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DIMENSION STONE IN WESTERN AUSTRALIA

Volume 2

DIMENSION STONES OF THE SOUTHERN, CENTRAL WESTERN, AND NORTHERN REGIONS

by JM Fetherston



Geological Survey of Western Australia

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FRONTISPIECE

Dimension stone in contemporary artwork. This sculpture is a whimsical interpretation in grey granite and bronze of quarrymen at work by Danish sculptor, Keld Moseholm. Sculpture by the Sea exhibition at Cottesloe, 2008

Government of **Western Australia**
Department of **Mines and Petroleum**

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Geological Survey of Western Australia

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Cover photograph:
The *Boogardie Orbicular* granite from the Mount Magnet district. This rare and visually attractive granite with its distinctive orbicular texture is destined for recognition as a spectacular dimension stone on international markets

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Dimension stone in Western Australia

Volume 2
Dimension stones of the Southern, Central Western, and Northern Regions

by

JM Fetherston

Abstract

This Mineral Resources Bulletin completes a two-volume series on dimension stone in Western Australia. The first volume reviewed the industry, and dimension stones in the southwest region of the State This volume encompasses 117 sites covering dimension stone quarries, prospects, and historical sites throughout three broad areas of the State. These include the southern region covering Albany, Esperance, Fraser Range, and Kalgoorlie–Boulder. The central western area extends from Mount Magnet to Shark Bay and north to the Ashburton River, and the northern region includes parts of the west Pilbara and southern Kimberley.

In these areas, major dimension stone rock types include granite and metamorphic rocks, black granite, marble, and sandstone. Minor dimension stone types comprise conglomerate and breccia, banded jasper, spongolite, coquinite, felsic volcanogenic rocks, and silica. Major operations, mostly active at some time over the last 40 years, include 19 granite and metamorphic rock quarries, 12 black granite quarries, and eight operations for both marble and sandstone. During this period, stones from many sites have been recognized in Australia and abroad as visually attractive, high-quality dimension stones for use in interior and exterior cladding of contemporary buildings, in impressive streetscapes, and in monumental works. Some have received architectural awards. Spectacular granites include *Desert Brown* from Esperance, *Verde Austral* from Fraser Range, *Kimberley Pearl* and *Kimberley Storm* from the west Kimberley region, and *Laguna Green* from Jerramungup. Other notable stone types include the award-winning *Kimberley Sandstones* and *Kimberley Quartzite* from Derby, *Kimberley Black* granite from the west Kimberley, and the beautiful *Pilbara Green* marble from the central west of the State.

Currently, the world market for dimension stone is dominated by low-cost producing countries such as China, India, and Brazil. Higher cost countries including Australia now find it difficult to compete in world markets. In Western Australia our strength lies in the export of small quantities of high-quality and often unique stone types in the form of 10 t blocks. In future years it is expected that the export situation may improve as the supply of local stone becomes less plentiful in more densely populated countries, especially in parts of Europe, and countries such as China and India need to divert an increasing amount of locally produced dimension stone into their own rapidly expanding domestic markets. This situation may encourage major international stone companies to invest in Western Australia, which has large resources of high-quality dimension stone unlikely to be affected by rapid urbanization.

In future, it is possible that 'stone supermarkets' could be developed in resource-rich areas such as the west Kimberley region with its high-grade granites, black granites, and sandstones, the Edmund and Ashburton Basins in the central west that contain a spectacular array of multicoloured marbles, and Fraser Range in the central south with an impressive suite of granites, black granites, and metamorphic rocks. Should these trends in the development of the State's dimension stone industry come to fruition, it will ensure Western Australia's position as a long-term exporter of high-quality dimension stone on world markets.

KEYWORDS: Western Australia, dimension stone, building stones, ornamental stone, monumental stone, granite, gneiss, granulite, black granite, marble, sandstone, quartzite, conglomerate, breccia, banded jasper, spongolite, coquinite, felsic volcanic rocks, silica, physical properties, mineral exploration, quarrying, natural resources, mineral economics, Yilgarn Craton, Pilbara Craton, Hamersley Basin, Gascoyne Province, King Leopold Orogen, Halls Creek Orogen, Albany–Fraser Orogen, Ashburton Basin, Edmund Basin, Kimberley Basin, Canning Basin, Southern Carnarvon Basin, Eucla Basin.

Chapter 1

Introduction

Object and scope

This Mineral Resources Bulletin completes a two-volume series on dimension stone in Western Australia. Volume 1 (Fetherston, 2007) presented a current review of the dimension stone industry including history of use, rock types and their physical properties, quarrying of stone blocks and added-value processing, world production and markets, and stone restoration techniques. A description of dimension stone quarries, prospects, and historical sites in the southwest region of the State completed the volume.

Volume 2 encompasses dimension stone quarries, prospects, and historical sites located in many other accessible parts of Western Australia. This includes the southern region covering areas around Albany, Esperance, Fraser Range, and Kalgoorlie–Boulder, and the central western region extending from the Mount Magnet area west to Shark Bay and north to the Ashburton River. The northern region comprises areas of the west Pilbara around Port Hedland, Karratha, Tom Price, and Newman, as well as areas of the southern Kimberley situated between Broome and Halls Creek. These regions are depicted in Plate 1.

In accordance with Volume 1, this publication is for the information of prospectors, geologists, dimension stone processors, architects, civil engineers, landscape designers and others interested in the current prospectivity, quarrying, processing and end-uses of spectacular dimension stones present in these areas of the State. It is also intended to serve in future years as a reference work of the State's current dimension stone resources for explorers and developers who may wish to take advantage of niche market situations that may arise both in Australia and abroad, and as a source of raw material for unique, architecturally designed buildings, monuments and landscape designs specifying Western Australian dimension stone. It should be noted that in this volume, as in Volume 1, names of dimension stones recognized by industry are shown in italics, e.g. *Laguna Green*.

A summary of current dimension stone operations throughout Western Australia including quarrying, stone processing, and applications is given in Fetherston (2008).

Sources of information

Sources of information in this Bulletin include both published and unpublished information, supplemented by data gathered on field inspections. Published information is derived from Geological Survey of Western Australia (GSWA) records, reports, bulletins, annual reports, explanatory notes, and geological maps. Other published information includes papers in journals, conference papers, and articles published in newspapers and magazines.

Unpublished information is obtained from open-file, statutory reports submitted to the Department of Minerals and Petroleum (DMP) by various mineral exploration companies. This is supplemented by unpublished data made available by dimension stone producers, prospectors, and persons involved in the collection and preservation of information relating to the historical development of a number of towns in the State.

Dimension stone sampled during field investigations was sourced from stone quarries, prospects and historic sites within the areas covered by Volume 2. All sites visited have been assigned accurate GPS grid reference values (MGA values, Zones 50–52) to assist in site relocation. Grid reference values for a small number of prospects and historic sites not accurately located are marked 'position approximate' or 'location uncertain'. Locations for all quarries, prospects, and historic sites are given in Appendix 3 and sites are listed in the DMP online 'MINEDEX' mines and mineral deposits database.

Most dimension stone samples were diamond cut and ground, or polished as reference specimens. These were digitally photographed prior to incorporation in the GSWA Core Library collection at Carlisle in Perth to be made available for inspection by industry and the public. Photographs of most reference specimens are included in a photo image gallery of dimension stones displayed in Appendix 4. Twenty-two samples of marble from significant dimension stone quarries and prospects in the Edmund and Ashburton Basins were selected for chemical oxide analysis for major elements and key trace elements. A pale green quartz sandstone from the Karratha area was also selected for the same form of analysis. Chemical analyses are presented in descriptions of individual dimension stone localities from which these samples were collected.

Also, the majority of specimens were submitted for thin-section preparation and petrographic description by Pontifex & Associates Pty Ltd (Purvis, 2009a–f). Petrographic descriptions presented with most dimension stone localities closely paraphrase these reports.

For the convenience of readers, tables displaying dimension stone nomenclature and physical properties have been reproduced from Fetherston (2008) and are presented in this volume in Appendices 1 and 2 respectively.

Abbreviations

Al	Aluminium
BIF	Banded iron-formation
BP	before present
CaO	calcium oxide
Fe	iron
ha	hectares
GSWA	Geological Survey of Western Australia
GPS	Global positioning system
JORC	Joint Ore Reserves Committee
K-feldspar	potash feldspar
m^3	cubic metres
Ma	million years (age)
MGA	Map Grid of Australia
MgO	magnesium oxide (magnesia)
Mm^3	million cubic metres
µm	micrometre
MPa	megapascal
Mt	million tonnes
t	tonnes
t/m^3	tonnes per cubic metre
USA	United States of America
UV	ultraviolet

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The assistance of persons involved in the collection and preservation of information relating to the historical development of a number of towns in the State is acknowledged. In particular, information provided on the source and application of stone blocks for building construction in the late 19th and early 20th Centuries by Ms Tess Thomson of the Eastern Goldfields Historical Society Inc., and Dr Bob Fagan (Kalgoorlie–Boulder), Mr Ian Murray (Bullabulling and Coolgardie), and Mr Kevin Anthony (Cue) is gratefully appreciated.

Chapter 2

Granite and metamorphic rocks

Southern region

Albany–Fraser Orogen

Albany — granite

The area around the City of Albany is well endowed with Mesoproterozoic granitic rocks, which include the 1174 Ma Albany Adamellite of the Esperance Supersuite, within the Nornalup Zone of the Albany–Fraser Orogen (Pidgeon, 1990). Immediately east and west of the city area are the large granitic masses of Mount Clarence and Mount Melville, respectively, and Willyung Hill located 10 km north of the city (Fig. 1). Most of the quarries in the city area were developed in the late 19th and early 20th centuries for the production of crushed aggregate and also for building blocks for a number of the city's early stone buildings (Fig. 2).

Mount Clarence historic quarry

The Mount Clarence historic quarry is located adjacent to Boronia Avenue, 1.5 km northeast of the Albany city centre (Fig. 1). This is a small quarry, possibly in excess of 100 years old, situated on a northwest outlier of Mount Clarence. This site appears to have been a source of rough-cut blocks for drains and dry stone walls, and possibly building material. The quarry rock varies from an inequigranular, grey syenogranite that is transitional to a fine-grained, grey, biotite monzogranite.

Petrographic description

Inequigranular, grey syenogranite transitional to monzogranite containing sericite or saussurite in plagioclase, clay–chlorite–epidote in biotite, dark hornblende, accessory opaque oxide and sparse zircon.

The sample contains scattered feldspar grains to 15 mm long, and the visually estimated mineralogy indicates 44% K-feldspar, 27% quartz, 21% plagioclase, 5% biotite, 2.5% hornblende and 0.5% oxide plus apatite, with sparse zircon to 0.2 mm long. The larger feldspar grains are weakly perthitic orthoclase and are accompanied by plagioclase laths to 6 mm long with strong sericite or saussurite alteration. Quartz forms in lenses to 10 mm or more in length with crystals to 6 mm long. Hornblende and biotite are both dark coloured and probably Fe-rich with minor opaque oxide and sparse zircon, rarely as much as 0.4 mm long. Biotite–quartz symplectites are observed, but myrmekite is fresh. Some of the hornblende may be altered to paler amphibole and clay–chlorite alteration is accompanied by epidote and prehnite partly parallel to the cleavage.

Mount Melville

Historic quarries

The upper western slopes of Mount Melville contain at least three very large and deep, abandoned quarries cut into the local, megacrystic syenogranite (Fig. 1). The rock is quite massive as evidenced by the large granite tors scattered throughout the area (Fig. 3). Today, these quarries are completely overgrown by regeneration of native bush and it is obvious that they have not been in use for many years, but they were almost certainly a major source of construction material for Albany from the late 1800s onward.

Albany Monumental Masons quarry

This quarry is also located on the upper slopes of Mount Melville, about 2 km west-northwest of the city centre (Fig. 1). The relatively small quarry is cut into massive, grey syenogranite with large, well-formed grey to pink K-feldspar megacrysts and local minor black xenoliths. This rock is known in the dimension stone industry as *Albany Granite* (Fig. 4; Appendix 4.1).

This is the site of the Albany Monumental Masons quarry and monumental workshop which has been manufacturing polished and engraved slabs and stone ornaments for many years. Today, the quarry is in care and maintenance as the operators now source their stone from quarries such as Willyung Hill, to the north of the city, and also from Esperance.

Petrographic description

Hornblende–biotite syenogranite with K-feldspar megacrysts, weak sericite-clay alteration and altered possible allanite, and rare zircons.

In this sample, grey megacrysts seem to be mostly less than 15 mm long and 8 mm wide. The visually estimated mineralogy includes 45% microcline, 27% quartz, 16% plagioclase, 9% biotite, 1.5% hornblende, 1% titanite and opaque oxide, and 0.5% altered possible allanite, indicating hornblende–biotite syenogranite. Apatite is disseminated and there are rare zircons about 0.05 mm in diameter. The megacrysts are weakly perthitic and have inclusions of quartz and plagioclase. The host is largely

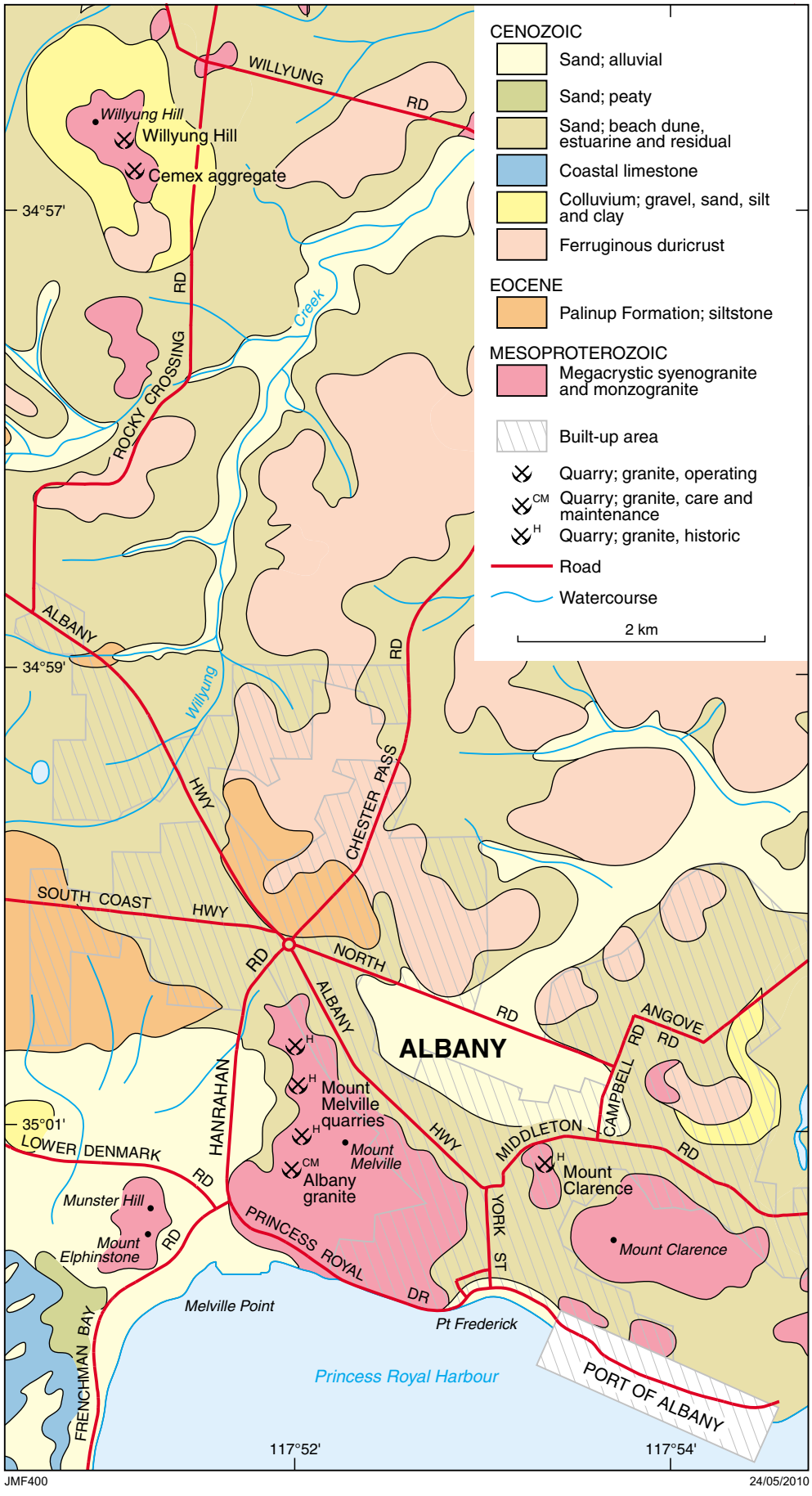


Figure 1. Geological map of the Albany area (modified after Gozzard, 1989).



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Figure 2. Dimension stone used in the Albany Courthouse. Completed in 1898, this historic building has a plinth and arched doorways constructed from blocks of roughly coursed Albany granite.



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Figure 3. Syenogranite tors on the upper slopes of Mount Melville in Albany. Largest tor has a volume of approximately 15 m^3.

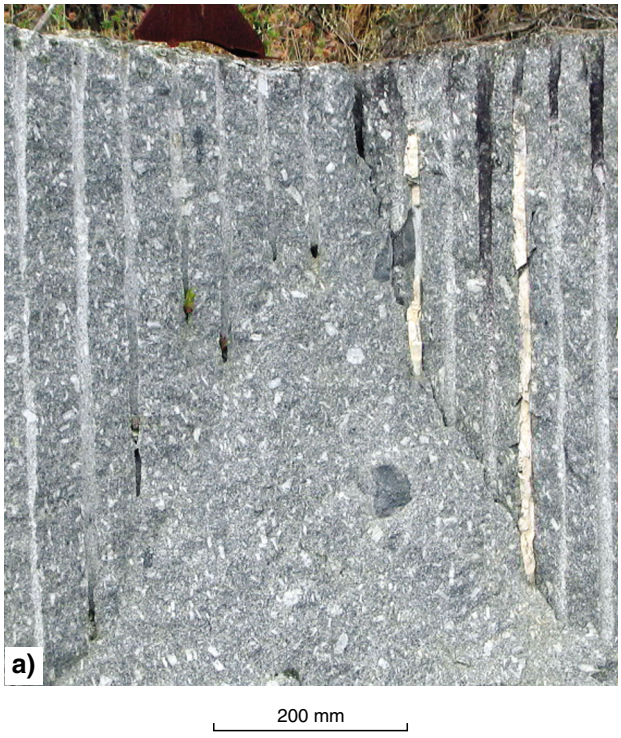


Figure 4. ***Albany Granite*, a megacrystic, grey syenogranite: a) granite exposed in Albany Monumental Masons' quarry, Mount Melville; b) memorial stone plaque at Mount Clarence.**

composed of quartz, plagioclase and minor K-feldspar to 3 or 4 mm in diameter as well as mafic grains and aggregates, mostly biotite with minor brown hornblende to 2 mm in diameter. Titanite, opaque oxide, and clay with some carbonate-altered possible allanite are disseminated, with accessory fine-grained apatite. The plagioclase has weak sericite-clay alteration and there is weak clay dusting in some K-feldspar grains.

Willyung Hill

Willyung Hill quarry is located 10 km north-northwest of the city (Fig. 1). At this site, Albany Monumental Masons have a small dimension stone quarry, approximately 10 m wide and 3 m high, located a short distance below the summit of the hill, and adjacent to Cemex Australia's very large aggregate quarry farther downslope (Fig. 5). At this site the Willyung Hill granite is a massive, megacrystic, grey biotite syenogranite but is substantially more leucocratic than the syenogranite at Mount Melville *(Albany Granite)*, possibly making the stone more visually attractive (Appendix 4.2). The large, well-formed K-feldspar megacrysts are aligned in a distinct north-trending igneous foliation. At the Willyung Hill quarry, the operators are cutting blocks suitable for transportation to their monumental works at Mount Melville.

Petrographic description

Megacrystic biotite syenogranite, with subparallel K-feldspar megacrysts in an igneous foliation with quartz, plagioclase, biotite, titanite, altered allanite, zircon, epidote, and apatite. Also, anomalously coarse, strongly zoned zircon crystals up to 1.5 mm are present.

Subparallel platy feldspar megacrysts to 25–30 mm long are seen in this sample in hand specimen but the thin section has subparallel megacrysts to 15 mm long. The visually estimated mineralogy has 42% microcline, 32% quartz, 17% plagioclase, 8% biotite, 1% titanite, and altered allanite(–chlorite–epidote). The overall composition is similar to the *Albany Granite* at Mount Melville and is also syenogranite. Minor apatite is disseminated and zircon is present as crystals to 1.5 mm long with the largest crystal being zoned and parallel to the foliation. The megacrysts are mostly 3–4 mm wide and may define an igneous foliation, with mostly granular quartz and plagioclase to 4 or 5 mm in diameter and decussate biotite aggregates to 5 mm long containing biotite flakes to 2 mm long as well as altered probable allanite, zircon, and apatite. Minor titanite is disseminated and some of the biotite has been altered to chlorite, locally with epidote in and adjacent to the chlorite. Weak sericitic alteration is seen in the plagioclase.

Esperance — granite

Desert Brown

The *Desert Brown* granite is located in the Esperance area on the State's southern coast. This granite belongs to the Esperance Supersuite of the Nornalup Zone, and is dated at approximately 1150 Ma (Nelson, 1995). In the Esperance area, an extensive, northeasterly trending, granitic mass is largely covered by a Cenozoic sandplain although crests of numerous, but mostly small, domes of granite, granitic gneiss, and migmatite remain exposed.

The Merivale Road quarry is situated about 14 km east-northeast of Esperance, on a small granitic dome at Mount Edward (Fig. 6). The north-trending dome, approximately 900 m in length by 200 m wide, has a moderately large quarry at its southern end that is host to the *Desert Brown* granite. *Desert Brown*, also formerly known as *'Salmon Pink'* or *'Perth Nutmeg'*, is a light brown, foliated, megacrystic, biotite syenogranite containing numerous pinkish-brown megacrysts of K-feldspar 25–30 mm in length.

The Merivale Road quarry is owned by AustralAsian Granite that operates on site under an extractive industry



Figure 5. Willyung Hill granite operations: a) Willyung Hill leucocratic syenogranite quarry; b) stockpile of blocks and slabs at Albany Monumental Mason's plant. White, vertical slabs (centre left) are Willyung Hill syenogranite.

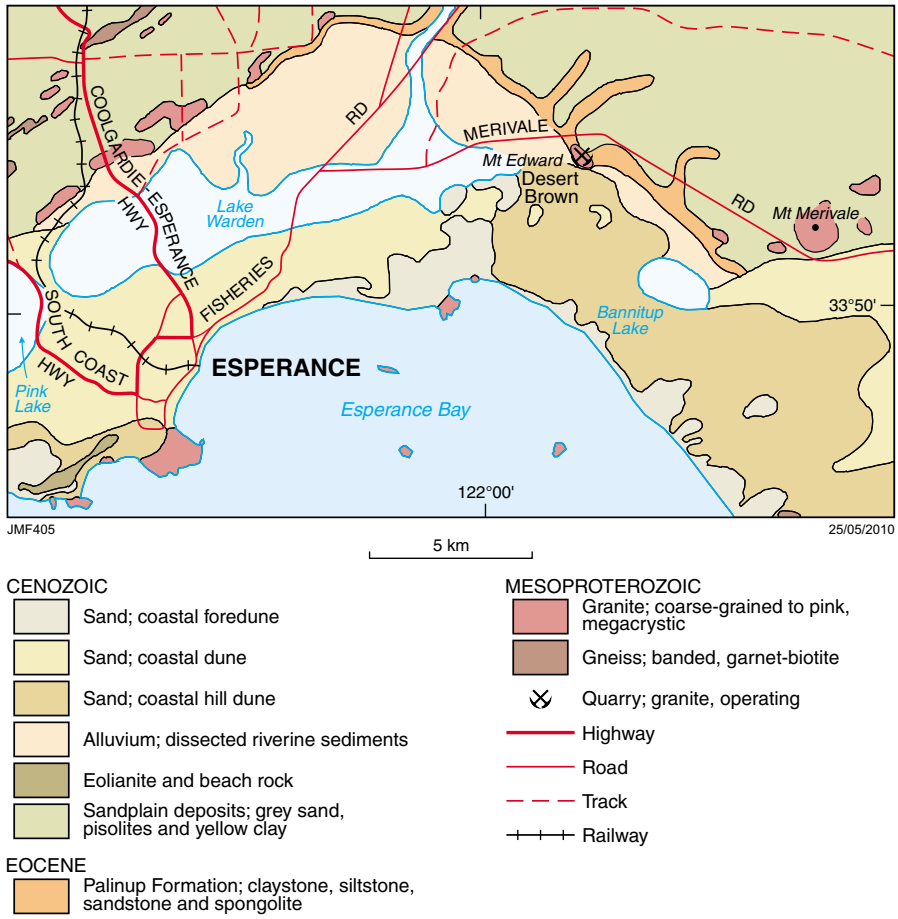


Figure 6. Geological map of the Esperance area (modified after Morgan, 1972).



Figure 7. *Desert Brown* block extraction operations at Merivale Road quarry, Esperance area (photo courtesy Melocco Stone).

licence. *Desert Brown* is quarried on a campaign basis according to demand from the construction and monumental industries. Past production figures indicate that in 2001 the company was producing about 1200 m^3 per annum (Industrial Mineral Services, 2001). Currently, the company maintains a large stockpile of 10 t granite blocks to meet existing orders. It is estimated that resources are probably adequate to meet current demand for at least the next decade.

The quarry is efficiently operated on three levels with accessible benches 4–5 m in height. Quarrying is carried out using the industry-standard Finnish method for block recovery in which large primary blocks are first cut out using close-spaced drilling and diamond wire sawing. In Figure 7, the primary block is then subdivided in a series of close-spaced drill lines into secondary blocks and finally into saleable 10 t blocks (Fetherston, 2007).

Desert Brown is a well-known dimension stone in the construction industry, being potentially suitable for most applications from monuments to cladding large-scale city buildings. The stone is a visually attractive, mottled, light-brown colour that takes a very high polish (Appendix 4.3), and has excellent physical properties, given by Melocco Stone (2009), that include:

- Absorption 0.243%
- Bulk density 2.636 t/m^3
- Compressive strength (dry) 206 MPa
- Flexural strength (dry) 13 MPa

Blocks have been used in a variety of projects mainly in Melbourne, Sydney, Perth, and South East Asia. Possibly the largest project undertaken to date was the cladding of the exterior of the ANZ Bank World Headquarters in Melbourne (Fig. 8). Other projects have included the Dhana Siam Project in Bangkok, Thailand, and exterior and interior cladding on four, ten-storey buildings in Taiwan.

Petrographic description

A biotite syenogranite with pinkish microcline megacrysts and weakly sericitized plagioclase together with accessory opaque oxide and traces of apatite and zircon.

The rock is rich in probable large pink K-feldspar grains to 12 mm in size and less abundant, white plagioclase to 8 mm in diameter. The visually estimated mineralogy includes 39% microcline, 35% quartz, 16–17% plagioclase, 5–6% biotite, 2.5% myrmekite, and 1.5% opaque oxide. This indicates a more felsic syenogranite than those from Albany. The microcline is pink in hand specimen and weakly hematite stained, with inclusions of quartz and plagioclase, and has minor myrmekite. Interstitial quartz is as much as 8 mm long and is mostly accompanied by plagioclase to 4 mm in diameter and biotite flakes to 3 mm long. Opaque oxide occurs as irregular grains to 1.5 mm long and there is minor apatite as well as zircon about 0.1 mm in diameter. Weak sericite alteration is seen in the plagioclase.

Fraser Range — gneiss, charnockite, and mafic granulite

The Fraser Range region comprises a series of north-northeasterly trending, steeply dipping, lenticular thrust slices that transect the Eyre Highway between 80 and 150 km east of Norseman. The Fraser Range Metamorphics lie within the Fraser Zone of the Albany–Fraser Orogen, adjacent to the southeastern margin of the Archean Yilgarn Craton. These metamafic rocks possibly represent a layered mafic intrusion or an uplifted section of lower crustal material and are dated about 1300 Ma (Spaggiari et al., 2009; Fig. 9).

The Fraser Complex constitutes a large part of the eastern extremity of the Albany–Fraser Orogen On the western flank of Fraser Range, the Fraser Complex consists predominantly of a series of mafic, orthopyroxene-rich granulite thrust slices containing abundant layers of garnet-bearing granitic gneiss in some areas, as well as metagabbro and charnockitic rocks. On the eastern side of the range, adjacent to the Eyre Highway, an additional thrust slice of the Fraser Complex comprises mostly metagabbro and amphibolite (Myers, 1985; Jones and Hall, 2004).

The Biranup Complex, also part of the Albany–Fraser Orogen, is located between the western edge of the Fraser Complex and the southeastern margin of the Yilgarn Craton and in this area comprises granitic and metasedimentary gneiss dated at about 1293 Ma.

Verde Austral, a charnockitic, gneissic granodiorite, is the only dimension stone currently in production at Mount Malcolm in the southern part of Fraser Range. Farther north, adjacent to the Eyre Highway, is the *Garnet Ice* quarry (a garnet-rich gneiss) currently in care and maintenance. Between 7 and 20 km north of the highway are three test quarries; American, Phill's, and Fantasia, as well as the Horseshoe prospect, located in areas of mafic granulite and gneiss.

Verde Austral

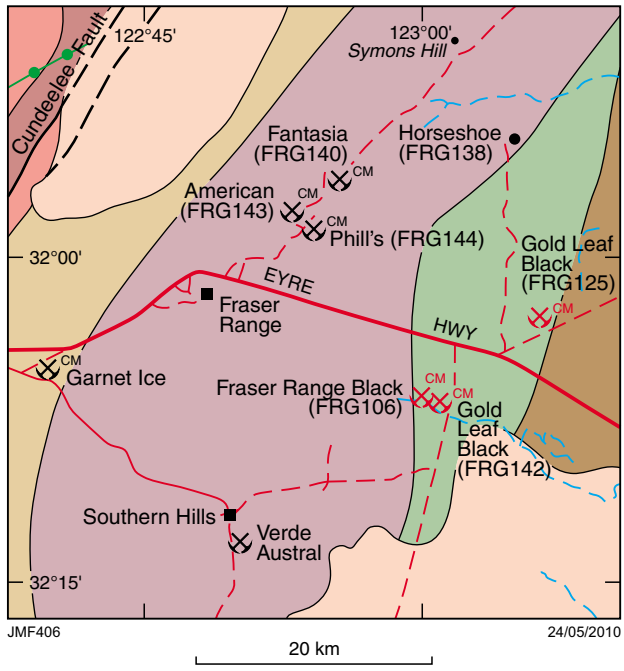
Verde Austral is a very hard, gneissic granodiorite. It is coarse-grained, greenish-grey rock that assumes a deep olive-green colour when polished. It has a charnockitic tendency based on its mineral content of orthopyroxene, plagioclase and orthoclase feldspars, and bluish-tinged quartz. Minor minerals include hornblende, biotite, opaque oxide, apatite, and zircon.

The *Verde Austral* quarry is located at Mount Malcolm, 100 km east of Norseman and about 30 km southeast of the Eyre Highway (Fig. 9). *Verde Austral* was first recognized as a potential dimension stone by Maritana Gold NL in 1988. The company subsequently changed its name to Fraser Range Granite NL and began to develop the initial quarrying operation. In the mid-1990s, Norwegian quarrying methods including specialized dimension stone drilling, diamond wire block sawing, and the creation of 6 to 8 m-high quarry faces, were introduced at the quarry to improve the quality and quantity of quarry blocks.





Figure 8. **Applications for *Desert Brown* granite: a) ANZ Bank World Headquarters in Melbourne is clad with slabs of *Desert Brown*; b) detail of *Desert Brown* slabs in the ANZ Bank building (full slab width is approximately 0.5 m).**



CENOZOIC
- Limestone, sandstone, lignite and spongolite

MESOPROTEROZOIC
Albany-Fraser Orogen
Nornalup Complex
- Granitic gneiss and granite

Biranup Complex
- Granitic and metasedimentary gneiss

Fraser Complex
- Mafic, orthopyroxene-rich granulite with garnet-bearing granitic gneiss, metagabbro and charnockite
- Dolerite, gabbro, metagabbro and amphibolite
- Mafic-ultramafic Jimberlana Dyke

ARCHEAN
Yilgarn Craton
- Granitoid rock
- Mafic schist, metabasalt, metadolerite, amphibolite and metasedimentary rocks
- Fault
- Fault, concealed
- Quarry; gneiss, operating
- CM Quarry; granulite, care and maintenance
- Prospect; granulite
- CM Quarry; black granite, care and maintenance
- FRG142 Fraser Range exploration site number
- Highway
- Road
- Track
- Ephemeral watercourse
- Homestead

Figure 9. **Geological map of the Fraser Range region (modified after Myers, 1985; Sanders, 2000; Jones and Hall, 2004).**

Since that time, the operation has changed ownership to Allied Granites Pty Ltd, and finally to the current owners, Dimension Stone Group Australia Pty Ltd.

The *Verde Austral* deposit at Mount Malcolm consists of mining lease M63/235, that contains the operating quarry. A former contiguous mining lease, M63/276, also known as 'The Dome' immediately north of the quarry lease, contains additional stone resources of lesser quality.

At the quarry site, operations extend over a comparatively large area. Owing to the stone's extreme hardness, and apparent paucity of jointing, the company has retained the 6 m-high quarry faces, but blocks are now cut entirely by diamond wire sawing to achieve maximum quality control. Operating quarry faces are orientated parallel to a steeply dipping, north-northeasterly trending foliation as it has been found that blocks cut parallel to this foliation plane produce the highest polish. Diamond wire sawing produces primary blocks 1.8 m wide × 6.0 m high × 8.0 m deep cut into the quarry wall (Fig. 10). In recent years, the area around the quarry has been drilled to 30 m depth. Results have shown that substantial resources of *Verde Austral* appear to be contained within a 200 m-wide, west-northwest trending zone. Currently, Dimension Stone Group Australia has opened a new bench at the lower 3rd level in the quarry exposing a high-quality, massive stone unbroken for depths of at least 8–10 m. The company estimates current dimension stone resources in the quarry area at about 6000 m^3 (~16 000 t).

Verde Austral is a very hard rock making it extremely durable in exterior applications. It is amenable to precision cutting into greenish-grey blocks, slabs, tiles and other more complex shapes (Fig. 11). When polished it takes on a visually attractive deep olive-green hue (Appendix 4.4). It has excellent physical properties, particularly for strength, given by Melocco Stone (2009):

- Absorption 0.068%
- Bulk density 2.660 t/m^3
- Compressive strength (dry) 240 MPa
- Modulus of rupture (dry) 12.7 MPa
- Flexural strength (dry) 16 MPa

Apart from some architectural and monumental applications for *Verde Austral* in Western Australia, the principal market appears to be in the eastern states, particularly in Sydney. In the mid-1990s the stone was used in the construction of prestigious buildings in Sydney City such as Governor Phillip Tower, Governor Macquarie Tower, First Government House Museum, and buildings at Darling Harbour, Later, the stone was one of three dimension stones specified by the Sydney City Council for use in upgrading public areas prior to the Olympic Games in 2000. For this purpose *Verde Austral* was used extensively as kerb stones and paving slabs in main streets and public places in central Sydney. Other paving projects included the Channel 10 building, Townhall House, and the Ritz Cinema, all in Sydney, and the Rockhampton Courthouse in Queensland.

More recently, applications for *Verde Austral* have begun to appear in Perth City with the redevelopment of the entrance to the Concert Hall (Fig. 12), the foyer of the Town Hall and a number of other sites in the city. It is understood that this stone may be used in the redevelopment of a number of public places in Perth in the near future.

Petrographic description

The gneissic granodiorite is weakly foliated and may be charnockitic. The visually estimated mineralogy includes 37% quartz, 42% plagioclase plus myrmekite, 10% orthoclase, 9–10% orthopyroxene, 1% hornblende, and 0.5% opaque oxide plus biotite as well as apatite and trace zircon to 0.15 mm in diameter. Quartz is irregularly disseminated with amoeboid interlocking grains to 2.5 mm in diameter as well as lenses or bands with quartz to 15 mm long, parallel to the foliation and 7 mm wide. Plagioclase is mostly less than 3 mm in diameter, but the K-feldspar (orthoclase bead perthite) is as much as 8 mm in diameter and locally encloses plagioclase. Mafic lenses are elongate and define a slightly irregular anastomosing foliation. These lenses are mostly composed of pale pink to green pleochroic orthopyroxene with less abundant olive-green hornblende and rare biotite as well as opaque oxide, apatite, and zircon. Fractures in orthopyroxene contain limonite and clay, with microfissures in feldspars also containing limonite.

Garnet Ice

The *Garnet Ice* quarry is located on mining lease M63/234, adjacent to the Eyre Highway, about 1 km north of Ten Mile Rocks, and about 85 km east-northeast of Norseman (Fig. 9). *Garnet Ice* is a garnet–biotite gneiss located within the Biranup Complex, an extensive area of Mesoproterozoic granitic and metasedimentary gneiss situated between the Fraser Complex in the east, and the Archean Yilgarn Craton to the west. The quarry was last mined around the late 1990s and since that time has been well managed in care and maintenance (Fig. 13).

Garnet Ice is a laminated and foliated garnet–biotite gneiss consisting mostly of white to cream, coarse-grained quartz, and microcline and plagioclase feldspars, interspersed with numerous, red garnets 2–5 mm in diameter, and irregular, elongated zones of dark grey to black, schistose biotite. It is these contrasting black and white, swirling zones, highlighted by the regularly distributed, well-rounded red garnets that give the polished rock its spectacular appearance (Appendix 4.5).

In the late 1990s, *Garnet Ice* was extracted from the quarry, measuring about 30 m in length and 15 m wide, by close-spaced drilling and diamond wire sawing into 10–15 t blocks. The material was marketed as a decorative stone for interior applications such as facades, floors and numerous forms of stone decoration. At the time, the stone attracted the attention of both domestic and overseas dimension stone suppliers (Western Australian Industrial Minerals Review, 1998). Currently, remaining resources appear to be extensive in the quarry area. Physical properties available for *Garnet Ice* are; absorption 0.08%, and flexural strength 12.7 MPa.

In the foyer of the Perth Town Hall, exfoliated slabs of *Garnet Ice* have been used in a spectacular floor setting in conjunction with slabs of *Verde Austral* (Fig. 14).



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Figure 10. ***Verde Austral*** **quarry wall showing diamond wire sawn primary blocks. The blocks measure approximately 1.8 m wide × 6.0 m high × 8.0 m into the quarry wall.**



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100 mm

Figure 11. Precision-cut kerb stone in ***Verde Austral.*** **The upper pale green surface has been exfoliated to provide a non-slip walking surface.**



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Figure 12. Exfoliated slabs of *Verde Austral* used in the new entrance to the Perth Concert Hall. Slabs are approximately 30 cm wide.



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Figure 13. *Garnet Ice* quarry looking southeast. Quarry walls clearly show evidence of close-spaced drilling and diamond wire sawing as block extraction methods.



Figure 14. Exfoliated *Garnet Ice* floor tiles (top left) used in the foyer of the Perth Town Hall. Adjoining green tiles are *Verde Austral,* also from Fraser Range.



Figure 15. A fine-grained, medium grey, laminated pyroxene granulite exposed at Phill's quarry.

Petrographic description

Garnet Ice is composed of quartz–microcline–plagioclase–garnet–biotite gneiss with titanite and minor epidote–allanite, apatite, zircon, and rare sulfide, and has a probable metasedimentary origin.

This laminated and foliated gneiss has a visually estimated mineralogy including 37% quartz, 17% microcline, 16% plagioclase, 14–15% garnet, 13–14% biotite, 1–2% titanite and <1% epidote(–allanite). Minor zircon is disseminated to 0.2 mm in diameter and there is accessory apatite. Bands of quartz, microcline and plagioclase to 4 mm in diameter alternate with lamellae rich in garnet to 4 mm in diameter and schistose biotite to 2 or 3 mm long accompanied by abundant titanite as well as minor epidote(–allanite) to 1.5 mm long, apatite, zircon, and rare sulfide. Lenses of syenogranite recrystallized quartzofeldspathic material are also common and locally contain myrmekite, with rare myrmekite also in coarse-grained plagioclase. This sample is probably a semipelitic metasediment, but is derived from a quartzofeldspathic sandstone.

Phill's quarry

Phill's quarry (also known as site FRG 144) is located in an area of mafic granulites on the western side of Fraser Range about 110 km east-northeast of Norseman (Fig. 9). In 1990, a small test quarry was opened at this site for Maritana Gold NL. The quarry, measuring 20 m wide × 15 m deep, was located near the crest of a small hill and block material was extracted by close-spaced drilling for testing in Perth. At that time, the stone attracted no commercial interest and the quarry remains in care and maintenance (Dechow, 1991; Fig. 15).

The rock is fine-grained, medium grey, laminated pyroxene granulite with a closely spaced foliation trending to the northeast (Fig. 16). The granulite is massive with vertical joints spaced at about 4 m. When polished, the rock becomes very dark with visually attractive magenta highlights (Appendix 4.6). No estimate of available resources at Phill's quarry have been made but these could prove extensive if further exploration was undertaken at lower levels in the hill.

Petrographic description

This fine-grained mafic rock is laminated and foliated and has a visually estimated mineralogy with 55% plagioclase, 34% pyroxene (mostly orthopyroxene), 7% biotite, 3.5% opaque oxide, and 0.5% apatite. The proportions of orthopyroxene and clinopyroxene are uncertain but there seems to be at least 5% clinopyroxene. Most grains are less than 1mm long, with plagioclase twin-planes, mostly at a low angle to the foliation and biotite flakes parallel to the foliation. The protolith may have been basalt or dolerite.

American quarry

Located about 2 km west-northwest of Phill's quarry, the American quarry (site FRG 143; Fig. 9) is another mostly fine grained, dark grey, foliated, biotite-bearing pyroxene granulite (Fig. 17; Appendix 4.7). Less common are bands of coarser mid- to dark grey material. Augen, 10–60 mm long and 10–15 mm wide, are present in places aligned parallel the prominent north-northeast foliation (Fig. 18). Minor quartz veins around 20 mm wide, containing mostly well rounded, red garnets up to 10 mm diameter, are also present (Fig. 19).

This test quarry was investigated in the early 1990s by Maritana Gold NL who opened the 30 m-wide quarry by close-spaced drilling to obtain blocks for evaluation. Available resources of accessible, good-quality stone at this site could range from moderate to large.

Petrographic description

This rock is of similar mineralogy to rock sampled from Phill's quarry with a visually estimated mineralogy including 56% plagioclase, 31% orthopyroxene, 8% clinopyroxene, 3.5% biotite, and 1.5% opaque oxide. It is laminated and foliated but the plagioclase grain boundaries are more irregular. However, the (010) planes are at a low angle to the foliation and the biotite is also mostly foliated but is less abundant. Some of the plagioclase is antiperthitic. Most grains are less than 1 mm long, but there are pyroxene grains to 2.0 mm long, parallel to the foliation. Minor apatite is disseminated. A single veinlet at a high angle to the foliation has quartz and minor carbonate accompanied by very minor biotite and actinolite.

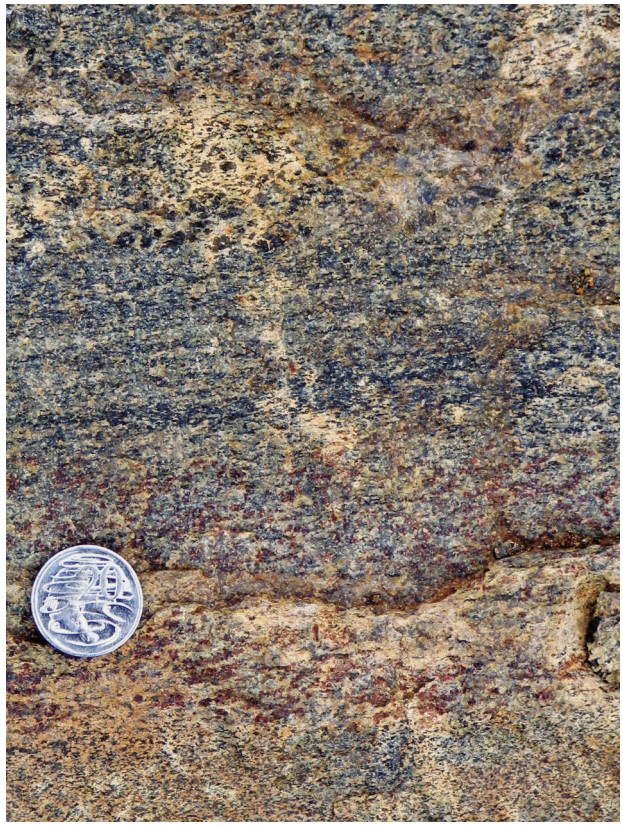
Horseshoe prospect

This mafic granulite prospect (site FRG 138) is located 130 km east-northeast of Norseman, and in the local area, 10 km south-southeast of Symons Hill (Fig. 9). This site was investigated in the early 1990s by Maritana Gold NL. At that time, two shallow, circular costeans were opened to expose numerous large core-stones beneath 1–2 m of calcrete and clay overburden (Fig. 20). Core-stones exposed in the costeans are up to 5 m long × 2.5 m wide, but the average length appears to be only 1–2 m (Fig. 21). Without further exploration at this site, available resources remain unknown.

The large core-stones were originally thought to be composed of a fine-grained gabbro but recent petrological studies by Purvis (2009d), described below, have shown the rock to be a fine-grained, hornblende-bearing, pyroxene granulite. The granulite is foliated, medium grey, and becomes very dark when polished (Appendix 4.8).

Petrographic description

This fine-grained mafic rock is composed of foliated mafic granulite with a visually estimated mineralogy containing 53% plagioclase, 25% orthopyroxene, 15% clinopyroxene, 4% opaque oxide, and 3% brown hornblende. Equant and elongate plagioclase grains from 0.2 mm to 2.0 mm long are mostly elongate at a low angle to the foliation. Orthopyroxene is locally 2.5 mm long, but clinopyroxene is mostly less than 1.0 mm in diameter with fine-grained opaque oxide and hornblende. Apatite needles to 0.5 mm long are disseminated and there is rare biotite.



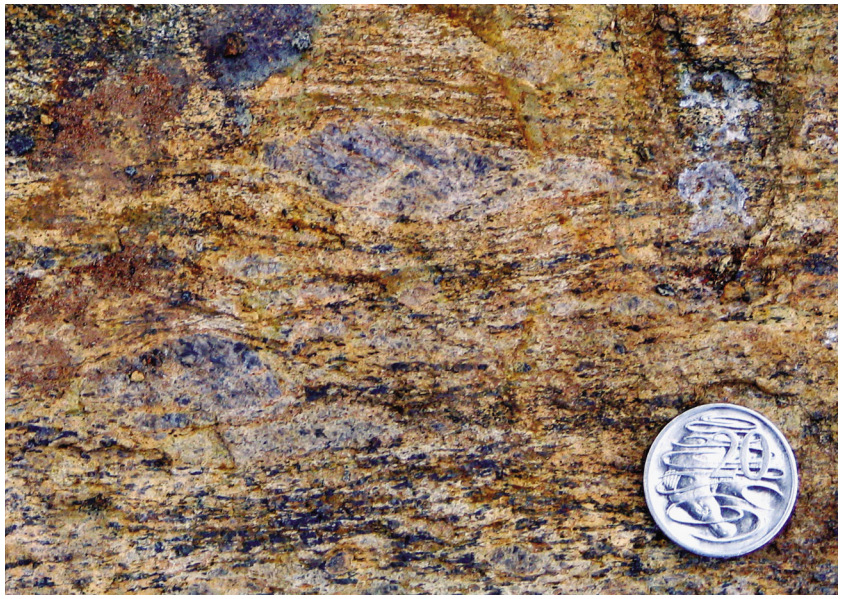
JMF463 12/07/2010

Figure 16. Detail of laminated pyroxene granulite at Phill's quarry.



JMF577 19/07/2010

Figure 17. Foliated, dark grey pyroxene granulite at the American quarry.



JMF578 19/07/2010

Figure 18. Augen, 10–60 mm long, in bands parallel to foliation, within pyroxene granulite at the American quarry.



JMF464 12/07/2010

Figure 19. Small quartz vein (20 mm wide), containing numerous, well-rounded, red garnets intruding pyroxene granulite.



JMF579 21/07/2010

Figure 20. Horseshoe prospect looking northeast, showing exposed surface of mid-grey pyroxene granulite. Exposed, near-surface boulders are 1–2 m in diameter.



JMF580 21/07/2010

Figure 21. Detail of 2 m-wide boulder of pyroxene granulite at Horseshoe prospect.

Fantasia quarry

The Fantasia test quarry (site FRG 140) is located on the western side of Fraser Range about 5 km northeast of the American quarry, and 110 km east-northeast of Norseman (Fig. 9). The quarry is sited high on the side of a prominent, northeasterly trending ridge. Exploration was initiated by Maritana Gold NL in 1991 and a number of blocks were extracted for evaluation as a potential dimension stone (Dechow, 1991). Currently, the 17 m-long quarry contains a single primary block of about 200 t that has been drilled and toppled from the quarry face (Fig. 22).

According to Jones and Hall (2004), rocks surrounding this locality consist of numerous zones of granitic augen gneiss (0.5 – 40 m wide) interlayered within zones of mafic granulite. The Fantasia quarry is located within a northeasterly trending zone of laminated, quartzofeldspathic, mylonitic, granitic gneiss, estimated at 40–50 m wide, interlayered within zones of foliated, pyroxene granulite. The pink-banded, granitic gneiss commonly contains feldspar-rich augen up to 50 mm length as well as garnet- and biotite-rich lenses parallel to the layering (Fig. 23; Appendix 4.9). The rock is quite massive with sparse joints up to 10 m separation orientated at right angles to the foliation.

At the quarry site the granitic gneiss layer appears to extend for at least several hundred metres along the cliff face indicating that resources of the Fantasia stone may be extensive.

Petrographic description

This rock is a quartzofeldspathic, mylonitc granitic gneiss. It is a finely laminated, pale pinkish rock with disseminated brownish grains of possible mafic material. The thin section indicates laminated mylonitic gneiss with quartz-rich and feldspathic lamellae that are largely microcrystalline as well as augen of plagioclase to 6 mm long and of mesoperthite to 4 mm long. Lenses rich in garnet have irregular grains to 4 mm long, but very minor biotite is mostly microcrystalline in lenses parallel to the layering. The overall composition is probably broadly granitic with approximately 35% quartz, 4–5% garnet, 1% biotite, and subequal amounts of plagioclase and K-feldspar. The plagioclase augen are veined by sericite.

Yilgarn Craton — Eastern Goldfields Terrane

Coolgardie — granite

Karramindie Soak

A granitic rock prospect is located at Karramindie Soak, 20 km east-southeast of Coolgardie and about 5 km northeast of the Coolgardie–Esperance Highway (Fig. 24). The area adjacent to the soak is a dimension stone prospect for Archean granite, investigated in 1994–95 by Dodsley Pty Ltd on mining lease M15/1019. The host rock is the Karramindie Monzogranite, a light grey, even-grained, biotite monzogranite with similar chemical properties and visual appearance to the Mungari Monzogranite, previously quarried in the Coolgardie area as *Mungari Grey* (Hunter, 1991). The Karramindie Monzogranite crystallized at about 2700 Ma (Oversby, 1975).

The Karramindie site consists of a series of scattered, relatively flat outcrops of monzogranite ranging from quite small up to 60 m in length and rising no more than a few metres above the surrounding sandplain (Fig. 25). Exploration conducted by Elkington (1995) on behalf of Dodsley Pty Ltd comprised a drilling program consisting of four diamond drillholes spaced over an area considered to be most suitable for a future quarrying operation (Fig. 26). A total of 30 m of monzogranite core recovered from the drillholes was subsequently evaluated for dimension stone potential.

Of the four holes, BKS 1 and 2 were drilled to 10.0 and 10.5 m respectively, whereas BKS 3 and 4 were short holes at 5.0 and 4.5 m. All holes recorded a continuous body of massive monzogranite evidenced by the sparsity of jointing with only one joint visible in the entire core. Minor thin quartz and quartzofeldspathic veinlets were also present but it was found there was little tendency for rock breakage along these intrusions. Some yellow staining of feldspars, due to weathering processes, was observed in the upper sections of the monzogranite in all holes to depths between 3.3 and 7.4 m. Below these zones the stone was found to be of excellent quality and integrity (Appendix 4.10).

Petrographic description

Fine-grained, quartz-rich, biotite monzogranite with minor chloritized biotite and clay(–muscovite) in plagioclase and accessory zircon.

This pale grey granitic rock has a visually estimated mineralogy of approximately 40% quartz, 32% microcline, 22% plagioclase, and 6% biotite(–chlorite) as well as accessory opaque oxide, muscovite, titanite, apatite, and zircon. Rare myrmekite occurs on plagioclase. Most grains are anhedral and lobate and from 0.3 mm to 3 mm in size, with partly chloritized unoriented biotite to 1 mm long and zircons 0.05 mm to 0.15 mm long. The plagioclase has weak clay alteration and rare secondary muscovite.

Mungari Grey

The *Mungari Grey* quarries are located about 14 km northeast of Coolgardie, along the Great Eastern Highway towards Kalgoorlie (Fig. 27). These quarries are situated in an area of north-northwesterly trending Archean granite known as the Mungari Monzogranite. This is a fine-grained, pale grey, even-textured granitic rock which crystallized in the late Archean (Fletcher and McNaughton, 2001).

The older Mungari quarry (Mungari Grey 1), adjacent to the Great Eastern Highway, was operated by Stone Industries of Australia on a campaign basis between 1991 and 1994. This operation, located on mining lease M15/465, was assessed as being capable of producing high-quality stone at the rate of 12 000 m^3 per annum from a possible resource of 6.1 Mm^3 (16 Mt). Operations ceased in 1994 when the mining lease was apparently forfeited. The abandoned quarry was later partially backfilled and rehabilitated.



JMF581 21/07/2010

Figure 22. Fantasia granitic gneiss quarry.



JMF582 19/07/2010

Figure 23. Detail of pink-banded granitic gneiss at Fantasia quarry.

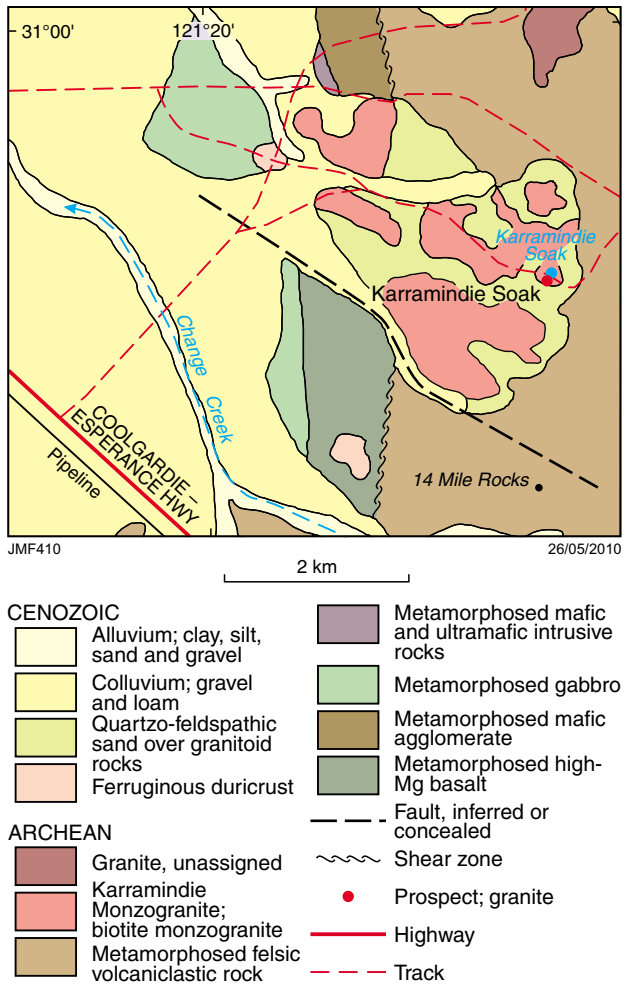


Figure 24. Geology of the area surrounding Karramindie Soak, Coolgardie district (modified after Hunter, 1988a).



Figure 25. A fresh exposure of pale grey monzogranite at Karramindie Soak.

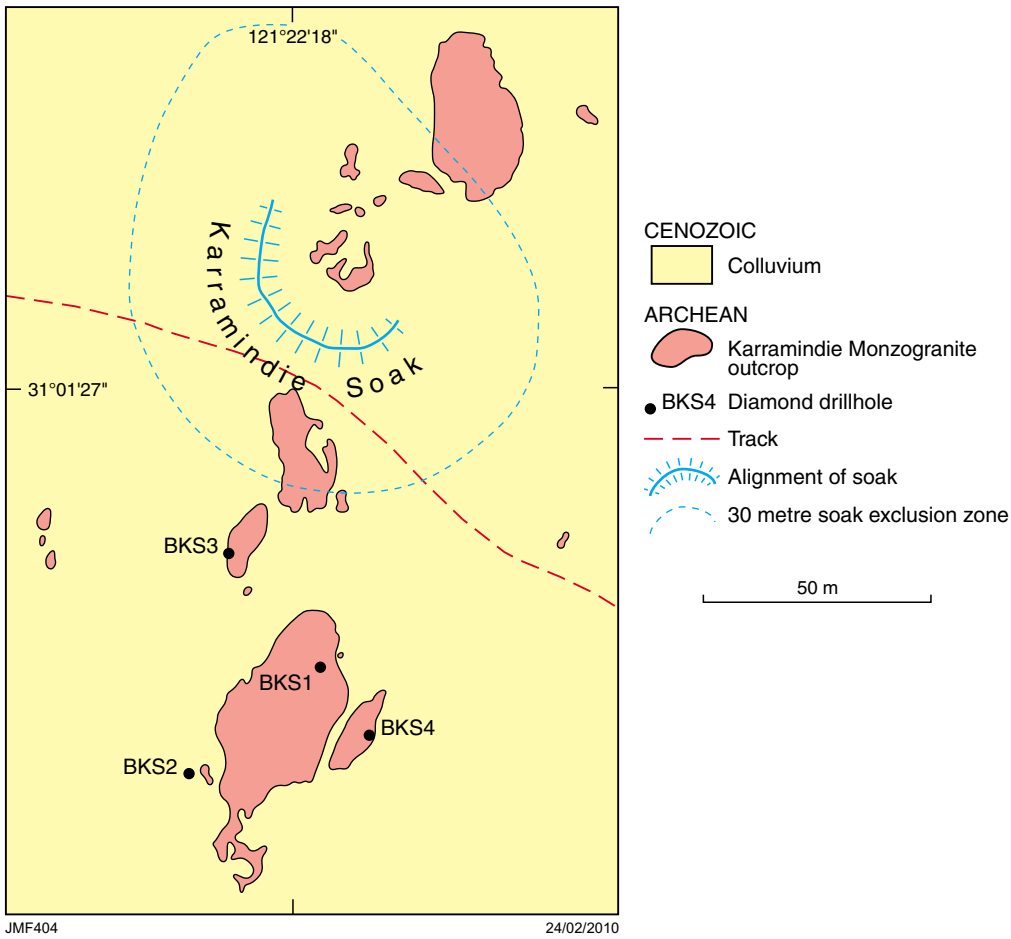


Figure 26. Location of diamond drillholes at Karramindie Soak, 1994 exploration program (modified after Elkington, 1995).

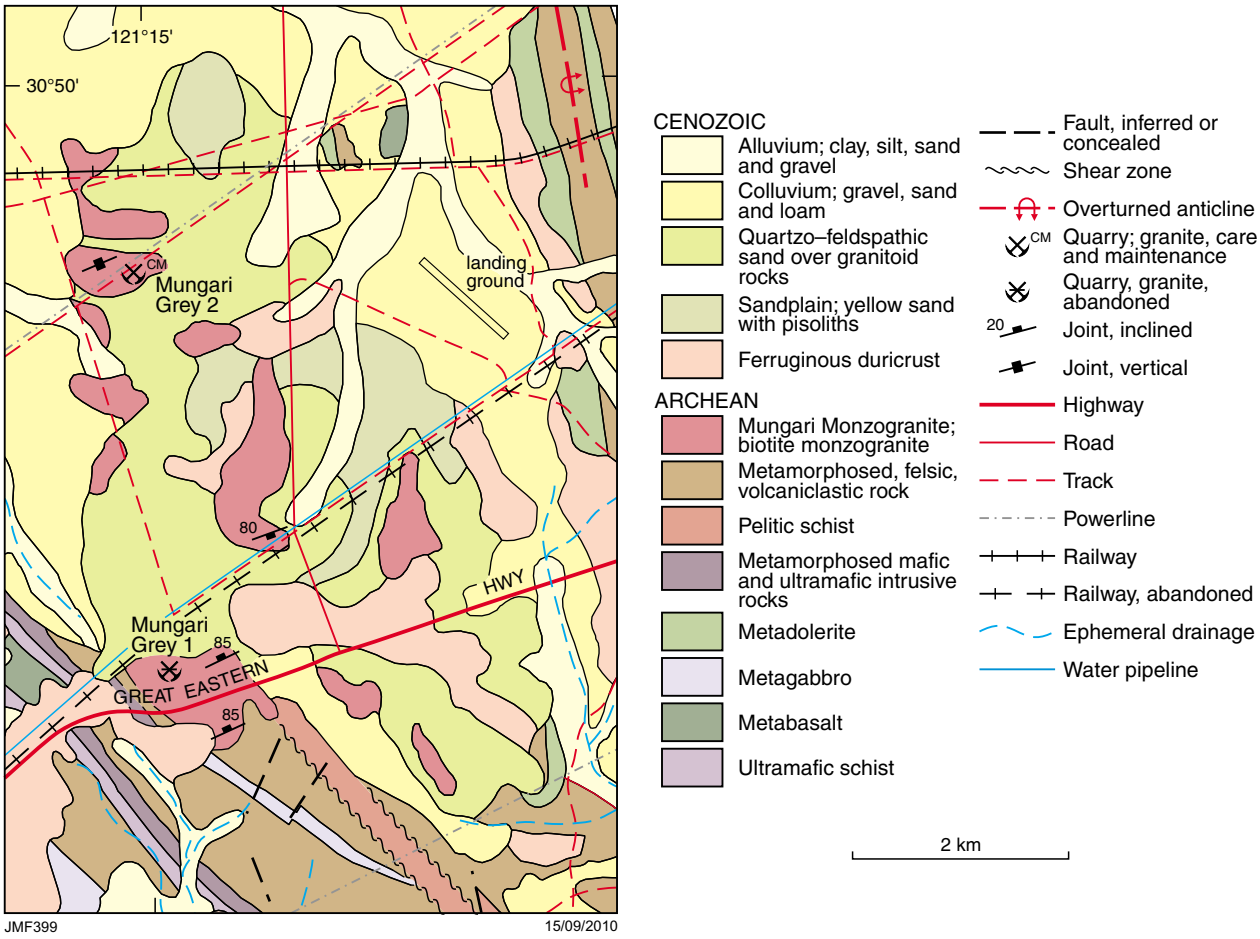


Figure 27. Geological map of the Mungari quarries in the Coolgardie area (modified after Hunter, 1988b).

In mid-1995, a new quarry owned by Mungari Granite Pty Ltd (Mungari Grey 2) commenced operations on mining lease M15/644, approximately 3.5 km to the north of the old quarry and adjacent to the Kalgoorlie–Coolgardie high-voltage power line. This site was selected to maximize extraction of 10 t granite blocks, following diamond drilling that indicated an area of relatively sparse jointing, with unweathered monzogranite close to the surface (Fig. 28). Stone resources in the quarry area were estimated at approximately 0.4 Mt with a 30% recovery rate to yield approximately 120 000 t. Available physical properties of the stone were given as:

- Absorption 0.55%
- Bulk density 2.482 t/m^3
- Modulus of rupture (dry) 24.6 MPa
- Flexural strength (dry) 15.4 MPa

A site investigation by the author, showed the monzogranite, exposed in the 30 m-wide quarry, to be generally massive with horizontal, near-surface unloading joints at 1.0 m separation. Below this, joint separation increased to more than 3.0 m in several quarry faces with a maximum depth of 4–5 m.

