minor occurrences
2. Eastern Goldfields of the Yilgarn Craton
Bulong
Coolgardie
Mount Burges
Lawlers
Eulaminna
Siberia (Waverley)
Comet Vale
minor occurrences
3. Minor occurrences in other tectonic units

Southern Cross Province, Yilgarn Craton

Ravensthorpe district

The commercially exploitable magnesite deposits in the Ravensthorpe district are located near the boundary

of the Archaean Yilgarn Craton and the Proterozoic Albany–Fraser Orogen. The geological succession in the Ravensthorpe area consists of mafic and ultramafic rocks alternating with sedimentary rocks and felsic volcanics, with a minimum age of approximately 2900 million years (Richards et al., 1966; Jeffrey, 1956). Middle to upper Eocene Pallinup Siltstone of the Plantagenet Group, unconformably overlying these older rocks (Thom et al., 1977), is a favourable host for magnesite mineralization. The siltstone is commonly fossiliferous, containing bivalves, gastropods, echinoids, bryozoans and sponges. The main magnesite deposits are in the Bandalup area associated with Archaean rocks and the overlying Tertiary Plantagenet Group.

Historical background

Important deposits of magnesite in the Ravensthorpe district are located at Bandalup, approximately 30 km east of Ravensthorpe (Fig. 26). However, magnesite in the district was first reported from the vicinity of Kundip in 1909 (Woodward, 1909). The first recorded application for a mineral tenement for magnesite was lodged in September 1913, when exclusive rights were sought to prospect and mine magnesite over 190 ha of land, 3.5 km north of Mount Desmond. However, prior to 1913 local magnesite had been used by the Phillips River Gold and Copper Company Ltd to manufacture bricks for lining converters. Between 1959 and 1984, 67 945 t of magnesite valued at \$1.25 million was produced from the Bandalup mine (Tables 29 and 30), comprising 20 292 t of magnesite extracted in the late 1960s by opencut mining from deposit N2W (Fig. 27), and a further 19 951 t from deposit N2E between 1983 and 1984. The 1983–1984 production of 16 729 t was shipped by Norseman Gold Mines NL to Queensland Alumina Limited. There has been no production since 1984.

Geology

The rocks in the area consist mainly of an Archaean sequence of alternating mafic and ultramafic rocks containing interbedded sandstone, quartzite, phyllite and chert (Fig. 17). Further east, and also near Kundip, these rocks are unconformably overlain by the Tertiary Plantagenet Group and superficial Quaternary deposits. The following is a summary of the stratigraphy of the rocks.

Quaternary — Residual soil, sand and alluvium
 Tertiary Plantagenet Group — mainly Pallinup Siltstone
 Proterozoic Mount Barren Beds — dolomite, phyllite and quartzite
 Archaean — granitic, sedimentary, felsic, mafic and ultramafic rocks

Two mafic units are recognized within the Archaean sequence. One unit outcropping mainly along the foot of the Ravensthorpe Range near Desmond and around Kundip (Thom et al., 1977) consists of basaltic lava, tuff and agglomerate with minor felsic volcanic rocks, and the other, exposed along the Jerdacuttup River and Bandalup Creek, contains pillow lavas with variolitic structures and amygdaloidal cavities. These rocks have undergone upper greenschist to amphibolite facies metamorphism. The ultramafic rocks are extensively serpentinized and are well-exposed on the eastern slope of the Ravensthorpe Range. They contain thin layers of chlorite–tremolite rock outlining sills or flows of peridotite. Talc, chlorite and amphibole schists are present in the shear zones. The ultramafic rocks commonly host magnesite deposits (Locations B1 to B8 and L1, Fig. 27).

The Archaean sedimentary sequence consists of weakly metamorphosed shale, siltstone, sandstone, polymictic conglomerate and chert. Some magnesite deposits are associated with these sedimentary rocks.

In the northern Bandalup Creek area, ultramafic rocks are overlain by the Tertiary Plantagenet Group and poorly lithified green sands that are commonly replaced by magnesite. The serpentinite at Bandalup Hill is capped by thick Tertiary laterite.

The Archaean rocks in the Ravensthorpe area are folded into an overturned synclinal structure with a northwesterly axis. The northeastern limb of the fold has southwesterly to southerly dips of about 40°, it is extensively intruded by granitoid. The beds in the southwestern limb dip steeply to the west. The synclinal structure is cut by a number of northeasterly and north-northeasterly trending faults.

Magnesite deposits in the Ravensthorpe area occur as massive, structureless bodies that overlie many rock types. Based on their geologic associations, they can be assigned to the two categories of deposits mentioned above: those associated with Archaean ultramafic rocks; and those associated with the Eocene Pallinup Siltstone of the Plantagenet Group (Ellis, 1941; Johnson and Gleeson, 1951; Simpson, 1952; Sofoulis, 1958; Butler, 1961; Faulkner, 1962; Thomas, 1972; Thom et al., 1977; Younger, 1985; and Locsei, 1986).

Magnesite deposits in Archaean ultramafic rocks

Residual magnesite deposits are developed over Archaean serpentinite, amphibolite, quartzite and schist. Faulkner (1962) defined two varieties of deposit — ‘a lean superficial type; and a dense accumulate type’. The

✕ PAST MAGNESITE PRODUCTION

Bandalup
 Coolgardie
 Bulong
 Northam (52)
 Westonia (20)
 Mount Hunt (42)

■ SIGNIFICANT DEPOSIT

Munglinup
 Mount Burges
 Lawlers
 Eulaminna
 Siberia (Waverley)
 Comet Vale

● MINOR OCCURRENCE

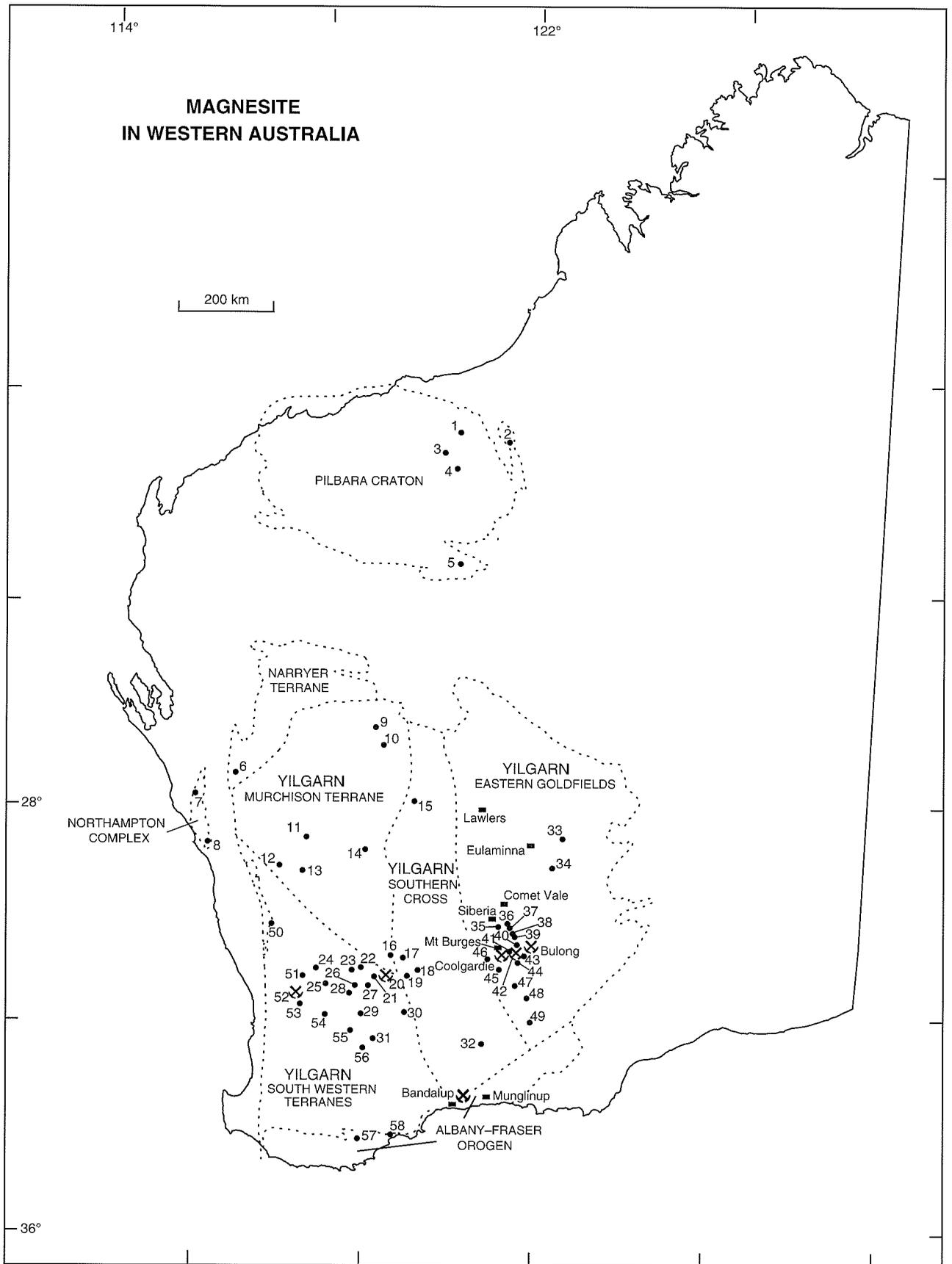
- | | |
|----------------------|-----------------------------------|
| 1 Bamboo Creek | 30 Lookout Hill |
| 2 Braeside | 31 Kondinin |
| 3 Warrawoona | 32 Bremer Range |
| 4 Lionel | 33 Laverton |
| 5 Jimblebar | 34 Eucalyptus |
| 6 Yallalong | 35 Ora Banda |
| 7 Geraldine (Ajana) | 36 Bardoc |
| 8 Northern Gully | 37 Broad Arrow |
| 9 Meekatharra | 38 Paddington |
| 10 Gabanintha | 39 Kanowna |
| 11 Yalgoo | 40 Kalgoorlie–Boulder |
| 12 Ninghanboun Hills | 41 Kurrawang |
| 13 Rothsay | 42 Mount Hunt |
| 14 Mulermurra | 43 Golden Ridge |
| 15 Sandstone | 44 Feysville |
| 16 Boodarockin | 45 Nepean |
| 17 Bullfinch | 46 Bullabulling |
| 18 Southern Cross | 47 Larkinville |
| 19 Moorine Rock | 48 Higginsville
(Hopbush Soak) |
| 20 Westonia | 49 Norseman |
| 21 Burracoppin | 50 Namban |
| 22 Nungarin | 51 Goomalling |
| 23 Kununoppin | 52 Northam |
| 24 Dowerin | 53 York |
| 25 Tammin | 54 Dangin |
| 26 Baandee | 55 Corrigin, Kumminin |
| 27 Merredin | 56 Kulin |
| 28 Doodlakine | 57 Stirling Range |
| 29 Ardath | 58 Pallinup River |

