GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

MINERAL RESOURCES BULLETIN 11

MOLYBDENUM, TUNGSTEN, VANADIUM AND CHROMIUM IN WESTERN AUSTRALIA

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MOLYBDENUM, TUNGSTEN, VANADIUM AND CHROMIUM IN WESTERN AUSTRALIA

by

J. L. Baxter B. Sc (Hons)

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FOREWORD

The proposal in 1972 to assess the economics of building a Jumbo Steel plant in Western Australia prompted a review of alloy metals required for the manufacture of steel. There is no current production of molybdenum, tungsten, vanadium or chromium in the State. Resources of vanadium are very large in titaniferous magnetite deposits but resources of the other metals reviewed here are small.

The author has investigated the resources of these metals by visiting most of the deposits and reported mineral occurrences. The results of his field investigation have been combined with data provided by mining companies in the bulletin. It contains basic information on the four metals concerned, including mode of occurrence, description of known deposits, notes on prospecting recommendations and a comprehensive list of references.

The bulletin should provide a useful reference for anyone interested in prospecting for these metals in this State.

1st June, 1978.

J. H. Lord
Director

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PREFACE

This bulletin is essentially a compilation of published and unpublished information on those Western Australian deposits of molybdenum, tungsten, vanadium and chromium considered to have some geological significance. It is not intended to be an exhaustive study of the metallogenesis of the metals, but rather to present a summary of available information on which further exploration or scientific studies may be based.

The main text of the bulletin is divided into four self-contained parts, one on each of the metals. This format allows for the future issue of separate sections of the bulletin should current developments make it necessary or desirable to revise the information on any of the metals.

In accordance with recent trends the ore deposits are described by tectonic provinces. This is a marked departure from the scheme of grouping deposits by Gold or Mineral Fields used in some earlier Mineral Resources Bulletins. Figure 1 shows the tectonic units referred to in the text.

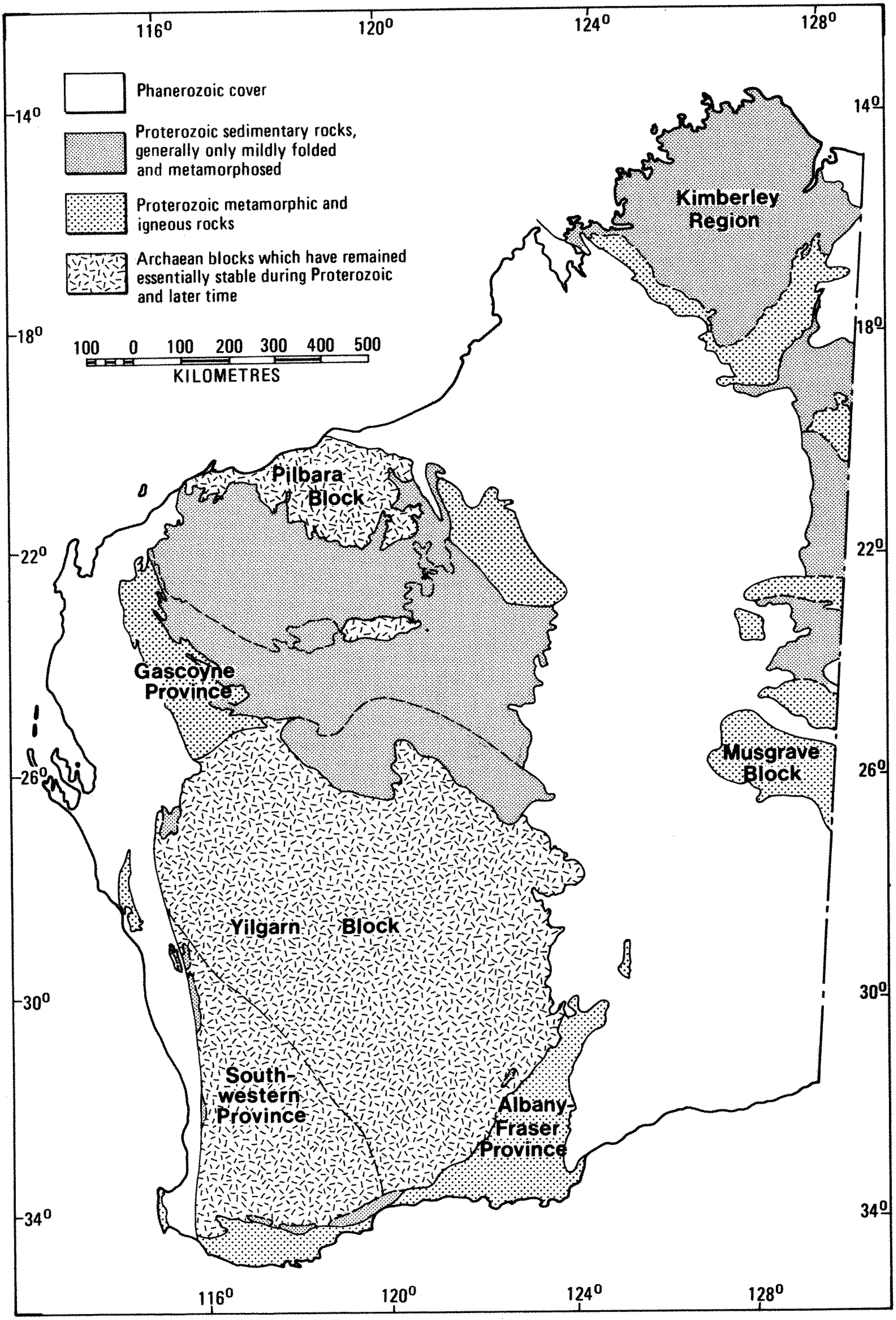

Figure 1. Tectonic provinces of Western Australia (GSWA 17392).

P A R T   O N E

M O L Y B D E N U M

PART ONE

MOLYBDENUM

INTRODUCTION

Molybdenum ores have not been mined economically in Western Australia, although small deposits of the metal have been worked in, or reported from, various parts of the state. In the past most localities have been in the Yilgarn Block, in quartz-rich veins associated with granitic rocks, but recent exploration in the eastern Pilbara Block has located disseminated deposits in granodioritic rock.

This part of the bulletin is designed to present the currently available information on molybdenum deposits and summarize the styles of mineralization which may be expected to be located in the state. Figure 2 shows the localities of the molybdenum deposits described in the text.

SOURCES OF INFORMATION

Information contained in the descriptions of the deposits has been obtained from earlier reports of the Geological Survey of Western Australia; files and records of the Department of Mines; the publication Minerals of Western Australia (Simpson, 1952); and reports submitted to the Department by various mining companies. Previous reviews of molybdenum have been published by Maitland (1919) and Simpson (1918). Additional technical data have been derived from Warden's Court proceedings collected during hearings of tenement applications. Some deposits were inspected by the author during 1972 and 1973. Where no reference is listed the information has been derived from either Simpson (1952) or files of the Department of Mines.

In general the localities reported in Simpson (1952) have been difficult to locate accurately, but those given in this bulletin can be expected to be within 1 minute of arc in both latitude and longitude. Further information on several deposits reported by Simpson (1952) has been gained by petrological examination of specimens held in the collections of either the Geological Survey of Western Australia or the Government Chemical Laboratories.

HISTORY OF MOLYBDENUM EXPLORATION AND PRODUCTION

During World War I a shortage of molybdenum for use in production of armour plating created a high market price for its ores, and led to prospecting for deposits in the state. During 1913 and 1914 most of the presently known molybdenite discoveries were reported for the first time; some of these deposits are said to have been discovered earlier, but owing to the low demand for the metal had not been developed. In 1913 the first tenement was taken up for molybdenum on Harrison's Reward deposit at Melville. This was followed in 1914 by Mulgine Hill, Davy's Reward, and Recovery in the Murchison; Mount Molybdenite and Lake Polaris in the Eastern Goldfields; and Rock of Ages in the Southwestern Province. This early exploration came to a halt at the end of World War I, and there was little interest in molybdenum exploration until World War II. The renewed interest was directed towards the Melville area and the Mulgine Hill deposits. Prior to 1960 most exploration was carried out by individual prospectors, and very little geological mapping or drilling was conducted on the deposits. The most extensive reports on the deposits emanate from Government sources, primarily the Geological Survey of Western Australia.

The total reported production of molybdenite from Western Australia is listed in Table 1.

TABLE 1. Total reported molybdenite production from W.A.

Mine	Concentrates (tonnes)	Grade (%)	MoS_2 (tonnes)
Rock of Ages	5	-	-
Mulgine Hill	78.74*	9.0	7.11
Mount Molybdenite	1.025	-	-
TOTAL:	84.765		

* Department of Mines estimate

The increasing awareness of the association of molybdenite with porphyry deposits led, in the 1960's, to several mining companies carrying out extensive exploration at Mulgine Hill which was thought to have some characteristics of a porphyry deposit. The search for porphyry-type deposits spread to the Pilbara in 1968, and led to the discovery of the Coppins Gap prospect which is currently being evaluated.

MOLYBDENUM MINERALS

The main ore mineral of molybdenum is molybdenite, which at the surface may be altered to powellite or ferrimolybdite. No other minerals carrying molybdenum are known to be of economic value in Western Australia.

Molybdenite (MoS_2)

Molybdenite is a metallic lead-grey mineral with a prominent cleavage. It is often confused with graphite from which it can be distinguished by a bluish-grey streak on paper or greenish-grey streak on porcelain. When burnt on charcoal molybdenite readily yields sulphur fumes. It occurs as disseminated crystals, crystal clusters or rosettes. The mineral is soft (Mohs hardness 1-1.5), and greasy to feel.

Powellite {$Ca(Mo,W)O_4$}

Powellite is a scheelite group mineral which is common in oxidized rocks whose parent contains tungsten and molybdenum minerals. The mineral has a hardness of 3.5 and is difficult to distinguish from other members of the scheelite group. It is usually creamy white to light brown, and translucent with a greasy appearance. It usually forms anhedral grains.

Ferrimolybdite ($Fe_2O_3.3MoO_3.8H_2O$)

Ferrimolybdite is a canary-yellow fibrous mineral which is commonly associated with limonite. The crystals are very brittle and usually break when touched.

USES OF MOLYBDENUM AND MOLYBDENUM ORES

The principal use of molybdenum, its ores and products is in the production of steel, particularly stainless steel. Its chief competitor is nickel, although both have speciality applications. Of the molybdenum steels produced most are used in automobiles, with lesser amounts in pipelines, tools, electrical uses, machine tools, and petroleum production. Recently an increase in the use of purified molybdenum disulphide as a lubricant has had an impact on the demand. Molybdenum is also used in the chemical industries for fertilizer manufacture, pigment production, catalysts, and similar purposes. Molybdenum metal is finding uses in the light filament and electronic parts industries, and in high temperature non-corrosive alloys. Research is continuing into further uses for molybdenum.

GEOLOGICAL SETTING OF MOLYBDENUM DEPOSITS

All molybdenite deposits in Western Australia are related to granitic intrusions. The deposits are all of probable Archaean age. Three types which have been recognized are: those concentrated in veins at the margins of stocks; those composed of disseminated molybdenite in granitic rocks; and those associated with gold-bearing quartz reefs in greenstone belts. Insufficient detailed information is available from molybdenite deposits in Western Australia to establish a more detailed classification; however, the classification of Canadian deposits given by Vokes (1963) may, as a first approximation, be applied to the Western Australian deposits.

The only deposits of molybdenite so far mined in Western Australia are quartz veins and quartz-rich pegmatites emplaced at the margins of granitic stocks in the Yilgarn Block. Molybdenite mineralization is usually at the margins of the veins, but may extend into the surrounding country rock. The molydenite mineralization is commonly accompanied by pyrite and may have associated fluorite, scheelite, or wolframite. It seems unlikely that any deposit of this type will be mined exclusively for molybdenite. The deposit at Mulgine Hill may produce molybdenum concentrate as a by-product, if scheelite production is initiated.

Porphyry-type disseminated molybdenite deposits accompanying extensive stockworks have been reported from Schummans prospect (p. 14) and Coppins Gap. At Coppins Gap the molybdenite is disseminated in a granodiorite which intrudes a succession of felsic and mafic volcanic rocks. Granitic dykes, accompanied by a stockwork of fine quartz veins, intrude a sequence of mafic volcanic rocks and sediments at Schummans prospect; molybdenite mineralization is concentrated in the country rock at the margins of the quartz veinlets. Neither of these deposits is considered to be economic at the present time, but exploration is continuing.

Minor molybdenite mineralization has been reported in the country rock of gold-bearing quartz reefs in the Yilgarn Block. In these deposits the molybdenite occurs as smears and crystal clusters on fracture and foliation planes in the wall rock up to 5 m away from the veins. The molybdenite in these deposits is erratically distributed and of no economic importance.

GEOCHEMISTRY OF MOLYBDENUM

Molybdenum is a rare mineral in the Earth's crust, having a clarke of between 1 and 1.5×10^{-4} per cent (Mason, 1966, p.44-49; Rankama and Sahama, 1950, p.625; Goldschmidt, 1958, p.555). It has a strong affinity with sulphur (chalcophile), but is also reported to have some affinity with iron (siderophile) and oxide earthy minerals (lithophile), but these are subordinate to the usual chalcophile character. Minor molybdenum has been recorded in the crystal lattice of silicate minerals, but is more common in rocks as molybdenite. Kuroda and Sandell (1954) and Davy (1973) have reviewed the geochemistry of molybdenum.

Molybdenum has been recorded in trace quantities from mafic and ultramafic igneous rocks (0.6-1.1 ppm and 0.4 ppm respectively), but is more often associated with felsic plutonic rocks (1.1 ppm). It tends to be concentrated in late-stage residual fluids and is usually deposited in pegmatites or quartz veins. Pneumatolytic (gaseous) transport of molybdenum is aided by the presence of volatile fluorine compounds. Molybdenite is commonly concentrated at the margins of the parent pluton or vein, but may be disseminated throughout the body.

Secondary dispersion of molybdenum

Secondary dispersion of molybdenum is dependent on pH and Eh of the surroundings. In alkaline conditions dispersion occurs as the molybdate ion (MoO_4^{--}) which is reasonably mobile, whereas in acid conditions the acid molybdate ion ($HMoO_4^-$) forms and this ion is virtually immobile. The partition between these ions occurs at pH6. Molybdate ions are precipitated in the presence of calcium and lead, to form powellite and wulfenite respectively. Acid molybdate ions are fixed in the presence of iron as ferrimolybdite. Secondary dispersion of molybdenum has been reviewed in detail by Hansuld (1966) and Davy (1973).

In Western Australia, acid surface conditions predominate in the vicinity of granite outcrops, and secondary dispersion of molybdenum is at a low level. At Mulgine Hill, Webb (1968) reports that the surface dispersion is restricted to the granitic stock, and that there is a slight enrichment in the top 10 m of the granite, with depletion between 10 and 20 m before reaching the unaltered rock. This may indicate that below the near-surface oxidizing zone at Mulgine Hill there is alkaline groundwater enabling movement of molybdenum ions.

EXPLORATION FOR MOLYBDENUM ORES

Prospecting for molybdenum usually involves direct search for the metal or its mineral. Geophysical methods are unsuitable for detailed prospecting but may be useful for regional structural surveys. Exploration is best directed towards geological mapping and geochemical surveys.

Geophysical methods

Molybdenum deposits are usually located at the margins of felsic plutons, and these margins can generally be delineated by regional airborne magnetometer surveys. Porphyry-type deposits are commonly associated with major lineaments, and these also can be detected from magnetic data. The disseminated distribution of molybdenite in porphyry-type deposits renders exploration for them by electrical means impractical.

Geological methods

In areas of favourable rocks with indications of molybdenum, detailed structural mapping, particularly of vein distribution, can indicate favourable zones of mineralization. Molybdenum tends to be concentrated in the late phases of pluton emplacement, and will be deposited preferentially in fracture zones and late-stage quartz veins and pegmatites.

Geochemical methods

Molybdenum responds well in geochemical surveys in the arid areas of Western Australia. The molybdenum content of soils and stream sediment samples varies according to groundwater pH which may fluctuate seasonally. It tends to be concentrated in the presence of iron and in the silt and clay fractions of soils. In Western Australia fine-grained (2.5-3.25 ϕ, 80-150 mesh) wind-blown sand commonly overlies residual soil; this sand should be avoided in geochemical surveys. Orientation sampling prior to full geochemical surveys is essential to establish the soil profile, to detect the presence of wind-blown sand, and to determine the soil pH conditions. Failure to carry out an orientation survey may lead to erratic results. Whole-rock analyses of felsic plutons during the orientation survey may assist in locating targets for later soil geochemistry. In general, molybdenum is considered to be anomalous in quantities exceeding 3 ppm which is the limit of detection for most rapid analytical methods. The general principles employed in geochemical surveys for molybdenum are laid down in Hawkes and Webb (1965).

PROSPECTING RECOMMENDATIONS

Coppins Gap, a porphyry-type molybdenum deposit, is located adjacent to an irregularity in the margin of the granitic batholith in the Pilbara Block. The mineralization appears to be associated with apophyses of the batholith. Prospecting batholith margins in this type of environment may lead to further discoveries of this style of mineralization in the Pilbara Block.

The Darling Range batholith (p. 9), in the Southwestern Province, contains numerous occurrences of molybdenite suggesting an intrinsic molybdenum enrichment of the body. Prospecting at the margin of the batholith for favourable fracture zones or stockworks may locate deposits worthy of further testing. Exposure in this area is poor, and prospecting would have to be by detailed mapping followed by geochemical survey.

The Mulgine Hill deposit is situated in a stock of granite which has intruded a greenstone belt at the margin of a larger batholith. Detailed mapping along the margin of the larger batholith may lead to discovery of favourable zones of fractures containing either molybdenum or tungsten mineralization.

THE DEPOSITS

SOUTHWESTERN PROVINCE

In the Southwestern Province small deposits of molybdenite have been reported in shear planes, quartz veins, and quartz-rich pegmatites in the enclosing schists and gneiss around the margins of granitic batholiths. A small amount of ore has been mined from the Rock of Ages at Swan View and McMillan's occurrence at Spencers Brook.

DARLING RANGE BATHOLITH

A fine to medium-grained adamellite-granite with locally extensive porphyritic phases forming a large batholith east of the Darling Scarp between Bald Hill in the north and Quindanning in the south has been named the Darling Range batholith. In the margins of this batholith small occurrences of molybdenite are common.

Rock of Ages
(Reward Lease 211H) (Lat.31°52'S, long.116°04'E)

The deposit is situated on the western side of John Forrest National Park, about 2.4 km north of the abandoned Swan View railway station. It is about 200 m east of the eastern boundary of Swan Location 1114, and is accessible to four-wheel drive vehicles on the National Park boundary track.

Talbot first reported on the deposit in 1914 and stated that it was known several years prior to this date. In 1914 the pit was 3 m long, 1.5 m wide, and 2 m deep; however, there is no record of sales of ore at this time. In 1918, Mr. L. Ives is believed to have mined a parcel of ore and is unofficially reported to have sold 5 t of concentrates. The pit in 1942 was 4 m long, 3 m wide, and 4.3 m deep, and in 1974 it was 7 m long, 3 m wide, and 13 m deep. Since 1918 there has been no record of production from the deposit.

Molybdenite and pyrite are disseminated in a grey, coarse, even-grained to porphyritic microcline granite. Pyrite occurs throughout the granite; molybdenite is concentrated in and near shear planes. Minor quartz veinlets, containing no molybdenite, appear to fill tension cracks in the granite in the vicinity of the deposit. The area is intruded by a dolerite dyke swarm but there is no apparent relationship between the mineralization and the dykes. Simpson reports the average grade of the deposit as 1 per cent MoS_2.

References: Talbot (1915), Miles (1944), Simpson (1918; 1952, p.246), Wilde and Low (1975).

McMillan's occurrence
(Lat.31°45'S, long.116°39'E)

McMillan's occurrence is about 3.2 km due south of the abandoned Spencers Brook railway station on Avon Location E. A small parcel of ore was obtained from the deposit in 1925 but no official details of grade or market values were recorded.

Molybdenite occurs on the margins and as a selvage to a series of thin quartz veins (2-50 mm wide) intruding a quartz-feldspar-biotite migmatite. Mineral layering in the migmatite strikes at 165°, dipping east at 65°. A small pothole has been sunk on the deposit. Pyrite and magnetite are commonly associated with the mineralization. Powellite pseudomorphs after molybdenite occur in the deposit and ferrimolybdite is developed as a weathering product.

The quartz veins contain minor chlorite and biotite. They trend at 055° and dip south at 75°.

References: Simpson (1952, p.245-246), and Wilde and Low (1975).

North Dandalup
(Lat.32°33'S, long.115°59'E)

Molybdenite was discovered at the contact of a pegmatite intruding a porphyritic granite between 15.2 and 21.6 m below the surface in a gold prospecting shaft 5 km southwest of North Dandalup. The shaft was sunk by Mr. A. Napier on the contact of a pyrite-bearing dolerite dyke. The workings consist of a shaft, 21.6 m deep, with three drives at 15.2 m, being 4.5 m to the east, 4 m to the west, and 3 m to the south. An assay of the ore indicated a grade of 0.11 per cent MoS_2.

References: Woodward (1917), Fisher (1945), Simpson (1918; 1952, p.245).

Mahogany Creek
(Lat.31°55'S, long.116°09'E)

In 1916, molybdenite was discovered about 1.2 km southwest of the abandoned Mahogany Creek railway station in a medium to coarse-grained quartz-oligoclase-microcline pegmatite intruding a fine to medium-grained biotite adamellite. The molybdenite is partially or wholly altered to powellite in surface exposures.

Reference: Simpson (1918).

Mokine
(Lat.31°42'S, long.116°35'E)

In a railway cutting 0.8 km north of Mokine siding molybdenite flakes up to 15 cm square and 1.5 mm thick occur on joint planes in an even-grained grey microcline granite.

Brookton
(Lat.32°26'S, long.116°55'E)

Mr. C. E. Adlard discovered molybdenite in creek-bed alluvium on Avon Location 12803 about 12 km south of Brookton. The surrounding rock is coarse-grained porphyritic muscovite-biotite granite, in which there are numerous quartz veins. No molybdenite was noted in the quartz veins.

Jimperding
(Lat.31°36'S, long.116°21'E)

Molybdenite occurs in a pegmatite intruding granitic rocks in the vicinity of the Jimperding gold workings.

Chittering Valley
(approx. Lat.31°30'S, long.116°05'E)

Molybdenite is reported by Simpson (1952) from mafic gneiss and epidotized granite in the Chittering Valley. In the mafic gneiss it is associated with magnetite, hematite, quartz and chlorite. No accurate location is available for this occurrence.

OTHER OCCURRENCES

Greenbushes
(Lat.33°53'S, long.115°58'E)

Molybdenite was discovered by Mr. E. Aurisch on a ridge southeast of the junction of Norlup Brook and the Blackwood River. Noldart reported that the molybdenite was scattered throughout a quartz-feldspar gneiss and was not concentrated sufficiently to be of economic interest.

Reference: Noldart (1956).

Waddouring Rock
(Lat.30°57'S, long.117°51'E)

Waddouring Rock is about 16 km south of Bencubbin, and has a water tank on its crest. Molybdenite, with associated pyrite, has been identified in biotite schlieren in granite intruded by small quartz veins at this rock.

Blackboy Hill
(Lat.31°15'S, long.116°29'E)

Molybdenite occurs in soil containing quartz and clay in the vicinity of the Blackboy Hill gold workings, 4 km northwest of Bolgart.

Quairading
(Lat.31°59'S, long.117°23'E)

Molybdenite, in association with talc and quartz, occurs about 3 km north of Quairading.

MURCHISON AND EASTERN GOLDFIELDS PROVINCES

Molybdenite occurrences and deposits in the Murchison and Eastern Goldfields Provinces are discussed in the one section as they are either in quartz veins associated with granitic-granodioritic stocks, or found as an accessory to gold mineralization. The Mulgine Hill deposit is exceptional in the group as it occurs in a quartz stockwork intruding a leucogranite stock. Molybdenite production from deposits in this area is low and, with the exception of a small parcel from Mulgine Hill, has not been reported to the Department of Mines. The deposits at Mulgine Hill and Mount Molybdenite have been drilled by exploration companies, but no economic concentrations of ore have been located.