The quarry operated from 1995 to about 2002 and during that time produced between 100 and 500 m^3 per month according to demand. Throughout this period, the quarry produced high-quality, even-grained blocks of *Mungari Grey* by close-spaced drilling and diamond wire cutting. These were processed into slabs, panels, and tiles for exterior and interior cladding of building projects both in Australia and overseas (Fig. 29; Appendix 4.11).

During the first half of this decade (2000–2010), demand for this stone appears to have decreased, and the quarry was put into care and maintenance and was subsequently sold to Southpac Ltd in April 2003.

Petrographic description

Weakly altered biotite monzogranite, with chloritized biotite, clay-clouded feldspars, and minor muscovite.

This fine-grained granitic rock has a visually estimated primary mineralogy of 38% quartz, 34% plagioclase, 25% microcline, 3.5% biotite, and 0.5% muscovite, indicating leucocratic biotite monzogranite. Rare, larger grains include K-feldspar to 4 mm and interstitial quartz to 5 mm in diameter as well as rare plagioclase to 4 mm long, but most grains are less than 2 mm long and subhedral or anhedral. The biotite has been chloritized and there is secondary muscovite in plagioclase as well as clay clouding in plagioclase and K-feldspar. Some of the biotite has pleochroic haloes suggesting microcrystalline zircon.

Yilgarn Craton — Southern Cross Terrane

Koolyanobbing–Coolgardie — granite

Boorabbin Rock

The Boorabbin Rock quarry is located on Water Reserve 2917, about 90 km west-southwest of Coolgardie and 2 km west of Boorabbin on the Great Eastern Highway (Fig. 30). This extensive quarry, about 110 m wide, was originally developed to supply crushed granite ballast to the now-abandoned, narrow-gauge railway to Kalgoorlie, adjacent to the highway.

The rock from the Boorabbin quarry forms part of the Late Archean Woolgangie Monzogranite, being a pale grey, medium- to coarse-grained biotite monzogranite (Appendix 4.12). The rock was dated by Fletcher and McNaughton (2001) at 2630 Ma. Similarities in age, mineral composition and structure make the monzogranite at Boorabbin Rock appear similar to the Karramindie and Mungari Monzogranites to the east in the Coolgardie area (Eastern Goldfields Terrane).

During the mid-1990s, the quarry was redeveloped as a dimension stone site on prospecting licence P15/3523 by Messrs Donnellan and Maynard for the purpose of obtaining bulk samples of monzogranite stone for testing and appraisal. A dimension stone quarry was developed high up on the southwestern end of the main Boorabbin quarry, and a small test quarry was established on the top surface of Boorabbin Rock a few hundred metres to the southwest. A large number of blocks were extracted from these sites using mainly close-spaced drilling assisted by thermal lance and low-impact explosives to free up primary blocks (Fig. 31). Currently, about 20 blocks, mostly less than standard 10 t quarry blocks, remain on site.

Petrographic description

Medium- to coarse-grained, undeformed biotite monzogranite with weak sericite–carbonate–chlorite alteration. Accessory opaque oxide, apatite, and zircon.

This mostly medium- to coarse-grained and undeformed granite has a visually estimated mineralogy with 40% quartz, 30% plagioclase, 24% microcline, 5–6% biotite, and minor amounts of sericite, chlorite, carbonate, altered allanite, opaque oxide, apatite, and rare zircon 0.1 mm long, indicating monzogranite. The quartz includes small, rounded grains enclosed in microcline and large interstitial grains that may be optically continuous over 15 mm or more in length. Plagioclase and microcline are as much as 6 mm in grain size with patches of sericite(–carbonate) in some of the plagioclase grains, locally in veins of possible albite. The microcline has inclusions of plagioclase, and rare myrmekite occurs in plagioclase grains. Biotite to 2 mm long has minor alteration to chlorite and rare allanite seems to have clay alteration. Fine-grained apatite is commonly associated with biotite or opaque oxide and rare zircon occurs as inclusions in biotite.

Darrine Rock

Darrine Rock is located about 2 km south of the Trans Australia Railway line and 35 km east-southeast of Koolyanobbing. The rock was inspected by Gordon (1965) who was carrying out a reconnaissance survey for potential sources of rock suitable for railway ballast for the new standard-gauge railway (Fig. 32).

The physical properties for dimension stone are quite similar to those required for high-grade ballast, in particular in composition, durability, bulk density, absorption,



Figure 28. *Mungari Grey* monzogranite exposed in the Mungari Grey 2 quarry.



Figure 29. Slabs of *Mungari Grey* granite forming part of the wall of the Westin Hotel in Melbourne. Slabs are approximately 0.5 m in length.

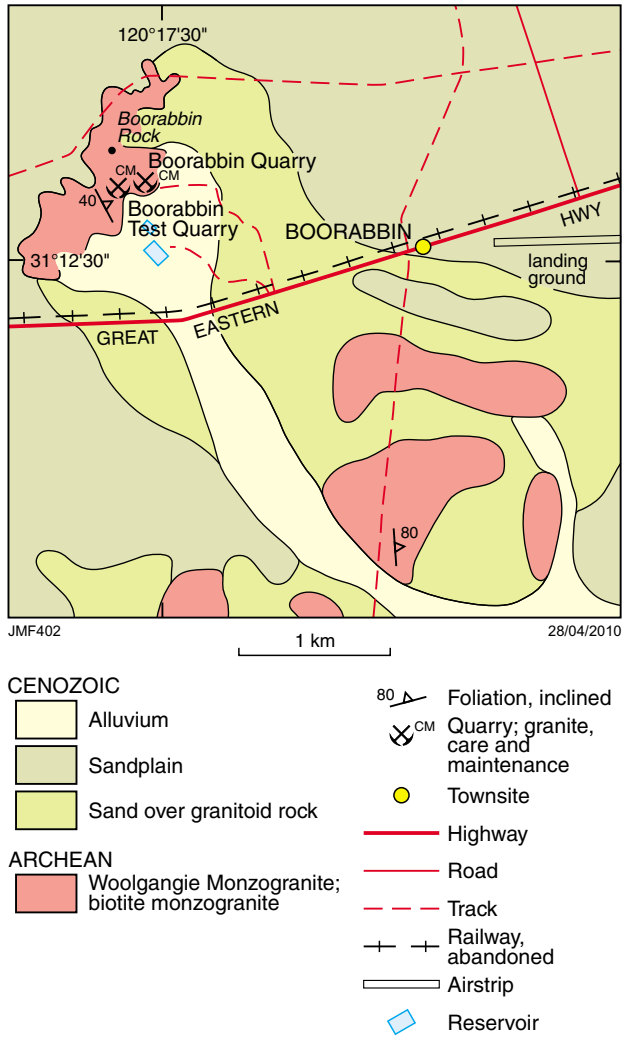


Figure 30. Geological sketch map of the Boorabbin area (modified after Hunter, 1988c).

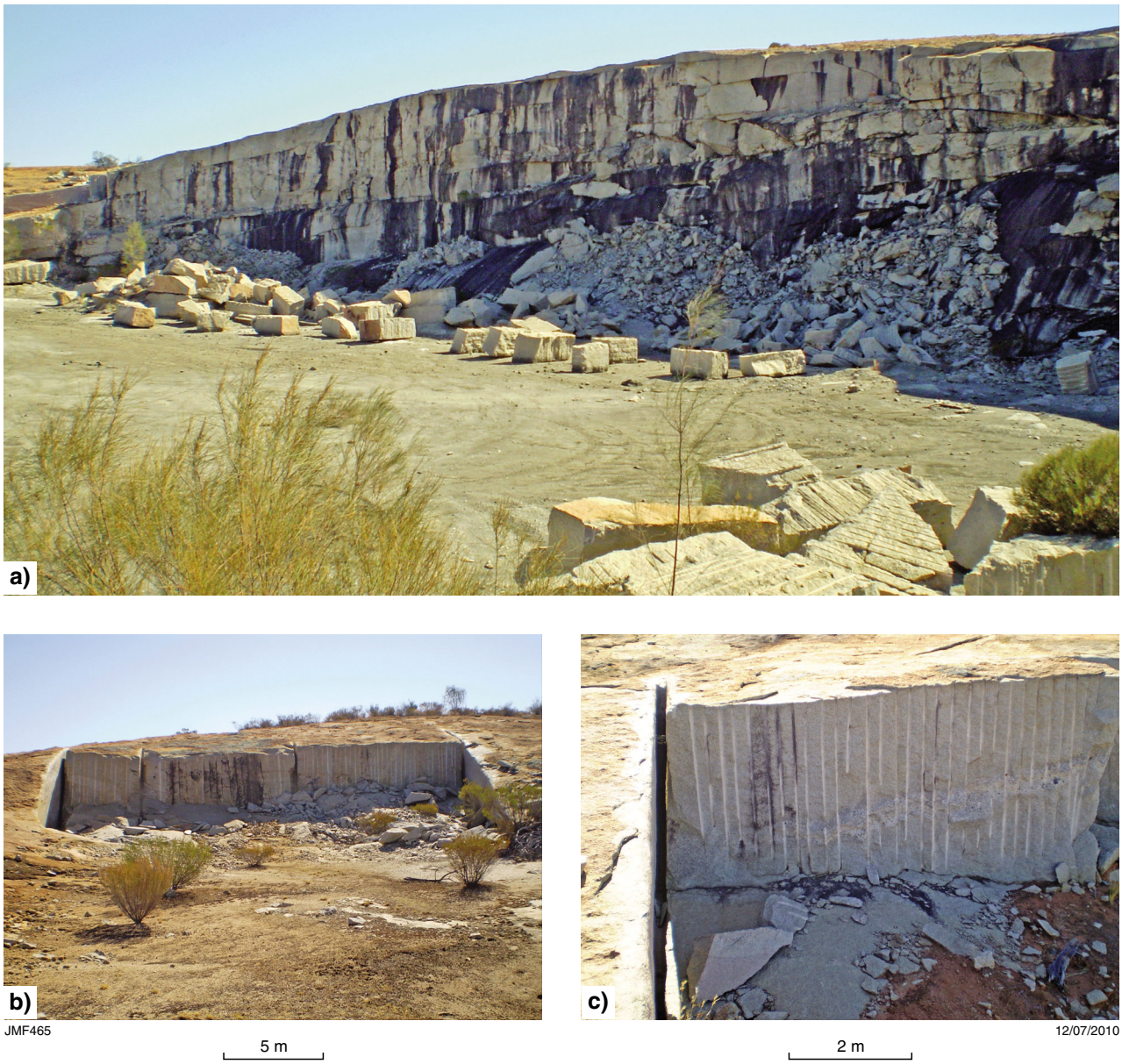


Figure 31. Monzogranite quarries at Boorabbin Rock: a) original quarry used for railway ballast showing near-horizontal unloading joints; b) small dimension stone test quarry high up on the rock; c) block removal techniques employed in larger stone quarry: thermal lance cutting of end walls, close-spaced drilling of rear wall, and under-block explosives to release primary block.

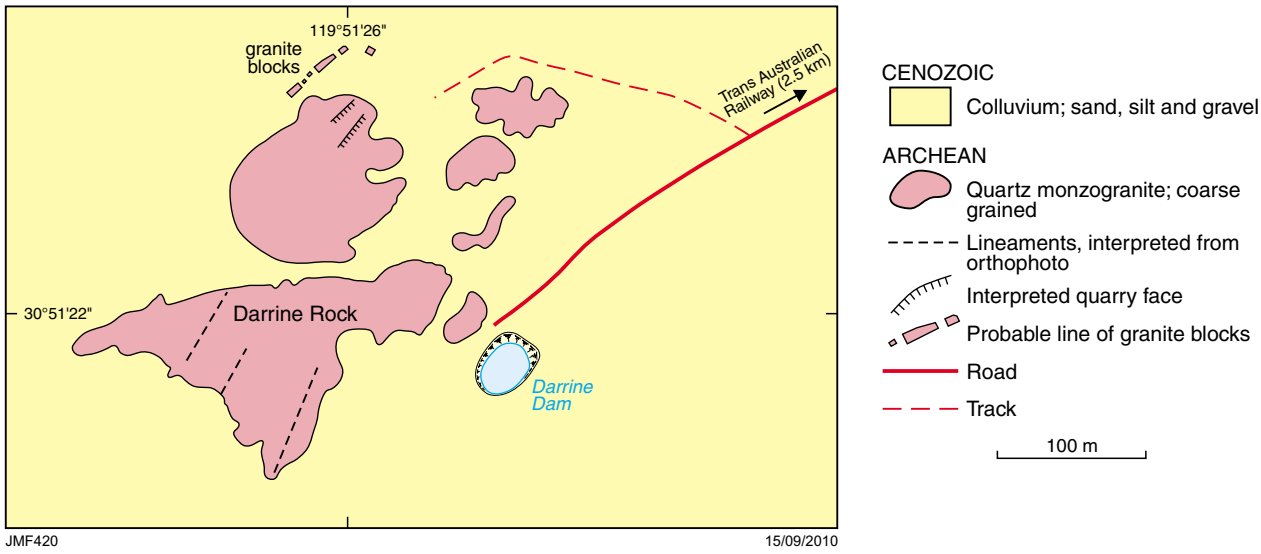


Figure 32. Geological sketch map of Darrine Rock, Koolyanobbing region.

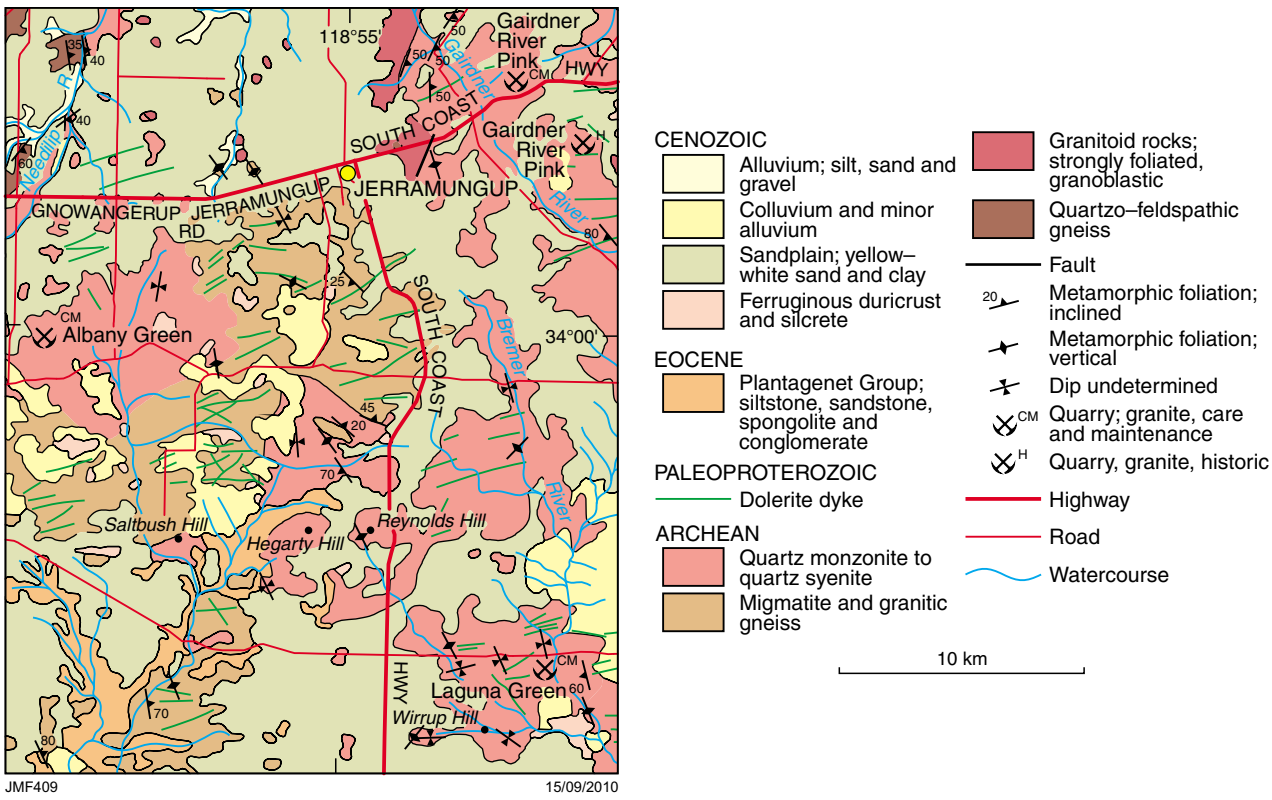


Figure 33. Geology of the Jerramungup area (modified after Thom and Chin, 1984; Thom et al., 1984).

hardness, toughness, and cleavage. Based on comments from the survey report, and the rock's close proximity to the main railway line, it can be inferred that Darrine Rock should also be considered a potential dimension stone source.

Located adjacent to Darrine Dam, the rock comprises several elongate, northeasterly trending outcrops of quartz monzonite covering an area of about 32 ha and rising to about 7 m above the surrounding plain. The quartz monzonite is coarse grained and of remarkably consistent grain size and texture. Surface weathering is apparently minimal, and structures are limited to horizontal unloading joints and a possible northeasterly trending foliation.

A close examination of the image of Darrine Rock, clearly visible on the SEABROOK orthophoto (1:100 000 map sheet), indicates the presence of two possible parallel quarry faces located at the northern end of the large granite outcrop situated on the northwestern side of the area as well as a possible line of encircling granite blocks placed on the open ground a few metres away (Fig. 32). This could indicate that the site may have been tested for its dimension stone properties subsequent to Gordon's survey.

Yilgarn Craton — South West Terrane

Jerramungup — granite

At various times over the last 40 years, three different granitic rocks have been sourced from the Jerramungup area (Fig. 33) with the original stone being the *Gairdner River Pink*, and in more recent years the *Albany Green* and *Laguna Green*. These rocks belong to a suite of late Archean granite, migmatite, and gneiss.

Albany Green

The *Albany Green* granite quarry is located 10 km west-southwest of Jerramungup in the southwest of the State (Fig. 33) and about 140 km northeast of Albany. The quarry was developed as a source of green granitic stone for Melocco Stone in the early 2000s. *Albany Green* was quarried over a comparatively short period on an extractive industry licence. Today, the quarry remains in care and maintenance.

Albany Green is a megacrystic quartz syenite with an overall greyish green colour despite the presence of large pale pink K-feldspar phenocrysts set in a green matrix (Appendix 4.13). The rock is quite massive, showing almost no evidence of jointing in the 6 m-high quarry walls. Blocks were extracted in an efficient operation by close-spaced drilling and diamond wire sawing from a single bench in the 40 m-wide quarry (Fig. 34).

Physical properties for *Albany Green* provided by Melocco Stone (2009) are as follows:

- Absorption 0.10%
- Bulk density 2.72 t/m^3
- Compressive strength (dry) 197 MPa
- Modulus of rupture (dry) 13.3 MPa
- Flexural strength (dry) 10.9 MPa

Stone blocks were transported to the eastern states for cutting and application in building projects, mostly in Sydney where the paving and cladding of Aurora Place remains a prime example (Fig. 35). In 2002, *Albany Green* was one of two dimension stones used in the construction of the Australian War Memorial commemorating the Battle of Isurava on the Kokoda Track in Papua New Guinea.

Petrographic description

Weakly altered, megacrystic hornblende–clinopyroxene–biotite quartz-syenite to syenogranite with accessory opaque oxide and apatite in mafic aggregates, with some rare zircon, chlorite–clay aggregates and carbonate in fractures.

This sample has K-feldspar megacrysts to 30 mm long. Although the visually estimated mineralogy may not be representative, it indicates quartz syenite transitional to syenogranite with 49% K-feldspar, 20% plagioclase, 18% quartz, 2.5% myrmekite, 3.5% clinopyroxene, 3% hornblende, 1.5% biotite, 1.5% chlorite-clay aggregates with some epidote. and 1% opaque oxide plus apatite, with zircon to 0.2 mm in diameter. The K-feldspar is very coarse grained as indicated and locally has oriented inclusions of fine-grained plagioclase. Separate plagioclase to 6 mm long is partly antiperthitic and rarely has sericite or saussuritic patches, locally surrounding mafic grains. Myrmekite is partly in plagioclase and partly in and adjacent to K-feldspar. Mafic grains are partly isolated and partly in lenses to 10 mm long with clinopyroxene, hornblende and biotite as well as opaque oxide, apatite, and rare zircon. Pyroxene, hornblende, and opaque oxide are mostly less than 3 mm in diameter. Biotite–quartz symplectites are less abundant than in the nearby *Gairdner River Pink* granite. Rare carbonate is present in hairline fractures, mostly in K-feldspar.

Gairdner River Pink

There are two quarries in the Jerramungup area from which the *Gairdner River Pink* was sourced (Fig. 33). A small, historic quarry, located 9 km east-northeast of Jerramungup, operated briefly around the early 1970s to supply stone for cladding external steps and a wall in the now-demolished R&I Bank that stood in Barrack Street, Perth City.

A larger *Gairdner River Pink* quarry is located 8 km northeast of Jerramungup. This quarry, about 30 m in length and 4 m deep, was considered for dimension stone by local operators but was rejected because of pre-existing damage caused by blasting in the quarry area. The operation remained as a source of aggregate for the local area during the 1980s (Fig. 36).

Gairdner River Pink is a megacrystic quartz syenite with pinkish-red K-feldspar phenocrysts in excess of 30 mm in length. It is has an unusual texture with large phenocrysts, together with smaller pink, yellow and cream crystals of mainly microcline and plagioclase feldspars and quartz, set in a black mafic matrix (Fig. 36; Appendix 4.14). It has been suggested that this stone may make a good paving stone with a non-slip, exfoliated surface finish.



JMF634 21/07/2010

Figure 34. *Albany Green* granite quarry showing the massive quartz syenite exposed in the 6 m-high wall.



JMF586 21/07/2010

Figure 35. Aurora Place, Sydney, paved and clad with slabs of *Albany Green* granite.

Petrographic description

Weakly altered, megacrystic biotite–clinopyroxene quartz-syenite, with microcline megacrysts, weakly sericitized plagioclase, quartz, and weakly chlorite–epidote–titanite-altered biotite. Accessory opaque oxide, apatite, and zircon.

This sample has pale pink K-feldspar crystals to 30 mm long in a groundmass with smaller feldspar grains and dark mafic areas. The thin section has two large feldspar crystals and its visually estimated mineralogy may not be representative but seems to indicate quartz syenite with 47–48% microcline, 18% plagioclase, 13–14% quartz, 6% myrmekite, 8% clinopyroxene, 5–5.5% biotite, 1.5% opaque oxide, and 0.2% apatite. The largest microcline grain is more than 25 mm long and 12 mm wide with inclusions of plagioclase and exsolved plagioclase lamellae. Minor myrmekite formed in and adjacent to K-feldspar crystals. There are also separate plagioclase laths to 6 mm long irregularly dusted with sericite. Quartz occurs as elongate grains to 8 mm or more in length and is interstitial to feldspars and mafic aggregates.

Mafic aggregates are semi-continuous across the thin section and contain clinopyroxene, biotite, magnetite and apatite as well as rare hornblende and zircons to 0.1 mm in diameter. Biotite–quartz symplectites are common and rarely pass into myrmekite. Some of the biotite has been altered to chlorite and possible titanite(–epidote) with rare fluorite. Hairline clay-filled fractures are rare and discontinuous.

Laguna Green

Laguna Green, a spectacular, gumleaf-green granite, is located about 20 km south-southeast of Jerramungup (Fig. 33). Situated in low hills, adjacent to the Bremer River, *Laguna Green* was quarried to 2004 by Wales Quarries on an extractive industry licence. Currently, the quarry is in care and maintenance.

In operation, the quarry was producing about 3000 m^3 per annum from massive, sparsely jointed granite extracted from quarry faces about 4 m high (Fig. 37). Primary blocks of about 150 t were removed by close-spaced drilling and thermal lance (flame-jet cutting). After toppling effected by hydraulic jacks and bucket loader, the primary block was cut into saleable 10 t blocks using an in-line slab drill. Blocks were then shipped out, either as two blocks loaded on a semi-trailer or packed inside a shipping container.

Laguna Green is a pale green, megacrystic quartz monzonite containing large grey-green phenocrysts of K-feldspar mostly 30 mm in length and set in a greenish matrix (Appendix 4.15). The stone has excellent physical properties, given by Granites of Australia (2003):

- Absorption 0.068%
- Bulk density 2.66 t/m^3
- Compressive strength (dry) 240 MPa
- Flexural strength (dry) 16 MPa

Laguna Green's visually attractive pale green colour and ability to take a high polish, combined with its superior physical properties, have made it suitable for use as a dimension stone in buildings and monuments. In the early 2000s, the stone was exported for use in construction projects in Japan, South East Asia, and New Zealand. In 2002, Sydney architects Tonkin Zulaikha Greer selected *Laguna Green* as the dimension stone to be used for the Australian War Memorial at Hyde Park Corner in London. As a result, about 200 t of stone was transported to London for processing into blocks and panels for the monument's construction. The completed monument, opened on Remembrance Day, 11 November 2003, was subsequently awarded two architectural prizes for Australian stone by the Australian Stone Advisory Council in 2006 (Fig. 38). Further information on *Laguna Green* is given in Fetherston (2004) and Stock (2004).

Petrographic description

Biotite–hornblende quartz monzonite with K-feldspar partly as very large phenocrysts. Accessory carbonate-altered probable pyroxene, opaque oxide, apatite, and rare zircon. Minor sericite in plagioclase.

Several large K-feldspar phenocrysts are scattered in this sample, in a relatively quartz-poor, plagioclase-rich groundmass. Thin section contains only one largely complete K-feldspar phenocryst, meaning that the visually estimated mineralogy is unlikely to be representative. However, within the area of the thin section there is about 12% quartz, 45% plagioclase, 34% K-feldspar, 5% hornblende, 1% biotite, 1% opaque oxide, and 0.5% apatite as well as myrmekite and altered possible pyroxene (1.5% in total). This indicates heterogeneous quartz monzonite.

The large K-feldspar grain is 25 mm long and 12 mm wide and is perthitic microcline, as are smaller grains of K-feldspar. Myrmekite is abundant adjacent to this larger K-feldspar crystal and also next to some smaller grains. Plagioclase, to 6 mm diameter, has inclusions of K-feldspar as well as biotite and quartz, but may have been partly resorbed. Mafic aggregates, with greenish-brown hornblende, opaque oxide and minor biotite, are abundant and contain most of the abundant apatite in this thin section. Sparse patches of carbonate(–green clay), to 3 mm in diameter, are also present in the mafic aggregates and seem to have been derived from clinopyroxene. Zoned euhedral zircon occurs to 0.3 mm diameter. Mostly weak sericite alteration is evident, with one plagioclase grain more intensely sericitized. Otherwise, carbonate and minor clay seem to have replaced pyroxene.

Central western region

Yilgarn Craton — Murchison Terrane

Mount Magnet area — granite and diorite

Melangata Green

The *Melangata Green* microdiorite prospect is located approximately 100 km west-northwest of Mount Magnet and about 20 km north-northeast of Melangata Homestead

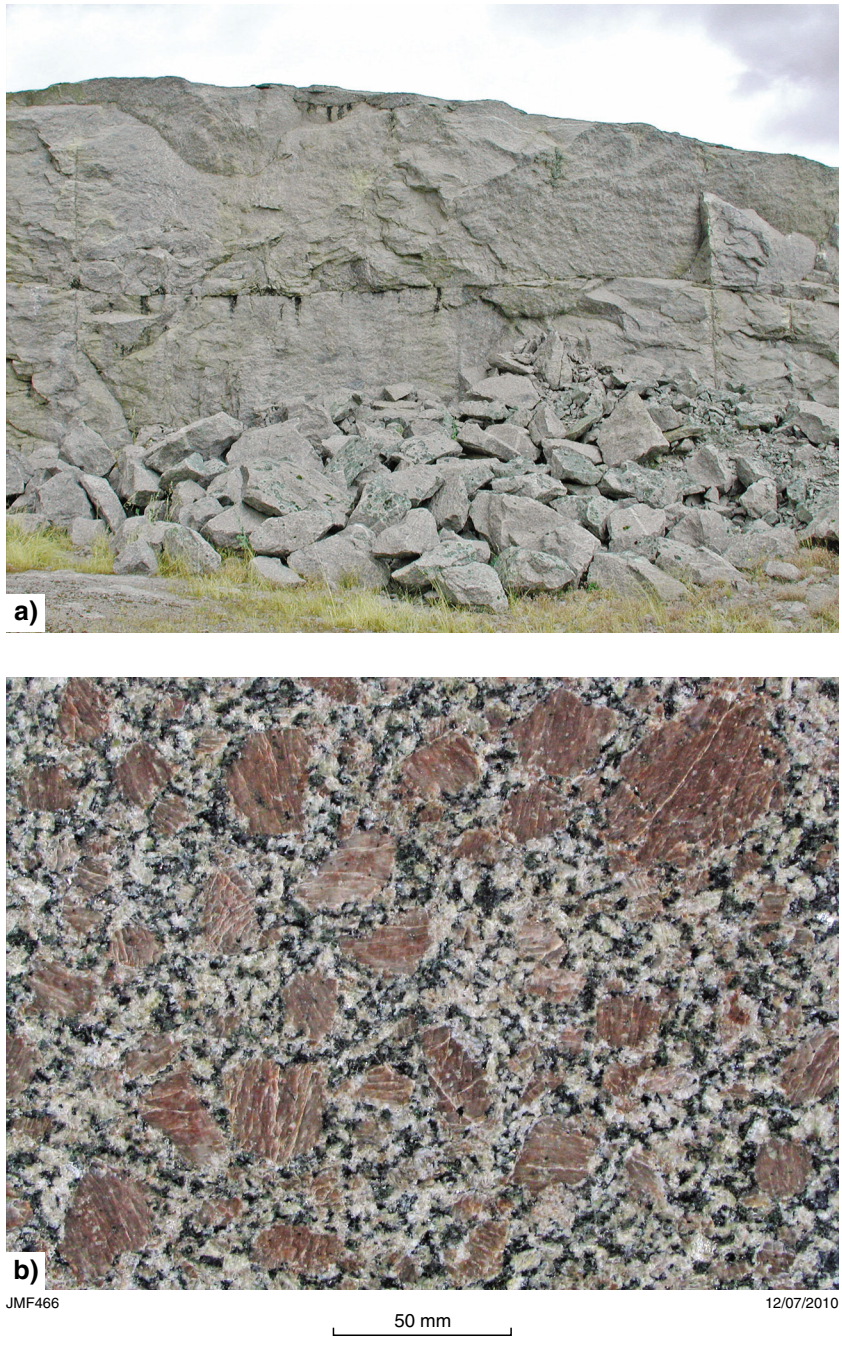
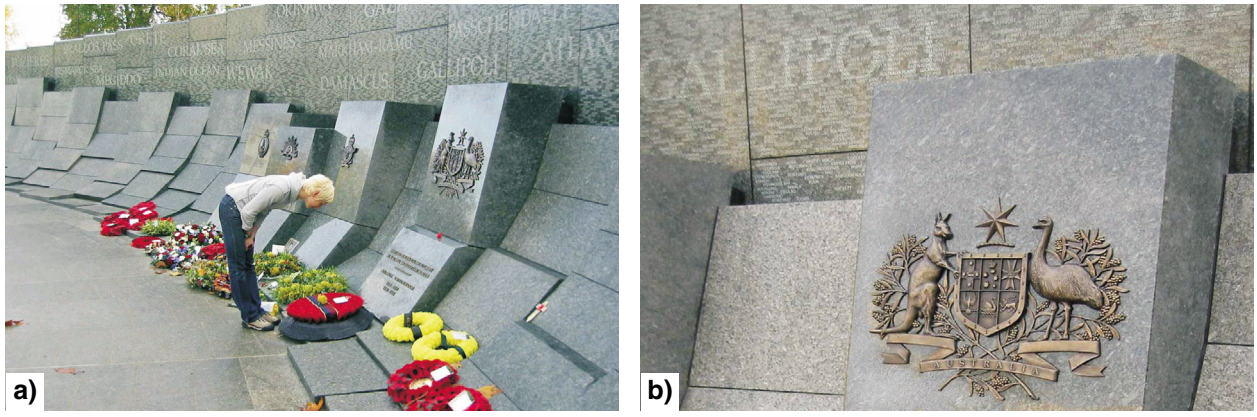


Figure 36. ***Gairdner River Pink*** **granite: a)** ***Gairdner River Pink*** **quarry; b) detail of the megacrystic quartz syenite set in an unusual black matrix.**



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Figure 37. *Laguna Green* granite quarry.



JMF467 16/09/2010

Figure 38. The Australian War Memorial at Hyde Park Corner in London: a) *Laguna Green* blocks and panels used in the monument; b) detail of polished and honed blocks and panels (photos courtesy Neil Mackenzie, Tonkin Zulaikha Greer, Architects).

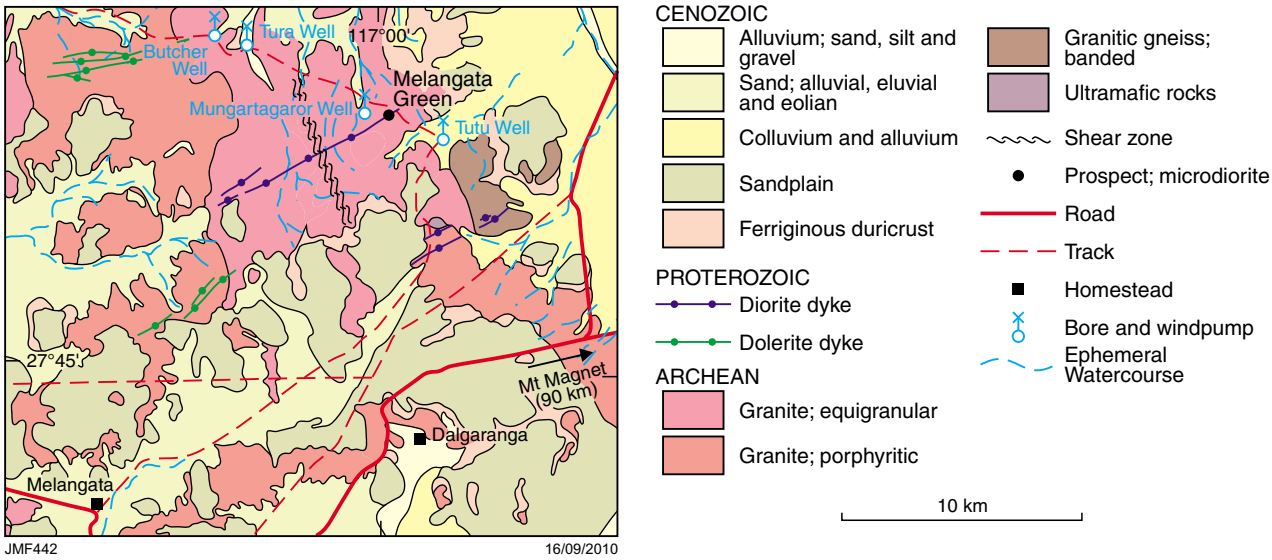


Figure 39. Geological map of the Melangata area (modified after Baxter et al., 1972; Watkins et al., 1986).

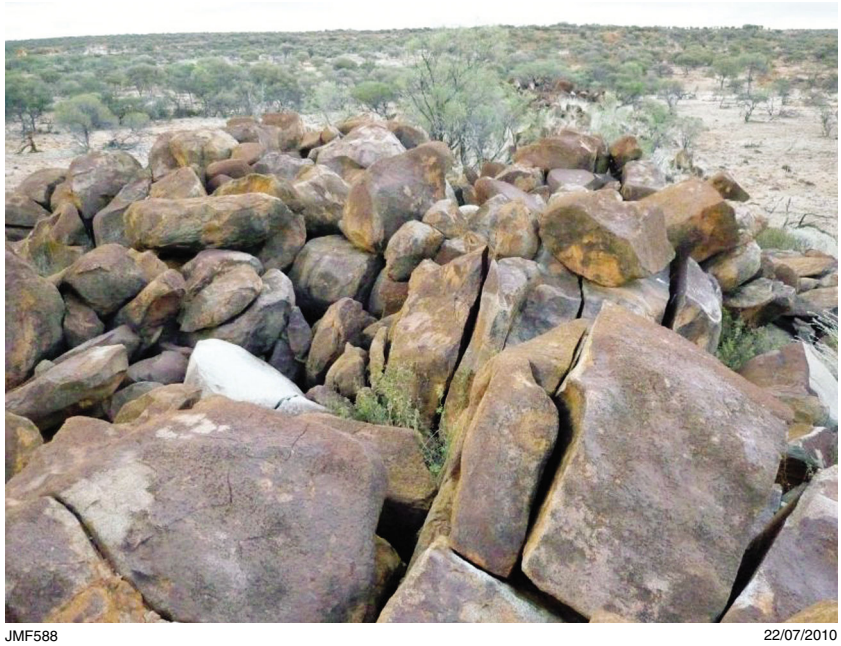


Figure 40. Large *Melangata Green* microdiorite boulders forming part of a 10 km-long dyke. Melangata Station area. View looking northeast.

(Fig. 39). The prospect forms part of a southeasterly trending, near-vertical, microdiorite dyke, about 10 km in length, located within exploration licence E59/999 owned by H & J Jones and Sons Pty Ltd. The actual prospect site is located where the track from Tutu Well to Butcher Well intersects a wall of large boulders forming part of the microdiorite dyke.

This extensive dyke is up to 40 m in scree width and about 3–4 m in height, and consists of a jumble of loosely packed, subrounded boulders, many between 0.5 and 1.0 m^3 in size. Boulders consist of a thin, weathered, brown skin covering a hard, unweathered mass of olive-green, quartz-rich microdiorite (trending to microtonalite) speckled with small clots of dark ferromagnesian minerals, mainly hornblende (Fig. 40).

Cutting and polishing trials have demonstrated that this hard rock cuts well into relatively thin sheets and achieves a high polish. It is suggested that, cut as a dimension stone, this rock may be suitable for visually attractive applications such as interior wall panels and tiles in an appropriate architectural setting (Appendix 4.16).

Petrographic description

Altered pyroxene–hornblende-bearing quartz microdiorite transitional to microtonalite with uralitic–chloritic alteration of pyroxene–albite–chlorite(–prehnite) in plagioclase, and clay–prehnite in biotite.

This dark greenish-grey mottled rock has disseminated interstitial quartz as well as very minor K-feldspar and seems to represent quartz microdiorite, transitional to microtonalite, rather than gabbro. The visually estimated mineralogy includes 68–70% plagioclase, 17% quartz, 9–10% chlorite-green hornblende/actinolite aggregates, 3% opaque oxide and small amounts of brown hornblende, K-feldspar, apatite, and altered biotite. Plagioclase laths from 0.4 mm to 4 mm long have been albitized with minor chlorite(–?prehnite). Interstitial quartz is disseminated, to 4 mm in diameter, and locally accompanied by K-feldspar, partly as rims on plagioclase and partly interstitial. Aggregates of chlorite, hornblende or actinolite, and opaque oxide, to 4 mm in diameter, commonly carry minor apatite. Most of the mafic aggregates have evidence of former clinopyroxene with cores replaced by chlorite and rims replaced by actinolite, but minor primary brown hornblende is also evident, originally rimming clinopyroxene. The biotite has clay alteration and lenses of prehnite parallel to the cleavage.

Boogardie orbicular granite

The *Boogardie Orbicular* granite deposit is located 35 km west of Mount Magnet. This unusual form of granite, located on Boogardie Station, is one of a few orbicular granite localities known worldwide. At Boogardie, the central tenement mining lease M59/28 owned by Mr K Seivwright, encloses the Boogardie quarry, which is currently in care and maintenance. Surrounding this tenement is a second mining lease M59/493, owned by H & J Jones and Sons Pty Ltd. This outer lease contains two significant exploration sites at the North prospect (a flat, oval-shaped area about 25–40 m in diameter where the upper surface of the orbicular granite is exposed), and the Middle prospect (a small, rectangular test costean; Fig. 41). At the Boogardie quarry site, there appear to have been no significant mining operations since the late 1990s, whereas exploration has occurred in more recent times at the North and Middle prospects to the north of the quarry (Fig. 42).

The orbicular granite is hosted by a pink, medium-grained, north-easterly trending, late Archean granitic rock, comprising myrmekitic biotite granodiorite that becomes tonalitic in places. Average composition is 51% plagioclase feldspar, 32% quartz, 10% microcline, 5.5% biotite, 1.5% opaque oxide and titanite, with minor apatite and zircon, and possible garnet (Fig. 43).

Information from previous diamond drilling programs indicates that orbicular granite bodies may have formed as saucer-shaped, sill-like structures within the host granodiorite–tonalite. Six drillholes completed in 1989, over the area of the Boogardie quarry revealed an oval-shaped body about 40 m wide (east–west) and at least 55 m long (north–south). Maximum thickness of the orbicular granite in the centre of the deposit was 11.4 m that tapered off in all directions to relatively small thicknesses at the outer rims (Fig. 44; Hensel, 1995).

Another body, possibly of similar structure, is located about 200 m to the northeast, in the area of the North and Middle prospects. At this site, an initial percussion drillhole in excess of 18 m depth, revealed the presence of orbicular granite with a thickness of 14 m. In late 2004, three diamond drillholes in the same area outlined a section of an orbicular granite body with a maximum thickness of 15 m (Hole 1) that thinned gradually to the southwest with thicknesses of 11 and 9 m in Holes 2 and 3 respectively (Fig. 41; Jones, P, 2009, written comm.).

Within the sill-like structures, abundant granitic orbicules are contained in a leucogranitic body of variable tonalitic composition. Towards the edge of the orbicular body in the Middle prospect, this leucocratic matrix comprises fine- to medium-grained, biotite tonalite–trondhjemite containing 59% plagioclase feldspar, 32% quartz, 7% biotite, and 1–2% opaque oxide and titanite, plus accessory apatite, and minor pyrite and zircon (Fig. 45).

The black and white, concentrically banded orbicules are of spectacular appearance. Orbicules are mostly ellipsoidal in shape but also include lesser numbers of near-spherical, irregular and broken shapes. Orbicules have an average length of about 140 mm along their longest axis by 75 mm in width. The largest orbicules observed by the author were in the range 150–200 mm in length while subspherical varieties were up to 140 mm in diameter. Within the tonalitic rock mass, orbicule spacing varies from orbicular masses in tangential contact with one another to a maximum separation of about 100 mm, although overall orbicule distribution appears roughly uniform throughout the rock (Fig. 46).

Individual orbicules are generally separated from the enclosing biotite granodiorite/tonalite matrix by a mid- to dark grey outer shell up to 10 mm thick comprising mainly fine- to medium-grained hornblende, biotite, and plagioclase feldspar, with minor opaque oxide, and titanite. A biotite-defined foliation is orientated parallel to

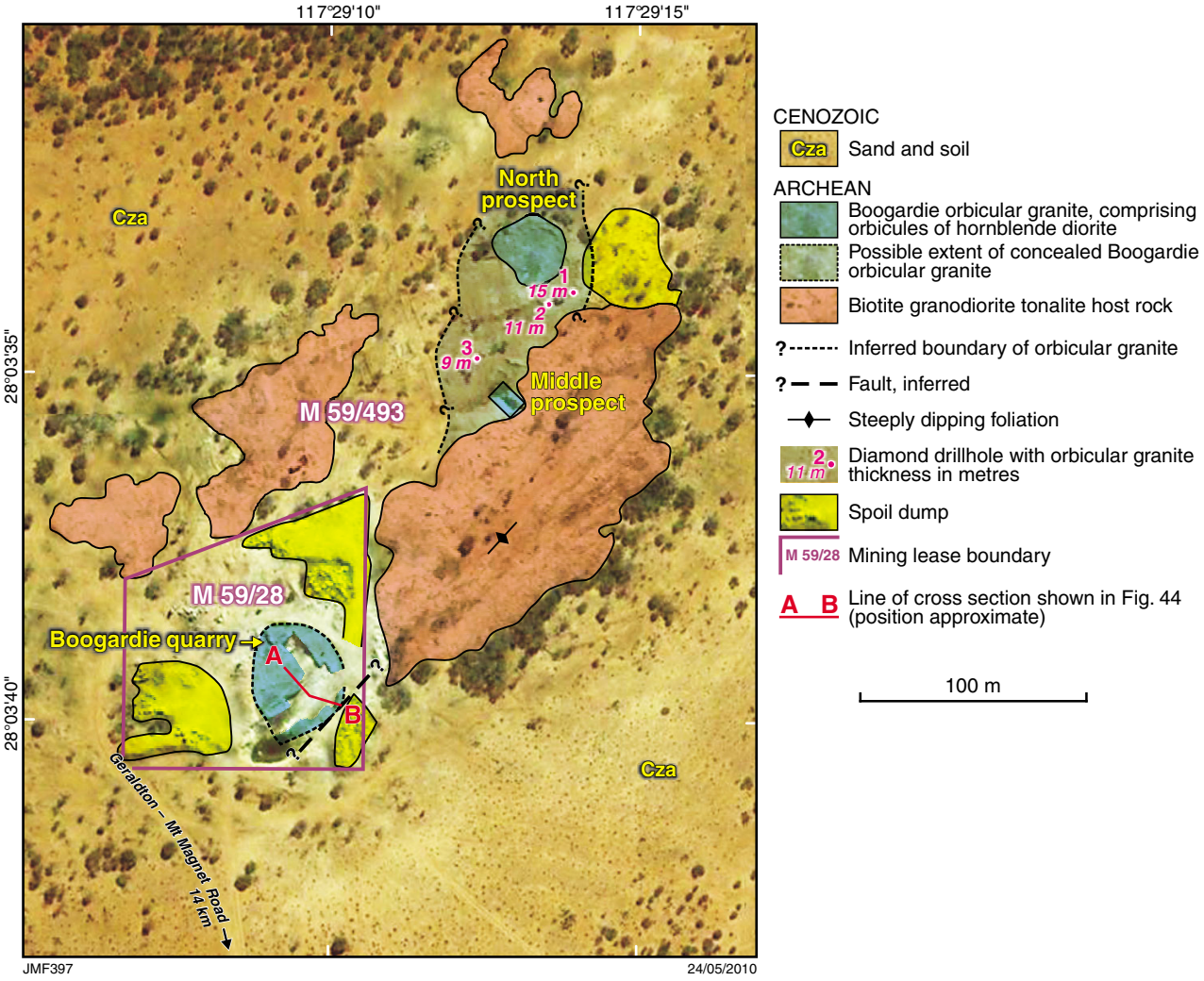
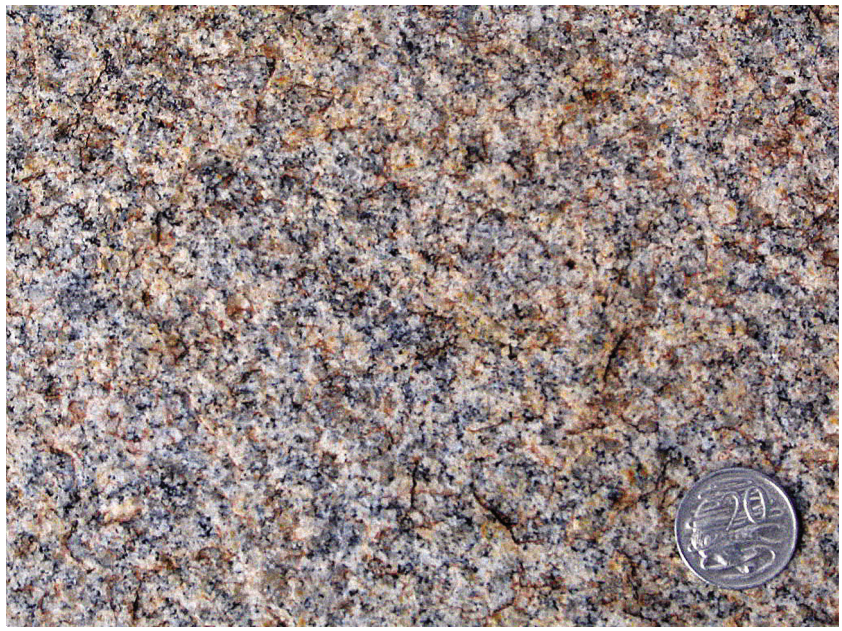


Figure 41. Geological sketch map of the *Boogardie Orbicular* granite quarry and exploration areas.

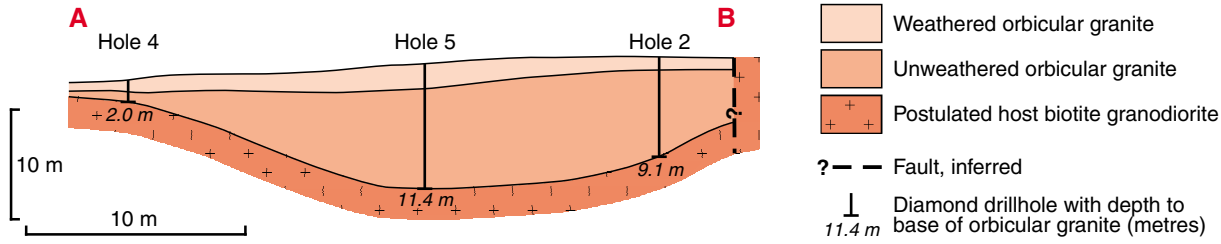


Figure 42. Boogardie quarry, looking north.



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Figure 43. Host biotite granodiorite/tonalite to the *Boogardie Orbicular* granite.



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Figure 44. Schematic northwest–southeast cross section through the Boogardie quarry shown in Figure 41 (modified after Hensel, 1995).



Figure 45. Orbicules contained in a leucocratic matrix of biotite tonalite–trondhjemite in the Middle prospect.



Figure 46. Orbicules enclosed in a granodiorite–tonalite matrix. Rock mass, including orbicules has been cut by a late-phase, pink pegmatite vein approximately 120 mm thick.

the outer surface of the shell. Inside this protective shell, orbicules have a hornblende diorite composition, being largely composed of plagioclase feldspar and hornblende with lesser amounts of biotite, opaque oxide and titanite. Orbicules usually contain 5–7 (or even more) major, well-defined, concentric zones of variable width, structural complexity, and mineralogy. Some major zones may be up to 15 mm in width and commonly contain large, irregular, elongate, radially aligned, hornblende grains interspersed with white plagioclase. These hornblende grains may extend across the entire width of the zone and are commonly tapered internally to a point. Major zones may also contain internal, concentric subzones evidenced by minor variations in mineralogical composition and texture within each zone. Interspersed between major zones are thinner, hornblende-poor leucocratic zones, comprising mostly granular plagioclase with minor opaque oxide and titanite. Also, other thin, dark zones appear to contain small, irregularly shaped hornblende grains (Fig. 47a–f).

Major orbicules may have central core zones of differing composition. The most common core type appears to be an orbicule formed around 'seed crystals' of coarsely crystalline, white plagioclase feldspar surrounded by a very coarse, radiating, black ferromagnesian mineral that is probably hornblende (Fig. 47a; Appendix 4.17). Other orbicules appear to have nucleated around fragments of mafic xenoliths of several types comprising schistose amphibolite or biotite–hornblende–plagioclase schist, whereas others have formed around broken, multi-layered fragments of previously formed orbicules (Bevan, 2007).

Also interspersed within the tonalitic matrix are many smaller orbicules, referred to as 'primitive' orbicules. These consist of a few zones of simple composition, largely of relict pyroxene within amphibole (Bevan, 2004).

Bevan (2004) proposed that the orbicules were formed by crystallization from a fluid-rich, supercooled, dioritic magma. Variations in orbicule type and layer structure reflect a very dynamic history of crystallization influenced by changes in magma composition and degree of cooling. The presence of broken fragments and variations in zone mineralogy indicates that proto-orbicules were very mobile in the magma chamber, probably propelled by convection currents within fluid-rich margins. Orbicules were eventually subject to gravity settling to form the deposit visible today. It is evident that at the time of settling, orbicules were still in a plastic state as they are often deformed or moulded together. Some orbicules appear to have been dragged along by the current while others show evidence of mass movement after settling.

At different times during the Proterozoic, the orbicular granite was intruded by a variety of steeply dipping dykes and veins. The earliest intrusion appears to be a north-trending, irregular, fine-grained, mid-grey dyke composed of biotite–quartz microdiorite, exceeding 1.0 m thickness in places. The microdiorite dyke was later cut by a series of relatively thin aplitic veins comprising fine-grained, leucocratic monzogranite. The final intrusive event was the intrusion of a conjugate set of pink, coarse-grained pegmatite dykes and veins that crosscut all previous dykes and veins, as well as the orbicular granite (Fig. 46). Thicknesses range from veins only 10–20 mm to dykes between 1 and 2 m across. Trends are in two directions, approximately east-northeast and south-southeast.

Further recent information on the nature and origin of the late Archean *Boogardie Orbicular* granite is given in Bevan and Bevan (2009).

At Boogardie, remaining orbicular granite resources are difficult to determine due to poor orbicular granite outcrop and limited drilling information. Hensel (1995) estimated that there was approximately 10 000 m^3 of stone remaining at the quarry site of which 4000–6000 m^3 (equal to approximately 11 000 – 16 500 t) could constitute saleable blocks. It is probable that most of this resource is located in the central, and north wall areas of the quarry (Fig. 42).

At the North and Middle prospects where the upper surface of the orbicular granite has been exposed, three drillholes have shown thicknesses from 9–11 m. These preliminary investigations have indicated that this unmined area may contain a substantial volume of high-quality orbicular granite suitable for dimension stone blocks. A follow-up drilling campaign could delineate the available resource.

Physical properties of the *Boogardie Orbicular* granite, as determined by Johnston (1985), have shown that the material falls well within acceptable ASTM standards given in Appendix 2 for the following tests:

- Absorption 0.11%
- Bulk density 2.76 t/m^3
- Compressive strength 138.8 MPa
- Modulus of rupture 15.66 MPa

Because of its visually spectacular orbicular structure, relative rarity, and ability to take a high polish, the orbicular granite has been quarried at different times, supplying mainly small consignments of ornamental blocks and slabs to artisans and monumental masons. Prime examples of completed works include high-quality ornamental works such as contemporary sculptures, interior decorative panels and tables (Fig. 48). Floating orbicular granite spheres, measuring up to one metre in diameter, are also popular.

Since the Boogardie quarry has been in care and maintenance for a number of years, current stocks held by dimension stone processors are becoming increasingly scarce. It is probable that this high-quality, specialty stone could command a substantial overseas market, particularly if exported in block form. In addition, the domestic market for interior polished slabs and ornamental pieces could probably be expanded if brought to the notice of stone retailers, architects, and artisans around the country.

Petrographic description

An orbicular granitic rock with a large orbicule of hornblende diorite separated from the biotite tonalite matrix by a 10 mm-wide, zoned hornblende–biotite–plagioclase outer shell.

The shell contains an inner zone rich in hornblende (about 43%). Plagioclase (21%) together with biotite (33%) increase in abundance towards the outer half of the shell to the exclusion of hornblende. The shell also contains irregularly disseminated opaque oxide and titanite with

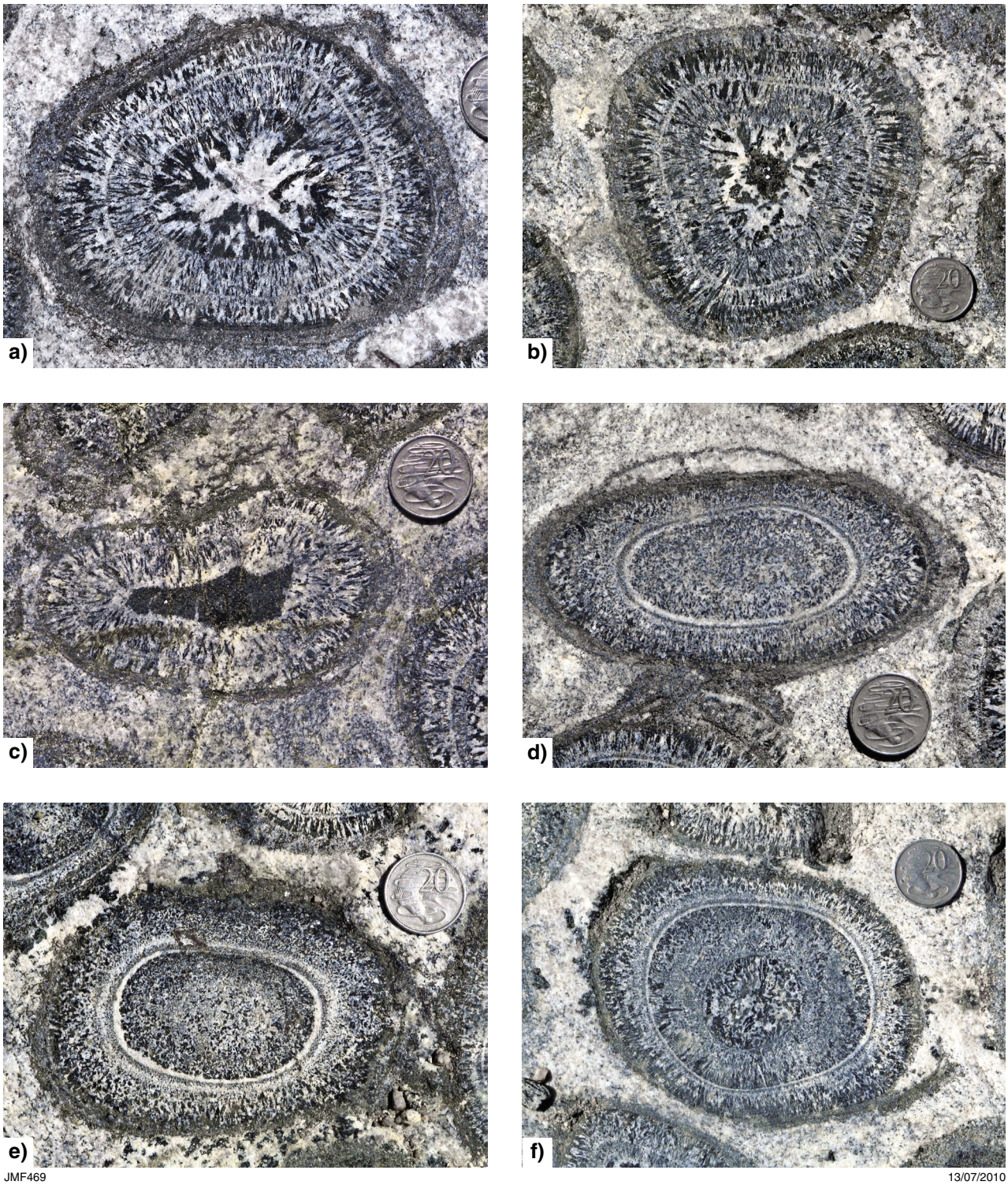
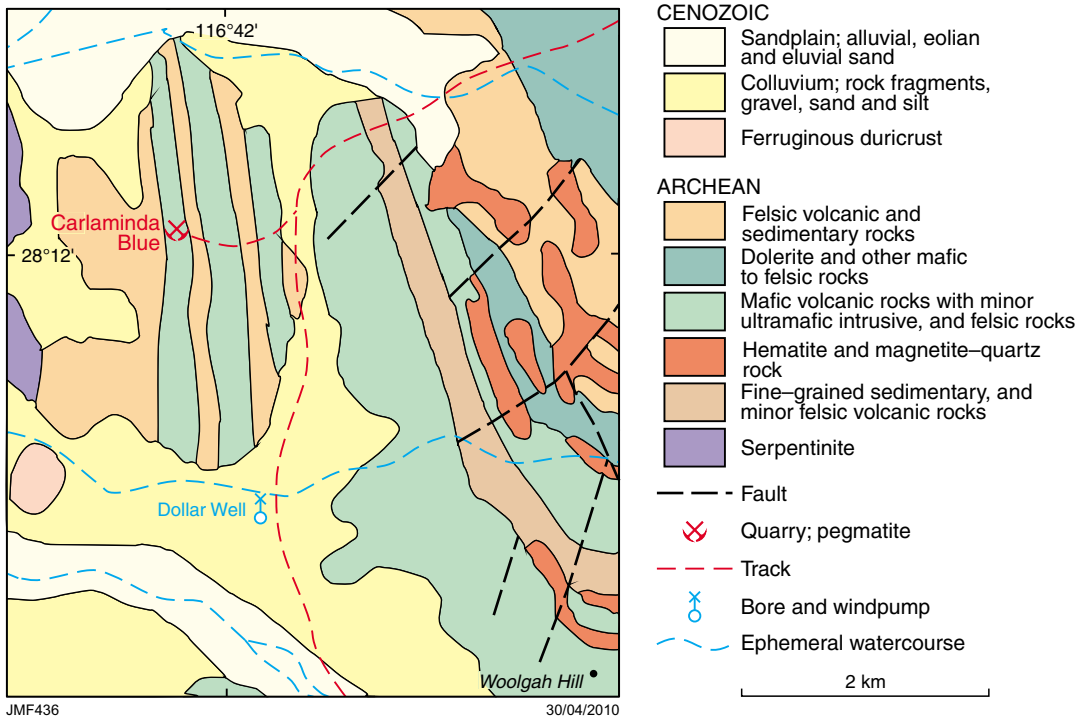


Figure 47. A selection of Boogardie orbicule types showing variations in concentric shells and central cores. Orbicules are enclosed by a grey outer shell approximately 10 mm thick. The most common orbicule variety with coarse, black, radiating hornblende crystals appears in photo (a).



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Figure 48. Office table crafted in high-grade *Boogardie Orbicular* granite (courtesy Mark Creasey).



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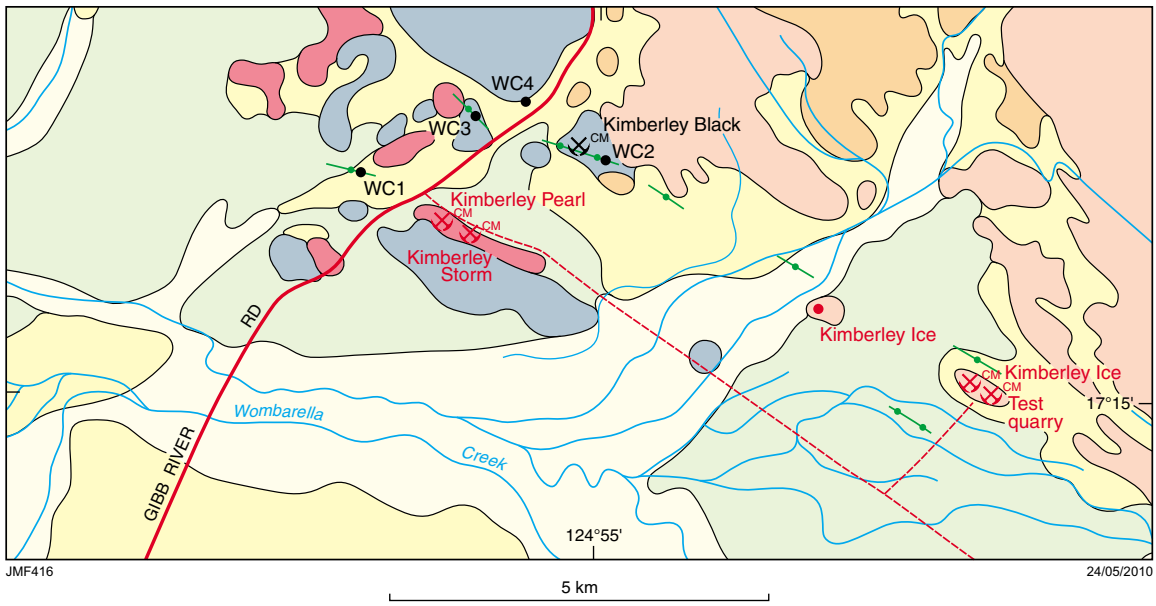
Figure 49. Geological map of the *Carlaminda Blue* quarry area, north of Yalgoo (modified after Muhling et al., 1975).