PBA29A

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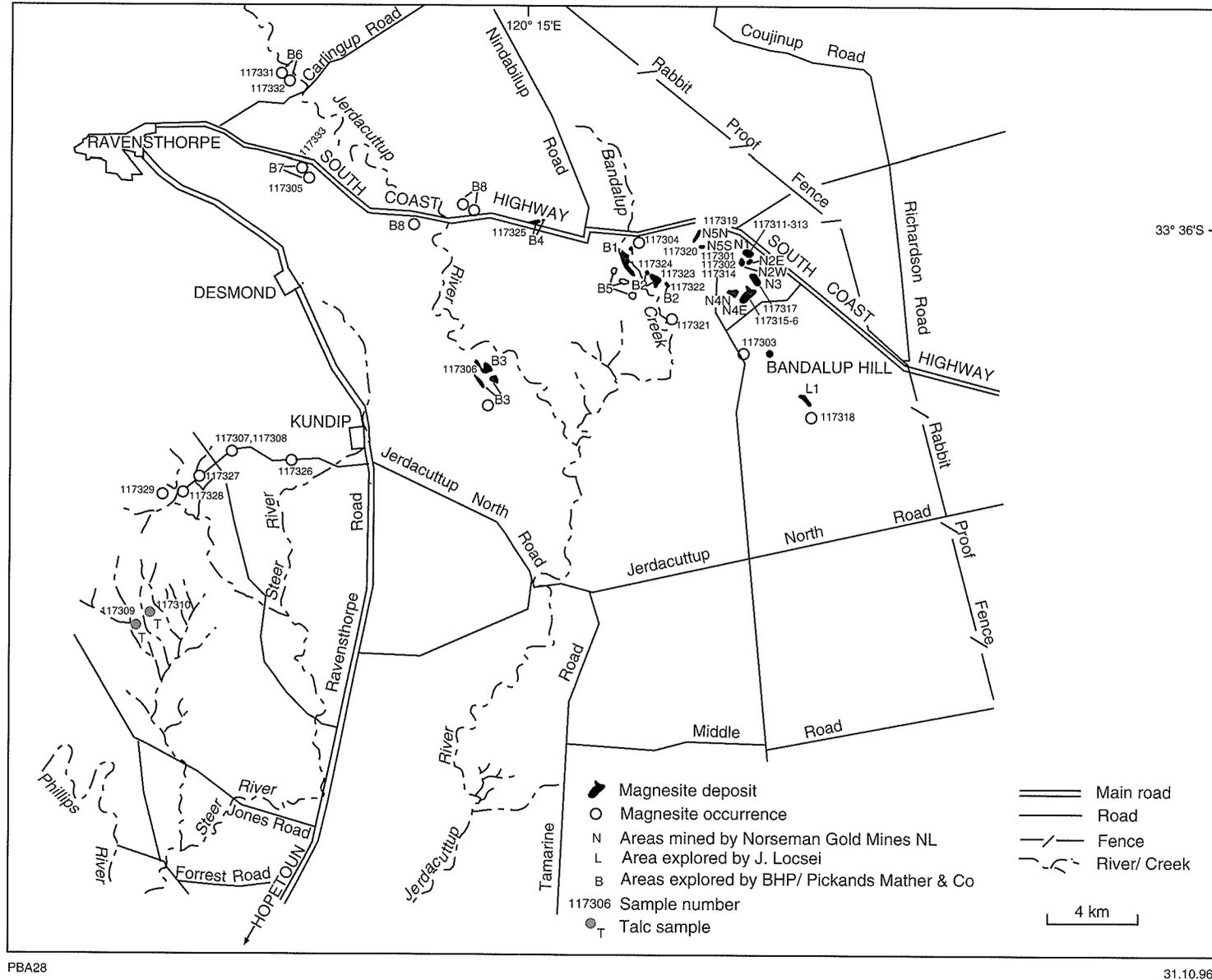
Figure 26. Magnesite in Western Australia: areas of past production, significant deposits and minor occurrences

lean type is usually 1.0 to 2.5 m thick, and overlain by a soil horizon typically 0.5 to 1.0 m thick. The dense type forms as lenticular lumpy bodies with well-defined margins, occurring at low-lying to intermediate physiographic levels, adjacent to creeks. Thickness varies



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PBA28

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Figure 27. Deposits and occurrences of magnesite in the Bandalup and Ravensthorpe area

between 0.5 and 10.0 m, and the lump magnesite varies from hard, flinty (locally dolomitic) material to soft, porous and chalky material, and at times lies directly on siliceous metasedimentary rocks. Basement rocks are commonly present as either isolated boulders or as thin remnants.

The following descriptions are based on exploration reports by Faulkner (1962) and Locsei (1986). Localities of the various deposits are shown on Figure 27.

B1, B2, B5 (Bandalup Creek, south of West Coast Highway)

Location: Lat. 33°37'20"S, Long. 120°18'50"E; RAVENSTHORPE

Magnesite is associated with small exposures of hornblende-bearing mafic rocks over an area of 37 ha. Johnson and Gleeson (1951), on a reconnaissance visit to the area, made a resource approximation of 330 000 t, based on generalized assumptions. Exploration pits show that magnesite is well-developed as boulders (concretions) between 2.5 and 5 m in diameter. Most boulders are massive although some are relatively soft and readily breakdown into finer material. Inferred resources for this area are about 176 500 t of lump magnesite (Faulkner, 1962).

B3 (6 km northeast of Kundip)

Location: Lat. 33°39'45"S, Long. 120°13'55"E; RAVENSTHORPE

South of the Jerdacuttup River, and approximately 6 km northeast of Kundip, is a magnesite occurrence associated with mainly serpentinitous schist. The inferred resource is more than 100 000 t. However, the deposit is considered to be uneconomic because of anticipated problems in selective mining of the deposit.

B4 (north of South Coast Highway)

Location: Lat. 33°36'00"S, Long. 120°15'30"E; RAVENSTHORPE

Three distinct magnesite bodies, typically in the form of dense surface accumulations, occur along and parallel to a creek. As indicated by pits, depth of magnesite does not exceed 3 m. A sample (117325) of magnesite studied using XRPD yielded less than 5% halite, and less than 1% of an unidentified component at peak 3.54Å.

The westerly exposures are associated with a heavy mantle of chalcedonic and jasperoidal silica. The inferred resource in this area is approximately 20 000 t.

B6 (eastern slope of Ravensthorpe Range and south of Jerdacuttup River)

Location: Lat. 33°33'05"S, Long. 120°08'10"E; RAVENSTHORPE

Outcrops of magnesite are restricted to the crests and upper slopes of prominent ridges, and are typically associated with mafic outcrops and heavy rubble. Minor outcrops of jaspilite, amphibolite and quartzite are also present. The depth of the magnesite ranges between 1.5 and 2.5 m. The resource available from this area is considered to be insignificant.

B7 (approximately 8 km east of Ravensthorpe)

Location: Lat. 33°35'05"S, Long. 120°08'45"E; RAVENSTHORPE

Magnesite outcrops in this area are associated with serpentinites, both are exposed along northerly trending ridges. Some magnesite outcrops contain surficial travertine. Small tonnages of magnesite, for use in the Ravensthorpe copper smelter, were obtained from this area in the early 1900s by surface picking and from shallow veins, but there is now insufficient lump magnesite available to be commercially significant.

B8 (14 to 17.5 km east of Ravensthorpe)

Location: Lat. 33°35'40"S, Long. 120°13'30"E and Lat. 33°36'20"S, Long. 120°12'00"E; RAVENSTHORPE

Scattered exposures of magnesite lie on the east and west of the Jerdacuttup River. Some outcrops have well-developed exteriors with 'cauliflower-like' appearance, and a thin travertine layer is commonly developed on surface nodules. These exposures are associated with metamorphosed mafic rocks and minor metasedimentary rocks. The magnesite is not very thick; there are no indications of significant reserves.

L1 (approximately 3 km southeast of Bandalup Hill)

Location: Lat. 33°39'55"S, Long. 120°23'40"E; RAVENSTHORPE

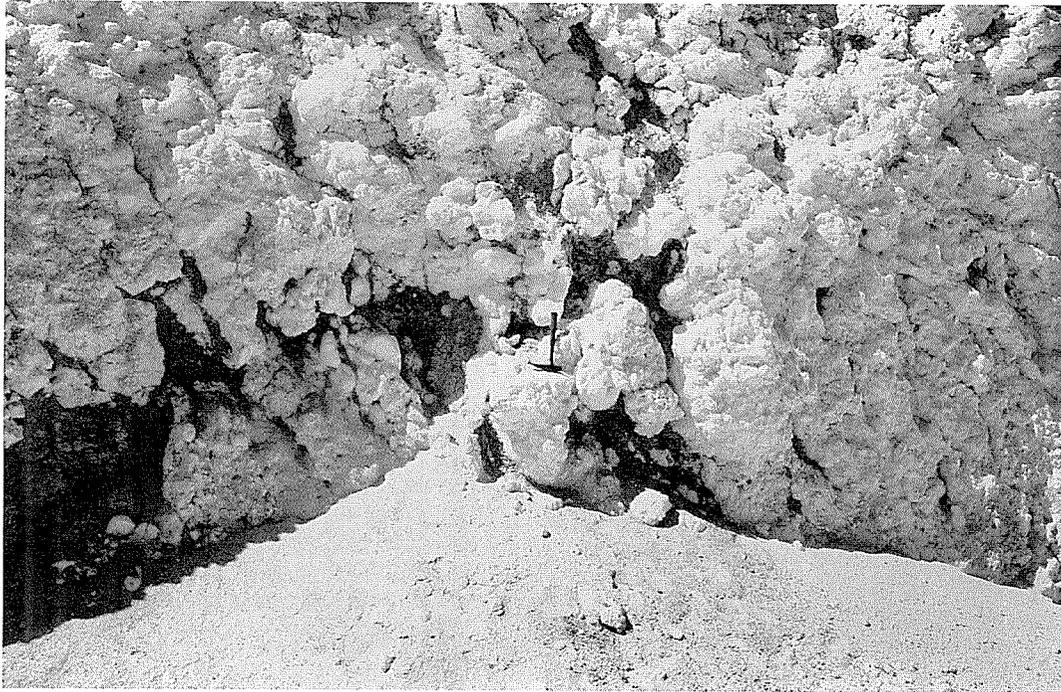
Magnesite overlies serpentinite on a laterite-capped hill, approximately 3 km southeast of Bandalup Hill. The magnesite is a hard, white material with karst-like surfaces, though in some outcrops it may contain a brown dolomitic coating, and in places the magnesite extends laterally under the laterite. Exploration drilling for nickel in the area intersected magnesite at depths of between 15 and 46 m in three holes, drilled at 100 m intervals (Locsei, 1986). Based on this information, Locsei has suggested that a deposit may contain in excess of 5 Mt of magnesite.

Magnesite in Eocene Pallinup Siltstone

Bandalup deposit (N1 to N5)

Location: Lat. 33°36'40"S, Long. 120°21'30"E; RAVENSTHORPE

Extensive replacement deposits of magnesite occur in sandy sediments of the upper Eocene Pallinup Siltstone,



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Figure 28. Photographs of magnesite exposures at Bandalup
Top: southern wall of exposure in deposit N4E
Lower: Costean in deposit N5N

approximately 3 km northeast of Bandalup Hill (Fig. 28), adjacent to the South Coast Highway. The Pallinup Siltstone unconformably overlies deeply weathered Archaean quartz–mica schist, metamorphosed sandstone and volcanic rocks, and the magnesite occurs at several levels separated by layers of Tertiary sand. The deposits are composed mainly of nodules of magnesite up to 0.75 m in diameter, but also contain soft earthy or clayey material that may be either structureless or incoherent. They have a maximum thickness of approximately 7 m, with an average mineable thickness of 4 m.

The Bandalup deposits are scattered, but fall into broad groups referred to as eastern, western and southern. Butler (1961) inferred a resource of approximately 455 700 t in three deposits, whereas Thomas (1972) proposed eight discrete deposits (Fig. 27) with a recoverable resource of approximately 1 167 000 t, based on exploratory percussion drilling and a bulk sampling program involving trenching and pitting.

Other magnesite occurrences

Impure, light-brown to grey, medium-grained, friable magnesite and dolomite are commonly exposed along a westerly track from Kundip (Fig. 27). Chemical analyses of five samples show MgO values ranging between 8.81% and 39.0% (Table 31). High percentages of nickel in some of these samples indicate derivation from ultramafic rocks.

Many other small occurrences of magnesite with no commercial significance are associated with sheared and altered ultramafic rocks in the Ravensthorpe area.

Quality of magnesite

Magnesite in Archaean rocks

Analytical data for magnesite samples associated with Archaean rocks in the area are given on Table 32. The results indicate a wide variation in chemical composition,

Table 31. Chemical analyses of magnesite from the Kundip area and Munglinup (major and trace elements)

GSWA no.	117307	117326	117327	117328	117329	117337	117338
Locality	Kundip	Kundip	Kundip	Kundip	Kundip	Munglinup	Munglinup
Lab no.	7	26	27	28	29	35	36
	percentage						
SiO ₂	5.39	7.48	4.26	7.16	5.34	1.11	0.11
TiO ₂	<0.05	0.08	<0.05	0.06	<0.05	<0.05	<0.05
Al ₂ O ₃	0.07	2.11	0.75	0.91	0.43	0.66	<0.05
Fe ₂ O ₃	0.34	0.33	0.36	0.25	0.15	0.07	<0.05
FeO	0.16	0.24	<0.1	<0.1	<0.1	<0.1	<0.1
MnO	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MgO	33.3	20.20	39.00	8.81	25.6	47.20	48.00
CaO	13.00	26.1	6.64	39.8	23.1	0.37	0.45
Na ₂ O	0.23	0.26	0.28	0.29	0.25	0.22	0.24
K ₂ O	<0.05	0.62	0.29	0.17	0.12	<0.05	<0.05
P ₂ O ₅	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
CO ₂	45.4	41.2	46.2	41.7	44.7	50.20	51.00
S	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01
H ₂ O ⁺	2.1	1.54	1.65	1.66	2.07	0.52	0.31
H ₂ O ⁻	0.48	0.59	0.55	0.56	0.75	0.12	0.12
Rest	0.19	0.13	0.07	0.14	0.12	0.08	0.01
Total	100.66	100.88	100.05	101.53	102.63	100.55	100.24
	parts per million						
As	<4	<4	<4	<4	<4	<4	<4
Ba	48	162	62	141	60	<11	<11
Cr	124	27	15	12	12	11	<4
Cu	33	95	17	32	57	143	39
La	<5	13	6	<5	<5	6	<5
Mn	271	102	153	88	285	45	26
Ni	610	33	19	31	42	176	13
Pb	<4	5	<4	<4	<4	<4	<4
Rb	<2	36	19	8	6	<2	<2
Sb	<4	<4	<4	<4	<4	<4	<4
Sr	628	588	329	868	722	10	23
V	<3	15	12	<3	12	16	3
Zn	10	28	9	4	4	148	26
Zr	<5	49	<5	89	27	29	27