MULGINE HILL
(Lat.29°11'S, long.116°59'E)

Mulgine Hill is about 15 km northeast of Rothsay, and can be reached by road from Paynes Find to the east or Perenjori to the west. It is shown on some maps as BA 8.

Molybdenite was produced from this deposit intermittently between 1914 and 1922; however, only a small amount of ore was raised. A 40-m long adit at an azimuth of 090°, having backs sloping from 17 m at the portal to 0.5 m, and a 2-m deep winze, 9 m from the portal, were the main results of mining on the deposit. Scattered over the hill there are about 30 trenches sunk on high-grade exposures, but none of these is more than 2 m deep. Estimates of production vary from 4.5 t of ore assaying 5 per cent MoS_2 (Hosking, 1938) to 300 t of ore assaying 4.5 per cent MoS_2 (Macandie, 1941).

The deposit was reviewed by Big Bell Mines Ltd, Broken Hill Proprietary Co. Ltd, and the Western Australian Government at the beginning of World War II, but no production was recorded. In 1966 Westfield Minerals (W.A.) N.L. drilled the western flank of the hill on a grid of 640 m by 182 m, and between 1967 and 1969 Newmont Pty Ltd carried out a drilling and mapping assessment of the hill. None of these exploration efforts revealed an economic concentration of molybdenite. Since 1969 Minefields Exploration N.L. have carried out extensive drilling of metamorphic rocks flanking the north side of the hill. Here they have delineated a zone of mixed metal mineralization, Schummans prospect, about 1 km north of Mulgine Hill, and report that it contains 120 Mt of ore with 0.033 per cent MoS_2, 0.047 per cent scheelite, and 0.033 per cent Cu.

Geology: Mulgine Hill is a stock of medium to coarse-grained leucogranite composed of quartz, microcline, sericitized plagioclase, and muscovite, with lesser amounts of fluorite and pyrite, and accessory zircon, epidote, zoisite, apatite, ilmenite, magnetite, and chrysocolla. The stock contains phases of even-grained and porphyritic granites which are massive in the core and foliated and sheared on the margins. The surrounding metasedimentary and mafic rocks dip away from the stock on the north, east and west. These surrounding rocks are equated with the lower mafic association recognized in the Yalgoo 1:250 000 sheet area (Muhling and Low, 1973), and are described in more detail by Collins (1975) and Part II of this bulletin.

The molybdenite mineralization is associated with a suite of quartz veins, which intrude the stock on a strike of 135° and dip near-vertically. The molybdenite is concentrated along the vein margins, but extends into the host rock for up to 50 cm. Where there is a cluster of veins, such as near the adit, mineralization can attain a width of up to 5 m, but in general it occurs in isolated pockets over the whole hill surface. The molybdenite appears to replace muscovite in the granitic host rock and is associated with fluorite and minor scheelite. At the surface, powellite pseudomorphs after molybdenite have been recorded. Typical analyses of the ore are presented in Table 2.

TABLE 2. Assays of Mulgine Hill molybdenum ore

Description of sample	MoS_2 (%)
Hand-picked ore, M.L.39	16.40
West M.L.50	6.93
Massive granite, G. Wakeham's P.A. 1.6 km east of M.L.49	3.09

Assays by E.S. Simpson, reported in Blatchford (1919).

Schummans prospect is associated with a stockwork of small quartz veins emanating from a series of granitic dykes, which appear similar in composition to Mulgine Granite.

Following the detailed exploration of Mulgine Hill it now seems unlikely that a molybdenite deposit of sufficient size to warrant mining will be discovered, although it is possible that small quantities of molybdenite will be obtained as a by-product of mining scheelite from the Hill prospect (p. 42), should this be developed.

References: Feldtmann (1917), Blatchford (1919), Maitland (1919), Maitland and Montgomery (1924), Hosking (1938), Macandie (1941), Matheson (1944a), Fisher (1945), Simpson (1952, p.243-244), de la Hunty (1958), Miles (1961), Jackson (1962), McLeod (1965), Westfield Minerals (W.A.) N.L. (1966), Newmont Pty Ltd (1967), Crozier (1968), Webb (1968), Hill (1969), McKenna and Partners (1971), Collins (1975).

MOUNT MOLYBDENITE
(Lat.28°38'S, long.121°24'E)

The Mount Molybdenite deposit was discovered by J.G. Thomas in 1914, and has been held as Reward Lease 45C and Mineral Lease 56C. It is about 27 km northeast of Leonora and 13 km northwest of Mertondale homestead. Some 25 kg of ore was sent away from the mine in 1914, but no grade was recorded. In 1918, a syndicate sank a 6 m inclined shaft on the deposit, and raised about 1 t of ore but this was not sold due to restrictions on sales of molybdenite during World War I. The deposit was drilled by Western Mining Corporation between 1966 and 1968, but no continuous zone of mineralization was located. The deposit has been known as The Terraces, Linger and Die, Dodgers Hill, Thomas's Show, Mertondale, and Leonora.

The mineralization is contained in the quartz core of a pegmatite which trends southwest, and dips at 45° to the southeast. The molybdenite occurs as scattered flakes throughout the quartz core and at the margins of the core. The molybdenite is free of arsenic and bismuth, but is altered to powellite in places at the surface. Assays of ore from the deposit are given in Table 3. The quartz core has been traced over a length of 100 m; it is lenticular, and varies in width from 5 cm to 1 m. A second molybdenite-bearing vein 3 m north of the main vein has not been worked. The enclosing pegmatite intrudes a medium to coarse-grained, banded biotite adamellite.

TABLE 3. Assays of Mount Molybdenite ore

Source	MoO_3 (%)
from dump	0.53
"	0.20
"	0.14
from ore in shaft	1.50

References: Clarke (1919, 1925), Maitland (1919), Simpson (1952, p.248), Thom and Barnes (1974).

CALLIE SOAK
(Lat.27°17'S, long.117°30'E)

Callie Soak is best known from the tungsten deposits at Martins Lode. However, two small deposits in the vicinity were prospected for molybdenite. These are Recovery and Molybdenite Show. The mineralization is related to late stage emplacement of quartz veins intruding the western margin of the

Poona-Dalgaranga batholith (Muhling and de Laeter, 1971). There is no recorded production from either deposit. Robertson (1915) reported the results of separation tests of the Callie Soak ore.

Recovery

(M.L.53) (Lat.27°16'46"S, long.117°31'03"E)

The Recovery deposit was first reported by L. Bonnar in 1914. It is about 450 m west of Martins Lode and can be reached on ungraded tracks leading south from the Coodardy-Noondie road about 13 km west of Coodardy homestead. This deposit has been known as Callie Soak, Callie Spring, Quartz Blow Lode, Wolframite-molybdenite Lode, and Bonnars P.A.

A shaft, 7.8 m deep, was sunk on the deposit on the northern contact of a quartz vein which trends 130° and dips 87° southwest. The vein is about 27 m long and less than 3 m wide. It intrudes a biotite-rich foliated porphyritic granite. Phenocrysts marking the foliation in the granite trend at 110°, and dip south between 70° and 85°, with a shallow plunge to the west.

Molybdenite is concentrated at the margin of the vein and in the enclosing host rock. Chalcopyrite and wolframite accompany the molybdenite. Scheelite occurs in the core of the vein in minor concentrations. A sample taken across the width of the vein assayed 2 per cent molybdenite, 10 per cent scheelite, and 1.5 per cent wolframite.

Molybdenite Show

(Lat.27°16'43"S, long.117°30'46"E)

The Molybdenite Show is about 100 m west of the New Lode wolframite prospect and about 500 m west of the Recovery shaft. A trench has been sunk on the deposit.

A small, vertically dipping feldspathic quartz vein, about 10 m long and 1 m wide, with a trend of 015° contains minor concentrations of molybdenite at its margins. It intrudes porphyritic granite. The molybdenite mineralization is accompanied by pyrite. Chalcedony stringers, parallel to the vein along the western margin, contain no mineralization. The core of the vein contains small isolated bunches of wolframite.

References: Woodward (1914, p.54), Robertson (1915), Maitland (1919), Matheson (1944b), Simpson (1952, p.241), Muhling and de Laeter (1971), Wright (1972), de la Hunty (1973).

MOLYBDENITE OCCURRENCES ASSOCIATED WITH GOLD MINERALIZATION

Molybdenite has been recorded in gold-bearing quartz veins and in zones of wall-rock alteration associated with gold mineralization in a number of mines in the Murchison and Eastern Goldfields Provinces. The grade of molybdenum in these deposits is insufficient to warrant extraction, even as a by-product, and, other than specimens, no molybdenum ore has been produced. A summary of the available information from these occurrences is given in Table 4. In general, the molybdenite occurs in fractures in the quartz reefs or wall-rock as thin sheets or isolated clots.

OTHER MINOR OCCURRENCES

Quartz veins associated with the margins of adamellite-granodiorite batholiths in the Murchison and Eastern Goldfields Provinces may contain small amounts of molybdenite. These deposits have rarely been prospected thoroughly, and generally have only minor surface workings on them.

Davy's Reward

(M.L.24) (Lat. $28^{\circ}39'$S, long. $116^{\circ}18'$E)

In 1914 Mr. C. Williamson reported a molybdenite-bearing vein in a hornblende adamellite about 1.75 km southeast of Barnong homestead. The vein is a quartz-rich pegmatite, and contains small amounts of molybdenite and pyrite. Commonly, powellite pseudomorphs molybdenite in the deposit. Simpson reported four typical analyses as 2.60, 1.32, 1.04 and 0.64 per cent MoS_2. The deposit has no economic potential.

TABLE 4. Molybdenite occurrences associated with gold mineralization in the Murchison and Eastern Goldfields Provinces

Mine name	Tenement	Location	Source of information	Remarks
Big Bell	GML 20/2293	Lat.27°19'S, long.117°39'E	Stillwell (1948), The Staff (1953), de la Hunty (1973)	Molybdenite in small veins on margins of quartz lenticules in gold ore; associated with pyrite, pyrrhotite, stibnite, marcasite, chalcopyrite, arsenopyrite, tetrahedrite, bournonite and sphalerite
Ark	GML 59/1063	Lat.29°15'S, long.117°41'E Paynes Find	Simpson (1952)	Molybdenite occurs as small flakes on the margins of quartz veins in the quartz-gold lode
Edna May	GML 77/2180	Lat.31°17'S, long.118°42'E 2.5 km north of Westonia	Blatchford and Honman (1917, p.100-101,227), Matheson (1940,1947), Simpson (1952, p.247, 700)	Molybdenite in clots on fracture planes in the gold bearing quartz vein and as small scales parallel to the foliation in the en-closing gneissic rock; associated with wolf-ram, galena, pyrite and marcasite
Wellington	GML 77/2331	Lat.31°16'S, long.119°22'E 3.2 km southeast of Southern Cross	Crabb, J. (unpublish-ed Dept Mines file report)	Molybdenite occurs in a quartz vein which contains 6.3 ppm gold
Radio	GML 77/2994	Lat.30°55'S, long.119°05'E	Matheson (1947, p.82)	Molybdenite, pyrite and chalcopyrite(?) are associated with gold mineralization in a quartz vein below the No.1 level in the mine
Buldania Bell	GML 63/779	Lat.32°03'S, long.122°02'E	Simpson (1952)	Foliated molybdenite is reported from the greenstone schist wall rock in the mine
Ensign	GML 15/1953	Lat.30°54'51"S, long.121° 11'26"E, 4.8 km NE Coolgardie	Simpson (1952)	Molybdenite reported as large grains in an amphibolite made up essentially of radiating hornblende crystals
Melba	GML 31/682	Lat.29°29'S, long.121°49'E	Jutson (1915, p.25)	Molybdenite occurs in a gold-bearing quartz vein intruding a tonalitic porphyry
Hidden Trea-sure	GML 31/766	Lat.29°47'S, long.122°22'E	Montgomery (1906)	Molybdenite and pyrite occur in the wall-rock schist of the western gold-bearing reef
Chapmans Find	GML 38/2150	Lat.27°52'S, long.123°22'E 2.4 km northeast of Jutson Rocks	Gourley (1924)	Molybdenite occurs on fractures in the quartz reef lode

References: Simpson (1952), Muhling and Low (1973).

Harrison's Reward
(M.L.26, M.L.38)(Lat.28°08'S, long.116°43'E)

Harrison's Reward was first pegged in 1913 by W. Harrison for molybdenum and bismuth. As far as can be ascertained no production from the deposit was sold although it is possible that small parcels produced during the sinking of three shafts were used as payment for supplies during development. The deposit is about 3 km northeast of Bottom well, and can be reached by a series of rough tracks from the abandoned Noongal townsite.

Molybdenite, with associated bismutite and minor scheelite, occurs in the quartz core of a pegmatite. The pegmatite has a trend of 142°, and dips 71° west parallel to the foliation of the enclosing metapyroxenite (now actinolite-tremolite rock). The metapyroxenite is a xenolith in a fine-grained foliated granite.

References: Simpson (1952), Muhling and Low (1973).

Already Well
(Lat.27°44'S, long.117°24'E)

A molybdenite concentration in a quartz vein intruding the contact between foliated medium-grained granite and a metagabbro in the vicinity of Already Well has no economic potential. The quartz vein intrudes the two rocks perpendicularly to the contact, and the contained molybdenite is in the form of scattered flakes or rosettes.

Reference: de la Hunty (1973).

Keogh Well
(Lat.27°46'S, long.117°20'E)

Molybdenite occurs as clusters in a quartz vein intruding a granitic rock about 500 m northwest of Keogh well. No further information on the deposit has been found.

Reference: de la Hunty (1973).

Mays Rock
(Lat.32°44'S, long.121°35'E)

Small flakes and rosettes of molybdenite in quartz veins and the adjacent granodioritic rock have been reported from Mays Rock, 8 km northeast of Kumarl Siding.

References: Simpson (1952, p.248), Doepel (1970).

Coleman's P.A.
(Lat.33°36'S, long.119°59'E)

Coleman's P.A. is situated 5.6 km southwest of Ravensthorpe on Oldfield Location 284. A shaft sunk on a molybdenite, azurite, malachite-bearing vein is on the contact between granitic rocks and a greenstone belt. The occurrence is immediately south of the Irelands Own (M.L.74/322) copper prospect.

Lake Seabrook
(Lat.30°58'S, long.119°42'E)

Molybdenite, in disseminated quartz veinlets intruding a hornblende pyroxenite at the contact with a granitic pluton, was discovered by The Broken Hill Proprietary Co. Ltd during nickel exploration on the shores of Lake Seabrook. The molybdenite mineralization has no economic significance.

Reference: Gartside (1972).

Lake Polaris
(Lat.31°14'S, long.119°20'E)

This deposit, at Southern Cross, on the western side of Lake Polaris, was discovered by Mr. Roberts prior to 1914. Mines Inspector J. Crabb reviewed it in 1914, and reported that a small parcel of ore was sent to Germany prior to 1914. The deposit is a quartz vein about 1 m wide which Crabb estimates contains 0.5 per cent MoS_2. The vein trends northerly and dips steeply east.

South Windarra
(Lat.28°37'S, long.122°14'E)

Small quantities of molybdenite are associated with felsic dykes cutting ultramafic rocks within the Windarra South nickel mine. The mineral is concentrated in the biotite-rich reaction zones adjacent to the dykes.

PILBARA BLOCK

Until recently the occurrence of molybdenite in the Pilbara Block was only as specimen material from Eleys, Mount Francisco, West Wodgina, and Globe Hill. All occurrences were in quartz veins. Recent exploration by Australian Anglo American Pty Ltd and Esso Exploration and Production Australia Inc. has located disseminated molybdenite and chalcopyrite mineralization in a granodiorite at Reedy Creek and Coppins Gap. These discoveries are currently being investigated by Esso Exploration and Production Australia Inc.

COPPINS GAP
(Lat.20°53'20"S, long.120°06'30"E)

The following description has been extracted from Marston (in prep.). The information has been collated from data submitted to the Department of Mines by Australian Anglo-American Ltd and Esso Exploration and Production

Inc. The writer has not visited the prospect.

Coppins Gap is approximately 11 km west-northwest of Bamboo townsite. The molybdenum-copper prospect is 1.5 km southwest of Coppins Gap, in the centre of a narrow east-striking belt of felsic to ultramafic metavolcanic rocks that dip northward at about 65^{o}. To the south a northern lobe of the Mount Edgar batholith has stoped into the belt, and marginally this intrusive is a massive, high level, biotite adamellite with round quartz phenocrysts, quartz veinlets and accessory pyrite and chalcopyrite.

The volcanic sequence is intruded by several subconcordant, lensoid to tabular bodies of dacite porphyry, characterized by brecciated and silicified contact zones which also contain mafic to ultramafic hornfelsic rocks (for example, diopside-hornblende-tremolite). These silicified zones are capped by Tertiary siliceous mantles and thus stand up as broken, rugged ridges. The youngest intrusive igneous phase is a fine to medium-grained granodiorite to quartz-oligoclase porphyry, which forms flat lying and rare dyke-like bodies, and is poorly represented at the present level of erosion. The granodiorite contains disseminated chalcopyrite, molybdenite and iron sulphides.

A multiple phase stockwork of quartz-carbonate veins (with or without chlorite, potash feldspar and biotite) which contains chalcopyrite, molybdenite, pyrite, pyrrhotite and rare sphalerite and scheelite has been emplaced in the volcanic sequence over an area of some 1 to 2 km^2. The stockwork is best developed in the silicified contact zones of the dacite porphyry and contains the better molybdenum-copper mineralization where intrusive bodies of granodiorite are also present. Scheelite and molybdenite concentrations occur together. Further wall-rock silicification along with sericitization, carbonatization and the rarer metasomatic development of potash feldspar, biotite or chlorite, are hydrothermal alteration features associated with the stockwork emplacement. The stockwork was evidently emplaced after deformation and regional metamorphism, but the presence in some veins of intergrown coarse flakes of randomly oriented chlorite or biotite with iron-copper sulphides, suggests recrystallization perhaps under the influence of a later thermal event.

In the period 1970 to 1973 Australian Anglo-American Ltd carried out a limited diamond-drilling programme which encountered low-grade iron sulphide-chalcopyrite-molybdenite mineralization in silicified porphyry and micro-granodiorite. The best intersection was 75.6 m assaying 0.23 per cent copper and 0.13 per cent molybdenum. A more detailed investigation by Esso Exploration and Production Inc. commenced in 1974, and to date twenty-three vertical diamond drillholes, spaced on a 250 m triangular grid, have been bored. Evaluation by that company is continuing.

References: Newton-Smith (1974), Semple (1975), Marston (in prep.).

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FIGURE 2 - KEY

1. Rock of Ages
2. McMillan's occurrence
3. North Dandalup
4. Mahogany Creek
5. Mokine
6. Brookton
7. Jimperding
8. Chittering Valley
9. Greenbushes
10. Waddouring Rock
11. Blackboy Hill
12. Quairading
13. Mulgine Hill
14. Mount Molybdenite
15. Callie Soak
16. Davy's Reward
17. Harrison's Reward
18. Already and Keogh Wells
19. Mays Rock
20. Coleman's P.A.
21. Lake Seabrook
22. Lake Polaris
23. South Windarra
24. Coppins Gap

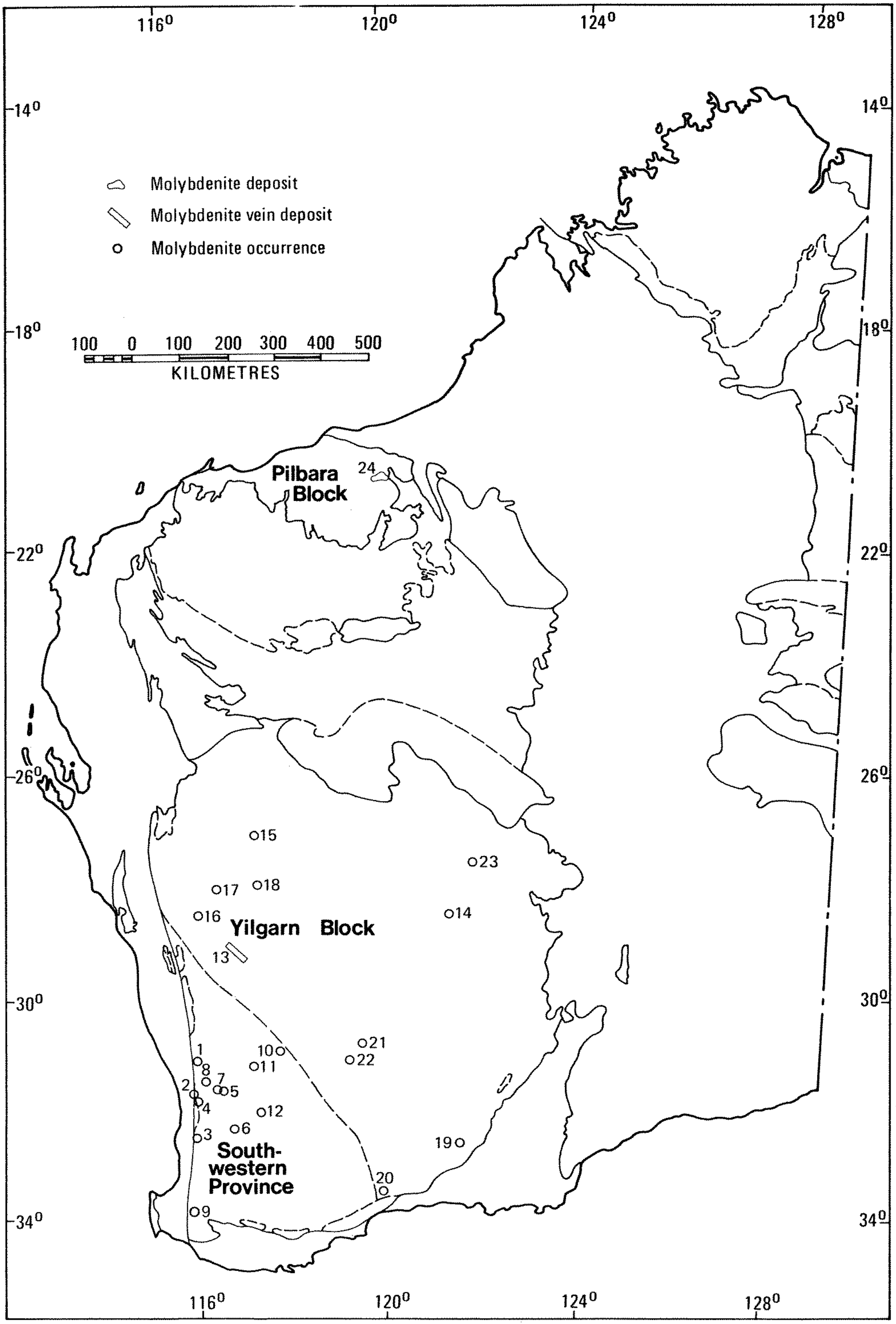

Figure 2. Metal occurrence map - molybdenum (GSWA 17393).

PART TWO

TUNGSTEN

PART TWO

TUNGSTEN

INTRODUCTION

The main production of tungsten ores in Western Australia has come from treatment of tailings dumps of old gold mines at Westonia and Davyhurst. Several mines have produced scheelite or wolframite as their principal mineral, but none of these has been on particularly large deposits. In 1971 a moderately large ore deposit containing scheelite was discovered on the northern flank of Mulgine Hill. This deposit has not been mined, but the prospecting company is attempting to raise capital for its opening.

The data presented in this bulletin are for those deposits which have been assessed or mined specifically for tungsten ores, or those in which tungsten ores have been recovered as an important by-product of other minerals such as gold. Gold mines from which scheelite has been obtained by treatment of the tailings are not described in detail in this bulletin.

Figure 3 shows the localities of the tungsten deposits described in the text.

SOURCES OF INFORMATION

Information presented in this bulletin has been obtained from earlier reports of the Geological Survey of Western Australia; files and records of the Department of Mines; Minerals of Western Australia (Simpson, 1952); and reports submitted to the Department of Mines by various mining companies.

Use was made of previous reviews of tungsten mineralization prepared by Maitland (1919) and Miles (1944). Some deposits were inspected by the writer during 1973-1974.

HISTORY OF TUNGSTEN EXPLORATION AND PRODUCTION

Tungsten is an important metal in the production of coating steels and ammunition, and this is reflected in the two early periods of exploration for scheelite and wolframite deposits in Western Australia. Most of the tungsten-bearing areas in the Yilgarn Block were discovered during World War I, the deposits at Callie Soak and Higginsville being the first to produce ore. During World War II known deposits were examined, and a little mining was carried out. The Korean war stimulated the discovery of deposits in the Pilbara Block, and again during this period, 1952 to 1953, a small amount of tungsten ore was produced in this state.