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Figure 50. Quarry face showing blue lepidolite mica interspersed with white albite feldspar and grey quartz. *Carlaminda Blue* quarry, Yalgoo area.

Figure 51. (below) Geology of the Wombarella Creek area. West Kimberley region (modified after Griffin et al., 1993).



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CENOZOIC
- Alluvium
- Black soil
- Party consolidated alluvium and colluvium

PALEOPROTEROZOIC
- Dolerite dyke
- Kongorow Granite; foliated, porphyritic, monzogranite and granodiorite
- Lennard Granite; foliated, coarse biotite monzogranite
- Wombarella Quartz Gabbro; medium- to fine-grained gabbro, quartz gabbro and quartz norite
- Richenda Microgranodiorite; foliated medium- to fine-grained granodiorite and tonalite

- CM Quarry; granitic gneiss, care and maintenance
- Prospect; granitic gneiss
- CM Quarry; black granite, care and maintenance
- Prospect; black granite: WC-Wombarella Creek
- Road
- Track
- Track, four wheel drive
- Watercourse

rare carbonate (3%). Biotite, to 3 mm in diameter, defines a foliation parallel to the outer surface of the shell, but the hornblende is poorly oriented.

The hornblende diorite orbicule contains about 68% plagioclase, 31% hornblende, and 1% biotite. It is concentrically zoned with two areas richer in hornblende separated by a narrow hornblende-poor zone of granular plagioclase. Plagioclase to 8 mm in diameter is accompanied by brownish-green hornblende to 4 mm with a weak radial arrangement in the outer hornblende-rich zone and minor biotite as very thin plates. Opaque oxide and titanite are most abundant in the plagioclase-rich zone.

Yalgoo — pegmatite

Carlaminda Blue

The *Carlaminda Blue* quarry is located 16 km north of the town of Yalgoo and about 6 km west-southwest of the abandoned Noongal townsite (Fig. 49). The quarry is currently owned by Zen Minerals Pty Ltd on mining lease M59/594.

At the quarry site, a white pegmatite body extends over 100 m in an east–west direction, is between 50 and 100 m in width, and is approximately 3.0 m thick. It is exposed at the surface in places; elsewhere depth of burial appears to be no more than 2 m.

The pegmatite, of probable Paleoproterozoic age, intrudes Archean metabasalt. The pegmatitic body is possibly a sill-like structure that appears to dip at a shallow angle to the west. In the quarry, massive, white albitic feldspar contains quartz megacrysts (>10 mm in diameter) as well as irregular quartz blebs and veins. Lepidolite mica is the other principal mineral component that occurs, with irregular masses varying from 5.0 mm to about 1.0 m in diameter. The colour of the mica varies from sky-blue to purple in different places around the quarry (Fig. 50). Lepidolite is also present as anastomosing, vein-like networks.

In recent years, it is known that quarry operators have exported quantities of the blue lepidolite to China for incorporation as the blue component in stone mosaics. Because of the stone's unusual blue colour and texture, it is suggested that this visually attractive stone may be suitable for artisanal applications such as shaped and polished wall-mounted display panels (Appendix 4.18).

Petrographic description

Lepidolite–albite–quartz pegmatite with rare possible zircon and garnet.

The hand specimen from which this thin section was taken shows heterogeneous material with abundant bluish lepidolite on one face but only small amounts of this blue mica on the opposite face. The thin section shows abundant probable albite as platy crystals to 8 mm long and 2 mm wide, largely unoriented or in fan-like aggregates. There is also abundant mica, apparently lepidolite, commonly as crystals to 6 mm long elongate normal to the (001) cleavage, but there are also less-elongate mica flakes, partly intergrown with albite(–quartz). Localized large grains of quartz occur, to 10 mm or more in diameter, with abundant fine-grained inclusions of albite. A single possible zircon is present, 0.3 mm long, with partly concentric zoning interrupted by a crystal of lepidolite. The mica is rarely intergrown with columnar quartz and irregular very small grains of probable garnet.

Northern region

King Leopold Orogen — Hooper Complex

Wombarella Creek — granitic gneiss

In the Wombarella Creek area, 135–140 km east-northeast of Derby, a number of granitic gneiss domes form part of the Paleoproterozoic Hooper Complex within the King Leopold Orogen. These granitic gneisses have been interpreted as being part of the extensive Lennard Granite and the locally restricted Kongorow Granite, both of which have intruded earlier Proterozoic metasedimentary rocks of the Marboo Formation (Griffin et al., 1993). Adjacent to the Gibb River Road, two granitic gneiss domes forming part of the Kongorow Granite, host the *Kimberley Pearl* and *Kimberley Storm* quarries. About 7 km to the east-southeast, two more domes within the Lennard Granite, have been investigated for dimension stone, one of which hosts the *Kimberley Ice* quarry (Fig. 51).

Kimberley Pearl

Located on mining lease M04/89, the *Kimberley Pearl* granitic gneiss is contained within an extensive, smooth, exfoliated whaleback granitic dome. Trending in a northwesterly direction, the dome measures approximately 375 m in length, with a maximum width of 100 m and an elevation of about 40 m above the surrounding plain (Fig. 52).

Kimberley Pearl is a medium grey, megacrystic, biotite–hornblende syenogranite gneiss (Fig. 53). When polished, it assumes a visually attractive pearlescent appearance making it eminently suitable for wall panels on buildings both interior and exterior as well as interior benchtops, vanity units and tiles (Appendix 4.19).

Technical specifications from Melocco Stone (2009) show *Kimberley Pearl* complies well with standard values given in Appendix 2:

- Absorption 0.02%
- Bulk density 2.67 t/m^3
- Compressive strength (dry) 104.4 MPa

Black Swan Quarries commenced quarrying at the site in 1989. Ramps were constructed onto the dome to allow access for the construction of a several quarry benches with walls up to 6 m high and up to 120 m in length at different elevations (Fig. 54). Original quarrying involved the use of thermal lances for the release of



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Figure 52. A smooth, exfoliated, 40 m-high, whaleback dome of Kongorow Granite. This dome is host to the *Kimberley Pearl* granitic gneiss quarries at Wombarella Creek (view looking northwest).



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Figure 53. *Kimberley Pearl,* a megacrystic, biotite–hornblende syenogranite gneiss at Wombarella Creek.

primary blocks. This technique was later replaced by close-spaced drilling for block removal. Later, another lower quarry with 6 m-high walls of massive *Kimberley Pearl* was established at the northwestern toe of the dome (Fig. 55).

Quarrying operations continued for about five years with block production rates reaching 500 m^3 per month. During this period a large number of blocks were produced and exported largely through the port of Broome to Italy, Japan, Taiwan, and capital cities in eastern Australia (Williams, 2004). Notable buildings clad with *Kimberley Pearl* include the John Fairfax headquarters in Chullora in Sydney, and Nomura Securities Building in Tokyo (Fig. 56). In 1992, a legal dispute resulted in the project being frozen and quarrying ceased. A large stockpile in the order of 100 well-cut blocks, up to 3.0 m × 1.5 m × 1.5 m in size, are still present adjacent to the quarry site (Fig. 54).

In 2004, Serenity Stone Pty Ltd, released a Notice of Intent to resume mining of the *Kimberley Pearl* dimension stone. The project was based on a proposal to extract 6000 m^3 per annum of high-quality stone from a non-JORC resource estimated to be in excess of 0.6 Mm^3 to 15 m below the surrounding plain level. Resource recovery, estimated at 70%, would be achieved by quarrying from a series of 4–5 m-high benches. Operations were planned to produce blocks 3.0 m × 1.5 m × 1.5 m that would be achieved by close-spaced drilling, diamond wire sawing, and expansive rock-splitting compounds. It was intended to truck saleable blocks to the port of Broome for shipment to markets both within Australia and overseas (Williams, 2004). Despite this proposal and other attempts since that time to revitalize the project, the *Kimberley Pearl* quarries currently remain in care and maintenance.

Petrographic description

Megacrystic, biotite–hornblende syenogranite gneiss with lamellae of fine-grained, recrystallized feldspathic material, and also coarse feldspars, recrystallized quartz and lenses of biotite and/or hornblende.

This syenogranite gneiss has relatively thick mafic lenses and comprises mostly coarse-grained feldspar. The visually estimated mineralogy includes lenses and lamellae of fine-grained recrystallized feldspar-rich material, augen of orthoclase, coarse-grained plagioclase and abundant interstitial recrystallized quartz. The thin section is estimated to have 47% orthoclase, 32% quartz, 12% plagioclase and myrmekite, 4–5% each of hornblende and biotite, and accessory amounts of epidote, apatite, and zircon. This indicates syenogranite gneiss. The orthoclase is as much as 25 mm long with inclusions of subhedral plagioclase. Separate plagioclase grains are 8 mm long and occur partly in aggregates to 10 mm long. Lamellae of quartz to 8 mm wide contain inequigranular quartz grains from 0.2 to 3 mm long. Mafic lenses to 3 mm wide have been recrystallized and are less foliated than in other gneisses in the Wombarella Creek area, with hornblende to 2 mm and biotite to 1 mm, but fine grained, and microcrystalline mafic minerals occur in and adjacent to lamellae of fine-grained feldspathic or quartzofeldspathic material. Epidote, apatite, and zircon are fine grained with zircon about 0.1 mm in diameter.

Kimberley Storm

The *Kimberley Storm* quarry is located on mining lease M04/202 about 400 m south of the *Kimberley Pearl* operations within a discrete area of the Kongorow Granite (Figs 51, 54). Situated on the southwest side of a small hill, the 50 m-wide quarry comprises two operating levels each 4 m high that formerly yielded numerous blocks of massive stone (Fig. 57).

Kimberley Storm is petrologically similar to *Kimberley Pearl* rock, being a megacrystic, biotite–hornblende syenogranite augen gneiss, despite its different visual appearance, with a much darker grey to black matrix of mafic minerals. These mafic minerals, mainly biotite and hornblende, are arranged as foliated laminae with swirling patterns to which the trade name of *Kimberley Storm* alludes (Appendix 4.20).

Technical specifications from Melocco Stone (2009) also show *Kimberley Storm* to comply well with values given in Appendix 2:

- Absorption 0.01%
- Bulk density 2.71 t/m^3
- Flexural strength (dry) 12.2 MPa

Little is known about operations at this site conducted by Black Swan Quarries during the 1980s apart from the fact that they produced a substantial quantity of high-quality stone blocks by close-spaced drilling. Blocks were sent to Sydney and Melbourne where they were slabbed into polished panels for projects including some of the exterior wall sections of the Crown Casino complex in Melbourne (Fig. 58).

Currently, mining lease M04/202 is owned by Serenity Stone Pty Ltd. Despite having been in care and maintenance for many years, the quarry is well-preserved as seen in Figure 57. Quarrying operations could quickly recommence should there be a resurgence in demand for this attractive stone. Also, there is a considerable stockpile of large blocks stored outside the quarry area (Fig. 54).

Petrographic description

Biotite–hornblende syenogranite augen gneiss with minor titanite and garnet, with accessory epidote, apatite, and zircon.

Lenses of granular feldspar are abundant in this sample with wavy lamellae rich in quartz and narrow foliated mafic lamellae. This sample is heterogeneous but the visually estimated mineralogy indicates 45–46% orthoclase, 21% plagioclase, 21% quartz, 7% biotite, 4% hornblende, and <1% total titanite, garnet, apatite, epidote, and zircon, indicating syenogranite gneiss. Augen of orthoclase to 12 mm in diameter are accompanied by plagioclase to 6 mm long and lenses of quartz, to 4 mm wide, containing quartz grains to 3 mm in diameter. Lamellae of inequigranular, mostly very fine grained feldspar(–quartz–biotite–hornblende) are abundant and parallel to anastomosing lenses with hornblende, biotite, titanite, and rare garnet as well as epidote and rare zircon about 0.1 mm in diameter. The orthoclase commonly has possible fractures filled with quartz, plagioclase, and rare carbonate(–titanite).

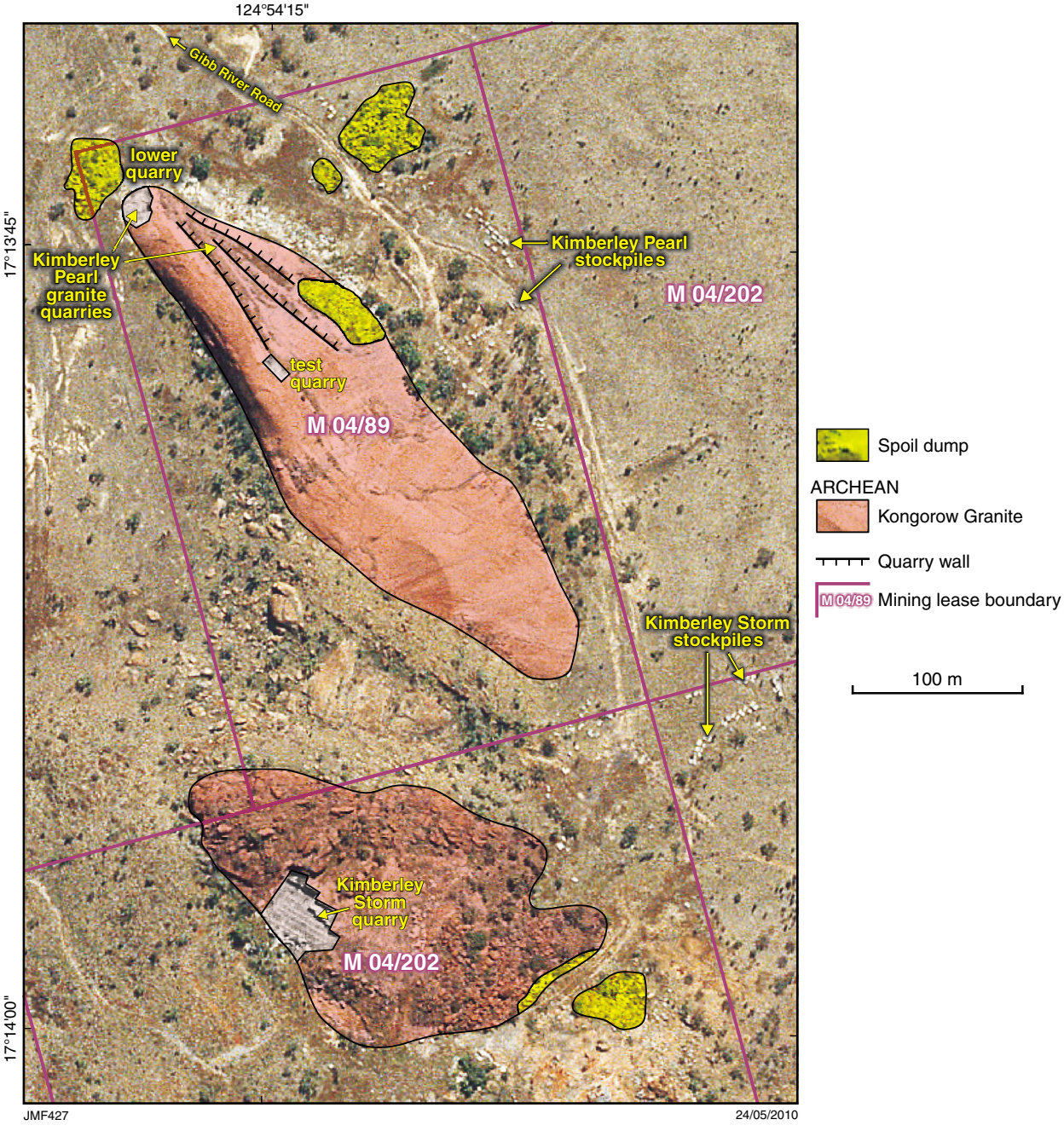


Figure 54. Sketch map of the Kongorow Granite domes containing the *Kimberley Pearl* and *Kimberley Storm* quarries at Wombarella Creek.



a)



b)

JMF470 13/07/2010

Figure 55. ***Kimberley Pearl*** **quarrying operations: a) cutting out primary blocks using close-spaced drilling; b) massive, 6 m-high wall of** ***Kimberley Pearl*** **in lower quarry (photo (a) courtesy Williams Group of Companies).**



JMF636 27/07/2010

Figure 56. ***Kimberley Pearl*** **slabs used as wall cladding in the Nomura Securities building in Tokyo (courtesy Williams Group of Companies).**



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Figure 57. The ***Kimberley Storm*** **quarry. This granitic rock is a megacrystic, biotite–hornblende syenogranite augen gneiss and forms part of the Paleoproterozoic Kongorow Granite. Wombarella Creek, West Kimberley region.**

Kimberley Ice

Approximately 7 km to the east-southeast of the *Kimberley Pearl* quarry, there are two exfoliated, whaleback granitic gneiss domes of *Kimberley Ice*, averaging 275 m in length × 65 m in width, and up to 30 m in height. Separated by about 2 km, these northwesterly trending domes form part of the Paleoproterozoic Lennard Granite (Fig. 51). In the mid-1990s, Dodsley Pty Ltd owned the mining tenements covering both domes. During 1995–96, the domes were explored and mapped in some detail.

Figure 59 displays the western dome, known as the *Kimberley Ice* prospect on mining lease M04/301, that was explored and mapped by Elkington (1996). Investigations showed that the northwestern area of the dome contained a large resource of massive granitic gneiss intersected by fine veins and dykes of microgranite, quartz, and pegmatite in two main orientations (northwest–southeast and east–west; Fig. 60). A small number of shaly xenoliths are also present. It was concluded that this area may not be suitable for dimension stone and that the southeastern section of the dome, still to be mapped, may be more consistent for dimension stone with possibly fewer dykes present. A polished tile from the prospect was retained for market appraisal.

Over the same period, the eastern dome on mining lease M04/302 was more thoroughly investigated by Elkington (1998) who carried out detailed mapping of the whaleback before embarking on a quarrying and bulk sampling project to test this promising dimension stone site (Fig. 61).

A small test quarry, high on the dome, was first opened to reveal the megacrystic nature of this granitic gneiss with its steeply dipping mineral foliation (Fig. 62). The larger main quarry, close to ground level on the northern face, was then opened to obtain a large quantity of 10 t blocks for an extensive bulk sampling and market evaluation exercise. The 6 m-high main quarry was found to consist of massive granitic gneiss with no evidence of any jointing, veins or dykes and revealed the visually attractive nature of this potential dimension stone (Fig. 63). Elkington (1998) also notes that the granitic gneiss is not uniform throughout the dome as zones of mafic inclusions are present in at least two other unspecified areas. With these considerations, Elkington estimated the total resource of uniform quality *Kimberley Ice* would be in the order of 0.1 Mm^3.

The bulk sampling exercise yielded 336 t of dimension stone with an excellent recovery rate of 70%. Of this material, 22 m^3 of high-quality blocks were sent for market appraisal and application in industry. Details of the destination of these blocks and construction projects in which they were used are unknown. A considerable number of 10 t blocks still remain stockpiled on site.

More recent sampling by the author has shown that *Kimberley Ice* is a leucocratic, megacrystic, foliated monzogranite–granodiorite gneiss containing K-feldspar augen to 40 mm, plus substantial amounts of coarse-grained plagioclase feldspar and quartz set in a foliated matrix consisting of laminae of recrystallized plagioclase, microcline and quartz together with less common biotite and hornblende (Appendix 4.21). Samples from both domes show a closely related mineralogy with the main quarry site in the eastern dome, being gneissic granodiorite to monzogranite, whereas the western prospect indicated gneissic monzogranite transitional to quartz monzonite.

Petrographic descriptions

Kimberley Ice quarry (eastern dome)

Megacrystic granodiorite to monzogranite gneiss with coarse-grained feldspars, lenses of quartz and recrystallized feldspar-rich material, also lamellae of mafic minerals (biotite–hornblende–epidote–allanite–garnet–titanite–zircon).

Augen of feldspar to 25 mm or more in length are evident in this sample, with a foliation defined by anastomosing biotite-rich lamellae. The thin section has more abundant quartz than the *Kimberley Storm* sample with 35% quartz (including 2% in recrystallized lamellae with feldspars and mafic minerals), 22–23% microcline (including 5% fine-grained recrystallized material), 45% plagioclase (25% coarse grained, 20% fine grained), 5% biotite, 1–1.5% hornblende, and smaller amounts of epidote, allanite, and garnet. This indicates transitional granodiorite to monzogranite gneiss. The thin section has microcline augen to 15 mm or more in length, plagioclase grains to 5 mm long and lenses of quartz to 4 mm wide containing quartz to 4 mm in diameter. Lamellae of recrystallized plagioclase, microcline, and quartz are also common, with less abundant lamellae of biotite and hornblende, locally with epidote or allanite, titanite, minor garnet, and rare zircon 0.1 mm in diameter. The plagioclase has sparse small patches of sericite.

Kimberley Ice prospect (western dome)

Megacrystic gneiss transitional from monzogranite to quartz monzonite, with augen of orthoclase and lamellae of biotite–hornblende–garnet(–epidote–titanite) composition.

This sample is composed of megacrystic augen gneiss with possible K-feldspar augen to 40 mm long and apparently biotite-rich lamellae defining an anastomosing foliation wrapping around the megacrysts. The gneiss is heterogeneous and the visually estimated mineralogy derived from the thin section may not be representative. The thin section has about 27% orthoclase as large augen and 25–26% relatively coarse grained plagioclase to 6 mm in grain size as well as recrystallized lamellae contributing 20% fine-grained plagioclase and 3–4% fine-grained quartz. Coarse quartz, to 3 mm in grain size, constitutes 15% of the thin section and occurs in anastomosing lenses to 3 mm wide. Mafic lamellae are also anastomosing and contribute 4–5% biotite, 3% hornblende, 1% garnet, and <1% epidote and titanite. The biotite is mostly less than 2 mm long, with hornblende to 3 mm and fine-grained granular garnet. The rock, as a whole, is possibly richer in orthoclase and mafic minerals than the sample from the eastern dome, and may represent monzogranite to quartz monzonite gneiss.



Figure 58. Polished wall panels of *Kimberley Storm* forming part of the Crown Casino complex in Melbourne.

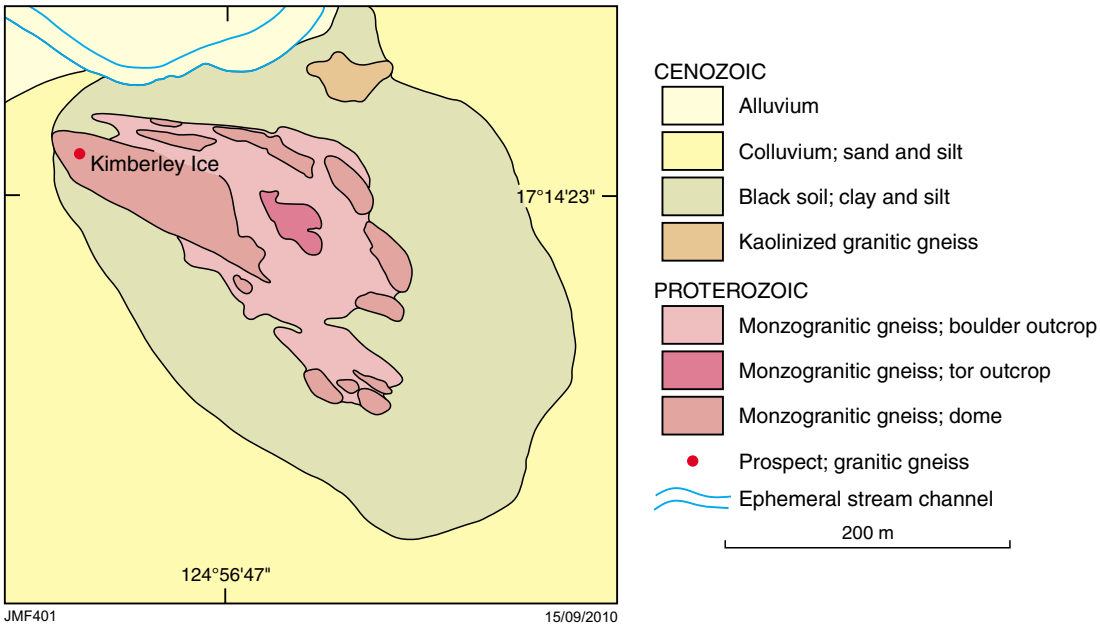
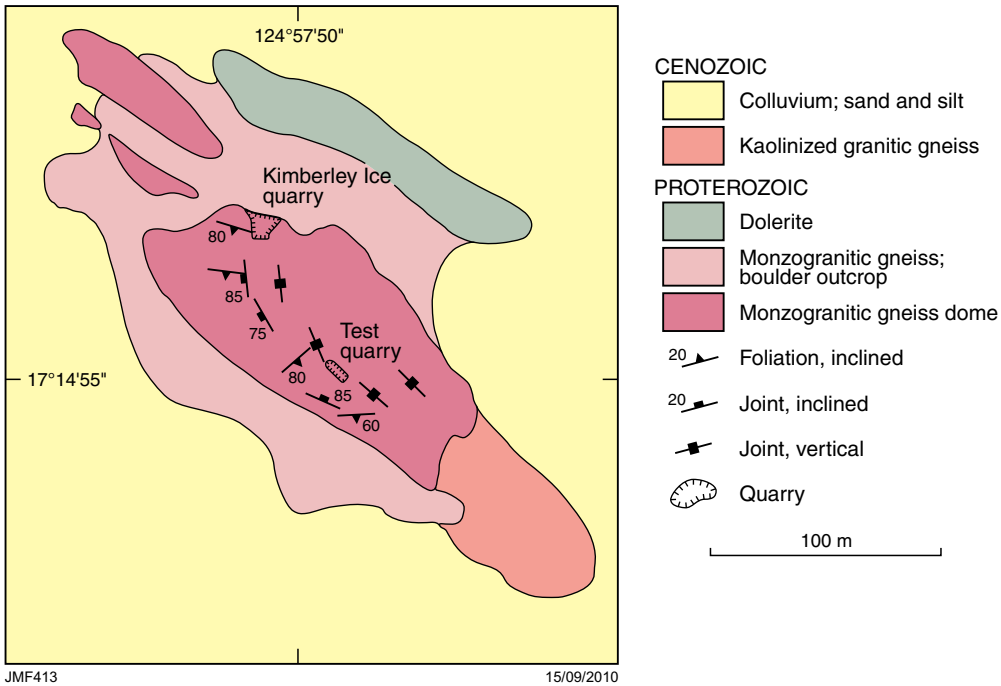


Figure 59. Geological sketch map of the *Kimberley Ice* prospect. Wombarella Creek area (modified after Elkington, 1996).



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Figure 60. The gently sloping, northwest pavement of the *Kimberley Ice* prospect. The whaleback dome is composed of monzogranitic gneiss forming part of the Paleoproterozoic Lennard Granite.



JMF413 15/09/2010

Figure 61. Geological sketch map of the *Kimberley Ice* quarries (eastern dome). Wombarella Creek area (modified after Elkington, 1998).





JMF472 13/07/2010

Figure 62. ***Kimberley Ice*** **test quarry: a) small quarry, 1.5 m deep, aligned along the northwest-trending axis of an exfoliated, 30 m-high whaleback dome of Lennard Granite; b) southwest wall of test quarry showing steeply dipping foliation of the monzogranitic gneiss.**





JMF473 13/07/2010

Figure 63. ***Kimberley Ice*** **main quarry: a) massive, 6 m-high walls of monzogranitic gneiss; b) detail of the foliated, megacrystic, leucocratic *Kimberley Ice.***

Chapter 3

Black granite (dolerite and gabbro)

Southern region

Albany–Fraser Orogen

Fraser Range — dolerite and metadolerite

Fraser Range Black

The *Fraser Range Black* granite quarry (also known as site FRG 106) is located about 115 km east of Norseman, and about 1.5 km west of the larger *Gold Leaf Black* quarry (site FRG 142; Fig. 64). The site was developed as a test quarry during 1990 and investigations continued until August 1991, when it was put into care and maintenance (Dechow, 1991). The quarry is comparatively small, being about 20 m wide on the western working face where a small area has been drilled and blasted for trial block removal (Fig. 65).

The rock is a black, fine-grained metadolerite, similar in mineral composition to the adjacent *Gold Leaf Black* dolerite at site FRG 142. Horizontal, unloading joints visible in the quarry face, display spacings ranging from 0.5 m in upper levels to 1.5 m at the base of the quarry. Resources could be extensive as the quarry is sited on one side of a ridge of fairly massive black granite (Appendix 4.22).

Petrographic description

A partially recrystallized, possibly ophitic olivine-bearing dolerite, with fresh plagioclase and recrystallized pyroxene–hornblende–olivine–oxide aggregates.

This sample may have been composed of dolerite similar to that described at site FRG 142 but has been metamorphosed and all of the mafic minerals have been recrystallized. The visually estimated mineralogy comprises 56% plagioclase, 25% pyroxene (all or mostly clinopyroxene), 10–11% hornblende, 6% olivine, and 2–3% opaque oxide. The plagioclase forms zoned laths to 3 mm long, set in a matrix of fine-grained recrystallized pyroxene(–hornblende) and minor fine-grained olivine. The olivine is similar in diameter to FRG 142 but may have been recrystallized. The opaque oxide is enclosed in brown hornblende and may have been partly replaced during metamorphism. Apatite is present in trace amounts.

Gold Leaf Black

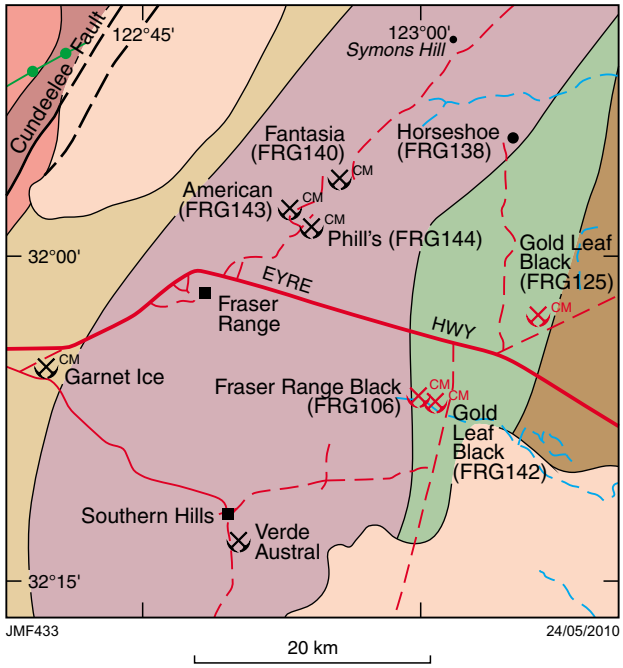
There are two *Gold Leaf Black* quarries situated on the eastern side of Fraser Range. The original and larger quarry at site FRG 142, is located about 115 km east of Norseman, and is approximately 5 km south of the Eyre Highway. The second quarry (site FRG 125), is about 125 km east-northeast of Norseman, and about 5 km north of the Eyre Highway (Fig. 64).

The *Gold Leaf Black* quarries were originally in operation in the early 1990s. At FRG 142, block extraction was in progress early in 1991 but was terminated in May of that year and the focus of operations shifted to the northern *Gold Leaf Black* quarry at FRG 125 that had been opened for testing in late 1990. At the latter site, operations continued for another two months until a sufficient number of blocks had been extracted for market evaluation (Dechow, 1991).

Gold Leaf Black, exposed in the quarries as a mid-grey to black dolerite, was removed as massive blocks up to 15 t (Fig. 66). At FRG 142 horizontal unloading joints are present with spacings increasing downwards from 0.5 to 1.5 m. Steeply-dipping joints are also present in a few places with a separation of around 1.5 m. Extraction methods varied between quarries with drilling and blasting techniques in evidence at FRG 125, whereas at FRG 142, it appears the main quarry walls were originally close-spaced drilled and, more recently, diamond wire sawn (Fig. 67). Although black granite resources at FRG 142 are probably extensive, at FRG 125 resources may be restricted owing to a considerable overburden of unconsolidated regolith and weathered dolerite.

In 1995, *Gold Leaf Black* was one of the stones specified for the Crown Casino in Melbourne, but it was not until 1998 that it was announced that full-scale quarrying operations were about to commence (Western Australian Industrial Minerals Review, 1998). It is understood that quarrying at FRG 142 actually commenced for a short period in the early 2000s and an estimated 3000 t of material was cut by diamond wire sawing. No information relating to marketing or end-uses for this material is available.

Gold Leaf Black is described as an ophitic, olivine–orthopryroxene-bearing dolerite. The reason for the



CENOZOIC

Limestone, sandstone, lignite and spongolite

MESOPROTEROZOIC
Albany-Fraser Orogen
Nornalup Complex

Granitic gneiss and granite

Biranup Complex

Granitic and metasedimentary gneiss

Fraser Complex

Mafic, orthopyroxene-rich granulite with garnet-bearing granitic gneiss, metagabbro and charnockite

Dolerite, gabbro, metagabbro and amphibolite

Mafic-ultramafic Jimberlana Dyke

ARCHEAN
Yilgarn Craton

Granitoid rock

Mafic schist, metabasalt, metadolerite, amphibolite and metasedimentary rocks

Fault

Fault, concealed

CM Quarry; black granite, care and maintenance

Quarry; gneiss, operating

CM Quarry; granulite, care and maintenance

Prospect; granulite

FRG142 Fraser Range exploration site number

Highway

Road

Track

Ephemeral watercourse

Homestead

Figure 64. Geological map of the Fraser Range region showing location of black granite quarries (in red) (modified after Myers, 1985; Sanders, 2000; Jones and Hall, 2004).



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Figure 65. Black, fine-grained metadolerite at the *Fraser Range Black* quarry.



JMF598 27/07/2010

Figure 66. A 15 tonne block of *Gold Leaf Black,* a fine-grained, mid-grey to black dolerite at quarry site FRG 142.



Figure 67. Diamond wire sawn, 4 m-high wall of *Gold Leaf Black* at quarry site FRG 142.

stone's name becomes apparent from reflections visible in a well-polished slab. As the slab is rotated from side to side there are moveable plays of golden light reflected by plagioclase laths, olivine grains, and microplaty dendrites enclosed in ophitic pyroxene crystals, in an effect known as schillerization. This spectacular optical effect, which enhances the black granite's attractiveness as a dimension stone, is seen in Appendix 4.23

Petrographic description

Gold Leaf Black is an ophitic olivine–orthopyroxene-bearing dolerite, with accessory opaque oxide, hornblende, biotite, and rare spinel. At FRG 142 this material is composed of olivine–hypersthene-bearing dolerite with ophitic pyroxenes. The visually estimated mineralogy includes 52% plagioclase, 21% clinopyroxene, 9% orthopyroxene, 5.5% olivine, 5.5% biotite, 4.5% hornblende, and 2.5% opaque oxide as well as accessory apatite. Rare inverted pigeonite is also evident. Plagioclase laths to 4 mm long and olivine grains to 2 mm long are enclosed in ophitic pyroxenes to 8 mm in diameter, with microplaty oxide dendrites also contributing to the schiller effect seen in hand specimen. Separate opaque oxide, rarely accompanied by possible exsolved green spinel, is commonly rimmed by brown hornblende and reddish brown biotite as aggregates to 4 mm long. Traces of chlorite and carbonate found in plagioclase but the rock is mostly fresh.

Mineralogy at FRG 125 is very similar to the mineralogy for FRG 142 with a composition estimated at 55% plagioclase, 32% pyroxene (including up to 3% orthopyroxene), 7–8% olivine, 2–3% each of hornblende and biotite, <1% opaque oxide, and very minor, granular inverted pigeonite.

Central western region

Edmund Basin

Glen Florrie — dolerite

Glen Florrie Black

The *Glen Florrie Black* granite prospect is located on a dolerite dyke close to Ballard Well about 48 km south-southeast of Nanutarra. The dyke forms a prominent north-northeasterly trending ridge extending over 3 km, adjacent to the Glen Florrie Station road (Fig. 68).

At this site, the Mesoproterozoic Glen Florrie dyke has intruded coarse-grained, gneissic rocks of the Paleoproterozoic Gascoyne Province, exposed as a narrow zone within the confines of the Edmund Basin. The dyke is composed of very fine to medium-grained, olivine-bearing dolerite, around 20 m wide, and dips vertically or very steeply to the west.

Exploration for black granite dimension stone took place between 1986 and 1997. Major investigations, comprising two diamond-drilling programs, was conducted by Australian Marble and Granite NL during 1989 and 1990 (Thiess Contractors, 1990a,b). A five-hole drilling program carried out in 1989 at the southern end of the dyke (drillholes GF1–5) was subsequently abandoned by the company after an area of Aboriginal significance was identified close to the exploration area. In 1990, drilling operations were moved to the north, well away from this area, and a program of nine diamond drillholes was completed over 1 km of strike length (GF6–GF14). The drilling program consisted of one vertical hole sited on the dolerite to test the depth of weathering and the true dip

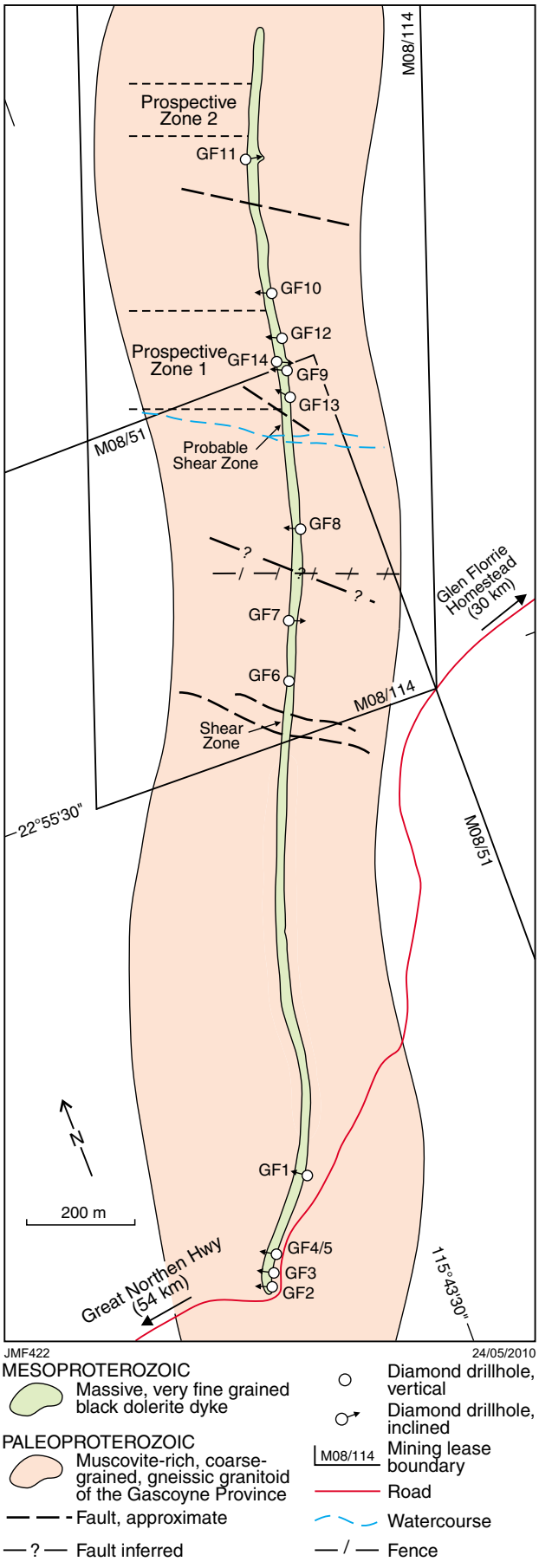


Figure 68. Geology of the *Glen Florrie Black* granite prospect (modified after Thiess Contractors, 1990a).

of joint sets (GF6). The other holes were collared in the weathered gneissic granite just outside the dyke and were inclined to drill through the dolerite at angles of 65º to the east (GF7, 11 and 14), and between 55º and 65º to the west (GF8–10 and 12–13). Depth of drilling varied from 35 m to almost 50 m below surface datum level (Figs 68 and 69).

During the drilling program it was noted that there was a close correlation between the size and continuity of boulder-sized, dolerite core-stones at the surface and fracture intensity at depth. Accordingly, changes in surface boulder size were used as key indicators of likely variations in subsurface fracture intensity along the length of the dyke. This relationship led to the targeting of two areas of interest (Prospective Zones 1 and 2) located in areas comprising mainly large surface boulders in continuous outcrops (Figs 69 and 70).

The 1990 Glen Florrie drilling program produced the following results:

- Depth to the base of the weathered zone varies from 14 to 22 m, below which the frequency of joint fracture intensity is reduced significantly and rock quality in terms of block size is markedly increased
- The dyke has a typically homogeneous texture being fine to medium grained, while colour varies from medium to very dark grey
- Fracture intensity across the dyke at any point appears to be uniform for that site
- It was confirmed that the majority of black granite cores, from 0.75 m to >1.0 m (core-stick length), were recovered from holes either within, or close to, Prospective Zones 1 and 2
- Core analysis indicated the presence of six joint-fracture sets. Of these, the subvertical and subhorizontal joint sets appeared to be dominant. These major orientations were deemed suitable to allow for the production of significant quantities of stone, assuming minimum block size of 600 mm × 600 mm × 900 mm within Prospective Zones 1 and 2 could be maintained.

At the conclusion of the drilling program, an estimate of potential economic volume in Prospective Zone 1 was calculated on a block sited between drillholes GF12 and GF13 and between 15 and 20 m below surface. Potential economic recoverable stone was estimated at 19 000 m^3 (over 50 000 t). This was based on a strike length of 110 m × 20 m (depth) × 20 m (width) with a near-50% recovery of saleable stone. It was proposed that economically extractible volumes could be substantially increased by extending the mineable block to the north of drillhole GF12, and below the 35 m depth limit. A program of additional drilling followed by test pitting to optimize joint-fracture orientation and spacing was recommended to fully evaluate this zone as a potential black granite resource.

Ground observations of the large boulder zone to the north of GF11 combined with the understanding of the outcrop/subsurface fracture pattern relationship suggests that Prospective Zone 2 may also contain a substantial quantity of economically recoverable stone. A further drilling and test-pitting program to prove up this zone was recommended (Thiess Contractors, 1990b).

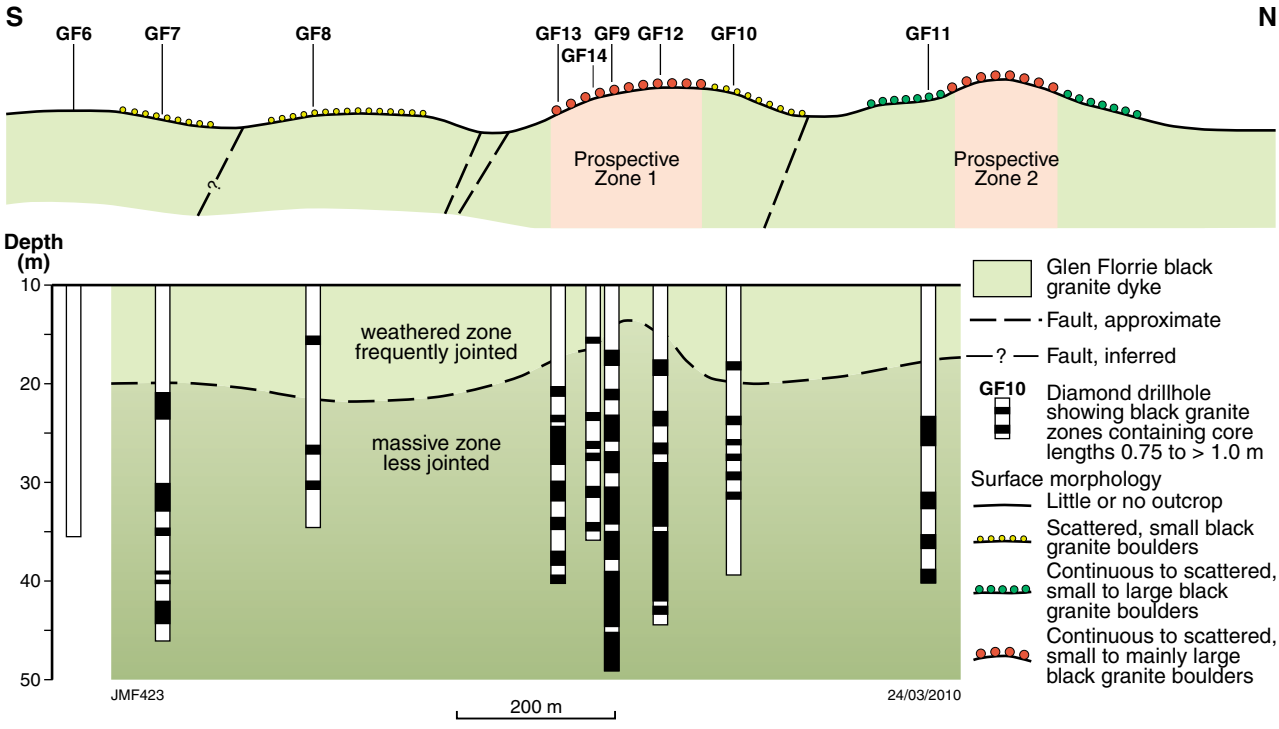


Figure 69. North–south, longitudinal section of the *Glen Florrie Black* granite prospect. Section shows prospective economic zones indicated by black granite cores returned from diamond drillholes (modified after Thiess Contractors, 1990b).

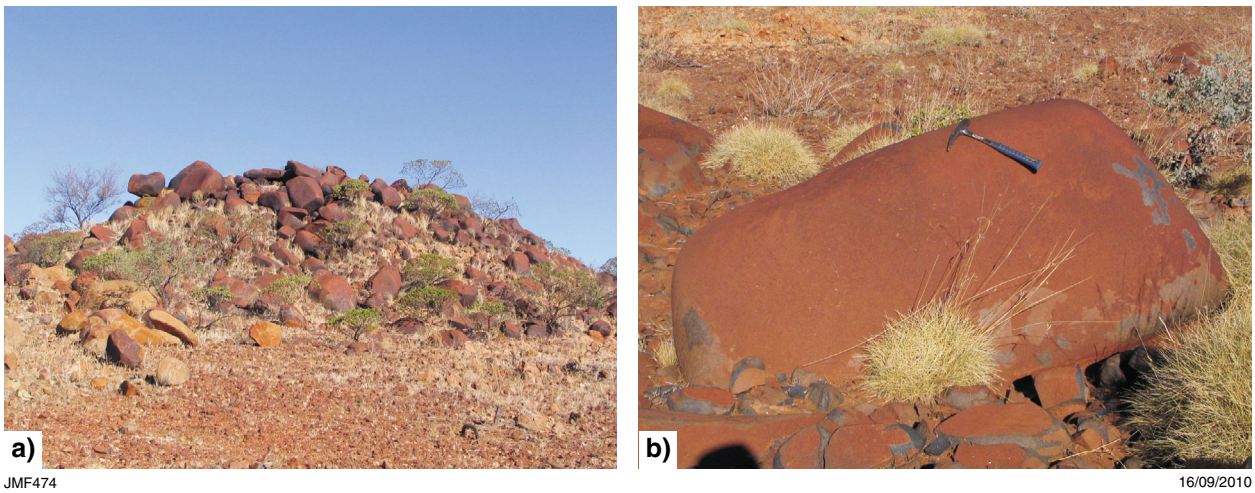


Figure 70. Black granite boulder outcrop at Glen Florrie prospect: a) an outcrop of continuous, large black granite boulders; b) a tabular black granite boulder approximately 1.5 m × 1.0 m.

Test cutting of high-quality slabs of *Glen Florrie Black* granite has yielded very hard, medium to dark grey specimens with a very fine grained, uniform texture. When polished the stone takes on a jet black, mirror-like appearance (Fig. 71; Appendix 4.24).

Petrographic description

This rock is fine-grained olivine-bearing dolerite with a visually estimated mineralogy containing approximately 56% plagioclase, 30% clinopyroxene, 11% magnetite, 2–3% olivine, and <1% biotite. Some of the plagioclase is over 2.0 mm long but most is about 1.0 mm, together with mostly granular pyroxene from 0.1 to 1.0 mm in diameter. The opaque oxide and olivine are 0.1 – 0.8 mm in diameter with rare, fine-grained biotite. Rare sericite is present in the plagioclase and in areas of possible mesostasis with accessory apatite.

Maroonah area — dolerite

Maroonah black

The Maroonah black granite is located at a site approximately 25 km east of Maroonah Homestead, and about 2 km southwest from the east branch of the Henry River (Fig. 72). The exact site of this prospect is approximate. The sample, supplied by local prospectors, Messrs R Pember and G Dellar, was sourced from a large sill-like dolerite structure in the area.

This fine-grained black granite contains around 55% plagioclase and 35% clinopyroxene and has an even-toned, speckled appearance when polished (Appendix 4.25).

Petrographic description

Dolerite with fine-grained primary or recrystallized clinopyroxene, and sparse olivine, K-feldspar, and biotite.

Like many decorative lithologies labelled ‘black granite’, this dolerite sample has a visually estimated mineralogy with possibly 55% plagioclase, 35% clinopyroxene, 7% opaque oxide, 2% olivine, and 1% K-feldspar. The plagioclase is in the form of euhedral laths to 2 mm long with opaque oxide and sparse, larger clinopyroxene grains to 1 mm or more in diameter. Most of the clinopyroxene is very fine grained but it is unclear whether this represents rapid crystallization or metamorphism. The oxide seems to be rich in ilmenite with less-abundant magnetite, as seen on the polished block. Sparse, fine-grained olivine has magnetite-filled fractures, and K-feldspar is clearly visible on the stained offcut. Rare biotite is disseminated, and minor sulfide grains, probably pyrrhotite and chalcopyrite, are also present.

Gascoyne Province

Maroonah area — dolerite

Chararoo Well

The Chararoo Well black granite prospect is located 25 km south-southeast of Maroonah Homestead in the Paleoproterozoic Gascoyne Province (Fig. 73). The prospect forms part of a major, intersecting dolerite dyke system that extends in a northerly direction for about 13 km. The dykes outcrop as prominent, high ridges that contain extremely large, sparsely jointed core-stones up to 10 m diameter in places, whereas in other areas core-stones are much reduced in size to around 1–2 m in diameter (Fig. 74). The unweathered, medium-grained dolerite is dark grey in colour and is coated by a thin, dark brown oxide skin.

In 1993, the dolerite dyke system was investigated for commercial-grade black granite by Dodsley Pty Ltd on former exploration licence E09/603. The company carried out a detailed sampling program over the two dykes extending from Chararoo Well for a distance of about 4 km to the south. Samples, sent for cutting and polishing to their Muchea factory near Perth, were assessed as being of little commercial value (possibly as material for the South East Asian funerary industry) owing to the presence of white feldspar flecking throughout (Elkington, 1994a).

A polished sample of Chararoo Well black granite is shown in Appendix 4.26.

Petrographic description

Weakly altered subophitic dolerite with hornblende, biotite, sericite, and chlorite.

About 67% of this sample is composed of weakly sericitized plagioclase as laths to 2 mm long accompanied by subophitic, partly clouded clinopyroxene 0.5 – 4 mm in diameter constituting about 25% of the thin section. Oxide and 2% granophyre make up the rest of the thin section, with opaque oxide aggregates to 4 mm long and rare apatite in granophyre. Minor late magmatic or secondary minerals include brown and green hornblende and biotite, and minor sericite and chlorite.

Manolini Well

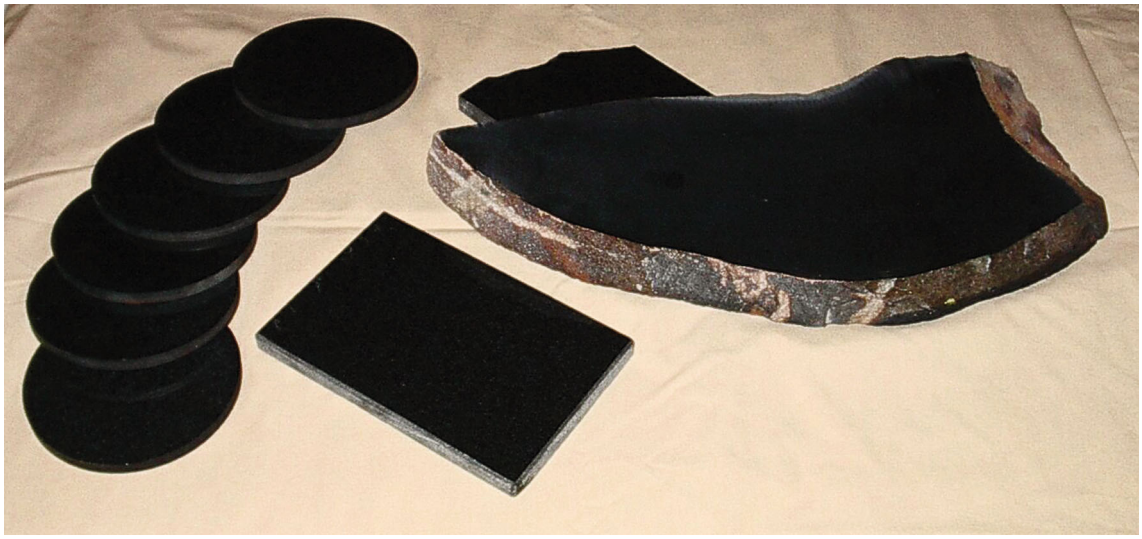
The Manolini Well black granite prospect is located 10 km northeast of Maroonah Homestead (Fig. 75). The black granite prospect is situated on a north-trending dolerite dyke over 3 km in length. The prospect was explored in 1994 by Dodsley Pty Ltd as part of a series of mainly small north-trending dolerite dykes in the local area. In terms of size and physical properties, the Manolini Well dyke appears to be the best of these dykes as a potential source of black granite (Elkington, 1994b).

The dyke was examined by the author and was found to be a very hard, relatively fine grained, dark blue to black dolerite, with mostly small blocks at the surface but in some places ranging up to massive blocks 1.5 m in width. It is possible that the core-stone size may increase with depth. The width of the steeply dipping dyke width was estimated at 15–20 m (Fig. 76).

A polished specimen of relatively fine, even-grained Manolini Well black granite is shown in Appendix 4.27.

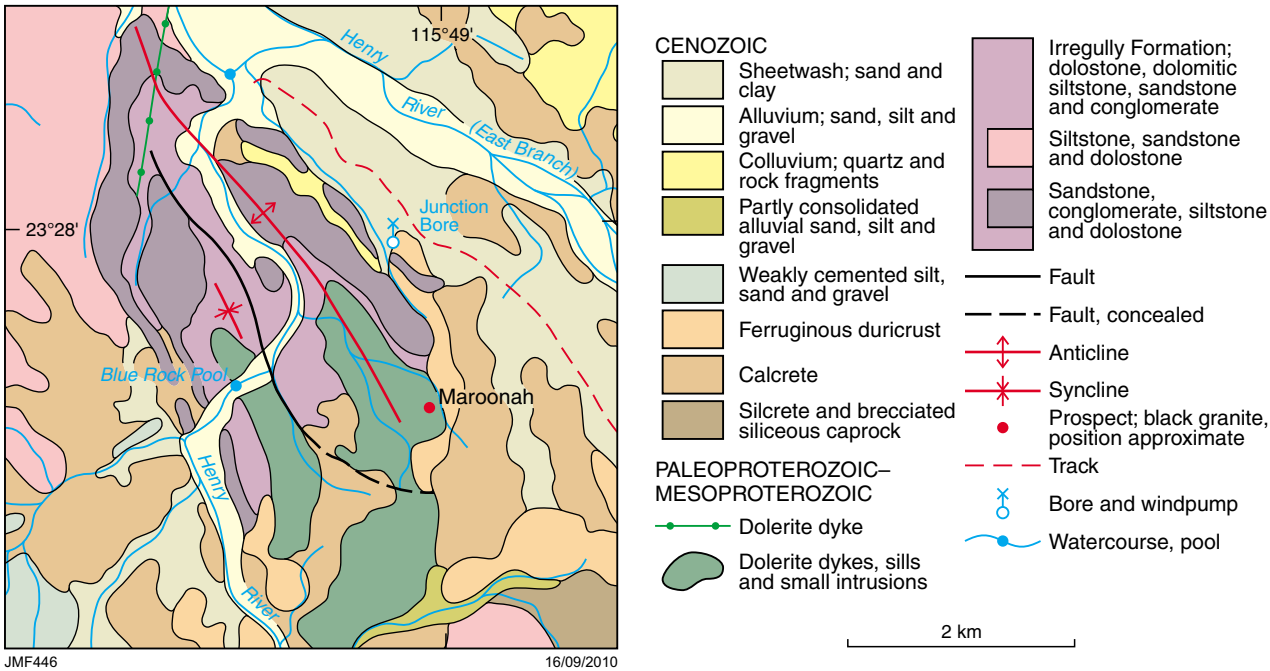
Petrographic description

Relatively fine grained dolerite with minor altered olivine and quartz as well as actinolite, chlorite, biotite, and sericite.



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Figure 71. Cut and polished samples of *Glen Florrie Black* granite. Black discs are approximately 6 cm diameter.



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Figure 72. Geology of the area surrounding the Maroonah black granite prospect (modified after Martin et al., 2004).

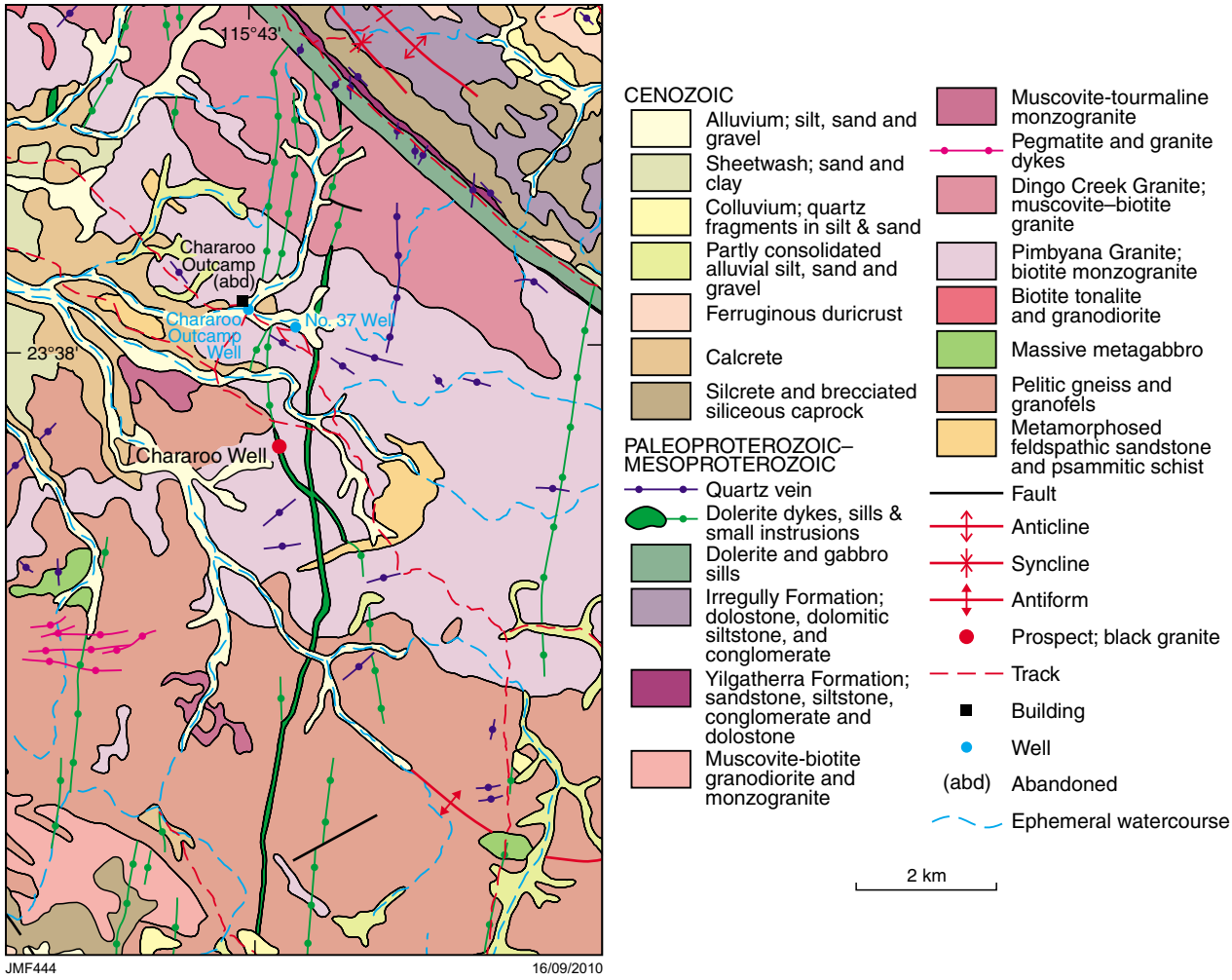


Figure 73. Geology of the Chararoo Well area (modified after Sheppard et al., 2004).

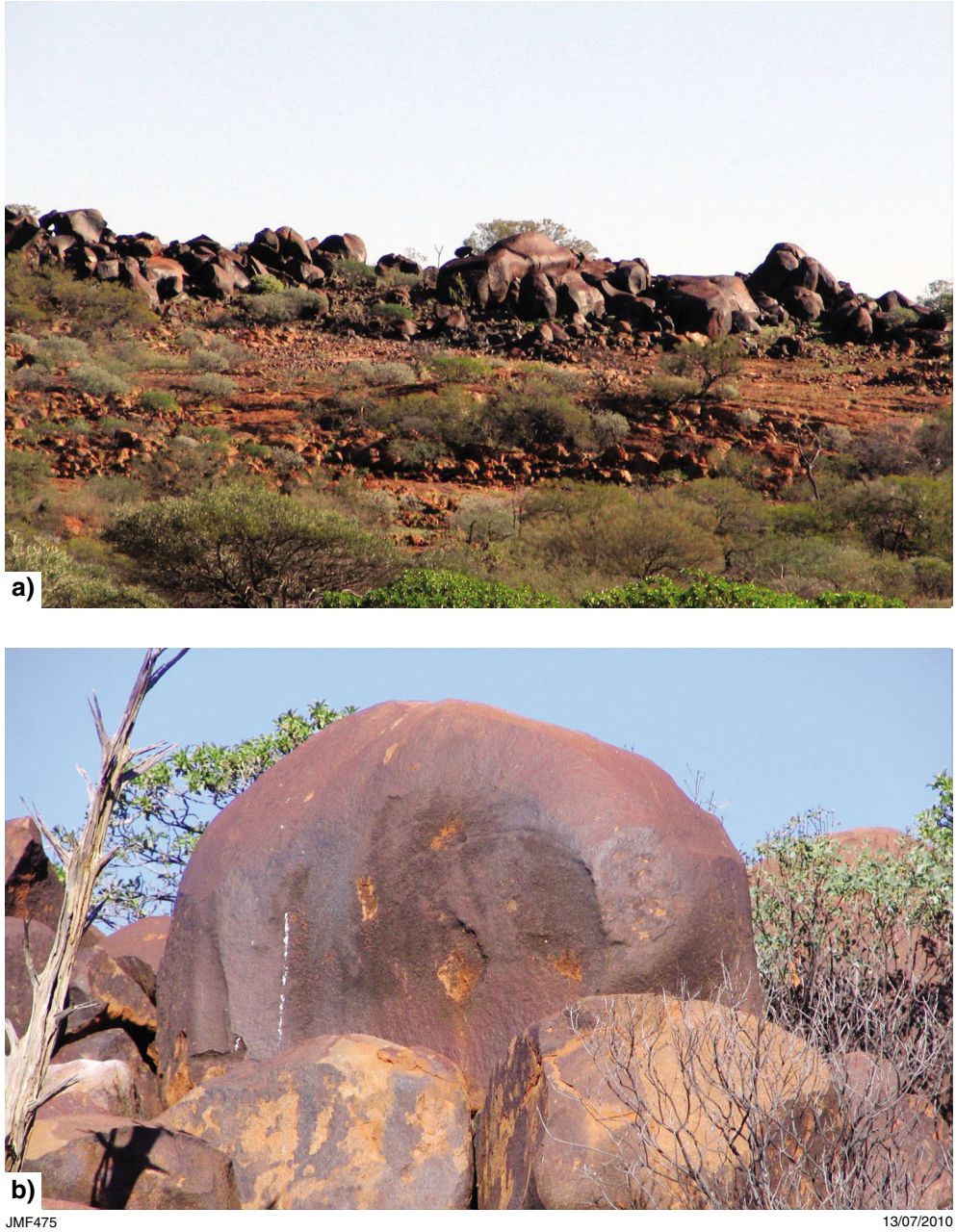


Figure 74. Chararoo Well dolerite dykes in the Maroonah area: a) western dyke at Chararoo Well (looking southeast) containing extremely large core-stones up to 10 m in diameter; b) detail of rounded core-stones up to 2.0 m in diameter in eastern dyke.