NOTES: Analyses: CC

Sample locations — 117307, 117326–117329 are indicated on Figure 27; samples 117337 — Lat. 33°39'35"S, Long. 120°51'14"E; 117338 — Lat. 33°39'45"S, Long. 120°51'14"E

Table 32. Chemical analyses of magnesite in Archaean associations in the Bandalup area (major and trace elements)

GSWA no.	BA1	BA2a	BA2b	BA3	BA4	BA5	117304	117305	117306	117318	117321	117322	117323	117324	117325	117331	117332	117333	
Locality							B1	B7	B3	L1	B2	B2	B2	B2	B4	B6	B6	B7	
Lab no.	790	791	792	793	794	795	4	5	6	18	21	22	23	24	25	31	32	33	
SiO ₂	4.28	36.08	41.30	19.56	1.17	1.39	0.72	9.71	0.74	<0.05	0.57	0.37	0.35	<0.05	<0.05	11.20	12.30	3.40	
TiO ₂	—	—	—	—	—	—	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.09	<0.05	
Al ₂ O ₃	0.38	2.63	6.35	0.43	0.16	0.26	0.17	0.23	<0.05	<0.05	<0.05	<0.05	0.10	<0.05	<0.05	0.74	1.54	0.15	
Fe ₂ O ₃	0.76	3.49	4.61	1.45	0.50	0.42	<0.05	0.81	0.18	<0.05	<0.05	0.06	<0.05	<0.05	<0.05	0.47	0.56	0.17	
FeO	—	—	—	—	—	—	<0.1	0.11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.44	0.92	0.44	
MnO	—	—	—	—	—	—	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
MgO	42.02	11.78	5.53	24.60	45.03	38.97	46.10	25.10	44.20	47.30	47.10	47.40	46.20	48.60	47.60	6.38	7.71	29.90	
CaO	2.09	16.70	11.50	15.13	1.90	8.92	1.98	20.40	3.47	0.98	1.37	1.28	1.68	0.42	0.48	37.50	38.40	18.30	
Na ₂ O	—	—	—	—	—	—	0.26	0.25	0.23	0.20	0.23	0.21	0.79	0.40	0.51	0.25	0.36	0.60	
K ₂ O	—	—	—	—	—	—	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	0.09	<0.05	
P ₂ O ₅	—	—	—	—	—	—	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	
CO ₂	46.73	21.16	9.40	32.57	49.55	48.62	50.00	41.10	49.40	50.80	50.80	51.00	49.90	52.00	51.70	36.10	35.60	45.30	
S	—	—	—	—	—	—	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.10	<0.01	<0.01	0.04	0.02	<0.01	
H ₂ O ⁺	—	—	—	—	—	—	0.90	2.56	0.94	0.24	0.50	0.42	0.99	0.36	0.28	3.43	2.97	0.98	
H ₂ O ⁻	—	—	—	—	—	—	0.23	1.04	0.21	<0.1	<0.1	<0.1	0.23	<0.1	<0.1	1.76	1.15	0.17	
Rest	—	—	—	—	—	—	0.04	0.20	0.07	0.18	0.03	0.02	0.02	0.01	0.01	0.18	0.16	0.12	
Total	96.26	91.84	78.69	93.74	98.31	98.58	100.40	101.51	99.44	99.70	100.60	100.76	100.36	101.79	100.58	98.60	101.87	99.53	
	parts per million																		
As	nd	nd	nd	nd	nd	nd	<4	48	<4	<4	<4	<4	<4	<4	<4	5	<4	<4	
Ba	nd	nd	nd	nd	nd	nd	17	55	<11	<11	<11	21	<11	<11	<11	135	136	<11	
Cr	nd	nd	nd	nd	nd	nd	5	249	159	40	58	11	6	<4	5	256	249	198	
Cu	nd	nd	nd	nd	nd	nd	27	123	73	10	47	30	54	18	27	106	106	21	
La	nd	nd	nd	nd	nd	nd	<5	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	
Mn	nd	nd	nd	nd	nd	nd	11	162	216	14	57	32	44	240	59	246	261	115	
Ni	nd	nd	nd	nd	nd	nd	22	470	129	1286	45	44	37	44	31	232	241	413	
Pb	nd	nd	nd	nd	nd	nd	25	16	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	
Rb	nd	nd	nd	nd	nd	nd	<2	2	<2	<2	<2	<2	<2	<2	<2	3	5	<2	
Sb	nd	nd	nd	nd	nd	nd	7	10	13	<4	4	<4	<4	<4	<4	<4	<4	9	
Sr	nd	nd	nd	nd	nd	nd	116	484	110	54	76	62	70	20	19	606	426	231	
V	nd	nd	nd	nd	nd	nd	3	23	3	<3	6	<3	5	<3	<3	22	33	15	
Zn	nd	nd	nd	nd	nd	nd	55	18	5	<3	<3	3	5	<3	15	11	15	5	
Zr	nd	nd	nd	nd	nd	nd	6	11	<5	20	14	16	14	30	30	35	25	<5	

NOTES: Samples 790–795, Bandalup Creek area — after Johnson and Gleeson (1951); analyses of samples 117304–117306, 117318, 117321–117325, and 117331–117333 — by CC
Sample locations 117304 — Lat. 33°36'17"S, Long. 120°18'32"E; 117305 — Lat. 33°35'06"S, Long. 120°08'46"E; 117306 — Lat. 33°39'45"S, Long. 120°13'54"E; 117318 — Lat. 33°39'56"S, Long. 120°23'38"E; 117321 — Lat. 33°38'14"S, Long. 120°19'23"E; 117322 — Lat. 33°37'18"S, Long. 120°18'53"E; 117323 — Lat. 33°37'10"S, Long. 120°19'00"E; 117324 — Lat. 33°37'08"S, Long. 120°18'36"E; 117325 — Lat. 33°36'07"S, Long. 120°15'18"E; 117331 — Lat. 33°33'05"S, Long. 120°08'00"E; 117332 — Lat. 33°33'08"S, Long. 120°08'15"E; 117333 — Lat. 33°35'03"S, Long. 120°08'46"E
nd — not determined

Table 33. Chemical analyses of magnesite in association with Pallinup Siltstone in the Bandalup area

GSWA no.	117301	117302	117311	117312	117313	117314	117315	117316	117317	117319	117320
Locality	N2W	N2W	N2E	N2E	N2E	N2W	N4E	N4E	N3	N5N	N5S
Lab no.	1	2	11	12	13	14	15	16	17	19	20
	percentage										
SiO ₂	0.16	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	1.91
TiO ₂	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Al ₂ O ₃	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Fe ₂ O ₃	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
FeO	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
MnO	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MgO	47.70	48.10	48.00	48.00	47.80	48.30	47.20	47.70	48.20	46.90	46.20
CaO	0.73	0.74	0.46	0.43	0.56	0.54	0.86	1.51	0.54	0.88	1.82
Na ₂ O	0.78	0.36	0.47	0.30	0.22	0.25	0.87	0.31	0.23	1.36	0.25
K ₂ O	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
P ₂ O ₅	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
CO ₂	50.30	49.90	50.30	50.30	51.20	50.60	51.00	50.90	51.20	49.80	49.30
S	0.06	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.08	<0.01
H ₂ O ⁺	0.50	0.42	0.34	0.40	0.31	0.36	0.77	0.47	0.26	0.54	1.05
H ₂ O ⁻	0.47	0.17	<0.1	<0.1	<0.1	0.10	0.49	0.15	<0.01	0.31	0.21
Rest	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.03	0.18	0.01
Total	100.71	99.70	99.59	99.45	100.10	100.16	101.25	100.05	100.46	99.88	100.76
	parts per million										
As	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Ba	<11	<11	<11	<11	<11	<11	<11	11	<11	<11	13
Cr	<4	5	<4	<4	<4	<4	<4	<4	<4	<4	<4
Cu	15	22	26	39	25	22	24	28	24	12	30
La	<5	<5	<5	<5	7	<5	<5	<5	<5	<5	<5
Mn	62	22	20	8	20	42	39	31	75	5	32
Ni	45	48	85	74	41	70	11	28	166	13	13
Pb	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4
Rb	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Sb	4	<4	<4	4	<4	<4	<4	<4	<4	7	<4
Sr	10	11	14	18	30	14	26	38	17	73	94
V	<3	<3	<3	<3	<3	<3	<3	<3	4	<3	<3
Zn	16	14	5	4	3	12	3	3	<3	3	3
Zr	15	29	30	30	27	31	21	22	31	7	11

NOTES: Analyses: CC
Localities are shown on Figure 27

and some samples can only be classified as silicates of magnesium and calcium. A summary of the chemical variations is given below:

	%	
MgO	5.53	to 48.60
CaO	0.42	to 38.40
SiO ₂	<0.05	to 41.30
Fe ₂ O ₃	<0.05	to 4.61
Al ₂ O ₃	<0.05	to 6.35
CO ₂	9.40	to 49.55

Typically, the samples contain higher amounts of Cr and Ni than those from the Pallinup Siltstone magnesites (Table 33), confirming their derivation from ultramafic rock. In particular, sample 117318 at locality L1, associated with laterite over serpentinite, has a Ni content of 1286 ppm.

Most of the magnesite deposits associated with the Archaean rocks in the region are subeconomic because of their small size and variable grade. However, deposits B1, B2 and possibly B5 adjacent to Bandalup Creek, are of high quality and contain mineable high-grade magnesite.

Magnesite in Eocene Pallinup Siltstone

Table 33 gives chemical analyses of eleven samples of magnesite collected from the deposits (Fig. 27). Note that deposits N1 to N5 may be subdivided further into east, west, north or south (annotated as E, W, N or S on the figure). These eleven samples are of higher quality than those with Archaean associations and show the following chemical variations:

	%	
MgO	46.20	to 48.30
CaO	<0.43	to 1.82
SiO ₂	<0.05	to 1.91
Al ₂ O ₃	<0.05	
Fe ₂ O ₃	<0.05	
TiO ₂	<0.05	

Trace element analyses indicate that the Cr content of these samples is low (<4 ppm), compared with those associated with the Archaean ultramafic/mafic rocks. Ni values are commonly lower and more uniform than values in magnesites from the Archaean association.

Silica occurs mostly as free silica and not as a silicate, whereas most of the deleterious lime is in the form of

calcite. XRPD studies of magnesite sample 117317 from the N3 deposit indicate less than 1% of an unidentified impurity at peak 3.54Å, but the lack of other diagnostic XRPD peaks made it impossible to identify the trace components in the sample. A factor that affects the quality of the Pallinup magnesite is the presence of a significant amount of montmorillonitic clay and chalky magnesite (Younger, 1985). The montmorillonite is extremely difficult to wash off because of its hydrophylic nature, and the handling of chalky material causes continuous attrition and creation of fines. Younger (1985) stated that the future of the magnesite deposits is uncertain unless a way can be found to produce crude coarse lump magnesite of +50 mm size.

Total reserves

Magnesite in Archaean rocks

A total inferred resource of 300 000 t of variable grade but likely to be in excess of 46% MgO is estimated to be present in the B1 to B5 deposits, but the other Archaean deposits are considered to be subeconomic. The L1 deposit, approximately 3 km southeast of Bandalup Hill, has a pre-resource estimate of some 5 Mt of magnesite (Locsei, 1986). However, this figure is based on information from only three drillholes and should be treated with caution.

Magnesite in Eocene Pallinup Siltstone

Thomas (1972) reported an indicated resource of 1 271 524 t of magnesite in the Pallinup Siltstone, 3 km northeast of Bandalup Hill. This total is made up of indicated and inferred resources of 1 167 028 t of +2" (+50.8 mm) and -2+1/4" (-50.8 mm +6.35 mm) material. Reserves in the tailings stockpile (-2" (-50.8 mm) material) are estimated to be 17 120 t. Another possible resource of 87 380 t is known in the top 12" (30.5 cm) of the deposit, and in the -1/4" (-6.35 mm) fractions.

Of these, deposit N2W contains about 15%, N3 about 12%, and N4E about 48% of the indicated resources (Younger, 1985). Deposit N2W also has the highest indicated quality of all the deposits, at 21.8% recoverable magnesite. Deposit N3 has 12.1%, and N4E has 18.6% recoverable magnesite.

Origin

The magnesite in the Ravensthorpe district was formed both as residual deposits associated with Archaean ultramafic and mafic rocks, and as a chemical replacement product within the Pallinup Siltstone.