TUNGSTEN MINERALS

Scheelite and wolframite are the main tungsten ores in Western Australia. Ferritungstite forms as an alteration product of both minerals at the surface.

Scheelite ($CaWO_4$)

Scheelite is a colourless to white, yellowish-white, or buff mineral with a white streak. It has a vitreous to adamantine lustre and an uneven to subconchoidal fracture. The specific gravity of the mineral is 6.1, and its hardness is between 4.5 and 5. Scheelite forms an isomorphous series with the mineral powellite ($CaMoO_4$). Any molybdenum in scheelite incurs penalties on sale of the mineral as a tungsten ore.

Wolframite {(FeMn)WO_4}

Wolframite is the general name for an isomorphous series between ferberite ($FeWO_4$) and hubnerite ($MnWO_4$). The mineral has a submetallic to metallic lustre, and is generally dark greyish to brownish black. The streak of wolframite is reddish-brown to brownish-black, and its cleavage is perfect in one direction, tending to produce tabular crystals in ores. The specific gravity is between 7.2 and 7.5, and the hardness 4 to 4.5.

Ferritungstite {$Fe_2(WO_4)(OH)_4$}

Ferritungstite is an earthy, yellowish to brown mineral formed by the alteration and hydration of scheelite or wolframite. It rarely occurs without the parent mineral.

USES OF TUNGSTEN

The most important uses of tungsten are in ferrotungsten alloys, and as cast or cemented carbides. The metal is also used in various chemical compounds, nonferrous alloys, and ceramics. Tungsten carbide and tungsten alloy steels are used in many machine tools which require cutting edges. Tungsten high-speed steels and die-steels retain hardness even at elevated temperatures. They are, therefore, suitable forhigh speed drilling, cutting, and milling, and for shaping metal by hot-forming methods. Tungsten-copper alloys are used in the manufacture of electrochemical machine tools. Alloys of cobalt, chromium, and tungsten are used for cutting and shaping other metals and alloys. Tungsten metal and alloys with copper or silver are used in electrical contact points, automobile distributor-points, and in high electrical conductivity wire for telephones, electric clocks, business machines, and remote-control devices. Tungsten wire is used to form cathodes for electron tubes and light bulbs. Tungsten rod is used to heat cathodes in transmitter tubes, and for inert arc welding of iron, steel, aluminium, copper, and nickel alloys. Chemicals derived from tungsten are used in textile dyes, ink, paints, enamels, and glass. The bright yellow tungsten trioxide is used in oil and water colours. Some tungsten compounds are used in luminescent pigments, X-ray screens, television picture tubes, and fluorescent lights.

Solid lubricants, lasers, and catalysts are also prepared from tungsten compounds. Armour-piercing projectiles, heating elements, flake sprays, and tungsten crucibles for reclaiming nuclear fuel are the main military applications for the metal.

Although no other metal completely substitutes for tungsten, minor quantities of tantalum, titanium, and chromium carbide, industrial diamonds, and aluminium oxide ceramics have been used as partial replacements. Molybdenum can be substituted for tungsten in tool steels, but the molybdenum steels have a lower melting point and do not retain hardness at higher temperatures. There is no adequate substitute for tungsten in electric-lamp filaments, but fluorescent lighting has reduced consumption of the metal for this purpose.

GEOLOGICAL SETTING OF TUNGSTEN DEPOSITS

In Western Australia tungsten ores have been found in greisen zones at the margins of granitic plutons; associated with quartz-rich pegmatites and granitic differentiates; and in shears in mafic to ultramafic rocks. In general, the tungsten ores are concentrated in the proximity of acid igneous plutons. All deposits in Western Australia are of Precambrian age. Generally, insufficient data is available to determine the detailed genesis of the Western Australian deposits, and the reader is referred to reviews of the Canadian (Little, 1959) and Swedish (Hubner, 1971) deposits for discussions of the types of tungsten mineralization found in similar Precambrian terrains.

Scheelite mineralization is a common associate of gold where the mines are located near the margins of granitic batholiths. The mineral is usually concentrated in the core of gold-bearing veins, or as discrete blebs up to 2 m away from the vein in the enclosing country rock. In these deposits scheelite is often accompanied by molybdenite, pyrite, and minor wolframite. Scheelite also occurs as discrete blebs in shears, apparently not connected with intrusive dykes or veins. In this type of deposit large scheelite concentrations can be erratically distributed along the shear. These deposits occur mainly in the vicinity of felsic plutons, and are probably derived from fluids emanating from the plutons.

Scheelite mineralization in metasomatic rocks at the contacts of granitic plutons is reported from the vicinity of Mulgine Hill and from the Gascoyne Province. In 1971 late stage scheelite mineralization in a greisenous margin of a leucocratic granite stock was located at Mulgine Hill. Fluorite, pyrite, and molybdenite are also present. The ore is concentrated at the boundary between a phlogopite-tremolite rock and a quartz-microcline-muscovite rock in a structural depression on the flank of the granite stock. Scheelite has been discovered in skarns (tactites) at the contact between granite and dolomite marble in the Gascoyne Province. The deposits are concentrated near the granite contacts on the flanks of structural domes. No large deposits have been reported from these occurrences.

Wolframite deposits occur in or immediately adjacent to quartz-rich pegmatites. The larger deposits occur where the pegmatites intrude schlieren and biotite-rich phases of granitic batholiths. Wolframite concentrates at the margins of the pegmatites where it is commonly associated with magnetite, pyrite, chalcopyrite, and molybdenite. The cores of such pegmatites commonly contain scheelite. Most occurrences are at the margins of large granite-adamellite batholiths.

Taylors Wolfram Reward in the Halls Creek Province is the only mined deposit in Western Australia in which tungsten and tin minerals are associated. In this deposit a zoned quartz vein containing scorodite, cassiterite, and wolframite has intruded a sequence of schists some distance away from a granitic pluton.

GEOCHEMISTRY OF TUNGSTEN

Tungsten is a lithophile element in terrestrial environments, and although detailed figures are not available it appears to have a clarke of between 0.5 and 2×10^{-4} per cent (probably in the vicinity of 1.5×10^{-3} per cent). The geochemistry of tungsten is reviewed by Krauskopf (1970) and Barabanov (1971). Tungsten is largely excluded from the lattices of rock-forming minerals, but may be present in trace amounts. Of the twenty or so known tungsten minerals only scheelite and the wolframite group (ferberite, wolframite, and hubnerite) are important, but stolzite, ferritungstite, and tungstite may appear as minor constituents in oxidized zones.

Tungsten occurs in trace quantities in mafic (0.5 to 1 ppm) and ultramafic (0.1 to 0.8 ppm) rocks, but is more abundant in felsic (1.3 to 2.4 ppm) igneous rocks. It is concentrated in late stage residual fluids, and deposition is usually restricted to pegmatites and quartz veins. Tungsten ores commonly form at high temperatures. Scheelite is usually precipitated by reaction of the ore fluids with calcic plagioclase, whereas wolframite is more commonly deposited where tungsten-bearing veins are in contact with melanocratic rocks containing Fe^{++} and Mn^{++}. The solubility of tungsten in ore solutions is dependent on pH, and precipitation appears to require the presence of Fe^{++}, Mn^{++}, or Ca^{++}.

Tungsten minerals are relatively stable during weathering, although in acid conditions both scheelite and wolframite will break down to form ferritungstite or tungstite. Secondary dispersion of tungsten occurs locally around ore deposits, but is not as strong as molybdenum. Supergene enrichment of tungsten is usually absent, but may occur locally. Placers of tungsten minerals are rare, although tungsten minerals are commonly preserved in eluvial deposits overlying a mineralized zone.

PROSPECTING RECOMMENDATIONS

The greisen type of tungsten deposits known at Mulgine Hill may occur in other localities where high level granitic stocks intrude metasedimentary and mafic successions. Prospective areas for this type of mineralization are the general vicinity of Mulgine Hill where further granitic stocks may be located in the subsurface, and on the northeastern margin of the Mosquito Creek Formation where several small stocks intrude metasedimentary rock. Skarn (tactite) deposits are known along the northern margin of the Gascoyne Province. Detailed photo-interpretation and structural mapping may reveal favourable zones for mineralization within metamorphosed dolomites of the Ashburton Formation.

Small deposits of tungsten mineralization are likely to be worked in the Melville, Higginsville, Comet Vale, and Callie Soak areas, but are unlikely to be of sufficient size to warrant large scale development. Martins Lode at Callie Soak is small, and may be developed for small scale mining. It is possible that similar types of deposit may be discovered elsewhere on the margins of the Poona-Dalgaranga batholith.

THE DEPOSITS

MURCHISON AND EASTERN GOLDFIELDS PROVINCES

Wolframite and scheelite have been recorded from many localities in the Murchison and Eastern Goldfields Provinces. Wolframite commonly occurs as a component of pegmatite at the margins of large granitic batholiths, whereas scheelite is more commonly associated with quartz veins and greisens within greenstone belts. The most important deposits in terms of production are gold mines at Westonia and Davyhurst, and scheelite mines at Comet Vale, but the Mulgine Hill deposits contain the largest reserves known at this time. Production from the Murchison and Eastern Goldfields Provinces is summarized in Table 5.

MULGINE HILL
(Lat.29°11'S, long.116°59'E)

The Mulgine Hill tungsten deposit is situated northwest of Mulgine Hill Trig (BA 8). It is accessible by a track branching from the gravelled Paynes Find-Rothsay road, about 15 km northeast of Rothsay. A light aircraft landing ground was established near the deposit, but its condition may deteriorate if not maintained. Minefields Exploration N.L. have established an exploration camp about 2 km west of the deposit.

History of exploration

Molybdenite has been known to occur at Mulgine Hill since 1914, and several exploration programmes have been directed towards assessment of molybdenum reserves. Most of this exploration treated the Mulgine Granite as the target host rock. In 1971, following drilling by Newmont Pty Ltd and Minefields Exploration N.L. on Schummans prospect, 1 km north of Mulgine Hill

TABLE 5. Production of scheelite and wolframite from the Murchison and Eastern Goldfields Provinces

MINING CENTRE Deposit name	Mine name tenement	Lessee	Years of production	Main mineral	Ore treated (t)	Concentrates therefrom (kg)	Metallic content WO_3 (kg)	Estimated value ($Aust.)
CALLIE SOAK								
Bald Hill	P.A.953*	E.Genge	1910	wolframite	20.3	-	863	170.00
	Socialist M.L.11	H.Paton & J.Hayes	1911	wolframite	197.1	-	6 200	1 754.00
	Sundry Claims		1913, 1916	wolframite	25.0	-	1 471	372.00
	Total				242.4	-	8 534	2 296.00
Martins Lode	M.C.25	F.A.Moss	1944	scheelite(?)	-	163.5	108.9	118.00
	M.C.38	Western Minerals Syndicate	1951, 1953	wolframite	-	9 256	5 367.2	26 130.60
	Total				-	9 419.5	5 476.1	26 248.60
New Lode	M.C.49	G.Poletti,R.Poletti & W.Gregory	1953	wolframite	203	436.2	151.4	626.0
TOTAL					-	-	14 161.5	29 170.60
YANDHANOO HILL								
Yandhanoo King	M.L.36	N.Lewis	1915	wolframite	10.41	250	121.90	54.00
	P.A.2325	N.B.Hassell	1942, 1943	wolframite	-	477	162.36	176.00
	P.A.2491	J.Trait & L.Pavey	1953	wolframite	9.14	164	94.17	440.00
	P.A.2470	Carter,King & Parry	1952, 1953	wolframite	-	703	414.72	2 081.90
	Total				-	1 598	793.15	2 751.90
Wolfram Queen	P.A.2485	J.R.Hards & A.Bowman	1952	wolframite	-	172	57.13	292.00
TOTAL					-	1 770	850.28	3 043.90
MELVILLE								
Santa Claus	P.A.2315	J.L.Neville	1943	scheelite	391.18	2 777.8	1 805.30	1 940.00
	P.A.2338	J.L.Neville	1943	scheelite	22.35	253.7	150.18	160.00
TOTAL					413.53	3 031.5	1 955.48	2 100.00

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TABLE 5 - continued

COMET VALE								
Lake View	Sundry Claims	-	1919	scheelite	26.9	741.56	480.77	248.00
	Lake View G.M.L. 5410[z]	H.Stacey, P.Maher & M.F.Maher	1919, 1920	scheelite	386.9	5 287.87	3 433.71	1 636.00
	King of the Hills G.M.L.5590[z]	F.G.Winter	1939	scheelite	10.2	145.4	92.04	56.70
	King of the Hills M.L.23[z]	Goldfields Australian Development Co. Ltd	1942, 1943	scheelite	149.4	377.8	173.05	119.52
	King of the Hills G.M.L.5757[z]	D.J.Evans & A.F. White	1953	scheelite	136.8	1 327.7	704.87	3 142.90
TOTAL					710.2	7 880.33	4 884.44	5 203.12
HIGGINSVILLE								
Milesis Scheelite	Milesis Scheelite G.M.L.5600	Norseman Gold Mines Ltd	1940	scheelite	813.7	9 964.6	6 363.81	3 920.00
	Milesis Scheelite P.A.5443	B.J.Milesi	1941	scheelite	-	529.6	346.5	202.70
	Milesis Scheelite G.M.L.5668	M.J.Mahoney	1942, 1944	scheelite	714.3	4 464.8	2 892.97	3 136.00
	Total				-	14 959.0	9 603.28	7 258.70
Sons of Erin	Sons of Erin G.M.L.4184	Forward Downs Ltd	1916	scheelite	101.6	2 790.5	2 148.67	752.00
War Time and Lucky Shot	War Time G.M.L.5666 and Lucky Shot G.M.L. 5714	M.Urlich "	1947, 1949	scheelite	-	1 393.4	924.92	1 038.60
Sundry Claims	-	-	1919, 1920	scheelite	87.1	924.6	599.50	310.00
TOTAL					-	20 067.5	13 276.37	9 359.30
NORSEMAN								
Hill End	Hill End G.M.L. 1215	J.Richards	1916	scheelite	6.1	660.4	363.22	-
Sundry Claims	P.A.1933	S.G.Baker	1943	scheelite	0.71	24.1	17.05	18.50
	-	-	1920	scheelite	0.42	61.6	40.38	20.0
TOTAL					7.23	746.1	420.65	-

TABLE 5 - continued

MINING CENTRE Deposit name	Mine name tenement	Lessee	Years of production	Main mineral	Ore treated (t)	Concentrates therefrom (kg)	Metallic content WO_3 (kg)	Estimated value ($Aust.)
ORA BANDA								
Ferris and Kearns	(Reported as Sundry Claims)	Ferris & Kearns	1920	scheelite	3.4	-	675.7	-
Argus's	P.A.4187W	R.Argus	1942	wolframite	0.28	278	162.5	-
TOTAL					3.68	-	838.2	-
KATHLEEN VALLEY								
Moriarty's	Moriarty's M.C.4	T.K.Moriarty	1952	scheelite	15.2	63.9	23.87	103.60
OGILVIES	P.A.2570[T]	J.Hutchinson	1951 - 1953	scheelite	26.6	1 683.8	1 195.68	5 559.00
	M.L.24[T]	Esperance Oil Syndicate	1955	scheelite	-	843.0	621.52	1 164.00
TOTAL					-	2 526.8	1 817.20	6 723.00
HOPES HILL		W.J.Grace & G.J.White	1953	scheelite	12.7	45.7	25.17	76.50
WATKINS	M.C.46	Watkins & Son	1952, 1953	wolframite	-	375.4	238.35	836.89

*This production may have been from Martins Lode.

Trig (BA 8), 120 Mt of inferred ore consisting of 0.047 per cent scheelite, 0.033 per cent MoS_2, and 0.033 per cent Cu was reported. This discovery was the first indication of disseminated mineralization in the vicinity of Mulgine Hill. Further prospecting revealed patchy mineralization 2.5 km northwest of the trig, at the Trenches, which is inferred to contain 83 Mt of ore calculated to a cut-off grade of 0.06 per cent Mo plus W, at an average 0.15 per cent WO_3 and 0.062 per cent MoS_2, from 13 drillholes (Sainsbury, G.M., pers. comm., 1978). Following this work attention was shifted to the northern flank of Mulgine Hill, and here, after drilling 140 diamond drillholes, Minefields Exploration N.L. have estimated the ore reserves reported in Table 6. This deposit is known as the Hill.

TABLE 6. Mulgine Hill tungsten ore reserves (the Hill deposit)*

Ore category	Cut-off % WO_3	Reserves (t)	Average grade % WO_3	90% confidence levels
Proved	0.25	1 095 000	0.709	$\pm$0.11% WO_3
	0.50	352 000	1.183	$\pm$0.20% "
	0.75	125 000	1.557	$\pm$0.25% "
Probable	0.25	529 000	0.525	$\pm$0.17% "
	0.50	129 000	0.843	$\pm$0.33% "
	0.75	26 000	1.152	$\pm$0.43% " (Extrapolated)
Total	0.25	1 624 000	0.649	$\pm$0.13% "
	0.50	481 000	1.092	$\pm$0.23% "
	0.75	151 000	1.488	$\pm$0.28% "

* Calculated by G.M. Sainsbury of Minefields Exploration N.L. and published with permission of the company.

Geology

The Mulgine Granite, a small stock of leucocratic muscovite granite which forms Mulgine Hill, intrudes a succession of chlorite schist, chlorite-actinolite schist, metamorphosed banded iron-formation, metasedimentary rocks, and minor ultramafic rocks. The succession is equated to the lowermost mafic association of Muhling and Low (1973). Quartz veins, sometimes containing molybdenite and fluorite, and dolerite dykes cut the granite and surrounding country rocks. The Mulgine Granite commonly has a sheath of greisen at its margin. North of the granite stock a related series of associated granitic dykes and quartz veins has intruded the country rock. Collins (1975) has described the geology in some detail.

Scheelite, molybdenite, fluorite, and chalcopyrite mineralization has been located in the greisen sheath north of Mulgine Hill (the Hill prospect) and in quartz veinlets associated with the granitic dykes north of Mulgine Hill (the Trenches and Schummans prospects).

The Hill: The Hill prospect is approximately 800 m northwest of Mulgine Hill Trig. More than 140 diamond drillholes and numerous costeans have been completed by Minefields Exploration N.L. during testing of the ore deposit.

The succession present in the prospect consists of an upper and lower felsic unit separated by an ultramafic-mafic unit. This suite is located in the core of an east-west trending canoe-shaped synform. The synform is superimposed on the north-dipping flank of the dome surrounding the Mulgine Granite. Layer parallel schistosity with numerous anastomosing veinlets are common throughout the structure. There is, however, a concentration of quartz veinlets in the core of the synform. Scheelite is deposited at the selvage of the quartz veinlets and as clots in the country rock between veins.

The lower felsic unit is a quartz-microcline-muscovite rock which contains minor plagioclase. The lower contact tends to be transitional with granitoid rocks of the Mulgine Granite. Quartz venation from hydrothermal alteration has introduced varying amounts of pyrite, scheelite, fluorite, and molybdenite into the rock. The introduced minerals are deposited as selvages and in the core of the quartz veinlets. The unit is thought to be a greisen sheet from the granite, but may have been originally a sedimentary rock.

The ultramafic-mafic unit is composed of a phlogopite-tremolite layer at the base, overlain by tremolite-chlorite-talc rocks. The phlogopite-tremolite rocks contain minor, but variable, amounts of quartz, carbonate, epidote, sphene, apatite, fluorite, pyrite, molybdenite, and scheelite. The phlogopite may be partly kaolinized muscovite. The tremolite-chlorite-talc rocks contain inherent accessory sphene and magnetite and introduced carbonate, molybdenite, epidote, muscovite, and chlorite. Both contacts of the ultramafic-mafic unit are fairly sharp. The upper contact is riddled with a fine net of quartz veinlets in which scheelite is concentrated. The unit is considered to be a lens of ultrmafic or mafic rock which has been subjected to hydrothermal metamorphism and potassium-metasomatism.

The upper felsic unit is a quartz-microcline-muscovite rock which contains minor andalusite, staurolite(?), pyrite, fluorite, scheelite, molybdenite, zircon, apatite, epidote, and sericitized plagioclase. Quartz veinlets occur throughout the unit, but are concentrated in the basal 10 m where there is a scheelite enrichment. The unit is considered to be a hydrothermally altered felsic igneous rock or aluminous sediment, but it may be a greisen sheet.

The principal scheelite ore zone in the prospect is at the contact between the upper felsic unit and the ultramafic-mafic unit. There is, however, locally rich zones in all three units.

Other mineralized zones: Schummans prospect is a large disseminated mineralized zone in a sequence of metabasalts and metasedimentary rocks. The sequence is intruded by even-grained granitic dykes. Scheelite, molybdenite, and chalcopyrite deposition is related to a network of quartz veinlets, apparently emanating from the granitic dykes. Scheelite generally occurs in the country rock up to 50 cm away from the veins, and molybdenite is contained within the veins along their margins.

The Trenches prospect occurs in a sequence of metabasalt and metasedimentary rocks which is intruded by numerous quartz veins. The molybdenite and scheelite are erratically distributed throughout the host rocks, and no controls to mineralization have been determined.

Other minor tungsten geochemical anomalies and scheelite occurrences have been reported up to 3 km north and west of Mulgine Hill, but none extend over a sufficiently wide area to warrant testing.

References: McKenna and Partners (1974), Sainsbury (1974), Collins (1975).

CALLIE SOAK
(Lat.27°17'S, long.117°30'E)

The Callie Soak deposits are about 11 km northwest of the abandoned Big Bell mining centre. They can be reached by road from Coodardy homestead on the Coodardy-Noondie road by turning south 6.6 km east of 12-Mile well, then proceeding 1.8 km along a mill run track to an old track to the west. At 0.2 km along this track a northerly fork leads to Martins Lode (2.6 km), Quartz Blow Lode (3.1 km), and New Lode (3.6 km). The southwesterly fork leads to the Bald Hill deposit by travelling 3.4 km, then 0.8 km along a westerly track to a prominent granite hill, which is 0.2 km to the north; the deposit is about 350 m north of the edge of the hill on the eastern edge of a sparsely vegetated patch.

History of exploration and mining

The Callie Soak deposits were first pegged by G.H. Munro in 1908 as M.L.6 and P.A.953 which were in the vicinity of Martins Lode. In 1910 0.863 t of WO_3 were obtained by E. Genge from 20.3 t of concentrate. In 1910 H. Paton and J.W. Hayes pegged the Bald Hill deposit as M.L.11, and in 1911 produced 197.1 t of concentrate containing 6.20 t of WO_3. During 1913 and 1916 further production from sundry claims in the area produced 25 t of concentrate containing 1.47 t of WO_3. The deposits lay idle until 1942 when Martins Lode was pegged by F.A. Moss; however, following geological investigations and the production of 164 kg of concentrates, the deposit was abandoned. In 1949 Anglo Westralian Mining Pty Ltd cut three channel samples across Martins Lode. In 1951 F. Forman and E. Scahill repegged the deposit as M.C.38 and produced 9.26 t of concentrate containing 5.37 t of WO_3. In 1953 G. Poletti, R. Poletti, and W. Gregory mined 203.2 t of ore for 0.437 t of concentrates containing 0.151 t of WO_3 from the New Lode. In 1969 Geotechnics (Aust.) Pty Ltd drilled eight percussion bores on the deposit for Greenstone Investments Pty Ltd and Carr Boyd Minerals Ltd. Samin Ltd acquired the claims in November 1969, and appraised the ore reserves by diamond drilling. They have reported indicated reserves of 185 900 t of ore to a depth of 40 m containing 0.33 per cent WO_3.

Geology

The Callie Soak deposits occur near the top of a porphyritic granite dome (Muhling, 1969) which contains local variations including even-grained granite, biotite granite, aplite, pegmatite, and granitic differentiates. The foliation in the granitic rocks trends in an east-northeast direction (050° to 080°) with dips of 40° to 87° south. A set of prominent fractures parallel to 075° contain lenses of granite differentiates including hornblende rock, quartz-hornblende-tourmaline rock, quartz-epidote rock, quartz-biotite rock, quartz-magnetite rock, and epidotized porphyritic granite. Late stage quartz-rich pegmatites intrude these differentiates and appear to have introduced tungsten mineralization. Martins Lode and New Lode are within a quartz-magnetite host rock intruded by numerous small quartz veins parallel to quartz-rich pegmatite; the Bald Hill lode is a quartz-rich pegmatite, intruding quartz-epidote and biotite granite. Wolframite is the most common mineral, although local concentrations of scheelite are known.