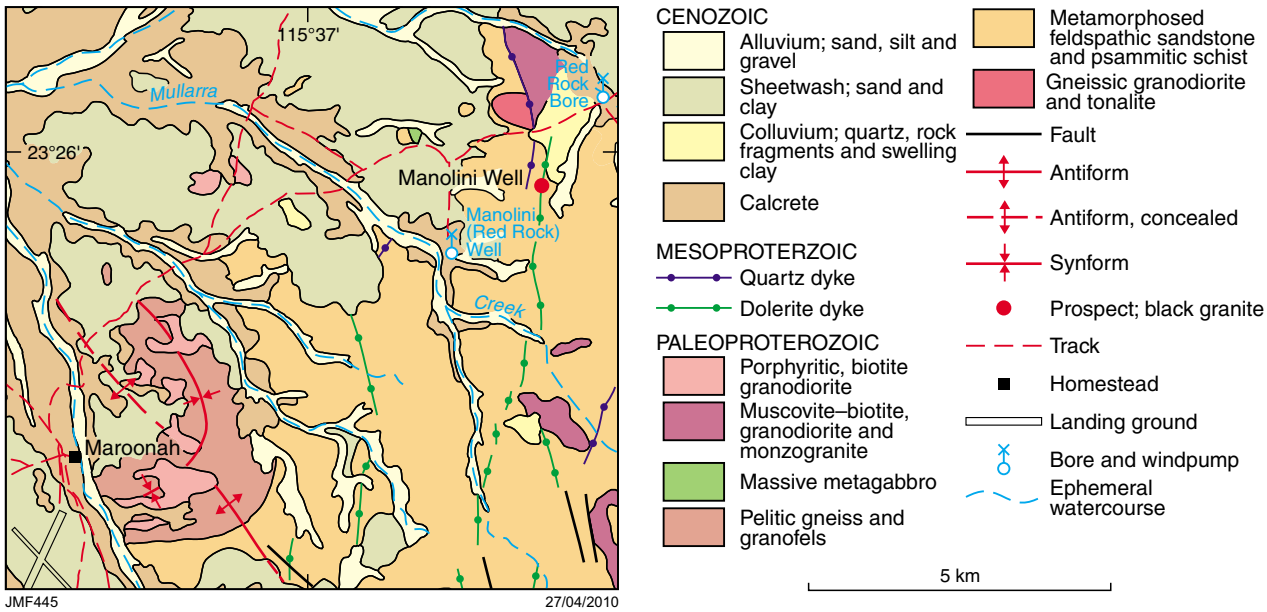


Figure 75. Geology of the Manolini Well area (modified after Martin et al., 2004).



Figure 76. Large core-stones up to 1.5 m in width at the Manolini Well black granite prospect.

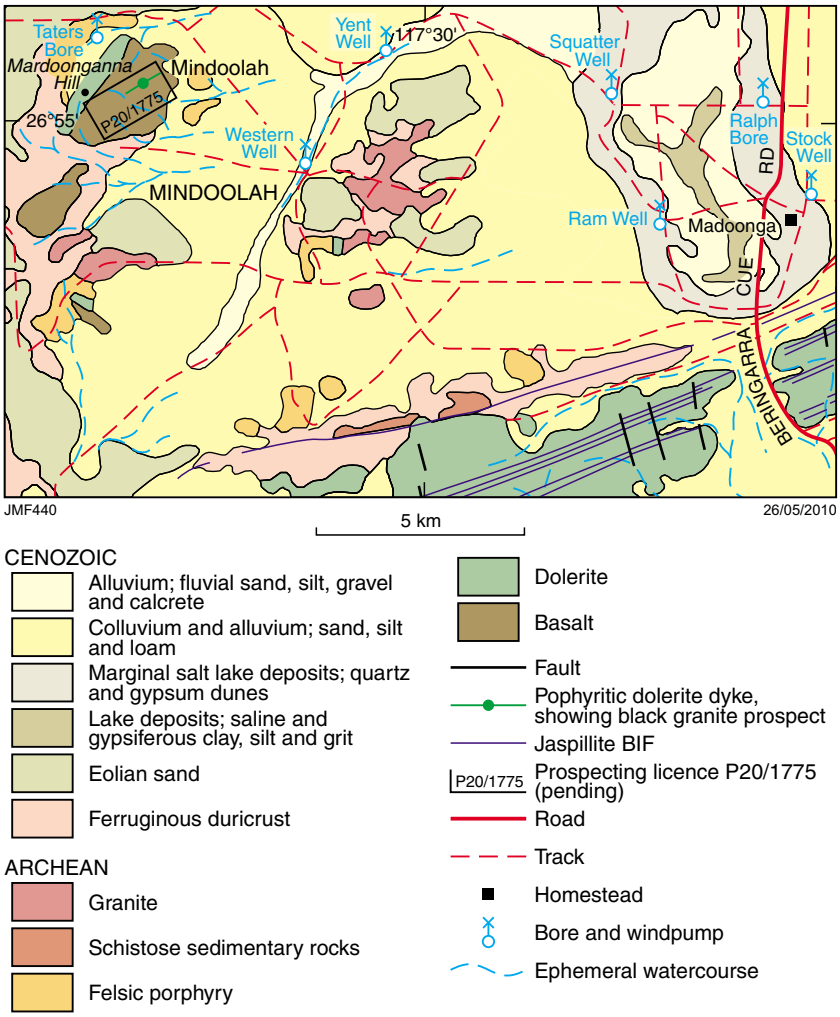


Figure 77 Geology of the Mindoolah area, northwest of Cue (modified after Elias et al., 1983).

Figure 78. (below) Surface outcrop of Mindoolah porphyritic dolerite. The stone displays numerous, protruding megacrysts of pale pink clinozoisite.



Plagioclase laths in this sample are mostly 0.2 – 2 mm long, with clinopyroxene as subophitic grains and aggregates to 1 mm in diameter and irregular masses of opaque oxide to 2 mm long. The visually estimated mineralogy includes 58% plagioclase, 33% clinopyroxene, 7–8% primary opaque oxide, and small amounts of quartz, actinolite, chlorite, and biotite as well as accessory apatite. Some aggregates of actinolite, chlorite, and secondary opaque oxide seem to have been derived from olivine to 1.5 mm in diameter, with oxide disseminated or along fractures. Minor actinolite is also seen in clinopyroxene and there are sparse, small patches of sericite in some of the plagioclase.

Yilgarn Craton — Murchison Terrane

Cue area — dolerite

Mindoolah porphyritic dolerite

This prospect is situated in hilly country in the Mindoolah area, 75 km northwest of Cue, and about 1.5 km east of Mardoonganna Hill (Fig. 77). In this area, the Mindoolah porphyritic dolerite dyke has intruded Archean basalt. The steeply dipping, east-northeasterly trending dyke is about 500 m in length and of variable thickness from less than 5 m to a maximum width of possibly 25 m. The dyke was prospected between 1999 and 2004 under mining lease M20/492 owned by Mr D Caesar. More recently, this lease has been replaced by prospecting licence P20/2122.

At the surface of the dyke, dark grey dolerite displays a reddish-brown oxidized skin containing numerous, protruding 'golf ball'-shaped megacrysts of pale pink clinozoisite that are considerably harder than the enclosing doleritic matrix (Fig. 78). These megacrysts average around 20 mm in diameter and range up to a maximum size of about 40 mm although there are zones along the dyke where the clinozoisite crystals tend to become much smaller and irregular in shape.

Trial mining has taken place in several small pits at the northeastern end of the dyke where a number of boulders have been extracted. Maximum core-stone size observed at or near the surface was about 0.75 – 1.25 m^3; most boulders appear smaller in size.

This stone, termed 'marshmallow rock' by local prospectors, has been slabbed and polished to display the spectacular pink clinozoisite megacrysts and has been manufactured into items such as polished spheres and coffee table tops (Fig. 79; Appendix 4.28). This stone is described further in Fetherston (2006).

Petrographic description

Metamorphosed, porphyritic dolerite with abundant, large, former intratelluric phenocrysts of plagioclase largely replaced by pale pink clinozoisite and minor quartz. Also, actinolite–albite–clinozoisite–sericite–chlorite–titanite–quartz aggregates have replaced plagioclase, pyroxene and opaque oxide in the matrix. A late-stage quartz vein contains clinozoisite, actinolite, and chlorite.

This sample is an excellent example of what is known as 'spotted cat' or 'native cat' rock. Large altered plagioclase phenocrysts to 35 mm long are abundant (>50%), but are almost totally altered to fine-grained clinozoisite with a pink tint in hand specimen, suggesting that they approach thulite (weakly manganiferous clinozoisite) in composition. The altered phenocrysts also contain lenses and veins of quartz and rare veins of iron-rich epidote. The completely metamorphosed matrix seems to have contained abundant pyroxene to 2 mm in diameter either replaced by actinolite with a uralitic habit or by bundles of subparallel needles with or without pale green chlorite, possibly Al-rich clinochlore. Abundant plagioclase has been altered to albite and clinozoisite(–sericite) and opaque oxide to fine-grained titanite. Trace quartz is also disseminated but may be metamorphic rather than being late magmatic although rare patches contain apatite. A late-stage narrow quartz vein contains clinozoisite, actinolite, and chlorite, mainly as overgrowths on wall rock minerals.

Mount Magnet area — gabbro

The Windimurra Complex is located approximately 40 km east of Mount Magnet. The complex is a large, north-northeasterly trending, elliptical, basin-shaped body in excess of 2300 km^2 in area. The Archean complex comprises an ultrabasic–basic, layered sequence ranging from dunite through magnetite to olivine-bearing gabbronorite, gabbro, and troctolite to leucogabbro and norite, then gabbronorite, and finally, olivine gabbro (Ahmat and Ruddock, 1990).

Between 1993 and 1994, and 1996 and 1997, Dodsley Pty Ltd carried out exploration on five prospects at Boulder Well, Mingyngura Hill, Naluthanna Hill, Palagea Rockholes, and Pioneer Well in the Windimurra Complex for deposits of high-grade black granite sourced from massive gabbro.

Boulder Well

The Boulder Well prospect is located on former prospecting licence P58/950 about 65 km east-southeast of Mount Magnet, and 9 km west-southwest of Windimurra Homestead (Fig. 80). In 1996, Elkington (1997) was given a brief to investigate a large area of sparsely jointed, medium- to coarse-grained gabbro as a possible source of black granite dimension stone. After some preliminary work, results of field investigations do not appear to have been reported.

Mingyngura Hill

Mingyngura Hill prospect is located 50 km east-northeast of Mount Magnet, and about 20 km south-southwest of Wondinong Homestead (Fig. 81). Elkington (1994c) reported difficult access to this site.

Exploration was carried out in an extensive area of medium- to coarse-grained gabbro outcrops within former exploration licence E58/133 and prospecting licence P58/1381 and was aimed at locating a large deposit of massive gabbro with joint spacings 2–3 m or greater. Investigations revealed that apart from two small areas of moderate to sparse jointing (ranging from 1 to >3 m



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Figure 79. Coffee table top manufactured from a polished slab of Mindoolah porphyritic dolerite.

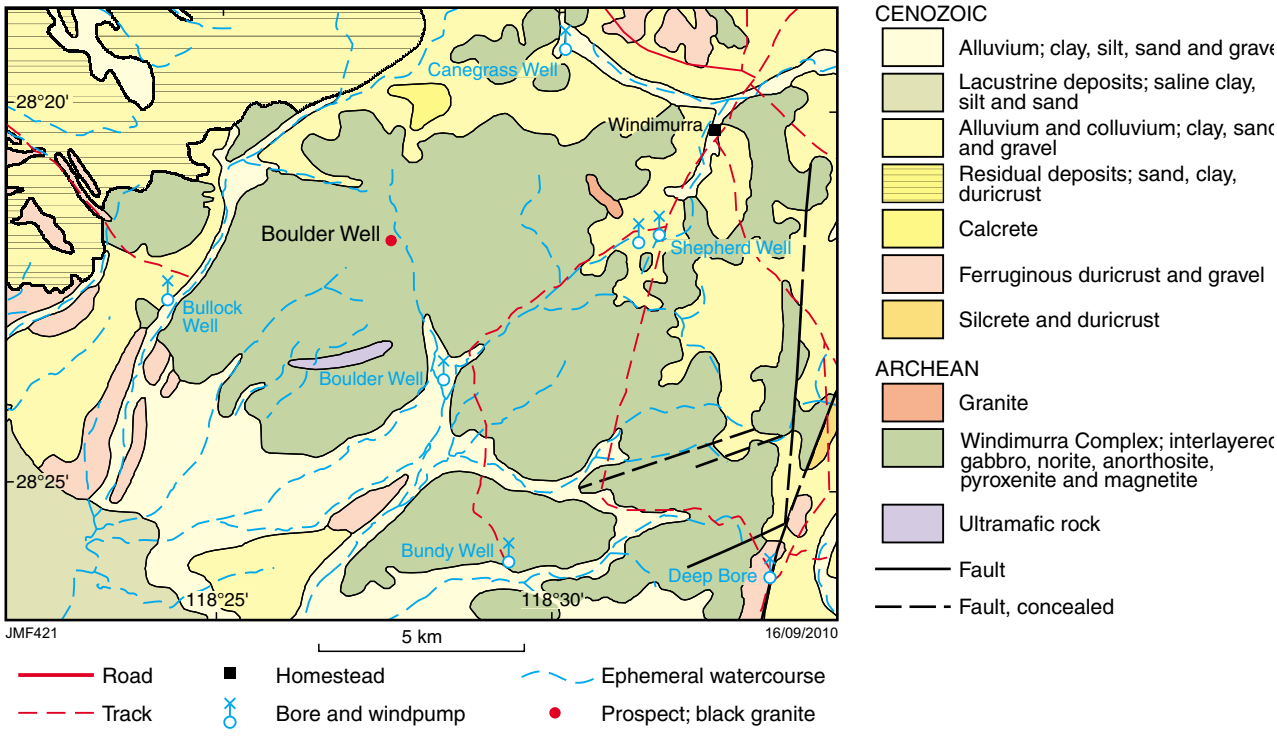


Figure 80. Geological map of the Boulder Well area (modified after Stewart et al., 1983; Baxter et al., 1982).

spacing) within the prospecting licence, all other areas of bouldery outcrop were found to be moderately to strongly jointed (<0.7 m spacing). Also, hilly areas surrounding the gabbro outcrop were covered with small-sized gabbro float with no large boulders on the surface. This would indicate that they were probably sourced from areas of close-spaced jointing.

It was recommended that future work should be confined to the central part of the area extending from the prospecting licence southwest to Mingyngura Hill to search for concealed areas of sparsely jointed gabbro (Elkington, 1994c).

Naluthanna Hill

This area is located within former exploration licence E58/132 and prospecting licence P58/949 about 60 km east-northeast of Mount Magnet, and 8 km south of Wondinong Homestead (Fig. 82). Elkington (1994d) reported difficult site access over expanding-clay flats and incised meandering streams to reach Naluthanna Hill where the prospect consists of four clusters of rocky hills comprising gabbro and pyroxenite.

Exploration to locate possible quarry sites for black granite dimension stone was carried out throughout the area. Many small areas of sparse to medium, and sparse jointing (ranging from 1 to >3 m spacing) were located in massive, medium- to coarse-grained gabbro. Some areas of sparse jointing in the vicinity of Naluthanna Hill and also at sites 5–6 km to the southwest appeared large enough to warrant further investigation. The remainder of the area was found to be mostly covered with moderate to strongly jointed gabbro boulders (<0.7 m spacing) and fine gabbro float. To date, no follow-up work at prospective sites appears to have been carried out.

Palagea Rockholes

The Palagea Rockholes exploration area is located 85 km east-southeast of Mount Magnet in the vicinity of the intersection of the Mount Magnet–Youanmi Road and the State's Rabbit Proof Fence (Fig. 83). At this locality, an extensive area of low hills consisting largely of medium- to coarse-grained gabbro is intruded by numerous pegmatite and quartz veins and dykes. The dark grey to black gabbro has a thin, oxidized, outer coating of brown, weathered material.

Most rock consists of small boulders of gabbro float (<0.5 m^3) while a few larger core-stones (around 2.0 m^3) are exposed on hill crests (Fig. 84). Exploration by Dodsley Pty Ltd in 1993–94 on exploration licence E58/135, only located a few small areas of sparse to moderate jointing (1–3 m spacing) in the northern area of outcrop at scattered sites south of Rosie Well. Most other areas of outcrop were rated as strong to moderate jointing (<0.7 m spacing) and were of little economic interest. It was concluded that there was no site with sufficient volume of sparsely jointed rock for a potential quarry site (Elkington, 1994e).

A polished slab of dark grey to black, coarse-grained black granite from Palagea Rockholes is shown in Appendix 4.29.

Petrographic description

Weakly metamorphosed plagioclase-rich gabbro with albite–myrmekite and clinozoisite–epidote(–prehnite) partly replacing plagioclase.

This sample is composed of coarse-grained plagioclase-rich gabbro with 68% plagioclase and 6% clinozoisite (–prehnite) as well as 25% actinolite and 1% opaque oxide. The plagioclase is subhedral as laths to 8 mm long locally invaded by albite(–quartz–actinolite–clinozoisite), commonly accompanied by myrmekite. Larger patches of actinolite are partly uralitic and partly recrystallized and seem to have replaced ophitic clinopyroxene to 10 mm in diameter. Irregular patches of clinozoisite–epidote commonly separate the actinolite from relatively less altered plagioclase and also replace plagioclase inclusions in actinolite. Opaque oxide to 2 mm in diameter may contain titanite.

Pioneer Well

Pioneer Well prospect is located on Windsor Station, 75 km east-northeast of Mount Magnet and about 6 km north of the station homestead (Fig. 85). In this area are three small hills (<30 m high) largely composed of massive, coarse-grained gabbro. Large core-stones are present, usually on higher parts of hills, where they may be exposed as massive blocks to 6.0 m long, 2.5 m wide, and to 2.5 m above ground surface (37.5 m^3) with average-sized boulders much smaller at around 0.5–1.0 m^3. Boulders are coated with a brown surface-weathered layer ranging from very thin to 5.0 mm thick and are subject to onion-skin surface exfoliation (Fig. 86).

This area was explored in 1993–94 on exploration licence E58/134 with the object of locating a black granite deposit comprising tens of thousands of cubic metres with sparse joint spacings of 2–3 m or greater (Elkington, 1994f). Field exploration revealed only five small areas of sparse to moderate jointing of 1–3 m representing areas of maximum block size. Other exposed areas generally had close joint spacings (<0.7 m), with the remainder of the hilly areas mostly covered with small boulders of gabbro-float material and considered to have probably originated from areas of close-spaced jointing. Although the areas of larger stone are readily accessible, it appears that no follow-up exploration was carried out.

A sample of dark grey to black, polished black granite from Pioneer Well clearly shows its coarse-grained gabbroic origin (Appendix 4.30).

Petrographic description

Weakly metamorphosed plagioclase-rich gabbro with actinolite, hornblende, clinozoisite, and rare prehnite.

This sample is composed of weakly metamorphosed plagioclase-rich gabbro with 64% fresh plagioclase as laths 1 to 12 mm long and 7% clinozoisite(–prehnite) as irregular patches in plagioclase. The remaining pyroxene is mostly interstitial to plagioclase as grains to 10 mm long, with 11% clinopyroxene and 3% orthopyroxene as well as 14% metamorphic amphibole varying from pale green

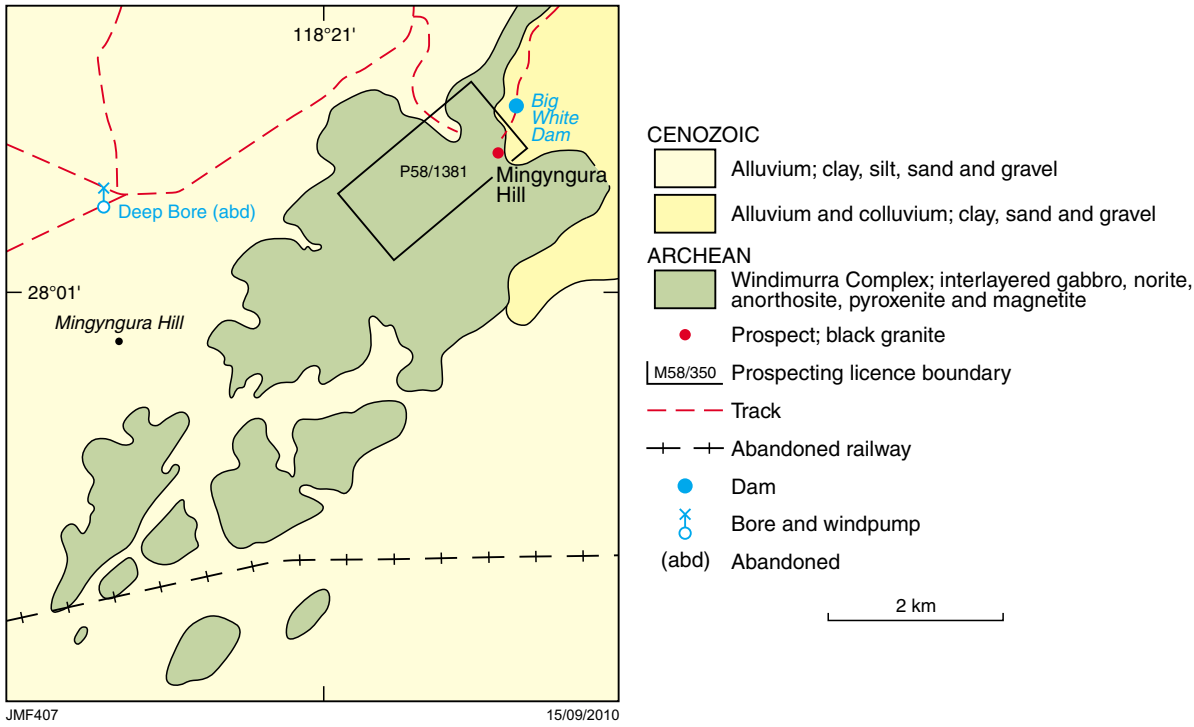


Figure 81. Geological sketch map of the Mingyngura Hill area (modified after Elkington, 1994c).

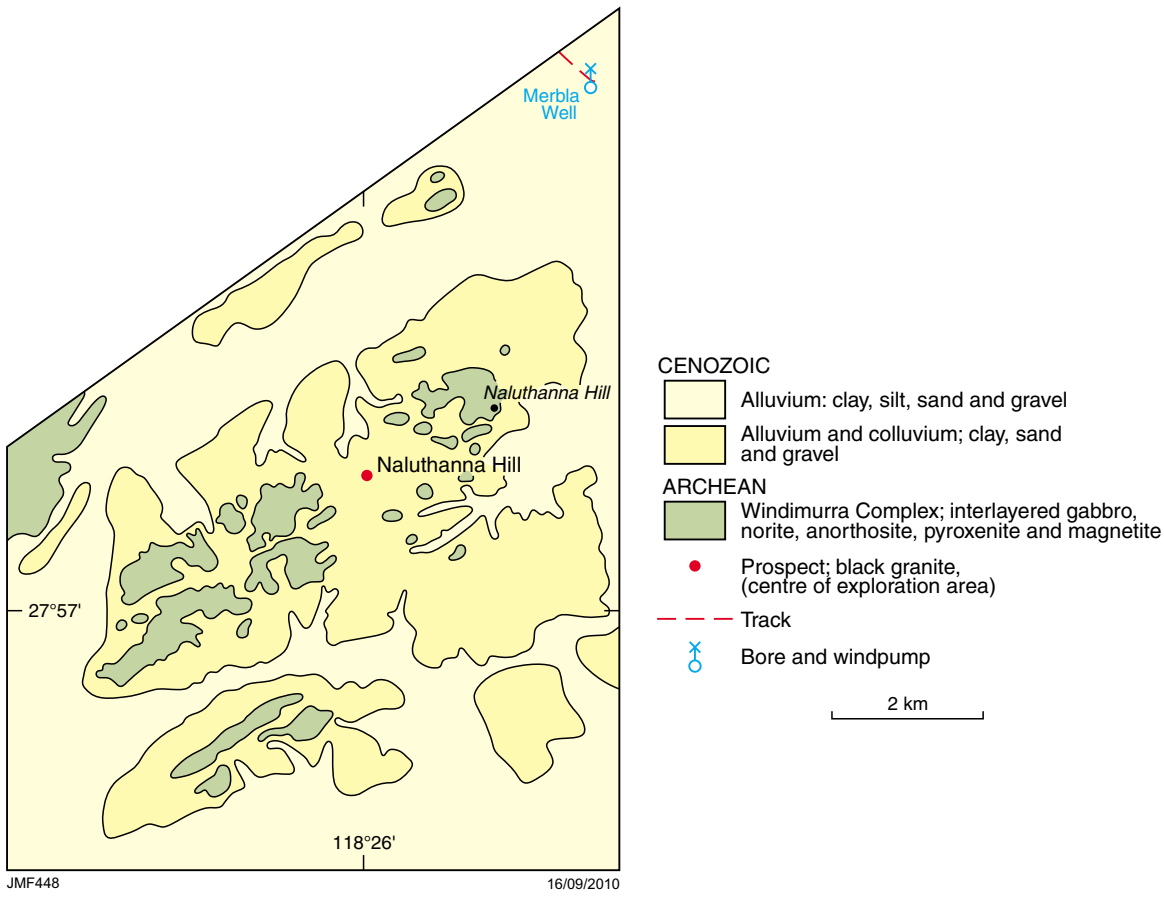


Figure 82. Geological sketch map of the Naluthanna Hill area (modified after Elkington, 1994d).

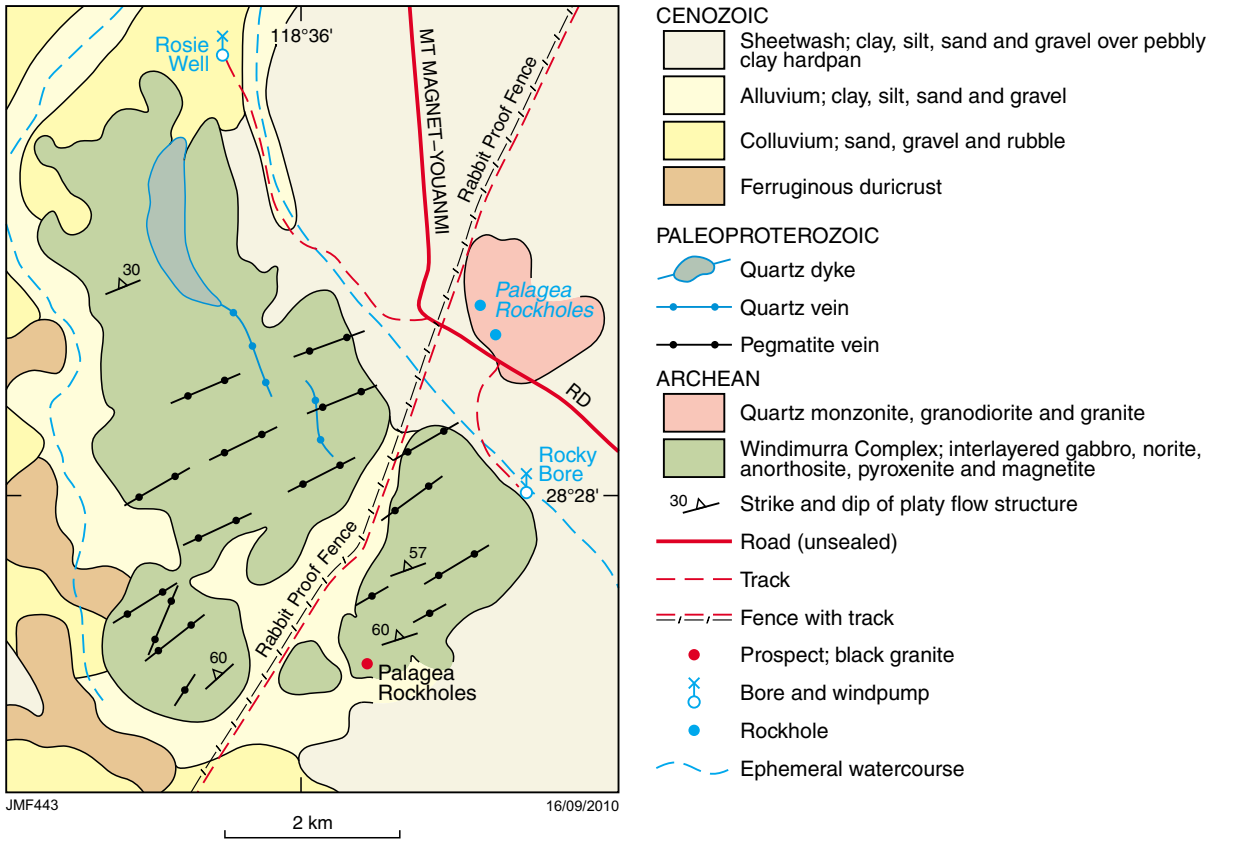


Figure 83. Geological sketch map of the Palagea Rockholes area (modified after Elkington, 1994e; Stewart et al., 1983).



Figure 84. Gabbro boulder-strewn hilltop in the southern part of the Palagea Rockholes prospect. Boulders range up to 2.0 m³ in size.

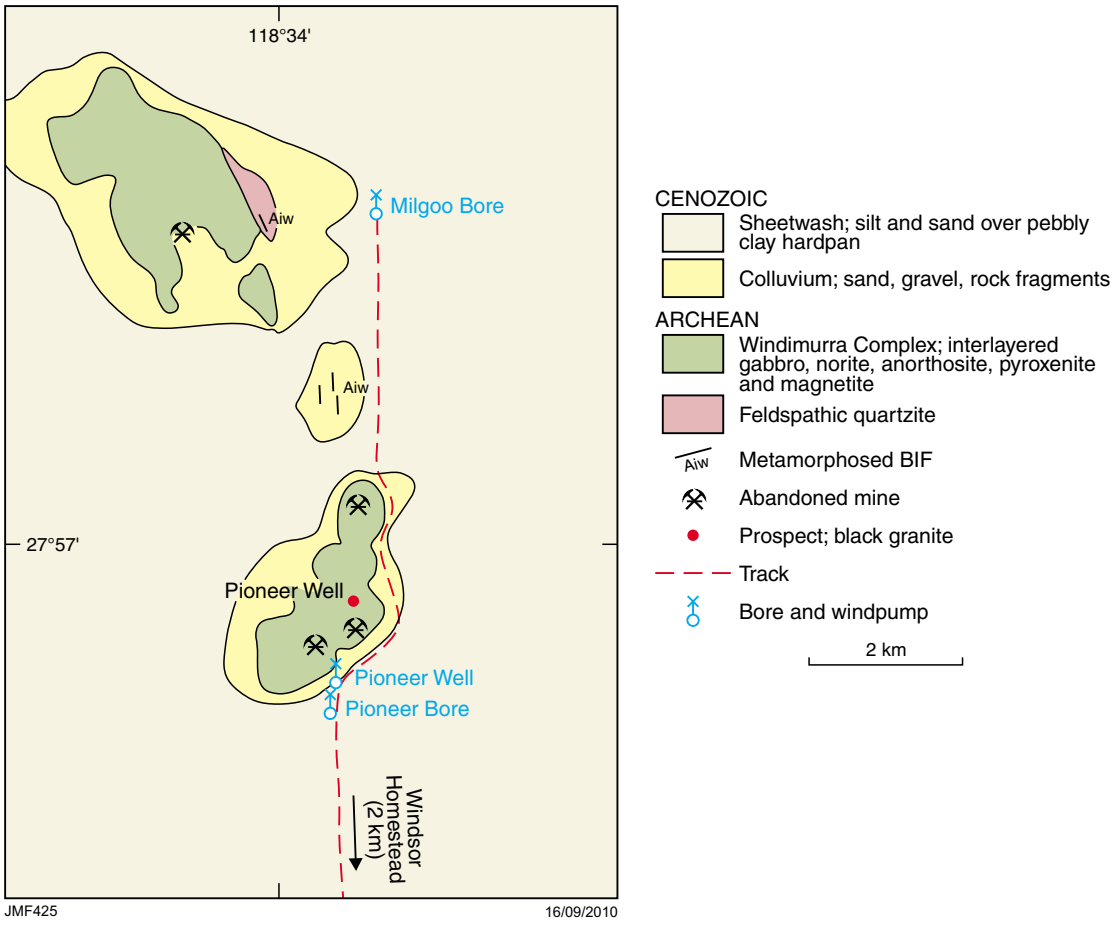


Figure 85. Geological sketch map of the Pioneer Well area (modified after Elkington, 1994f).



Figure 86. A massive, exfoliated boulder of coarse-grained gabbro at Pioneer Well black granite prospect. The boulder measures 2.5 m wide × 2.5 m high.

actinolite to darker green probable hornblende adjacent to opaque oxide grains to 3 mm in diameter (1%). Most of the actinolite is uralitic but some seems to be recrystallized and fibrous to prismatic. Some of the hornblende may have replaced titanomagnetite as it contains oriented plates of ilmenite. There is also rare leucoxene, rare biotite and trace sulfide partly altered to limonite.

Paynes Find area — gabbro

Doodhoowooroo

The Doodhoowooroo black granite prospect is located 55 km east-northeast of Paynes Find, and about 12 km south of Narndee Homestead in the central west of the State (Fig. 87). This area was explored by Dodsley Pty Ltd in 1994 within the area of exploration licence E59/498. The exploration area is situated within the Narndee Complex, an Archean layered, mafic to ultramafic complex that in this area comprises north-northwesterly trending zones of medium- to coarse-grained gabbro, gabbronorite, pyroxenite, peridotite, and troctolite (Ruddock, 1990).

At that time, the company was targeting suitable sites comprising large volumes of black granite from areas of sparse joint spacings 2–3 m (or even wider) that would produce large blocks of quality stone. Exploration of the area located several sites 2–3 km east of Doodhoowooroo Rockhole comprising three, north-northwesterly trending gabbro hills. This target area contained areas of moderate joint spacings between 1 and 3 m. In the surrounding area, average joint spacings were around 1.0 m. It was concluded that the target area contained insufficient volume of suitable high-quality stone for a viable quarry operation (Elkington, 1994g).

Yilgarn Craton — Narryer Terrane

In the extreme north of the Yilgarn Craton, the Archean Narryer Terrane abuts against the Paleoproterozoic Gascoyne Province in a narrow, southwest-trending structure known as the Errabiddy Shear Zone. This shear zone contains deformed late Archean granites, and granitic gneisses of the Narryer Terrane interleaved with the Paleoproterozoic Camel Hill Metamorphics, a suite of metasedimentary and metamafic igneous rocks, probably sourced from the Gascoyne Province (Occhipinti et al., 2001).

Within the Errabiddy Shear Zone are many sets of extensive, southwest-trending dolerite dykes. During the 1990s, two exploration sites for black granite were investigated at Erong Springs, and at Gum Creek Well near Yalbra Homestead.

Erong Springs — dolerite

Erong Springs

This black granite prospect is located 220 km northwest of Meekatharra, approximately 10 km east of the old Erong Springs Homestead. At this site, exploration for black granite was carried out in 1994 by Marble and Granite Industries NL, and from 1995 to 1996 by Mr RW Thackwell on exploration licence E09/692 (Fig. 88). Exploration at this site centred on a large dolerite dyke, about 3 km in length and forming part of a linear chain of extensive, west-southwesterly trending dolerite dykes that intrude Paleoproterozoic metamorphic and granitic rocks.

According to Halligan (1994), the dolerite dyke is about 7 m width, with sharp marginal contact zones with host rocks, and is best exposed on the higher parts of dyke where three orthogonal joint sets are apparent (Fig. 89). Joint spacing appears to limit the maximum block size to less than 1 m^3 and the dyke is also cut by a number of oblique faults, with both factors probably tending to reduce the available black granite resource.

Apart from the contact zones, the Erong Springs black granite is very fine grained with an excellent even-toned, black hue and takes a very high polish. Extensive work during 1995–96 demonstrated that the stone was of very high quality and was particularly suitable for jet-black artisanal carving with a number of works being produced (Fig. 90). In 1998, an application was made to extract an initial sample of 3000 t of black granite for evaluation but it appears that this was not followed up (North, 1998).

Yalbra — dolerite

Gum Creek Well

The Gum Creek Well black granite prospect is located about 265 km east-southeast of Carnarvon, and approximately 7 km west-northwest of Yalbra Homestead, within exploration licence E09/900 formerly owned by Foster Pty Ltd (Fig. 91). The prospect is situated on an extensive series of west-southwesterly trending dolerite dykes that intrude Paleoproterozoic metamorphic rocks.

The exploration area was visited by the author at a site about 5 km east of the prospect, situated on an extension of the Gum Creek Well dolerite dykes, closer to Yalbra Homestead (Fig. 91). Here, the dykes outcrop in short, 40 m-wide, linear ridges. The boulders forming these ridges are coated with a thin, dark brown, weathered oxide layer overlying a hard, blue-black, fine-grained dolerite. No large black granite core-stones were evident with the largest boulder being no more than 0.25 m^3 and the average stones being 20 cm × 15 cm × 15 cm in size (Fig. 92). The small size of the boulders is most likely attributable to multiple sets of close-spaced joints present at this site. It is possible that the block size may become larger, closer to Gum Creek Well prospect to the west.

A highly polished specimen of Gum Creek Well black granite demonstrates the visual attractiveness of this hard, fine, even-grained stone (Appendix 4.31).

Petrographic description

Fine-grained dolerite with minor green hornblende rimming and replacing clinopyroxene.

The dolerite in this thin section is fine grained with 56% plagioclase, 35% clinopyroxene, 4% hornblende,

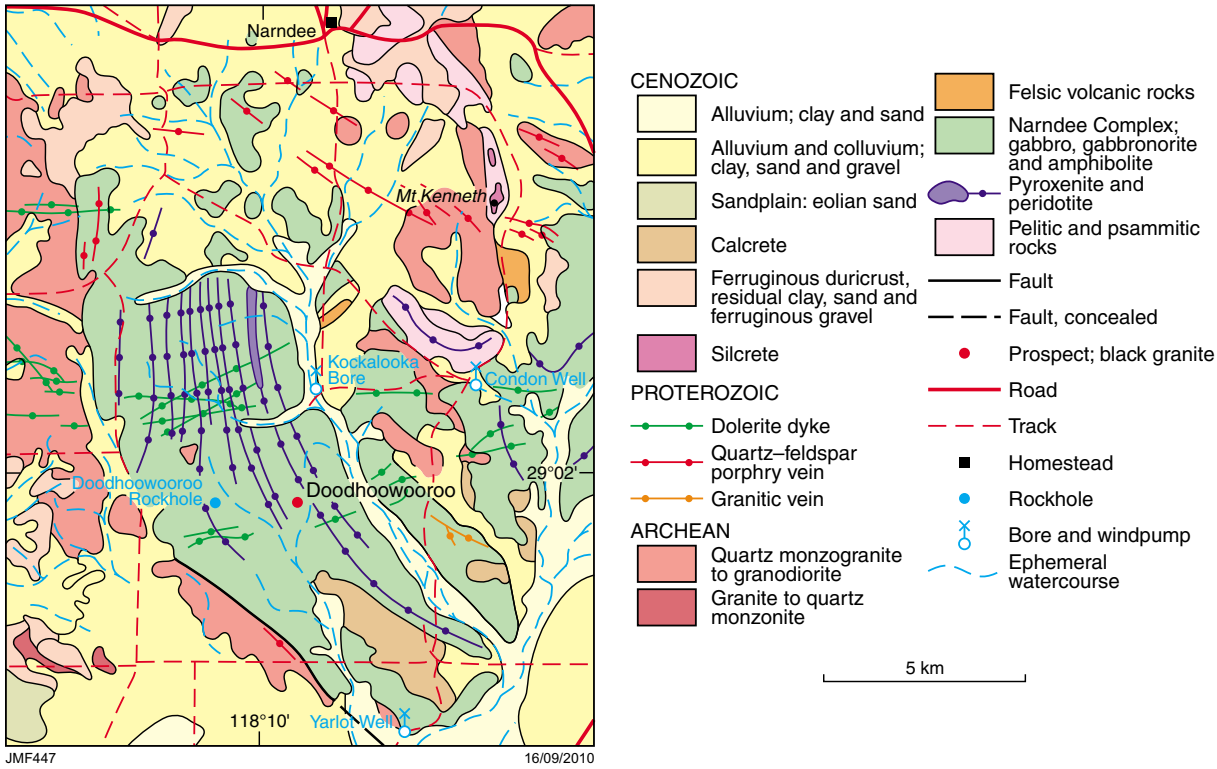


Figure 87. Geology of the Doodhoowooroo area (modified after Lipple et al., 1982; Baxter et al., 1982).

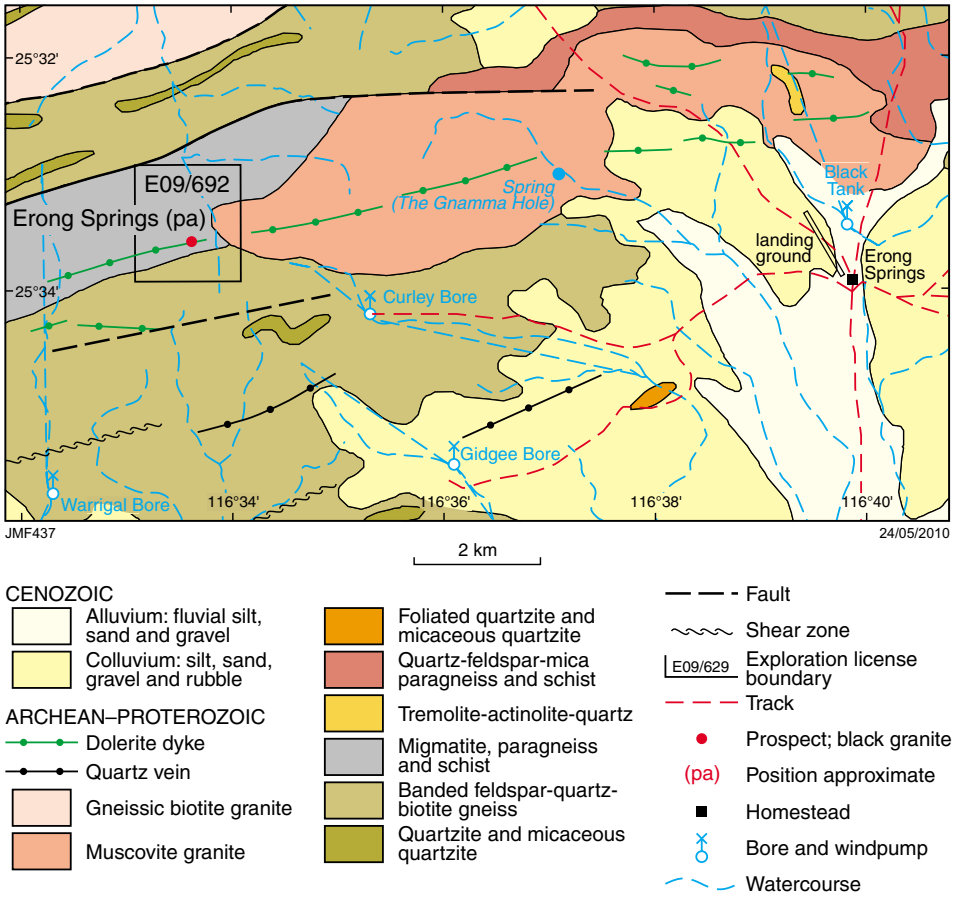


Figure 88. Geology of the Erong Springs area (modified after van de Graaff et al., 1983).



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Figure 89. View looking along the Erong Springs dolerite dyke. The largest exposed boulders (about 1 m^3) are seen at the crest of the peak (after Halligan, 1994).



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Figure 90. A highly polished frog figurine carved from fine-grained Erong Springs black granite.

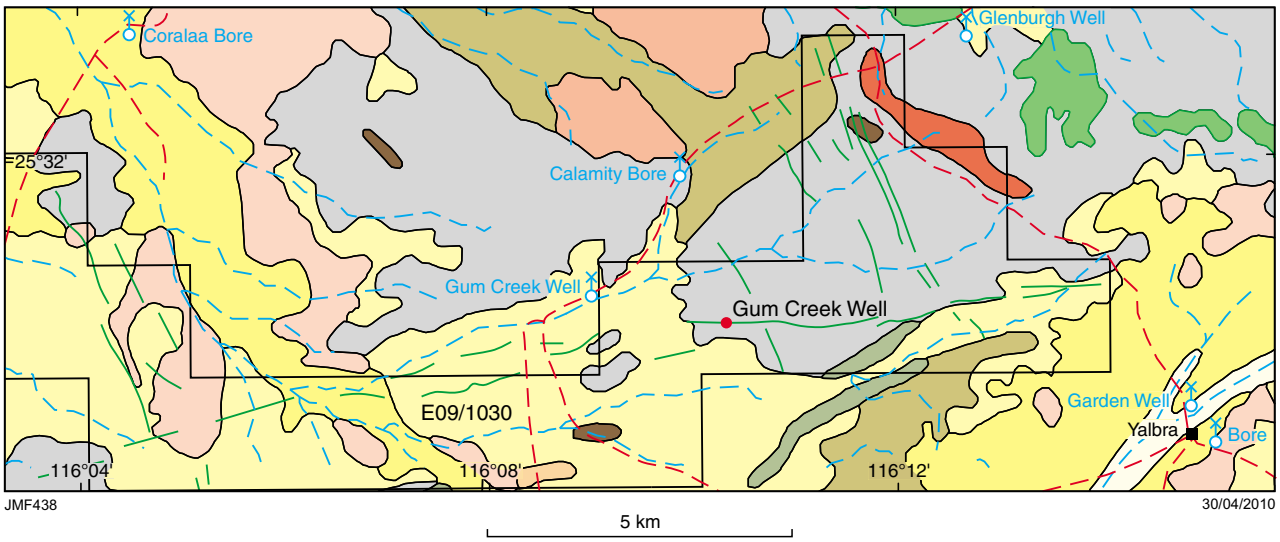


Figure 91. Geology of the Gum Creek Well area (modified after van de Graaff et al., 1983).

and 5% opaque oxide. The plagioclase is mostly less than 0.5 mm long and dusted with cryptocrystalline opaque oxide, with sparse plagioclase to 1 mm or more in length. Most of the clinopyroxene is also fine grained, with rare grains to 1.5 mm in diameter with a subophitic texture. Some of the pyroxene has been rimmed and replaced by green hornblende. The opaque oxide is interstitial and up to 1 mm in diameter.

Northern region

Halls Creek Orogen — Lamboo Complex

Halls Creek — gabbro

McIntosh

In 1994, Clutha Minerals Ltd identified the McIntosh black granite prospect within exploration licence E80/1553. The McIntosh prospect is located close to Springvale Station, about 50 km north of Halls Creek. The black granite forms part of the layered gabbro Springvale Intrusion, part of the Paleoproterozoic Lamboo Complex, in the east Kimberley region (Fig. 93).

As a result of their field investigations, Clutha Minerals demonstrated that the Springvale Intrusion is a composite body intruded by younger Paleoproterozioc granites. The older, western intrusion comprises a central core of ultramafic rocks surrounded by an outer zone of medium- and fine-grained, layered and massive gabbros. The fine-grained material commonly contains breccia zones with a gabbroic matrix rich in feldspar. In contrast, the younger, eastern intrusion has a core of fine-grained, magnetite-poor, moderately feldspathic gabbro without ultramafic phases, and the outer zone contains massive gabbros, rich in magnetite.

Investigations over both intrusions revealed little potential for dimension stone in the western intrusion, and exploration then concentrated on the magnetite-rich, massive gabbros in the southeastern part of the eastern intrusion. A core sample from a drillhole immediately north of Springvale Homestead and adjacent to the Panton River, gave indications of the presence of good-quality black granite at this locality. Bulk samples were subsequently taken from a potential quarry site nearby (Fig. 93). Cutting and polishing of two slabs from separate sites revealed a medium- to coarse-grained, dark grey to black gabbro with a minor greenish tinge. The stone also displayed a weak layering effect possibly defined by magnetite crystal alignment.

The company concluded that the McIntosh gabbro prospect was a potential dimension stone site with significant stone resources and physical characteristics possibly superior to the well-known Black Hill norite stone from South Australia. Several other potential areas, north of the suggested quarry site and east of Springvale Homestead, were considered worthy of follow-up work. Further economic assessment of the project was recommended but appears not to have been carried out (Temby, 1994).

Petrographic description

Petrographic analysis from Temby (1994) indicated an approximate mineral content of 57% pyroxene, 40% feldspar, and 3% magnetite. Some of the pyroxene appeared to form continuous zones up to 50 mm × 40 mm diameter. Grain size ranged from 1.0 to 1.5 mm for feldspar, and to 3.0 mm for pyroxene.

Kimberley Basin

Inglis Gap — gabbro

Kimberley Jade

The *Kimberley Jade* prospect is located in the King Leopold Ranges on mining lease M04/90, about 150 km east-northeast of Derby and 1 km northwest of the Mount Hart Road (Fig. 94). Between 1988 and 1991, a small quarry was established at this site and test blocks were removed by close-spaced slab drilling by Black Swan Stone Industries Pty Ltd, and later by Granite Resources of Australia Pty Ltd (Fig. 95).

Kimberley Jade is an olivine gabbro that outcrops along the axis of an open, northwest-trending valley, and is possibly a sill-like body located within a granophyric unit that forms part of the Paleoproterozoic Hart Dolerite (Fig. 94). The medium-grained gabbro consists of roughly equal amounts of plagioclase feldspar with crystal laths to 6.0 mm in length, and elongate clinopyroxene grains to 12 mm, together with altered olivine. Taking a high polish, this stone has a visually attractive, checked texture of white plagioclase laths with deep-green overtones contrasting with a greenish-black matrix (Appendix 4.32).

At the prospect, the gabbro outcrop extends several hundred metres in a northwesterly direction and is about 40 m in width. The test quarry contains relatively massive, unweathered gabbro displaying vertical joints with a 1–3 m separation. Assuming block size increases with depth, resources of *Kimberley Jade* may be extensive. Corkery (1988) reported an estimated resource of 0.62 Mm^3 of material suitable for blocks and tiles. Considering the site is relatively flat and situated above the level of valley drainage, future quarrying operations would be reasonably straightforward.

Petrographic description

Altered, weakly granophyric, olivine-rich gabbro with clays and opaque material partly or completely replacing olivine, minor biotite, sericite and saussurite, smectite(–chlorite) and possible stilpnomelane as well as disseminated sulfide.

This sample is medium-grained mafic material with a granular texture in hand specimen. It has a visually estimated mineralogy with about 36% plagioclase, 34% clinopyroxene (possibly titanaugite), 16% altered possible olivine, 8% opaque oxide, 5% granophyres, and almost 1% disseminated sulfide, mostly pyrrhotite. Plagioclase laths to 6 mm long are weakly aligned across the thin section and are accompanied by equant (subophitic) and elongate clinopyroxene grains with one

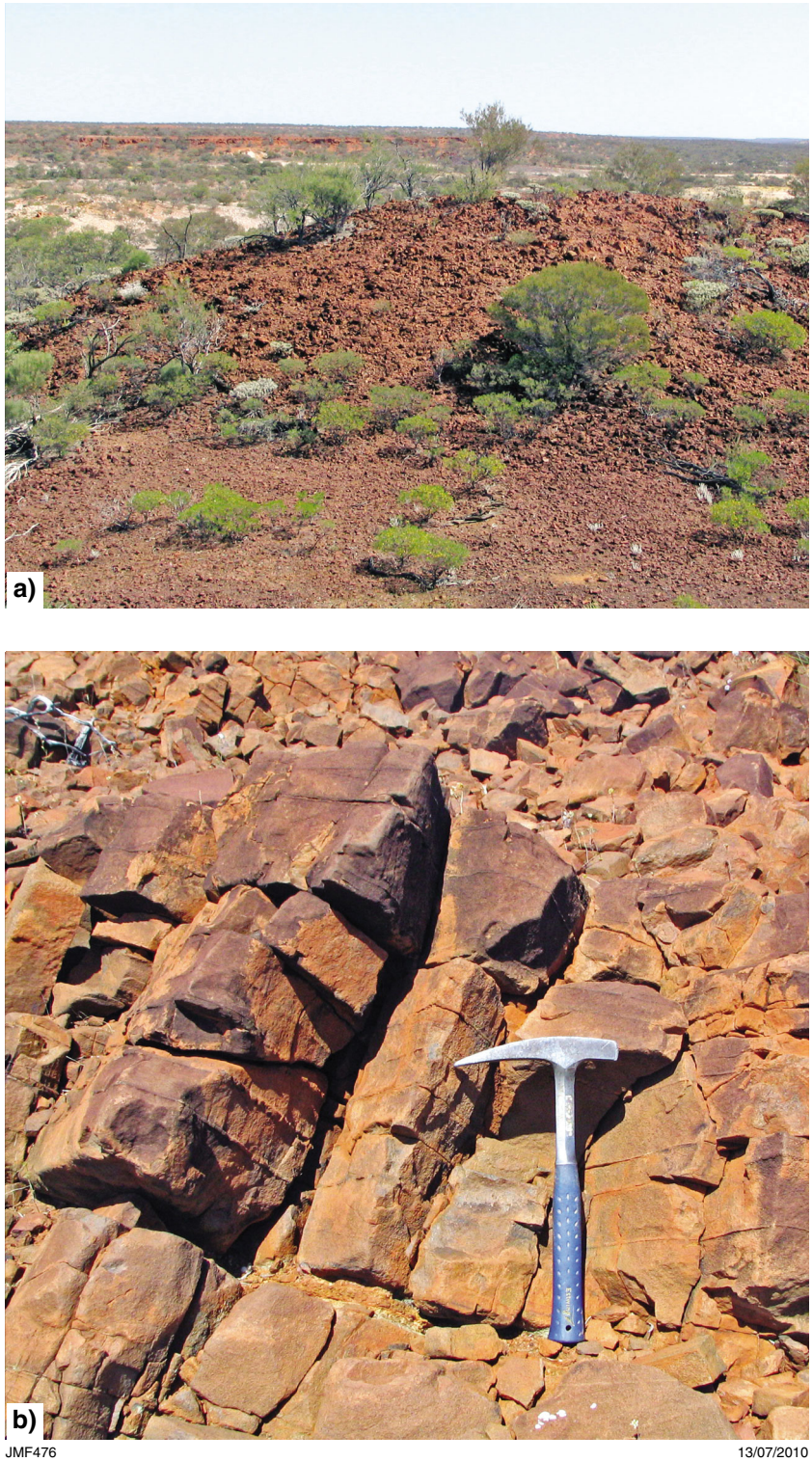


Figure 92. Gum Creek Well black granite sample site: a) dolerite dyke looking west, showing small size of surface boulders; b) detail of surface outcrop showing small boulders formed by close-spaced jointing.

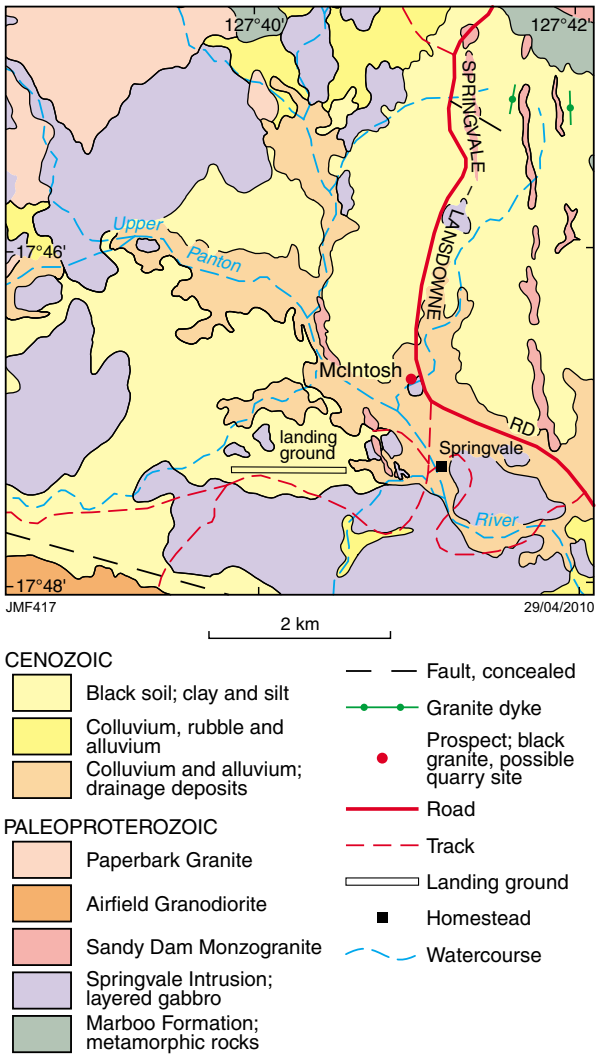


Figure 93. Geological map of the McIntosh black granite prospect, Springvale area, East Kimberley (modified after Tyler et al., 1997).

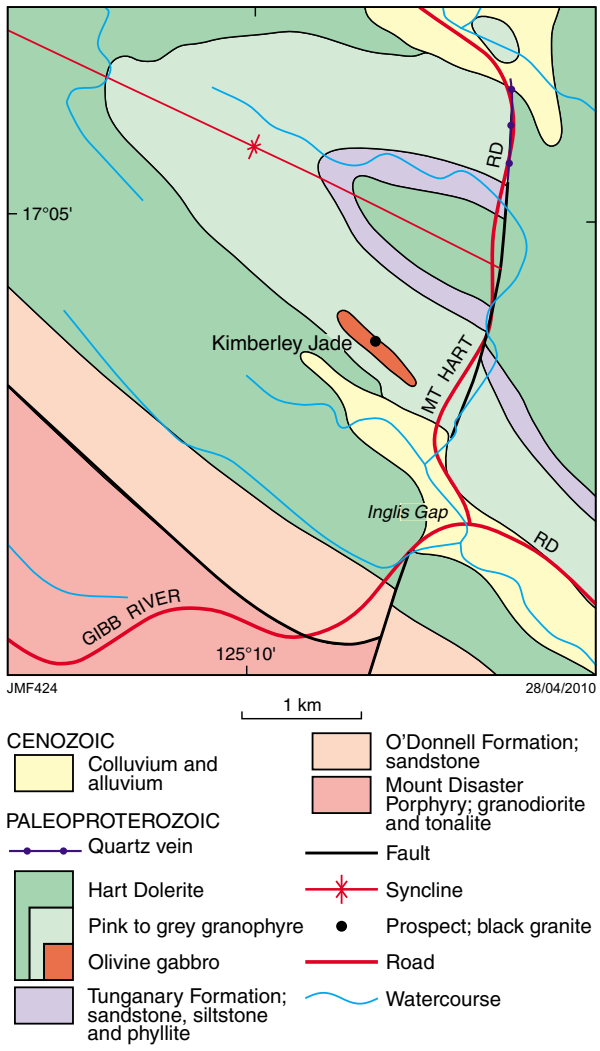


Figure 94. Geological map of the Inglis Gap area showing the location of the *Kimberley Jade* prospect (modified after Griffin et al., 1993).



Figure 95. Test quarry at *Kimberley Jade* prospect, Inglis Gap, West Kimberley region.

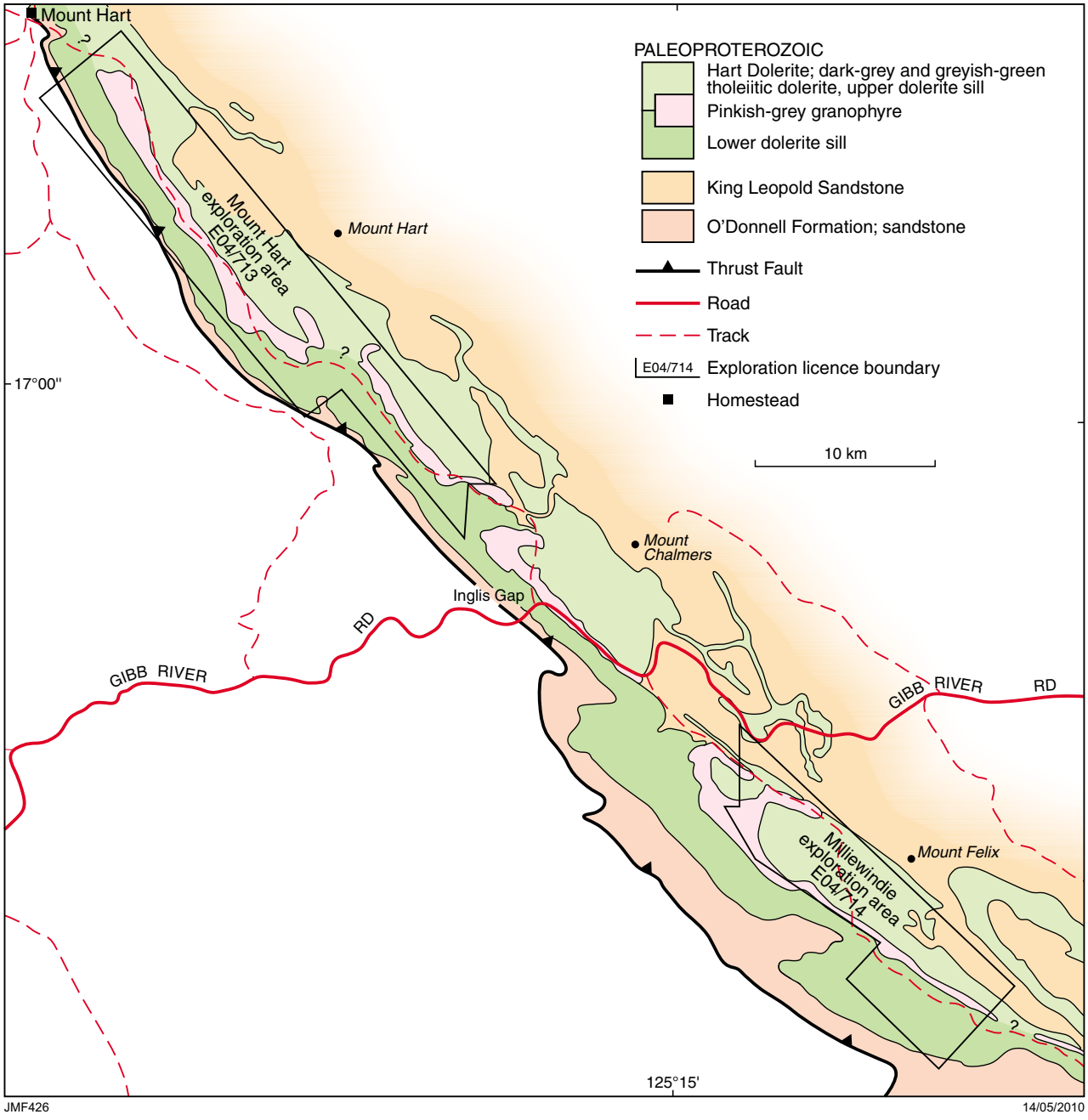


Figure 96. Generalized geological map of the Mount Hart and Milliewindie exploration areas for dimension stone (modified after Temby, 1992).

elongate grain about 12 mm long. Clays and unidentified opaque material occur with apparently residual olivine in grains to 5 mm long, some parallel to the foliation. Primary opaque oxide is commonly rimmed by or intergrown with green or brown clay or biotite, with some ilmenite–biotite/clay symplectites. Minor granophyre contains apatite and minor clay. Minor sulfide seems to be pyrrhotite and may be of primary magmatic origin. The plagioclase has irregular weak sericite and saussurite alteration or veining by brown or green clay. Included with the olivine, opaque material and clay-rich aggregates are aggregates of olive-green possible smectite some with chlorite or brown clay, or both, without opaque oxide but locally with flakes and rosettes of possible stilpnomelane. The stilpnomelane suggests low-temperature hydrothermal alteration.