Residual deposits

Field relationships suggest that residual weathering of high magnesian basalts and ultramafic rocks during the Cainozoic gave rise to most of the magnesite deposits in these rocks. The high Cr and Ni content of these deposits strongly supports this, and chemical transformation may be explained by the processes described by Abu-Jaber

and Kimberley (1992), referred to in chapter 5 of this Bulletin.

Chemical replacement deposits

Butler (1961) suggested that magnesite within the Pallinup Siltstone was due to deposition of magnesite from solutions containing magnesium extracted from the serpentinites. He considered that the presence of nodular bodies throughout the deposit gave support to such a mechanism. He also suggested that the restriction of the deposit to shallow depths favoured supergene enrichment. The depletion of Cr and Ni in these samples is in agreement with such a hypothesis. It is possible that alkaline groundwater, rich in magnesium derived from weathered serpentinites, percolated through sandy sediments of the Late Eocene Pallinup Siltstone following their post-Eocene uplift above sea level (Fetherston, 1987). The magnesite probably replaced poorly lithified green sands of the Plantagenet Group, and is separated by layers of unreplaced sands. The various stages of replacement can be observed up to the final stage of coarse nodular magnesite.

Munglinup

Location: Lat. 33°39'35"S, Long. 120°51'15"E; RAVENSTHORPE

Munglinup is approximately 75 km east of Ravensthorpe. Magnesite was found in a shaft sunk for graphite on a tributary of the Oldfield River (Blatchford, 1917; Simpson, 1952). Magnesite is developed between foliae of graphite and seems to be a weathering product of carbonated peridotite within gneissic host rocks. The continuity of the peridotite can be traced by surface magnesite boulders, which commonly contain opal.

Magnesite is also widely associated with graphite veins in a number of trenches in 'Halberts main zone' of graphite workings at Young River. Two analyses from this locality indicate that the magnesite is of high quality, containing 47.2% and 48.0% MgO respectively (Table 31). The proportion of magnesite in veins increases southward.

Minor occurrences

Magnesite is commonly associated with serpentinitous ultramafic rocks in many localities in the Southern Cross Province of the Yilgarn Craton. Available information on some of these occurrences is summarized in Table 34, and available analytical data is summarized in Table 35.

Eastern Goldfields, Yilgarn Craton

A brief description of the geology of the Eastern Goldfields is given in Chapter 4. All known occurrences

Table 34. Minor occurrences of magnesite in the Southern Cross Province of the Yilgarn Craton

Locality	Lat. (S) (approximate)	Long. (E)	Remarks	References
Ardath	32°01'50"	118°05'40"	Surface boulders of compact white magnesite, a few kilometres east of the Ardath railway siding	Simpson (1952)
Baandee	31°36'40"	117°59'00"	'Coralloidal' boulders of dense white magnesite thought to be associated with a serpentinitic dyke, found approximately 12.8 km north of the railway line	Simpson (1952)
Boodarockin	31°00'20"	118°48'00"	Specimens of hard, dense, fine-grained, cream-coloured magnesite have been collected. They have an appearance similar to marble	Simpson (1952)
Bremer Range	32°31'20"	120°41'00"	A small amount of hard flinty magnesite is known from this locality	Simpson (1952)
Bullfinch	30°56'00"	119°05'00"	White magnesite is associated with serpentinous rocks located between Bullfinch and Golden Valley, and occurs in significant quantities. Hard, soft and pure varieties are present. Some contain chalcidony. The exact location is not given	Simpson (1952)
Burracoppin	31°20'20"	118°24'45"	Hard, pure magnesite that contains 2.5% SiO ₂ occurs approximately 9.6 km northwest of Burracoppin. A more siliceous and friable variety present at the surface contains 16% SiO ₂	Simpson (1952)
Doodlakine	31°36'40"	117°52'15"	White magnesite boulders occur in this location. The occurrence is possibly of no commercial value	Simpson (1952)
Dowerin	31°11'40"	117°02'30"	Scattered nodules of hard white magnesite, weighing 1–13 kg, overlie an anthophyllite–biotite gneiss in the immediate vicinity of the chrysoberyl workings in this locality (Block DAA 41). Similar nodules are also known to occur associated with the greenstone schist in the area	Ellis (1963)
Kondinin	32°30'00"	118°16'00"	Scattered white boulders of magnesite have been collected from this location	Simpson (1952)
Kununoppin	31°12'40"	117°55'20"	Boulders of magnesite are scattered over an area of about 0.8 hectares, approximately 11 km south of Kununoppin. The location is approximately 0.8 km from a farm owned by Mr Clausen in 1940	Ellis (1963)
Lookout Hill	31°59'20"	119°03'20"	Creamy white, cryptocrystalline boulders of magnesite are known at Lookout Hill, a few kilometres southeast of Holleaton, associated with mafic rocks. Magnesite boulders are also found just south of Holleaton	Simpson (1952)
Merredin	31°29'20"	118°17'00"	Magnesite boulders of the 'usual kind' are said to be present at this location	Simpson (1952)
Moorine Rock	31°16'00"	119°07'20"	Boulders of dirty white cryptocrystalline magnesite occur northwest of the siding at Moorine Rock	Simpson (1952)
Nungarin	31°11'20"	118°06'00"	Large quantities of creamy white, hard, micro-crystalline magnesite occur on the farm owned by Mr G. J. McCorry. Small lenticular and angular cavities are common. A typical analysis is given in Table 35	Clarke (1914); Simpson (1952); Ellis (1963)
Sandstone	27°58'40"	119°16'30"	Clarke (1914) noted a deposit of 'cement' of exceedingly dense character, approximately 2 km west of Sandstone, in the northern portion of old Pyx Claim. This proved to be magnesite and was considered to be siliceous	Clarke (1914); Simpson (1952); Ellis (1963)
Southern Cross	31°16'00" 31°21'35"	119°21'00" 119°21'00"	Magnesite occurs at many isolated locations within the Southern Cross district. A location approximately 3.2 km south of the town could yield large tonnages of commercial quality, and contained 45.02% MgO (≅94.1% MgCO ₃) (Table 35), whereas samples taken 12 km south of the town are slightly porous and chalky	Simpson (1952); Ellis (1963)

Table 34. (continued)

Locality	Lat. (S) (approximate)	Long. (E)	Remarks	References
Tammin	31°30'00"	117°25'00"	Numerous boulders of magnesite up to 4.5 kg in weight were found in a cleared paddock, approximately 17.5 km bearing 330° from Tammin. The magnesite is hard and lies on a grey, clayey loam mixed with quartz grit. It is considered to be high grade, although the quantity available is very small. The country rock is weathered gneiss and granitoid with pegmatite, as seen from the heaps of rock on the cleared paddock, but there is also float material of a mafic rock in the area	Simpson (1952); Ellis (1963)
Westonia	31°16'35"	124°38'20"	Large nodules and boulders of pure magnesite have been collected from a lease known as Edna May Deeps, where small bands of Archaean peridotite and serpentinite are known to occur. In 1963 production of 22 t valued at \$177 was recorded from MC60. Concretions of impure magnesite are also known in soil near Bodallin Soak	Blatchford and Honman (1917); Simpson (1952); Ellis (1963)

of magnesite in this province are associated with serpentinitic ultramafic rocks of the greenstone belts, and are confined to an area bounded by Lawlers to the north, Norseman to the south, Coolgardie to the west, and Bulong to the east. None of the occurrences is exploited at present, although there has been past production from some localities. The last recorded production was 95 t from Coolgardie in 1967, out of a total production of 2929 t between 1938 and 1967 (Table 29). However, Bulong — known to contain larger deposits than Coolgardie — had produced only 1583 t up to 1956. Most occurrences elsewhere in the Eastern Goldfields appear to be small and have not been exploited commercially. A number, however, have potential for development, although information on these is sparse.

Table 35. Chemical analyses of magnesite from Nungarin and Southern Cross

Sample no.	Nungarin 7	Southern Cross 30	Southern Cross 31
	percentage		
CO ₂	51.04	46.05	49.13
MgO	46.08	42.98	45.02
FeO	0	0.14	0
CaO	1.00	0.70	0
MnO	0	0	0
SiO ₂	0.60	6.66	2.56
Al ₂ O ₃	0.25	0.64	1.09
Fe ₂ O ₃	0.03	1.28	0.73
TiO ₂		0.06	
H ₂ O ⁺	0.24	0.73	nd
H ₂ O ⁻	Inc. above	1.13	nd
NaCl		tr	nd
SO ₃		0	
Total	99.24	100.37	98.53

NOTES: after Simpson (1952)
nd — not determined
tr — trace

Bulong

Location: Lat. 30°45'00"S, Long. 121°50'00"E; KURNALPI

Historical background

Bulong is an abandoned townsite 37 km east of Kalgoorlie. The presence of magnesite about 4 km east-northeast of the town has been known to the Department since 1897, and samples were collected for quality assessment in 1904 (Feldtmann, 1916, 1919; Simpson, 1952). In September 1913, application was made for a reserve of 258 ha, between Bulong and the western edge of Lake Yindarlgooda, and in 1914 bulk samples of Bulong magnesite were sent by The Magnesia Syndicate Limited to South Australia and Germany. Results were encouraging and 838 t were mined and marketed between 1915 and 1918 (Table 29). There was no production between 1919 and 1940 due to competition from suppliers in New South Wales and South Australia. Demand for the mineral increased during World War II because of restrictions in overseas supplies, particularly from Austria. To meet its steelmaking needs, Broken Hill Proprietary Limited (BHP) acquired and surveyed mineral claim MC 10Y, and produced 628 t during the years 1941, 1947, 1949 and 1951 (Table 29). In 1946 and 1956, 108 t were produced from mineral claims MC 3Y and PA 1409Y, and in 1977 there was recorded production of 9 t from MC 25/1109. The total output from the area between 1915 and 1956 was 1583 t valued at \$5344 (Table 30), but there is no record of production since 1978.

Physiography

The ridge west of the main magnesite area is approximately 80 m above the bed of the salt lake, and extends a considerable distance to the south before it widens out to become a complex of hills approximately 5 km southeast of the abandoned townsite.

to about 5 km north-northeast of the Unknown mine, a strike length of more than 70 km. To the south, the complex grades into ultramafic rocks that continue around the Bulong Anticline to about 16 km east of Mount Monger homestead.

Magnesite deposits occur mostly within the siliceous caprock of the serpentinized peridotites of the Bulong Complex exposed at the western edge of Lake Yindarlgooda.

To the southwest of the Bulong Complex are some medium- to coarse-grained Archaean gabbros that have formed in either an intrusive or extrusive environment. To the east of the Archaean sequence are Recent alluvial deposits, mainly confined to Lake Yindarlgooda, which consist of gypsum, saline clay and silt.

Magnesite deposits

The largest magnesite bodies in the area lie within a northerly trending unit nearly 3.7 km long and parallel to the western edge of Lake Yindarlgooda that consists of siliceous and serpentinous rock with magnesite (Fig. 30). Within this unit magnesite is widespread. One deposit ranges in width from approximately 600 m in the north and central area to 100 m in the south, and covers about 150 ha, with the southern end of the deposit being approximately 1.2 km from the south side of the basin (Feldtmann, 1919; Simpson, 1952). Immediately south of Magnesite Creek, surface deposits of nodular magnesite have a maximum thickness of around 0.3 m and cover an area of approximately 6 ha. Other, smaller, deposits in the area include one to the south and three to the north of the main unit. The northernmost deposit is the largest of these, and is about 1.5 km north of Magnesite Creek, occupying a basin about 800 m long and more than 600 m wide, an area of approximately 36 ha. A few insignificant occurrences are also present north of the above deposits, and also in two places at the contact zone of pebble breccias and serpentinite.

Field evidence indicates that magnesite in all the above deposits was formed in situ, and occurs as veins of variable strike and dip within serpentinite of the Bulong Complex. The various stages of replacement of the host serpentinite can be seen, even up to advanced stages in which silica veins occur as stockworks with magnesite (Thom, 1976). Most veins are subhorizontal and short, and both parallel and crosscutting veins are common. Some of the large veins strike at 015°, with steep west-southwesterly dips (Feldtmann, 1919). The veins form small, resistant ridges (Fig. 31). The thickness of the veins varies from a few mm to 0.5 m. There are three abandoned quarries in the area around Magnesite Creek. The dimensions of these quarries vary from 12 m to 42 m in length, 5 m to 6 m in width and 3 m to 6 m in depth. The information from the quarries, along with test pits and shafts, indicates the depth of magnesite mineralization to be approximately 5 m. The magnesite vein density in the quarries and the surrounding pits is over 50%, and a few hundred metres to the south the veining decreases to around 40%. Further south a trench approximately 3 m deep indicates a vein density of approximately 30%. The magnesite in the

deposits is white, dense (or very slightly porous) and fine grained.