Martins Lode (M.L.6(?), M.C.25, M.C.38): The largest mass of quartz-magnetite-biotite rock, thought to be a granite differentiate, is referred to as Martins Lode. It contains the most significant reserves of wolframite in the Callie Soak area. The lens is about 85 m long, 36 m wide in the centre, and 40 m deep. Porphyritic granite is exposed both to the north and south of the lens. Martins Lode, which has been drilled by Samin Ltd and Geotechnics (Aust.) Pty Ltd, contains indicated reserves of 185 900 t of ore containing 0.33 per cent WO_3 to a depth of 40 m.

The quartz-magnetite-biotite host rock has a general trend of 045° and dips vertically. Quartz veinlets intrude the deposit parallel to 045° and 135°. The wolframite accompanies these veins, forming veinlets and blebs at their margins. Chalcopyrite and molybdenite are commonly associated with the wolframite.

Bald Hill (M.L.11, M.C.39, M.C.24): The Bald Hill lode was originally known as the "Socialist". It is in a quartz-rich pegmatite intruding a biotite-rich granite near the crest of a large granitic hill. The deposit was mined from a shaft 5 m deep. Most of the production from Callie Soak prior to 1950 came from this deposit.

Wolframite and scheelite occur in a flat south-dipping (5° to 15°) quartz-rich pegmatite in which the ore plunges at about 20° along 205°.

Wolframite tends to be at the margin of the pegmatite. Assays of the ore range from 0.22 to 0.75 per cent WO_3.

New Lode: About 1 km west of Martins Lode, a similar quartz-magnetite-biotite rock has been mined for wolframite. This deposit has been known as New Lode or Other Lode. The host has a general strike of 040° dipping northwest at 70° to 85°. It is intruded by a quartz pegmatite vein which strikes 060° and dips 40° to 60° north. One parcel of ore mined from this deposit yielded 151 kg of WO_3 at an average grade of 0.074 per cent WO_3.

Other mineralized zones: A small deposit known as the "Molybdenite Show" about 100 m west of New Lode contains a small amount of wolframite and molybdenite. The ore-bearing vein strikes 015° and is nearly vertical. Wolframite lies within the vein, and molybdenite occurs at the margin.

Wolframite, scheelite, and molybdenite have been reported about 500 m west of Martins Lode on the northern side of the large quartz blow. This deposit is known as the Quartz Blow Lode. Wolframite and molybdenite occur in bunches at the margins of the vein, which has a general trend of 130° and dips 87° southeast. It intrudes the foliated porphyritic granite.

References: Woodward (1914), Robertson (1915), Maitland (1919), Mann and Moss (1942), Matheson (1944), Forman (1951a, 1951b), Muhling (1969), Ward (1969), Roberts (1971), Wright (1972), de la Hunty (1973).

YANDHANOO HILL

Two tungsten deposits have been worked at Yandhanoo Hill, northeast of the abandoned Bonnie Venture mining centre. The Yandhanoo King deposit was first pegged in 1914 by N. Lewis, and was followed shortly by the discovery of the Wolfram Queen deposit.

Yandhanoo Hill comprises a sequence of banded iron-formation, quartzite, and volcanogenic felsic sediments, isoclinally folded into a south-plunging syncline. The succession is intruded by quartz veins and silicic pegmatites which are both parallel to the bedding and cross cutting.

The Yandhanoo King deposit was originally pegged as M.L.36, then M.L.31, and finally P.A.2491 in the Yalgoo Goldfield. The deposit is accessible on old tracks from Yandhanoo well which is about 4 km south of Mount Singleton and 4.5 km east of the Great Northern Highway. The track follows a fence west for about 1 km, then, passing through a gate, it winds through thick scrub for about 3 km to a turnoff to the east. The main workings are to the north about 0.2 km along this track.

The Wolfram Queen deposit was originally pegged as M.L.44, and later as P.A.2485 in the Yalgoo Goldfield. It is located about 0.7 km northeast of the Yandhanoo King deposit. The track passing Yandhanoo King has a northerly turnoff, about 1.4 km along which the main workings are reached near the top of a hill.

Yandhanoo King

(Lat.29°31'39"S, long.117°13'36"E)

The deposit has been known as the Yandhanoo King North, Wolfram King South, Oversight, Wolfram King, Monarch, and Carters.

Workings on the lease consist of two adits, driven into a south-facing hill slope. They are 9.2 m apart vertically, the upper adit being 27.7 m long and the lower one 40 m long. A winze connects the adits and extends 9.2 m below the lower adit. From the upper adit a quartz-wolframite vein, 0.3 m wide, has been stoped for 1.8 m above the back over a length of 12.3 m. Most stoping has been carried out from the lower adit. South of the adits, on the opposite side of the valley a line of trenches and pits has been sunk on quartz stringers.

Geology: The deposits are contained in discontinuous quartz-rich pegmatite stringers intruding a sequence of quartzite, sandstone, conglomerate, and felsic tuff. At the adit there are four veins, between 5 and 11 cm wide, with wolframite and mica concentrated at their margins. The enclosing country rock is kaolinized. Most of the early production came from the upper adit. The bedding in the country rock strikes 180° and dips steeply west. The veins have a strike of 040° to 050° and dip easterly at 50°. The adit produced 10.41 t of ore containing 0.25 t of concentrate with 0.12 t of WO_3, earning $54 in 1915. As far as can be ascertained no further ore was won from this deposit. The reserves are low; the lower adit has no vein for 27.7 m of its length and the face in the upper adit exposes a vein only 4 cm wide. A grab sample of the ore yielded 0.039 per cent WO_3.

The trenches and pits south of the adit are sited on a series of quartz-rich pegmatites in a fresh quartzite host. The veins strike 070^o and dip southerly between 30^o and 60^o. Wolframite and muscovite are intergrown at the vein margin. The veins are discontinuous, the maximum length being 9.2 m. In 1953, 9.14 t of ore from these deposits was mined yielding 0.16 t of concentrate, containing 94.2 kg of WO_3. An analysis of this ore is presented in Table 7.

It is possible that a further small quantity of ore could be won from this deposit by gouging, but it is unlikely to support a mine of any significant size.

TABLE 7. Analysis of wolframite ore from Yandhanoo King

Oxide	Per cent
FeO	21.29
MnO	2.51
MgO	nil
WO_3	76.30
(Ta_2O_3 NbO_5)	0.62
As_2O_5	nil
H_2O^+	trace

S.G. 7.37, $FeWO_4$:$MnWO_4$::89:11
Analyst: E.S. Simpson.

Wolfram Queen
(Lat.29^{o}31'19"S, long.117^{o}13'15"E)

The deposit has been worked from three parallel trenches on the crest of a hill. The central trench is 25 m long, 7.7 m deep, and 50 cm wide. It underlays south at 65^o. On either side of this trench are costeans 2 m deep and 1 m wide on small quartz reefs. On the western side of the hill an adit has been driven 36 m in an endeavour to intersect the reef at depth, but no ore was encountered.

Geology: The host rocks in the vicinity of the main workings are cherty banded iron-formation, polymictic conglomerate, and chlorite schist. They have a regional strike of 180° and dip from 30° to 40° west. The wolframite-bearing quartz veins strike 085° and dip south between 60° and 90°. The host rock is brecciated along the boundaries of the veins.

Wolframite, which occurs throughout the quartz veins, is associated with hematite. In some places hematite encloses wolframite crystals. The veins are lenticular, the main vein being 50 cm wide at the ends of the workings and up to 3 m wide in the centre. Vughs are common in the veins. In 1952 this deposit produced 172 kg of concentrates containing 57.2 kg of WO_3.

The lenticular shape of the ore and the failure of the adit to intersect mineralized veins suggest that reserves in this deposit are insignificant.

References: Woodward (1916, p.6-7), Wunzar (1917), Maitland (1919), Adams (1942), Dunlop (1951), Simpson (1951, p.278), Ellis (1953b).

MELVILLE

A mafic to ultramafic succession is intruded by porphyritic adamellite and an associated suite of scheelite-bearing pegmatites. Scheelite was mined from the Santa Claus deposit by three shafts.

Santa Claus

(Lat.28°09'11"S, long.116°44'19"E)

The Santa Claus deposit is about 4 km north-northwest of the abandoned Noongal townsite from where it can be reached by various rough tracks.

The workings consist of a shaft about 4 m deep, a glory hole 4 m deep and about 12 m in diameter, a trench 8 to 10 m long, two shafts about 2.5 m deep and several small pits. Most of the ore was obtained from the deep shaft and the adjacent glory hole. In 1943, 413.53 t of ore were mined from the deposit to yield 3.03 t of concentrates containing 1 955.48 kg of WO_3. The deposit has also been known as Nevilles Scheelite.

Geology: The host rock of the mineralization is a chlorite-talc-tremolite schist which has a regional strike of 150°, and dips west between 50° and 60°. About 100 m west of the deposit a biotite-rich porphyritic granite and a fine to medium-grained dolerite intrude the ultramafic schist parallel to the regional strike. Shears, parallel to 140° and generally dipping west, have affected all rocks in the vicinity of the deposit.

Scheelite is associated with clots up to 10 cm in diameter, in a chlorite-talc-tremolite schist. There are no quartz veins in the ore zones. The distribution of scheelite in the deposit is irregular and may occur within the shears or in the surrounding country rock. Veins of adamellite intrude the ultramafic at depth, but are only exposed in drillholes.

Placer Prospecting (Australia) Pty Ltd drilled eight percussion drillholes along the deposit in both the ultramafic host and the nearby adamellite, but were unable to locate the deposit at depth. The highest assay for W in the ultramafic was 300 ppm and in the adamellite 170 ppm. The reserves in the deposit are low, although small parcels of ore may be won in the vicinity of the old workings.

References: Forman (1944), Johnson (1950), Simpson (1951; 1952, p.532), Ellis (1953a), Mather (1973).

Minor occurrences

In the Melville area numerous pegmatites contain small amounts of beryl, lepidolite, muscovite, molybdenite, and scheelite. Although these pegmatites have received some attention from prospectors, and in one locality have been drilled, no economic tungsten deposits have been located in them.

Noongal (Lat.28°10'33", long.116°43'50"E): Placer Prospecting (Australia) Pty Ltd drilled 5 holes in a zone of granitic rocks intruding mafic schist. They located irregularly disseminated tungsten minerals in the granite. One drillhole intersection assayed 0.17 per cent W over 9 m.

Reference: Mather (1973).

COMET VALE

The Comet Vale mining centre has been one of the state's major scheelite producers. The deposits are associated with quartz veins intruding a suite of metabasalts. There is no evidence of pegmatite in the area, but an even-grained granite has intruded the northern end of the belt. Scheelite was first produced from the Lake View mine in 1919 as a by-product of gold, but in the later years of the mine's history only scheelite ore was mined. The Sand Prince West gold mine, about 2 km west of the Lake View, is reported to contain scheelite associated with gold below the water table, but there is no record of any production. Most of the scheelite ore produced at Comet Vale was concentrated at the Coolgardie State Battery.

Lake View
(Lat.29°56'46"S, long.121°08'12"E)

The Lake View lease, originally taken out by H. Stacey, P. Maher, and M.F. Maher in 1911 yielded gold almost continuously up to 1932. The first scheelite was produced in 1919 and further parcels of ore were treated in 1920, 1939, 1942, 1943, and 1953. The deposit was worked exclusively for scheelite in 1942, 1943, and 1953.

The Lake View deposit can be reached by rough tracks going easterly from the abandoned townsite of Comet Vale. It is by the shore of Lake Goongarrie about 2.3 km east of Comet Vale. There was formerly a battery at the mine site.

The main workings consist of two deep shafts and three adits along a quartz reef. About 20 m north of the main reef, a pit on a vein bearing 120° was worked during World War I.

Geology: Scheelite is deposited along a shear zone with a general trend of 080°, in an 18 m break in a large quartz reef which trends at about 100°. Access to the workings is from an inclined adit on the southern side of the ridge. Gold was won from the margins of the quartz reef by means of two adits on the eastern end of the ridge. Scheelite was deposited in discrete bunches within an actinolitic schist along the shear zone. Small amounts of azurite, malachite, and native copper were reported to be associated with the scheelite. An assay of the scheelite is given in Table 8.

TABLE 8. Analysis of scheelite from Comet Vale

Oxide	Per cent
WO_3	80.03
MoO_3	nil
CaO	19.56
Na_2O	nil
CuO	nil
PbO	nil
Cr_2O_3	nil
Fe_2O_3	0.11
SiO_2	0.18
H_2O^+	0.02
Al_2O_3	0.06
S.G.	6.09

Analyst: E.S. Simpson

Production of scheelite from this deposit is summarized in Table 5. Considerable difficulty was experienced in obtaining a saleable product, due to the inefficiency of concentrating equipment available at the time of production. However, it is unlikely that large reserves of scheelite remain in this deposit.

References: Jutson (1921, p.73), Miles (1944, p.81-82), Simpson (1952, p.535), G.S.W.A. Plan 1163.

HIGGINSVILLE

Erratic scheelite mineralization is commonly associated with gold in most mines in the Higginsville area. In general the mineral is associated with quartz veins intruding a suite of mafic to ultramafic rocks. All quartz veins exhibit pinch and swell features with the best concentrations of scheelite being located in the pinches. Production of scheelite has been erratic, ore being produced in 1916, 1919, 1920, 1940-1944, and 1947-1949. The majority of the deposits were mined for gold, with scheelite as a by-product, but some were mined exclusively for scheelite. The total production from the Higginsville mining centre is 20 067.5 kg of concentrates yielding 13 276.37 kg of WO_3. Most of this ore was obtained from Milesis Scheelite mine, with the remainder coming from the Sons of Erin gold mine, War Time, Lucky Shot, and sundry claims. A summary of the production is given in Table 5.

Milesis Scheelite
(Lat.31°44'55"S, long.121°42'52"E)

Milesis Scheelite mine was originally opened by Mr B.J. Milesi as a gold mine in the late 1930s. In 1939 Norseman Gold Mines Ltd acquired the lease, but abandoned it after a trial production run in 1940. The lease is located southeast of Higginsville Station and is still worked periodically by prospectors. There is a hut, power plant, and head frame at the mine.

The workings consist of three lines of shafts and open cuts. Most of the workings are about 10 m deep, and are abandoned. The operating shaft is approximately 30 m deep, with several drives following the lode for about 40 m to the north. There are several open stopes above the 40 m drive.

The deposit produced 14 959.0 kg of concentrates containing 9 603.28 kg of WO_3 between 1940 and 1944. At present there are several kilograms of broken ore in the mine. Simpson (1952) reports that in 1940, 72.6 tonnes of concentrates assaying 71 per cent WO_3 were mined, and that prior to this date 87.38 tonnes of concentrates have been produced.

Geology: The deposit consists of three quartz veins which intrude mafic to ultramafic rock, and trend generally northerly, but converge towards the northern end of the lease. The westerly reef contains the main scheelite ore, and gold was the main mineral mined in the eastern reef, although some scheelite has also been produced.

In the main lode scheelite occurs as large clots in the core of the quartz reef. In the deeper parts of the mine the reef has a bifurcation separated by about 50 cm of country rock. The operators report that discreet veins of scheelite occur in the wall rock adjacent to both quartz veins, and the best concentrations are on flexures in the veins. Gold in the veins is contained in iron-stained leaders which are best developed in pinches. An analysis of the scheelite ore is given in Table 9.

This deposit may produce scheelite as a prospector's mine, but is unlikely to contain sufficient reserves to support a large operation.

TABLE 9. Analysis of scheelite from Milesis Scheelite mine

Oxide or Metal	Per cent
WO_3	80.42
CaO_3	19.42
MnO	nil
Fe_2O_3	0.15
SiO_2	0.11
H_2O^+	0.02
H_2O^-	nil
MoO_3	tr.
Cr_2O_3	nil
Cu	nil
Pb	nil

Analyst: E.S. Simpson

References: Hughes (1938), Simpson (1952).

Sons of Erin
(Lat.31°44'57"S, long.121°42'57"E)

On the Sons of Erin Gold Mining Leases at Higginsville one vein was mined for its scheelite content. This was located on the south end of G.M.L. 15/4184, about 100 m northeast of Milesis Scheelite mine.

A shaft 9.1 m deep was sunk on the scheelite-bearing vein, but only a small amount of development was carried out from the shaft. The records indicate that 101.6 t of ore was mined containing 2 790.48 kg of scheelite concentrates, with 2 148.67 kg of WO_3. Mines Inspector J. Crabb reported in 1916 that a considerable parcel of ore was sent to England prior to that year, but no official record was kept of the WO_3 content.

Scheelite is contained in a quartz vein, which dips steeply south, intruding a mafic and ultramafic succession. It is concentrated in the core of the vein which is up to 38 cm wide.

References: Crabb (1916a), Simpson (1952, p.537).

ORA BANDA

Wolframite and scheelite have been mined from quartz veins which intrude the Archaean succession at Ora Banda. Information on the deposits is slightly confused as the positions of the two deposits are not known accurately.

Ferris and Kearns occurrence
(Lat.30°21'40"S, long.121°06'40"E)

The deposit is reported to be 2.4 km northeast of the Golden Mount gold mine at Ora Banda. This description differs slightly from that given by the original prospector, but the coordinates given above are preferred. Mining was restricted to a shallow hole on the deposit. Production from this occurrence appears to have been recorded as from sundry claims (Ora Banda), and amounts to 3.403 t of ore yielding 675.7 kg of WO_3.

Wolframite was mined from a quartz-rich pegmatite containing muscovite, where it is accompanied by bismite and scheelite. Ferritungstite occurs as an alteration product of wolframite at the surface. Simpson reports that a sample of picked ore assayed 9.5 per cent WO_3, and six grab samples contained an average of 0.32 per cent WO_3.

References: Wilson (1930), Simpson (1951, p.279).

Argus occurrence
(Lat.30°22'20"S, long.121°05'00"E)

Wolframite was mined from P.A.4187W by Mr R. Argus in 1942. Due to the poor description of the locality, the coordinates given above should only be taken as a guide. The deposit is said to be 6.5 km northeast of Ora Banda.

A series of shallow pits has been sunk on a quartz blow. None of the pits is more than 2 m deep. The deposits produced 284 kg of ore containing 278 kg of concentrates with 162.5 kg of WO_3, in 1942.

Wolframite is patchily distributed at the margins of the quartz vein. Associated with the quartz vein, but occurring in the wall rock, are minor quantities of scheelite, galena, and malachite. Assays of five samples of the ore gave 2.73, 5.06, 1.29, 2.84, and 4.21 per cent WO_3 respectively.

Reference: Wunzar (1942).

NORSEMAN

Scheelite mineralization associated with gold has been reported from mines in the Norseman gold mining centre. Production is recorded from Hill End and Old Oversight mines, but no large deposit is known. All of the deposits occur in quartz veins intruding the Archaean succession.

Hill End
(Lat.32°12'32"S, long.121°47"50"E)

The Hill End mine (G.M.L.1215) is located 2.41 km on a bearing of 124° from the Norseman Post Office. In 1916 Mr J. Richards produced 6.1 t of ore containing 660.4 kg of concentrates with 363.22 kg of WO_3 from the deposit.

The scheelite occurs in a quartz vein with a mean strike of 135° and a vertical dip. The vein has been traced over 45 m at the surface, and is 0.3 m wide in the 12-metre deep shaft.

References: Campbell (1906), Crabb (1916b), Maitland (1919).

Old Oversight
(Lat.32°13'45"S, long.121°47'50"E)

The Old Oversight mine is 3.2 km south of Norseman. It was originally pegged as G.M.L.914, but was later included in G.M.L.1390 in the Dundas Goldfield.

In 1918, 20 t of scheelite ore of unrecorded grade was treated at a private battery owned by Rawlings and Rumble in Norseman.

The scheelite ore won from this mine was restricted to a quartz vein, 25.4 cm wide, intersected in the shaft at a depth of 18 m. The scheelite ore was traced along the vein for a distance of 9 m in a drive. Scheelite was not recorded from any other part of the workings.

Reference: Crabb (1918).

MINOR OCCURRENCES

Moriarty's occurrence
(M.C.4) (Lat.27°29'S, long.120°31'E)

Moriarty's occurrence is in the bed of a creek about 4.8 km northwest of the Kathleen Valley Hotel. Scheelite ore was mined from the deposit in 1952. Mr T.K. Moriarty crushed 8.5 t of ore at Cue in 1952 for 38.5 kg of scheelite concentrates, and the Mines Department Statistics Branch record that in the same year Mr J. Jones obtained 15.2 t of ore from the deposit for a yield of 63.9 kg of concentrates, containing 23.87 kg of WO_3. It is not known whether these figures cover the same ore.

Scheelite occurs in a quartz-rich pegmatite associated with grossularite-pyrope, clinozoisite, and vesuvianite.

Ogilvies Find
(Lat.28°03'45"S, long.122°19'56"E)

The Ogilvies Find deposit is situated 72 km north of Laverton, about 800 m east of the abandoned Erlistoun townsite. The deposit was first mined by J. Hutchinson and E. Chase in 1951, and subsequent parcels were obtained in 1952, 1953, and 1955. It has yielded 2 526.8 kg of concentrates containing 1 817.20 kg of WO_3. The deposit has been held as P.A.2548T, P.A.2570T, and M.L.24T.

Scheelite is deposited in quartz veins intruding a metadolerite and metaperidotite sequence. The veins range in attitude from parallel to the country rock foliation to anastomozing.

References: Berliat (1953), Thomas and Meharry (1954a and b), Gower (1974).

Lake Seabrook
(Lat.30°53'39"S, long.119°35'37"E)

The Lake Seabrook prospect is approximately 12 km southeast of Koolyanobbing townsite. It can be reached on a track trending easterly off the main road, 7.5 km south of Koolyanobbing.

Scheelite-fluorite mineralization has been found by Barrier Exploration N.L. in chloritic schist and amphibolite near the contact with a granitic gneiss. These rocks are intruded by granite. The scheelite is carried in quartz-epidote skarn-like veins parallel to the foliation of the host rock. Very fine-grained fluorite is distributed erratically in the wall rocks of the veins. Testing of the prospect is continuing.

References: Morton (1975a and b).

Hopes Hill
(Lat.31°11'15"S, long.119°16'45"E)

The Hopes Hill occurrences is 0.4 km southwest of the abandoned Hopes Hill townsite. A parcel of 12.7 t of ore was obtained from the deposit by W.J. Grace and G.J. White in 1953. The parcel yielded 45.7 kg of concentrates containing 25.17 kg of WO_3.

The shaft from which the ore was raised was not found but the country rock in the vicinity of the claim is chlorite schist intruded by quartz veins and porphyry. Numerous shallow prospecting shafts, presumably for gold, have been sunk in the vicinity of the tenements.

Watkins occurrence
(M.C.46) (Lat.27°06'30"S, long.117°33'40"E)

Watkins occurrence is 5.9 km south of Sunday well, which is about 10 km east of Poona and 47 km northwest of Cue. In 1952-1953, 238.85 kg WO_3 were produced from 375.4 kg of concentrates mined from the deposit.

Wolframite occurs in a quartz vein intruding fine-grained, sheared actinolite-feldspar rock. The vein has a strike of 190° with a vertical dip. Wolframite is concentrated on the eastern wall of the vein.

Dallisons Reward
(G.M.L.115) (Lat.33°45'S, long.120°01'E)

Dallisons Reward is 18 km west-southwest of Kundip and is accessible by rough tracks from the northwest. In 1907 a parcel of ore yielded 943.4 kg of concentrates assaying 75 per cent WO_3. This lease has also produced 1.2 kg of gold.

The scheelite occurs in quartz veinlets at the base of a fine-grained quartzite. The quartzite is in contact with a quartz diorite.

References: Simpson and Gibson (1907), Thom and others (1977).

TUNGSTEN MINERALS ASSOCIATED WITH GOLD MINES

In the Murchison and Eastern Goldfields Provinces, scheelite is a common accessory mineral in gold deposits. Mines at Westonia and Davyhurst have produced large tonneages of scheelite, mostly during recycling of tailings. In a survey by King (1966) tailings from gold mines at Westonia (Edna May), Southern Cross (Frasers), Day Dawn (Great Fingal), Davyhurst (Golden Pole), and Kookynie were shown to contain between 0.2 and 0.5 per cent W. Those gold mines known to have produced scheelite, and those in which scheelite is known as a common accessory mineral are summarized in Table 10.