Mount Hart — dolerite

Hart dolerite

Mount Hart and Milliwindie

The Mount Hart and Milliewindie exploration areas for dimension stone are located in the King Leopold Ranges, 160 km east-northeast, and 165 km east of Derby, respectively. Inglis Gap is centrally located between the two northwesterly trending areas (Fig. 96).

In 1992, areas of Paleoproterozoic Hart Dolerite within exploration licences E04/713 (Mount Hart) and E04/714 (Milliewindie) were briefly investigated for their dimension stone potential by Clutha Minerals Ltd. In these areas the dolerite consists of at least two major, generally conformable, northwesterly trending sills with each sill being capped by a layer of pinkish-grey granophyre and often separated by a thin siltstone unit. Exploration revealed the presence of extensive zones of multicoloured xenoliths from a diverse range of rock types within the sills, particularly in the very fine grained, and strongly jointed upper sill. Accordingly, investigations for dimension stone targeted the medium- to coarse-grained, grey to green, ophitic dolerite present in the lower sill.

It was concluded from the overall high frequency of xenoliths present in the Hart Dolerite, that xenolith-free zones were unlikely to be present in the lower sill dolerite in either exploration area. This factor, coupled with strong jointing present throughout most of the dolerite within the tenements, indicated there was little potential for black granite production. The tenements were subsequently relinquished (Temby, 1992).

King Leopold Orogen — Hooper Complex

West Kimberley — dolerite

The West Kimberley region around Wombarella Creek, Quarry Camp, and Fairfield and Carpenter Gap, located between 130 and 160 km to the east of Derby, were principal sites for the quarrying of black granite in the State from the early 1970s until the mid-1990s. Over this period a large quantity of high-quality stone was exported to Japan for the monumental stone industry. During this period it was realized that the Japanese stone industry regarded the intensity of 'blackness' as the stone's most important property. Fine grain size and uniformity of texture were also rated as important properties but less so than blackness. Also, the presence of white minerals, however small, was not acceptable (Halligan, 1986). These criteria had a marked influence on the selection of sites with the potential to produce the highest quality material to match the specifications. Also, the accurate assessment of blocks to match export-grade standards was an important skill for maintaining Japanese stone orders.

Carpenter Gap

The Carpenter Gap black granite exploration area is located about 150 km east of Derby and about 8 km east of Windjana Gorge. Formerly, access was by track via Carpenter Gap from the Tunnel Creek – Windjana Road over a distance of about 5 km. Currently, access to the area is difficult due to washouts, overgrowth of tracks, new fences and locked gates (Fig. 97).

In 1993, this area was explored by Teedale Pty Ltd who investigated a swarm of northwest-trending, Paleoproterozoic dolerite dykes intruding regionally metamorphosed sedimentary rocks of the Marboo Formation, also of Paleoproterozoic age. Dykes in this area range from straight to curvilinear and are mainly near vertical, but there are also a number of dykes dipping to the northeast at angles as low as 30º.

During this exploration, the main area of interest appears to have been a dyke located about 4 km east-northeast of Carpenter Gap. At this locality, old black granite workings cover about 1 ha along the side of a prominent dyke that ranges to 30 m above the surrounding plain and extends for about 1 km in a northwesterly direction (Fig. 97). Boulder outcrops are present at various locations along the dyke. Large boulders were estimated to weigh up to 20 t. Samples taken from this dyke indicate the presence of very fine grained black granite extending along its entire length. Samples, subsequently cut and polished, not only confirmed the very fine grained nature of the stone but also demonstrated that it would also take a very high polish.

At least six other dykes in the area, situated no more than 5 km from the present site, in directions ranging from north to east, were also examined during the survey. Some of these dykes also contain abandoned black granite workings. Dykes ranged in length from only a few metres to massive structures up to 2.5 km in length with heights ranging from a few metres to 120 m above ground level. Grain sizes ranged from fine to coarse, and white spotting, flecking, and green and black random lines were present in places. Random fracturing was present at some sites. Some dykes contained massive faces of black granite with little evidence of fracturing.

Overall, these dykes were found to contain coarse- to fine-grained, high-quality black granite with excellent black colour and polish, and the potential to yield a high price on the dimension stone market. Bovell (1993) recommended that more field work be undertaken, including bulk

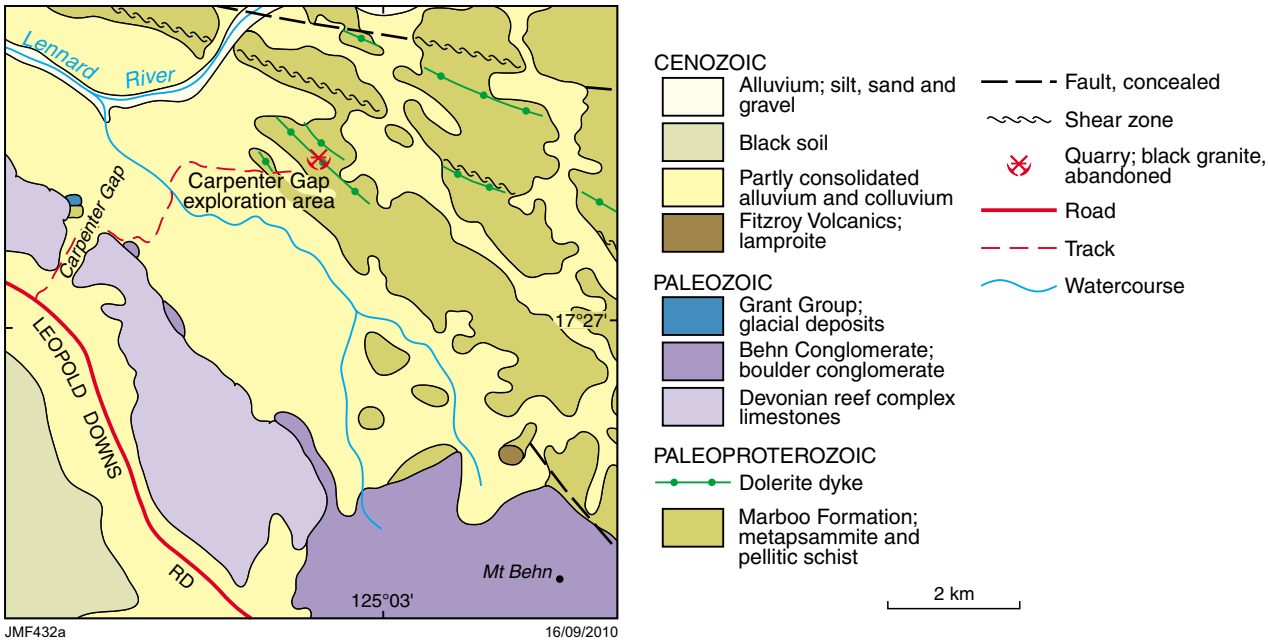


Figure 97. Geological map of the Carpenter Gap area, West Kimberley region (modified after Griffin et al., 1993).

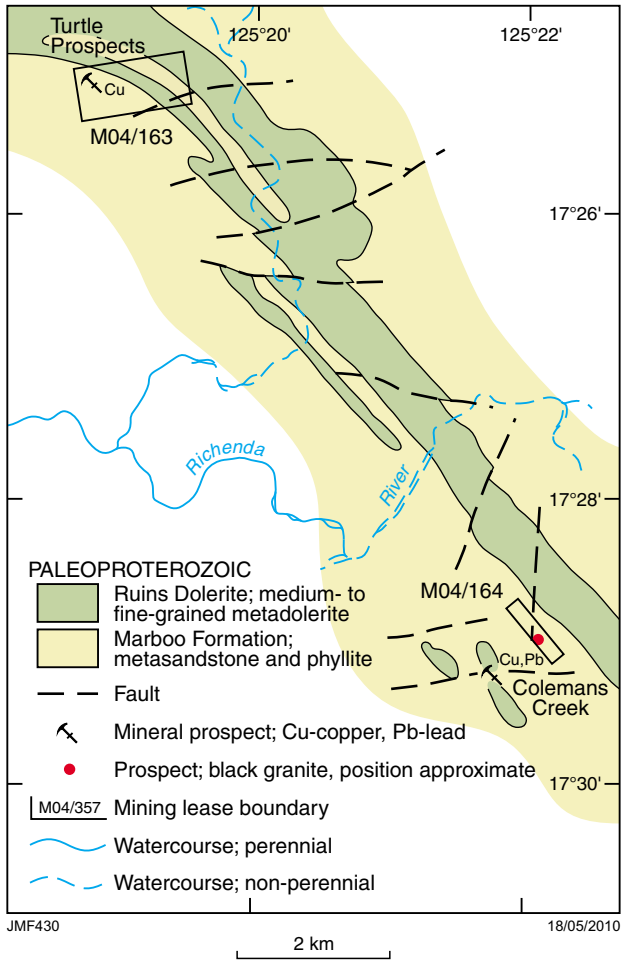


Figure 98. Geological sketch map of the Colemans black granite prospect, West Kimberley region (modified after Barnes, 2000).

sampling, to assess degree of weathering, fracture patterns, and commercially recoverable resources.

Colemans prospect

Colemans prospect is located about 80 km north-northwest of Fitzroy Crossing in the west Kimberley region. The prospect, adjacent to the Richenda River, was originally accessible from the Tunnel Creek – Windjana Road, about 30 km to the south. Currently, access to the site is difficult owing to washouts and overgrowth of tracks (Fig. 98).

The prospect is located on a large doleritic dyke structure forming part of a northwest-trending belt of the Paleoproterozoic Ruins Dolerite that intrudes metasedimentary rocks of the Marboo Formation, also of the same age. The area was first investigated in 1988 by Moonbeam Nominees Pty Ltd who identified three swarms of parallel, northwest-trending dykes in the area. These vertically dipping dykes are up to 50 m wide and are spaced approximately 100 m apart. The company identified four types of black granite in this area:

- Fine-grained black; located in narrow dolerite dykes or close to dyke margins in wider structures. The stone is of high quality but is affected by severe cracking in places
- Coarse-grained black; found in the centre of larger dolerite dykes and pods
- Black and white; fine-grained black granite containing porphyritic rosettes of white feldspar crystals to 1.0 cm in diameter
- Black dolerite; a massive, inferior quality stone that does not take a fine-quality finish.

The company collected samples from 26 sites that were subsequently cut and polished and sent to Italy and Japan for expert evaluation (Moonbeam Nominees, 1988).

In 2000, a smaller area was reinvestigated for dimension stone at Colemans Camp on former mining lease M04/164 by New Millennium Resources NL. Barnes (2000) described two types of black granite present within the lease area:

- Black granite; described as being the typical dolerite for the region that has been mined to the northwest (probably around Quarry Camp)
- 'Snowflake black Granite'; which is almost certainly the same stone as the 'black and white' porphyritic black granite mentioned above. The stone is described as containing large rosette crystals of white feldspar up to 2 cm in diameter with a separation of about 5 cm. It is described as 'a spectacular rock that may have some use in the decorative industry', perhaps in the stone flooring and furniture market.

Fairfield

The former Fairfield black granite quarrying operations are located 80 km north-northwest of Fitzroy Crossing. Access is by way of a track leading 8 km northeast from the Tunnel Creek – Windjana Road. Between 1988 and 1990, exploration and quarrying at several sites was carried out by Kimberley Granite Resources Pty Ltd on exploration licence E04/529 and mining lease M04/199 (Fig. 99).

The Fairfield quarries are situated at the southern end of an extensive swarm of north- to northwest-trending mafic dykes. In this area, Paleoproterozoic metadolerite/amphibolite dykes intruded foliated metasedimentary rocks including metasandstone, phyllite, and micaceous schist of the Marboo Formation, also of Paleoproterozoic age (Griffin et al., 1993). In the immediate vicinity of the Fairfield mining lease, there are numerous metadolerite dykes together with many other probable dykes identified from airphoto interpretation. These near-vertical dykes form linear ridges up to 40 m higher than the surrounding ground surface. Some dykes extend intermittently for over 2 km along strike. Also present in the area are a comparatively small number of quartz veins to 2 m wide.

The Fairfield metadolerite dykes display a range of grain sizes that vary from the sought-after fine-grained, even-textured black granite, to medium- and coarse-grained varieties. Fine-grained dykes with elevations generally less than 10 m above the ground surface occurred predominantly in the western sector of the Fairfield lease (Fig. 100). Also, small, fine-grained dykes of high-grade black granite, less than 3 m in width, commonly occur within much larger medium- to coarse-grained dykes. This is interpreted to have resulted from discrete pulses of dolerite during the intrusion phase (Garlick, 1988).

Preliminary mapping of the area resulted in a resource estimate of 1.5 Mt based on dyke lengths measured from airphoto interpretation, field observations of apparent dyke width, a bulk density of 3.0 t/m^3, and a quarry depth limit of 10 m.

In 1988, selected dykes were drilled to establish locations for black granite quarries. Thicknesses for unweathered black granite commonly ranged from 2 to 7 m, although in at least two holes, unweathered thicknesses of 14.5 and 18.5 m were recorded. Black granite from various sites was graded in the following categories:

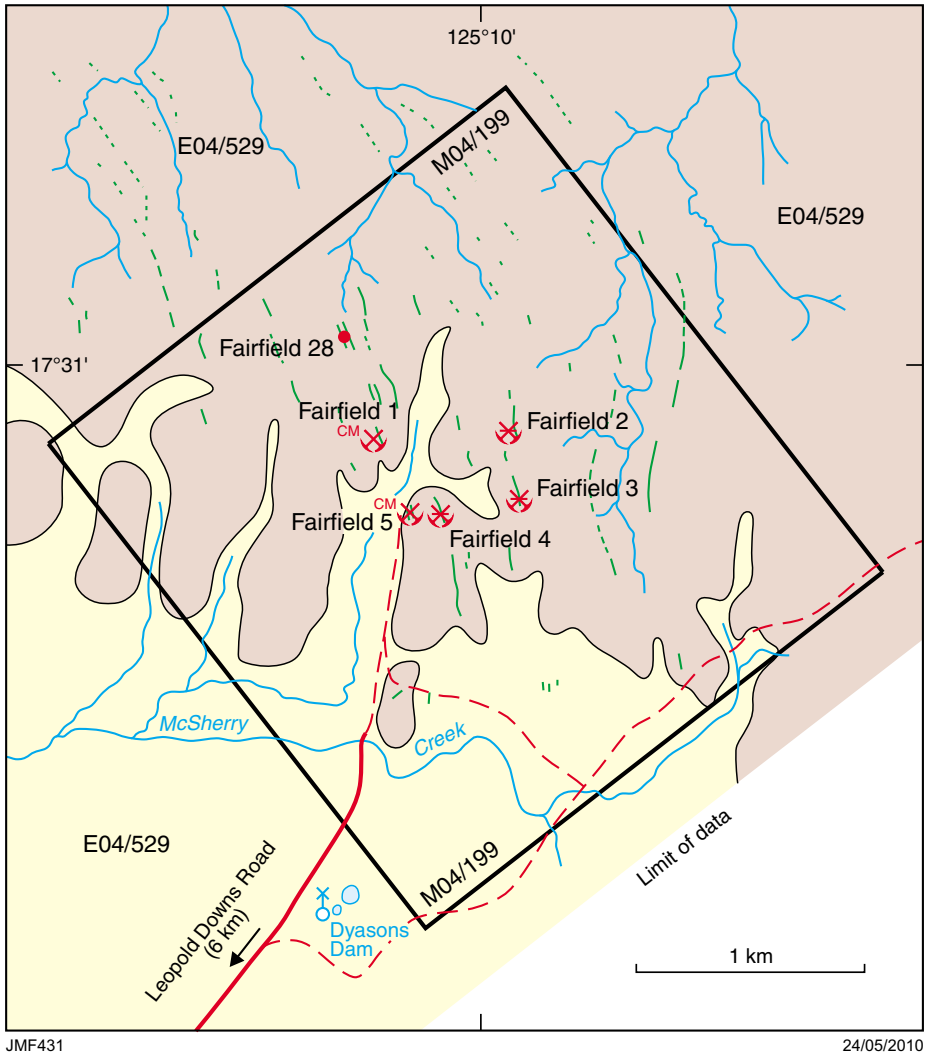
- fine-grained, even-textured, high-grade black granite in dykes less than 5 m wide, some with brittle fracture
- medium- to coarse-grained material suitable for wall and paving applications (Appendix 4.33)
- medium- to very coarse grained material (some containing white feldspar phenocrysts) of doubtful application
- waste material.

Quarrying of blocks was carried out at five sites (Fairfield 1–5) from 1988 to 1990. A sixth site (Fairfield 28) was listed as a dimension stone prospect (Fig. 99). The Fairfield project was abandoned sometime in 1990 after the operating company apparently went into liquidation. Today, only two partially water-filled quarry sites remain open in a care and maintenance situation (Fig. 101).

Petrographic description

Metamorphosed dolerite with abundant amphibole, less-abundant plagioclase, opaque oxide partly altered to titanite, and narrow quartz veinlets.

This sample is composed of metamorphosed dolerite with a visually estimated mineralogy of 62% recrystallized amphibole, 33% plagioclase, 4–5% opaque oxide–titanite



CENOZOIC
- Black soil and alluvium

PALEOPROTEROZOIC
- Marboo Formation; metasandstone and phyllite
- Metadolerite dyke
- Metadolerite dyke (photo–interpreted)
- CM Quarry; metadolerite, care and maintenance
- Quarry; metadolerite, abandoned
- Prospect; metadolerite
- M04/119 Mining lease boundary
- E04/529 Area of exploration licence
- Road
- Track
- Watercourse
- Bore

Figure 99. Geological sketch map of the Fairfield area, West Kimberley region (modified after Tennent, 1989).

aggregates, and sparse quartz-filled veinlets. There is evidence of former pyroxene prisms to 4 mm long, but most seems to have been granular and less than 1 mm in diameter. Relatively fine grained plagioclase seems to have been partly replaced by amphibole, probably hornblende or actinolitic hornblende. Weak saussurite alteration is also evident in some of the plagioclase. The opaque oxide is mostly less than 0.5 mm in diameter and partly replaced by titanite. Segmented quartz veinlets about 0.1 mm wide contain minor hornblende.

Wombarella Creek and Quarry Camp mining areas

These major black granite mining areas lie between 135 and 150 km east of Derby. In this area, northwesterly trending, unmetamorphosed dolerite dykes intrude both the granitic and metasedimentary rocks of the Paleoproterozoic Hooper Complex (Fig. 102). Dykes are mostly vertically inclined, range from 2 m to more than 30 m in thickness, and often form narrow, steep-sided ridges rising up to at least 50 m above the surrounding alluvial plains. Dykes commonly form closely spaced, parallel, en echelon pairs, and can frequently be traced in outcrop for distances in excess of 1 km (Hardcastle and Richards, 1987).

The black, fine- to medium-grained, tholeiitic dolerite is extremely fresh, being virtually unweathered except for a very thin, dark brown to black outer skin. The majority of dykes are of uniform texture across their width with narrow, fine-grained selvages at their contacts with host rocks. A few dykes are strongly zoned and display fine-grained, chilled contact margins that pass rapidly into a medium- and ultimately coarse-grained core, as is the case at the New Quarry.

Joint weathering at the surface commonly results in extensive outcrops of mostly medium-size, blocky boulders. Large joint-controlled, rectangular boulders that commonly occur at depth beneath the surface boulder scree are the source of the sought-after, fine-grained, lustrous black granite dimension stone. This stone takes a high polish suitable for blocks, slabs, and tiles used in the construction and monumental stone industries.

Wombarella Creek

At Wombarella Creek, four black granite prospects, designated WC1–WC4 on Figure 102, are located on either side of the Gibb River Road about 135 km east-northeast of Derby. In the same area, the *Kimberley Black* granite quarry has been mined intermittently since 1972.

Wombarella Creek prospects

Wombarella Creek black granite prospects WC1–WC4 are contained within mining leases M04/84–86 and 88 respectively. During the late 1980s to mid-1990s they were owned by Black Swan Stone Industries Pty Ltd and since that time the leases have been held by Mr C Sim. Apart from WC4, these prospects contain relatively steep sided, northwesterly trending, blocky dolerite ridges, some with extensive boulder scree. Dykes have intruded either the Paleoproterozoic Wombarella Quartz Gabbro, or the Lennard Granite and rise to an average height of about 50 m above the surrounding plain.

Dykes on WC1 and WC2 have been variously estimated to be 250–400 m in length and 10–15 m in width. Little additional information relating to past exploration for these prospects appears to have been reported except for Corkery (1988), who made the following preliminary volumetric estimates of black granite resources to 15 m below ground level for blocks and tiles:

	Blocks (1–>2 m³)	*Tiles (<1 m³)*
• WC1 (M04/84)	75 000 m³	80 000 m³
• WC2 (M04/85)	110 000 m³	120 000 m³
• WC3 (M04/86)	115 000 m³	30 000 m³
• WC4 (M04/88)	12 500 m³	15 000 m³

Kimberley Black granite quarry

The *Kimberley Black* granite quarry at Wombarella Creek, located about 135 km east of Derby and 1 km northeast of the *Kimberly Pearl* granite quarry, is contained within mining lease M04/87, which was also originally owned by Black Swan Stone Industries Pty Ltd from about the mid-1980s to mid-1990s, and thereafter by Mr C Sim (Fig. 102).

The quarry is located in the centre of a 50 m-high, northwest-trending ridge that may be up to 30 m thick. At this site, an extremely fine grained, black dolerite dyke has intruded the foliated, Paleoproterozoic Lennard Granite. Jointing within the dolerite appears to be variable with core-stones varying from less than 1 m³ (possibly from near surface) to 20–30 m³, indicating joint spacings ranging from less than 1 m to over 3.5 m.

From 1988 to the early 1990s, Black Swan Stone Industries conducted quarrying operations in which larger black granite core-stones were extracted from the upper central section of the ridge and moved to a stockpile area situated on the sandy plain close to the base of the slope (Fig. 103). Here, stone was classified according to its saleability for slabbing with acceptable high-quality material being jet black, very fine grained, without visible flaws, and polishing to a mirror-like finish. Also, block size was classified according to volume and shape (Fig. 104). In this deposit, the ideal block size of around 1 m × 1 m × 3 m was probably difficult to achieve due to jointing, and consequently most blocks produced appear to have been less than 3 m in length.

Technical specifications for *Kimberley Black* granite given by Meteor Stone (2004) are:

- Absorption 0.12%
- Bulk density 2.7 t/m³
- Compressive strength 140 MPa
- Modulus of rupture (dry) 15 MPa

During the quarrying phase, selected stone from Wombarella Creek was exported primarily to Japan where there has always been great demand for high-quality black granite for use as headstones in the funerary industry (Fig. 105). In later years, black granite was also used in Perth for polished panels in the building industry and as decorative paving cobbles in streetscapes (Fig. 106; Appendix 4.34).



JMF609 27/07/2010

Figure 100. Fine-grained metadolerite ridge located 100 m north of Fairfield 1 quarry (view looking north).



JMF610 28/07/2010

Figure 101. Fairfield 1 black granite quarry. Currently in care and maintenance.

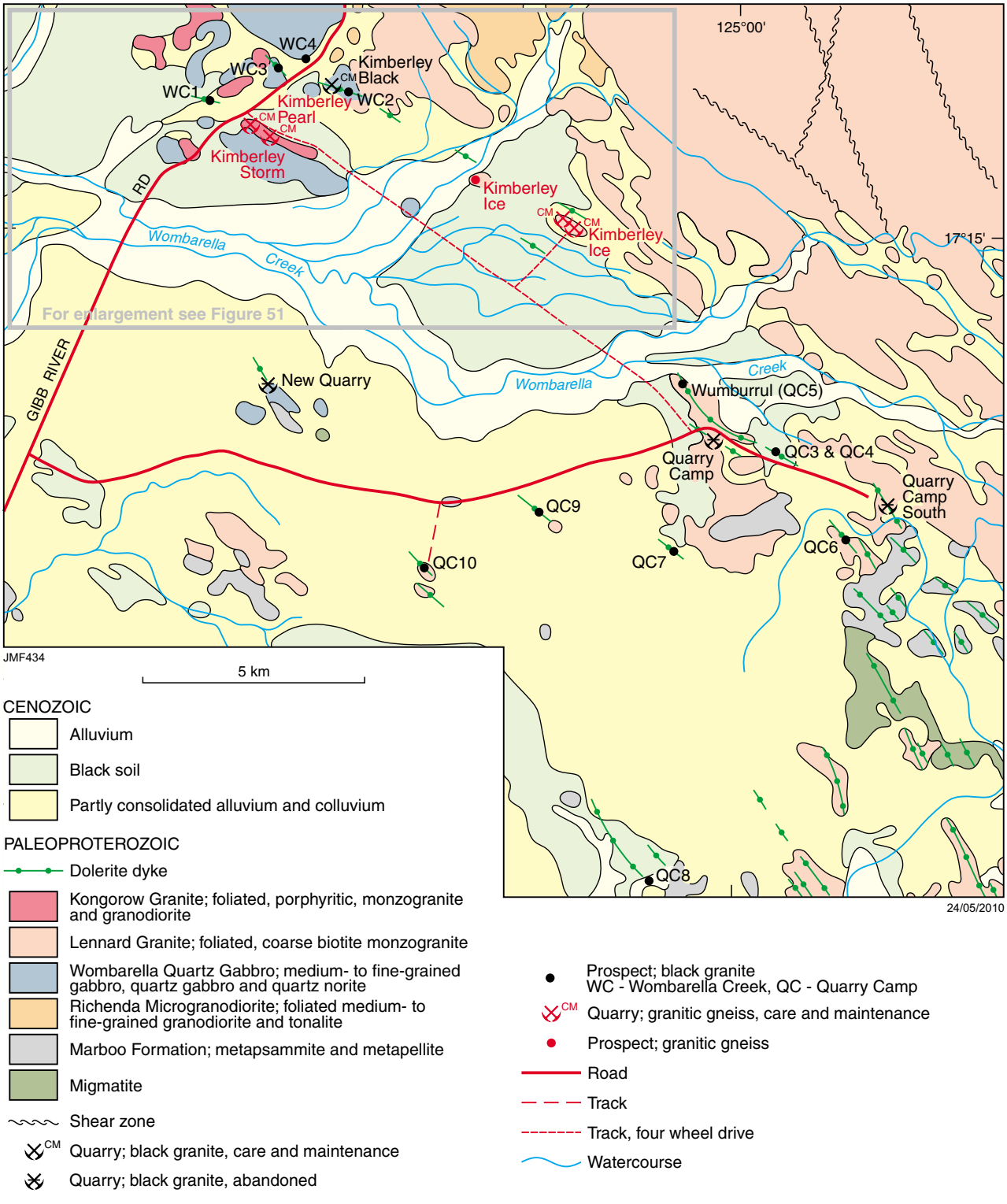
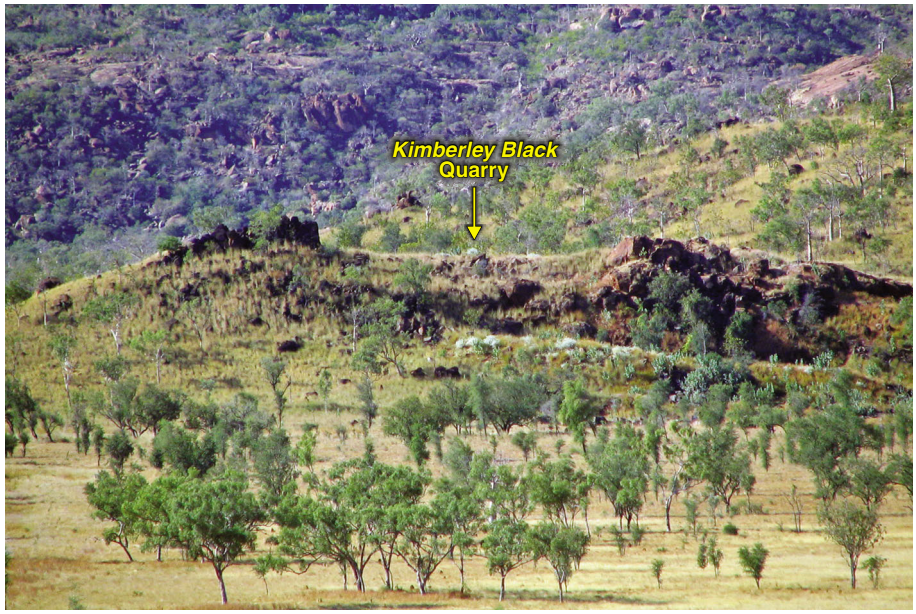


Figure 102. Geological map of the Wombarella Creek and Quarry Camp black granite quarries and prospects (modified after Griffin et al., 1993).



JMF457 27/04/2010

Figure 103. View looking northeast to the *Kimberley Black* quarry at Wombarella Creek. The quarry is situated in the cleft of a 50 m-high dolerite dyke.



JMF611 28/07/2010

Figure 104. A 1.5 m³ block of high-grade *Kimberley Black*. Black granite stockpile *Kimberley Black* quarry.



JMF612 28/07/2010

Figure 105. **An example of the use of high-quality black granite in the Japanese funerary industry. The headstone is from the Japanese Cemetery in Broome.**



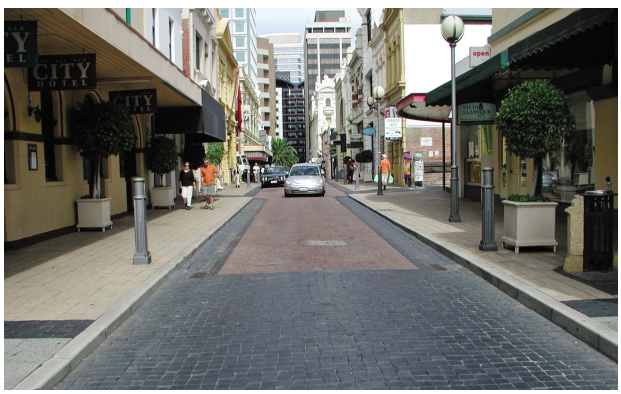


Figure 106. **Applications for black granite in the construction and streetscaping industries: a) polished black granite panels used in the lower walls and forecourt of Septimus Roe Square in Adelaide Terrace, Perth; b) streetscape in *Kimberley Black* paving cobbles, King Street, Perth (photo (b) courtesy Meteor Stone).**

After cessation of quarrying, Hayes (2003) estimated that total remaining measured, indicated and inferred resources of black granite on mining lease M04/87 totalled 0.234 Mm^3 with recoverable reserves estimated at 0.116 Mm^3. Today, the remaining stockpile at the site contains approximately 150 black granite core-stones ranging from less than 1 to 15 m^3.

Petrographic description

Fine-grained dolerite with sparse plagioclase phenocrysts, subophitic pyroxene, rare olivine, minor opaque oxide, actinolite, biotite, and chlorite.

This fine-grained slightly greenish-grey dolerite has subequal amounts of plagioclase and clinopyroxene accompanied by 3–4% opaque oxide, a single fractured olivine grain 1.5 mm in diameter, minor actinolite and biotite, rare chlorite, and trace apatite. Relatively minor plagioclase phenocrysts occur, to 4 mm in diameter, but most of the plagioclase is less than 1 mm long, with ophitic and subophitic pyroxene mostly less than 1 mm in diameter. The plagioclase is partly brownish in thin section with cryptocrystalline oxide possibly present, and rarely contains microcrystalline clay or phyllosilicate. Some of the pyroxene has been altered to actinolite, particularly adjacent to narrow fractures containing actinolite(–chlorite–opaque oxide). Oxide is also present along fractures in olivine. Partly skeletal, opaque oxide is commonly rimmed by minor biotite.

Quarry Camp area

The Quarry Camp area is situated south of Wombarella Creek, approximately 145 km east of Derby (Fig. 102). The area is host to at least 80 prominent, north-northwesterly trending dolerite dykes intruding Paleoproterozoic metasedimentary rocks and the Lennard Granite. These dykes extend from the area around Quarry Camp southeast to the Lennard River, a distance of about 20 km (Hardcastle and Richards, 1987). The preliminary exploration of many sites in the Quarry Camp area, was discussed in some detail by Halligan (1985). These prospects are designated QC3–9, including the Wumburrul prospect (QC5), to match Halligan's prospect numbers. Prospect QC10 is described by Hardcastle and Richards (1987).

Between 1984 and the early 1990s a number of quarrying operations were established in and around the Quarry Camp area by the Gossati family, and the Parry Corporation. As with black granite from the Wombarella Creek quarry, black granite extracted from the Quarry Camp area was also marketed as *Kimberley Black*.

Quarry Camp operations

This quarrying venture at Quarry Camp was operated initially by the Gosatti family between 1984 and 1988. During this period the operators opened two quarries situated towards the southeastern end of a set of three parallel en echelon dykes that extend over 2 km in a prominent northwest-trending ridge (Fig. 102).

Black granite from these quarries consists of high-quality, fine- to medium-grained, jet-black, weakly porphyritic dolerite, and was probably of superior grade to black granite available at the time from Africa and India. In these quarries weathering is well advanced along joint planes, especially those close to dyke margins. This weathering process has resulted in the formation of large numbers of blocky core-stones, some with dimensions exceeding 3 m × 2 m × 1 m (Fig. 107). During this early mining period, about 600 t of core-stones were extracted from the quarries and partially squared into saleable sizes of *Kimberley Black* granite and exported to markets in Japan.

From 1988 to the early 1990s, the Gossati Quarry Camp operations were operated by the Parry Corporation. In this renewed operation on former mining leases M04/49 and 74, core-stones were close-spaced drilled in situ and released from the rock mass using light explosives to 'pop' blocks free. Large blocks were then transported by back-hauling on triple trailers 1800 km to the company's processing works at Muchea, 40 km north of Perth. At the Muchea factory, export-quality *Kimberley Black* blocks were diamond sawn on the outside for quality control prior to container packing. These blocks were exported from Fremantle, primarily to Japan for use as headstones in the funerary industry. Black granite blocks destined for domestic consumption were diamond sawn into smaller blocks and slabs according to architectural specifications and then processed to a high polish with a mirror-like sheen (Appendix 4.35).

Domestic grade *Kimberley Black* granite from Quarry Camp was sold to monumental masons, and to the construction industry for both exterior cladding of office buildings as well as for interior use as decorative wall cladding, floor tiles and office fittings. In Perth, a number of prestige buildings such as the Sheraton Hotel and the BankWest Tower feature *Kimberley Black* granite, mainly in their internal ornamentation. At the same time, large quantities were also shipped to Melbourne for use in the construction of new offices (Sunday Times, 1988).

Petrographic description

Weakly porphyritic dolerite with sparse plagioclase phenocrysts, and disseminated late magmatic quartz as well as opaque oxide and rare sulfide.

This dolerite has a visually estimated mineralogy with 55% plagioclase, 31% clinopyroxene, 9% opaque oxide, 3.5% late magmatic quartz, and small amounts of disseminated biotite and actinolite as well as accessory apatite. Sparse plagioclase phenocrysts are 2 to 4 mm long but the largest phenocryst has a core with a zoning pattern partly truncated by an irregular rim on two sides, suggesting resorption and reprecipitation. Outer zones in the phenocrysts have a pale brown tinge, probably due to iron staining. The groundmass plagioclase is as much as 1.5 mm long and has pale brown cores and clear rims rarely containing apatite. Granular subophitic clinopyroxene is mostly less than 1 mm in diameter, with interstitial opaque oxide to 2 mm long commonly rimmed by actinolite and/or biotite. Actinolite also rims some pyroxene grains with pale amphibole followed by bluish-green amphibole and rare rosettes of fibrous dark green amphibole. Rare sulfide to 0.2 mm in diameter is disseminated and may be pyrrhotite. The actinolite and biotite may be of subsolidus or metamorphic origin.

Quarry Camp South

In 1987 Black Granite Pty Ltd (Parry Corporation) operated a number of black granite pits situated on two dolerite dykes about 4 km southeast of Quarry Camp (Fig. 102). These quarries, located on former mining lease M04/154, were sited on a low, relatively narrow, northwest-trending ridge extending over a distance of 250 m. This deposit contained large volumes of high-quality black granite contained in well-jointed, natural benches where blocks were extracted by close-spaced drilling. In the six months between May and November 1987, it was recorded that the operation produced over 600 m^3 of black granite boulders. A sizeable proportion of these were transported to the Muchea facility, described above, for processing into blocks and slabs (Hardcastle and Richards, 1987).

New Quarry

The New Quarry, 135 km east of Derby and about 5 km east of the Gibb River Road, was operated briefly by the Parry Corporation Ltd and McDonald Mining Pty Ltd in the mid-1980s on former mining lease M04/227 (Fig. 102). At the site, a large dolerite dyke approximately 800 m in length and 20 m in width outcrops intermittently over relatively level ground. Three trial pits were opened and over 50 blocks of black granite were excavated.

During these excavations the dyke was found to be strongly zoned, consisting of fine-grained, chilled contact zones, about 1 m in width on either side, abutting the host Lennard Granite. These contact zones are visible as black, low ridges over the weathered surface of the ground. Dyke rock between the outer contact zones is poorly exposed but on excavation the grey to dark grey dolerite was found to range from medium to coarse grained with the coarser material forming most of the inner dyke (Fig. 108).

Assessment of excavated blocks revealed that the grainsize varied from fine to very coarse with the majority of blocks being coarse to very coarse. This factor, coupled with cracking and the poor shape of many blocks, plus the difficulty encountered in the removal of large core-stones at only a few metres below surface level, led to the site being abandoned. This decision was based on the limited quality material available for Japanese clients, and also because the remaining stone was of inferior grade compared with the high-quality *Kimberley Black* produced nearby at the Wombarella Creek quarry (Halligan, 1986).

Quarry Camp prospects QC3 and 4

Prospects QC3 and 4 (Fig. 102) are comparatively small northwest-trending dolerite dykes located on low hills and with dimensions of about 50 and 120 m in length and 12 and 8 m in width respectively. These dykes, located on former mining lease M04/101, are probably extensions of the Quarry Camp dyke system located only 0.75 km to the northwest. Exposure is limited, except for a trial pit excavated at each prospect that revealed core-stones mostly around 1 m^3 with some larger stones ranging up to 8 m^3. The dolerite is fine grained and dark grey in colour, and the quality of a hand specimen of black granite from prospect 3 was described by Halligan (1986) as 'exceptional'.

Quarry Camp prospect QC6

Prospect QC6 (Fig. 102), is located on a dolerite dyke on a low ridge about 3 km to the southeast of Quarry Camp on former mining lease M04/100. This site is probably the southernmost extension of the Quarry Camp dyke system. This narrow dyke is approximately 200 m long and 8 m in width. Despite the presence of large unweathered core-stones up to 3 m^3, the quality of the fine-grained stone was rated as poor because it appeared that it was not black enough for use in the ornamental stone industry (Halligan, 1986).

Quarry Camp prospect QC7

Prospect QC7 (Fig. 102) is situated about 3 km south of Quarry Camp on former mining lease M04/73. The prospect consists of two parts with the northern dyke possibly displaced from the larger southern section by faulting, or alternatively, the structure may comprise two north-northwesterly trending, en echelon, parallel dolerite dykes. The northern dyke is approximately 60 m long and 8 m wide, whereas the southern dyke extends discontinuously over 180 m with an average width of 6 m. The dykes cap relatively low ridges up to 20 m above the surrounding plain with blocks of 1 m^3 commonly exposed in outcrop (Fig. 109).

The fine-grained, dark grey dolerite is described as being somewhat similar to the dolerite present at Quarry Camp. The stone displays an excellent consistency along the entire length of the structure and polishes to a deep, lustrous black, and is rated in the highest quality category for black granite with a 'good plus' grade with excellent potential for application in the monumental industry (Appendix 4.36; Halligan, 1986).

Petrographic description

Moderately deformed dolerite with bent plagioclase laths and secondary actinolite and biotite.

This sample is somewhat similar to the dolerite from Quarry Camp but lacks plagioclase phenocrysts. The visually estimated mineralogy includes 55% plagioclase, 34% clinopyroxene, 7% opaque oxide, and 4% actinolite plus biotite as well as accessory apatite. The plagioclase is mostly less than 1 mm long with pale brown cores and clear rims, but is commonly bent and deformed with fractures filled by actinolite. The opaque oxide is also commonly spidery and apparently deformed and is intergrown with, or may have been replaced by, actinolite and/or biotite. The clinopyroxene, to 0.8 mm in diameter, is granular or subophitic and commonly rimmed or partly replaced by actinolite, but seems to be largely undeformed.

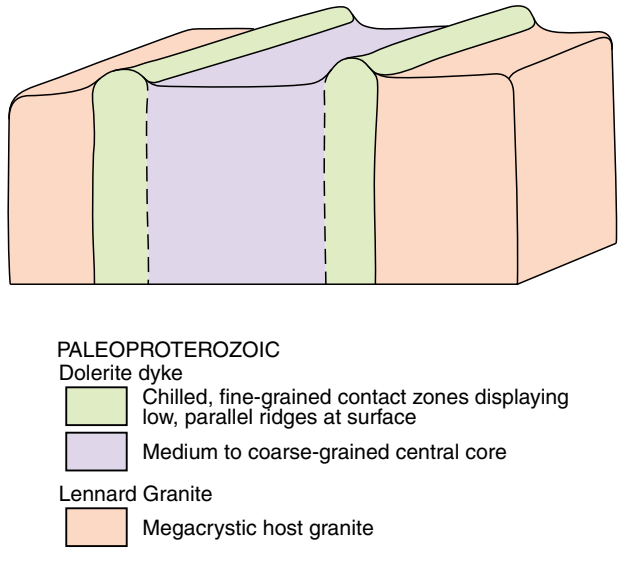
Quarry Camp prospect QC8

Prospect QC8 (Fig. 102) is located on former mining lease M04/62 about 150 km east of Derby, and 10 km south of Quarry Camp. According to Halligan (1986), the prospect consists of a pair of closely spaced, parallel dolerite dykes occupying a low, north-northwesterly trending ridge, 10 m high and 120 m long, with possible northerly extensions of



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Figure 107. **Large *Kimberley Black* core-stones remaining in a disused quarry at Quarry Camp, Wombarella Creek area. Some core-stones exceed 2.0 m³ in size.**



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Figure 108. **Strongly zoned dolerite dyke present at New Quarry, Wombarella Creek. The dyke displays fine-grained outer contact zones with low ridges exposed at surface, and a medium- to coarse-grained central core zone (modified after Halligan, 1986).**



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Figure 109. **Boulders of dark grey, fine-grained dolerite up to 1.0 m³ exposed in the northern dyke of Quarry Camp prospect 7 (QC7) (after Halligan, 1985).**

30 m indicated by float boulders. Dyke widths vary with the easterly dyke being 10 m wide, whereas the westerly one has a width of about 6 m.

The dolerite is dark grey and medium grained, with a very even texture throughout the prospect. Jointing is well developed in the easterly dyke with many blocks with faces measuring 3 m × 2 m. Many high-quality black granite blocks, measuring around 1.5 m^3 have been removed from a test pit at the southeastern end of this dyke.

Quarry Camp prospect QC9

Prospect QC9 (Fig. 102) is located about 4.5 km southwest of Quarry Camp on former mining lease M04/63. Once again, this prospect consists of a pair of northwest-trending, parallel dolerite dykes that intrude the Paleoproterozoic Lennard Granite. The two dykes, each of about 7 m width and spaced about 30 m apart, form part of a prominent ridge about 20 m high. The southwestern dyke is more prominent, being exposed over most of its 250 m length (Fig. 110).

Jointing is well developed in this deposit, although very large slabs are available in the central section of the southwestern dyke where the outcrop indicates that block size may increase markedly with depth (Fig. 111). Also, at the northern end of the northeastern dyke, blocks of 2 m^3 are exposed in surface rubble. The black granite at this prospect is generally of high quality, being very dark grey, fine grained, and of uniform texture, with the possibility of large block sizes being available (Halligan, 1985).

Quarry Camp prospect QC10

Prospect QC10 (Fig. 102) is situated on former mining lease M04/92, about 140 km east of Derby and 1.5 km south of the Quarry Camp road, and was explored at various times during the 1980s by Black Granite Pty Ltd (Parry Corporation) and McDonald Mining Pty Ltd. The prospect covers a steep-sided, northwest-trending dolerite ridge about 35 m high and 200 m long with a maximum thickness of about 50 m. Joint spacing appears to vary from 1 to 2 m, indicating the potential for large core-stones of fine-grained dolerite.

Previous exploration by Black Granite Pty Ltd, involved extraction of large numbers of black granite core-stones from the ridge and placing them in rows for quality assessment. The largest boulders observed by the author exceeded 20 m^3, although the majority of stockpiled stones were no more than 1–2 m^3 (Fig. 112). On site examination of the black granite showed it to be very fine grained with a dark bluish-black coloration with minor spotting in places. Stone quality of large blocks appeared to be reasonably high (Appendix 4.37).

The prospect was estimated by Hardcastle and Richards (1987) to contain a substantial dolerite resource of 73 000 m^3 available above ground level. At that time, it was recommended that the prospect was the best available for development in the Quarry Camp area in terms of available black granite resources, quality and potential block size, access, and overheads.

Petrographic description

Fine-grained subophitic dolerite with minor biotite, hornblende, and actinolite

Fine-grained, black dolerite makes up this sample with a visually estimated mineralogy containing 54% plagioclase, 41% clinopyroxene, 4% opaque oxide, and 1% actinolite together with hornblende and biotite. Rare apatite is disseminated. Plagioclase from 0.2 to 2 mm in diameter has pale brown and clear zones, rarely with clear cores enclosing clinopyroxene and opaque oxide. Subophitic clinopyroxene has clear and brown or purplish zones suggesting some titanaugite. Interstitial partly skeletal opaque oxide is as much as 2 mm in diameter, commonly rimmed by actinolite or biotite. Minor brown hornblende and actinolite also occur adjacent to pyroxene. A single grain in amphibole may be zircon or baddeleyite and is 40 μm long.

Wumburrul prospect (QC5)

Wumburrul prospect (QC5) occupies the 700 m section covering the northwestern ends of two, northwest-trending, en echelon dolerite dykes extending over 1 km from the Quarry Camp quarrying operations to the southeast (Fig. 102). The Wumburrul portion of these dykes comprises a rugged ridge up to 50 m high covered by mining leases M04/119–122 (Fig. 113). These tenements have been registered to Mr C Sim since the mid-1980s. Prior to this time the area was leased to Mr D de Biasi from 1979 to about 1985. During this period, black granite quarrying was carried out by trenching in the central part of the Wumburrul ridge and large, rectangular blocks up to 2–3 m^3 were extracted (Fig. 114).

The larger northern dyke, is approximately 20 m wide and occupies the central spine of the ridge. Along the crest is a prominent alignment of blocky boulders, with many shaped as rectangular prisms up to 1 m^3 (Fig. 114). It is probable that block size may increase with depth. In the Wumburrul area, the southern dyke is much narrower (possibly 6 m wide) and is concealed beneath the lower slope of the ridge. The Wumburrul black granite is fine to medium grained and appears to consist of high-quality material.

Since the early 1990s, several prospectors have shown interest in developing this prospect but to date it appears no firm proposals have been made.

Petrographic description

Porphyritic dolerite with plagioclase phenocrysts, very minor olivine, and sparse late magmatic or secondary minerals (hornblende, actinolite, biotite, and chlorite).

The visually estimated mineralogy for this sample includes 59% plagioclase (perhaps 25% phenocrysts and 34% groundmass plagioclase), 33% clinopyroxene, 7% opaque oxide, less than 1% olivine, and less than 1% brown hornblende, actinolite, and biotite. The plagioclase phenocrysts are as much as 5 mm long and have large unzoned cores and zoned rims. The groundmass plagioclase is mostly less than 1 mm long. Mostly equant clinopyroxene to 2 mm in diameter is subophitic with interstitial opaque oxide to 1.5 mm in diameter commonly

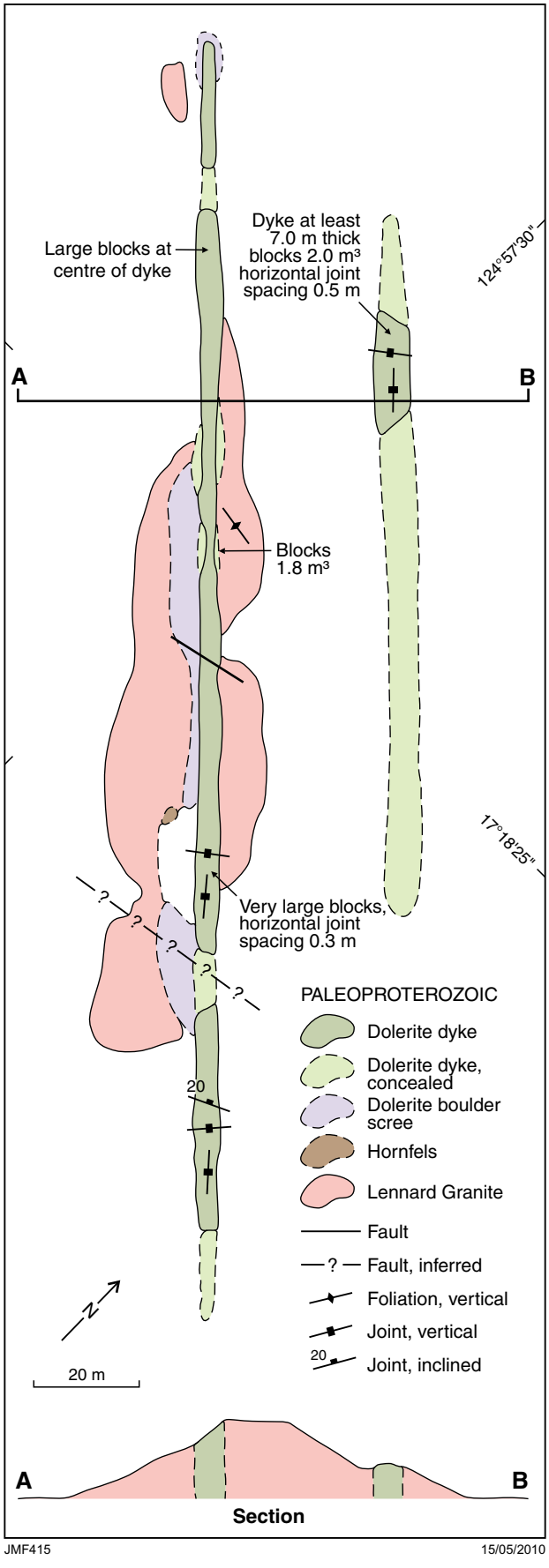
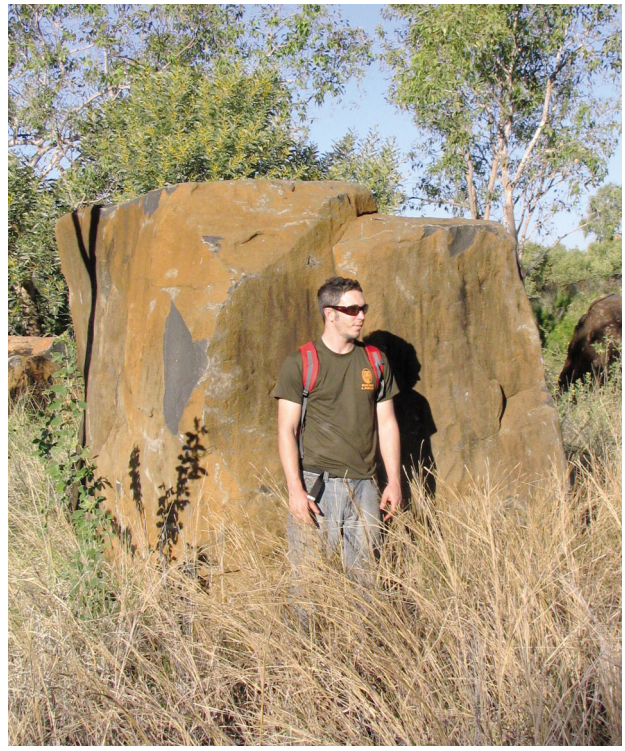


Figure 110. A pair of dolerite dykes forming a prominent northwest-trending ridge at Quarry Camp prospect 9 (QC9). This structure is typical of many dykes present throughout the region (modified after Halligan, 1985).



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Figure 111. **Large blocks of black granite outcropping at the southern end of the southwestern dyke at Quarry Camp prospect 9 (QC9). Block size is seen to increase downwards with blocks 2 m in length × >1 m in height at the base of the section (after Halligan, 1985).**



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Figure 112. **A large, very fine grained black granite corestone extracted from Quarry Camp prospect 10 (QC10).**

Figure 113. **(below) View looking northeast towards a rugged ridge of massive dolerite forming the Wumburrul prospect (QC5).**



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rimmed by actinolite and biotite. Olivine to 1 mm in diameter has been veined by opaque oxide and partly altered to chlorite and magnetite. A narrow crosscutting vein seems to be filled with unusually fibrous prehnite.



Figure 114. **Black granite at Wumburrul prospect: a) a large block of black granite (about 2.0 m^3) extracted during early quarring operations; b) rectangular blocks around 1.0 m^3 in size, forming the spine of the Wumburrul ridge (looking southeast).**

Chapter 4

Marble

Central western region

There are numerous deposits of marble distributed over a wide area of the central western region of the State. Many deposits have been quarried at different times over the last 40 years, and others have considerable potential as dimension stone for future application. Of these, 11 deposits are located in the western end of the Paleoproterozoic Ashburton Basin, and the western part of the overlying Paleoproterozoic–Mesoproterozoic Edmund Basin contains about 20 deposits (Fig. 115). Outside of these basins, the only other high-quality marble dimension stone deposit identified to date is located to the south at Weedarrah within the Paleoproterozoic Gascoyne Province.

Apart from the *Cheela Marble* in the Ashburton Basin, almost all other marbles examined are designated as dolomitic marbles, with chemical contents ranging from 24 to 41% CaO and 11 to 22% MgO (Table 1). The marbles also display a wide range of textures and colours with textures ranging from fine to coarsely crystalline, to banded, veined, stylolitic, stromatolitic, and brecciated.

There is considerable variation in marble colours ranging from pure white, through cream, yellow, orange, pink to deep red and brown, as well as green, mauve, grey, and black. Apart from overall chemical determination, analytical results were also examined to determine whether variations in colour could be attributed to anomalies in chemical compositions of different coloured marbles. Of the twenty marbles submitted for whole rock and trace element analysis, almost no anomalous results are apparent except for slightly elevated levels for Fe_2O_3 of 2.58% recorded for the *Wyloo Marble* (Table 1). Trace element values, particularly for elements such as chromium, nickel, copper, lithium, and vanadium, are generally quite low. Apart from a few elevated barium values probably unrelated to marble colour, it appears that trace element values bear little relationship to colour in these marbles (Table 2).

Subsequently, some explanation for the coloration of green marbles became evident from thin-section descriptions. These descriptions revealed that in most cases metamorphic recrystallization had resulted in the formation of green serpentinite minerals present in many of these rocks.

Thin-section descriptions also revealed that the migration of iron-rich minerals such as hematite and limonite may have been at least partially responsible for the coloration of brown, red, pink, mauve, and yellow marbles. The coloration of other marbles such as grey, and black remains uncertain but Purvis (2009c) suggested that the dark coloration may be attributable to the presence of disseminated, cryptocrystalline carbonaceous matter.

The fact that Western Australian marbles are almost entirely of dolomitic composition may prove to be an advantage during a future resurgence in demand. High-quality dolomitic marbles used in dimension stone applications generally have a number of advantages over traditional calcitic marbles used in similar applications. Firstly, dolomitic marbles are mostly harder than calcitic varieties, allowing dolomitic marble blocks to take a much finer cut finish, and this property also makes them less prone to damage. The increased hardness of dolomitic marble may also enable artisans to achieve very finely finished carved surfaces. Secondly, dolomitic marbles are more resistant to acid attack than calcitic varieties, and the dolomitic stone can be used in high-risk areas; for example, in industrial areas where exposure to acid rain may occur.

Ashburton Basin

In the Ashburton Basin, four marble deposits are spread over a distance exceeding 200 km from White Gate Well in the Pannawonica region, southeast through Wyloo and Cheela to the Success deposit 60 km west-northwest of Paraburdoo (Fig. 115). In addition, there are seven other named deposits in the area between Wyloo and Cheela whose precise locations are unknown. All Ashburton Basin marbles are hosted by the Paleoproterozoic Duck Creek Dolomite of the Wyloo Group, dated at about 1830 Ma.

Pannawonica

White Gate Well

The White Gate Well marble prospect is located in an area of Duck Creek Dolomite adjacent to White Gate Well about 25 km west-southwest of Pannawonica (Fig. 115). Discovered by a prospector in the early 1990s, a specimen of good quality, red and cream marble was sourced from a large outcrop at the site.

Wyloo–Paraburdoo

Cheela

The *Cheela Marble* deposit is located on a low, west-northwesterly trending ridge on Cheela Plains Station

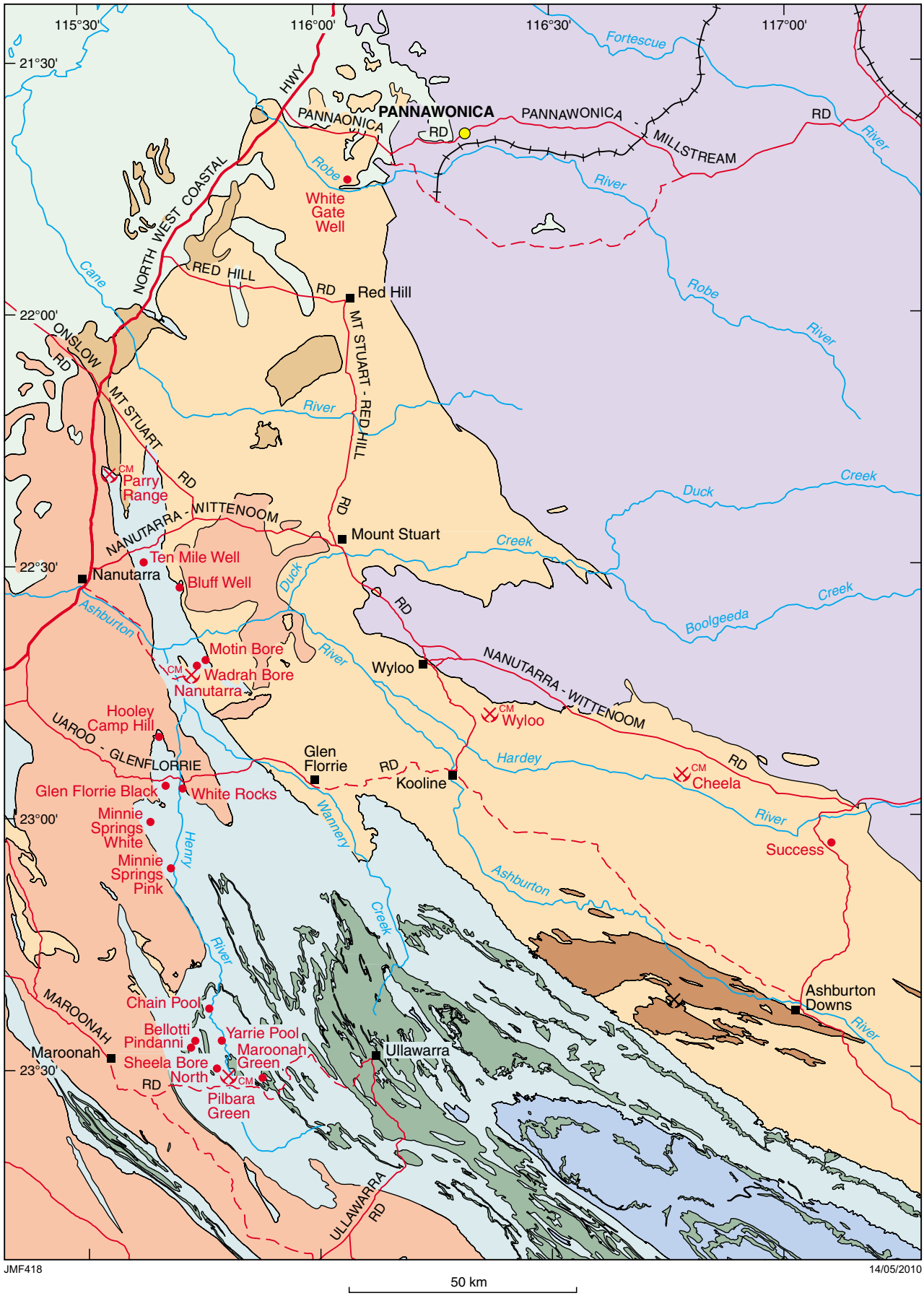
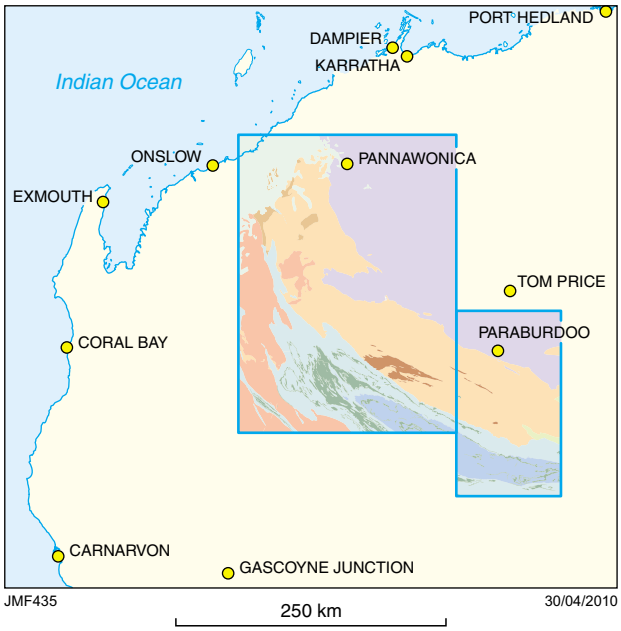
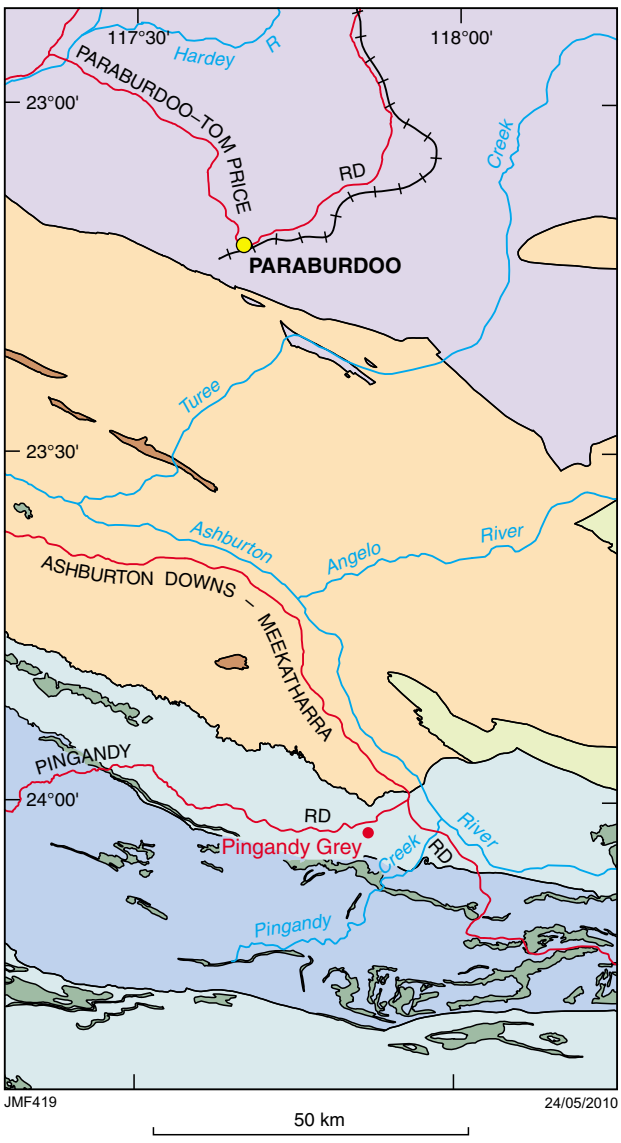


Figure 115. Generalized geological map showing the distribution of marble quarries and prospects within the Edmund and Ashburton Basins.