Quality

Chalcedonic and opaline silica, derived from the host rock serpentinites are common impurities of magnesite in the area. Nickeliferous magnesite in various shades of green was noted at some localities (Williams, 1970). XRPD studies on sample 117355 Lat. 30°45'04"S and Long. 121°50'06"E (Fig. 30) indicate 75–85% magnesite, 10–20% quartz, and traces of chlorite, interlayered chlorite and mica, and possibly smectite.

Chemical analyses of five samples, collected from abandoned quarries and the surrounding area (Table 36), show the following range of chemical compositions:

	%	
MgO	31.60	to 46.2
CaO	0.15	to 1.15
SiO ₂	2.84	to 32.80
Al ₂ O ₃	<0.05	
Fe ₂ O ₃ + FeO	<0.1	

Iron oxide and alumina, although not significant impurities, result in discolouration of the calcined material. Soluble salts (mainly NaCl) may be impregnated in the magnesite, which entails washing for many industrial uses. Selective mining is required to overcome serious impurity problems.

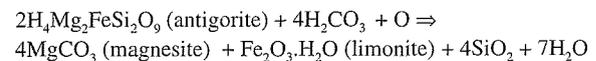
The high Ni and Cr content of the samples confirm an ultramafic source for the magnesite.

Resources

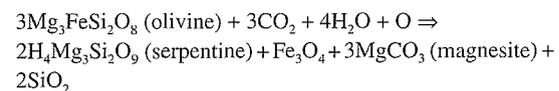
Although the published information from Bulong lacks resource figures, the area probably contains a substantial resource of recoverable magnesite of high quality.

Origin

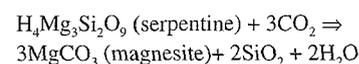
Simpson (1952) considered the Bulong deposit to be a normal product of carbonation of serpentine-rich rocks by meteoric waters rich in carbonic acid, and postulated the following reaction:

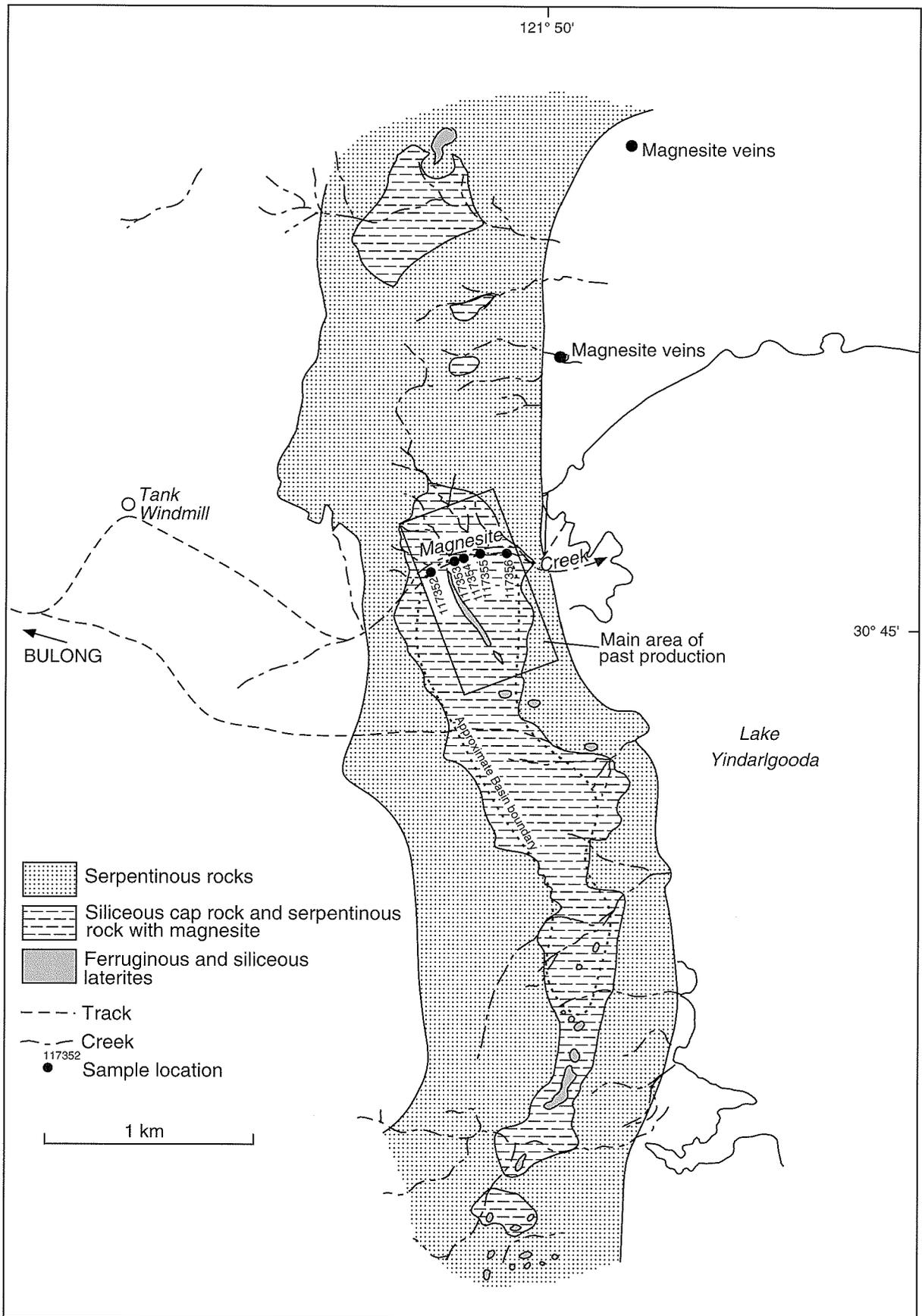


Feldtmann (1919) suggested that magnesite was formed by the carbonation of olivine as well as serpentine, as follows:



or





PBA25

31.10.96

Figure 30. Main geological units associated with magnesite at Bulong, and sample locations for magnesite

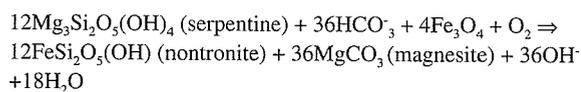


PBA117

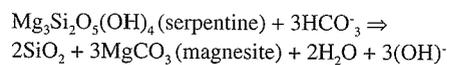
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Figure 31. Veins of magnesite at Bulong. Photographs taken at sample location 117354 (shown on Figure 30)

Another plausible mechanism for the alteration of serpentine in ultramafic rocks is given by the following chemical reactions (Abu-Jaber and Kimberley, 1992):



or



Coolgardie

Location: Lat. 30°53'40"S, Long. 121°11'20"E; KALGOORLIE

Simpson (1952) regarded Coolgardie as being second only to Bulong as a source of magnesite in Western

Table 36. Chemical analyses of magnesite from Bulong (major and trace elements)

GSWA no.	117352	117353	117354	117355	117356
Lab no.	11	12	13	14	15
	percentage				
SiO ₂	29	19.5	32.8	16.8	2.84
TiO ₂	<0.05	<0.05	<0.05	<0.05	<0.05
Al ₂ O ₃	<0.05	<0.05	<0.05	<0.05	<0.05
Fe ₂ O ₃	0.05	<0.05	<0.05	<0.05	<0.05
FeO	<0.1	<0.1	<0.1	<0.1	<0.1
MnO	<0.05	<0.05	<0.05	<0.05	<0.05
MgO	33.5	38.00	31.6	39.7	46.2
CaO	0.29	0.21	0.15	0.35	1.15
Na ₂ O	0.16	0.18	0.16	0.20	0.23
K ₂ O	<0.05	<0.05	<0.05	<0.05	<0.05
P ₂ O ₅	<0.05	<0.05	<0.05	<0.05	<0.05
CO ₂	35.4	41.00	34.5	41.8	48.4
S	0.04	0.02	<0.01	<0.01	0.01
H ₂ O ⁺	1.25	0.68	0.81	0.63	0.80
H ₂ O ⁻	<0.1	<0.1	0.15	0.23	0.26
LOI	0.02	0.01	<0.01	<0.01	0.01
Rest	0.07	0.09	0.06	0.07	0.07
Total	99.76	99.68	100.23	99.78	99.96
	parts per million				
As	<4	<4	<4	<4	<4
Ba	<11	<11	<11	22	<11
Cr	17	6	5	13	<4
Cu	6	6	7	6	11
La	<5	<5	<5	<5	<5
Mn	132	194	187	123	163
Ni	471	629	415	426	507
Pb	<4	<4	<4	<4	<4
Rb	<2	<2	<2	<2	<2
Sb	<4	<4	<4	5	5
Sr	<5	<5	<5	<5	<5
V	<2	<2	<2	<2	<3
Zn	<3	<3	<3	<3	<3
Zr	19	24	18	24	25

NOTES: Locations of samples are shown on Figure 30
Analyses by CC

Australia. The production of magnesite from the area to date is 2929 t valued at \$16 536, of which 2834 t was produced between 1938 and 1956 and the remaining 95 t in 1967 (Tables 29 and 30). The material has been used in refractories and in the production of Sorel cement.

Geology

The main rock types distinguished in the area are fresh to altered and metamorphosed varieties of Archaean ultramafic rocks, basalt and gabbro (Fig. 32). The magnesite in the area occurs with serpentinite.

Magnesite localities

Feldtmann (1919), McMath (1950) and Simpson (1952) described occurrences of magnesite in an area approximately 6.5 km northeast of Coolgardie (Fig. 32). McMath (1950) stated that the magnesite occurs as flat lenses along two ridges trending east-northeast, and suggested the

possibility of similar lenses at depth. The magnesite at the surface is hard and nodular, and that at depth is soft but coherent. Simpson (1952) described scattered boulders extending 180 m in a northwesterly direction within soil overlying weathered serpentinite. A pit containing loose boulders and pebbles of magnesite extending to a depth of 7.6 m was described from the same area. Magnesite is found on former mineral leases ML87 (6.5 km northeast of Coolgardie), ML91 and ML92 (7 km northeast of Coolgardie) as a series of shallow veins, and is typically microgranular, porous and friable. Simpson (1952) also mentioned a small occurrence on former ML77 (5.5 km northeast of Coolgardie), and on ML78 (1 km east of Coolgardie) magnesite in shallow veins associated with asbestiform actinolite.

An occurrence of relatively pure magnesite associated with mafic to ultramafic rocks was noted in a trench (Lat. 30°54'35"S, Long. 121°12'10"E) a few kilometres east of the gold mining area (sample 117349, Fig. 32).

Quality

The analyses of a number of samples of magnesite from the above mineral leases (Table 37) indicate that they are of high quality, having MgO ranging from 42.19 to 47.36%. Two analyses given by McMath (1950) indicated that soft coherent magnesite assaying 47.25% MgO (\equiv 98.82% MgCO₃) has a higher MgO content than the hard nodular magnesite that assays 42.19% MgO (\equiv 88.24% MgCO₃). Three samples gave high nickel values, suggesting an ultramafic source. Typically, Cr is also high.

Origin

Field relationships and chemical data strongly suggest that the magnesite has formed as an alteration product of serpentinite. The chemical reactions involved could be those postulated by Abu-Jaber and Kimberley (1992), discussed in Chapter 5.