PILBARA BLOCK

Wolframite has been mined by prospectors in the Pilbara Block from pegmatites and quartz veins associated with some of the post-tectonic granitic batholiths (2.6-2.7 m.y. old). Tin deposits associated with the batholiths are generally devoid of wolframite. Scheelite is rare in the Pilbara Block but has been recorded associated with gold at the Ard Patrick and Stray Shot mines (Table 6), and in silicic pegmatites in the country rock south of the Cookes Creek Granite. Production is summarized in Table 11.

COOKES CREEK

The Cookes Creek Granite is an unfoliated medium to coarse-grained granite, with equigranular and porphyritic phases, which intrudes mafic rocks of the Salgash Subgroup (Hickman, 1975). Late stage differentiates of the granite intrude both the body of the batholith and the marginal mafic rocks. Small quantities of tungsten ores have been produced from several pegmatites within the batholith, and from one pegmatite on the southwestern margin.

TABLE 10. Scheelite occurrences associated with gold mineralization in Western Australia

Mining centre	Mine name	Tenement	Location (Latitude Longitude)	Source of information	Remarks
MURCHISON AND EASTERN GOLDFIELDS PROVINCES					
PAYNES FIND	Ark	GML 1063	29°14'55"S 117°41'15"E	Simpson (1952)	Produced 29.4 kg of scheelite concentrates with 20.3 kg WO_3 in 1953
	Astor South	GML 1190	29°15'10"S 117°41'20"E	Simpson (1952), H.Taylor (pers. comm.)	No production
	Sweet William	GML 607	20°14'55"S 117°41'10"E	Simpson (1952)	No production. Paynes Find gold is in north-trending shears in mafic igneous rock; scheelite associated with gold
LENNONVILLE	Groses Empress	GML 964M	28°00'30"S 117°49'30"E	Simpson (1952)	Scheelite associated with pyrite in a quartz reef
CUE	Homeward Bound	GML 1211	27°25'54"S 117°51'34"E	Simpson (1952)	Scheelite found with gold in quartz veins
	Welcome	GML 1308	27°24'34"S 117°53'24"E	Simpson (1952)	Scheelite found with gold in quartz veins
SOUTHERN CROSS	Frasers	GML 4081	31°14'20"S 119°09'05"E	Saint-Smith and Farquharson (1913)	Large masses of scheelite in the footwall actinolite schist on No.5 level; attempts to treat the tailings from the mine have not recorded production
MARVEL LOCH	Boulder Lode	GML 714	31°28'00"S 119°28'00"E	Blatchford (1915), Simpson (1952)	Fine-grained scheelite is in quartz veins intruding host rock on 30 m level of mine
HOLLETON	Hollows Find	PA 1052	31°53'00"S 119°00'00"E	Simpson (1952)	Scheelite is in gold concentrates
WESTONIA	Edna May	GML 3447 TL 132	31°17'00"S 118°40'00"E	Dept Mines Statistics Branch	Tailings from this mine produced 108 440 kg of concentrates containing 69 545.34 kg WO_3 from 123 352 t of sand between 1943 and 1948
COOLGARDIE	Hampton Block 59	ML 1*	31°07'34"S 121°14'26"E	McMath (1950)	J.P.Baker produced 88.3 kg of concentrates containing 46.17 kg WO_3 in 1949
	Hampton Plains	PPL 463*	-	Dept Mines Statistics Branch	R.K.McRae produced 149.6 t ore for 2 575.3 kg concentrates containing 1 653.66 kg WO_3 between 1952 and 1955

TABLE 10 - continued

Mining centre	Mine name	Tenement	Location (Latitude Longitude)	Source of information	Remarks
	Surprise	GML 316	30°57'30"S 121°15'15"E	Le Mesurier (1949)	Scheelite is associated with calcite and dolomite
	Tindals	GML 5259 PA 7765	30°59'S 121°10'30"E	Miles (1953), Denholm (1967)	Scheelite occurs in main mine on No.3 and 6 levels; P.L.Short produced 3.77 t of ore containing 2 641.01 kg WO_3 between 1964 and 1967
COOLGARDIE	Leslie Norma	GML 5671 ML 106	30°56'57"S 121°10'16"E	Dept Mines Statistics Branch	W.A.Kent produced 1 944.5 kg of concentrates for 2 820.23 kg WO_3 between 1943 and 1955
	Bayleys	GML 5290	30°56'30"S 121°10'40"E	Le Mesurier (1949)	Scheelite associated with carbonated ultramafic
	Spare Time Lease	-	30°57'S 121°12'E	Honman (1914), Simpson (1952)	Scheelite intergrown with quartz in an auriferous vein
	Brownhill Extended	GML 3961	30°46'00"S 121°30'10"E	Simpson and Gibson (1912), Simpson (1952)	Scheelite concentrated in high grade gold ore
KALGOORLIE	Mount Charlotte	GML 191	30°43'43"S 121°28'01"E	Simpson (1952)	Scheelite is a common accessory in quartz veins
	Hannans Reward	GML 265E	30°44'40"S 121°19'40"E	Simpson (1952)	Scheelite in wall rock of auriferous lode
NORSEMAN	Record	GML 498	32°09'30"S 121°47'45"E	Campbell (1906), Simpson (1952)	Scheelite in auriferous lode
	Resurgam	GML 874U	30°02'40"S 120°37'50"E	Simpson (1952)	Scheelite in quartz lode and wall rock
DAVYHURST	Golden Pole	GML 459U	30°02'30"S 120°37'40"E	Simpson (1952)	Scheelite in quartz lode and actinolitic wall rock. Linnett and Hawkins treated 3 353 t of tailings producing 17 752 kg concentrates containing 12 337.5 kg WO_3 between 1954 and 1964
VICTORY	Victory	GML 1118	28°30'24"S 121°01'45"E	Simpson (1952)	Scheelite deposited at contact between porphyrite and greenstone
CLAMPTON	Clampton	PA 2380	29°57'S 119°06'E	Simpson (1952)	Scheelite in auriferous quartz veins

Table 10 - continued

BIRRIGRIN	Birrigrin	GML 209B	27°30'30"S 119°31'00"E	Simpson (1952)	Scheelite in gold concentrates
				PILBARA BLOCK	
MOSQUITO CREEK	Ard Patrick	GML 143	21°51'16"S 120°26'13"E	Simpson (1952)	Scheelite associated with gold in quartz veins. Assays given WO_3 50.93% and 45.1%
MARBLE BAR	Stray Shot	GML 1050	21°11'S 119°45'E	Simpson (1952)	Scheelite in auriferous quartz veins intruding basaltic tuff

*Hampton Plains private property leases

TABLE 11. Production of scheelite and wolframite from the Pilbara Block

Mining centre	Tenement	Lessee	Years of production	Main mineral	Ore treated (tonnes)	Concentrates therefrom (kg)	Metallic content WO_3 (kg)	Estimated value ($Aust.)
Ard Patrick	GML 307L	G. Brachi	1957	Scheelite	3.05	190	137.9	276.50
Cookes Creek	MC 60L, 61L	Western Wolfram NL	1954	Scheelite	2.54	1 713	1 225.8	3 734.00
Cookes Creek	MC 395L	D.W. McLeod	1967	Wolframite	-	701	408.1	1 278.91
Cookes Creek	MC 30L-32L	E. MacDonald	1952	Wolframite	-	1 908	1 246.8	6 919.80
Cookes Creek	MC 26L-28L	D.W. McLeod	1951-1952	Wolframite	-	19 170	12 534.9	67 858.10
Cookes Creek	Crown Land	D.W. McLeod	1951	Wolframite	-	3 142	2 167.6	12 426.00
Burrows Well	MC 244,245	D.W. McLeod	1952	Wolframite	-	621	412.9	2 400.00
Black Gin Point	PA 352WP	A.E. Glasson	1968	Wolframite	-	620	349.1	603.46
Talga Talga	Crown Land	J.E. Thompson	1951	Wolframite	-	162	95.2	552.00

Deposits within the Cookes Creek Granite
(Lat.21°38'23"S, long.120°21'40"E)

Two deposits have been mined from pegmatite veins in the Cookes Creek Granite. The mining operations were restricted to small trenches along the pegmatite exposures. These deposits were worked together by a party of prospectors who grouped their production. They have produced 24.9 t of concentrates containing 16 357.4 kg of WO_3. Most of this ore was mined in 1951 and 1952.

Geology: The southern group of workings is situated in a quartz-rich pegmatite intruding a medium to coarse-grained equigranular granite. The vein is between 10 and 20 cm wide. It has been worked to a depth of 10 m in some places, and has a trench 200 m long cut into it. The vein continues to the east across the granite contact into a fine to medium-grained mafic rock. It strikes 110°, and dips between 80° south and 70° north. Mineralization is concentrated on the northern side of the vein, and extends for 10 cm into the granitic host. Wolframite is the principal ore mineral, but in the selvage of the vein scheelite, fluorite, and muscovite occur as accessories.

The northern workings comprise shallow pits sunk on a small pegmatite. The occurrence is similar to the southern working, but mineralization is less intense.

Deposit at margin of the Cookes Creek Granite
(Lat.21°39'07"S, long.120°26'37"E)

Australian and New Zealand Exploration Company has located 28 occurrences of scheelite around the margins of the Cookes Creek Granite, but none of economic interest. Scheelite and wolframite have been mined from a small deposit south of the Cookes Creek Cranite. This deposit is accessible from the Mosquito Creek-Police Creek track, about 23 km north of Mosquito Creek. The workings are on the western side of the road, and consist of several shallow shafts and an adit. There has been 1.71 t of concentrates produced containing 1 225.88 kg of WO_3.

Geology: The mine is situated in a quartz-rich pegmatite intruding a medium-grained mafic rock. The quartz vein is emplaced along cleavage planes in the country rock, and dips steeply north. The vein commonly has a selvage of actinolite, muscovite, fluorite, wolframite, and scheelite. At the southern end of the workings this selvage is restricted to the western side, and it is from here that most of the ore was mined.

Reference: Lockhart (1975).

OTHER MINOR OCCURRENCES

Burrows Well
(Lat.21°34'00"S, long.119°31'33"E)

The Burrows Well wolframite occurrence is situated 200 m on a bearing of 205° from Burrows well. It can be reached by rough tracks east and south of the abandoned Split Rock homestead. A small parcel of ore mined from the deposits in 1952 yielded 0.62 t of concentrates containing 412.9 kg of WO_3.

The ore came from a vertically dipping northerly trending quartz vein intruding a coarse even-grained adamellite on the eastern margin of the Cooglegong Adamellite. The wolframite is concentrated along the eastern side of the vein.

Black Gin Point
(Lat.21°13'00"S, long.118°22'00"E)

A deposit of malachite and wolframite in a quartz vein intruding a fine to medium-grained metabasalt has been worked by a trench 200 m long and up to 1.5 m deep. The deposit is about 7 km northeast of the Friendly Creek tin mine, from which several tracks provide access. A parcel of ore from the deposit yielded 620 kg concentrates for 349.1 kg WO_3 in 1968.

Wodgina
(Lat.21°11'00"S, long.118°39'00"E)

Scheelite has been reported from within quartz veins and in mica schist adjacent to the veins from Kingstons scheelite lease and M.L.86 at Wodgina.

Friendly Creek
(Lat.21°14'01"S, long.118°18'16"E)

Scheelite occurs as a minor constituent of the cassiterite-gold placer deposit mined at Friendly Creek.

Talga Talga

A small quantity of wolframite ore has been collected from Crown Lands at Talga Talga. There is no information as to the location of this deposit.

SOUTHWESTERN PROVINCE

Wolframite has been recorded from two localities in the Southwestern Province, but neither has produced ore. Both deposits are associated with granitoid rocks and pegmatites. Neither is considered to warrant investigation.

Boyagarra
(Lat.32°17'48"S, long.117°10'43"E)

At Boyagarra, a quartz-rich pegmatite intruding an Archaean granitic rock is reported to contain wolframite associated with magnetite and chalcopyrite. The vein strikes 020° and dips east. Two bulk samples of the mineral assayed 0.3 and 10 per cent WO_3.

References: Campbell (1908), Simpson (1951, p.276).

Grass Valley
(Lat.31°35'15"S, long.116°46'17"E)

Wolframite was reported in surface float over a distance of 30 to 40 m on a hill slope in Avon Location 2809, about 5 km north of Grass Valley. There is no exposure of rock containing wolframite in the location, but one piece of the mineral was attached to a granitoid matrix which is thought to be of pegmatitic origin.

Reference: Blatchford (1918).

HALLS CREEK PROVINCE

King Sound tin-tungsten deposit
(M.L.146H-M.C.28W) (Lat.16°69'S, long.124°40'30"E)

The King Sound tin-tungsten deposit is about 32 km north-northwesterly from Napier Downs Station homestead, and about 193 km by road from Derby. It can be reached from Napier Downs on a track to Limestone Springs (29.4 km), then overland in a northerly direction for 9.6 km. The mine has also been known as Taylors Wolfram Reward, Federal Downs Wolfram mine, King Sound tin mine, Clara Hill mine, or as Wolfram Hill.

The deposit was first pegged in 1907 as "Taylors Reward Lease", M.L.146H. Plant was established on the mine between 1909 and 1913. According to the Mines Department Statistics Branch, 27.43 t of ore and concentrates were mined yielding 2 029.44 kg WO_3 and earning \$240.00 between 1909 and 1910. In 1940 production of 1 501.7 kg of concentrates yielded 808.53 kg WO_3 from the Napier Downs area, probably from this deposit.

Geology: The geology of the deposit is described in detail by Blatchford, Finucane, and Blockley.

The host rocks of the mineralization are metamorphosed shale, greywacke, and sandstone of the Halls Creek Group. The bedding strikes 070°, dipping 60° to 70° southeast. Prominent cleavage strikes 115° dipping 80° south.

Cassiterite-wolframite mineralization occurs primarily in subparallel anastomosing quartz veins, which are parallel to the host-rock cleavage. The veins intrude in a belt 400 m long, and between 3 and 20 m wide. Three other sets of quartz veins are reported in the ore zone, one parallel to bedding, one dipping 60° south into the main veins, and a later set of flat-dipping veins. Bulges in the main anastomozing veins occur at bedding-cleavage intersections. The mineralized veins are zoned, with scorodite (hydrous ferric arsenate) on the margins, cassiterite near the scorodite, and wolframite throughout the quartzose core. Table 12 shows available assay information.

References: Campbell (1909), Woodward (1909), Blatchford (1914), Finucane (1938), Simpson (1952), Harms (1959), Gellatly and others (1969), Blockley (in prep.).

GASCOYNE PROVINCE

Kilba Well
(Lat.22°46'38"S, long.115°32'54"E)

The Kilba Well prospect is located 5 km southwest of the well, from which it is accessible by a rough track. It has been investigated by Australian and New Zealand Exploration Company who conducted a 9-hole drilling programme on the deposit in 1975.

Porphyritic granite has intruded a Proterozoic sequence of metamorphosed dolomite and quartz-muscovite schist in the vicinity of the prospect. Scheelite, associated with vesuvianite and grossularite, has been found near the contact of the granite and metadolomite. The mineralization is concentrated in the limbs of isoclinal folds on the flanks of a dome cored by the granitic intrusion.

Reference: Kruger (1975).

TABLE 12. Assay results from the King Sound tin-tungsten mine

Location	Width	$\%SnO_2$	$\%WO_3$	Source	Remarks
Main trench, No.1 vein	-	1.24	.09	Blatchford (1914)	Probably No.1 open cut
Main trench, No.1 vein	-	.86	.06	"	" " "
Main trench, No.2 vein	-	4.86	.77	"	" " "
Concentrate	-	23.74	32.46	"	" " "
No.1 cut, South vein	76 mm	2.16	.27	Finucane (1938)	Represents 18.3-metre length
No.1 cut, North vein	28 mm	2.82	.26	"	Represents 12.2-metre length
No.1 cut " "	-	1.90	2.20	"	Dump sample
No.2 cut " "	15 mm	.40	.30	"	Represents 4.6-metre length
No.2 cut " "	-	1.50	3.11	"	Dump sample
No.3 cut " "	18 mm	.16	.66	"	Represents 21.3-metre length
No.4 cut " "	76 mm	1.26	2.02	"	Represents 3.0-metre length
Concentrate	-	84.6	not det.	Simpson (1948)	

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FIGURE 3 - KEY

1.	Mulgine Hill	12.	Hopes Hill
2.	Callie Soak	13.	Watkins occurrence
3.	Yandhanoo Hill	14.	Dallisons Reward
4.	Melville	15.	Cookes Creek
5.	Comet Vale	16.	Burrows Well
6.	Higginsville	17.	Black Gin Point
7.	Ora Banda	18.	Wodgina
8.	Norseman	19.	Boyagarra
9.	Moriarty's occurrence	20.	Grass Valley
10.	Ogilvies Find	21.	King Sound
11.	Lake Seabrook	22.	Kilba Well

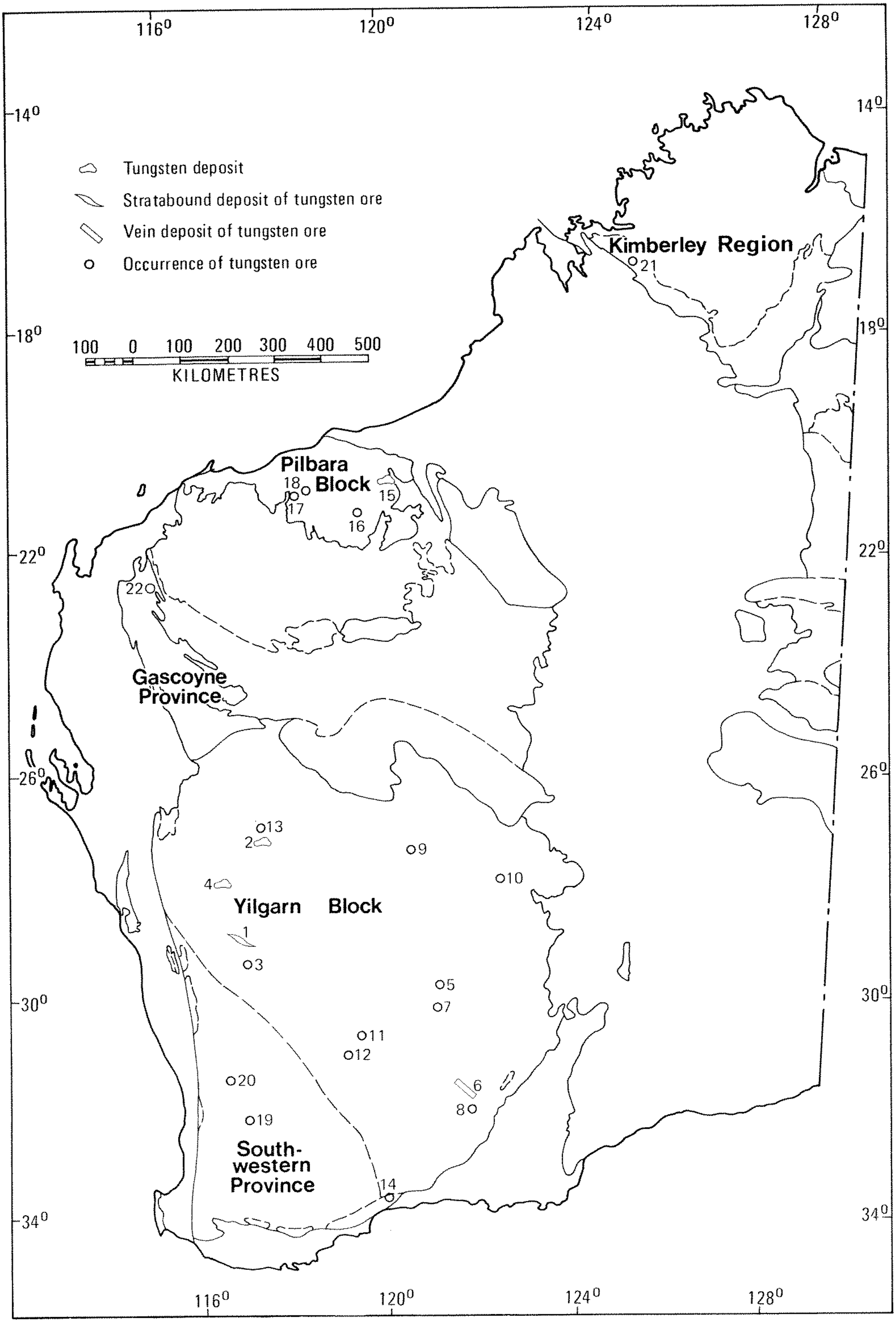

Figure 3. Metal occurrence map - tungsten (GSWA 17394).

P A R T   T H R E E

V A N A D I U M

PART THREE

VANADIUM

INTRODUCTION

This part of the bulletin is a review of those deposits in Western Australia which contain vanadium as the main ore constituent. All of these deposits are titaniferous vanadiferous magnetite. Vanadium enrichment associated with lead deposits, such as at Braeside, and uranium ore bodies, such as at Yeelirrie, are not described in this bulletin. Heavy mineral sands containing vanadiferous minerals suitable for concentration and separation are not known in Western Australia.

At present there is insufficient data available to review the genesis of the vanadiferous magnetite deposits in Western Australia, but a bibliography and brief summary of data reported from overseas deposits should allow the prospector an introduction to the literature and the general framework of discussion on the origin of the deposits. A detailed bibliography of vanadium is presented by Fischer and Ohl (1970).

Figure 5 shows the localities of the vanadium deposits described in the text.

SOURCES OF INFORMATION

The information used to compile this bulletin has been obtained essentially from private reports of mining companies submitted to the Department of Mines as a statutory obligation under Regulations 218 and 218A of the Mining

Act. I am indebted to these companies for the permission to use these reports. The brief review ofthe vanadium deposits published by Jones (1965) is effectively the only published report on vanadium and it is from this report that the bulletin hopes to extend. A comprehensive bibliography of Western Australian deposits appears at the end of this part, however, much of the information in these reports is not generally available, as the reports are confidential.

HISTORY OF VANADIUM EXPLORATION

The first reported concentration of vanadium minerals in an ore deposit was from the Braeside lead field (Finucane, 1938), where minor vanadinite occurs in seams a few centimetres wide in the lodes. This deposit does not have any economic importance for vanadium. Deposits at Gabanintha, Andover, and Coates were reviewed in 1959 as possible iron deposits, but generally were found to be unsuitable due to a high titanium content (Connolly, 1959). In 1960 Mangore (Australia) Pty Ltd undertook a regional survey of vanadiferous titaniferous magnetite deposits in Western Australia and were successful in locating deposits at Balla Balla, Andover, Gabanintha, Yarrabubba, and Coates, and this company carried out drilling on the Coates and Gabanintha deposits. By the end of 1962 the company had determined that these deposits contained reasonably large quantities of ore at grades between 0.54 and 1.24 per cent V_2O_5, and several attempts to overcome treatment difficulties were made. In 1963 the company decided to abandon exploration for vanadium in Western Australia. Thus, the first attempt to establish vanadium ore deposits in this state was unsuccessful.

Following the withdrawal of Mangore (Australia) Pty Ltd, the Department of Mines, through the Engineering Chemistry Division, undertook a series of concentration tests on the Coates ore, while the deposit was temporarily reserved by the Minister. This work was moderately successful in laying down a procedure for preparing a vanadium concentrate suitable for treatment. The results were reported by Morris and Hewson (1965).

In 1965 and 1966 Garrick Agnew Pty Ltd undertook a new review of the world market potential for vanadium, and entered into exploration of the deposits in Western Australia. In 1966 they applied for tenements over the

Balla Balla, Andover, and Coates deposits. Exploration, accompanied by further metallurgical testing by many industrial chemical organizations, led to the establishment of a successful process for separation of vanadium from the Coates ore, and the company is presently negotiating with the State Government to establish a mine and treatment plant at Coates. Drilling of the Balla Balla deposit has revealed large reserves, but to date no firm proposals for the development of the deposit has been forthcoming; the Andover deposit proved to be small and uneconomic.