MESOZOIC
- Northern and Southern Carnarvon Basins

PALEOPROTEROZOIC–MESOPROTEROZOIC
- Dolerite and gabbro sills
- Collier Basin
- Edmund Basin (dolomitic marble located within the Irregully Formation)

PALEOPROTEROZOIC
- Bresnahan Basin
- Mount Minnie Basin
- Blair Basin
- Gascoyne Province
- Ashburton Basin (dolomitic marble located within the Duck Creek Dolomite)

ARCHEAN–PALEOPROTEROZOIC
- Pilbara Craton; Turee Creek, Hamersley and Fortescue Basins, and Pilbara granite-greenstone terrane

- CM Quarry; marble, care and maintenance
- Prospect; marble
- Townsite
- Homestead
- Highway
- Road
- Track
- Railway
- Watercourse

Table 1.Major element analyses of marble from quarries and prospects in the Ashburton and Edmund Basins and Gascoyne Complex

Quarry/prospect	*Colour*	*GSWA sample no.*	*SiO_2*	*Al_2O_3*	*CaO*	*MgO*	*Fe_2O_3*	*K_2O*	*Na_2O*	*P_2O_5*	*SO_3*	*TiO_2*	*MnO*	*LOI**	*C*	*Cl*	*F*
															Percentage		
Ashburton Basin																	
Cheela	light grey	189811	8.48	1.89	46.60	1.82	1.02	0.70	-0.01	0.039	-0.01	0.09	0.04	39.10	10.60	-0.01	0.03
Wyloo	dark grey, beige, pink	189813	9.66	1.86	31.60	13.10	2.58	0.66	-0.01	0.031	-0.01	0.09	0.16	40.00	10.90	0.02	0.02
Edmund Basin																	
Glen Florrie	black	189844	2.70	0.15	29.90	21.00	0.34	0.09	-0.01	-0.001	-0.01	-0.01	0.02	45.40	12.60	-0.01	-0.01
Hooley camp Hill	pale mauve	189849	3.94	0.79	29.60	20.40	0.47	0.34	-0.01	0.006	-0.01	0.02	0.04	44.00	12.30	0.01	0.02
White Rocks	cream	189807	2.77	0.41	30.00	20.60	0.31	0.25	-0.01	0.007	-0.01	0.02	0.03	45.20	12.40	-0.01	0.02
Pilbara Green	green	189803	13.60	1.20	29.80	19.20	1.50	0.01	-0.01	0.009	0.01	0.05	0.14	34.30	5.03	0.01	0.05
Bellotti	pale green	189851	21.60	0.30	27.80	20.80	0.51	0.01	-0.01	0.005	0.30	0.01	0.05	27.80	5.70	0.02	0.24
Pindanni	green	189854	17.90	1.67	30.70	18.10	1.09	0.02	-0.01	0.021	0.04	0.08	0.05	29.90	6.50	0.01	0.20
Chain Pool	medium-grey	189853	22.40	1.31	24.30	15.10	0.85	0.89	-0.01	0.028	-0.01	0.06	0.03	34.70	9.56	0.01	0.02
Maroonah Green (1)	green	189804	10.80	1.28	40.50	10.90	0.79	-0.01	-0.01	0.011	-0.01	0.07	0.05	35.40	8.91	0.02	0.03
Maroonah Green (2)	green	189852	13.20	1.29	37.60	13.20	0.87	-0.01	-0.01	0.014	-0.01	0.07	0.05	33.50	8.10	0.01	0.04
Yarrie Pool	grey-green	189850	20.20	2.40	26.90	20.60	1.35	0.04	-0.01	0.016	0.01	0.12	0.05	28.00	5.71	0.01	0.05
Motin Bore	cream–pale pink	189848a	1.92	0.09	30.60	21.10	0.20	0.06	-0.01	0.005	-0.01	-0.01	0.03	45.60	12.70	0.02	0.01
Motin Bore	red	189848b	7.41	1.55	27.70	19.30	0.81	0.61	-0.01	0.014	-0.01	0.06	0.05	42.10	11.60	0.02	0.02
Nanutarra Rosso Venezia	red	189815	7.90	1.84	27.20	18.90	1.01	0.68	0.01	0.012	-0.01	0.08	0.11	41.90	11.50	0.01	0.03
Nanutarra Austral Dream	cream–pale brown	189814a	7.92	1.32	29.00	17.90	0.75	0.47	-0.01	0.013	0.10	0.06	0.07	42.30	11.60	0.02	0.03
Nanutarra Austral Pearl	off-white	189814b	1.06	0.31	30.40	21.00	0.38	0.10	-0.01	0.005	-0.01	0.01	0.07	46.30	12.90	0.01	0.02
Parry Range	white–cream	189817	2.01	0.55	29.80	20.80	0.51	0.30	-0.01	0.009	-0.01	0.02	0.08	45.60	12.60	0.02	0.01
Ten Mile Well	pale yellow	189816a	4.14	0.58	29.00	20.50	0.40	0.40	-0.01	0.009	-0.01	0.02	0.02	44.60	12.40	0.01	0.02
Ten Mile Well	pink	189816b	4.94	0.81	28.50	20.20	0.55	0.35	-0.01	0.015	-0.01	0.03	0.01	44.30	12.20	0.01	0.02
Gascoyne Complex																	
Weedarrah	white	189842a	0.20	0.07	31.20	21.80	0.14	0.01	-0.01	0.018	-0.01	-0.01	0.01	46.30	13.00	0.02	-0.01
Detection Limits			*0.01*	*0.0*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.001*	*0.01*	*0.01*	*0.01*	*0*	*0.01*	*0.01*	*0.01*

NOTE: * LOI = loss on ignition at 1000°C

about 60 km east-southeast of Wyloo Homestead (Fig. 115). There are two small quarries at this site, each about 3 m deep, from which large diamond wire blocks were sawn. The quarries were owned and operated by Marbloc (WA) Pty Ltd around 1987, and from 1998 by Whitecrest Enterprises. It is believed that most mining operations were carried out by the former owners in the late 1980s.

Cheela Marble, also known as *Capricorn Grey*, is a foliated, very fine grained calcitic marble that contains a variety of structures including small-scale folds, filled fractures, white calcite veins, and stylolites (Appendix 4.38). The structure appears to dip about 50º to the northeast. The marble exhibits considerable colour variation ranging from mainly light to dark grey to cream, and also pink, and grey-green varieties. The only known application for *Cheela Marble* is as polished floor tiles in the entrance foyer of ANZAC House in Saint Georges Terrace in Perth (Fig. 116).

Petrographic description

Foliated, very fine grained, calcitic marble, derived from limestone, with a coarse-grained carbonate vein with minor quartz and a narrow carbonate–quartz vein.

This sample is mostly grey marble or carbonate rock with a pale vein. The host rock is mostly fine-grained carbonate to 0.2 mm in diameter with interstitial microcrystalline carbonate and may be slightly clouded, but any impurities are too fine grained for optical identification. This material is strongly foliated parallel to the visible vein and there may be some phyllosilicate, but this is again too fine grained for positive optical identification. The vein is from 4 to 6 mm wide with two offshoots, one at a low angle to the vein and one at a high angle to the vein. Carbonate grains to 7 mm long occur in the vein with interstitial and crosscutting lenses of quartz and a narrow, later carbonate–quartz vein subparallel to the main vein. Staining with acidified alizarin red and potassium ferricyanide indicates calcite as the only carbonate present.

Wyloo

Located adjacent to the Wyloo–Kooline road, about 17 km southeast of Wyloo Homestead, the brecciated, dolomitic *Wyloo Marble* quarry was operated in 1974–75 by Kinetic Mining Pty Ltd (Fig. 115). During this period the company produced saleable marble blocks by close-spaced drilling and diamond wire sawing. More recently, around 1986–87, the quarry was owned by Marbloc (WA) Pty Ltd, operators of the *Cheela Marble* quarry. There appears to be no record of any new quarrying at Wyloo at that time, although *Wyloo Marble* resources were estimated to be in excess of 179 100 m^3 to a depth of 18.3 m with an average recovery rate of 59% and a saleable block volume of about 98 500 m^3. Also, it was stated that Marbloc intended to export 49 marble blocks totalling 177 m^3 to Italy (De Angelis, 1987). Today, it is uncertain whether this export operation actually took place as many original quarry blocks still remain on site (Fig. 117).

One of the few known applications for *Wyloo Marble* is in the floor of the foyer of the Police Headquarters building in Adelaide Terrace, Perth.

The *Wyloo Marble* comprises visually attractive, dark grey-green, intensely brecciated, dolomitic marble originally interbedded with a fine-grained red-brown material with a chert-like appearance (possibly fine-grained quartz), that has been intensely brecciated into fragments and irregular blocks ranging from less than 1 cm to large clasts up to 1.0 m in diameter. Subsequently, this material has been recemented by veins of coarse-grained, pink, sparry carbonate, probably of dolomitic composition (Appendix 4.39).

De Angelis (1987) suggested that the brecciation of the *Wyloo Marble* may be attributed to diagenetic solution features, developed in the original dolomite, that were possibly affected by later tectonic events, resulting in brecciation followed by recementation by veins of pink carbonate.

Petrographic description

The rock comprises areas of breccia with cream carbonate and quartz-rich fragments in a dark matrix of carbonate with hematite, chlorite, quartz, and possible sericite or talc, cut by zoned veins of a pink and cream mineral, probably dolomite.

This sample has a banded vein of cream and pink marble invading breccia with cream, mostly carbonate-rich, fragments in a grey matrix. The hand specimen has a small area of pink carbonate vein material and contains dark grey material with poorly defined but mostly angular cream fragments. Fragments seem to be more abundant in the thin section than are clearly visible in the hand specimen and are mostly platy or rectangular and as much as 10–15 mm long. The angular fragments are composed largely of foliated fine-grained carbonate. A large, rounded fragment about 12 mm in diameter is composed of a micromosaic of fine-grained quartz, cut by abundant carbonate veins, locally containing probable hematite as well as quartz and sericite or talc. The dark matrix also seems to be composed of carbonate clouded by disseminated hematite and rare pale magnesian chlorite, possibly clinochlore. Small lenses, to 1.5 mm long, composed of schistose clinochlore and/or possible sericite or talc are also present. Some areas contain very minor quartz, locally composite with colourless phyllosilicate and/or hematite.

The pink carbonate is marginal to a possibly boudinaged vein 10–40 mm wide not well represented in thin-section but composed of coarse-grained sparry carbonate, probably dolomite. This postdates the formation of the breccia.

Success

This marble prospect is located on Cheela Plains Station, about 60 km west-northwest of Paraburdoo, and 3 km southwest of Success Bore (Fig. 115). Discovered by a prospector a number of years ago, this site is situated in a large outcrop of Duck Creek Dolomite, adjacent to the Ashburton Downs road, and contains high-quality, multicoloured marble.

Other marble deposits in the Cheela–Wyloo area

Other potential marble deposits in the Duck Creek Dolomite located between Wyloo and Cheela are

Table 2. Trace element analyses of marble from quarries and prospects in the Ashburton and Edmund Basins and Gascoyne Complex

Quarry/prospect	*Colour*	*GSWA sample no.*	*As*	*Ba*	*Co*	*Cr*	*Cu*	*Li*	*Mo*	*Ni*	*Pb*	*Sn*	*V*	*Zn*	*Zr*
								Parts per million							
Ashburton Basin															
Cheela	light grey	189811	5	64	-5	-10	8	4	-0.5	10	5	-1	25	22	20
Wyloo	dark grey, beige, pink	189813	3	79	5	10	4	3	-0.5	8	3	-1	30	34	19
Edmund Basin															
Glen Florrie	black	189844	-1	265	-5	-10	4	1	-0.5	4	3	-1	10	10	1
Hooley camp Hill	pale mauve	189849	2	29	-5	-10	6	4.5	-0.5	6	6	-1	15	16	6
White Rocks	cream	189807	2	17	-5	-10	4	3	-0.5	4	7	-1	5	28	8
Pilbara Green	green	189803	4	85	-5	-10	8	1	-0.5	10	-1	-1	20	42	16
Bellotti	pale green	189851	4	4 460	-5	-10	2	0.5	-0.5	6	-1	-1	10	36	28
Pindanni	green	189854	6	52	-5	10	8	-0.5	-0.5	6	1	-1	20	22	21
Chain Pool	medium-grey	189853	2	67	-5	-10	10	5.5	-0.5	4	3	-1	15	12	39
Maroonah Green (1)	green	189804	2	7	-5	-10	24	-0.5	-0.5	4	6	-1	20	14	39
Maroonah Green (2)	green	189852	5	23	-5	-10	16	-0.5	-0.5	6	6	-1	20	24	33
Yarrie Pool	grey-green	189850	8	10	5	10	4	0.5	-0.5	10	2	-1	25	28	82
Motin Bore	cream–pale pink	189848a	1	10	5	-10	4	1.5	-0.5	4	2	-1	10	6	-1
Motin Bore	red	189848b	1	37	-5	-10	6	9	-0.5	4	6	-1	10	14	11
Nanutarra Rosso Venezia	red	189815	2	45	5	-10	14	9	-0.5	8	36	-1	20	44	18
Nanutarra Austral Dream	cream–pale brown	189814a	2	42	-5	-10	6	8.5	-0.5	8	6	-1	15	14	16
Nanutarra Austral Pearl	off-white	189814b	2	10	5	-10	6	6	-0.5	4	8	-1	10	10	2
Parry Range	white–cream	189817	-1	15	-5	-10	8	2	-0.5	4	3	-1	15	16	5
Ten Mile Well	pale yellow	189816a	-1	52	-5	-10	6	4	-0.5	4	3	-1	15	18	7
Ten Mile Well	pink	189816b	2	42	5	-10	6	12	-0.5	8	2	-1	15	12	7
Gascoyne Complex															
Weedarrah	white	189842a	2	5	5	-10	6	1.5	-0.5	2	2	-1	10	16	5
Detection Limits			*1*	*1*	*5*	*10*	*2*	*0.5*	*0.5*	*2*	*1*	*1*	*5*	*2*	*1*

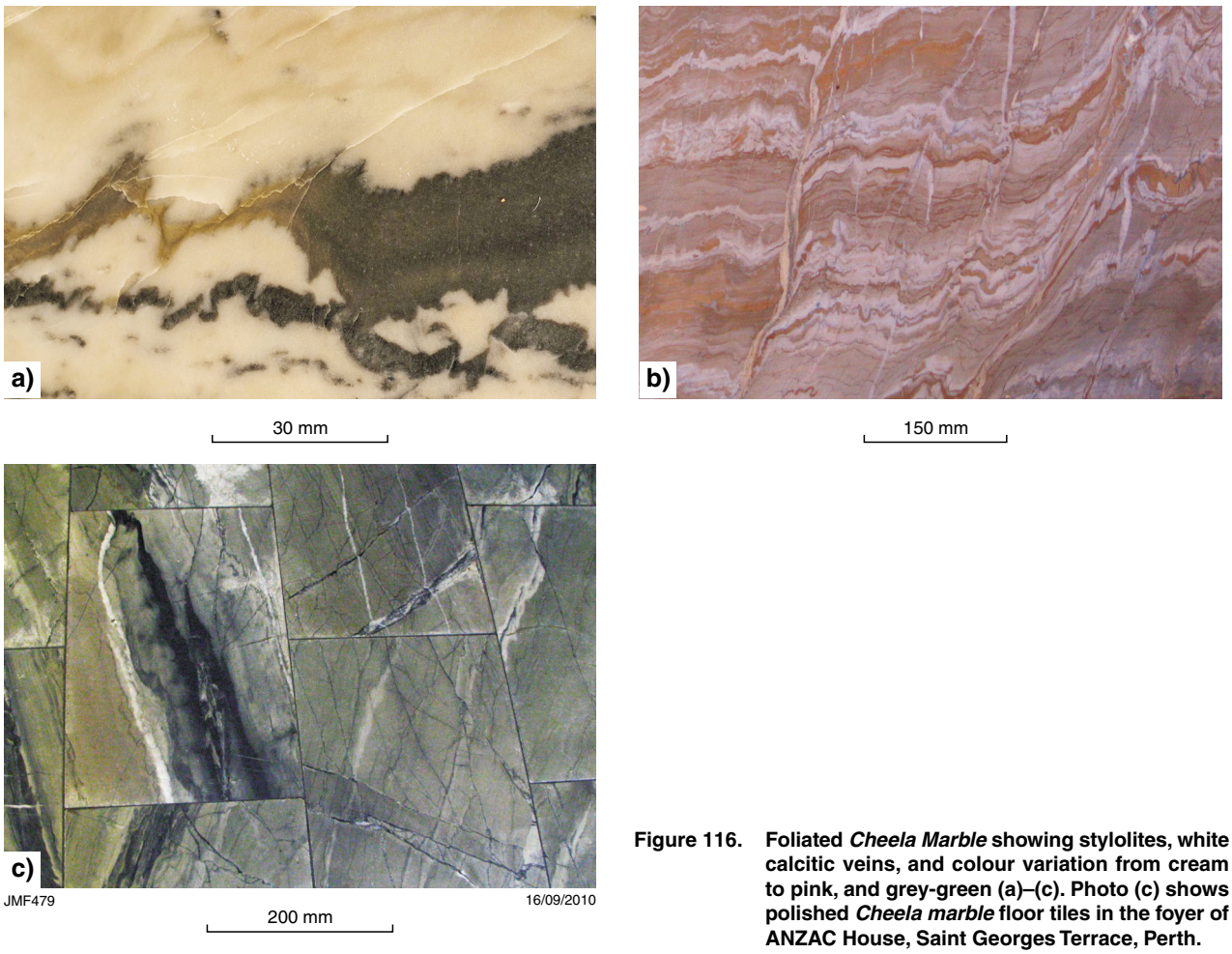


Figure 116. Foliated *Cheela Marble* showing stylolites, white calcitic veins, and colour variation from cream to pink, and grey-green (a)–(c). Photo (c) shows polished *Cheela marble* floor tiles in the foyer of ANZAC House, Saint Georges Terrace, Perth.

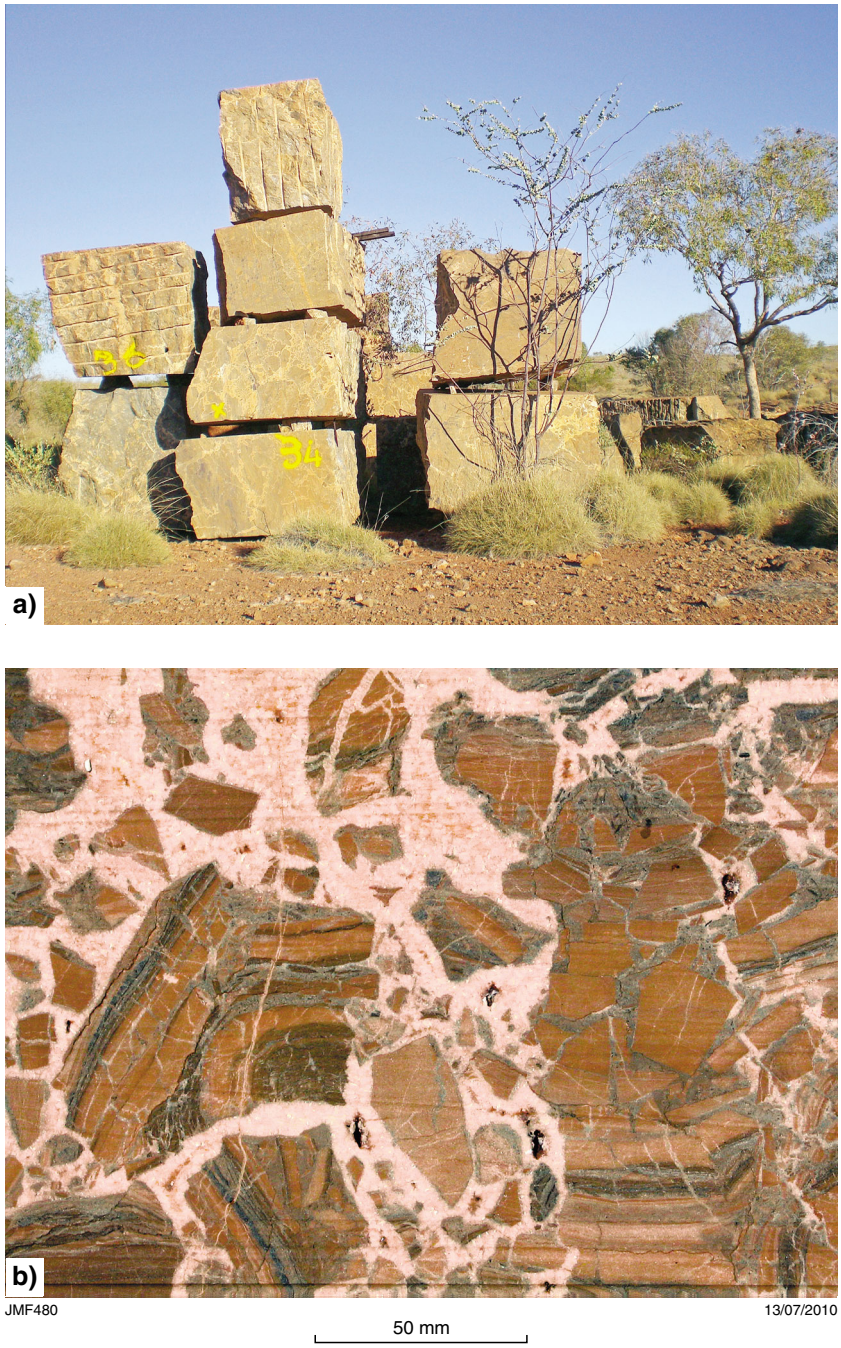


Figure 117. ***Wyloo Marble*** **quarry site: a) stockpile of marble blocks (mostly <1 m³) remaining on site since the last quarrying operation in 1974–75; b) marble in the wall of the Wyloo quarry. The stone comprises intensely brecciated, grey-green, dolomitic marble, interbedded with red-brown, chert-like material later recemented by pink veins of coarse-grained carbonate.**

mentioned in De Angelis (1987). Of particular note are two deposits in the Cheela area on former exploration licence E08/89. *Swan Black* is a black marble taking a high polish with a stated resource of 6 Mm^3. *Gala Mauve* is a pinkish-grey to mauve marble that may have sufficient resources for a viable quarrying operation.

Other named varieties in the Cheela area on E08/89 include:
- *Cheela Grey* (a massive, dark grey marble with off-white veining)
- *Beasley Pearl* (similar to Cheela Grey but with less-prominent veining)
- *Wonangara Rose* (a 40 m-thick unit, presumably rose pink in colour).

Marble varieties in the Wyloo area on former exploration licence E08/69 include:
- *Wyloo Smoky Pink* (an attractive variety possibly 40 m thick, containing pink and white veins and minor buff-coloured stylolites)
- *Kooline Opal* (an unveined variety associated with Wyloo Smoky Pink containing deep green-grey stylolites).

Unfortunately, no locational or other information is provided about these deposits. At some time in the future, new exploration will be required to relocate these deposits.

Edmund Basin

Of the 20 dolomitic marble deposits located in the western end of the Paleoproterozoic–Mesoproterozoic Edmund Basin, almost all are located in three discrete areas; western Glen Florrie Station (5), Maroonah Station (7), and Nanutarra (7), while the *Pingandy Grey* marble is located about 90 km south of Paraburdoo (Fig. 115). All Edmund Basin marbles are hosted by the Paleoproterozoic–Mesoproterozoic Irregully Formation, described as a dolostone, in part stromatolitic, together with dolomitic siltstone, quartz sandstone, and conglomerate (Thorne et al., 2006).

Glen Florrie

Glen Florrie black

Glen Florrie black marble is known only from a single outcrop beside the Glen Florrie Station road about 45 km south-southeast of Nanutarra (Fig. 115). This site was located in 2006 by prospector Mr B Kayes who collected a grab sample. The marble is very dark grey to black, extremely fine grained, and contains lighter, fine veins, possibly quartz, and stylolites (Appendix.4.40). Considering the rarity of black marble in this region, this site is probably worthy of further investigation.

Petrographic description

Dolomitic carbonate with irregular, partly subparallel, possible intraclasts of microcrystalline carbonate and interstitial coarser grained carbonate and stylolite-like lamellae with opaque material. Lenses of quartz occur, partly oblique to weak layering, and there is a quartz–carbonate vein.

This dark grey rock is composed largely of dolomitic carbonate. Irregular masses of microcrystalline carbonate to 40 mm long may represent fragments (e.g. intraclasts) and are separated by areas of coarser carbonate to 0.2 mm in diameter. Many of the smaller masses are subparallel and may represent bedding, but other masses are elongate at a high angle to the smaller masses. There are also narrow stylolite-like lamellae with unidentified microcrystalline opaque material and rare patches of microsparry quartz with opaque material or brownish possible limonite. The layering seems to be weakly contorted adjacent to crosscutting lenses at about 60° to the overall layering, and contain quartz and carbonate. There is also a planar quartz–carbonate vein subparallel to the overall layering. The origin of the colour in this sample is uncertain but cryptocrystalline carbonaceous matter may be disseminated.

Hooley Camp Hill

Hooley Camp Hill prospect is located about 35 km south-southeast of Nanutarra, and 12 km to the north-northwest of the *White Rocks* marble deposit (Fig. 115). The deposit is situated in relatively inaccessible hilly country to the west of the Henry River with poor track access. The area covered by exploration licence E08/1307 was explored between 2003 and 2007 by a consortium led by Deacon Nominees Pty Ltd.

The exploration licence contains large outcrops of slightly karstified, mainly white marble ranging to 60 m above the level of the surrounding plain. The extensive surface outcrop of massive marble boulders, 1.5 – 2.5 m in length, indicates that the area may contain a substantial resource of marble of dimension stone grade. The area of high-grade white marble also contains discrete areas of pale pink, pink–mauve, red, and minor green marble. A thin-sectioned sample of mauve-coloured marble (collected by the prospectors) was designated as a hematite-stained dolomitic carbonate containing minor quartz and mica as well as carbonate lenses, veins, and stylolites (Appendix 4.41).

In an effort to further the future development of this marble resource, Deacon Nominees undertook testing, cutting and polishing of selected marble specimens, followed by a market appraisal program. To date, no results have been announced.

Petrographic description

Mostly fine-grained, hematite-stained dolomitic carbonate with minor quartz and mica, with lenses of sparry carbonate(–quartz).

Much of this sample is fine-grained, irregularly hematite-stained dolomitic carbonate with minor irregularly disseminated quartz, partly as polycrystalline lenses and only rarely associated with very fine grained detrital muscovite, suggesting some authigenic quartz. Some areas have micritic pellets and interstitial microsparry carbonate but other areas are more uniformly micritic with hematite

partly in stylolites. Lenses of sparry and fibrous carbonate to 8 mm long locally contain minor quartz. An irregular vein from 5 to 7 mm wide contains abundant carbonate to 2 mm in diameter that has been cut by later lenticular quartz veinlets.

Minnie Springs

Minnie Springs is located in remote country adjacent to the Henry River, approximately 60 km south-southeast of Nanutarra. Currently, access to this area is difficult with poor or non-existent tracks and for this reason was not visited by the author. The area around Minnie Springs was explored between 1998 and 1994 and extensive areas of pink and cream, and also white marble were identified (Appendix 4.42).

Minnie Springs Pink

This pink marble prospect is located at the junction of the Henry and Telfer Rivers about 65 km southeast of Nanutarra (Fig. 115). *Minnie Springs Pink* marble was located within mining lease M08/56 and was first explored by Australian Marble and Granite NL in the late 1980s. The company identified significant thicknesses of pink and cream marbles in the area.

In 1993, the area was again investigated for pink marble by Moonstone Resources NL in exploration license E08/650. These investigations revealed a massive, pink marble unit between a highly weathered, laminated basal dolomite, and an overlying, horizontally bedded, buff to grey dolomite. The pink marble outcrops as massive beds between 2 and 5 m in thickness in cliff faces over 8 m high. Massive pink marble is readily identified by the presence of purple stylolites in fresh rock. Total thickness of massive pink marble was estimated in excess of 10 m over the prospect of an area measuring approximately 500 m × 300 m. Studies of samples collected from the site indicate that the pink marble is very fine grained to cryptocrystalline and exhibits a subtle streaky to mottled texture (Brown, 1994).

Later that year, a large block of pink marble was bulk sampled by the company and shipped to Perth for cutting and polishing. Market research was undertaken and polished samples were exhibited overseas with some degree of interest being shown. It was concluded that there was an oversupply of this type of marble on world stone markets at that time and it was decided not to continue with this project.

Minnie Springs White

The *Minnie Springs White* marble prospect is located in an extensive area of marble about 11 km northwest of the *Minnie Springs Pink* deposit on the Henry River (Fig. 115). Access to this area is difficult over hilly terrain of marble ridges with no access tracks. The *Minnie Springs White* exploration area was located within mining lease M08/131 and was explored in the early 1990s by Australian Marble and Granite NL. It is known that the company identified large areas of white marble in the area but no other details are available.

White Rocks

The *White Rocks* marble deposit is located at Ballard Well on the Glen Florrie Station road, about 55 km south-southeast of Nanutarra and close to the Henry River (Fig. 115). This area was explored during 2004–05 by Mr B Kayes on exploration licence E08/1486.

This deposit extends over many hectares and consists of a series of close-spaced, low hills with large, grooved boulders of creamy white marble outcropping at the surface. Surface jointing is not readily visible but the large surface boulders indicate the rock could be massive at depth (Fig. 118). The rock is composed of mainly dolomitic marble with thin lenses and veins of carbonate and quartz, and uncommon stylolites (Appendix 4.43). Further exploration in the form of a diamond drilling program would be required to assess joint patterns and make a preliminary estimate of available resources.

The *White Rocks* marble may be the same stone as the *'Glen Florrie Ivory'* named by De Angelis (1987) as a marble in the Glen Florrie area. The name of the stone and the description of the deposit as being 'present in outcrops raising [sic] some 20–30 m from the surrounding flat plains….' closely resembles the *White Rocks'* marble colour and outcrop appearance. De Angelis (1987) also provided a preliminary resource estimate of 24 Mm^3 (requiring drill testing for verification), and states that the cut and polished material is of good quality 'and would be well suited for use in Australia and South East Asia'. Since De Angelis provides no precise locational details for *Glen Florrie Ivory* it is not possible to verify whether these two marble localities are one and the same.

Petrographic description

Mostly microcrystalline dolomitic carbonate with lenses and veins of carbonate(–quartz) and rare colourless phyllosilicate, both disseminated, and in stylolites with leucoxene.

Clear microcrystalline dolomitic carbonate dominates this sample, with grains mostly 10–50 μm in diameter and rarely as much as 0.1 mm. Irregular lenses of coarser carbonate to 8 mm long and 2–4 mm wide contain grains to 0.5 mm in diameter with a granoblastic or granoblastic-interlobate texture. Rare quartz grains occur in the fine-grained carbonate and in some of the irregular lenses and also in subparallel carbonate veins to 0.5 mm wide, with quartz to 0.3 mm in diameter. Rare stylolites are subparallel to the veins, but are partly crosscutting and contain leucoxene and colourless phyllosilicate (muscovite or phlogopite) with rare phyllosilicate also disseminated.

Maroonah

Pilbara Green

The *Pilbara Green* marble quarrying operation is located 25 km east-southeast of Maroonah Homestead and adjacent to Sheela Bore, 1.3 km to the southeast (Fig. 115). At this site, covered by mining leases M08/133 and 175, are three green marble quarries; east, west, and a central test quarry. The large east quarry has been the main area for the

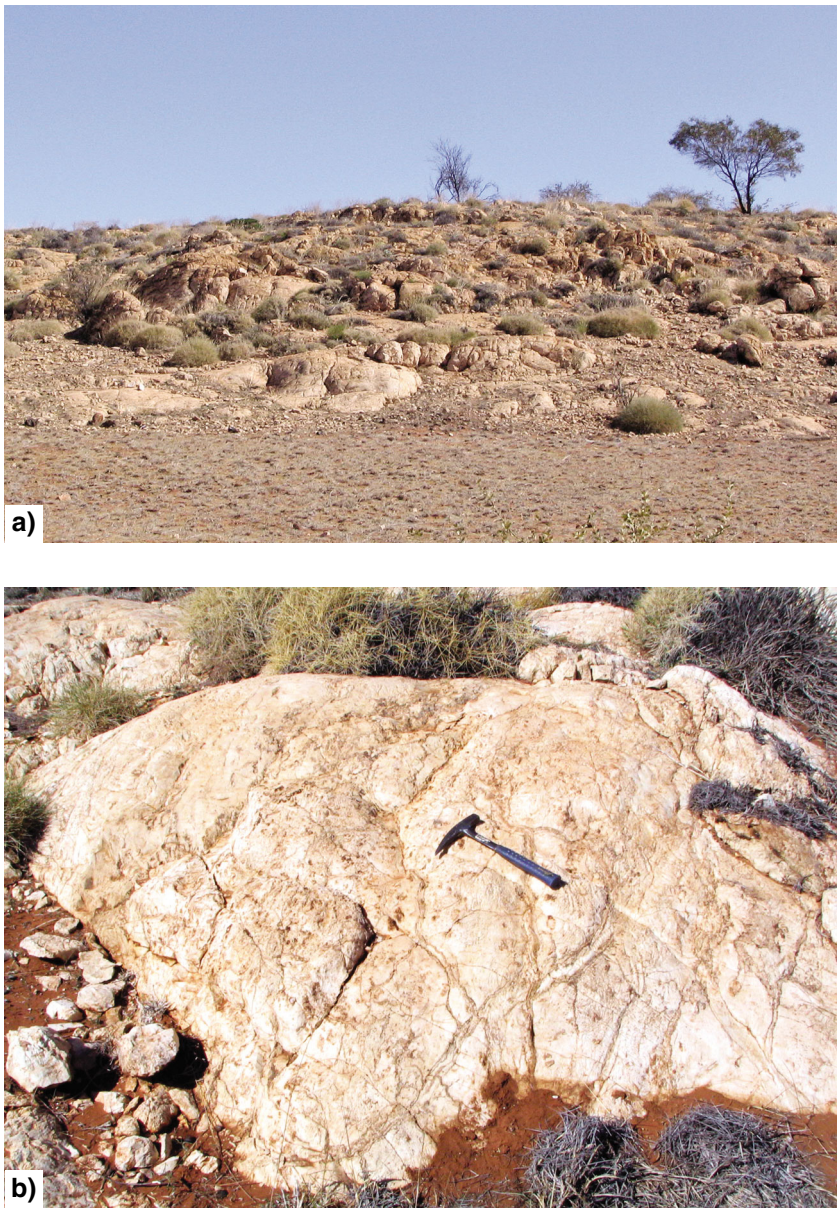


Figure 118. White Rocks marble prospect looking west, Glen Florrie area: a) Low hill composed of large boulders of white to cream marble; b) detail of cream marble boulder at surface, approximately 2 m in width.

extraction of dimension stone. Quarrying has been carried out, producing relatively small tonnages on an intermittent basis, since about 2001. The first operators were Dodsley Pty Ltd, who marketed the stone as *'Desert Green'* from 2001 to 2005. The operation was then taken over by Pilbara Stone Pty Ltd who renamed the green marble *'Pilbara Green'*. In the last few years the quarries have been in care and maintenance pending further exploration to determine optimum quarrying directions as described below.

Observations in the main northwest wall of the east quarry show the upper horizon of the green marble located beneath 7 m of overburden, composed of an upper layer described as basaltic tuff, overlying a lower composite layer of bedded marble and tuff. In this area, the dip of bedding ranges from 10º to 15º in a northwesterly direction into the quarry wall and adjoining hill. Core recovered from drillhole SBM 1, approximately 16 m northwest of the quarry face, indicates an increase in overburden thickness at this point to around 10 m overlying about 11 m of high-quality green marble (Charsley, 2003). These observations indicate that, with the current orientation of the east quarry, overburden thickness will continue to increase as mining continues and it will become necessary either to reorientate the quarry or shift operations to a new site.

Pilbara Green dolomitic marble ranges from pale to dark green and greenish grey in colour. It is extremely fine grained and is characterized by pale stromatolitic banding as well as prominent, highly irregular swirling bands and patches of deep green (possibly chlorite and serpentine), white calcite, and dark grey bands of mainly opaque oxides (Fig. 119; Appendix 4.44). *Pilbara Green* takes an extremely high polish, and will also readily accept both honed and sandblasted surface finishes.

In recent years, all *Pilbara Green* quarry blocks were finely cut by diamond wire sawing and several years ago a considerable quantity of blocks remained in a stockpile on site. It appears that over approximately six years of operation, blocks transported off site were largely exported to M+Q Italia (an Italian-based international dimension stone trading house) where slabs intended for interior wall and floor applications were distributed, mainly into Europe and the Russian Federation.

Petrographic description

Heterogeneous serpentine-bearing, dolomitic carbonate rock (dolomite–calcite–serpentine) with segmented bands rich in opaque oxide as well as carbonate (mostly calcite), chlorite, and rare phlogopite.

This pale green marble has parallel joints with slickensides defining lineations in different orientations and a folded and fragmented dark band 1–2 mm wide. The thin section has large areas of clouded microcrystalline to very fine grained carbonate passing into areas with minor to abundant decussate, fine-grained, green serpentine, possibly antigorite. There are also small patches of very fine grained microsparry carbonate and small aggregates with isotropic chlorite as well as clouded microcrystalline carbonate. Larger areas of microcrystalline and apparently foliated clear carbonate occur close to the disrupted dark microband. The dark microband has abundant microcrystalline possible opaque oxide, carbonate, and decussate possible clinochlore accompanied by rare phlogopite in one segment. The segments are possibly boudins to 10 mm or more in length and locally suggest more than one microband.

Staining with acidified alizarin red and potassium ferricyanide suggests that the clouded carbonate is mostly



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Figure 119. ***Pilbara Green*** **marble test quarry. Photo shows large cut blocks, up to 1.3 m × 1.6 m, of banded, green marble. Maroonah area.**

dolomite with minor calcite, but that calcite dominates in and adjacent to the dark segmented lamellae in the microbands described above.

Maroonah — Henry River exploration area

In 2006, Pilbara Stone Pty Ltd established a marble exploration area mainly within former exploration licence E08/1888, and E08/1963 (pending) located between 16 and 26 km to the east of Maroonah Homestead. This area contains at least four marble prospects of varying texture and colour (mainly shades of green and grey) that are described below:

Bellotti and Pindanni

Bellotti and Pindanni are two closely spaced, green marble prospects, (on former prospecting licences P08/460 and P08/462 respectively), about 17 km east-northeast of Maroonah Homestead (Fig. 115). In this area, the top of the green, stromatolitic marble of the Irregully Formation is located at or close to the surface and has a low dip in an easterly direction.

At Bellotti in early 2008, Pilbara Stone carried out a 15-hole diamond drilling program covering the prospect from north to south. Of the 15 holes drilled, most recorded 3–7 m of overburden overlying the marble zone. Twelve holes recovered high-quality, green marble averaging 10 m in thickness, indicating the likelihood of a considerable marble resource, with dimension stone quality improving from west to east. Most holes bottomed in an underlying sill of black dolerite (Robinson, 2008).

High-quality marble recovered from drillholes ranged from pale green, generally at the top of the sequence, through apple green to dark green, mostly at the base. The marble is heterogeneous, being composed of mostly very fine grained, dolomitic carbonate that passes into various zones containing green serpentine, and also occurs with lenses and possible veins of clear, granular carbonate. High-quality material, selected from diamond drillhole cores, was subjected to dimension stone testing to demonstrate that the marble takes a very high polish (Appendix 4.45a).

Currently, little is known about the nearby Pindanni prospect on former prospecting licence P08/462 except that it contains surface outcrops consisting of folded, irregularly banded, mid- to dark green dolomitic marble (Appendix 4.45b). Results of petrographic analysis indicate that the marble is composed of very fine grained, micritic, dolomitic carbonate with very minor antigorite (a green mineral of the serpentine group).

Petrographic description (Bellotti marble)

Heterogeneous, partly folded, dolomitic carbonate–serpentine aggregate with probable antigorite commonly defining two foliations at right angles, locally folded.

This is an extremely heterogeneous rock on all scales with irregular carbonate-rich zones passing gradationally or suddenly into carbonate–serpentine, serpentine–carbonate, and serpentine-rich zones. The carbonate is mostly very fine grained but some areas, including a folded lens, have fibrous carbonate and interlaminated serpentine. There are also lenses and possible veins of clear granular carbonate. The serpentine varies from very fine grained to relatively coarse grained in areas with fibrous carbonate. Most of the carbonate is aligned in two directions at right angles to each other, with one direction dominant or to the exclusion of the other in some areas (e.g. those areas with fibrous carbonate). In fine-grained areas both directions are developed to various degrees. A few areas also have fan-like aggregates of serpentine. The serpentine throughout seems to be antigorite.

Petrographic description (Pindanni marble)

Folded, micritic, dolomitic carbonate with very minor antigorite, partly in fractures.

Clouded, micritic, dolomitic carbonate dominates this sample and seems to define a folded layering with variations in grainsize between layers. One area has elongate, possibly platy slivers of clouded micritic carbonate, about 0.5 mm long, of uncertain origin. Very minor decussate antigorite is disseminated and occurs with more abundant carbonate in narrow fractures roughly parallel to the axial planes of the folds. Some of these fractures have minor, probable opaque oxide along their margins.

Chain Pool

The Chain Pool marble prospect is located within prospecting licence P08/563 on the western side of the Henry River about 26 km east-northeast of Maroonah Homestead (Fig. 115). In recent years, this prospect was briefly prospected by Pilbara Stone who discovered a substantial quantity of massive, dolomitic marble.

This mid-grey, dolomitic marble comprises large areas of stromatolitic laminations interspersed with extensive zones of laminated (and possibly brecciated) marble fragments (Appendix 4.46).

Petrographic description

This stone displays a distinct contact between laminated, dolomitic marble, and a possible breccia composed of fragments of laminated marble with interstitial, very fine grained, carbonate-cemented sandstone.

Part of this thin section is occupied by laminated, mostly micritic dolomitic marble with lamellae containing silt to very fine sand-sized quartz grains and interstitial carbonate. This passes into a zone of possible breccia with platy or flaggy fragments of very fine grained marble on a millimetre to centimetre scale with interstitial lenses rich in single-crystal quartz grains about 0.1 mm in diameter (very fine to fine sand) with interstitial microsparry carbonate as well as leucoxene and rare tourmaline, muscovite/sericite and possible zircon. Some of the marble fragments are laminated with variations in the grain size of the carbonate, and some have sparse quartz-bearing lamellae or rare flakes of sericite.

Sheela Bore North

Sheela Bore North prospect is sited on former prospecting licence P08/461, located about 24 km east-southeast of Maroonah Homestead and about 2 km northwest of the *Pilbara Green* quarry (Fig. 115). Although the prospect is currently owned by Pilbara Stone Pty Ltd, little exploration appears to have taken place at this site. From the limited information available on this prospect, it probably contains mid- to dark green marble similar to that available in the nearby *Pilbara Green* quarry.

Maroonah Green

The *Maroonah Green* marble prospects are located adjacent to the Henry River East, about 30 km east-southeast of Marooonah Homestead and 7 km east of the *Pilbara Green* marble quarries (Fig. 115). The main prospect is sited in the area of mining lease M08/82, and owned by Messrs T Deacon and G Dellar. Good-quality green marble is also reported from surrounding exploration licence E08/1351, owned by Bambi Pty Ltd and Deacon Nominees.

Originally prospected by Australian Marble and Granite NL in the late 1980s, and by the current owners in the early 2000s, mining lease M08/82 surrounds a high, west-northwesterly trending ridge 2.5 km in length, comprising large outcrops of massive stromatolitic and dolomitic marble, dipping at about 20º to the southeast. Marble outcrops have a slightly karstified appearance with a thin, dark brown, oxidized surface coating that gives way to hard, green-grey dolomitic marble directly beneath the surface. This area may contain a large resource of high-quality marble (Fig. 120; Appendix 4.47).

Petrographic description

This mottled, grey-green and cream, irregularly foliated, dolomitic marble comprises areas of micritic dolomitic carbonate with minor serpentine and opaque material.

The thin section has abundant, clouded micritic carbonate apparently pulled apart and veined by masses of fine columnar or fibrous clear carbonate, 2 mm or more wide, arranged in a parallel orientation across the thin section. Some areas of clouded micrite contain rare serpentine, possibly antigorite. Rare opaque material is also present, largely in areas of clouded micrite.

Yarrie Pool

Yarrie Pool dolomitic marble prospect is situated 25 km east-northeast of Maroonah Homestead, and 1.5 km south of Yarrie Pool on the Henry River (Fig. 115). Prospected by Messrs R Pember and G Dellar between 2005–07, the Yarrie Pool material is a massive, green-grey stromatolitic, serpentine marble containing lamellae and lenses of dark coloured serpentine or chlorite. This stone is very hard and takes a high polish (Appendix 4.48).

Petrographic description

A green-grey marble containing serpentine with clouded carbonate and antigorite, and folded lenses and lamellae of serpentine or possibly low-Al chlorite, and lenses of foliated clear carbonate.

The thin section shows irregular layers and zones that are variously rich in clouded carbonate and serpentine and chlorite, together with lamellae and lenses of pure schistose serpentine or low-Al chlorite. Also present are domains with abundant decussate antigorite serpentine and lesser carbonate, and other areas of carbonate with little or no serpentine. The phyllosilicate in the lenses and lamellae seems to have a lower birefringence compared with that of the antigorite and this may indicate low-Al chlorite. The fine-grained carbonate is commonly foliated with carbonate grains and lenses of microcrystalline opaque material parallel to the foliation. Some of the serpentine or low-Al chlorite is in folded lamellae parallel to the carbonate foliation, but there is also a crosscutting possible fracture filled with the same material. Some of the folds are tight and almost isoclinal but others are open or irregular. There are also lenses to 10 mm or more in length and 4 mm wide with fibrous clear carbonate parallel to the foliation in the host rock.

Nanutarra

Nanutarra, a roadhouse and homestead located on the North West Coastal Highway about 270 km southwest of Karratha, is the point of reference for seven variously coloured marble prospects and quarries within a 35 km radius (Fig. 115).

Bluff Well

Bluff Well marble prospect, located about 20 km east of Nanutarra in the Parry Range, is a close-spaced series of marble ridges that trend in a north-northwesterly direction for about 40 km. The prospect lies within mining lease M08/315 owned by Pilbara Stone Pty Ltd (Fig. 115).

In 2005–06, the company explored the area and followed up with some preliminary drillholes. A ‘butterscotch’-coloured marble was found to overlie an off-white marble with buff highlights. It was soon discovered that this area was difficult to explore as the quality of marble recovered from drillholes was found to be inferior to the high-quality marble present at the surface. To date, no further exploration results have been reported from this site.

Motin Bore and Wadrah Bore

This area is also under investigation by Pilbara Stone Pty Ltd. Since 2005, the company has focused on marble exploration within the southern half of their exploration licence E08/1408 in the vicinity of Wadrah and Motin Bores, 30 and 35 km southeast of Nanutarra respectively (Fig. 115).

North of Motin Bore, a red, brecciated marble is exposed in a north-northwesterly trending ridge about 1.5 km long. This marble, with a thickness of about 20 m, forms part of the basal section of the Edmund Group unconformably overlying Paleoproterozoic schists of the Pooranoo Metamorphics.



Figure 120. ***Maroonah Green*** **dolomitic marble; a) massive outcrops of karstified, stromatolitic marble; b) exposed block of hard, grey-green marble possibly suitable for dimension stone applications .**

In 2006, the company drilled 12 diamond drill holes to the east of Wadrah Bore, that yielded white to cream, near-surface marble overlying pink marble at depth. A further six holes were drilled in an area approximately 2 km north of Motin Bore. Drilling in this area yielded cream and pink marble overlying deep-red brecciated marble (Appendix 4.49a,b). Cores recovered from these holes indicate a lithology similar to the white, cream and underlying red, brecciated marble present at the nearby Nanutarra quarries.

Recently, the company has been conducting exploration to the west of Motin Bore to locate a suitable quarry site for high-grade white to cream marble.

Petrographic description — Motin Bore, cream marble

Heterogeneous dolomitic marble with areas of sparry carbonate(–quartz) and clouded, partly pelletal areas with interstitial microplaty carbonate or with disseminated very small rhombs of carbonate.

This sample has irregular millimetre- to centimetre-scale lenses of clear sparry carbonate(–quartz), between which are irregular areas of largely clouded, commonly micritic carbonate, commonly with granular or pelletal textures to 2.5 mm in diameter, or with disseminated, small rhombohedral crystals of carbonate about 0.1 – 0.25 mm long. The pellets have clouded, microsparry carbonate as cement and commonly have finer grained, more highly clouded rims and less clouded cores.

Petrographic description — Motin Bore, red marble

Partly brecciated, dolomitic marble with detrital quartz, muscovite, and hematite. Also contains interstitial areas of microsparry quartz, locally enclosing hematite and hematite-stained shale, and anastomosing zones of mostly sparry carbonate(–quartz) with zones of microsparry and micritic carbonate.

One end of this thin section is occupied by fine-grained marble with sparsely disseminated mostly silt-sized quartz grains, thin flakes to 0.5 mm long, including muscovite and hematite flakes apparently derived from detrital biotite. Small spots of earthy hematite are also disseminated. The rest of the thin section seems to represent possible solution breccia in which several fragments have minor silt-sized quartz as well as muscovite and earthy hematite. The other areas are zoned from clouded very fine grained carbonate zones into coarser, partly microsparry carbonate areas with interstitial patches of earthy hematite or hematite-flooded sericitic shale or claystone. There are also interstitial areas of clear sparry carbonate. Anastomosing, irregular vein-like zones to 3 mm wide have segments of sparry carbonate and areas with successive lamellae of microsparry, micritic and sparry carbonate. Some of the sparry lenses contain crystal-lined cavities filled with quartz.

Nanutarra red and white marble quarries

The Nanutarra quarries are located on mining lease M08/149 about 30 km southeast of Nanutarra and 4 km east of the Henry River (Fig. 115). Owned by Stone Dimensions of Australia Pty Ltd, these quarries produced white and red marble blocks on a campaign basis for a number of years until 2008, when they were placed in care and maintenance.

Within the mining lease, white and red marbles from the basal Irregully Formation are exposed at the surface as a series of low hills. These units, dipping easterly between 10º and 20º, comprise up to 20 m of white to cream marble, overlying a basal sequence of 25–30 m of mahogany-red brecciated marble. The red marble unconformably overlies low- to medium-grade schists of the Paleoproterozoic Pooranoo Metamorphics.

White quarry

The white marble quarry is located near the crest of a low hill on the central western side of M08/149. The quarry measures about 30 m × 30 m with diamond wire sawn walls up to 6.0 m high of massive white marble from which 25 t blocks of white marble are extracted (Fig. 121a). Marble resources in the vicinity of the quarry appear to be extensive.

Different areas of the quarry yield three distinct high-quality, dolomitic marbles that are selected, quarried and stockpiled separately, and sold as three named varieties illustrated in Appendix 4.50:

- *Austral Pearl* — a white to pale grey marble containing fine white veins
- *Austral Dream* — largely composed of irregular, anastomosing bands and veins of white and pale to mid-brown marble
- *Austral Brown* — appears to be a variety intermediate between *Austral Pearl* and *Austral Dream* comprising a white to pale grey marble matrix containing fine white veins and irregular, pale to mid-brown swirling patches.

Petrographic description — *Austral Pearl*

Veined, micritic, weakly ferroan and non-ferroan dolomitic marble with fine-grained and coarse-grained sparry carbonate veins and apparently leached stylolite-like veins with fibrous clinochlore.

This sample is also heterogeneous but mostly cream coloured in hand specimen. It has large irregular masses of clouded, micritic carbonate making up perhaps two-thirds of the thin section, cut by irregular veins of coarser grained sparry carbonate mostly less than 1.5 mm wide. Lenses to 5 mm wide are composed of carbonate to 0.4 mm in diameter with sparse, disseminated quartz. Large, irregular, weakly ferroan dolomite veins to 6 mm wide have marginal zones of relatively fine grained carbonate and cores of coarse-grained granular carbonate to 2 mm in diameter. There are also largely vuggy stylolite-like veins with minor fibrous probable clinochlore. Other areas have narrow carbonate veins.

Petrographic description — *Austral Dream*

Heterogeneous micritic, fine- to coarse-grained, weakly ferroan and non-ferroan dolomitic marble with probable fragments of quartz-rich to sericite-rich, schistose or



Figure 121. **Nanutarra marble quarries: a) massive white marble quarry face, 6 m high in the Nanutarra white quarry; b) red quarry from which the mahogany-red *Rosso Venezia* marble is extracted from the 5 m-high walls.**

crenulated metasiltstone and narrow lamellae with quartz, sericite, and clinochlore.

This sample is variously mottled and banded and contains:

- Bands and irregular lenses of clouded micritic carbonate on various scales, including very irregular masses intimately intergrown with other types of carbonate
- Areas of clearer carbonate with undulose extinction or a fibrous character such that individual grains are poorly defined. This material is abundant where clouded micritic carbonate is in irregular masses. Also, minor quartz and phyllosilicate are present as well as rare, colourless, probable tourmaline
- Lenses or fragments to 4 mm long composed of very fine grained quartz with minor weakly schistose possible sericite and lamellae rich in strongly schistose sericite in a planar or crenulated schistosity. These lenses or fragments, which seem to represent metasiltstone, contain minor leucoxene and carbonate and rare tourmaline
- Narrow, anastomosing, possibly stylolitic or shear-related lamellae with quartz, schistose phyllosilicate and schistose pale magnesian chlorite (clinochlore) with or without carbonate. Some voids may represent leached material, rarely with pressure shadows
- Irregular lenses to 12 mm × 4 mm composed of coarse-grained sparry carbonate to 1.5 mm in diameter
- Probable veins of carbonate with lenses of quartz also occur in the main mass of clouded micritic carbonate.

Red quarry

The lower, red marble quarry is located in the central south of M08/149 about 300 m south-southeast of the white quarry. The quarry, about 30 m long × 20 m wide × 5 m deep, is diamond wire cut into the upper slopes of a low hill. Last mining on this site was in December 2006 and since then supplies have been maintained from a large stockpile of sawn 10 t blocks (Fig. 121b).

High-quality stone from this site is termed *Rosso Venezia*, a massive, mahogany-red brecciated dolomitic marble containing a variety of mostly minor red, white, green and grey veins and lenses (Appendix 4.51).

Petrographic description — *Rosso Venezia*

Hematite-stained, very fine grained carbonate with hematite-rich micritic zones adjacent to lenses of sparry carbonate and small patches and zones of hematite-rich carbonate. Later carbonate–quartz veins and carbonate veins are also present.

This sample is pinkish red, apparently dolomitic marble with sparse veins. It is mostly composed of very fine grained carbonate stained by earthy hematite, commonly with rare quartz, sericite and hematite apparently replacing small platy crystals. There are also irregular zones of clouded micritic carbonate, richer in hematite, around lenses and veins of coarser sparry carbonate from 1 to 6 mm long or in irregular lenses with patches of slightly coarser carbonate. Irregular zones of carbonate about 30 μm in diameter have interstitial earthy hematite. Some areas have small lenses of similar carbonate around irregular small patches of earthy hematite. Veins up to 1.5 mm wide contain granular or columnar carbonate and columnar quartz suggesting oblique vein opening and there is a vein of columnar carbonate without quartz.

Applications for Nanutarra marbles

Nanutarra marbles are not only visually attractive, but also may be thinly cut because of their natural hardness, and also take a very high polish. Apart from their high compressive strength, other physical properties for Nanutarra marbles, estimated by Stone Dimensions of Australia (2007), and given here, are quite high compared with ASTM standards for marble listed in Appendix 2:

- Absorption 0.05%
- Modulus of rupture (dry) 26 MPa
- Abrasion resistance 34 Ha

Locally, a variant of *Austral Dream* has been used as attractive interior wall panelling on the ground floor of the Allendale Square building in Saint Georges Terrace in Perth (Fig. 122). Similar material was also used as floor tiles in the main hall of the Perth Railway Terminal in East Perth. Also, Nanutarra marble was exported for a number of years to the international dimension stone trading house, M+Q Italia, in Italy, for distribution to European markets.

Parry Range

The Parry Range marble quarry is located 25 km north-northeast of Nanutarra, and about 2 km northeast of the North West Coastal Highway by way of an overgrown track (Fig. 115). The quarry, located on mining lease M08/139, was originally owned by Kinetic Mining Pty Ltd. The company operated for a comparatively short time in 1974 before the owners went into receivership. Reasons advanced for the company's demise were the high cost of transport to the nearest port for export or by road to Perth, as well as a number of technical difficulties in processing the stone. The quarrying in the early 1970s employed diamond wire sawing and close-spaced drilling to obtain well-shaped, 10 t marble blocks, some of which remain on site. During the quarry's short operational life it is recorded that blocks were exported, probably to Italy, while the remainder appear to have been transported to Perth for sale.

The marble is generally massive and very fine grained in white to cream bands (Fig. 123; Appendix 4.52). Large vertical and inclined solution pipes penetrate the marble in the quarry walls. Pipes are up to 0.4 m wide and are filled with ferricrete and soil as shown in Figure 123. These pipes are not obvious in the finely sawn quarry floor indicating that the marble may prove more massive at depth. Since operations ceased in 1974, the quarry has remained in a state of care and maintenance for more than 35 years.

Petrographic description

Pelletal dolomitic marble with interstitial microsparry to sparry carbonate with sparse carbonate veins and a stylolite containing chlorite, and minor areas of weakly ferroan dolomite.



Figure 122. Interior wall panel of cream Nanutarra marble. Allendale Square, Saint Georges Terrace, Perth.

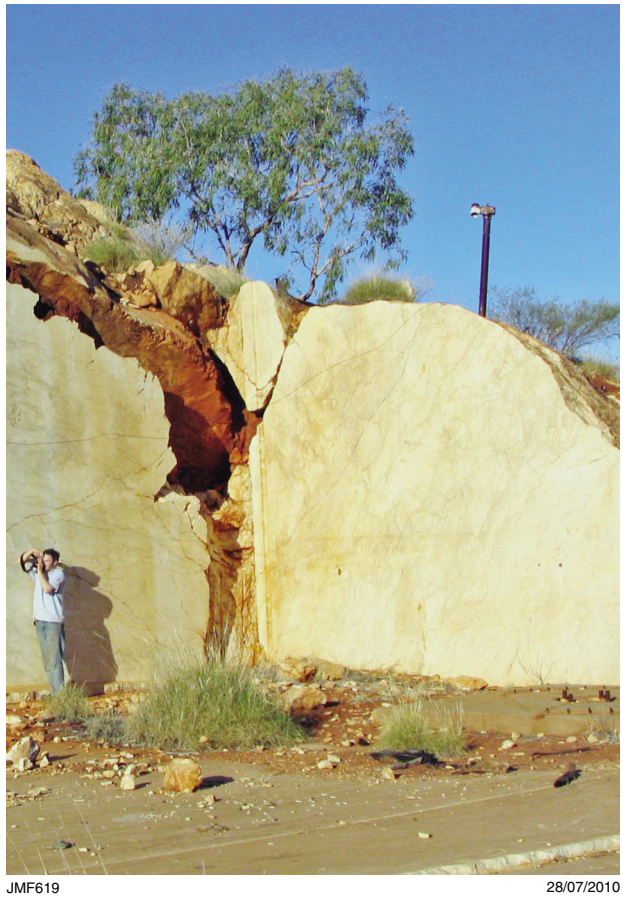


Figure 123. Massive, 6 m-high, diamond sawn walls of Parry Range cream marble quarry. Note the 0.4 m-wide, vertical solution pipe, penetrating the marble at centre.

The thin section contains abundant micritic probable pellets to 2 mm in diameter as well as possible fragments or concretions to 2 mm in diameter composed of microsparry carbonate rimmed by micrite. Interstitial microsparry and sparry carbonate is common and there are scattered irregular voids. The micrite is weakly clouded but the material is too fine grained to be identified optically. Sparse veins to 1 mm wide contain columnar carbonate and there is a stylolite with pale magnesian chlorite, probably clinochlore.

Ten Mile Well

Ten Mile Well is a bore and tank located 14 km east-northeast of Nanutarra, adjacent to the western edge of the Parry Range (Fig. 115). Although the area has been partially explored for dimension stone in recent years, there appears to be no published information available on marble resources of the central-western Parry Range. Accordingly, the area was visited by the author to gain a preliminary assessment of potential resources.

In the Ten Mile Well area, the Parry Range forms a series of close-spaced, north-northwesterly trending dolomitic marble ridges up to 100 m above the surrounding plain. A very extensive tract of exposed marble may be observed from the top of the westernmost marble ridge at this locality. The exposed marble at this site varies from cream to yellow and pink (Fig. 124; Appendix 4.53), and is intersected by a number of vertical joint sets enlarged by the dissolution of stone. Jointing, together with steeply dipping beds, would probably preclude quarrying operations in this area. Future exploration of such an extensive area of marble may locate suitable quarry sites elsewhere in the northern Parry Range.

Petrographic description — yellow marble

Limonite-stained, micritic dolomitic marble as pellets and possible intraclasts or lamellae, partly folded, with carbonate and limonite-filled fractures.

This pale yellow marble has abundant yellow limonite-stained probable pellets and elongate intraclasts, locally with frayed ends, as well as possible lamellae. These clouded components seem to define an irregular layering, which in places appears to have been folded into open folds. The possible pellets are from 0.2 mm to about 1 mm long but the possible intraclasts and lamellae are longer. Interstitial sparry carbonate is common and there are narrow carbonate- and limonite-filled fractures with ferroan dolomite.

Petrographic description — pink marble

Heterogeneous, weakly hematite-stained, dolomitic marble with minor quartz and sericite and a vein stained by limonite.

This pale pink marble has irregular areas of clouded micrite passing into microcrystalline areas with anastomosing vein or capillary-like lenses of slightly coarser carbonate. A possible fragment of micrite has a rim of authigenic quartz and carbonate, and patches and grains of quartz are irregularly disseminated. One possibly detrital quartz grain has a fringe of quartz resembling an optically continuous overgrowth with possible sericite normal to the grain boundary. The marble is stained lightly with earthy hematite and there is an irregular, hairline carbonate vein stained with yellow limonite.

Paraburdoo area

Pingandy Grey

The *Pingandy Grey* dolomitic marble is located in the eastern Edmund Basin about 90 km south of Paraburdoo (Fig. 115). This marble was located in the early 2000s by local prospector Mr B Kayes. Currently, little is known about this grey marble except that there appears to be a moderately large resource of high-quality marble that may be suitable as dimension stone.

Gascoyne Province

Gascoyne Junction

Weedarrah

The *Weedarrah Marble* quarry is located 60 km east of the town of Gascoyne Junction and about 6 km south-southeast of Weedarrah Homestead. The quarry is reached by a track extending about 5 km west from the Cobra – Dairy Creek road (Fig. 125).

The site was originally explored in 1981–82 by Newmex Exploration. At that time, the company drilled one large-diameter diamond drillhole that penetrated 50 m of marble before bottoming in granite. Recovery from the drillhole was 100%. Subsequently, the core was examined and geotechnically logged to determine orientation of fracture planes. Later, a preliminary slot was opened up in the northern contact of the marble to obtain bulk samples for fracture analysis and trial polishing. Other tests carried out included petrology, chemical analyses, and physical properties.