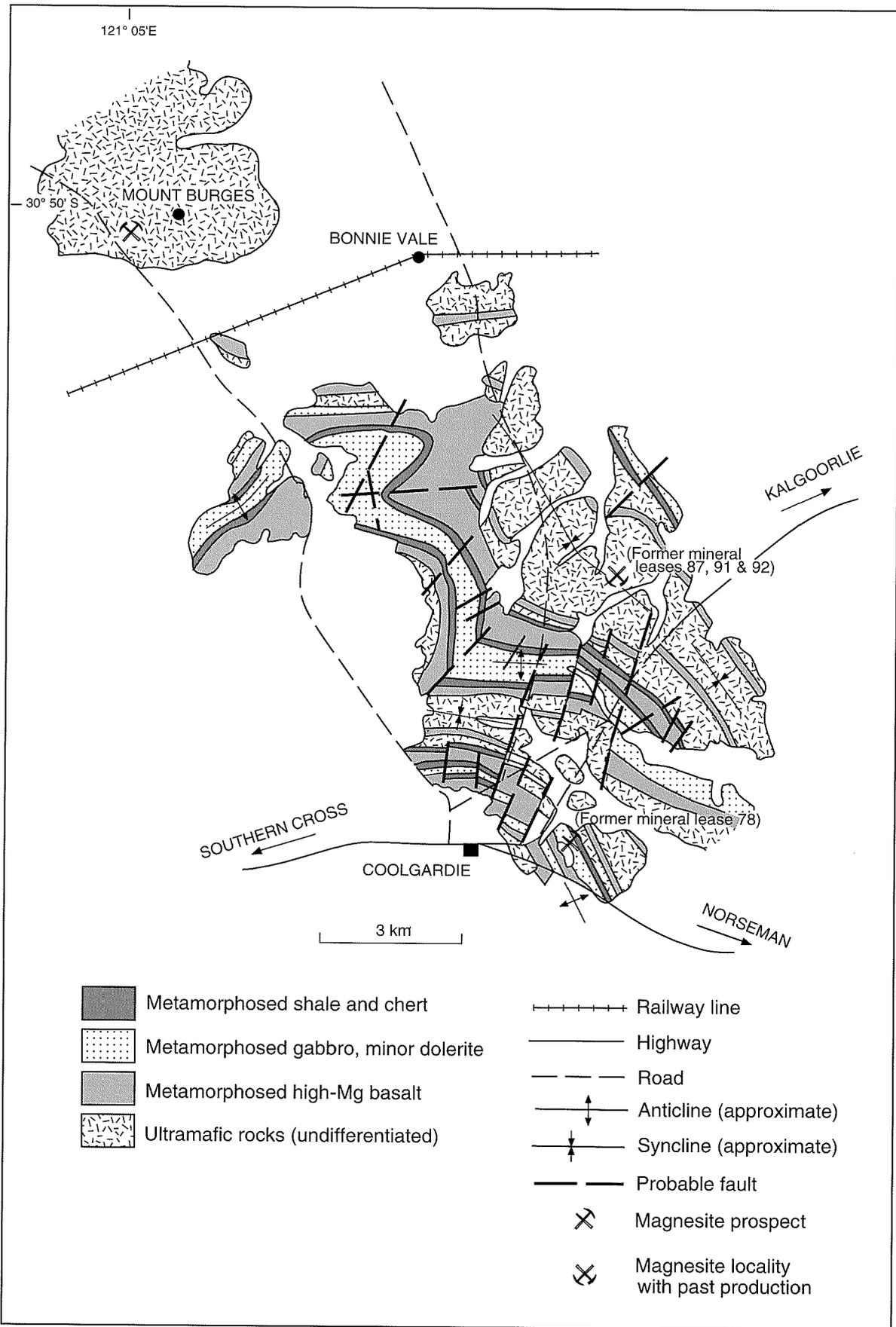
Mount Burges

Location: Lat. 30°50'40"S, Long. 121°05'05"E; KALGOORLIE

Abundant creamy-white magnesite boulders are reported from a location north of a hill 22.5 km along the Kunanalling road from Coolgardie (Simpson, 1952). Scattered outcrops of magnesite, ranging from light creamy brown to creamy white, also occur in several locations approximately 4 km north-northwest from the railway track, along Eight Mile Rock – D road (Fig. 32). The magnesite in some of these outcrops is cryptocrystalline, hard to soft, and seems to be of good quality. However, two samples collected from the area had MgO values ranging from 39.6% to 44.8% with a significant amount of silica (Table 37).

Lawlers

Location: Lat. 28°03'55"S, Long. 120°38'46"E; LEONORA



PBA27

23.11.95

Figure 32. Generalized geological map, showing the main areas of magnesite at Coolgardie (after Hunter, 1988)

Table 37. Chemical analyses of magnesite from Coolgardie and Mount Burges (major and trace elements)

GSWA no.	117347	117348	117349	17	18	19	20	21	22	23	24	25	26	6564/48	6565/48	117343 Mount Burges	117344 Mount Burges
	percentage																
SiO ₂	2.57	0.70	0.71	0.12	0.14	0.12	0.06	0.20	0.24	0.36	0.72	6.04	0.63	0.57	0.04	9.48	4.26
TiO ₂	<0.05	<0.05	<0.05	—	—	—	—	—	—	—	—	—	—	—	—	<0.05	<0.05
Al ₂ O ₃	<0.05	<0.05	<0.05	0.23	0.17	0.44	0.22	0.09	0.34	0.21	0.60	0.75	1.04	—	—	<0.05	<0.05
Fe ₂ O ₃	0.11	0.07	0.09	0.01	0.05	0.04	tr	0.08	0.04	0.07	0.06	1.07	(a)	0.15	0.04	0.15	0.06
FeO	<0.1	<0.1	<0.1	tr	0	0	0	tr	—	—	—	tr	0	—	—	<0.1	<0.1
MnO	<0.05	<0.05	<0.05	0	0	0	0	tr	—	—	—	tr	—	—	—	<0.05	<0.05
MgO	43.50	45.00	46.70	47.36	46.64	47.20	47.50	47.03	47.72	47.77	47.14	43.44	46.95	42.19	47.25	39.60	44.80
CaO	3.27	2.91	1.37	0.22	0.04	0.94	0.28	0	0.02	0	0.02	0.98	0	5.07	0.03	5.02	1.94
Na ₂ O	0.21	0.21	0.21	—	—	—	—	—	—	—	—	—	—	—	—	0.20	0.19
K ₂ O	<0.05	<0.05	<0.05	—	—	—	—	—	—	—	—	—	—	—	—	<0.05	<0.05
P ₂ O ₅	<0.05	<0.05	<0.05	—	—	—	—	—	—	—	—	—	—	—	—	<0.05	<0.05
CO ₂	47.60	49.10	50.60	51.85	50.93	51.60	51.29	51.20	51.88	51.35	51.25	45.75	51.23	50.22	51.78	41.40	46.20
S	0.05	0.06	0.03	—	—	—	—	—	—	—	—	—	—	—	—	<0.01	0.01
H ₂ O ⁺	1.69	1.00	0.81	—	—	—	0.19	0.58	—	—	—	—	—	—	—	2.69	1.70
H ₂ O ⁻	0.21	0.11	0.17	tr	—	—	0.17	0.38	—	—	—	—	—	—	—	1.70	0.69
NaCl	—	—	—	—	—	—	0.17	0.92	—	—	—	—	nd	—	—	—	—
SO ₃	—	—	—	—	—	—	0.01	0.14	—	—	—	—	0	—	—	—	—
KCl	—	—	—	—	—	—	—	0.05	—	—	—	—	—	—	—	—	—
Ba ₂ O	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—
MgCl ₂	—	—	—	—	—	—	—	0.15	—	—	—	—	—	—	—	—	—
Rest	0.05	0.07	0.09	—	—	—	—	—	—	—	—	—	—	—	—	0.07	0.07
Total	99.26	99.23	100.78	99.79	97.97	100.34	99.89	100.82	100.24	99.76	99.79	98.03	99.85	98.20	99.14	100.31	99.92
	parts per million																
As	<4	<4	11	—	—	—	—	—	—	—	—	—	—	—	—	<4	<4
Ba	22	23	17	—	—	—	—	—	—	—	—	—	—	—	—	11	235
Cr	27	44	36	—	—	—	—	—	—	—	—	—	—	—	—	61	21
Cu	23	35	45	—	—	—	—	—	—	—	—	—	—	—	—	32	36
La	<5	<5	<5	—	—	—	—	—	—	—	—	—	—	—	—	<5	<5
Mn	41	284	211	—	—	—	—	—	—	—	—	—	—	—	—	59	59
Ni	174	270	481	—	—	—	—	—	—	—	—	—	—	—	—	173	144
Pb	<4	<4	<4	—	—	—	—	—	—	—	—	—	—	—	—	<4	<4
Rb	<2	<2	<2	—	—	—	—	—	—	—	—	—	—	—	—	<2	<2
Sb	4	6	4	—	—	—	—	—	—	—	—	—	—	—	—	<4	6
Sr	114	149	45	—	—	—	—	—	—	—	—	—	—	—	—	250	109
V	9	6	5	—	—	—	—	—	—	—	—	—	—	—	—	11	6
Zn	4	8	14	—	—	—	—	—	—	—	—	—	—	—	—	8	6
Zr	<5	<5	20	—	—	—	—	—	—	—	—	—	—	—	—	<5	6

NOTES: Samples 117347–117349 analyses — CC; Samples 117347 — Lat. 30°53'03"S, Long. 121°10'57"E; 117348 — Lat. 30°53'38"S, Long. 121°11'21"E; 117349 — Lat. 30°54'36"S, Long. 121°12'09"E; Samples 117343 — Lat. 35°50'03"S, Long. 121°04'28"E; 117344 — Lat. 30°49'52"S, Long. 121°04'41"E; Samples 17–26 — after Simpson (1952); Samples 6564/48 and 6565/48 — after McMath (1950)

nd — not determined

tr — trace

(a) included above



PBA119

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Figure 33. Photograph of surface pebbles and boulders of magnesite at Lawlers

A large deposit of magnesite is located approximately 4 km northwest from Joes Bore and approximately 11 km east of the office of the Lawlers Gold Project, approximately 115 km northeast of Leonora. The main deposit covers an area about 1.6 km long and 300 to 400 m wide, but the depth is unknown (Thom, 1976; Thom and Barnes, 1977). Other deposits lie south and west of the main deposit.

The magnesite in the main deposit is hard and indurated on the surface and has a layered appearance at shallow depth. Discontinuous flat-lying layers of thick nodular magnesite occur within the soil, and scattered pebbles and boulders of magnesite are common on the surface (Fig. 33). Magnesite is solid at one metre depth, but has not been tested below this. XRPD studies of sample 117368 from this location (Lat. 28°03'56"S, Long. 120°38'46"E) indicated 85–95% magnesite, less than 5% quartz, and traces of calcite, dolomite, chlorite, interlayered chlorite and mica, and possibly smectite.

South of the main deposit, magnesite on the surface tends to be chalcedonic, slightly discoloured, and impure. Sample 117371, collected 500 m south of 117368, assayed 43.3% MgO, and XRPD studies indicated 55–65% magnesite, 5–10% calcite, 5–10% dolomite, 15–25% sepiolite, and <5% quartz. Chemical analyses of seven samples collected from north to south in the main deposit indicate that MgO contents varied between 42.30% and 46.60% with the exception of the low values in sample 117370 that assayed 24.6% MgO and 24.4% CaO (Table 38); this latter sample is also more ferruginous (0.18% Fe₂O₃) and weathered than the other samples. The Fe₂O₃ contents of the rest of the samples were <0.05%. The Cr content of all the samples is comparable to those

collected from other localities such as Bulong, but the Ni content is lower.

There has been no production from the deposit, but a small quantity excavated from a pit of approximately 5 m × 5 m × 1.5 m has been dumped close to a track along a power line located about a kilometre north of the deposit. There are no outcrops of other rock types in the vicinity of the pit. However, nearby holes drilled in search of gold indicate that the area consists dominantly of weathered ultramafic to mafic rocks.

Eulaminna

Location: Lat. 28°57'40"S, Long. 121°47'00"E (approximately); LAVERTON

Outcrops of magnesite occur approximately 1.6 km east of the old Eulaminna railway station, on the Leonora–Laverton road (Clarke, 1925b; Thom, 1976). The magnesite is associated with a north-trending ridge of ultramafic rocks, and the outcrops are fairly continuous for about 2 km. The deposit is thought to be shallow, small, and to have a high silica content, although no systematic work has been done to assess the grade and reserves.

Siberia (Waverley)

Location: Lat. 30°14'30"S, Long. 120°59'55"E; KALGOORLIE

Siberia is now an abandoned township, with a large number of old mine shafts sunk into sheared, chloritic ultramafic rocks. Magnesite was encountered when excavating a Government well on Reserve 4251, and

Table 38. Chemical analyses of magnesite from Lawlers (major and trace elements)

Lab no.	24	25	26	27	28	29	30
GSWA no.	117367	117368	117369	117370	117371	117372	117373
	percentage						
SiO ₂	0.99	1.67	2	3.53	2.07	1.78	2.3
TiO ₂	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Al ₂ O ₃	<0.05	<0.05	<0.05	0.18	<0.05	<0.05	<0.05
Fe ₂ O ₃	<0.05	<0.05	<0.05	0.18	0.05	<0.05	<0.05
FeO	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
MnO	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MgO	46.6	46.3	45.4	24.6	43.3	45.9	42.3
CaO	0.9	0.94	2.53	24.4	4.13	1.77	5.14
Na ₂ O	0.37	0.27	0.22	0.22	0.18	0.18	0.18
K ₂ O	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
P ₂ O ₅	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
CO ₂	48.7	48	48	44.7	48	48.7	48
S	0.06	0.11	<0.01	<0.01	<0.01	<0.01	<0.01
H ₂ O ⁺	0.74	0.88	0.97	1.36	1.08	0.92	1.43
H ₂ O ⁻	0.21	0.14	0.56	0.23	0.27	0.2	0.34
Rest	0.04	0.43	0.06	0.16	0.05	0.04	0.07
Total	98.61	98.74	99.74	99.56	99.13	99.49	99.76
	parts per million						
As	<4	<4	<4	<4	<4	<4	<4
Ba	<11	43	28	469	29	23	44
Cr	99	196	111	20	24	77	16
Cu	15	26	20	30	23	15	29
La	<5	<5	<5	<5	<5	<5	<5
Mn	391	181	185	103	175	190	338
Ni	15	10	10	17	11	29	21
Pb	<4	<4	<4	<4	<4	<4	<4
Rb	<2	<2	<2	<2	<2	<2	<2
Sb	<4	6	<4	<4	<4	<4	<4
Sr	187	3 923	313	779	329	178	445
V	3	<3	<3	9	9	<3	7
Zn	<3	4	3	3	3	<3	4
Zr	<5	<5	<5	8	<5	<5	<5

NOTES: Analyses—CC;
 samples 117367, 117368 and 117369 are all close by at Lat. 28°03'56"S, Long. 120°38'46"E;
 sample 117370—Lat. 28°04'21"S, Long. 120°38'28"E;
 sample 117371—Lat. 28°04'22"S, Long. 120°38'41"E;
 sample 117372—Lat. 28°04'33"S, Long. 120°38'44"E;
 sample 117373—Lat. 28°04'43"S, Long. 120°38'53"E

subsequent drilling has indicated that the occurrence is significant (Simpson, 1952; Ellis, 1963). One sample from this location contained 47.09% MgO (\cong 98.6% MgCO₃) (Table 39). Magnesite has also been found in shafts sunk in alluvium in the same area.