In 1967 the Geological Survey of Western Australia discovered a deposit, possibly the largest in the state, in the Jameson Range; this deposit was ultimately tested by Westfield Minerals N.L., who relinquished the area in 1968 concluding that it was uneconomic due to its isolation. No further work has been undertaken on this deposit which is now included in a large Aboriginal Reserve.

In 1968 Greenstone Investments Pty Ltd applied for tenements covering deposits of vanadiferous magnetite at Barrambie. After a little exploration a new company, Ferrovanadium Corporation N.L., was formed in 1970 to explore this deposit fully. They were successful in locating a large deposit of vanadiferous ore, and according to their reports have overcome initial difficulty in treating the ore. The company is currently attempting to finance the establishment of a treatment plant at Barrambie.

During mapping of the Yalgoo 1:250 000 geological sheet, a deposit of titaniferous vanadiferous magnetite was reported in the Buddadoo Range, south of Yalgoo (Muhling and Low, 1973). No detailed evaluation of this deposit has been undertaken by an exploration company.

In 1971 Western Mining Corporation Ltd discovered the secondary carnotite deposit in calcrete at Yeelirrie, and if this deposit is brought into production vanadium may be produced as a by-product of the mining operation. This discovery led to extensive exploration of calcrete deposits; several other deposits, which are generally smaller than Yeelirrie, have been identified, but none have been brought into production. This type of deposit will not be described in detail in this bulletin.

VANADIUM MINERALS

The most important vanadium-bearing minerals that have been discovered in Western Australia are vanadiferous titaniferous magnetite and carnotite, but vanadinite, descloizite, mottramite, roscoelite, pucherite, clinobisvanite, and brackebuschite have been recorded from various mines and localities in the state. Vanadium-bearing titaniferous magnetite is impossible to distinguish from magnetite without chemical analysis. Vanadinite has been reported from Braeside, Mount Dockrell, Duck Creek, Talga Talga, Western Shaw, Dixon Range, Melville, Fields Find, Holleton, Paynesville, Pinyalling, Baumgartens Find, Burbanks, Burbidge, Carmans Find, Coolgardie, Eenuin, Menzies, Mulline, Nevoria, and Parker Range. Carnotite has been reported from Point Salvation, Poona, Yinnietharra, Yeelirrie, Yamarna, Mount Seabrook, and Mundong Well. Descloizite has been discovered at Braeside and Galena, associated with lead mineralization. Mottramite occurs associated with lead-copper ores from Braeside, Mangaroon, and Kununurra. Roscoelite, a mica, has been reported from gold ores at Kalgoorlie and the Comet Mine, Marble Bar. Pucherite has been recorded in small quantities in gold mines at Westonia, Bell Chambers, Holleton, and Niagara. A new mineral, clinobisvanite (Bridge and Price, 1974) has been described from the mining centres of Wodgina, Menzies, Westonia, Yinnietharra, Londonderry, Corinthia, Yandill, and Paynes Find. Brackebuschite has been reported from Braeside.

PROPERTIES AND USES OF VANADIUM

Vanadium is a hard, lustrous, steel-grey metal with a melting point of about 1900°C, and when pure has a good resistance to salt-water corrosion. It is a poor conductor of heat and electricity by comparison with copper and aluminium. The metal is malleable and ductile, except in the presence of hydrogen. At high temperatures in the presence of carbon, oxygen, and nitrogen, the metal combines to form carbides, oxides, and nitrides. The metal is similar to steel and can be cold-rolled or welded with argon arc. The main use of vanadium is as an alloy with steel to which it imparts toughness, resistance to shock or impact, and resilience. In most alloying capacities it responds similarly to molybdenum, chromium, nickel, manganese, titanium, silicon, and aluminium.

SUPPLY AND DEMAND OF VANADIUM

A recent review of the supply and demand of vanadium on the world market is presented by Brown and others (1974) who report that the main demand for vanadium in the future will be in the production of high strength, low alloy steel, particularly for structural, pipeline, and automotive applications. Vanadium is available from many parts of the world and reserves in general are extensive compared with the present and projected world demands.

The steel industry uses 93 per cent of all vanadium produced at present, the remainder being consumed by the titanium and chemical industries. Within the steel industry the main areas in which vanadium alloys are employed are high strength, low alloy steels, tool steel, alloy steel, plain carbon steel and open-die-forging steel. The future expansion of the vanadium market is seen to be in the development of high strength components in motor cars, such as bumpers, and frames, and in the pipeline industry. Both these uses are expected to expand considerably in the near future.

The demand for vanadium in the western world in 1973 was reported to be 17.21 kt and it is forecast to reach 23.42 kt by 1980. The known reserves of producing mines and those capable of being brought into production, together with the likely increase in uranium production from carnotite products in the future, is sufficient to supply the world's demand for the metal, and may lead to a reduction in the market price, making it more competitive with other alloy metals such as molybdenum, tungsten, and chrome. It is apparent that the world reserves of vanadium are sufficient to meet projected requirements and new deposits coming into the market will find difficulty in obtaining consumers for their products.

GEOLOGICAL ASSOCIATIONS

Three geological associations are known for vanadium in Western Australia:

1. Titaniferous magnetite deposits associated with gabbroic rocks;
2. Secondary carnotite deposits in calcrete;
3. Deposits of vanadinite, mottramite and other minerals associated with base metal ores in quartz veins.

These associations are common in other Archaean shields of the world and are reviewed in Fischer (1975a and b). In Western Australia the main resource of the metal is in titaniferous magnetite deposits.

TITANIFEROUS MAGNETITE DEPOSITS

Vanadiferous titaniferous magnetite occurs in layers within anorthositic and gabbroic bodies in several places in Western Australia. Proterozoic and Archaean stratiform layered intrusions are known to contain titaniferous magnetite concentrations. Commonly the magnetite bands are at the base of an igneous differentiation cycle, but usually the mineralized cycle is not the lowest in the intrusion. The magnetite layers are marked by a sharp basal contact and a disseminated upper contact with the enclosing gabbro. Magnetite usually forms large skeletal cumulus grains within the oxide bands where it is accompanied by feldspar, and it tends to be intercumulus in the disseminated zones. Ilmenite as distinct grains or exsolution lamellae within the magnetite is a common accessory in the oxide bands. Vanadium appears to be concentrated preferentially in either ilmenite or magnetite but is more common in magnetite. Pyrite and chalcopyrite are common accessory minerals in layered titaniferous magnetite deposits.

CALCRETE DEPOSITS

Calcrete deposits (Jackson and van de Graaff, in prep; Dall'Aglio and others, 1974; Langford, 1974) containing carnotite and other uranium ores have been discovered in the northeastern part of the Yilgarn Block. These deposits consist of chemically precipitated uraniferous ores in calcrete (terrestrial limestone) formed along ancient drainage channels. The concentration of carnotite appears to be related to present or past water tables within the calcrete. Carnotite is disseminated in irregularly distributed blebs above and below the present water table. In all the deposits so far reported the water stored in the calcrete is saline. These deposits are primarily uranium resources.

VEIN DEPOSITS

Vein deposits with vanadiferous minerals are widespread in Western Australia, but there is rarely sufficient enrichment to warrant prospecting. The only significant deposit is at Braeside where a quartz vein carrying lead minerals has an associated vein with a selvage of vanadinite and other minerals. This vein is less than 15 cm wide and is not continuous for the length of the ore body.

GEOCHEMISTRY OF VANADIUM

The geochemistry of vanadium has been described by Goldschmidt (1962), Rankama and Sahama (1968), and Wedepohl (1969). It is the 22nd most abundant element in the crust and averages about 150 ppm in igneous rocks. Its ions substitute and replace those of iron, titanium, and chromium in titaniferous magnetite, ilmenite, and chromite. Vanadium is common in a range of valency states and forms complex anions which are commonly associated with uranium, niobium, and rare earths. Organic complexes are thought to be the prime host of vanadium in hydrocarbon deposits.

Secondary dispersion of vanadium during weathering in arid conditions is common. It tends to be concentrated in the presence of clay minerals, in the presence of carbonate minerals such as calcite or dolomite, and in iron-rich weathering products such as laterite. Trivalent vanadium is fairly insoluble, whereas the quinquevalent form is fairly soluble in both acid and alkaline solutions; it seems likely that the mobility of vanadium is connected with the presence of quinquevalent vanadium ions. Vanadium is mobile in both weathering and hydrothermal processes but appears to have a dependence on the composition of the accompanying liquids.

In titaniferous magnetite deposits of Western Australia there is an enrichment in vanadium content of the oxide bands in the zone of weathering accompanying the formation of hematite from magnetite. Vanadium appears to remain in the mineral structure as substitution for iron and possibly titanium ions. Vanadium is reported to be able to replace aluminium, iron, and to some extent, magnesium and silica in ferromagnesian minerals. The mineral kaersutite at Jameson Range is an example of vanadium being incorporated in the lattice of a silicate mineral. Vanadium is uncommon in olivine-bearing rocks.

EXTRACTIVE METALLURGY OF VANADIUM*

The chemistry of vanadium is complex and processes for extraction and recovery of vanadium from its ores are not simple. A range of metallurgical techniques has been developed to deal with the different types of ore.

Vanadium usually occurs in combination with some form of iron, uranium, phosphorus, carbon, lead, or zinc, and the most frequently applied process of separation consists of conversion of the vanadium minerals to a water soluble sodium salt by roasting the pulverized ore with a sodium compound. Sodium chloride is normally the most economical source of soda but sodium carbonate and sodium sulphate are also used.

The vanadium must be in the pentavalent state for an efficient reaction and if the ore contains vanadium in lower valency states, then the minerals must be oxidized before water soluble vanadium compounds can be formed. Accordingly an oxidizing atmosphere must be maintained in the reaction zone of the roaster. Most of the problems arise from side reactions between the sodium compound and associated minerals in the ore. Selectivity of attack on vanadium alone is enhanced by the maintenance of oxidizing conditions.

The ore can be roasted as mined or more often after a prior concentration step. For the processing of titaniferous magnetites a preliminary concentration by wet magnetic means is frequently used to separate a vanadium enriched fraction.

It is usually necessary to agglomerate the pulverized ore before roasting, and pelletizing is the most common method. The roasting is normally carried out in a rotary kiln, although both shaft and multi-hearth furnaces have been used for this purpose.

Leaching of the roasted material, which is termed "calcine", with water

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* Compiled by B. Goodheart, Engineering Chemistry Division, Government Chemical Laboratories

produces a neutral or slightly basic solution containing up to 90 per cent of the vanadium values of the ore. Vanadium may be precipitated by acidifying this leach solution to form sodium hexavanadate, which is commonly referred to as "red cake".

The red cake usually contains co-precipitated contaminants and on calcination gives an 88 to 92 per cent V_2O_5 "fused oxide" product. A purified grade may be manufactured by redissolving red cake, adding an ammonium salt, and crystallizing ammonium metavanadate. This can be decomposed by heating to a final vanadium oxide product approaching 99.9 per cent purity.

The recovery of vanadium as a by-product of leaching procedures for uranium extraction has been widely practised in the United States of America. Most of the uranium operations are based on acid-leach circuits and many of these carnotite type ores contain appreciable quantities of vanadium. The vanadium values are normally separated by liquid ion exchange methods employing either amines, quaternary ammonium compounds, or organophosphorus compounds as the extracting agent. In general, the separation of vanadium and uranium can be accomplished by solvent extraction or ion exchange methods, or by selective precipitation and refining techniques.

Solvent extraction can also be employed to concentrate and purify water leach solutions resulting from the conventional salt-roast process.

Methods are also in use for the recovery of vanadium from vanadium-rich slags, which result from the smelting of titaniferous magnetites or other iron ores. Derivation from lead-zinc ores after pre-concentration and smelting is also practised. In South Africa, a pre-reduction and electric-arc smelting process is employed to produce pig iron and a vanadium-rich slag, and in Finland, iron-oxide pellets and vanadium oxide are gained from a salt-shaft-furnace process.

The slags can be processed to vanadium pentoxide or converted direct to ferrovanadium, which is produced in a number of grades predominantly for steel-making usage, or to various vanadium-iron-carbon alloys.

High purity vanadium metal ingot is produced by thermic reduction of the oxide followed by electron-beam melting purification.

Due to the great variety of mineral associations, it is difficult to predict the most likely source and processing methods for the vanadium of the future. However, it seems probable that for titaniferous magnetite ores of the type that occur in Western Australia recovery by one of the variations of the salt-roast techniques will continue to be of major importance.

PROSPECTING RECOMMENDATIONS

Large tonneages of vanadium ore are known in Western Australia. Most of this material is low grade and requires complex metallurgical processing to extract vanadium from the ore. Although there may be further layered anorthositic gabbro bodies which may contain vanadium ore, the more rewarding approach to development of vanadium reserves would be to investigate further metallurgical processes with a view to producing low cost $V_2 0_5$ slag or red cake, and thereby open the market leading to further uses of vanadium alloys.

THE DEPOSITS

Vanadiferous titaniferous magnetite concentrations in gabbroic rocks occur in the Murchison, Eastern Goldfields, and Southwestern Provinces of the Yilgarn Block, and in the Pilbara and Musgrave Blocks. With the exception of the Jameson Range occurrence in the Musgrave Block, all deposits are of Archaean age. Due to similarities in form and host rocks, those deposits in the Murchison and Eastern Goldfields Provinces have been described together. The localities referred to in the text can be found on a map of Western Australia produced by the Department of Mines (1970).

Up to 1976 there has been no production of vanadium in Western Australia. The Barrambie and Coates deposits are currently the subject offeasibility and treatment studies and plans have been announced to bring these ore deposits into production.

Anorthositic gabbros containing vanadiferous titaniferous magnetite have been located at Barrambie, Yarrabubba, Gabanintha, Windimurra, Buddadoo, and Bremer Range. All deposits are segregations in stratiform intrusive rock; the magnetite bands are associated with anorthositic phases of the intrusion. The deposits are Archaean, they intrude Archaean layered successions, and are in turn intruded by granitic rocks. The deposits between Gabanintha and Windimurra have been interpreted as being comagmatic intrusions (de la Hunty, 1973) or a single intrusion (Korsch, 1971; Hockley, 1971). There is no definitive evidence for these interpretations currently available although the lithology is similar.

The deposits at Gabanintha, Yarrabubba, Barrambie, and Windimurra have been drilled to assess their economic potential, and currently Ferrovanadium Corporation N.L. are attempting to raise finance for the development of the Barrambie deposit. There is a large tonneage of ore available from these deposits containing between 0.5 and 1.4 per cent V_2O_5.

BARRAMBIE
(Lat.27°25'S, long.119°07'E)

The Barrambie prospect is about 73 km north of Sandstone on a well-formed gravel road between Sandstone and Meekatharra. It is about 12 km in length along the eastern side of the road. The deposit is about 450 km northeast of the port of Geraldton.

Prospecting and development

The Barrambie deposits were first reviewed by Greenstone Investments Pty Ltd in 1968; then in 1970 a new company, Ferrovanadium Corporation N.L. was formed to explore the deposits in detail. During this phase of exploration the deposit was geologically mapped, several diamond drillholes were sunk and large test parcels were sent to the United States of America for engineering and metallurgical testing. Ore reserves of 37.5 Mt at an average grade of 0.46 V_2O_5 were delineated by the company at this time. The best development of ore was located on M.C.37B, and the ore zone extends over M.Cs 32B to 39B with extensions on M.Cs 45B, 46B and 1473B. Quarries named the Cove and the Bay have been established on M.C.37B. In March, 1973, the company announced that treatment of ore from the deposit to soluble slag, high grade ferrovan slags, and chemicals was feasible, and initiated attempts to negotiate partners in development of the deposit. To date no announcement of the partner or a consumer for the planned production has been made.

Geology

The vanadium mineralization is contained in the Barrambie Intrusion, an anorthositic gabbro which intrudes the Archaean metamorphic succession and is in turn intruded by Archaean granitic rocks. The metamorphic succession in the vicinity of the deposit consists of sheared metasedimentary rocks including hematite schist, chlorite schist, quartz-chlorite wacke, and banded iron-formation. All these rocks are intruded by fine-grained dolerite dykes which are considered to be of Proterozoic age.

The Barrambie Intrusion (Korsch, 1971) is between 500 and 1 700 m thick and is exposed over a strike length of about 80 km. It is a layered intrusion with alternation of anorthositic and gabbroic rocks throughout, but with predominance of gabbro on both margins and anorthosite in the core. Titaniferous magnetite bands have been located in the gabbros on either side of the core, but are best developed within the anorthosite. The magnetite is generally coarsely crystalline on the western side and finer grained in the east. There are three main zones (up to 25 m wide) of magnetite concentration in the anorthosite, each comprising up to 12 distinct magnetite bands. These bands are accompanied by disseminated magnetite in the interstitial anorthosite. Irregularly distributed lenses of magnetite have been located in the marginal gabbroic zones; in some places these lenses are up to 4 m wide. The suite of rocks indicate cumulus magnetite and plagioclase in the anorthosite with some intercumulus magnetite, particularly on the eastern side. The gabbroic rocks appear to have cumulus labradorite with minor magnetite, accessory apatite, and varying amounts of intercumulus plagioclase. Magnetite commonly contains exsolution lamellae of ilmenite in massive oxide bands. The silicate rocks contain skeletal magnetite crystals with fine-grained irregular massive grains which may be intercumulate. The gabbro has been faulted in some zones but deformation is generally less severe than in the surrounding sedimentary rock. It is metamorphosed in the greenschist facies and has been epidotized in some parts.

References: Heuck (1962), Jeppe (1970), Wyatt (1972).

GABANINTHA
(Lat. 26°56'S, long. 118°38'E)

The vanadium prospect is 2.2 km west of Gabanintha (46.5 km south of Meekatharra) and is accessible on tracks between the Gabanintha and Porlell mines. The deposit is exposed in a discontinuous ridge 6.5 km long, of which the northern 2.9 km contains the best developed ore.

The deposit was drilled to a depth of 61.5 m by Mangore (Australia) Pty Ltd in 1961, and they demonstrated 8.56 Mt of indicated reserve assaying 1.24 per cent V_2O_5 and 15.5 per cent TiO_2. The deposit is now held by Garrick Agnew Pty Ltd as MCs 51/33-44.

Geology

The deposit consists of a series of titaniferous magnetite bands in a medium to coarse-grained anorthositic gabbro which intrudes the surrounding Archaean succession. The gabbro strikes north-northwesterly with a dip of 50° to 60° west. Exposure of the gabbro at the surface is poor between the magnetite bands. The magnetite is concentrated in anorthositic gabbro; both margins of the intrusion are gabbroic in composition. Both the gabbro and anorthositic gabbro are almost completely saussuritized, some having cumulate plagioclase crystals with interstitial actinolite. The intrusion has been extensively faulted, causing fragmentation of the magnetite-rich zone into eight distinct areas containing a total of 20 isolated lenses (Table 13).

The magnetite-rich zone has three main bands separated by anorthositic gabbro. The western band has a series of 1-m thick discontinuous lenses over a width of 30 m. This is underlain by about 20 m of unmineralized gabbro. The central band has between three and seven magnetite layers up to 2 m thick over a width of 40 m. There is a thin barren gabbro up to 5 m thick separating the

TABLE 13. Ore-lens widths, lengths and grades, Gabanintha vanadium prospect

Lens	Length (m)	Av. width (m)	Av. grade V_2O_5 (%)	Height above 605 m contour (m)
A	49.2	24.5	1.27	12.3
B	80.0	13.8	1.20	12.3
C	126.1	15.4	1.23	12.3
D	123.0	9.2		11.7
E	55.4	24.6	1.18	21.5
F	46.1	21.5	1.24	21.5
G	73.8	24.6	1.22	32.3
H	92.3	15.4	1.33	26.1
I	421.5	15.3	1.22	26.1
J	283.1	9.2	1.24	15.3
K	33.8	6.1		4.6
L	123.1	9.2	1.27	9.2
M	101.5	9.2	1.26	3.1

Dimensions from Ward (1960), assays from Heuck (1962).
Lenses N to T have been identified as a southern extension of the deposit, but none are of large size.

central and eastern bands. The eastern band has three to four magnetite layers up to 3 m thick in a width of 50 m. The footwall contact of the magnetite bands is sharp against the gabbro; the hanging-wall contact is accompanied by a zone of disseminated magnetite. The magnetite bands are composed of aggregates of polygonal martized magnetite grains up to 5 mm across. Ilmenite forms irregular inclusions within the martite grains. Magnetite disseminated in the anorthosite is accompanied by leucoxene. Magnetite is disseminated in the gabbro for about 100 m west of the magnetite-rich zone. Some lenses of magnetite contain disseminated pyrite but it is not common in the deposit.

References: Gibson (1904), Maitland (1904, 1919), Connolly (1959), Ward (1960), Heuck (1962), Abendroth (1962), Jones (1965).

OTHER DEPOSITS

Yarrabubba
(Lat.27°02'S, long.118°41'E)

The Yarrabubba deposit is located on the northern boundary of Yarrabubba Station. It is accessible on tracks from the Meekatharra-Sandstone road, about 12 km north of Yarrabubba homestead and then about 4 km east.

The deposit was tested to a depth of 30 m by Mangore (Australia) Pty Ltd in the early 1960s, who demonstrated inferred reserves of 1.98 Mt of magnetite with an average grade of 1.3 per cent V_2O_5. It is now held as M.C. 51/33 by Garrick Agnew Pty Ltd.

Geology: The deposit consists of a single band of titaniferous magnetite about 2 km long and between 1 and 3 m wide in an anorthositic gabbro. The gabbro has been intruded by even-grained granitic rock within 200 m of the magnetite band on the eastern and western sides. Both gabbro and granite are intruded by east-west trending dolerite dykes. These dykes displace the magnetite band up to 5 m, and are up to 20 m wide where they cut the magnetite band. Minor quartz veins intrude the gabbro on the western side with a trend parallel to the foliation of the gabbro. The magnetite is microcrystalline and massive. It is laid down parallel to the foliation in the gabbro, dipping east between 50° and 80°. The gabbro has been extensively epidotized, and sphene after skeletal ilmenite is present. Porphyroblasts of actinolite probably after pyroxene occur in the gabbro.

References: Heuck (1962).

Windimurra
(Lat.28°23'S, long.118°33'E)

The Windimurra deposit is exposed about 500 m east of the Windimurra woolshed and extends for 5 km to the south in a discontinuous line. The deposit has been reviewed by Mangore (Australia) Pty Ltd.

Geology: Very little is known about the geology of this deposit in the immediate vicinity of the magnetite bands. However, it is known that the bands are lenticular, generally less than 130 m long and 3 m wide. Six lenses have been located and these are roughly en echelon along the strike of the gabbroic host. The nature of the gabbro has not been reported. It is part of the Windimurra Intrusion which is a large gabbroic intrusion with anorthositic bands.

Buddadoo
(Lat.28°42'19"S, long.116°28'63"E)

The Buddadoo deposit is situated about 18 km east-southeast of the abandoned Gullewa mining centre (about 50 km by road southwest of Yalgoo). The best access to the deposit is 9 km southeast of Gullewa to Cattle Station well and then 12.5 km east past Buddadoo well. The magnetite bands are exposed about 1.2 km northeast of the track.

Geology: The Buddadoo Gabbro intrudes a sequence of banded iron-formation and minor sedimentary and felsic volcanic rocks, and is intruded on its eastern margin by fine-grained granitic rocks. The granitic rocks have removed some of the eastern side of the gabbro.

Muhling and Low (1973) have described the gabbro and divided it into an upper border zone, composed of fine-grained doleritic granophyre; a mixed zone, composed of dolerite, gabbro, anorthosite, and pyroxenite; an oxide zone, composed of martite (after titaniferous magnetite), anorthosite, and gabbro; and a basal zone of gabbro, anorthosite, and minor pyroxenite. Most of the minerals in the gabbro are metamorphic; the anorthosites are albite-epidote rocks and the gabbros are oligoclase-amphibole rocks.

Layering and cumulus textures are well developed in the basal and oxide zones, and in the lower half of the mixed zone. Magnetite-plagioclase bands in the oxide zone have cumulus plagioclase and both cumulus and intercumulus magnetite.

The oxide zone consists essentially of lenses of vanadiferous titaniferous magnetite. It can be traced for a strike length of 4.6 km and varies in width from 190 m in the centre to 1 m at the northern end. There is a repeated sequence of anorthosite, gabbro, and martite throughout the zone with a maximum of 24 bands of martite in the centre. The bands range from 0.3 m to 4 m thick (Fig.4). Analyses of 10 bands taken across the sequence are presented in Table 14. The V_2O_5 content decreases from 1.1 per cent at the base to 0.37 per cent in the upper band.