In 1989, mining lease M09/51 was granted and in the early 1990s a small trial quarry known as Cameron's opencut, was initiated. The quarry measured about 7 m wide × 30 m long with a maximum depth of about 5 m from which blocks were extracted by diamond wire sawing (Fig 126). It appears the quarry operated only for a comparatively short period before being put into care and maintenance and remains in this state to the present day. Current owners of mining lease M09/51 are Stone Enterprises Pty Ltd.

At the Weedarrah quarry site, the Paleoproterozoic marble is enclosed by mainly steeply dipping, dark green, weathered mica schist and amphibolite and minor quartzite. The marble is present as a lens-shaped body forming a low, northwest-trending ridge. The lens has a maximum outcrop width of 50 m and length of 175 m, tapering to a point at the northwestern end (Johnston, 1983).

The dolomitic marble consists of pure white, fine- to very coarse grained, interlocking carbonate crystals that polish to a mirror-like finish (Appendix 4.54). Much of the quarry is penetrated by steeply dipping, anastomosing veins of pale green, schistose serpentine of variable thickness, ranging from approximately 20 mm to 1.5 m in width (Fig. 126). Within these veins the marble appears to have



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Figure 124. Cream, dolomitic marble exposed at Ten Mile Well in the Parry Range.

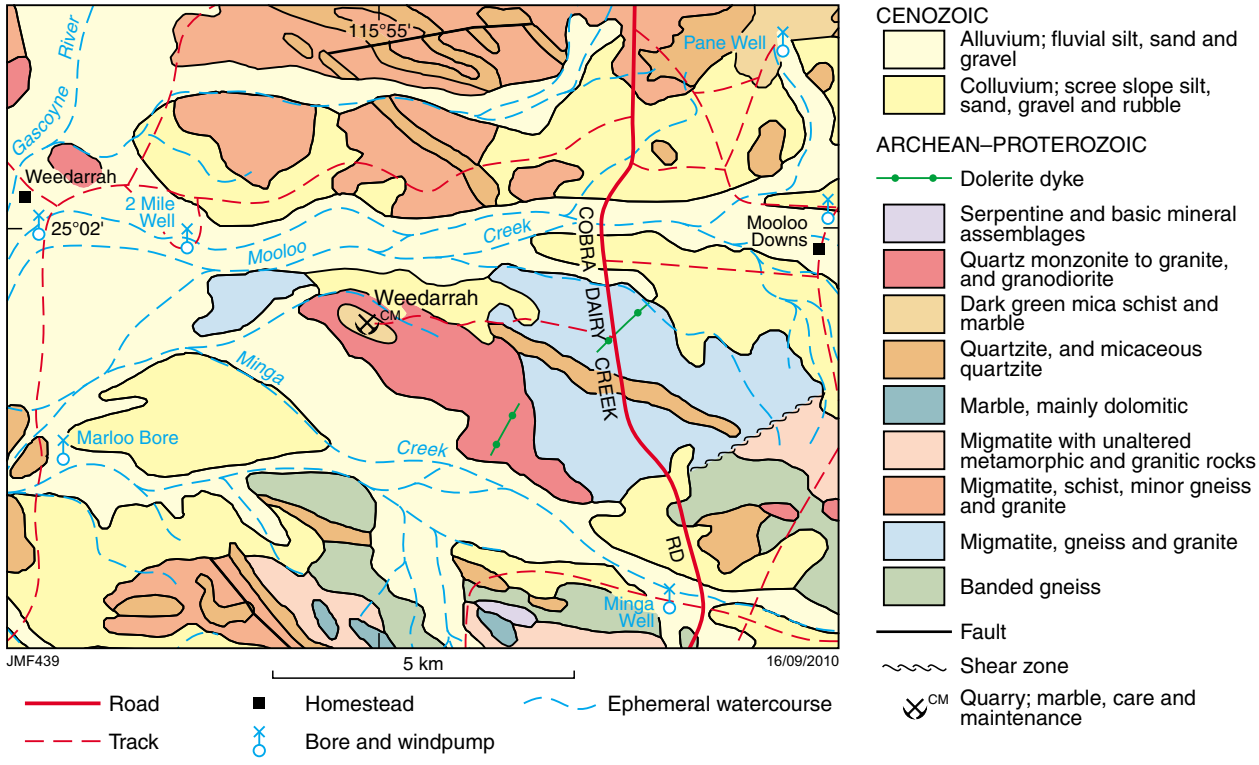


Figure 125. Geology of the Weedarrah area (modified after van de Graaff et al., 1983).

been brecciated into fine to coarse pieces ranging from subrounded to highly irregular, broken shapes. Jointing is mostly subhorizontal and varies from 1 m to more than 3 m spacing in places.

Average physical properties for *Weedarrah Marble* given by Johnston (1983) mostly exceed the ASTM standards for marble listed in Appendix 2. In addition to the high polish that can be obtained with this stone, these physical properties indicate that the dolomitic white marble has hard-wearing, durable characteristics that compare more than favourably with imported calcitic marbles:

- Absorption 0.084%
- Bulk density 2.851 t/m^3
- Compressive strength 191 MPa
- Modulus of rupture 21 MPa
- Abrasion resistance 14.57 Ha

From field observations and data from one drillhole, Johnston (1983) estimated a total marble resource of 161 000 m^3 from the lens-shaped structure. A conservative recovery rate of 30% was determined from an analysis of fracture patterns. On this basis, the resource was estimated to yield 48 000 m^3 of marble blocks.

Petrographic description — white marble

Pure dolomitic marble with a round patch of possible prehnite or Mg–Al-rich chlorite.

This sample is almost pure, coarse-grained carbonate to 15 mm in diameter with interlocking anhedral grains. A single small circular patch 1 mm in diameter has inequigranular phyllosilicate that may be prehnite or a thick section of clinochlore or amesite, that is partly microcrystalline and partly granular (up to 1 mm in diameter).

Petrographic description — green vein in white marble

Serpentine–carbonate schist with abundant, probable antigorite.

This sample is mostly schistose, probable antigorite with 25% microcrystalline carbonate. The antigorite defines a principal schistosity with conjugate schistosity planes at 15° in one direction from the main schistosity and another at 25° in the opposite direction. The serpentine is mostly less than 0.2 mm in diameter.

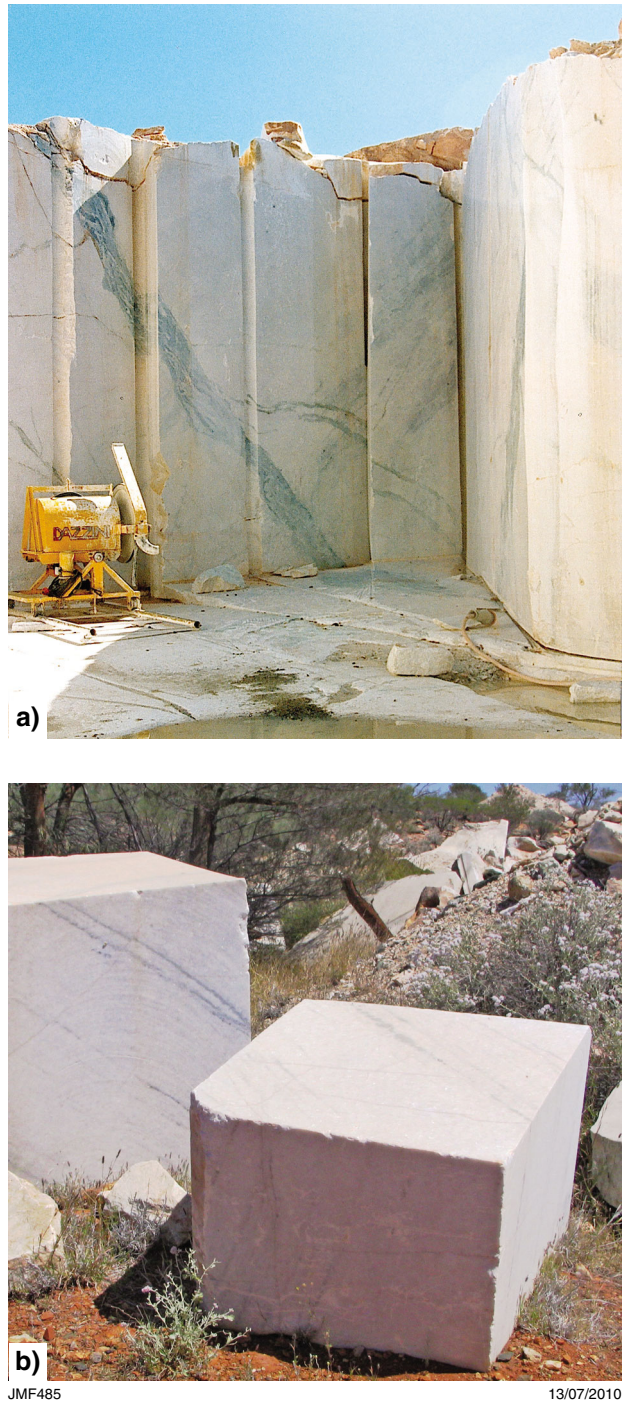


Figure 126. ***Weedarrah Marble*** **quarry, Weedarrah Station area: a) marble quarry in operation, early 1990s. Steeply inclined vein of pale green serpentine is visible in rear wall; b) blocks of white Weedarrah marble, up to 0.5 m^3, displaying thin veins of pale green serpentine (photo (a) courtesy TE Johnston).**

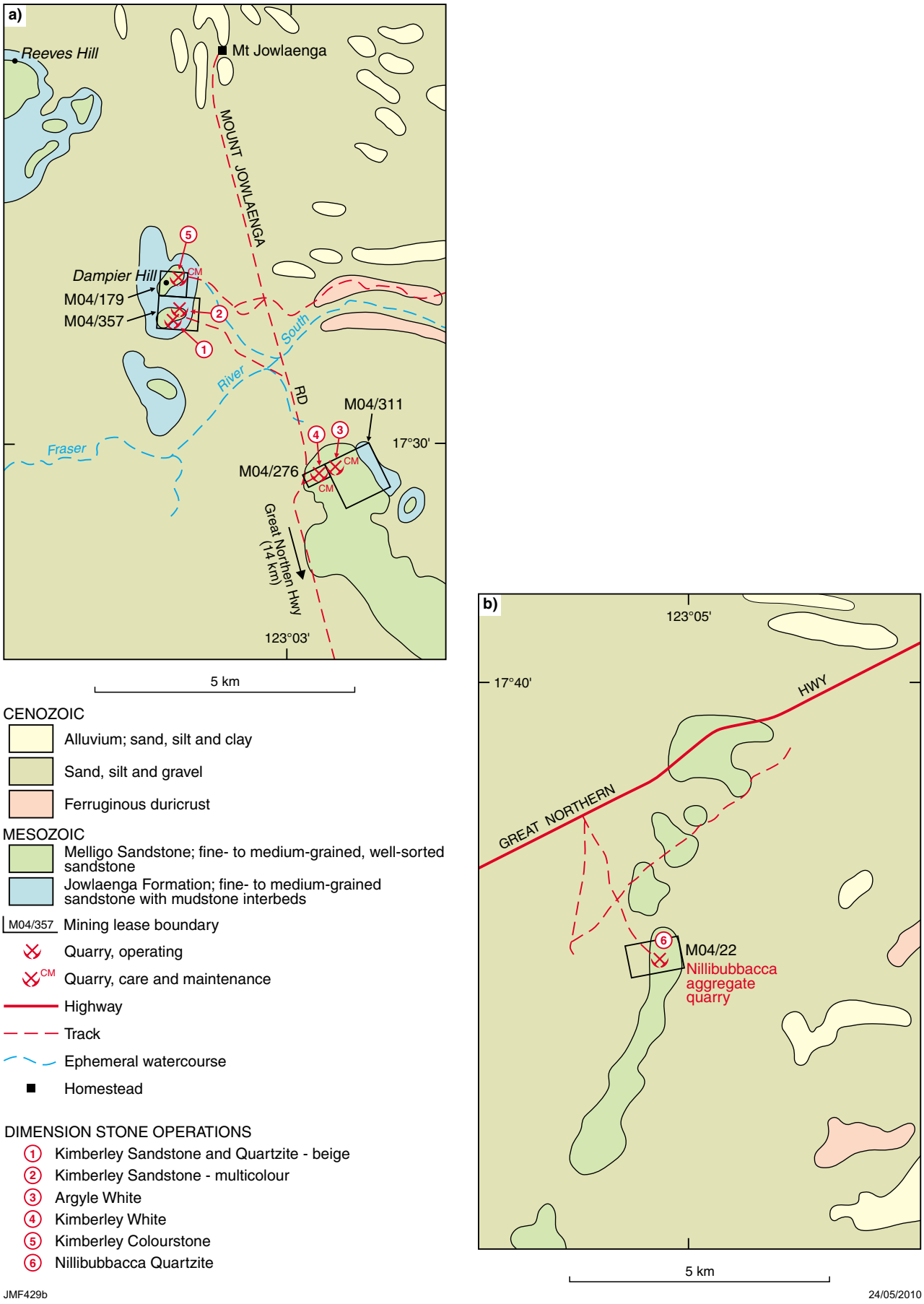


Figure 127. Geological maps of *Kimberley Sandstone* and *Kimberley Quartzite,* and *Nillibubbacca Quartzite* quarrying operations: a) Mount Jowlaenga area; b) Nillibubbacca quarry area (modified after Towner et al., 1980).

Chapter 5

Sandstone

Northern region

Canning Basin

Derby region — sandstone and 'quartzite'

Kimberley Sandstone and *Kimberley Quartzite* deposits are located in two discrete areas, both 70 km west-southwest of Derby. The principal area of interest is located in the Mount Jowlaenga area about 23 km north-northwest of the Great Northern Highway. A much harder variety of the *Kimberley Quartzite,* known as *Nillibubbacca Quartzite,* is present at Nillibubbacca Quarry, about 3 km south-southeast of the same highway (Fig. 127).

Stone quarried in this area is from the Early Cretaceous Melligo Sandstone, a fine-grained, well-sorted and well-rounded sandstone, partly laminated and subject to silicification in places. Silicification of the sandstone, particularly of upper levels, probably took place during the late Cenozoic and has formed hardened ridge cappings and thick outer casings on some hillslopes. This hardened, quartzitic sandstone has been termed 'quartzite' by dimension stone operators who have developed a viable niche market for this stone.

Mount Jowlaenga operations

In the Mount Jowlaenga area, the almost flat-lying Melligo Sandstone outcrops as a series of relatively steep, north-westerly trending, rounded hills in the north of the area around Dampier and Reeves Hills. In the south, in the vicinity of mining lease M04/311, the sandstone forms a steep-sided escarpment with a hard, resilicified capping (Figs 127, 128).

Kimberley Sandstone

In the main area of operations adjacent to Dampier Hill, Meteor Stone operates two quarries on mining lease M04/357. Both quarries operate from 3–4 m-high stone cutting walls on terraced benches situated midway up the slopes of two hills to permit access to specified grades of sandstone suitable for dimension stone block and slab production. The southern quarry (No. 1 on Figure 127a) produces diamond sawn blocks of visually attractive, cream to pale beige, quartz-rich, fine-grained *Kimberley Sandstone* (Fig. 129; Appendix 4.55). Two hundred metres north, the multicoloured quarry (No. 2) produces a quartz-rich, fine-grained, hematitic sandstone in a wide variety of colours, principally red, yellow and mauve arranged in attractive random patterns and often enhanced by spectacular liesegang banding (Fig. 130; Appendix 4.56). Blocks and slabs are removed from this site by close-spaced block drilling.

Technical specifications for *Kimberley Sandstone* given by Meteor Stone (2004) are all within the ASTM standards for high-quality sandstone suitable for dimension stone applications given in Appendix 2:

- Absorption 3.5%
- Bulk density 2.1 t/m^3
- Compressive strength (dry) 70 MPa
- Modulus of rupture (dry) 12 MPa

Petrographic descriptions

Kimberley Sandstone — cream to pale beige

Quartz-rich fine-grained sandstone with minor limonite(–leucoxene) grains, zircon, tourmaline and muscovite, and polycrystalline quartz in pale brown isotropic, possibly opaline material.

The sample contains abundant, subrounded mostly single-crystal quartz grains that range from 0.1 to 0.25 mm in diameter and indicate fine-grained sandstone. There are also sparse polycrystalline quartz grains, mostly cherty, as well as grains altered to limonite(–leucoxene). Zircons to 0.1 mm long are disseminated as well as tourmaline and rare muscovite. The cement is all isotropic and mostly pale brown, giving the colour to the sandstone, but some darker spots may contain diffuse leucoxene or anatase, or quartz–anatase–zircon cement. The main material has a refractive index similar to that of quartz and may be opaline, but X-ray diffraction analysis may be useful in resolving the mineralogy. Some grains have rims of limonite and some rare micropores are also rimmed by limonite, suggesting dissolved detrital grains.

Kimberley Sandstone — multicoloured, hematitic

Quartz-rich fine-grained sandstone with minor hematite, tourmaline, zircon, and muscovite; most of the cement is isotropic with possible leucoxene and red areas are further flooded by earthy hematite.

This sample has irregular dark red, pale red, and white bands. Angular, subangular, and rounded single-crystal quartz grains in this thin section are mostly less than 0.2 mm long with rare elongate quartz and muscovite grains to 0.3 mm long that are roughly elongate parallel to the layering. These indicate fine-grained sandstone.



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Figure 128. Blocky, resilicified ridge capping of Melligo Sandstone in the south of the Mount Jowlaenga area. Surface blocks are up to 0.75 m² in area × 0.3 m thick.



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Figure 129. Fine-grained, beige *Kimberley Sandstone* exposed in a 3 m-high diamond sawn quarry face. Meteor Stone quarry 1, Mount Jowlaenga area.

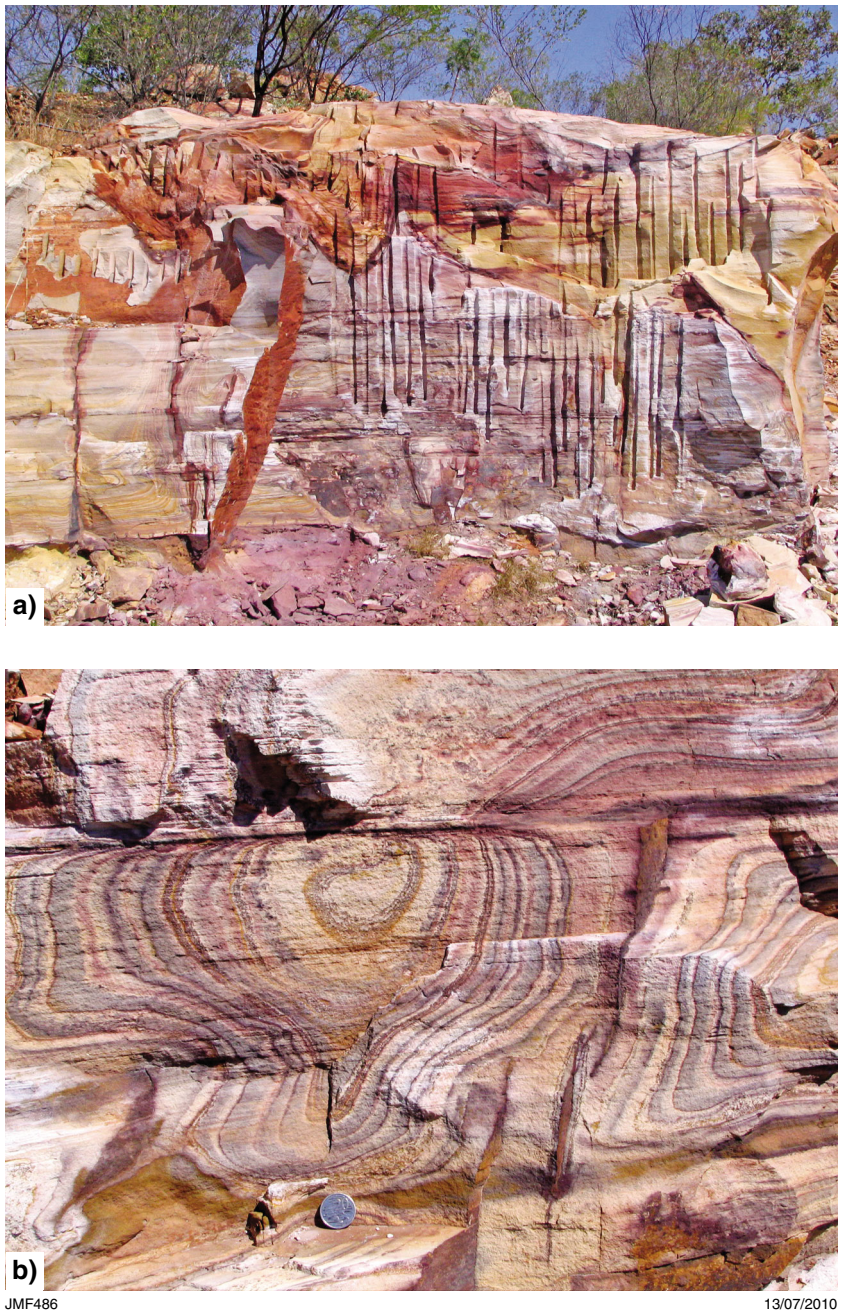


Figure 130. Meteor Stone's multicolour *Kimberley Sandstone* quarry 2 near Dampier Hill: a) quarry wall displaying randomly distributed coloration present in the sandstone around this site; b) spectacular, concentric, multicoloured liesegang rings that produce visually attractive patterns in the stone.

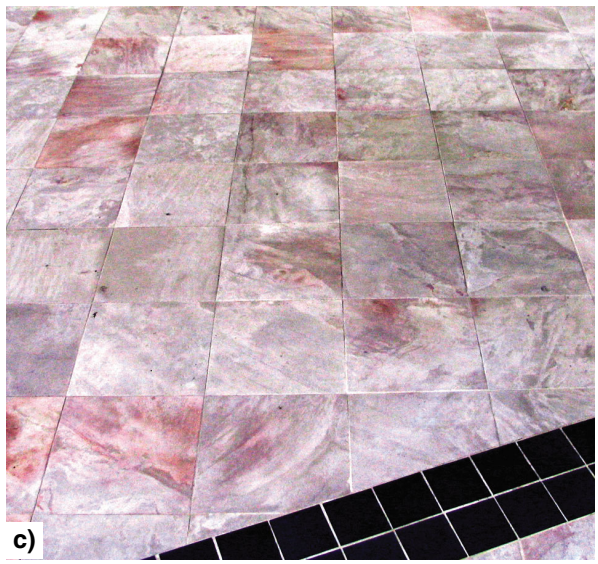


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Figure 131. Rectangular blocks of partially resilicified *Argyle White* sandstone, Mount Jowlaenga area. Blocks are up to 1.0 m³.



a)



c)



b)



d)

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There are also sparse cherty polycrystalline grains as well as rounded hematized grains. Rare zircon to 0.1 mm in diameter is accompanied by less abundant tourmaline. The pale layers seem to have possibly isotropic cement clouded by leucoxene or quartz–anatase–zircon, with flooding by earthy hematite in the red layers. Boundaries are irregular and diffuse suggesting a non-primary origin for the colour bands. Very narrow microfissures are seen in the isotropic cement, and sparse microporosity suggests dissolved detrital grains. A clay-rich layer at one end of the thin section contains relatively small single-crystal quartz grains.

Kimberley Quartzite

Within certain areas of mining lease M04/357 the Melligo Sandstone has been differentially hardened by late Cenozoic silicification (Fig. 127a). Silicification appears to have formed a case-hardened outer sandstone layer that occurs as stone exposed on, or close to, the surface of hillslopes in the modern landscape and overlying the softer sandstone within. It is from these outer zones that Meteor Stone sources blocks of the notably harder material known as *Kimberley Quartzite*. Meteor Stone sources two varieties of this material from these hardened zones, namely *Kimberley Quartzite – beige,* and a beige variety with pinkish-red overtones known as *Kimberley Quartzite – salmon pink* (Appendix 4.57).

Technical specifications for *Kimberley Quartzite,* also from Meteor Stone (2004), clearly show the increased strength of this stone compared with that of the *Kimberley Sandstone* from the same area, with marked increases in compressive strength, modulus of rupture, and bulk density, as well as a reduction in absorption, indicating a significant reduction in porosity. Values given below are more consistent with ASTM standard values for quartzitic sandstone rather than for true quartzite (Appendix 2):

- Absorption 2.3%
- Bulk density 2.4 t/m3
- Compressive strength (dry) 110 MPa
- Modulus of rupture (dry) 21 MPa

Argyle White sandstone

The *Argyle White* test quarry is located in mining lease M04/311 in the south of the Mount Jowlaenga area (Fig. 127a). At this site, fine- to medium-grained Melligo Sandstone outcrops as steep-sided mesa country with hardened sandstone ridge capping that extends as much as 20 m down exposed cliff faces. At the test quarry site high up on the slope, Meteor Stone have extracted almost cubic, blocky, sandstone boulders of hard, white or pale beige sandstone averaging around 1 m^3 (Fig. 131). Diamond sawn slabs are pale beige with minor pale mauve spots or irregular lines arranged in attractive, random patterns (Appendix 4.58). Currently, the company is evaluating the marketability of this stone.

Figure 132. (opposite) Applications for *Kimberley Sandstone* and *Kimberley Quartzite:* a) slabs of beige sandstone cladding exterior walls of the contemporary Motorola Building at the University of Western Australia; b) 150 mm-square, beige and red sandstone tiles used to decorate an open area of Federation Square in Melbourne; c) salmon-coloured *Kimberley Quartzite* tiles, together with a band of *Kimberley Black* granite tiles, forming the forecourt of Saint Martin's Tower, Perth City; d) *Kimberley White* sandstone blocks forming a 3 m-high wall as part of an ornamental pool landscape, Cable Beach Resort, Broome.

Petrographic description

Medium-grained, quartz-rich sandstone with less abundant isotropic matrix clouded by leucoxene, as well as polycrystalline quartz, leucoxene–limonite, and muscovite.

This white sandstone contains possibly 15–20% cement, which is less abundant compared with the previous samples of *Kimberley Sandstone*, and has more abundant subangular to rounded single-crystal quartz grains to 0.4 mm long, indicating medium-grained sandstone. Sparse polycrystalline quartz grains occur, as well as grains altered to leucoxene(–limonite) and rare muscovite. Also, the cement is again isotropic and clouded with possible leucoxene. Minor porosity seems to represent dissolved detrital grains but there are fractures rimming some quartz grains and within the matrix, suggesting shrinkage, partly away from the detrital grains.

Kimberley White sandstone

Immediately west of the Argyle White mining lease M04/311, Meteor Stone owns another small mining lease, M04/276 (Fig. 127a). This lease is situated over a low outcrop of Melligo Sandstone on the sandplain beneath the *Argyle White* sandstone escarpment. The white, fine-grained, laminated sandstone, termed '*Kimberley White',* is much softer than the overlying *Argyle White* stone.

In the early 1990s, a small quarry of approximately 30 m × 12 m and about 3 m depth was developed (dimension stone quarry No. 4). This operation exposed mainly white, flat-lying sandstone beds varying from 0.3 to 1.0 m in thickness with little evidence of vertical jointing. Other pale coloured sandstone beds were also found to be present. During this time, it was estimated that almost 550 t of high-quality white sandstone, with some blocks, up to 3.4 t, were removed from the quarry. The recovery rate of useable stone was estimated at 50–60% of total stone quarried. Although quarrying reached only 3 m below ground level, it was predicted that high-quality sandstone could extend to a considerable depth beneath the current quarry floor (DBK Quarrying Services, 1992).

Most of the white sandstone from this operation was sent to Broome for a major landscaping project while the remainder was sent to Perth for further evaluation following cutting and polishing trials.

Applications for stone from Meteor Stone quarries

Applications for *Kimberley Sandstone* are numerous with the stone mostly being diamond sawn for the manufacture of slabs used for decorative wall cladding. It has also found use both as rough- and machine-cut floor tiles as part of major architectural projects such as Federation Square in Melbourne. Examples of these uses are shown in Figure 132a,b. Also, together with Donnybrook Sandstone



Figure 133. ***Kimberley Colourstone*** **quarry and application: a) blocky boulders of red and cream Melligo Sandstone forming the 1.0 m-thick** ***Kimberley Colourstone*** **horizon at the Dampier Hill quarry; b) block of** ***Kimberley Colourstone*** **used as a World War II monument, Carnarvon Street, Broome.**

from the State's southeast, *Kimberley Sandstone* featured prominently in an outstanding contemporary design as part of the gold medal prize-winning, Australian exhibit at the 2008 Chelsea Flower Show in London (Discovering Stone, 2008).

Because of its superior hardness and lower abrasion (wear) rate, *Kimberley Quartzite* has found acceptance as high-quality floor tiles as well as decorative wall cladding applications. It is also featured in Federation Square in Melbourne. Another application of the salmon pink variety used as visually attractive outdoor pavement tiles is shown in Figure 132c.

In the early 1990s, *Kimberley White* sandstone was used in the landscaping of gardens, ornamental pools and waterfalls at Cable Beach Resort in Broome (Fig. 132d).

Kimberley Colourstone

The *Kimberley Colourstone* quarries are located in the almost flat-lying Melligo Sandstone at Dampier Hill on mining lease M04/179 registered to Mr C Sim (Fig. 127a). At this location, the main quarry is located high up on the relatively steep side of Dampier Hill to access a blocky, bright red and cream sandstone bed about 1 m in thickness. This quarry extends as a level terrace for several hundred metres around the contour of the hill. The second, smaller quarry is located on the hill immediately to the south at the same elevation above the sandplain. The fine-grained, ferruginous, quartz-rich sandstone quarried from this horizon, was extracted as relatively hard, well-jointed rectangular blocks approximately 1 m^2 in area × 0.75 m thick (Fig. 133a).

In operation, these quarries produced rough cut blocks and pavers for use in walls and landscaping in the local area. More regularly shaped blocks were used in monumental work and smaller pieces were worked by local artisans largely for the tourist trade (Fig. 133b; Appendix 4.59). The quarries appear to have been in care and maintenance for a considerable number of years.

Petrographic description

Fine-grained, quartz-rich sandstone with microcrystalline quartz and hematite-flooded grains: pale bands have isotropic material and possible leucoxene, further flooded by hematite in red lamellae and bands.

Pink, red, and dark red lamellae and bands (1 to >25 mm thick) are seen in this sample. The largest fragment of sandstone has irregular pale reduction spots at one end. Angular, single-crystal quartz grains from 0.05 to 0.25 mm long are abundant and indicate fine-grained sandstone. Polycrystalline cherty quartz grains are minor and accompanied by more abundant hematized grains than the previous samples of similar fine-grained sandstone. Yellowish clay-rich grains occur rarely in hematite-rich bands. Paler areas are rich in material that is isotropic and pale brown in transmitted light and whitish in low-angle incident light, passing into areas that are opaque and white in low-angle incident light (leucoxene or quartz–anatase–?zircon) with or without microcrystalline earthy hematite. Dark areas are flooded by hematite with small reduction spots showing probable leucoxene. There is very minor microporosity, again suggesting dissolved grains.

Nillibubbacca operations

Nillibubbacca Quartzite

South of the Great Northern Highway, the Melligo Sandstone is exposed as a narrow band of low outcrops trending southwest for around 18 km. About 3 km south-southeast of the highway, the Nillibubbacca quarrying operation, owned by Kimberley Quarry Pty Ltd, produces large quantities of hard, crushed sandstone material, mainly for use as concrete and road aggregate on mining lease M04/22 (Fig. 127b).

The extreme hardness of sandstones around the Nillibubbacca quarry area, may be attributed to a much more strongly developed degree of silicification than that present in sandstones to the north around Dampier Hill and the Argyle White quarry. At Nillibubbacca quarry the quartz-rich, white to pale brown, fine- to medium-grained silicified sandstone forms hard, blocky boulders up to 1 m^3 in volume that display a prominent conchoidal fracture pattern (Fig. 134a).

The *Nillibubbacca Quartzite* was trialled several years ago for dimension stone applications. Despite the stone's visually attractive appearance and ability to take a moderate to high polish, testing revealed that the stone was difficult to cut because of its apparent hardness (Appendix 4.60). Since that time, artisans have discovered the stone's excellent properties for the execution of finely detailed relief in sculptures, and several large works have been completed or are currently in production in the local area (Fig. 134b).

Petrographic description

White, quartz-rich, fine- to medium-grained sandstone, with minor hematite-stained polycrystalline quartz grains and rare tourmaline in an opaline silica cement with minor porosity.

This white sandstone has abundant, subrounded single-crystal and polycrystalline quartz grains to 0.3 mm in diameter. Polycrystalline grains are relatively minor (5%), mostly fine grained and cherty and partly stained by earthy hematite. Interstitial material (20–25%) is composed of clouded opaline silica with possibly 5% porosity. Minor tourmaline is present as small angular chips as well as rare, small grains of leucoxene.

Hamersley Basin

Karratha

Karratha Stone

The operating *Karratha Stone* quarry is located in an extensive area of quartz sandstone in the Pinderi Hills area, approximately 40 km south-southeast of Karratha (Fig. 135). Located adjacent to the Tom Price Railway Road, the quarry forms part of mining lease M47/1, one of three contiguous mining lease areas. These leases

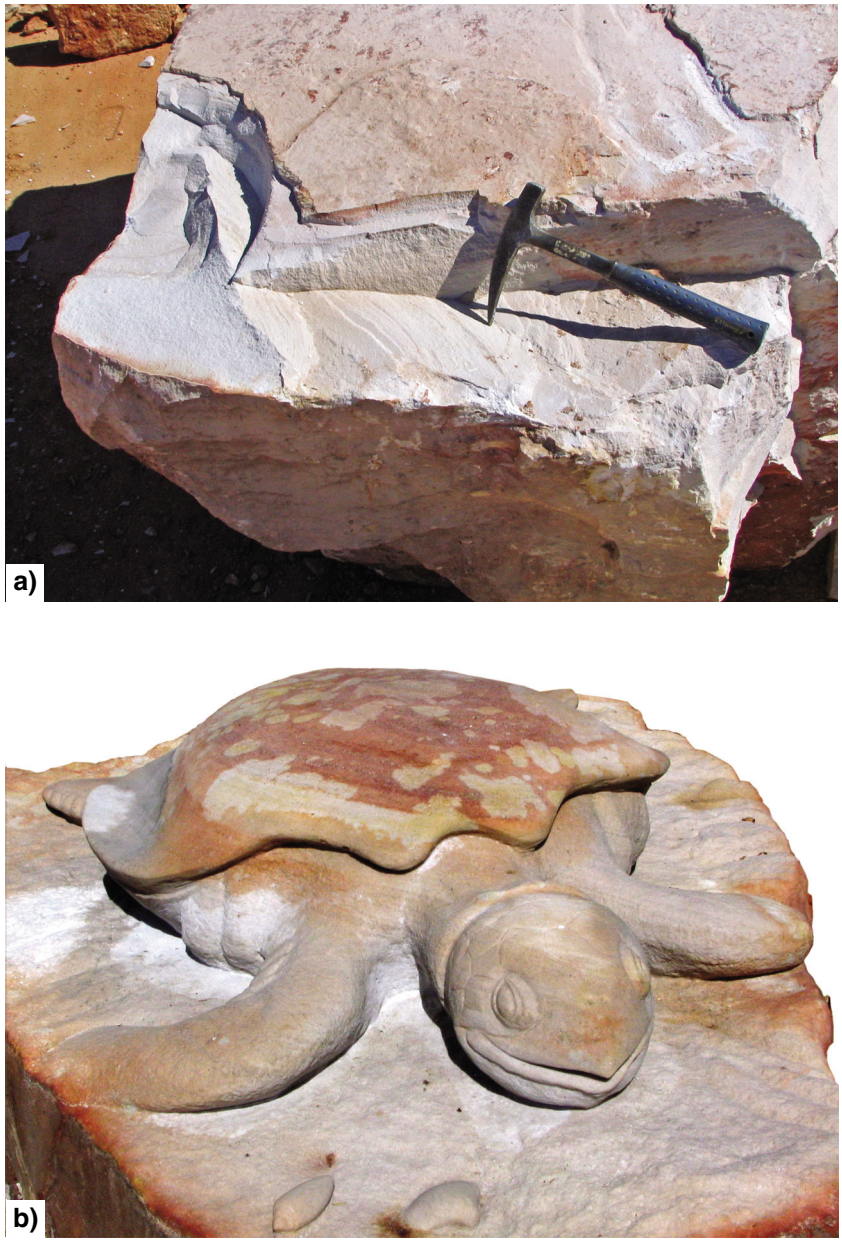
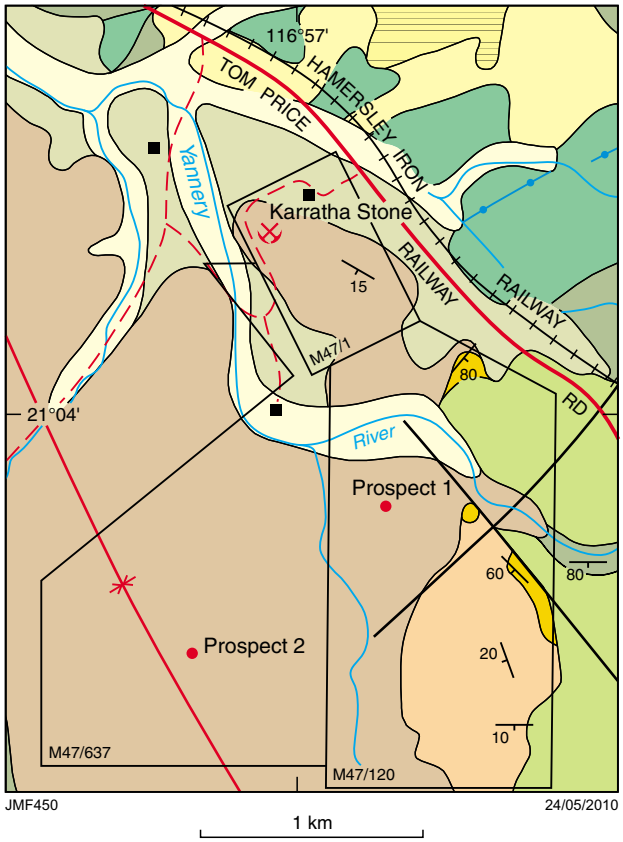


Figure 134. ***Nillibubbacca Quartzite*** **from the Nillibubbacca aggregate quarry, Derby region: a) a blocky boulder of very hard, fine-grained, resilicified, quartzitic sandstone displaying a prominent conchoidal fracture pattern; b) a finely detailed turtle sculpture carved by a local artisan from a block of** ***Nillibubbacca Quartzite*****.**



CENOZOIC
- Alluvium; sand and gravel
- Colluvium; sand, silt and gravel
- Sheetwash; sand, silt and clay
- Colluvium; dissected by recent drainage

ARCHEAN
- Quartz Vein
- Cooya Pooya Dolerite; fine medium-grained dolerite
- Hardey Formation; sandstone, conglomerate, siltstone, shale and tuff
- Hornfelsed felsic volcanic and sedimentary rock
- Poorly sorted sandstone, siltstone, and minor shale and conglomerate
- Metamorphosed gabbro and dolerite
- Metamorphosed basaltic rock

- Fault
- Syncline
- 15 Bedding showing strike and dip
- Quarry; sandstone, operating
- Prospect; sandstone
- M47/1 Mining lease boundary
- Road
- Track
- Railway
- Building
- Watercourse

Figure 135. Geology of the area surrounding the *Karratha Stone* quarry, Pinderi Hills area (modified after Kojan and Hickman, 2000) .





Figure 136. *Karratha Stone* quarry at Pinderi Hills: a) Archean sandstone of the Hardey Formation dipping gently to the southwest; b) an example of medium- to coarse-grained *Karratha Stone* with prominent liesegang banding.

Table 3. Major and trace element analyses of quartz sandstone from the Karratha Stone quarry

GSWA sample no.		*Detection limits*
189818a		
Major elements	**Percentage**	
SiO_2	81.3	*0.01*
Al_2O_3	8.58	*0.01*
CaO	1.16	*0.01*
MgO	2.74	*0.01*
Fe_2O_3	0.77	*0.01*
K_2O	2.41	*0.01*
Na_2O	0.01	*0.01*
P_2O_5	0.009	*0.001*
SO_3	0.02	*0.01*
TiO_2	0.09	*0.01*
MnO	0.01	*0.01*
LOI*	2.91	*0.00*
C	0.33	*0.01*
Cl	0.01	*0.01*
F	0.02	*0.01*
Trace elements	**Parts per million**	
As	3	*1*
Ba	148	*1*
Co	-5	*5*
Cr	20	*10*
Cu	10	*2*
Li	2	*0.5*
Mo	0.5	*0.5*
Ni	8	*2*
Pb	24	*1*
Sn	-1	*1*
V	10	*5*
Zn	20	*2*
Zr	41	*1*

NOTE: * LOI = loss on ignition at 1000°C

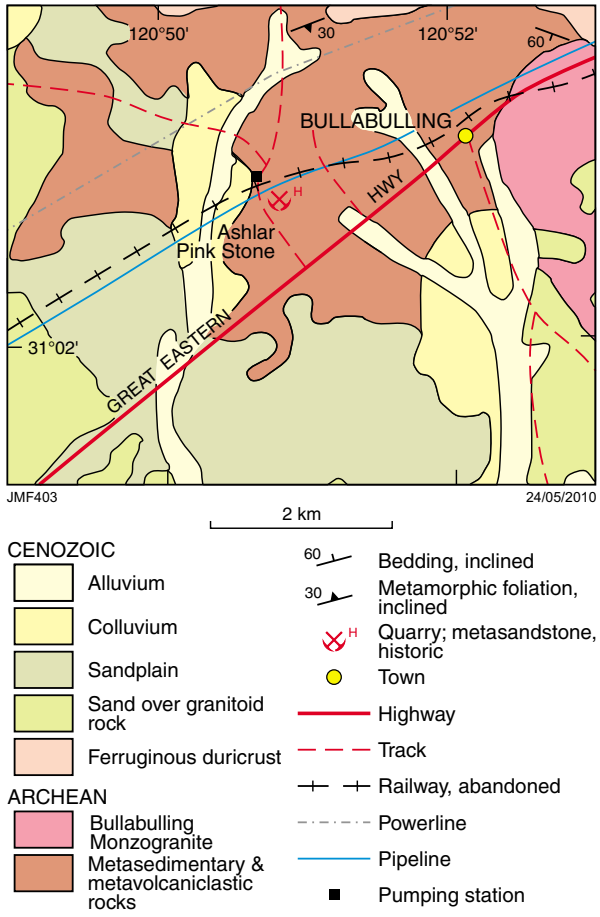


Figure 137. Geology of the Bullabulling area (modified after Hunter, 1988c).



Figure 138. The historic *Ashlar Pink Stone* quarry, 2 km west-southwest of Bullabulling.

extend over a substantial exposure of the Archean Hardey Formation, that is composed largely of quartz sandstone but also includes conglomerate, siltstone, shale, and tuff. Mining leases M47/1 and M47/120 are currently owned by Mr N Bell, while mining lease application M47/637 is registered to Mr D North.

Quarrying operations are located within a specific horizon of gently dipping quartz sandstone, up to 30 m thick, set into the northern side of a low hill. Considerable colour variations characterize the stone within the quarry. While most stone is a pale- to mid-brown colour, stone from different sites or layers varies from orange brown to red, dark brown, and mauve. Liesegang banding is also common (Fig. 136).

Much of the stone has a faint, pale green hue initially attributed to possible traces of base metals such as copper, chromium, or nickel. Analytical tests disprove this suggestion since all oxide values were in the normal range and base metal trace element values were rated as low to very low (Table 3). Subsequent petrological examination suggests that the pale green colouration may be caused by the presence of microcrystalline mica (sericite and phengite) and clay (illite) contained in interstitial material within the stone.

Stone extraction is achieved using an excavating machine to rip up stone layers which break easily along specific parallel, parting planes forming blocks of relatively consistent thicknesses mostly ranging from 2 to 10 cm and sometimes larger. Slabs of about 5 cm thickness, obtained by this extraction process, tend to have roughly triangular or subrectangular outlines and may reach 1 m^2 in area and are marketed as high-quality paving stones. Thicker sandstone blocks, 8–10 cm thick, 30–40 cm in length, and 15–20 cm in height are marketed as random-sized wall blocks that may be squared up by stone masons before assembly. The remaining irregularly shaped material is sold as crazy paving slabs for incorporation in paths and walls.

Technical specifications for *Karratha Stone*, supplied by Karratha Stone (2003), appear to fall well within ASTM standard values for sandstone (Appendix 2) and include:

- Absorption 0.5%
- Bulk density rated as ‘dense’
- Compressive strength 95.5 MPa
- Modulus of rupture 6.9 MPa

Karratha Stone has been used as a building stone at many sites in Karratha as entrance walls to the town’s airport and industrial estate, and also in public parks and private residences. Other works include a footpath mural at the entrance to Roebourne Police Station, and in Perth as internal floors and a staircase at Observation City Hotel, and external walls of recent buildings at Kings Park (Appendix 4.61).

Petrographic description

Quartz-rich, coarse-grained sandstone with minor polycrystalline grains, muscovite and altered biotite as well as leucoxene and hematite; interstitial sericite, illite, or phengite is common.

Abundant, mostly angular and subangular single-crystal quartz grains in this sample are from 0.25 to 1 mm in length, suggesting coarse-grained sandstone. These quartz grains rarely enclose sericite, apatite, or zircon. Polycrystalline quartz grains are not abundant, probably less than 10% and are mostly fine grained but some grains contain sericite, leucoxene or limonite, and one grain has lamellar possible hematite. Very minor detrital muscovite is disseminated as well as sericite–hematite or possible chlorite(–hematite–leucoxene) apparently derived from detrital biotite. Accessory leucoxene is disseminated. Interstitial material makes up possibly 20–25% of the thin section and is microcrystalline decussate sericite, illite or phengite, and may be the cause of the pale green colour as seen in hand specimen.

Southern region

Yilgarn Craton — Eastern Goldfields Terrane

Bullabulling

Ashlar Pink Stone

The *Ashlar Pink Stone* quarry is an historic dimension stone site, located 2 km west-southwest of Bullabulling town site, close to the old, abandoned Perth–Coolgardie railway line. The quarry is sited in an area of Archean metasedimentary and felsic metavolcaniclastic rocks (Fig. 137). At this site a small quarry has been cut out to a depth of about 4 m exposing a basal layer of deep pink to orange metasandstone beneath a white, kaolinized horizon and an overlying layer of weathered, reddish-brown surficial material (Fig. 138).

Ashlar Pink Stone was quarried for building blocks from this site, on mining lease No. 22, from as early as 1896 by the Wilke Brothers partnership. This stone was used for the construction of about 50 buildings, including houses and cottages built along the old railway line between Coolgardie and Southern Cross, as well as many buildings in Coolgardie that included the railway station, post office, Wilke’s Hotel, and the imposing Warden’s Court (Fig. 139). *Ashlar Pink Stone* was also used to construct the railway station in Kalgoorlie (Murray, 2003).

Ashlar Pink Stone was apparently easy to quarry but became relatively hard on exposure to air. In addition, the stone’s workability and attractive colouration would have made it a natural choice for building stone applications at that time (Appendix 4.62). Also, it would seem probable, in view of the large number of buildings constructed from this material, that there were additional quarries in this area extracting the same material. The whereabouts of other sites is currently unknown.

Petrographic description

Weathered, apparently metamorphosed sandstone; quartz–feldspar–biotite–muscovite schist with residual muscovite and quartz as well as kaolinite and hematite(–limonite).



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Figure 139. Warden's Courthouse, Coolgardie, constructed of blocks of *Ashlar Pink Stone* from Bullabulling.

This sample is rich in apparently metamorphic quartz from 0.2 to 2 mm in diameter, commonly as interlocking grains. Interstitial areas are partly rich in limonite(–hematite) and kaolinite, but also contain flakes of muscovite, some of which are shredded and interlaminated with kaolinite, with some patches of kaolinite(–muscovite) containing lamellar hematite or leucoxene, suggesting former biotite. However, some of the muscovite is poikiloblastic and has inclusions of quartz, and some kaolinite–hematite patches may represent former feldspar.

Chapter 6

Conglomerate and breccia

Central western region

Ashburton Basin

Wyloo area

Three Corner Conglomerate

The Three Corner Conglomerate prospect is situated on a high, east-trending ridge approximately 30 km east-southeast of Wyloo Homestead, and adjacent to the Nanutarra–Wittenoom Road (Fig. 140). This conglomerate, known as the Three Corner Conglomerate Member, forms the lowermost part of the Paleoproterozoic Beasley River Quartzite that unconformably overlies Archean–Paleoproterozoic rocks of the Hamersley Basin, which consist of BIF, shale, chert, mudstone, dolomite, and felsic volcanics (Fig. 141).

The close-packed conglomerate consists largely of subrounded to angular, laminated fragments of BIF, mostly deep red in colour together with lesser numbers of orange, brown and dark grey to black fragments. Fragment size mostly ranges from 20 to 100 mm in length (with some fragments considerably larger) and fragment length is generally parallel to the conglomerate bedding. The rock appears to be cemented by microcrystalline cherty quartz set in a sand of coarse, angular BIF particles (Appendix 4.63).

According to Trendall (1979), fragments in the conglomerate were derived from Hamersley Basin rocks with the banded BIF fragments being characteristic of the Weeli Wolli Formation, whereas the more rounded fragments were probably derived from Woongarra Volcanics, and clasts not readily identifiable, probably from other iron-rich formations of the Hamersley Group.

Although this stone is quite hard and takes a high polish with spectacular visual effects, it can be somewhat brittle and may require careful cutting. This property would probably limit its use to visually attractive, decorative, interior wall and floor tiles. Their main application would be in areas such as contemporary office foyers and boardrooms for the creation of striking visual effects.

Petrographic description

Conglomerate of laminated quartz–hematite BIF fragments with possible cement composed of cherty quartz.

Angular to subrounded fragments to 40 mm or more in diameter are present in this thin section and seem to be cemented by quartz. The fragments have microbands of hematite and quartz and mesobands of microcrystalline cherty quartz with small aggregates of hematite. Some of the hematite lamellae are microcrystalline but others are diffuse and earthy. A triangular area of possible cement is occupied by microcrystalline cherty quartz.

Yilgarn Craton – Murchison Terrane

Fields Find

Asteroid Breccia

The *Asteroid Breccia* dimension stone is located on a prospect 45 km northwest of Paynes Find, about 6 km southeast of the old Fields Find gold mining area (Fig. 142). The prospect was explored between 2006 and 2008 by Royal Resources Ltd, and Australian Gem Resources under mining lease application M59/727.

Sited adjacent to the northern extension of Mongers Lake, the *Asteroid Breccia* prospect is contained in a conglomeratic lens within a suite of Archean sedimentary rocks, mainly pelitic to semi-pelitic quartz–feldspar-rich rocks. The *Asteroid Breccia* is a conglomerate containing clasts mostly 10–20 mm but up to 40 mm in size, ranging from subrounded to angular in shape. The clasts are mainly chert and jasper with some quartz, set in a pink-coloured, cherty quartz matrix. The stone is very hard and takes a high polish (Appendix 4.64). It is suggested that this material would be suitable for spectacular, ornamental stone carvings.

Petrographic description

Sandy conglomerate with quartz, chert, and jasper in a cherty matrix, partly within fractures.

Well-rounded granules and small pebbles are abundant in this thin section and as much as 8 mm long. These larger fragments are mostly chert or banded jasper with various proportions of cherty quartz and earthy hematite in lenses or lamellae. Some of the chert and jasper fragments are weakly stained by earthy hematite and some have internal quartz veinlets, but some chert fragments are not clearly differentiated from the matrix. The matrix material also occupies a fracture in a jasper fragment and is composed of cherty quartz. Mostly angular single-crystal and rare polycrystalline quartz grains range from less than 0.1 mm to 3 mm in maximum dimension.

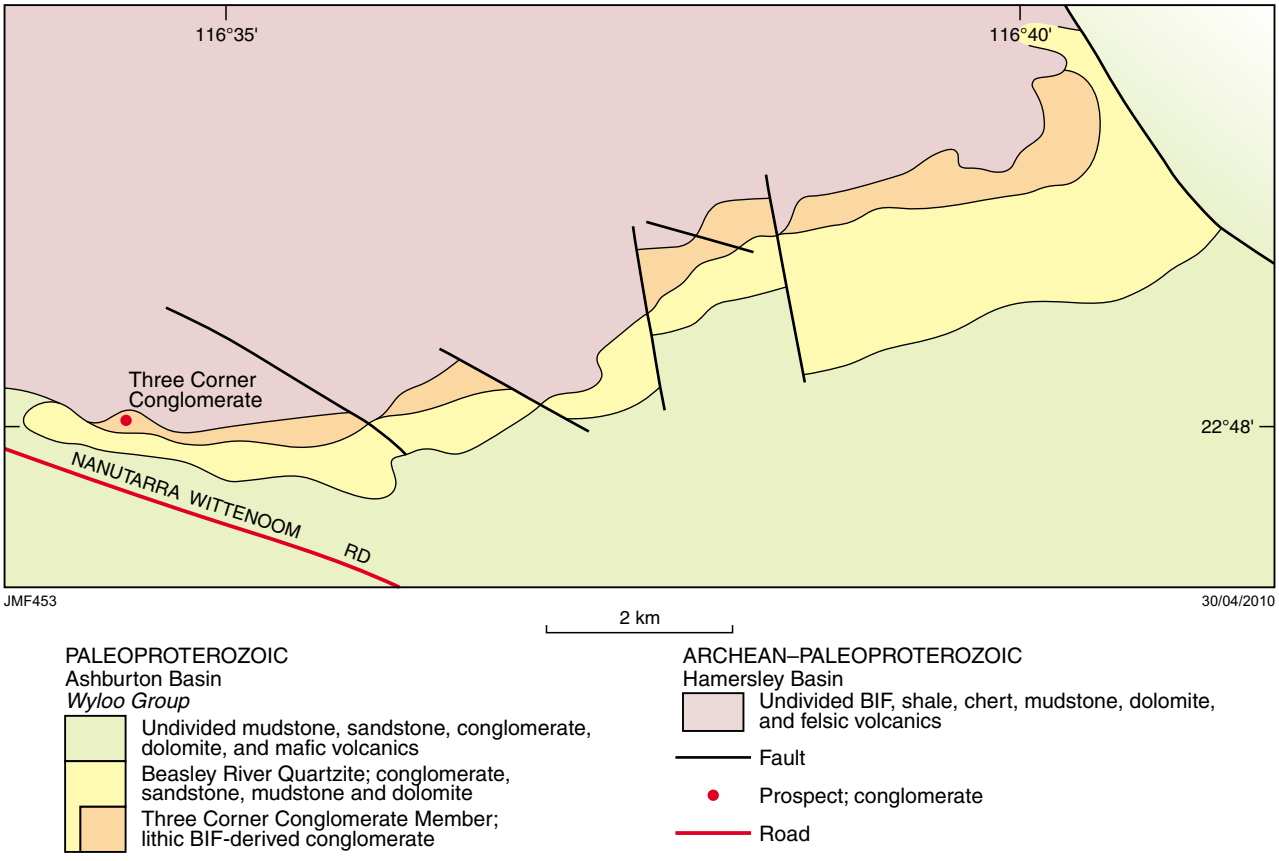


Figure 140. Geological sketch map of the distribution of the Three Corner Conglomerate (Thorne, AM, 2003, written comm.).

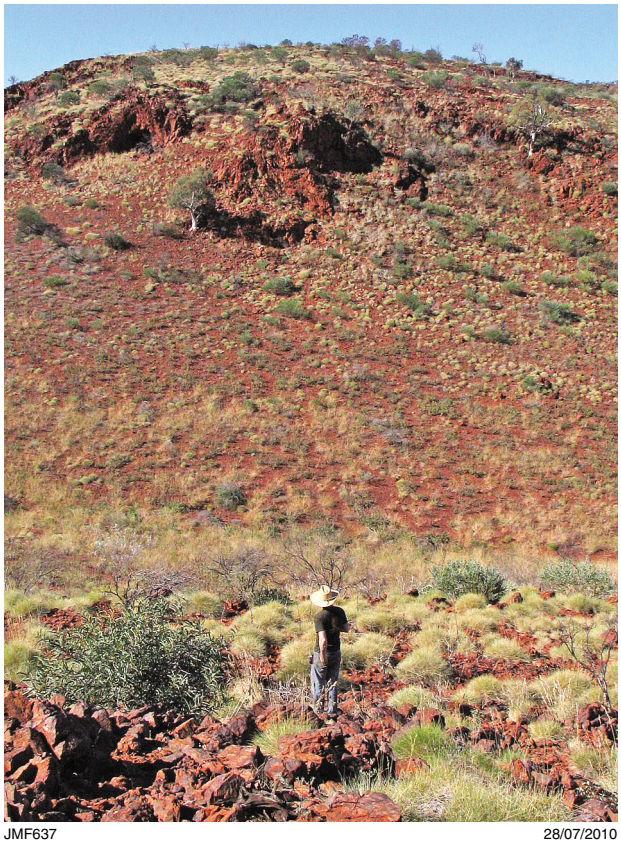


Figure 141. A steep, east-trending ridge of massive Three Corner Conglomerate in the Wyloo region.

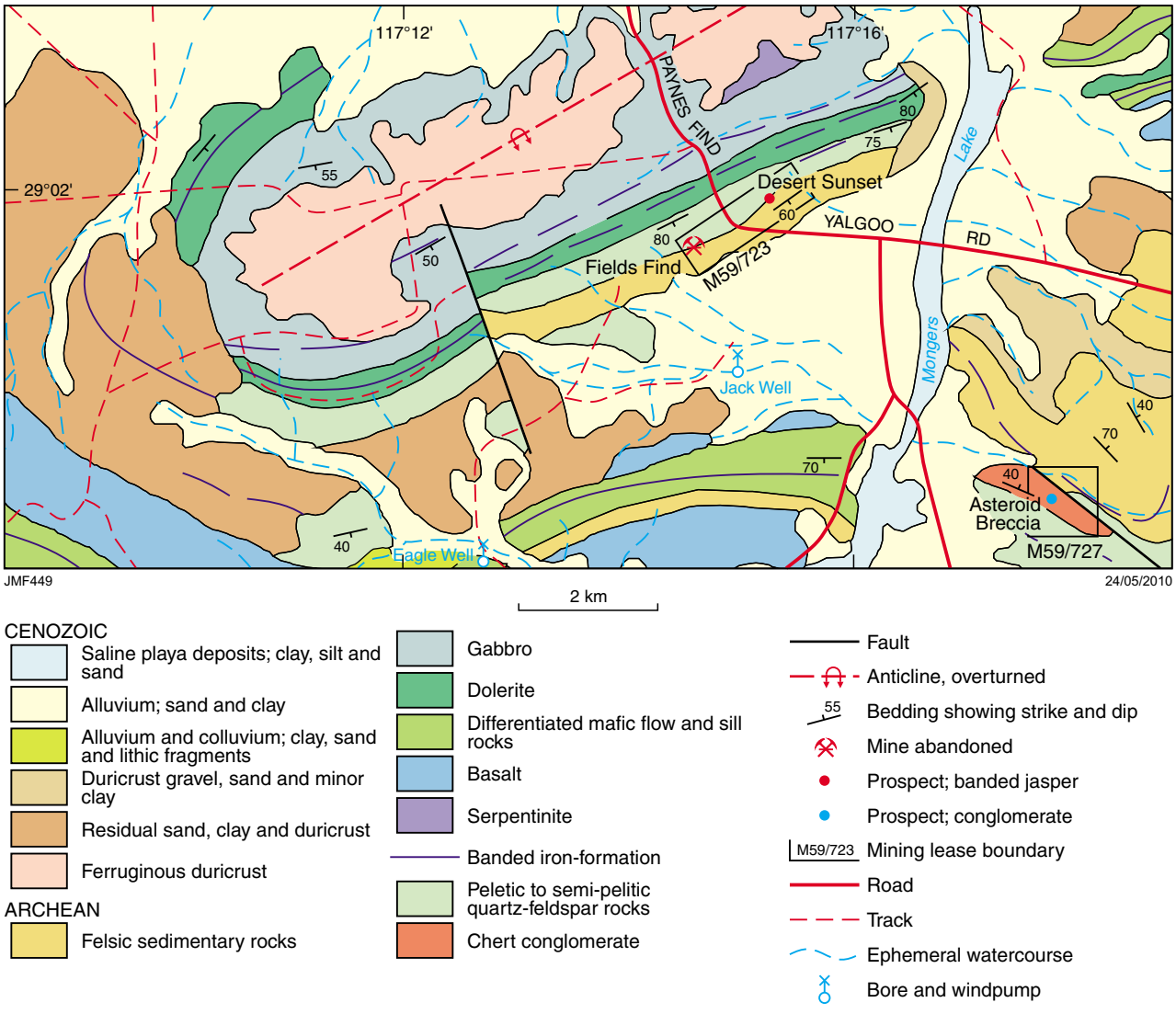


Figure 142. Geology of the Fields Find area (modified after Lipple et al., 1982).

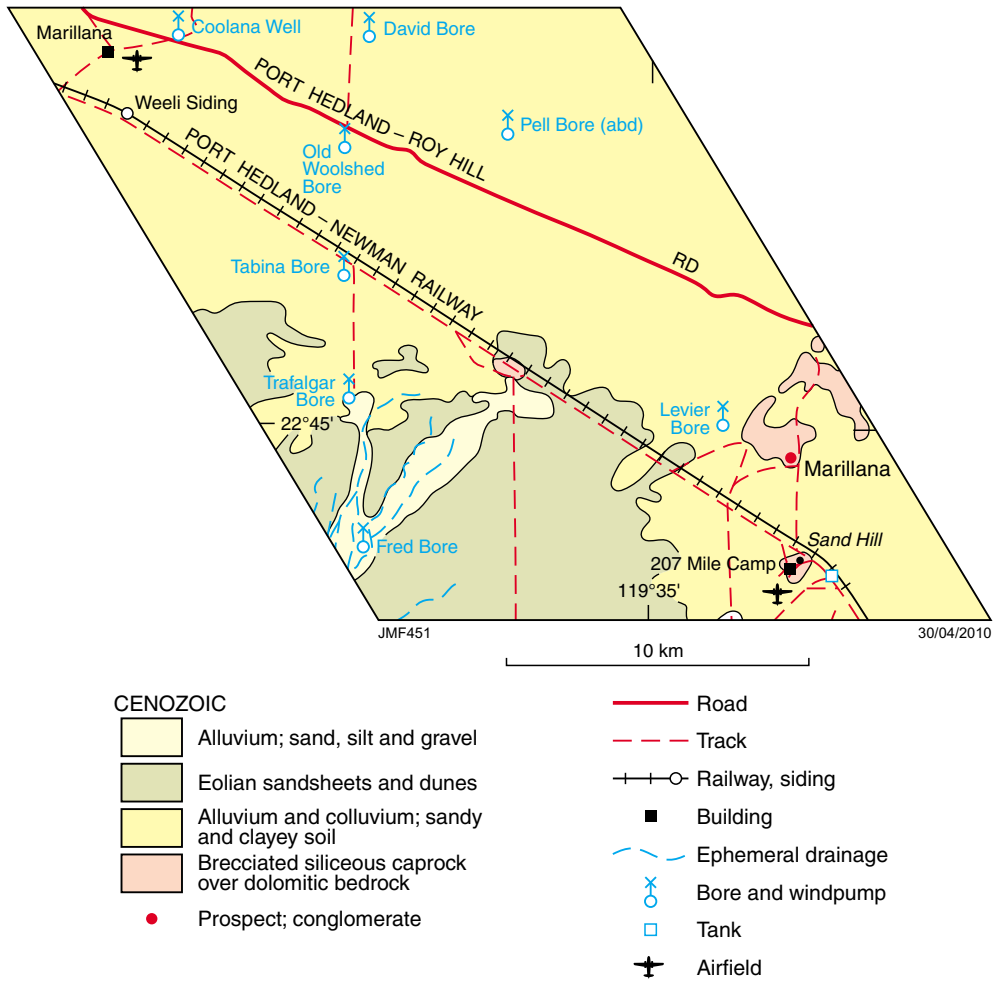


Figure 143. Geological map of the Marillana area, Fortescue River Plain, east Pilbara region (modified after Thorne and Tyler, 1996).