The area is accessed by the road to the Davyhurst mine from the main Kalgoorlie–Menzies road. At Lat. 30°14'39"S, Long. 120°59'50"E, approximately 1.5 km east of the junction at Siberia, pure creamy-white magnesite occurs as isolated boulders associated with chert, chalcedony and ironstone in some excavated gravel dumps. Two samples, 117364 and 117365, collected from this locality assayed 41.50% and 40.40% MgO respectively and contained high silica (Table 39). The high Ni content of these samples (3719 ppm, 5466 ppm) suggest their source rocks are ultramafic. The occurrence is probably not commercial.

Comet Vale

Location: Lat. 29°56'40"S, Long. 120°07'50"E; MENZIES

Magnesite-bearing rocks are known about 1.5 km from the old railway station at the abandoned town of Comet Vale. Commercially exploitable deposits were known in some localities in the Comet Vale area, and in 1920 a small tonnage was mined. Porcelaneous nodules of magnesite associated with greenstone containing talc schist, serpentinite and carbonated peridotite, occur at the Gladstone gold mine and southeast and east of the town. The analyses of three samples from this location indicated that MgO percentages vary from 44.96% (\cong 87.3% MgCO₃) to 48.38% (\cong 99.1% MgCO₃), with two samples having 5.76 and 4.76% SiO₂ due to the presence of chalcedony (Table 39) (Feldtmann, 1919; Jutson, 1921; Simpson, 1952; Ellis, 1963).

Sample 117366 (Lat. 29°56'42"S, Long. 120°07'49"E), collected approximately 300 m east of the Menzies–Kalgoorlie road at Comet Vale, was cryptocrystalline, hard, and white or creamy in colour. However, chemical analysis of this sample gave only 36.60% MgO with a high silica content (Table 39). Here, magnesite is scattered over an area of approximately 10 m × 25 m and has been tested by a small pit of about 2 m × 2 m × 1 m. The high Ni content of 710 ppm in the sample suggests the derivation of magnesite from ultramafic rocks close by. Approximately 100 m northeast of this site is a small shaft with dumps of ultramafic chloritic schist with thin veins and coatings of magnesite.

Magnesite also occurs on a laterite ridge east of Comet Vale, and on the western shore of Lake Goongarrie (a few km east of Comet Vale). The rocks along the shore of Lake Goongarrie are carbonated and contain antigorite, talc, chromite and approximately 10% of a slightly ferruginous magnesite. An asbestos vein associated with magnesite occurs approximately 3.2 km north of the Goongarrie locality.

Minor occurrences

Table 40 gives some details of minor occurrences in the Eastern Goldfields of the Yilgarn Craton, with some sparse geological information.

Minor occurrences in other tectonic units

The following tectonic units contain a number of minor occurrences of magnesite. The available information on these is summarized in the tables indicated:

South Western terranes of the Yilgarn Craton (Tables 41 and 42)

Murchison terrane, Yilgarn Craton (Table 43)

Northampton Complex (Table 44)

Narryer Terrane (Table 44)

Albany–Fraser Orogen (Table 44)

North Pilbara granite–greenstone terrane (Table 45)

Table 39. Chemical analyses of magnesite from Siberia, Comet Vale, Kalgoorlie, Bullabulling and Hopbush Soak (major and trace elements)

Locality	Siberia	Siberia	Siberia	Comet Vale	Comet Vale	Comet Vale	Comet Vale	Kalg-oorlie	Kalg-oorlie	Bulla-bulling	Hopbush Soak
Sample no.	32	117364	117365	14	15	16	117366	28	29	10	27
	percent										
CO ₂	51.62	43.2	42.1	51.72	48.10	46.84	40.70	51.80	50.42	51.83	51.54
MgO	47.09	41.5	40.4	48.38	44.96	45.38	36.60	47.63	38.43	47.29	46.50
FeO	0	<0.1	<0.1	0	0	Tr	<0.01	0.01	—	0	0
CaO	tr	0.16	0.32	0	0	1.63	1.76	0.12	10.52	0.30	1.04
MnO	0	<0.05	<0.05	0	0	0	<0.05	tr	—	0	—
SiO ₂	0.16	12.9	12.9	0.50	5.76	4.76	20.1	0.01	0	0.42	0.20
Al ₂ O ₃	0.61	<0.05	0.21	0.28	1.38	0.90	<0.05	—	0.37	0.66	0.14
Fe ₂ O ₃	0.20	0.08	0.25	(a)	(a)	(a)	0.05	—	(a)	(a)	(a)
H ₂ O ⁺	0.16	1.44	2.13	0	—	tr	0.56	0.15	tr	—	0.18
H ₂ O ⁻	0.12	0.17	0.37	tr	—	tr	<0.1	(a)	0.08	—	(a)
NaCl	tr	—	—	—	—	—	—	—	—	—	—
SO ₃	0.08	—	—	—	—	—	—	tr	—	—	—
SrO	—	—	—	—	—	—	—	—	0.06	—	—
TiO ₂	—	<0.05	<0.05	—	—	—	<0.05	—	—	—	—
Na ₂ O	—	0.21	0.21	—	—	—	0.17	—	—	—	—
K ₂ O	—	<0.05	<0.05	—	—	—	<0.05	—	—	—	—
P ₂ O ₅	—	<0.05	<0.05	—	—	—	<0.05	—	—	—	—
S	—	<0.01	<0.01	—	—	—	<0.01	—	—	—	—
Rest	—	0.49	0.72	—	—	—	0.11	—	—	—	—
Total	100.04	100.15	99.61	100.88	100.20	99.51	100.05	99.72	99.88	100.50	99.60
	parts per million										
As	—	<4	<4	—	—	—	<4	—	—	—	—
Ba	—	<11	<11	—	—	—	19	—	—	—	—
Cr	—	21	31	—	—	—	31	—	—	—	—
Cu	—	37	46	—	—	—	13	—	—	—	—
La	—	<5	<5	—	—	—	<5	—	—	—	—
Mn	—	69	169	—	—	—	94	—	—	—	—
Ni	—	3 719	5 466	—	—	—	710	—	—	—	—
Pb	—	<4	<4	—	—	—	<4	—	—	—	—
Rb	—	<2	<2	—	—	—	<2	—	—	—	—
Sb	—	4	4	—	—	—	<4	—	—	—	—
Sr	—	10	23	—	—	—	95	—	—	—	—
V	—	<3	8	—	—	—	<3	—	—	—	—
Zn	—	<3	3	—	—	—	<3	—	—	—	—
Zr	—	25	21	—	—	—	6	—	—	—	—

NOTES: Samples 117364–117366 — analyses CC; Locations: sample 117364 — Lat. 30°14'28"S, Long. 120°59'55"E; sample 117365 — Lat. 30°14'39"S, Long. 120°59'50"E; sample 117366 — Lat. 29°56'42"S, Long. 120°07'49"E; other samples — after Simpson (1952)

tr — trace

— — not determined

(a) included with above

Table 40. Minor occurrences of magnesite in the Eastern Goldfields of the Yilgarn Craton

Locality	Lat. (S) Long. (E) (approximate)	Remarks	References
Bardoc	30°21'00" 121°18'00"	Magnesite boulders of the 'usual type' are said to occur west of Hilda GML2495, where underlying rocks are Archaean greenstones	Simpson (1952)
Broad Arrow	30°26'40" 121°20'00"	Magnesite occurs as boulders and shallow veins, possibly in commercial quantities, associated with a weathered ultramafic rock. Most of the high-grade material contains more than 98% MgCO ₃ and is slightly porous and friable, but some magnesite is harder and contains significant chalcedony, including one example which contained more than 62% chalcedony	Simpson (1952)
Bullabulling	30°58'00" 120°55'00"	Specimens of high-grade white magnesite have been collected from boulders and shallow veins at a locality 11 km northeast of the railway siding. A typical specimen from the locality assays 98.92% MgCO ₃ (Table 39) At Gibraltar, approximately 8 km southeast of Bullabulling, a few veins of magnesite are associated with mafic schists, notably on the Lloyd George GML4580. They are considered to be too small to have any commercial value	Simpson (1952); Feldtmann (1925); Ellis (1963)
Eucalyptus	29°12'00" 122°11'00"	A good outcrop of magnesite is reported at the 12 mile peg (19.3 km) on the Yundamindera-Linden road, just southeast of Eucalyptus. The quality of the magnesite is said to be similar to that mined at Bulong	Honman (1917); Simpson (1952)
Feysville	30°57'00" 121°36'00"	Rocks containing fuchsite-quartz-breunnerite occur at the Celebration GM, and are thought to have formed by the carbonation of serpentinous rocks	Simpson (1952)
Golden Ridge	30°51'00" 121°40'00"	Ferruginous magnesite (breunnerite) occurs in association with chlorite and talc in rocks approximately 1 km north of a quartz blow on GML3945	Simpson (1952)
Higginsville (Hopbush Soak)	31°45'00" 121°42'00"	Cream and white magnesite is known from a location 3.2 km north of Hopbush Soak, east of Higginsville. A typical sample from this location contained 46.50% MgO (Table 39). A small superficial deposit of magnesite is associated with ultrabasic rocks, at a location between the 412 and 413 mile pegs (663 km and 664.6 km)	Simpson (1952); Sofoulis (1966)
Kalgoorlie-Boulder	30°44'00" 121°28'00"	Ferruginous magnesite (breunnerite) is found at a number of localities in the Kalgoorlie-Boulder area as follows: a bright-green fuchsite-quartz-breunnerite rock forms several narrow bands in the greenstone complex just east of Kalgoorlie, in what is presently an active area of gold mining; a rock from Mount Charlotte (GML211) contained 16% ankerite and 38.1% breunnerite; and another from Hyman GML4406 contained 49.2% breunnerite and 4.6% ankerite Serpentine rocks on the northwestern shore of Hannans Lake have broad zones of massive, coarsely crystalline, olive-coloured carbonate material and one analysis indicates that there is 38% breunnerite and 19% ankerite present. Other constituent minerals include fuchsite, actinolite, quartz, magnesite, chromite and rutile.	Simpson (1952)

Table 40. (continued)