TABLE 14. Analyses from Buddadoo Vanadium Deposit

Sample No.*	Titanium dioxide (TiO_2)	Chromium (Cr)	Vanadium (V)
per cent on dry basis			
27841	16.6	0.26	0.62
27842	15.7	0.13	0.55
27843	13.8	0.10	0.41
27844	17.8	0.15	0.47
27845	19.5	0.13	0.47
27846	20.3	0.14	0.39
27847	20.2	0.05	0.35
27848	20.3	0.03	0.31
27849	21.3	0.05	0.28
27850	21.3	0.06	0.21

Platinum in each sample was less than 0.12 g/t

*Location shown in Fig.4

Analyst: Government Chemical Laboratories

References: Muhling and Low (1973).

Bremer Range
(Lat.32°32'21"S, long.120°46'47"E)

The Bremer Range prospect is about 5 km south of Lake Metcalf on MCs 63/501 to 63/515. It was drilled during a programme to test the area for base metal concentrations by a Unimin-Laporte Joint Venture.

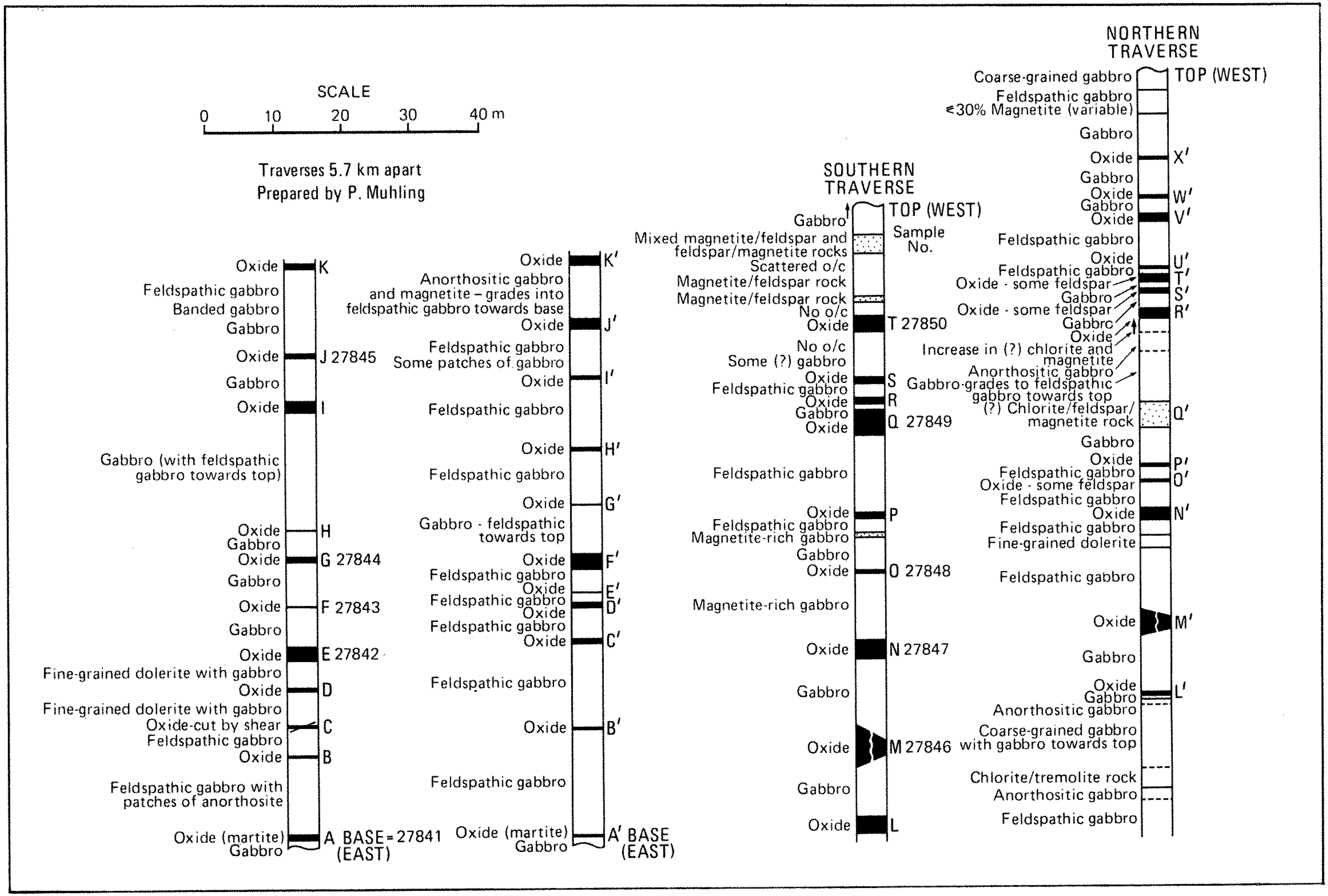

Figure 4. Distribution of oxide layers in the Buddadoo vanadium deposit (GSWA 17395)

Geology: Titaniferous magnetite in a pyroxenite-leucogabbro layered intrusion in the base of the Maggie Hays Formation contains between 0.23 and 0.54 per cent V_2O_5. The magnetite is exposed in the east limb of a north-plunging anticline as discontinuous lenses. Two partial analyses of the magnetite gave an average of 24 per cent Ti, 5 400 ppm V, 145 ppm Cr, 127 ppm Ni and 243 ppm Cu. The magnetite is concentrated at the base of a pyroxenite phase in the layered intrusion.

References: Eshuys and others (1972), Gower and Bunting (1972).

SOUTHWESTERN PROVINCE

Gabbroic intrusions containing bands of magnetite have been recorded from Coates and Tallanalla in the Southwestern Province. Exposure in this province is generally poor due to sand and laterite cover. It may be that further gabbros containing magnetite will be discovered by detailed mapping in conjunction with low level airborne magnetometer surveys.

COATES
(Lat.31°44'30"S, long.116°24'03"E)

The Coates prospect is 3.5 km east-northeast of Wundowie on the southern limit of Timber Reserve 14275. It is about 3 km north of the Great Eastern Highway and is immediately north of a spur of the 'narrow' gauge railway line. The deposit has been drilled by Mangore (Australia) Pty Ltd and Garrick Agnew Pty Ltd, and a published reserve of 31.06 Mt of indicated ore containing 0.56 per cent V_2O_5 has been calculated for the deposit. Garrick Agnew Pty Ltd is undertaking feasibility studies with a view to converting a charcoal iron furnace at Wundowie into a vanadium extraction plant. The company plans to commence production in the near future.

Geology: The Coates vanadium deposit occurs in lenticular magnetite lenses at the core of the layered Coates Gabbro. The gabbro is poorly exposed in an area of extensive lateritization, but appears to be between two granitic plutons. It has a general strike of 120° dipping southwest at 70°. Pegmatites containing albite-oligoclase-perthite and quartz, and fine to medium-grained dolerite dykes intrude both the Coates Gabbro and the surrounding granitic rocks. The age relationships of the rocks exposed at Coates prospect is unclear as there have been several different periods of acid plutonic activity, and no good exposure of the gabbro-granite contact has been observed.

The Coates Gabbro is about 1 km long and up to 600 m wide. It is composed essentially of three layers: a leucogabbro, a magnetite gabbro, and a gabbro. The leucogabbro on the footwall is plagioclase rich and anorthositic. It contains no magnetite, although it usually assays between 0.03 and 0.06 per cent V_2O_5. The magnetite gabbro contains 20 to 40 per cent magnetite and ilmenite, about 20 per cent hornblende, and up to 40 per cent labradorite, with varying amounts of biotite, epidote, and diopside-augite. The magnetite is commonly deposited as intercumulus grains between plagioclase laths. Magnetite is concentrated in lenticular layers within the magnetite gabbro which can contain up to 80 per cent oxide mineral. The ilmenite-magnetite ratio varies but is generally about 4:1. Exsolution of ilmenite in magnetite, and hematite in ilmenite is common. The vanadium is concentrated in magnetite, although small amounts occur in ilmenite. The magnetite gabbro contains between 0.3 and 0.7 per cent V_2O_5. The hanging-wall gabbro contains 40 to 70 per cent mafic minerals and generally contains small amounts of disseminated magnetite. It contains between 0.1 and 0.2 per cent V_2O_5. The contacts between the three layers are usually sharp, but magnetite concentrations occur in both footwall and hanging-wall gabbros adjacent to the magnetite gabbro. Pyrite and pyrrhotite are common, and chalcopyrite and pentlandite have been noted in the magnetite gabbro and hanging-wall gabbro.

The gabbroic sequence has been subjected to intense weathering and lateritization. It is kaolinized to a depth of 20 to 40 m and this is capped by laterite 3 to 15 m thick. Development of laterite over the magnetite gabbro is residual, preserving the original texture of the gabbro at the surface. Hudson has determined a stability relationship for minerals in the deposit during weathering, indicating ilmenite as the most stable, followed by magnetite, amphibole, and feldspar. The V_2O_5 content of the laterite cap is commonly higher than the underlying gabbro. On the southwest flank of the deposit a detrital lateritic deposit has formed which is slightly enriched in V_2O_5. The ore body has been divided into lateritic "caprock", kaolinized "lower oxidized", and "primary" ore. The "caprock" is considered to be ore if it contains more than 0.5 per cent V_2O_5 and less than 10 per cent SiO_2. Indicated reserves of between 1.5 and 1.2 Mt averaging

0.88 per cent V_2O_5 and 5.7 per cent SiO_2 have been estimated by McKay. This ore is reported to be capable of treatment. "Lower oxidized" ore is less consistent in composition and distribution than "caprock" and the inferred tonneage is reported at between 5.9 and 7.0 Mt averaging 0.55 per cent V by McKay. Reserves from the "primary" ore have not been completely delineated, but the deposit contains minimum indicated reserves of 39 Mt to a cut-off grade of 0.4 per cent and an average grade of 0.51 per cent V_2O_5 according to McKay.

References: Abendroth (1962), Heuck (1962), Jones (1965), Muskett and others (1965), Hudson (1967), McKay (1971), Garrick Agnew Pty Ltd (1971, 1972).

MINOR OCCURRENCE

Tallanalla
(Lat.33°09'S, long.116°08'E)

A gabbro containing magnetite bands was discovered by Mr R. Shalders at Tallanalla. The surface exposure is poor; however, oxides bands can be traced for up to 500 m, being generally less than 2 m wide. The bands are lenticular. The gabbro has a general strike of 130° and dips southwest between 50° and 60°. Assays of magnetite from the deposit are shown in Table 15.

TABLE 15. Assays of magnetite ore* from Tallanalla

Sample No.	V_2O_5 (%)	TiO_2 (%)	Fe (%)
22387A	0.22	5.48	48.8
22388	1.12	11.6	53.2
22390	0.25	19.8	51.2
22391	0.29	18.5	47.1

*Grab samples
Analyst: Government Chemical Laboratories

Titaniferous magnetite has been known from Andover in the Pilbara Block since 1938, but it was not until the early 1960s that the vanadium content was determined. During regional exploration at this time a new deposit was located at Balla Balla.

BALLA BALLA
(Lat.$20^{o}48'$S, long.$117^{o}47'$E)

The Balla Balla deposits are about 11 km north of Whim Creek. Access is from the old position of the Northwest Coastal Highway, 3.2 km west of Whim Creek and then 8 km in a northerly direction towards Balla Balla Landing. The deposit is on the western side of the road. It is currently held by Garrick Agnew Pty Ltd as MCs 47/342 and 47/402.

The deposits were first reviewed by Mangore (Australia) Pty Ltd in 1961 and 1962. They estimated the ore reserves as 1.938 Mt averaging 0.75 V_2O_5. In 1966 Garrick Agnew Pty Ltd took up ground over the deposit and continued the investigation. This company still holds the ground.

Geology

The three main deposits are situated in low hills about 400 to 500 m long, 50 to 80 m wide and rising 10 to 15 m above the plain. Two smaller deposits occur about 2 km southeast of the main deposits, in low hills.

The three main deposits are located in a saussuritized metagabbro sequence in which there is variation from leucogabbro to anorthosite. The sequence has a general strike of 080^{o} to 100^{o} and dips gently north at 25^{o} to 30^{o}. The area in the vicinity of the deposits is faulted parallel to 020^{o} and 140^{o}, and both sets of faults dip steeply east.

The westernmost hill in the main deposit has anorthositic gabbro and medium to coarse-grained gabbro exposed on the southern side.. The oxide bands are generally less than 50 cm thick, but there are up to 12 bands across the hill separated by thin bands of chloritic rock. The northern side of the hill is covered by magnetite scree.

The central hill consists of a thin magnetite banded zone bounded by chalcedony capping on the north and gabbro on the south. There does not appear to be as many bands of magnetite in this hill as in the western hill, but exposure is poor.

The eastern hill is composed of epidotized gabbro and anorthosite, but is apparently intruded by dolerite dykes as there are large areas of fine-grained dolerite scree on the hillslope. Two shafts have been sunk on the magnetite band, one 7.8 m deep and the other 10.4 m deep. The magnetite bands are between 10 and 50 cm thick, separated by 1 to 10 cm of chloritic rock.

The two low hills southeast of the main zone consist of lenticular magnetite bands in a leucogabbro. These deposits are small and would not constitute economic deposits in their own right.

The magnetite-rich bands in all deposits consist of an intimate mixture of ilmenite and magnetite with feldspar. Some ilmenite has been replaced by sphene. Sphene surrounds ilmenite grains, replaces ilmenite exsolution lamellae, and forms irregular veins through magnetite grains. There has been no research reported on the location of vanadium in the ore.

Reference: Jones (1965).

MINOR OCCURRENCE

Andover
(Lat.20°51'S, long.117°04'E)

The Andover deposits are about 10 km west of Woodbrook (Andover) Station which is about 20 km south of Roebourne. The deposit is 2.5 km east-northeast of Black Hill well and is accessible on tracks from Carlow Castle and the station.

The Andover deposits were first reported by Telford and Finucane and were reviewed by Connolly, Mangore (Australia) Pty Ltd in 1960, and Garrick Agnew Pty Ltd in 1966. The deposit is said to contain 17 lenses of titaniferous magnetite. It is unlikely that any large tonneage of ore will be obtained from this deposit.

Geology: The host rock at Andover is a saussuritized metagabbro which contains both cumulus and intercumulus magnetite. The general strike of the foliation is 080^{o} dipping north between 50^{o} and 65^{o}. The ore-bearing gabbro has been intruded by a younger, fine to medium-grained gabbro which contains no magnetite, and the whole succession is intruded by aplite veins.

The magnetite lenses are discontinuous and generally less than 200 m long and 2 to 5 m wide. They generally contain feldspar matrix, and in some bands ilmenite has been replaced by sphene. Pyrite occurs disseminated in some parts of the gabbro. The tonneages available for individual lenses are low, and the distribution of different lenses makes the deposits only of marginal economic interest.

References: Telford and Finucane (1939), Connolly (1959), Jones (1965).

MUSGRAVE BLOCK

The Musgrave Block is a Proterozoic igneous and metamorphic complex of granulite and dominantly acid intrusives overlain unconformably by the Bentley Supergroup which is composed of volcanic and sedimentary rocks and is intruded by the Giles Complex, a suite of gabbros. The Giles Complex and Bentley Supergroup have been subjected to low-grade regional metamorophism in some places. For a more detailed description the reader is referred to Daniels (1974).

Gabbros of the Giles Complex have been subdivided into four named units:

Jameson Range Gabbro
Blackstone Range Gabbro
Hinckley Range Gabbro
Michael Hills Gabbro.

The Jameson Range and Blackstone Range Gabbros are known to contain bands of vanadiferous titaniferous magnetite. A detailed description of the gabbro bodies is given in Daniels (1974). The deposits in the Blackstone Range Gabbro are thin and discontinuous and are restricted to the northern side of Bell Rock Range.

JAMESON RANGE
(Lat.25°48'26"S, long.127°36'25"E)

Jameson Range is about 120 km east-northeast of Warburton Mission and about 20 km north of a road connecting the mission with Wingelinna. Westfield Minerals N.L. carried out reconnaissance surveys of the deposits in 1967 and established several tracks into the deposit; however, the state of these tracks is not known. The deposits are contained within a large Aboriginal Reserve and a permit to enter the reserve must be obtained from the Department for Community Welfare.

The Jameson Range vanadium deposits were discovered by the Western Australian Geological Survey during mapping of the Scott and Bentley 1:250 000 Sheet areas in 1966 (Daniels, 1967, 1970 and 1972). In 1967 Westfield Minerals N.L., in conjunction with other companies, evaluated the deposits and concluded that the remoteness of the locality was prohibitive for economic mining of the magnetite ore.

Geology

The Jameson Range Gabbro has been divided into four zones by Daniels (1974), and of these, Zone 2 and Zone 4 are known to contain vanadium deposits. Details on the chemistry and petrography of the zones is given by Daniels.

Northeast of Jameson Range in Zone 2 of the gabbro a poorly exposed sequence of olivine gabbro and pyroxene gabbro contains thin bands of titaniferous magnetite. In some cases the olivine gabbro contains up to 40 per cent magnetite. The composition ranges from 1.4 to 1.11 per cent V_2O_5 at Turkey Hill to 0.57 to 0.76 per cent V_2O_5 at Jameson Range. The gabbros contain the mineral kaersutite which accounts for part of the vanadium in the rock. The opaque minerals appear to contain about 1.4 per cent V_2O_5. Continuity of bands and their distribution is difficult or impossible to determine as they are covered by an extensive laterite sheet. The laterite contains surprisingly low vanadium values (0.39 to 0.46 per cent V_2O_5) indicating some depletion of V_2O_5 in surface conditions.

Southwest of Jameson Range in Zone 4 of the gabbro in a suite of troctolite, gabbro, and anorthosite there are at least six bands up to 3 m thick, with a range of assays from 0.34 to 1.33 per cent V_2O_5. The magnetite bands can be traced from Domeyer Hill (Lat.25°40'14"S, long.127°27'36"E) for 37 km in a southeasterly direction; the exact thickness varies from a total of about 1 m up to 60 m in short sections. The basal oxide band of Zone 4 is persistent and contains an average of 1.2 per cent V_2O_5. Generally, the higher bands have decreased tenor ranging from 0.34 to 1.1 per cent V_2O_5 with an average of 0.79 per cent. Chemistry of the oxide bands indicate that the base of the gabbro is richer in V, Ti, Al, and Mn; and Fe, Cr and P increase upwards in the zone.

Southeast of Jameson Range, about 10 km west of Mount Elliott, thin titaniferous magnetite horizons in a suite of gabbro, anorthosite, and olivine-rich rocks were discovered by Westfield Minerals N.L. while mapping the area. Daniels (1974) has correlated these with Zone 4. At this locality at least six bands of magnetite have been reported averaging 0.3 m wide. One band has been traced by Westfield Minerals N.L. for about 20 km. It consists of four seams of magnetite, which total 0.5 to 2.5 m wide and contain between 0.42 and 1.5 per cent V_2O_5.

Chemical analyses of the titaniferous magnetite from Jameson Range is presented in Table 16. A summary of the oxide variation in the Jameson Range magnetite deposits is shown in Table 17.

References: Daniels (1967, 1970, 1971, 1972, 1974), Schupp (1967), Willemse (1969).

TABLE 16. Analyses of titaniferous magnetites from Zone 4, southeast Jameson Range

	10974/6	10974/10	10974/12	10974/14	10974/15	10975/2
SiO_2	2.93	1.40	1.35	2.36	2.25	1.32
Al_2O_3	3.68	5.42	5.99	5.78	3.42	3.65
FeO	18.90	10.78	29.54	10.03	6.36	11.12
Fe_2O_3	48.06	56.86	38.33	56.68	61.86	58.71
MgO	2.95	1.93	2.59	1.47	0.89	2.30
TiO_2	19.17	20.78	19.62	20.03	21.03	18.52
MnO	0.31	0.20	0.29	0.26	0.26	0.21
P_2O_5	0.03	0.02	0.01	0.01	0.06	0.05
Cr_2O_3	1.13	0.38	0.41	0.37	0.46	1.04
V_2O_5	1.14	1.25	1.23	1.14	1.29	1.05
S	0.04	0.04	0.01	0.03	0.04	0.03
NiO	0.10	0.10	0.12	0.11	0.10	0.13
H_2O^+	1.80	1.20	0.77	1.93	1.74	1.83
H_2O^-	0.15	0.07	0.07	0.11	0.28	0.12
	100.39	100.43	100.33	100.31	100.04	100.08

All values in per cent

Analysts: R.S. Pepper 10974/6; 10974/15; 10975/2
J.R. Gamble 10974/10; 10974/12; 10974/14 (Daniels, 1974)

TABLE 17. Comparative summary of the oxide variation in titaniferous magnetite, Jameson Range and Bushveldt

	JAMESON RANGE GABBRO (after Daniels, 1974)								Bushveldt titaniferous magnetite (after Willemse, 1969)
	Location 1		Location 2		Location 3		Location 4		
	A	B	A	B	A	B	A	B	
V_2O_5	1.11-1.40	1.25	1.05- 1.29	1.18	1.07- 1.33	1.20	0.71-0.81	0.76	1.40-1.60
TiO_2	17.2-21.0	19.1	18.52-21.03	19.86	18.20-27.19	23.37	15.9-20.9	19.0	12.2-13.9
Al_2O_3	4.06-4.47	4.26	3.42- 5.99	4.66	2.46- 5.74	4.49	2.35-4.53	2.88	2.53- 3.5
Cr_2O_3	0.38-0.63	0.50	0.37- 1.13	0.63	0.03- 0.18	0.11	0.14-0.29	0.27	0.13-0.45
P_2O_5	0.03-0.04	0.03	0.01- 0.06	0.03	0.01- 0.04	0.03	0.08-0.24	0.13	<0.05
NiO	0.10-0.15	0.12	0.10- 0.13	0.11	0.03- 0.08	0.06	0.02-0.05	0.04	0.04-0.10

A = range. B - mean value. All values in per cent.

Location 1 = Zone 2, northeast of Turkey Hill.

Location 2 = Area southeast of Jameson Range.

Location 3 = Base of Zone 4, southwest of Jameson Range.

Location 4 = Top of Zone 4, southwest of Jameson Range.

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FIGURE 5 - KEY

1. Barrambie
2. Gabanintha
3. Yarrabubba
4. Windimurra
5. Buddadoo
6. Bremer Range
7. Coates
8. Tallanalla
9. Balla Balla
10. Andover
11. Jameson Range

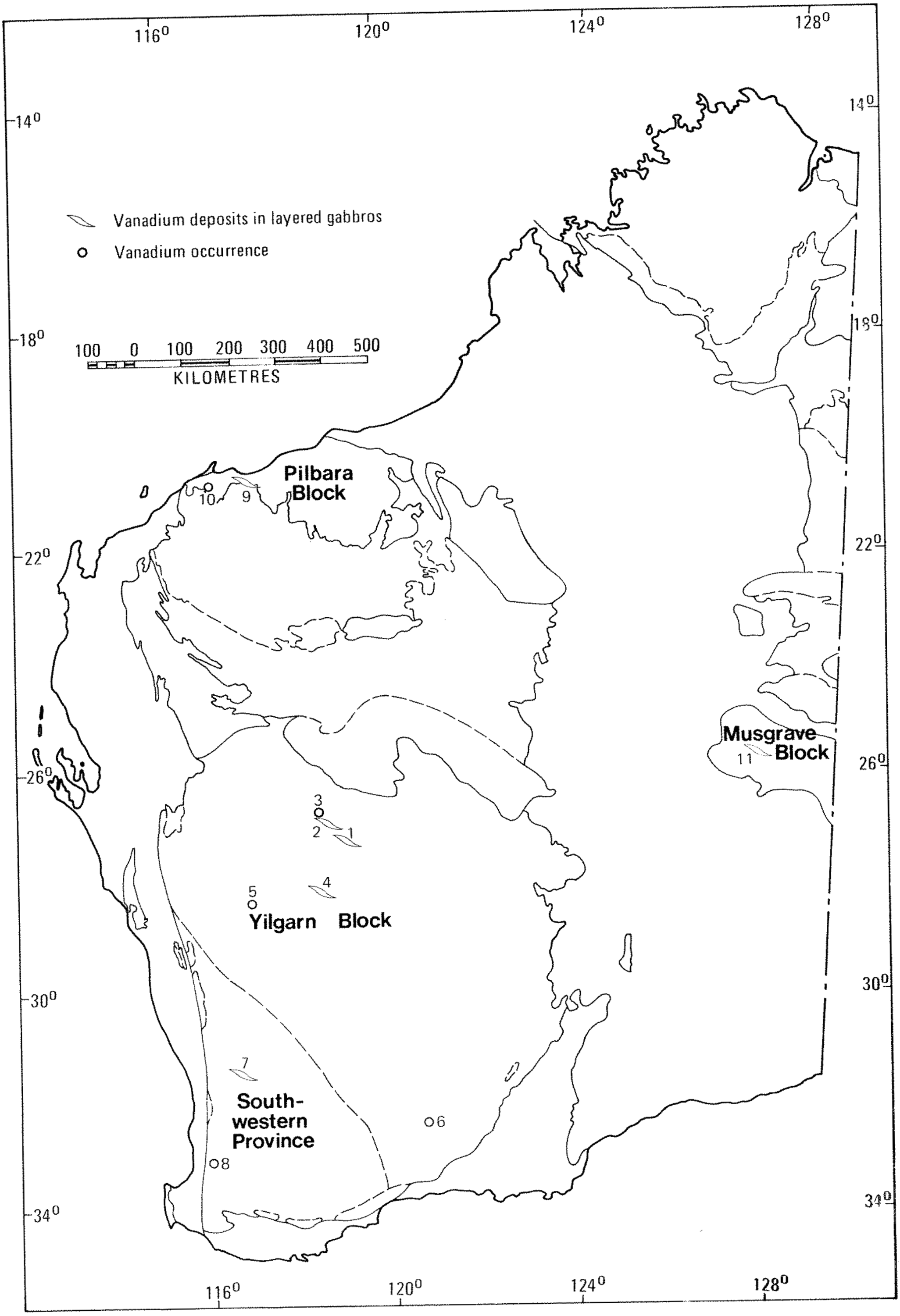

Figure 5. Metal occurrence map - vanadium (GSWA 17396).

PART FOUR

CHROMIUM

P A R T   F O U R

C H R O M I U M

INTRODUCTION

Chromium ore minerals are reasonably common in nickel deposits in Western Australia, but are rarely concentrated sufficiently to claim economic interest. This part of the bulletin aims to present descriptions of the known chromite ores in the state which have been, or might be, considered as source areas for chromium ore. Those deposits where chromite is associated with nickel deposits such as at Kambalda (Ewers and Hudson, 1972), or as disseminations in ultramafic rocks are not described.

Figure 6 shows the localities of the chromium deposits described in the text.

SOURCES OF INFORMATION

Most of the data presented in this bulletin has been compiled from private company reports. Earlier descriptions of the Coobina deposit by the Geological Survey of Western Australia and the Bureau of Mineral Resources have provided a basis for the description of the Coobina deposit. Coobina, Taccabba Well, and Imagi Well were visited briefly by the author in 1971 and 1972.

HISTORY OF CHROMIUM EXPLORATION

The first exploration of chromite deposits was initiated by the Aerial Geological and Geophysical Survey of Northern Australia in 1937 when a map of the southern portion of the Coobina deposits was prepared by Finucane (1938). In 1950 L. Ives pegged part of the Coobina deposits and interested the Government in testing the extent of the chromite reserves in the deposit (Matheson, 1951; de la Hunty, 1953). During the period 1952-1957 chromite ore was mined from Coobina by L. Ives and The Broken Hill Proprietary Company Ltd. After 1957, little was done with the deposit until 1968-1969 when The Broken Hill Proprietary Company Ltd drilled several individual lenses, drove an adit and mapped the deposits in detail. Currently the deposit is not worked and all exploration has ceased. During the exploration boom in Western Australia (1966-1971) many exploration companies assessed the metalliferous potential of ultramafic bodies throughout the state. This led to the location of chromite deposits at Salt Creek, West Bendering, Imagi Well, and Taccabba Well. All of these deposits were tested and considered to be uneconomic. In 1972-1975 the Western Australian Geological Survey began remapping the Pilbara Block and during this programme chromite occurrences at Pear Creek and Nobs Well were located. At present there is no active exploration for chromium in the state.

CHROMIUM MINERALS

The only important ore mineral of chromium is chromite which is a chromium-iron spinel. The mineral is black in grains, but may be yellowish to red in thin sections. It is slightly magnetic. The streak is brown. The mineral is often confused with magnetite, but can be distinguished readily by its weaker magnetism and brown streak. In serpentinites chromite is often accompanied by magnetite. Fuchsite, a chromium mica, has been reported from several belts of metamorphosed sediments in the state.

USES OF CHROMIUM ORES

Chromium is the most common additive in steel production, and although most chromium ore is consumed in the steel industry, it is also a common component of nonferrous alloys. Chromium is a raw material for the chemical industry, pigment manufacture, metal coating, and the production of leather goods. The recent increase in the price of zircon has opened up the market for chromite refractory linings and bricks.

GEOLOGY OF CHROMITE DEPOSITS

Chromite deposits in Western Australia occur in two distinct environments; layered peridotite-gabbro intrusions; and granulite to upper-amphibolite facies metamorphosed basic to ultrabasic rocks. There is insufficient data available to correlate the types of mineralization with the general classification of stratiform or podiform types, but all deposits occur in layered rocks, and the chromite bands are lensoid. For detailed descriptions of the classic chromite deposits the reader is referred to Wilson (1969).

Chromite deposits in layered peridotite-gabbro intrusions are known at Coobina, Nobs Well, Pear Creek, and the Bulong Complex. The chromite tends to form flat sheets at the base of differentiation cycles, they are not continuous, and are usually less than 2 m thick. The deposit at Coobina is a highly serpentinized and chloritized peridotite-gabbro intrusion with numerous isolated chromite lenses. Most of the lenses are conformable, but some cross the foliation of the enclosing serpentinite. The occurrence in the Bulong Complex is in a thin basal zone of a large mafic-ultramafic igneous complex. The chromite layer here is parallel to the host-rock foliation and occurs as a single layer. Nobs Well and Pear Creek occurrences are contained in peridotite intrusions and consist of thin discontinuous chromite lenses associated with zones of disseminated chromite.

The Imagi Well, Taccabba Well and West Bendering deposits occur in layered mafic-ultramafic rocks metamorphosed in the granulite to upper-amphibolite facies. The chromite lenses are concentrated in moderately compact zones parallel to the lithological layering preserved in the host rocks. The lenses are disrupted by faulting and younger granitoid intrusion. All of these deposits occur in a high grade metamorphic zone which marks the western and northern margins to the Murchison and Eastern Goldfields Provinces.

The Salt Creek occurrence is in a mafic to ultramafic gneissic remant of the Albany-Fraser Province. The Panton Sill and Lamboo occurrences are located in ultramafic bodies in the Alice Downs Ultrabasics of the Lamboo Complex within the Halls Creek Mobile Zone.

GEOCHEMISTRY OF CHROMIUM

In general, chromium is lithophile but in the absence of oxygen it has some chalcophile tendencies (Rankama and Sahama, 1968). Chromium commonly occurs in the trivalent and hexavalent ions. Chromium occurs in minerals either as spinel (chromite) or may substitute for aluminium, iron, or magnesium in clinopyroxenes, hornblende, and forsterite. Chromates are formed, but these are not verycommon.

In Western Australia the most abundant chromium mineral is chromite; however, there are occurrences of fuchsite in metamorphic rocks.

PROSPECTING RECOMMENDATIONS

Many ultramafic bodies in Western Australia were investigated during the exploration boom (1966-1971) but no large chromite deposits were located. It seems that although several large layered ultramafic bodies are known to contain small lenses of chromite, there is a low potential for discovery of a large chromite concentration in the state.

Prospecting the Nobs Well and Pear Creek deposits may lead to further discoveries of chromite lenses in the ultramafic suites, although it would appear likely that these lenses will be discontinuous. Chromite lenses in the Alice Downs Ultrabasics have been reported from three places, and may warrant further investigation.

THE DEPOSITS

Western Australia has the largest known chromite deposit in Australia and this deposit is considered to be only marginally economic as the grade of material and the discontinuity of the chromite bands makes marketing and mining of the deposit very difficult. The deposit is at Coobina, in the Sylvania Dome. All other occurrences are small with low concentrations of chromite and have no demonstrable economic potential.

COOBINA
(Lat.23°29'45"S, long.120°16'35"E)

The Coobina deposit is situated west of the Mundiwindi-Roy Hill road in the western end of Coobina Range. It can be reached by road from Meekatharra along the old Great Northern Highway. The track into the deposit is 39 km north of Mundiwindi, immediately north of the Coobina Creek crossing, and then 10 km west on a graded track to the deposit. The hill containing the chromite lenses has numerous tracks over it. These are in different states of repair and may be eroded and overgrown in a few years if not kept in reasonably consistent use. A bore site at an exploration camp north of the range yields potable water in sufficient quantities for camp use.

History

The Coobina deposits were first reported by Blatchford (1925) and Montgomery (1925). Simpson (1925) reported assays of the chromite ore ranging from 42.58-46.53 per cent Cr_2O_3, indicating low grade ore suitable for refractories but unsuitable for production of ferrochrome. Talbot (1926) reported further on the occurrence at Coobina and reported one assay of 54 per cent Cr_2O_3. Some detailed mapping and sampling of the deposits were carried out by Finucane (1938), and this is the most complete description yet published. In 1950 Mr L. Ives pegged part of the chromite deposit. In 1951 Matheson (1951) reviewed the deposits and recommended drilling to assess the value of the ore. This drilling was not completed due to the inaccessible nature of the country; however, one drillhole was completed (de la Hunty, 1953). The Broken Hill Proprietary Company Ltd acquired all of the leases in the Coobina area between 1953-1969, and undertook a mapping and drilling programme including a further six diamond-drillholes and four percussion-drillholes designed to establish the geometry of the several chromite lenses. During their exploration an adit was driven below a major lens of chromite and several quarries were established on larger lenses. At the present time there is no exploration of or production from the Coobina chromite deposits.

Production

Chromite was produced from the Coobina deposits between 1952 and 1957 (by Mr L. Ives and The Broken Hill Proprietary Company Ltd). The grade of ore varied between 42.01 and 46 per cent Cr_2O_3. The total production for the deposit is 14 650.43 t. The Broken Hill Proprietary Company Ltd produced chromite in 1952, 1954, 1956, and 1957 and Mr L. Ives produced chromite during 1953 and 1954.

Geology

The chromite deposits are located in the western end of Coobina Range. The range consists of a central core of serpentinite flanked by Archaean granitic rock. At the western end of the range a roughly oval area composed of serpentinite and an associated gabbro contains most of the chromite lenses. The gabbro has a diffuse contact with the serpentinite and appears to indicate that the sequence is overturned. The foliation of the sequence strikes north and northeasterly dipping east and southeasterly at 40° to 70°. Both the gabbro and serpentinite are intruded by granitoid rocks.

The serpentinite-gabbro unit has formed by the serpentinization of a layered peridotite. Most of the original texture has been destroyed by metamorphism and shearing.

Petrological studies of the rock suite indicate that the peridotite is now essentially serpentine with minor, variable, amounts of chlorite, talc, carbonate, chromite and magnetite. Shapes of original igneous olivine and pyroxene grains are pseudomorphed by serpentine, talc, and fine-grained magnetite aggregates.

The gabbro consists of actinolite poikiloblasts up to 2.5 mm long in a fine-grained granoblastic groundmass of quartz, epidote, plagioclase, and actinolite, with accessory biotite, chlorite, opaques, sphene, and metamict allanite. In places, original plagioclase crystals are pseudomorphed by quartz and epidote.

The main group of chromite lenses occurs in the western end of the Coobina Range. The Broken Hill Proprietary Company Ltd have named this area "The Blob". They have mapped more than 200 individual lenses of chromite ranging from 5 to 150 m in length and 1 to 6 m in width. All chromite lenses have a sharp southern contact and a diffuse northern contact. Commonly a zone of disseminated chromite extends into the serpentinite from the diffuse lens margin. Up to three parallel lenses of chromite may occur, separated by 10 to 15 m of serpentinite, in areas of major concentration, but the lenses are more commonly isolated. The chromite ore consists of aggregates of euhedral to subhedral chromite crystals, 0.1 to 2 mm across, with intergranular chlorite. This indicates that complete separation may require fine grinding. The composition of individual lenses varies between 46.4 and 50.8 per cent Cr_2O_3 and the Cr_2O_3:FeO ratio from 2.3:1 to 1.35:1. This variation does not appear to be consistent as a differentiation trend within the body. An analysis of a bulk sample is given in Table 18.

TABLE 18. Analysis of bulk sample of chromite ore, Coobina

Oxide	Per cent
Cr_2O_3	46.16
MnO	0.26
Al_2O_3	10.89
Fe_2O_3	2.78
FeO	20.48
MgO	11.04
SiO_2	5.76
H_2O	2.21

Analyst: Government Chemical Laboratories

References

Blatchford (1925), Montgomery (1925), Simpson (1925), Talbot (1926), Finucane (1938), Matheson (1951), de la Hunty (1953), Le Mesurier (1953).

OTHER DEPOSITS

PILBARA BLOCK

While regional mapping in the Marble Bar and Yarrie 1:250 000 sheet areas, officers of the Geological Survey of Western Australia reported two ultramafic bodies containing chromite lenses (Hickman and Lipple, 1975).

Nobs Well
(Lat.20°50'S, long.120°11'40"E)

The Nobs Well occurrence is 3 km northeast of Nobs well, about 6 km southwest of the Bamboo Creek mining centre.

A serpentinized peridotite sill intruding the Archaean Duffer Formation has pods of chromite near the basal contact. Disseminated chromite in crystals between 1 and 2 mm in diameter occur throughout the peridotite. Assays of three samples of the chromite-rich layers reported 2 200, 4 000 and 31 500 ppm Cr.

Pear Creek
(Lat.20°53'S, long.119°31'E)

The Pear Creek occurrence is about 5 km south of the point at which Pear Creek crosses the Great Northern Highway.

A serpentinized peridotite which intrudes a fault line separating the Archaean Gorge Creek and Warrawoona Groups has chromite concentrated within it. Chromite is also disseminated throughout the ultramafic body.

The deposit has been drilled but no data are available from this work.

YILGARN BLOCK

Chromite deposits have been recorded from two geological environments within the Yilgarn Block. Three of the occurrences are located in upper-amphibolite to granulite facies metamorphic rocks in a high grade metamorphic belt which bounds the Murchison and Eastern Goldfields Provinces. These are associated with ultramafic bodies which occur in a gneissic terrain. Chromite has also been recorded in a segregated layer within the Bulong Complex. Some assessment has been made of all of these deposits including diamond drilling, costeaning, and geological mapping, but no deposit of economic significance has been identified.

Imagi Well

(Lat. $26^{o}11'53''$S, long. $116^{o}12'33''$E)

The Imagi Well chromite prospect is located on Byro Station and occurs in an area which runs approximately northeast from Imagi well. It is accessible on station tracks, from Mardagee woolshed via Franks bore, or from the Mullewa-Gascoyne Junction road through Scott well, and then 8 km along a southeasterly track to Imagi well. The prospect was investigated by Electrolytic Zinc Company Australasia Limited who concluded that there were insufficient reserves to warrant detailed exploration drilling.

The chromite occurs as discontinuous lenses in a sequence of amphibolites which range in composition from quartz amphibolites to pyroxene amphibolites. These rocks form part of a regional gneissic complex. The metamorphic grade is determined at upper amphibolite facies, but many of the rocks show signs of retrograde metamorphism.

The continuity of different lithologies within the gneissic complex has not been determined. The exposure in the area is very poor. The regional strike of the sequence is 020^{o}, dipping west between 80^{o} and 85^{o}. Rupture of the regional foliation has occurred along faults which trend 070^{o} and dip steeply south.

Taccabba Well
(Lat.26°05'27"S, long.116°37'57"E)

The Taccabba Well occurrence of chromite occurs below the flood plain of the Murchison River. There is no exposure at the surface. The centre of the deposit is about 4 km west of Milly Milly homestead on the road by Byro, about 1 km north of the road. Most of the deposit is covered by up to 20 m of alluvial sediment. The area has been prospected by Pacminex Pty Ltd who concluded that there were insufficient reserves to warrant further exploration.

In one diamond drillhole (DDH 1) a banded sequence of felsic and mafic rocks with one thin chromite-bearing ultramafic unit was intersected. The entire succession had been metamorphosed in the granulite facies. The sequence had a regional northeasterly strike and a steep westerly dip. The chromite ore is approximately parallel to the regional strike. This prospect is not considered to be of any economic significance.

Reference: Horsley (1974).

West Bendering
(Lat.32°23'27"S, long.118°08'55"E)

The West Bendering occurrence is located about 26.8 km east of Corrigin on the western side of a saltpan. The deposit has been drilled by Electrolytic Zinc Company Australasia Limited.

A metamorphosed mafic to ultramafic complex containing layers of amphibole lherzolite, harzburgite, and serpentinite (possibly after dunite), which has generally undergone high grade metamorphism contains thin chromite lenses. Bands of chromite have been located within the amphibole lherzolite member of the sequence. In some sections up to 10 per cent chromite have been recorded (W. Morgan, pers. comm., 1974).

Bulong Complex
(Lat.30°46'11"S, long.121°50'17"E)

The chromite occurrence in the Bulong Complex occurs on the east side of a norite hogback hill about 30 m high. It is 0.8 km south of the Bulong vermiculite deposits, and about 100 m west of the track between the vermiculite mine and Canyon dam. The deposit occurs at the base of a norite intrusion and has been exposed in several places by costeans. The chromite zone is about 15 to 20 cm wide and has been traced parallel to the strike for about 1 km. The chromite is accompanied by serpentine. There does not appear to be sufficient chromite in this deposit to warrant detailed exploration.

Reference: Moeskops (1973).

ALBANY-FRASER PROVINCE

Salt Creek
(Lat.29°32'36"S, long.124°55'04"E)

The Salt Creek occurrence is about 2.5 km south of Salt Creek, from a point at which Salt Creek takes a prominent turn from the north to the east. The deposit has been known as the Datum prospect. It is accessible on gravel roads and ungraded tracks from either Laverton, or the Trans Australian Railway.

The chromite potential of these deposits was tested by Mineral Search and Development Ltd during 1971. Discontinuous irregular chromite lenses occur in metaperidotite which intrudes a high grade metamorphic gneissic sequence. The chromite appears to be concentrated at the base of the ultramafic body. The metaperidotite is intruded by granitic rocks.

References: Cheeseman (1971), Lynch (1971a, b), van de Graaff and Bunting (1974).

Chromite occurrences have been reported from the Alice Downs Ultrabasics in the Lamboo Complex of the Halls Creek Province. These occurrences consist of layered chromite in metamorphosed peridotite and gabbro. At Lamboo and the Panton Sill these bands are well developed, but contain too high a proportion of iron to be a source for chromium.

Panton Sill
(Lat.17°47'43"S, long.127°48'34"E)

The Panton Sill is situated some 37 km north of Halls Creek on the west side of the Great Northern Highway. The locality is marked on the Dixon Range 1:250 000 geological map sheet.

Chromite in the Panton Sill occurs as disseminated grains, primary segregated bands, and secondary veins. In one zone which is up to 10 m wide and more than 1 km long, steeply dipping chromite bands up to 3 cm thick are intercalated with altered ultramafic rocks. Secondary chromite veins up to 100 m long and 60 cm wide occur within the sill. Assays of grab samples are presented in Table 19. Hamlyn (1975) has reported on the alteration of chromite from the Panton Sill.

TABLE 19. Assay of chromite ore from Panton Sill

	Per cent
Cr	22.3
Fe	21.6
Ni	0.12

Analyst: Government Chemical Laboratories

References: Dow and Gemuts (1967, 1969), Hamlyn (1975).

Lamboo
(Lat.18°27'57"S, long.127°19'30"E)

The Lamboo occurrence is situated about 10 km north of Lamboo homestead. The occurrence is shown on the Mount Ramsay 1:250 000 geological map sheet.

Several bands of chromite are reported from a zone about 6 m wide near the base of a serpentinized peridotite. Chromitite lenses 50 m long and up to 10 m wide occur within the zone which can be traced around most of the peridotite body. The chromite deposits are too small and low grade to warrant exploitation.

References: Roberts and others (1968), Dow and Gemuts (1969).

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FIGURE 6 - KEY

1. Coobina
2. Nobs Well
3. Pear Creek
4. Imagi Well
5. Taccabba Well
6. West Bendering
7. Bulong
8. Salt Creek
9. Panton Sill
10. Lamboo

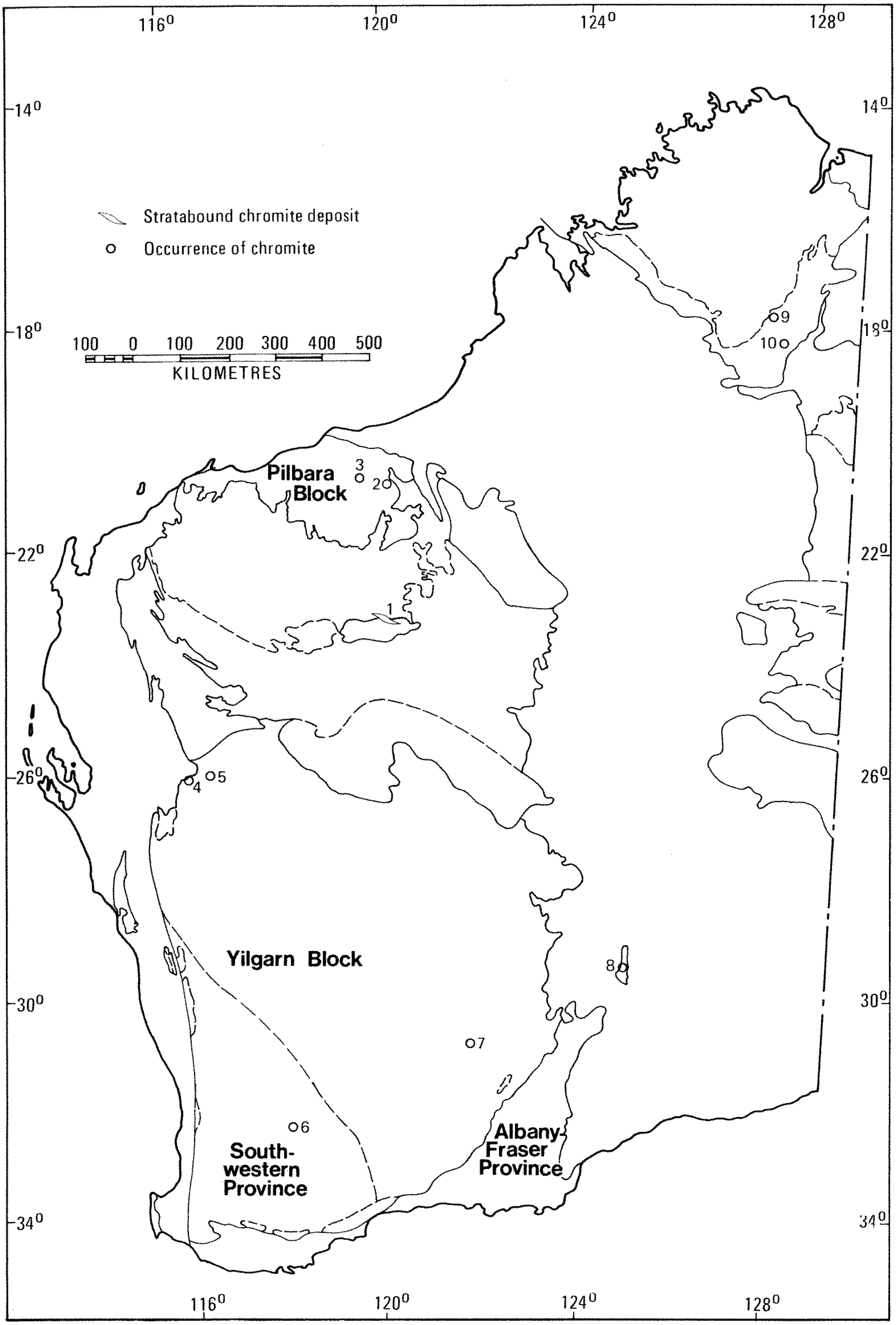

Figure 6. Metal occurrence map - chromium (GSWA 17397).

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