Locality	Lat. (S)	Long. (E)	Remarks	References
	(approximate)			
Kalgoorlie-Boulder (cont.)			<p>Talcose bands are also present</p> <p>Rocks from a small area near Bonnie Lass GML796, to the east of the city, show less carbonation but more talc and little or no quartz. Analysis indicates 13.0% breunnerite and 16% ankerite</p> <p>Surface concretions and shallow veins of relatively pure magnesite are associated with breunnerite at a few localities. An analysis of a sample from Belgravia GML4419 east of the city indicates 99.09% MgCO₃, and close to this location a fibrous white magnesite with jasper carries appreciable SrO and CaO</p> <p>Magnesite impregnated with chalcedony is found between the old Leviathan Battery and Mount Hunt</p>	
Kanowna	30°30'00"	121°24'30"	Ferruginous magnesite (breunnerite) occurs in carbonated greenstones in this area, one analysis indicated that the greenstone contains 13.2% breunnerite and 35.8% ankerite. Rocks with fuchsite-magnesite-quartz assemblages are known in the Main Reef zone at Kanowna	Jutson (1912); Simpson (1916, 1952); Ellis (1963)
Kurrawang	30°51'40"	121°20'00"	A peculiar form of indurated magnesite, probably formed by concretionary action in the laterite profile, occurs on the breakaways of the eastern slope of the Kurrawang ridge, approximately 5 km south-southeast of Kurrawang	Honman (1914); Simpson (1952); Ellis (1963)
Larkinville	31°28'20"	121°28'30"	Irregular veins of apparently siliceous magnesite are known in the altered greenstones of the area. A dense, hard, pure white variety of magnesite also occurs at the surface in a few places	Feldtmann (1935); Simpson (1952); Ellis (1963)
Laverton	28°37'40"	122°24'00"	Boulders of good quality, dense, white magnesite, sometimes with a chalky surface, occur in surface soil at Laverton	Simpson (1952)
Mount Hunt	30°50'40"	121°30'30"	According to the records of the Department of Minerals and Energy, in 1956 287 t of magnesite valued at \$1326 was mined from MC17E held by R. L. Jones. No other information is available on this deposit	DME production statistics (unpublished)
Nepean	31°10'00"	121°05'00"	Large boulders made of intimate mixtures of white cryptocrystalline magnesite and chalcedony in approximately equal proportions have been collected from the surface. Some boulders are covered with a thin layer of cream-coloured travertine	Simpson (1952)
Norseman	32°12'00"	121°46'00"	<p>Nodular magnesite was found in a small shear zone in an adit at the Hardy Norseman GML21. White cryptocrystalline magnesite is found in the surface soil near the Nellie May GML873, 14.5 km northeast of Norseman, and a sample contained 96.5% MgCO₃ and 3.5% CaCO₃. Peridotites, pyroxenites, and norites are widespread in the area</p> <p>Magnesite also occurs as a deep weathering product over ultramafic rocks associated with the Jimberlana intrusion that extends from northeast of Norseman to Round Top Hill on</p>	<p>Campbell (1906); Simpson (1952); Gower and Bunting (1976)</p> <p>Gower and Bunting (1976)</p>

Table 40. (continued)

<i>Locality</i>	<i>Lat. (S) Long. (E)</i> <i>(approximate)</i>	<i>Remarks</i>	<i>References</i>
Norseman (cont.)		LAKE JOHNSTON. Magnesite is more abundantly developed over the ultramafic portions of the intrusion	
Ora Banda	30°22'00" 121°02'30"	Boulders of magnesite are scattered over the surface of serpentinitic rocks southwest of Ora Banda townsite, especially near the Black Flag road	Jutson (1914); Simpson (1952); Ellis (1963)
Paddington	30°29'40" 121°20'00"	Dense white magnesite and chalcedonic magnesite boulders occur on the surface and as shallow seams associated with serpentinite approximately 1.6 km south of the railway siding. Talc-breunnerite schist occurs in an old mine dump near a serpentinous rock (exact location not given)	Simpson (1952); Feldtmann (1915)

Table 41. Minor occurrences of magnesite in the South Western terranes of the Yilgarn Craton

Locality	Lat. (S) Long. (E) (approximate)	Remarks	References
Corrigin and Kumminin	32°19'40" 117°52'00"	Analyses of two bulk samples of boulders of hard cryptocrystalline magnesite from a location just south of Corrigin contained 46.92 and 44.56% MgO (Table 42). Hard, white concretionary magnesite also occurs at a few places north and south of the road from Kumminin to Corrigin, and large boulders of magnesite occur on Fawcetts Farm in the Kumminin area. One sample from Fawcetts Farm contained 46.64% MgO. Commercial deposits are unknown	Simpson (1952); Ellis (1963)
Dangin	32°02'40" 117°18'00"	Numerous veins of magnesite up to 7.6 cm thick occur in weathered mafic rocks in a railway cutting approximately 2 km west of Dangin. Magnesite nodules are also developed in soil in this area. While the magnesite is high grade, the quantity available is thought to be insignificant for any commercial operation. Small quantities of white coralloidal magnesite are developed on a mafic dyke intruding granitic gneiss on location 12487 north of Dangin	Ellis (1963); Simpson (1952)
Goomalling	31°17'40" 116°50'00"	Occasional nodules of magnesite are known in soil covering serpentine rocks in the immediate vicinity of the town	Simpson (1952)
Kulin	32°40'20" 118°09'30"	White boulders of magnesite are common in the vicinity of Kulin, and high-grade nodular magnesite occurs approximately 2.4 km northeast of Kulin, on the southeastern side of the railway line. However, no large deposits of commercial value are known	Simpson (1952); Ellis (1963)
Namban	30°23'00" 116°00'30"	Large boulders of hard white magnesite are known from Wards Farm, 3.2 km west of the railway station. The material is said to have been used to make the font in a church at Moora	Simpson (1952)
Northam	31°39'20" 116°42'30"	Between 1948 and 1950 there was recorded production of 4338 t of magnesite, valued at \$19 437, from private property, located approximately 4.5 km east of Northam close to the Great Eastern Highway (Tables 29 and 30). The material was used as a flux in the charcoal-iron industry at Wundowie. It is of poor quality, and around 38% MgO and 41% CO ₂ . Dense white magnesite boulders also occur on the slopes of Mount Dick	Simpson (1952)
York	31°50'40" 116°45'30"	Small amounts of magnesite are known from a location 4.8 km north of York, overlying ultramafic dykes. The analysis of a typical specimen indicates that it is high grade, containing 47.62% MgO (≈99.61% MgCO ₃) (Table 42)	Simpson (1952); Ellis (1963)

Table 42. Chemical analyses of magnesite from Corrigin, Kumminin, York, Bamboo Creek and Jimblebar, and breunnerite from Warrawoona

Locality Sample no.	Corrigin 4	Corrigin 5	York 9	Kumminin 6	Bamboo Creek 1	Jimblebar 2	Warrawoona 5787	Warrawoona 5757
				percentage				
CO ₂	51.20	50.13	51.35	50.90	24.48	50.31	32.60	23.03
MgO	46.92	44.56	47.62	46.64	20.22	42.10	28.89	32.30
FeO	0	0	0	0	5.74	1.57	3.52	4.72
CaO	tr	1.92	0	tr	0	4.62	2.68	Tr
MnO	0	0	0	0	tr	–	0.35	0.11
SiO ₂	0.60	1.02	0.58	1.16	47.00	–	26.65	30.63
Al ₂ O ₃	1.00	1.74	0.42	1.56	1.92	–	2.03	1.68
Fe ₂ O ₃	(a)	(a)	0.30	(a)	(a)	–	2.06	5.94
H ₂ O ⁺	–	–	0.24	–	–	–	0.92	0.52
H ₂ O ⁻	–	–	0.26	–	–	–	0.16	0.15
Na ₂ O	–	–	–	–	–	–	0.29	0.41
K ₂ O	–	–	–	–	–	–	0.09	0.11
TiO ₂	–	–	–	–	–	–	0.16	0.52
FeS ₂	–	–	–	–	–	–	0.17	0.20
Total	99.72	99.37	100.77	100.26	99.36	98.60	100.57	100.32

NOTES: after Simpson (1952)
(a) included above
tr = trace

Table 43. Minor occurrences of magnesite in the Murchison terrane of the Yilgarn Craton

Locality	Lat. (S) (approximate)	Long. (E)	Remarks	References
Gabanintha	26°56'00"	118°39'00"	Lumps of surface concretionary magnesite associated with a rock containing veinlets of chrysotile and magnetite were recovered from the Lady Alma copper mine (ML4). Concretionary magnesite occurs at a location 33.5 km east of Nannine on the Sandstone–Meekatharra road, in the vicinity of the 'Copper King' workings	Simpson (1952); Ellis (1963)
Meekatharra	26°36'00"	118°30'00"	Magnesite is known in narrow veins and as boulders at several localities around Meekatharra. At Ingliston United GML, many veinlets of magnesite occur in the lode formation, and boulders are strewn over the surface of the lease. Lumps of magnesite embedded in laterite overlie carbonated peridotites and pyroxenites at the Ingliston Extended GML (GML398), and specimens of magnesite were found down to 24 m as white porcelanous material, or occasionally as friable masses, intergrown with a white magnesium silicate, possibly sepiolite Two types of breunnerite-bearing rocks are known in the Meekatharra area. At the Paddys Flat Group of mines, especially in the Commodore, Ingliston, Ingliston Extended and Globe GMLs fuchsite–breunnerite–quartz rock derived from carbonated peridotites is characterized by the presence of bright-green chromium mica. The breunnerite in these rocks is white to pale-green in colour, and a typical specimen assays 8.59% FeO, 0.87% Fe ₂ O ₃ , 35.69% SiO ₂ , 26.20% CO ₂ , and 20.46% MgO. Talc–breunnerite–ankerite rock is also found in the Paddys Flat area, but is generally less abundant than the fuchsite–breunnerite–quartz rock at Meekatharra	Farquharson (1912); Clarke (1916); Simpson (1952); Ellis (1963)
Mulermurra	28°53'00"	118°12'00"	H. W. B. Talbot (1920) reported a 'deposit of impure and opalized magnesite' associated with a greenstone ridge approximately 0.8 km south of Mulermurra. The greenstones at the southern end of the ridge may be sheared and weathered peridotite	Talbot (1920); Simpson (1952); Ellis (1963)
Ninghanboun Hills	29°12'00"	116°25'00"	A few boulders of creamy white magnesite are associated with the serpentine and mafic rocks at the eastern end of the Ninghanboun Hills	Simpson (1952)
Rothsay	29°17'00"	116°52'00"	A few boulders of creamy white porcelanous magnesite associated with serpentinized Archaean greenstones occur at GML101 in the Rothsay GM	Simpson (1952)
Yalgoo	28°21'00"	116°41'00"	Surface boulders of magnesite occur near the Dollar GM	Simpson (1952)

Table 44. Minor occurrences of magnesite in the Northampton Complex, Narryer Terrane and the Albany–Fraser Orogen

<i>Locality</i>	<i>Lat. (S)</i> <i>(approximate)</i>	<i>Long. (E)</i> <i>(approximate)</i>	<i>Tectonic unit</i>	<i>Remarks</i>	<i>References</i>
Geraldine (Ajana)	27°46'00"	114°41'30"	Northampton Complex	Boulders of dense white magnesite with specks of graphite were found by Mr R. C. Wilson at a location on a lead mining lease east of Mary Springs. The area consists of granite and gneiss with veins of graphite intruded by dolerite dykes	Simpson (1952)
Northern Gully	28°43'00"	114°55'00"	Northampton Complex	Brunnerite occurs as a gangue mineral with siderite, quartz and galena at the Lady Sampson lead mine	Simpson (1952)
Yallalong	27°26'00"	115°31'00"	Narryer Terrane	Small amounts of magnesite and long, fibrous, silicified tremolite are associated with ultramafic rocks south of Yallalong homestead	Hocking et al. (1982)
Pallinup River	34°26'00"	118°48'20"	Albany–Fraser Orogen	'Coralloidal' and fossil-like concretions of white microgranular magnesite occur at a location 9.6 km inland from the mouth of the Pallinup River. A vein of magnesite was also noted in weathered serpentinite near a graphite vein in the same area	Simpson (1952)
Stirling Range	34°24'00"	118°02'00"	Albany–Fraser Orogen	Magnesite boulders have been collected from the foot of the Stirling Range, but the exact location is not known	Simpson (1952)

Table 45. Minor occurrences of magnesite in the north Pilbara granite–greenstone terrane

<i>Locality</i>	<i>Lat. (S)</i> <i>(approximate)</i>	<i>Long. (E)</i> <i>(approximate)</i>	<i>Remarks</i>	<i>References</i>
Bamboo Creek	20°56'00"	120°12'00"	Small veins of coarsely crystalline white to pale-grey magnesite occur in a greenstone in the Kitchener GM. An analysis of some fine-grained material from a depth of 128 m in a bore indicates that it is brunnerite (Table 42)	Simpson (1952)
Braeside	21°12'00"	121°01'00"	Magnesite occurs as a gangue mineral with limonite, siderite and calcite in a low-grade vein of copper ore (malachite) in basalt	Simpson (1952)
Jimblebar	23°28'00"	120°11'00"	White magnesite filling small short veins up to 5 cm thick in older Precambrian jaspilites occurs east of Jimblebar Gap in the Ophthalmia Range. An analysis of a sample gave 42.10% MgO (Table 42)	Simpson (1952)
Lionel	21°39'40"	120°06'30"	A coarsely crystalline vein of ferruginous magnesite was found in serpentine rock in a shaft at one of the asbestos leases. Another vein of similar appearance at the same location proved to be ankerite	Simpson (1952)
Warrawoona	21°20'00"	119°53'00"	The Archaean peridotites throughout this area are highly carbonated and contain significant amounts of finely granular ferruginous magnesite that is probably derived from antigorite and other ferromagnesian minerals. Analyses of two samples from near the Juneau GML 479 and near GML 531 are given in Table 42	Simpson (1952)

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