Northern region

Hamersley Basin

Newman area

Marillana Conglomerate

Located 75 km north-northwest of Newman, and about 25 km southeast of Marillana Homestead, the Marillana conglomerate prospect was explored in the early 2000s by prospector, Mr B Kayes (Fig. 143).

The prospect, situated in a large area of Cenozoic alluvial and colluvial material distributed over the surface of the Fortescue River Plain, appears to be contained within a small area of brecciated, siliceous caprock overlying dolomitic bedrock.

This beige-coloured stone, classified as a matrix-supported conglomerate or sedimentary breccia, is composed largely of brown, red, and cream, oval to angular clasts up to 60 mm in length × 20 mm width set in a brecciated, sandy siltstone matrix (Appendix 4.65). This visually attractive stone is quite hard and takes a high polish.

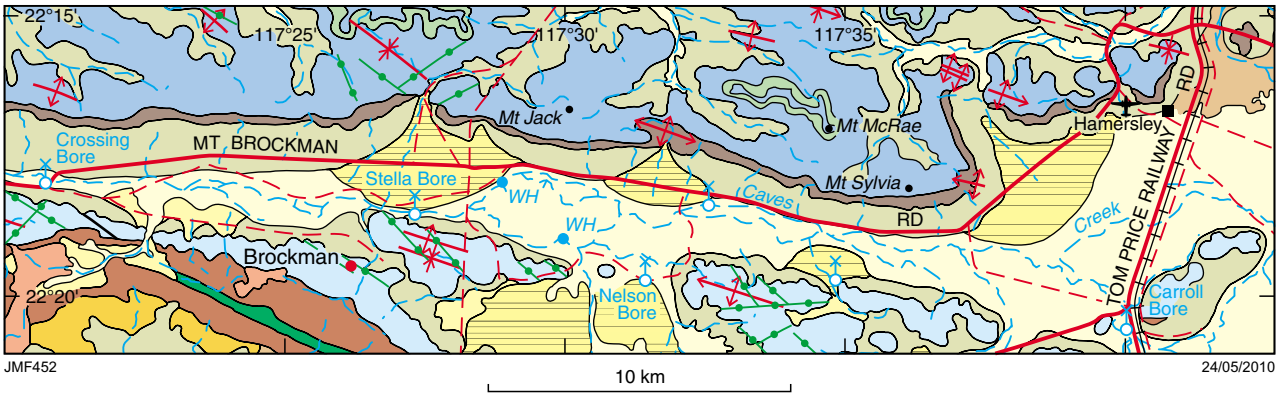
Petrographic description

A matrix-supported conglomerate or sedimentary breccia comprising variously hematite-rich, quartz-rich, and carbonate-rich fragments. This includes laminated, possibly hydrothermal, quartz-rich fragments, and rich microcrystalline granular to prismatic quartz, as well as carbonate-rich, and earthy hematite-rich fragments, in a matrix of mostly sandy siltstone.

Red, brown, grey, and white fragments to 50 mm long are visible in this sample in hand specimen but the thin section has few red fragments and reddish areas of matrix. In the thin section the most abundant fragments are laminated on a scale of 0.05 to 1.5 mm and have narrow lamellae of microcrystalline clouded quartz alternating with lamellae of very fine grained granular to prismatic quartz about 20–70 μm in diameter. One fragment may have been cut at a low angle to the layering, and some fragments have been further fractured and fragmented. Another fragment has an attached vein of granular quartz about 1 mm wide. Clay-rich fragments also occur, enclosing within them cherty quartz-rich fragments. Pale fragments are rich in clouded carbonate, but small red fragments either consist of earthy hematite or have lamellae of earthy hematite and cherty quartz. The matrix seems to be poorly sorted, sandy siltstone with sparse single-crystal quartz grains to 0.8 mm long, some hematite-stained areas, abundant quartz, and interstitial clay. Hematite-stained clay lenses are also present.



Figure 144. ***Desert Sunset*** **red and yellow-banded jasper from Fields Find area. Coloured bands range from about 10 to 100 mm in thickness.**



CENOZOIC

- Alluvium; silt, sand and gravel
- Colluvium; quartz and rock fragments in soil
- Alluvium and colluvium; sandy and clayey soil
- Colluvium; partly consolidated quartz and rock fragments in silt and sand matrix
- Calcrete
- Robe Pisolite; pisolitic limonite river channel deposits

ARCHEAN–PALEOPROTEROZOIC

- Metadolerite dyke

Hamersley Group

- Metadolerite sills in Hamersley Group
- Brockman Iron Formation; BIF, chert and pelite
- Mount McRae Shale and Mount Sylvia Formation; pelite, chert and BIF
- Marra Mamba Formation; chert, BIF and pelite

Fortescue Group

- Metadolerite sills in Fortescue Group
- Jeerinah Formation; pelite, metasandstone, chert, and basic and felsic volcanic rock
- Bunjinah Formation; metabasaltic flows and breccia, metamorphosed volcanic sandstone, and minor chert

- Fault
- Anticline, showing plunge
- Syncline
- Prospect; tiger eye jasper
- Road
- Track
- Railway
- Homestead
- Landing ground
- Ephemeral watercourse
- WH Waterhole
- Bore and windpump

Figure 145. Geology of the Mount Brockman area (modified after Blight et al., 1996).

Chapter 7

Banded jasper and tiger iron

Central western region

Yilgarn Craton — Murchison Terrane

Fields Find

Desert Sunset banded jasper

The Fields Find *Desert Sunset* banded jasper prospect, adjacent to the old gold mine of the same name, is located 50 km northwest of Paynes Find (Fig. 142). Over the period 2006–08, the prospect area was explored by Royal Resources Ltd, and Australian Gem Resources on mining lease application M59/723.

In the area of the mining lease application, Archean mafic, felsic, and sedimentary rock units contain interlayered, steeply dipping BIFs. These outcrop discontinuously in a southwesterly direction over a distance of approximately 2 km and range from a few metres to tens of metres in thickness. The BIFs in this area are rich in zones of coloured and banded jasper and contain relatively minor amounts of iron. Close examination revealed that these rocks are banded, limonite–hematite–quartz jasper containing visually attractive, broad red and yellow bands (Fig. 144; Appendix 4.66).

In 2008, follow-up exploration, including diamond drilling, was carried out to assess stone quality and possible resources. From these investigations, it was estimated that the prospect could contain a non-JORC resource of 0.9 – 1.2 Mt of high-grade banded jasper from a 10 m-thick body, over a strike length of 0.8 km. It was also proposed that the site could be mined on a campaign basis according to market demand. Mining could be by large block removal using a large-capacity excavator and blocks freighted to the Perth region for processing for the domestic market, or sent by container to overseas processing works, possibly in Italy or South East Asia.

In 2008, polished samples of *Desert Sunset* banded jasper were exhibited at the Marmomacc international trade fair in Verona, Italy. This unusual and attractively banded dimension stone received some strong interest.

Petrographic description

Banded limonite–hematite–quartz jasper with reduction spots and lenses rich in quartz(–chalcedony), cut by fractures with limonite or quartz or both, including partly quartz-rimmed voids.

This sample has bands on a millimetre to centimetre scale with various proportions of yellow or brownish limonite(–goethite–reddish earthy hematite). Some bands also contain or consist of microcrystalline quartz(–chalcedony), whereas others have small reduction spots (0.7 mm in diameter) of the same composition. This suggests there is low temperature silica throughout. Some quartz is also visible as diffuse lenses. The bands with reddish, earthy hematite are irregularly mottled. Crosscutting fractures are variously filled with limonite and microcrystalline quartz and there is a vein with limonite and irregular voids, commonly rimmed by microcrystalline quartz.

Northern region

Hamersley Basin

Mount Brockman

Brockman tiger eye jasper

Adjacent to the Caves Creek valley, about 55 km northwest of Tom Price, the Brockman tiger eye jasper prospect is situated on prospecting licence P47/1319, owned by Mr D Vaughan (Fig. 145). This prospect is located within the Archean Marra Mamba Formation (an important source of iron ore in the Pilbara region), which comprises chert, BIF, and pelitic rocks.

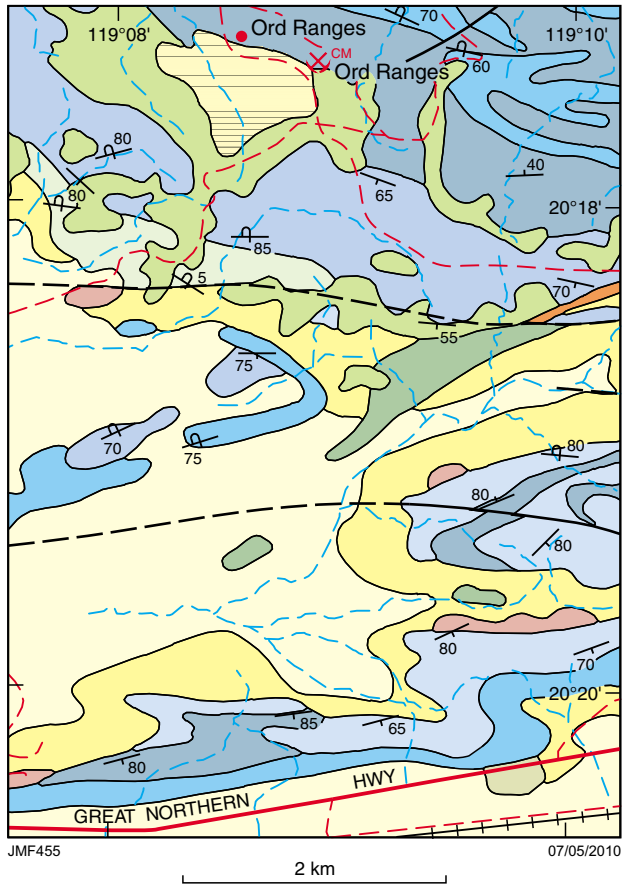
During 2005, the prospect was explored by costeaning using a heavy-duty excavator. This work uncovered a very large boulder of multicoloured, banded jasper interspersed with golden tiger eye. The boulder was removed by heavy machinery and transported to Perth for cutting into thick slabs approximately 3.5 m in length × 0.5 m in height and the costean backfilled and rehabilitated.

The polishing of this visually attractive rock has revealed its truly spectacular structure comprising multiple bands of green, blue, red, and orange jasper interspersperspersed with extensive bands and large, triangular-shaped blebs of golden tiger eye. The tiger eye has a chatoyant optical effect, in which a moveable, silky, golden sheen is reflected from the fine, parallel fibres present in the mineral (Fig. 146).

In recent years, large, polished slabs of this stone up to 3.0 m long × 0.5 m high have been displayed to some acclaim at stone trade fairs, most notably at the world-famous gem and semi-precious stone fair at Tucson, in Arizona, USA. Large slabs of Brockman tiger eye



Figure 146. Brockman tiger-eye jasper, Mount Brockman area.



CENOZOIC
- Sheetwash; silt, sand and gravel
- Colluvium; outwash fans of sand, silt and gravel
- Eolian sandsheets
- Colluvium; consolidated clay, silt and sand

MESOZOIC
- Callawa Formation; sandstone, siltstone and conglomerate

ARCHEAN
- Porphyry; metamorphosed
- Gabbro; metamorphosed

Nimingarra Iron Formation; metamorphosed
- Chert; laminated, weakly banded to massive, and chert and jaspilite
- Laminated white and grey chert, siltstone, sandstone and jaspilite
- Massive to weakly banded white chert
- Fine-grained sandstone and siltstone beds
- BIF, jaspilite, chert, and carbonaceous shale
- Ultramafic schist

- Fault
- Fault, concealed
- Bedding inclined
- Bedding vertical
- Bedding overturned
- CM Quarry; tiger iron, care and maintenance
- Prospect; tiger iron
- Highway
- Track
- Railway
- Ephemeral drainage

Figure 147. Geology around the Ord Ranges tiger iron quarry and prospect (modified after Smithies, 2002).





Figure 148. Ord Ranges tiger iron: a) massive BIF core-stones exposed in the Ord Ranges quarry (view looking north) b) a pair of polished tiger iron book-ends showing folded bands of hematite, cherty quartz, and golden tiger eye (courtesy Mr B Kayes).

jasper have since been marketed as visually spectacular slabs, designed for display as interior wall features in contemporary offices, boardrooms, and other architect-designed buildings (Appendix 4.67).

Petrographic description

A thick (50 mm) band or vein of possible minnesotaite (limonite-altered tiger eye) contained between layers of a banded host metasedimentary rock with veins of red earthy hematite, and hematite- and limonite-filled fractures and hematite-flooded zones.

An apparent vein to 50 mm wide dominates this saw-cut hand specimen consisting of compact fibrous orange-brown tiger eye, situated between layers of banded, grey, host metasedimentary rock with veins of red earthy hematite oblique to the layering. In thin section, the tiger eye is composed of decussate or fibrous possible minnesotaite intricately permeated by limonite. The host-rock is composed of compact dark grey decussate and microspherulitic possible minnesotaite, with lenses rich in fine-grained possibly oxidized opaque oxide. Lenses of fibrous quartz attached to the opaque oxide seem to represent pressure shadows and are roughly parallel to the layering. Irregular fractures have been filled by limonite and hematite and locally have envelopes flooded by hematite. X-ray diffraction analysis should be used to confirm the identity of the minnesotaite.

Pilbara Craton

Ord Ranges

Ord Ranges tiger iron

The Ord Ranges tiger iron deposits are located in the Ord Ranges about 60 km east of Port Hedland and immediately west of the north-flowing De Grey River (Fig. 147). In this area tiger iron deposits are present within a highly folded BIF, jaspilite, chert, and shale unit within the metamorphosed Archean Nimingarra Iron Formation.

About 2004, a small test quarry some 30 m across and 7.0 m deep was excavated at the Ord Ranges tiger iron site. This prospect forms part of prospecting licence P45/2514 owned by Messrs T Kapitani and J Pas. The main quarry, approximately 500 m to the east-southeast, is located on mining lease M45/67, currently owned by Zen Mining Pty Ltd. This is a comparatively large quarry measuring about 100 m in length, 50 m wide, and 15–20 m deep (Fig. 148). Although the quarry has been in care and maintenance for a number of years, a stockpile of large stones remains in a holding area close by.

Tiger iron consists mostly of alternating layers of microcrystalline red hematite and cherty quartz, with lenses and lamellae of golden tiger eye. The tiger eye was formed by the complete replacement of crocidolite by hard, fibrous quartz and limonite (Appendix 4.68). In the past, tiger iron has been used as decorative wall and floor tiles, table tops and in a diverse range of ornaments.

Petrographic description

Oxidized, folded BIF with oxide and chert microbands and lenses and lamellae of tiger eye composed of fibrous quartz and limonite.

This sample is composed of irregularly folded, oxidized BIF with some intrafolial folds that extend intermittently across layers. Oxide-rich BIF bands, on a millimetre to centimetre scale, alternate with lenses and lamellae of tiger eye. The oxide-rich bands are internally laminated with microbands mostly from 0.1 to 1.0 mm in apparent thickness. These bands are alternately rich in earthy or microcrystalline hematite and microcrystalline cherty quartz. Some quartz-rich lamellae also contain small irregular nodules with cores of quartz and rims of hematite. These bands have been irregularly folded and also cut by fractures and microfaults lined by hematite. Lenses and lamellae of tiger eye are as much as 5 mm wide and composed of mostly curved fibres of quartz and limonite or hematite, locally overprinted by coarse-grained quartz containing contorted lamellae of limonite or by fine-grained quartz. Narrow crosscutting fractures are also filled with fine-grained quartz.

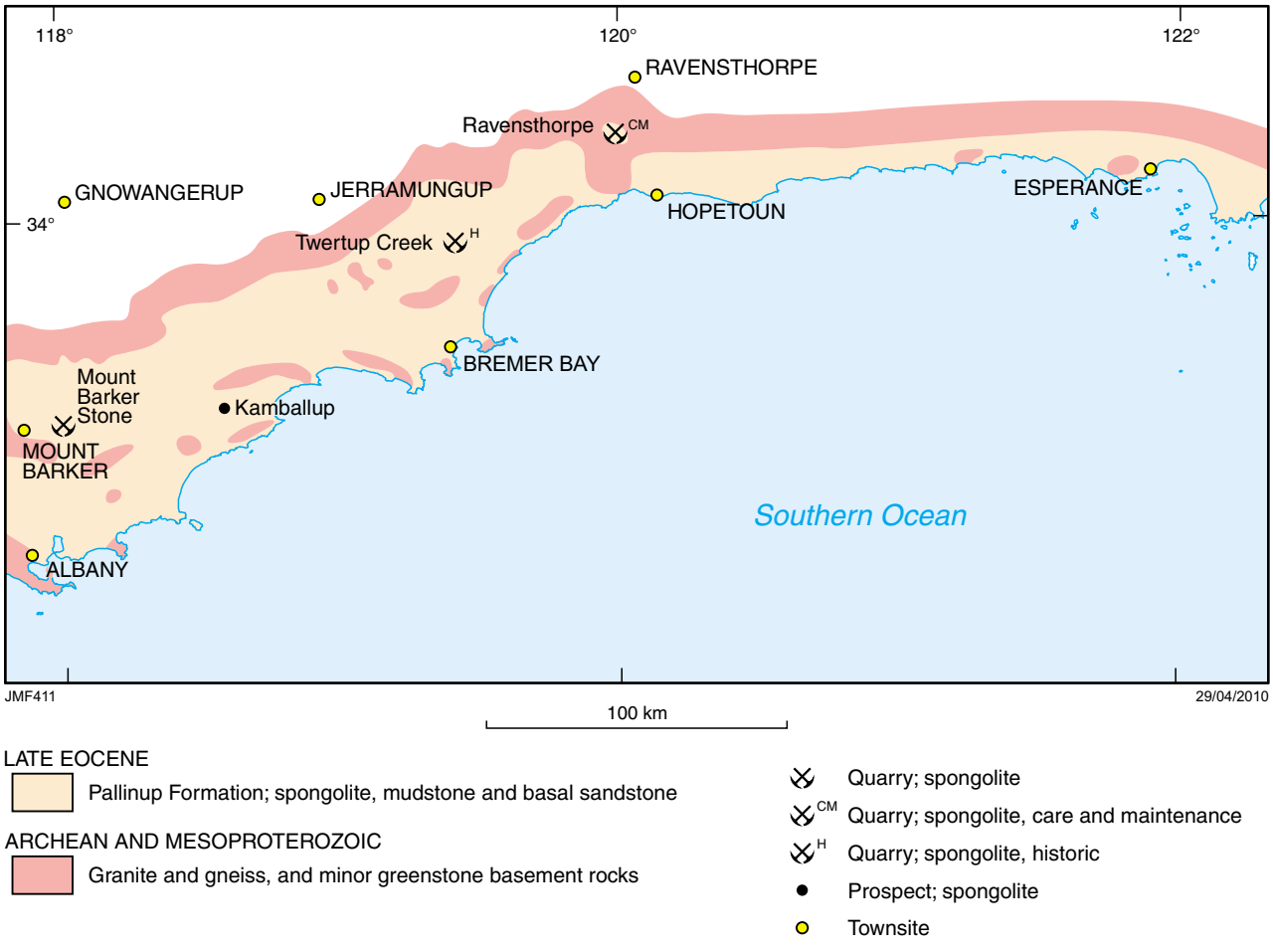


Figure 149. Generalized extent of the Pallinup Formation between Albany and Esperance showing locations of spongolite quarries and prospect (modified after Gammon et al., 2000).

Chapter 8

Spongolite

Southern region

Eucla Basin

Spongolite is a fine-grained, light-weight, porous rock composed mainly of spicules (small siliceous rods) that formed the skeletons of fossil sponges. In Western Australia, spongolite can be found in the Late Eocene Pallinup Formation (Plantagenet Group) along the southern coast of the State from Albany eastwards to Esperance and beyond, and inland as far as Norseman (Gammon et al., 2000; Fig. 149).

In the local area from Albany to Esperance, spongolite has been used as a building stone because of its visually attractive, off-white to pale yellow or beige colouration, light weight and good insulating properties, moderate strength, and the ease with which it may be sawn into building blocks. Between 1960 and 1990, spongolite was quarried sporadically from quarries at Twertup Creek, and Ravensthorpe. In 1979, it was recorded that total production for that year was 4193 t (Thom et al., 1984). More recently, spongolite has been quarried from Mount Barker, where it is known as *Mount Barker Stone*.

Mount Barker

Mount Barker Stone

The *Mount Barker Stone* spongolite operations, owned by Mount Barker Stone Pty Ltd, are located 12 km east of the town of Mount Barker on mining lease M70/80 (Fig. 149). Currently, the older quarry is partly filled with water but the method of block extraction, using a quarry saw to cut the flat-lying to gently dipping spongolite into finished-size blocks prior to removal from the pit, is still clearly visible (Fig. 150a). About 100 m north of the quarry, the next phase of mining operations has been completed where a spongolite prospect site has been cleared and levelled to form a cutting floor so that block cutting operations may commence without delay when the next phase of campaign mining commences (Fig. 150b).

Spongolite at this site is fine grained, off-white to cream coloured, and of moderate hardness when dry (Appendix 4.69). Towards the upper part of the spongolite horizon there is evidence of resilicification in the form of harder veins of siliceous, opaline material with the appearance of white porcelain. This weathering effect was also noticed by Ellis (1948) who collected samples for testing of the stone's refractory properties. These tests revealed that the fired spongolite had a porosity of 49.10% and a density of 1.05 t/m^3 clearly illustrating the stone's light-weight nature. More recent testing determined that the stone has low compressive strength, between 3.3 and 5.4 MPa (dry) (Stone Supply and Construction, 1999).

In recent years, spongolite blocks from Mount Barker have been used mainly in the local area although some blocks have been used for ornamental purposes as far away as Perth. The principal application is in the construction of walls for both commercial and residential buildings either as complete structures or as decorative features along with other building materials. An example of an ornamental application using large blocks of *Mount Barker Stone* to enhance a main entrance is shown in Figure 151.

Petrographic description

The spongolite consists of a mass of abundant, random sponge spicules and sparse siliciclastic debris (minor quartz, clay fragments, muscovite, tourmaline, and rutile) in a matrix of opaline silica (Fig. 152).

The sample examined contains abundant opaline sponge spicules to 2 mm long and possibly 7–8% angular single-crystal quartz grains about 0.1 mm in diameter, and small clay-rich fragments. The spicules are mostly hollow rods but some branching and bifurcating forms occur. Occasional cross sections have radial structures. The matrix appears to be opaline with small patches or fragments of pale material containing poorly preserved pale spicules. Some microporosity may also be present.

Kamballup

In the late 1980s, it was proposed to develop a small spongolite prospect at Kamballup, about 30 km east-northeast of Mount Barker (Fig. 149). At that time, the deposit was enclosed by mining lease M70/316. The owners, Messrs B May and M Fong, intended to develop the site as a quarry for cutting spongolite blocks. The finished blocks were to be transported by road to both local customers and to the Perth metropolitan area. No further information is available and it appears the proposed development did not proceed.

Ravensthorpe

Ravensthorpe quarry

The Ravensthorpe spongolite quarry is adjacent to Moir Road, about 14 km south-southwest of the town of

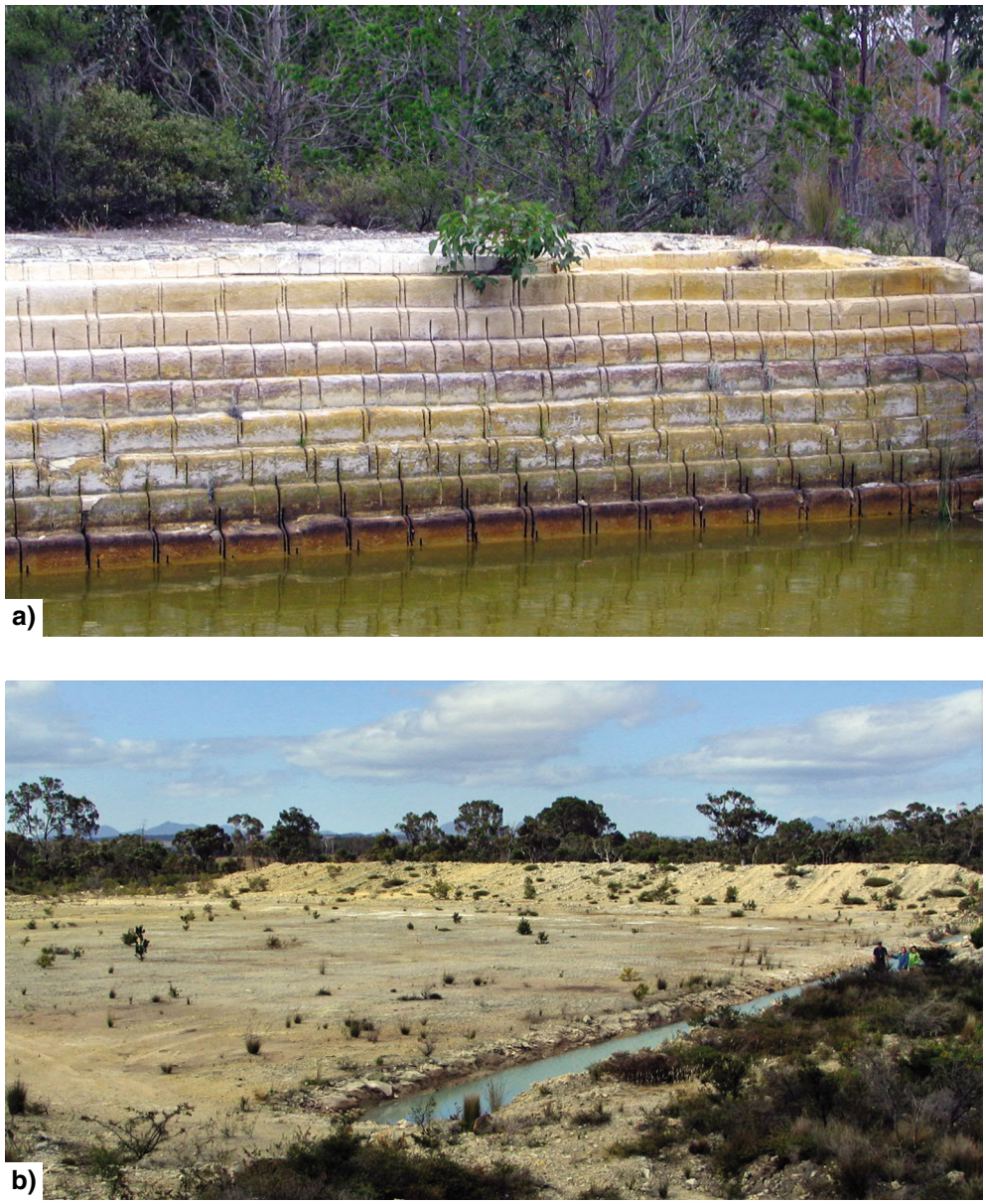
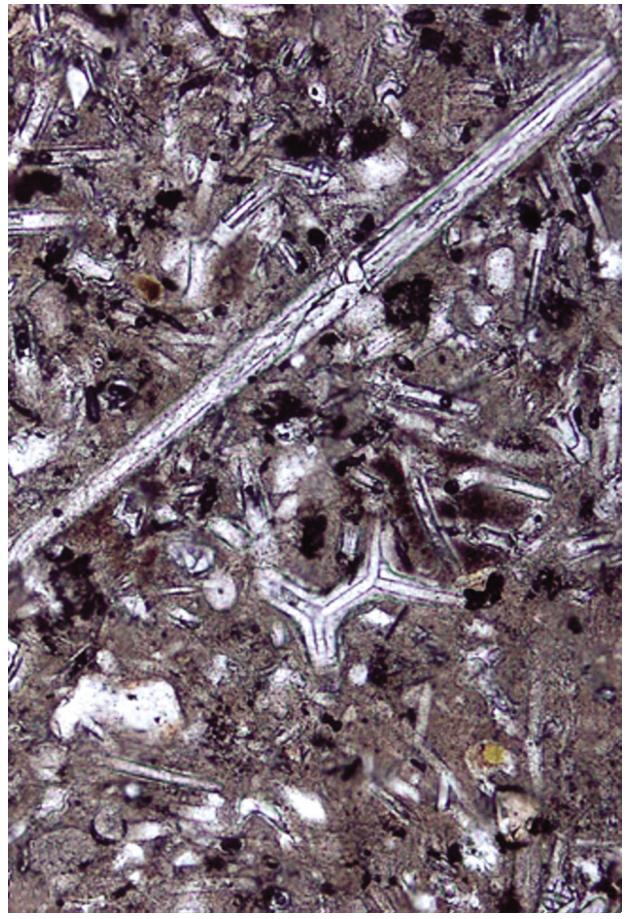


Figure 150. ***Mount Barker Stone*** **spongolite quarries 12 km east of Mount Barker: a) the upper 2 m of the older quarry showing sawn spongolite blocks prior to extraction; b) new quarry with levelled upper floor ready for block sawing operations.**



JMF628 28/07/2010

Figure 151. ***Mount Barker Stone*** **blocks used as ornamentation around a main entrance. Plantagenet Wines building in Mount Barker.**



JMF493 14/07/2010

Figure 152. Photomicrograph of siliceous sponge spicules in spongolite from Mount Barker (ordinary light, magnification × 100; after Purvis, 2009d).



JMF629 28/07/2010

Figure 153. Sawn spongolite blocks used in a wall in Ravensthorpe (blocks are approximately 0.5 m in length).

Ravensthorpe (Fig. 149). The quarry was in operation from the 1960s to the 1980s, during which time many houses were built of spongolite blocks in the town and surrounding area (Fig. 153). For example, it is reported that the quarry produced 2994 t for the year 1979 (Thom et al., 1984). Since that time, there appears to have been little activity at the site.

Bremer Bay

Twertup Creek

The Twertup Creek quarry is located approximately 41 km north of Bremer Bay (Fig. 149). This was a large quarry, situated on mineral claim MC1062H, from which spongolite building blocks were cut during the 1970s and 1980s. During this period it was recorded that the quarry produced 873 t in 1978 (Thom and Chin, 1984). Since that time, the quarry area has been incorporated into the Fitzgerald River National Park and is no longer available for quarrying.

Chapter 9

Other dimension stones

Coquinite

Central western region

Southern Carnarvon Basin

Hamelin Pool, Shark Bay

In the southeastern extremities of Shark Bay, older beach ridges as well as current beaches are composed of small white to cream bivalves, locally known as Hamelin Cockle *(Fragum erugatum)*. This shelly material, known as the Hamelin Coquina, washed up around the shorelines fringing the hypersaline waters of Hamelin Pool and Lharidon Bight (Fig. 154). The coquina is of Holocene age and has been deposited in these environments over the last 4000 years until the present day. Over this period, deposits up to 4 m thick, 1 km wide, and more than 50 km long have formed largely as a result of storms and cyclones (Townsend, 1996).

Behind the modern shoreline, this shelly material has been cemented by the precipitation of calcium carbonate forming, on exposure to air, relatively well indurated coquinite beach ridges. At times during the twentieth century, two quarries operated intermittently, sawing shell blocks for the construction of local buildings and walls (Fig. 155; Appendix 4.70). Buildings include the historic Saint Andrews Church (1954) and the Old Pearler Restaurant located in Denham, and Carbla Homestead east of Hamelin Pool.

Flagpole Landing

The shell block quarry is located adjacent to the historic telegraph station at Flagpole Landing in the far south of Hamelin Pool. This historic quarry is in care and maintenance and has been accessed in recent times only as a source of hand sawn coquinite blocks for the repair of historic buildings and other constructions in the Shark Bay area (Fig. 155).

Petrographic description

Loose aggregate of small bivalve mollusc shells composed of granular calcite.

This sample is a weakly cemented aggregate of mollusc shells (probably bivalves) to 10 mm long, with smooth and ribbed (costate) varieties locally having hinges. The shells are composed of granular calcite with interstitial voids.

Carbla Point

At Carbla Point, approximately 17 km to the north-northeast of Flagpole Landing, is an abandoned, historic coquinite quarry. This quarry also produced coquinite building blocks but apparently has not been in operation for many years.

Felsic volcanogenic rocks

Central western region

Yilgarn Craton — Murchison Terrane

Cue historic stone

The historic gold mining town of Cue is located 80 km north of Mount Magnet in the central west of the State (Fig. 156). Dating from the 1890s, Cue is host to many attractive stone buildings of the period. Notable among these are the Government Buildings built in 1896 to house, amongst other things, the police station and post office (Fig. 157). Other notable stone buildings dating from around 1895–1905, include the former Bank of New South Wales, the Gentlemen's Club (now the Shire of Cue Offices), Bell's Emporium, the old gaol, and the ruins of the old Cue hospital. Today, the exterior stone colour of most of these buildings is an attractive orange-brown but there are also some buildings in a cream/white stone (Appendix 4.71).

According to local historian, Mr K Anthony, the stone used to construct the majority of these buildings, known as *Perth Porphyry*, was sourced from a shallow shaft about 0.5 km north of the town. This is situated in a light-coloured area of ground known locally as the 'Pearling Grounds'. This locality cannot be positively confirmed because the building stone has been identified in the petrological description below as a weathered, altered, felsic volcanic rock, and the site in which it is supposedly located has been mapped as granodiorite (Fig. 156). More geological interpretation and historical research is required to establish a definite source for this building stone. Felsic volcanic rocks occur at several localities in the Cue district, especially in the Day Dawn area, about 7 km southwest of Cue where porphyritic, felsic volcanic rocks are present.

Petrographic description

Kaolinite–illite–quartz–leucoxene-altered felsic volcanic rock.

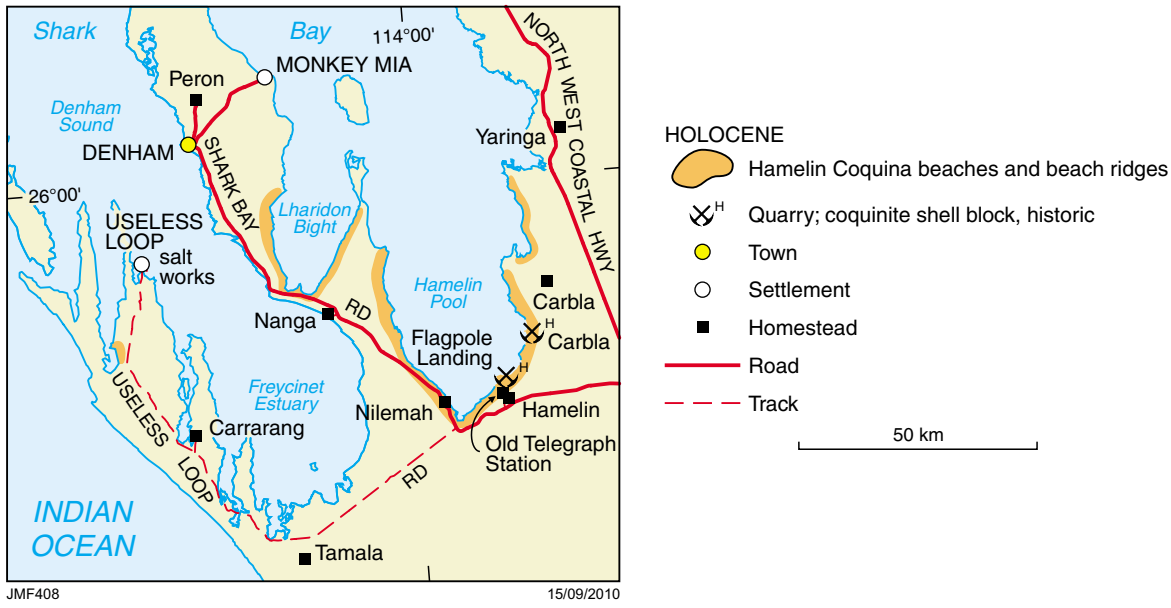


Figure 154. Distribution of Hamelin Coquina shoreline and beach ridge deposits at Shark Bay (modified after Townsend, 1996).



Figure 155. Shell block quarrying at Shark Bay: a) coquinite block wall at Monkey Mia. Block length is approximately 0.5 m; b) historic, hand-sawn shell block quarry at Flagpole Landing, Hamelin Pool.

This pale rock has sparse (3–4%) partly fractured quartz phenocrysts to 3 mm in diameter but is mainly composed of clay and mica minerals formed by weathering processes. These include illite(–kaolinite) derived from feldspar phenocrysts to 3 mm long, leucoxene-rimmed kaolinite(–illite)-altered mafic phenocrysts to 2 mm long, and an altered microcrystalline groundmass with quartz, sericite or illite, kaolinite, and sparse leucoxene.

Southern region

Yilgarn Craton — Eastern Goldfields Terrane

Kalgoorlie–Boulder

White Cliff Ashlar Stone

The White Cliff historic quarry is located within Government Reserve 37800 in an area of south Boulder, approximately 9 km south of the centre of Kalgoorlie City. The White Cliff quarry, that first appears on the 1902 Geological Map of Kalgoorlie (Maitland and Campbell, 1902), is located in a northwest-trending, zone of metamorphosed, Archean felsic volcanic and volcaniclastic rocks that form part of the Black Flag Group (Fig. 158).

At the quarry site, rocks consist of a variety of extremely weathered, clay-rich saprock and mottled saprolite most probably derived from felsic volcaniclastic rock, mainly tuff and other volcanic sedimentary rocks. Colours range from white to cream, yellow, red, and mauve, and liesegang banding is common. In the quarry, some weathered cut blocks remain. These blocks were extracted using drill and tap rods some of which still lie in the quarry or whose marks are still visible (Fig. 159; Appendix 4.72).

The *White Cliff Ashlar Stone* was quarried from around the mid-1890s until the early part of 20th Century. It was found that stone from this site was easy to cut into large blocks and to shape and dress in standard sizes. Also, after some exposure to the atmosphere, the ashlar stone hardened appreciably making it an acceptable building material with many applications. The stone also had considerable character with variations in colour and markings including attractive banding patterns. An advertisement by The Ashlar Building Stone Quarry Syndicate in the Kalgoorlie Miner newspaper of Thursday 19 May 1898 proclaims: "… and have Unlimited Quantities of First Class Building Stone Available — Stone acknowledged by experts to be without doubt the best in the district."

During this period, 13 hotels were built of *White Cliff Ashlar Stone* including the Palace Hotel in Kalgoorlie, the Court Hotel in Boulder, and the Boulder Block Hotel in Fimiston. Other buildings included the Wesley and Congregational Churches in Kalgoorlie, the Boulder Central, South Boulder, and Kalgoorlie Central State Schools, and the Boulder United Friendly Societies Hall. Perhaps the best-known example is the Kalgoorlie Government Public Buildings and clock tower that still contains the Post Office. Some 110 years since their construction, most of these buildings are still standing and are in generally good condition, owing largely to the quality and durability of the stone and the skill of the stone masons (Fig. 160). Other common applications for ashlar stone included structures in and around local mines, including mountings for boilers and retaining walls.

Petrographic description

Descriptions for two different samples from the White Cliff quarry, representing weathered material probably derived from felsic, volcaniclastic rocks are given here. These correspond with the images shown in Appendix 4.72:

(a) Red-banded quartz–sericite–clay that may have been derived from tuff, tuffaceous sedimentary rock, or quartz-phyric rock with xenoliths.

Sparsely scattered angular single-crystal quartz grains in this sample are from 0.1 to 3 mm long and appear to include quartz phenocrysts. There are also fragments from 1 to 4 mm long composed of quartz, clays and hematite (locally with clay and limonite) apparently derived from feldspar phenocrysts. The matrix is rich in microcrystalline quartz, sericite and indeterminate clay and has hematite in subparallel probable liesegang bands. This sample may represent tuff, tuffaceous sedimentary rock, or quartz-phyric rock with xenoliths.

(b) Cream to yellow, clay-rich, pebbly possible volcanogenic sedimentary rock or tuff with banded shale and possible volcanic fragments together with volcanic single-crystal quartz grains in a foliated clay-rich matrix.

This sample contains unsorted lithic fragments as well as areas with relatively minor angular single-crystal quartz grains to 2 mm in diameter in a fine-grained, foliated clay-rich matrix. One of the larger fragments is at least 20 mm long and over 10 mm wide and appears to be composed of bedded sericite-rich shale with beds of different grainsizes. Irregular spots and lenses of earthy hematite occur within this fragment. Another fragment, over 15 mm long and 5 mm wide, is clouded and clay-rich with disseminated single-crystal quartz grains and irregular voids. Smaller fragments are poorly defined, microcrystalline, and variously quartz rich to clay rich without inclusions of quartz or altered feldspar. Fractures filled with clays and quartz cut across the largest fragments and the adjacent matrix. This sample may represent a pebbly tuff or a sedimentary rock of partial volcanic origin.

Opaline silica

Northern region

Pilbara Craton

Wodgina

Wodgina opaline silica

The Wodgina opaline silica prospect is located approximately 95 km south of Port Hedland, and about 5 km north of the Wodgina tantalite mine (Fig. 161). The exact location of this prospect is uncertain but according

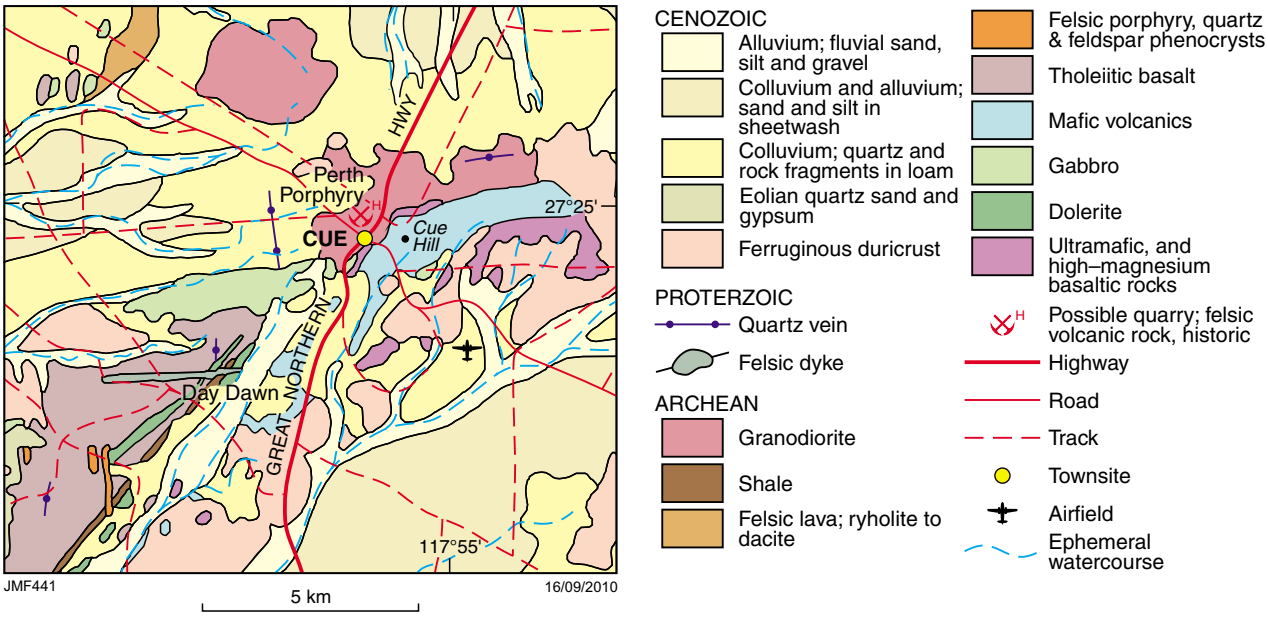


Figure 156. Geological map of the Cue district (modified after Watkins et al., 1986).



Figure 157. Government Buildings located in Cue in the State's central west. Constructed in 1896, these historic buildings were constructed from local stone, probably *Perth Porphyry,* a weathered, felsic volcanic rock.

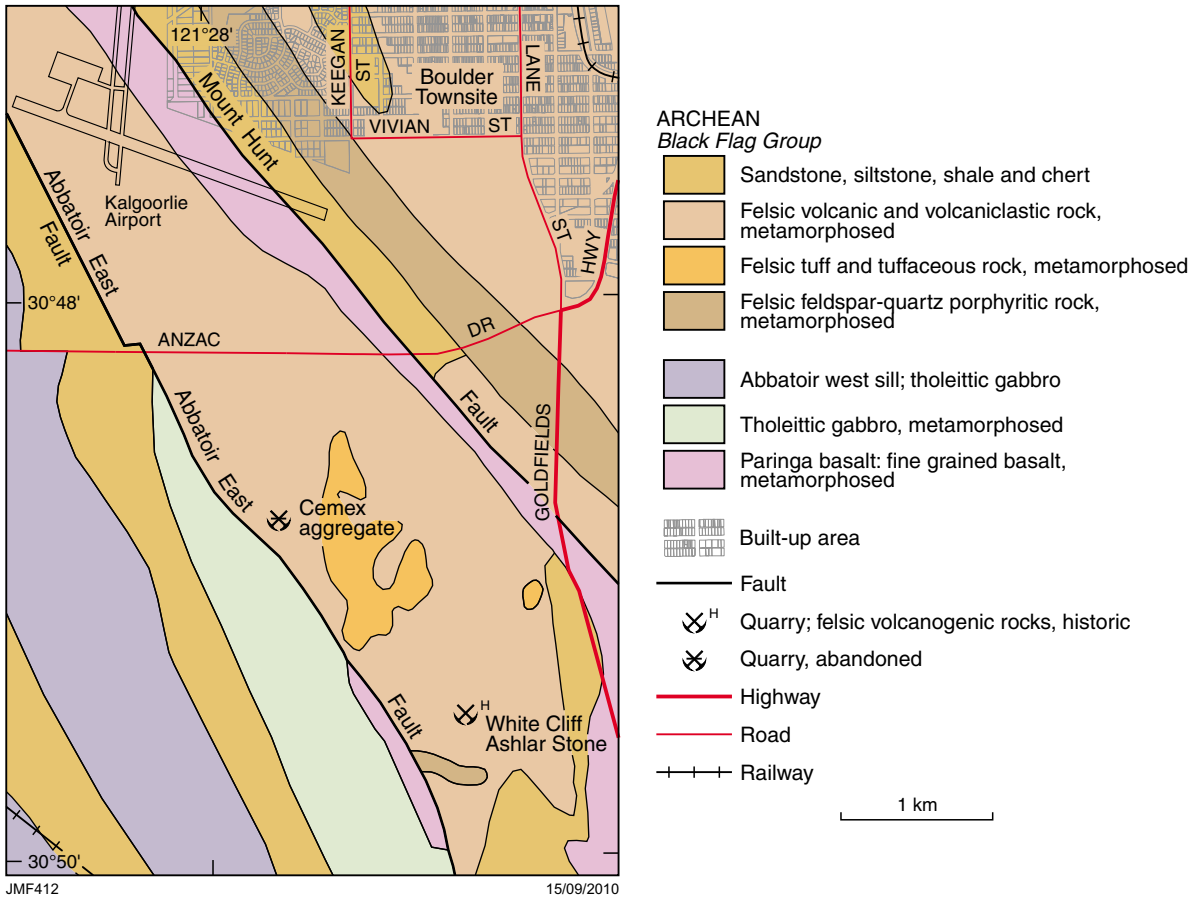


Figure 158. Solid geology map showing location of White Cliff quarry, City of Kalgoorlie–Boulder (modified after Kojan, 2007).



Figure 159. The historic *White Cliff Ashlar Stone* quarry about 3 km south of Boulder. A weathered ashlar stone block is visible behind the person in the foreground.



Figure 160. **Applications of *White Cliff Ashlar Stone* in Kalgoorlie–Boulder historic buildings: a) Post Office, Kalgoorlie; b) Court Hotel, Boulder; c) detail of hand-faced ashlar blocks, approximately 350 mm in length.**

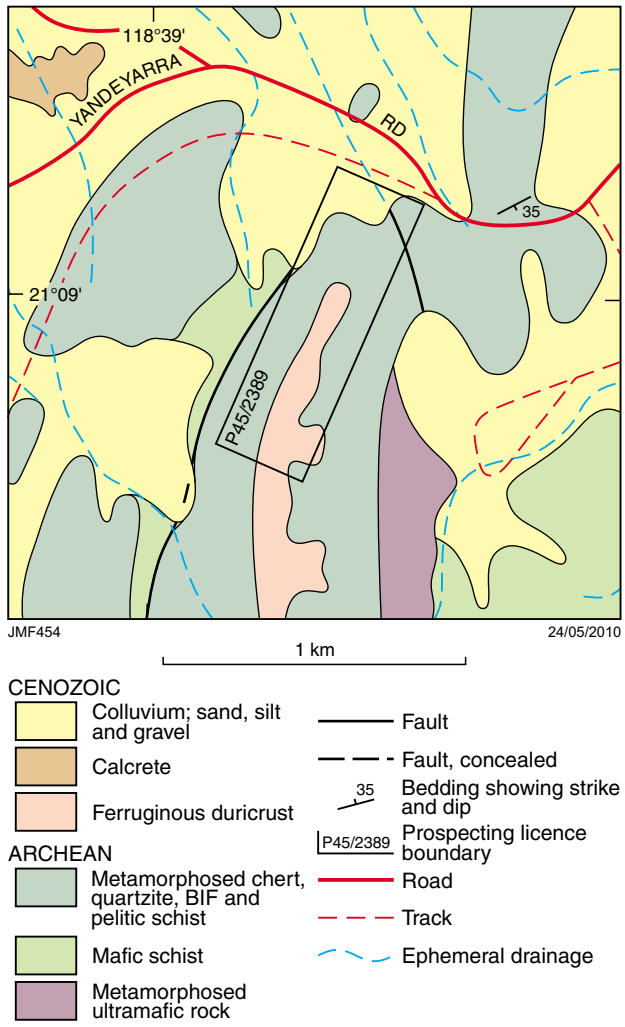


Figure 161. **Geological map of the area surrounding prospecting licence P45/2389 containing the Wodgina opaline silica prospect (exact location unknown) (modified after Blewett et al., 2001).**

to information from prospectors, it appears to lie within prospecting licence P45/2389, which surrounds a high, south-southwesterly trending mesa.

On two occasions, the author unsuccessfully attempted to locate the prospect site. It may be exposed as a ridge capping or enclosed within a steep section of this rugged terrain. The mesa appears to comprise mostly steeply dipping layers of Archean BIF and pelitic schist on the western side, and quartzite on the east.

The original specimen of opaline silica from this area, supplied some years ago by prospecting licence owners, Messrs I Duggan and J Skeffington, appears to be composed of pale beige to mid-brown irregular masses of microcrystalline sideritic carbonate up to 10 mm long and 5 mm wide, set in a white, vein-like matrix of opaline silica (Appendix 4.73a).

Also at that time, the opaline silica's property of fluorescing under short-wave UV light was recognized. When hard, polished slabs of this stone are exposed to this form of radiation, the opaline silica fluoresces in brilliant green and blue colours (Appendix 4.73b). It has been suggested that polished wall slabs of this very hard material could be used to decorate nightclub walls to take advantage of the stone's fluorescent property under pulsing UV light for an extremely spectacular optical effect.

Petrographic description

Fragments of microcrystalline carbonate (siderite) set in opaline silica cement including microspherulitic and microcrystalline chalcedony; also irregular patches of microcrystalline brown carbonate.

In hand specimen, this sample has a network of millimetre- to centimetre-scale white veins of matrix, and beige to brownish fragments. The thin section has rounded masses of relatively clear microcrystalline carbonate, probably siderite, to 10 mm long and 5 mm wide. The interstitial vein/matrix material is dominated by opaline silica but has microspherulitic lenses of chalcedony as well as microcrystalline quartz(–chalcedony). Some of the opal has irregular zones of microcline carbonate that is more brownish in colour than that in the fragments and is intergrown with opal and chalcedony. The opal is mostly isotropic but contains irregular anisotropic microfissures and lamellae, locally with a cross-fibre texture.

Chapter 10

Summary and future trends

This Mineral Resources Bulletin completes the two-volume series on dimension stone in Western Australia. Volume 1 (Fetherston, 2007) presents a current review of the dimension stone industry in which the history, physical aspects, quarrying techniques, processing, marketing, and stone restoration are discussed. Also included, is a description of dimension stone quarries, prospects, and historical sites in the southwest region of the State extending south from Geraldton to Margaret River, and east to Bruce Rock.

Volume 2 encompasses dimension stone quarries, prospects, and historical sites spread over accessible areas elsewhere in Western Australia. This includes the southern region covering areas around Albany, Esperance, Fraser Range, and Kalgoorlie–Boulder. The central western region extends from the Mount Magnet area west to Shark Bay and north to the Ashburton River, and the northern region includes areas of the west Pilbara around Port Hedland, Karratha, Tom Price, and Newman, as well as areas of the southern Kimberley region between Broome and Halls Creek.

This volume is based primarily on major dimension stone rock types; granite and metamorphic rocks, black granite, marble and sandstone, as well as an assortment of minor stones including conglomerate and breccia, banded jasper, spongolite, coquinite, felsic volcanogenic rocks, and silica. These rock types are listed within their broad regional context and tectonic unit. A total of 117 sites are described comprising 51 quarries, 56 prospects, and 10 historic sites. Of these, granite and metamorphic rock quarries have constituted the major operations with 19 quarries active at some period, mostly over the last 40 years, and some in operation to the present day. This is followed by black granite with 12 quarries, and marble and sandstone operations with eight quarries each.

Also included in Appendix 5 of this Bulletin is an addendum to Volume 1, where new information has recently become available on two dimension stone prospects in the Wambyn area, 20 km west of York. This includes more up-to-date information on the Wambyn black granite deposit as well as information relating to the Hurricane Hill saprolite, an unusual regolith material with potential application for paving stone.

Over the past 40 years, marketing of dimension stone produced in areas covered by this volume has tended to be directed mostly to the Australian domestic market with granites such as *Desert Brown* from Esperance, and *Verde Austral* from Fraser Range being shipped in large quantities to the eastern states, especially to Sydney and Melbourne for cladding of contemporary office buildings and in extensive streetscapes. *Kimberley Black* granite from the west Kimberley region was largely transported to Perth for processing and ultimate use in cladding buildings both locally and interstate. Currently, there is extensive use of the spectacular *Kimberley Sandstones* and *Kimberley Quartzite* from the Derby region for applications such as the paving and cladding of the award-winning Federation Square project in Melbourne. Also, beautiful coloured marbles, such as the *Pilbara Green* from the central west of the State, and the visually attractive *Kimberley Pearl, Kimberley Storm*, and *Albany Green* granites have all found applications in the construction industry throughout Australia.

Export markets for 10 t dimension stone blocks have centred largely on South East Asia with large quantities of high-quality *Kimberley Black* having been sent to countries such as Japan and Taiwan, especially for use in the funerary industry. Spectacular granites such as the *Kimberley Pearl* have been exported for use in building industry as polished panels and slabs in countries such as Italy, Japan, and Taiwan. Also, the gumleaf-green *Laguna Green* granite from Jerramungup in the central south of the State was used in the construction of the Australian War Memorial at Hyde Park Corner in London, where it received a number of architectural awards.

In 2010, the world market for dimension stone is dominated by low-cost cut stone-producing countries, especially China, India, and Brazil. This situation has meant that higher cost stone-producing countries, notably Australia, are for the most part unable to compete in stone cutting and polishing industries. Currently in Western Australia, our strength lies in the export of small quantities of high-quality and often unique stone types in the form of 10 t blocks.

It is quite possible that in future years Western Australia's export of dimension stone may improve markedly. This projection is due to a number of factors. The first of these is that in some of the more densely populated areas of the world, especially in more developed parts of Europe, dimension stone quarries are increasingly being closed down because of accelerating urbanization trends. This has the effect of causing these countries to import increasing quantities of high-quality stone for use in building construction and streetscape projects.

Secondly, future trends in rapidly developing countries such as China and India are likely to ensure that increasing

quantities of locally produced dimension stone are diverted into their own expanding domestic markets to cope with increasing local demand with correspondingly less material available for export.

Thirdly, the world dimension stone industry is becoming aware that Western Australia has considerable resources of high-grade and also unique types of spectacular stone, such as the *Boogardie Orbicular* granite, that may not be available anywhere else. Also, it is probable that most of the State's dimension stone resources will be available for development in future years without any likelihood of constriction of supply through increased urbanization.

Accordingly, it is possible that this situation may encourage large stone companies, experienced in the development of international dimension stone projects, to invest in new production areas in the State. It is possible that 'stone supermarkets' could be developed in resource-rich areas such as the high-grade granites, black granites and sandstones of the West Kimberley region, the multi-coloured marbles present in the extensive dolomites of the Edmund and Ashburton Basins in the central west, and in the high-grade granites, black granites, and metamorphic rocks of the Fraser Range region in the central south. Also, there are many individual deposits of high-quality stone, often of unique appearance, that may be available for future development such as the *Laguna Green* granite at Jerramungup, and the *Boogardie Orbicular* granite in the central west.

Should these trends in the development of the State's dimension stone industry come to fruition, it will ensure Western Australia will become a long-term exporter of high-quality dimension stone to world markets.

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Appendix 1

Dimension stone nomenclature and equivalent rock types

Commercial name	*Rock type*	*Commercial name*	*Rock type*	*Commercial name*	*Rock type*
Granite	Granite	**Basalt or trap rock**	Basalt	**Marble**	Marble
	Quartz monzonite		Andesite		Metalimestone
	Granodiorite		Dacite		Dolomitic marble
	Quartz diorite		Diorite[a]		Travertine marble
	Tonalite		Dolerite[a]		Serpentine marble
	Monzonite		Gabbro[a]		Onyx marble
	Diorite		Amphibolite[a]		Calc-schist
	Syenite		Peridotite[a]		
	Larvikite		Pyroxenite[a]	**Green marble**	Serpentinite
	Charnockite				Diopsidic marble
	Rhyolite	**Sandstone**	Sandstone		Peridotite
	Dacite		Quartz arenite		
	Granite gneiss		Feldspathic sandstone	**Greenstone**	Metabasalt
	Granofels		Arkose		Metadolerite
	Granulite		Litharenite		Metagabbro
			Ferruginous sandstone		Serpentinite
Black granite and grey granite	Dolerite		Calcareous sandstone		
	Gabbro		Conglomerate	**Slate**	Slate
	Hyperite				Siltstone and sandstone[a]
	Norite	**Quartzite and quartzitic sandstone**	Quartzite		Mica schist[a]
	Diorite		Quartzitic sandstone		Phyllite
	Peridotite				Metamudstone
	Anorthosite	**Flagstone**	Sandstone		
	Pyroxenite		Quartzite	**Other dimension stones**	Diatomite
			Siltstone		Tripolite
Trachyte	Trachyte		Slate		Spongolite
			Limestone		Alabaster
Bluestone	Basalt				Pumice
	Andesite	**Limestone**	Limestone		Scoria
	Feldspathic sandstone		Calcitic limestone		Tuff
	Siltstone (blue-grey)		Dolomitic limestone		Ignimbrite
	Bluestone		Calcarenite		Steatite/pyrophyllite
	Brownstone		Dolomite		Jasper
			Travertine		Tiger iron
Multicolour	Orthogneiss		Calcareous tufa		Hornfels
	Paragneiss		Coquinite		Schist
	Granulite		Oolitic limestone		Mylonite
	Migmatite				Lateritic duricrust
					Porcellanite

NOTE: (a) Fine-grained varieties

SOURCE: Fetherston (2007)

Appendix 2

Physical properties and ASTM standard specifications for the main dimension stone groups

Stone	*ASTM test*	*Absorption (weight %) C97 (max.)*	*Bulk density (t/m³) C97 (min.)*	*Compressive strength (MPa, dry) C170 (min.)*	*Modulus of rupture (MPa dry) C99 (min.)*	*Flexural strength (MPa, dry) C880 (min.)*	*Mohs hardness*	*Knoop microhardness*	*Abrasion resistance: Taber index (Ha) C1353 (min.)*	*Linear thermal expansion coefficient (µm/m/°C)*	
Granite		0.1 – 3.0	2.6 – 2.7	80–310	9.5 – 18.8	8–18	5–7	400–620	90–160	5–11	
	Granite	*0.4*	*2.56*	*131*	*10.34*	*8.27*	–	–	*25*	–	
Black granite (dolerite, gabbro and norite)		0.1 – 1.8	2.8 – 2.9	110–300	15–20	15–28	5–6.5	380–560	60–100	4–7	
Bluestone (basalt) (blue–grey metasiltstone)		0.3 – 4.0 0.87	2.7 – 2.9 2.7	50–280 209	10–90 19.1	11–16 na	4–6.5 na	360–480 na	50–90 48	2–5 10.3	
Sandstone (medium density)		2.0 – 25.0	2.0 – 2.6	20–240	5–13	4–16	2–7	na	5–40	2–12	
	Sandstone	*8*	*2.00*	*27.6*	*2.4*	–	–	–	*2*	–	
Quartzite		0.1 – 1.5	2.6 – 2.7	110–350	10–100	10–25	5–7	450–740	20–70	8–16	
	Quartzite	*1*	*2.56*	*137.9*	*13.9*	–	–	–	*8*	–	
	Quartzitic sandstone	*3*	*2.40*	*68.9*	*6.9*	–	–	–	*8*	–	
Limestone (medium density)		0.3 – 20.0	2.2 – 2.6	20–230	4–11	4–20	2–3	90–230	6–28	2–6	
	Low density	*12*	*1.76*	*12*	*2.9*	–	–	–	*10*	–	
	Medium density	*7.5*	*2.16*	*28*	*3.4*	–	–	–	*10*	–	
	High density	*3*	*2.56*	*55*	*6.9*	–	–	–	–	–	
	Calcarenite		19.0 – 27.5	1.5	3.5	na	2.5	na	na	na	na
Marble		0.1 – 1.5	2.6 – 2.7	40–190	4–30	7–19	2–4	80–220	8–35	3–7	
	Marble	*0.2*		*52*	*7*	*7*	–	–	*10*	–	
	Calcitic marble	–	*2.60*	–	–	–	–	–	–	–	
	Dolomitic marble	–	*2.80*	–	–	–	–	–	–	–	
	Serpentine marble	–	*2.69*	–	–	–	–	–	–	–	
	Travertine marble	–	*2.31*	–	–	–	–	–	–	–	
Slate		0.1 – 2.5	2.6 – 2.7	50–300	62	35–55	3–5	na	8–20	3–9	
	ASTM test	*C121*	–	–	*C120*	–	–	–	*C1353 (min.)*	–	
	Slate:exterior	*0.25*	–	–	–	–	–	–	*8*	–	
	– across grain	–	–	–	*62.1*	–	–	–	–	–	
	– along grain	–	–	–	*49.6*	–	–	–	–	–	

NOTES: *ASTM standard values in italics*
na: not available
µm: micrometres

SOURCE: Fetherston (2007)

Appendix 3

Location of quarries, prospects, and historic sites

Name	Operation	Status	Location	MGA values Zone	Easting	Northing	Owner/former owner	Tenement/licence
GRANITIC AND METAMORPHIC ROCKS								
Southern region								
Albany–Fraser Orogen								
Albany								
Albany Granite (Mount Clarence historic quarry)	Quarry	Historic site	1 km NE of Albany	50	581095	6124477	No owner	
Albany Granite (Mount Melville)	Quarry	Care and maintenance	2 km WNW of Albany	50	579055	6124135	Albany Monumental Masons	EIL
Albany Granite (Mount Melville historic quarries)	Quarry 1 Quarry 2 Quarry 3	Historic sites	2 km NW of Albany	50	579155 579092 579071	6124748 6124984 6125230	No owner	
Willyung Hill — granite	Quarry	Operating	10 km NNW of Albany	50	577586	6132791	Albany Monumental Masons (subleased from Cemex Aust.)	EIL
Esperance								
Desert Brown — granite	Quarry	Operating	14 km ENE of Esperance	51	410430	6259956	AustralAsian Granite Pty Ltd	EIL
Fraser Range								
American — granitic augen gneiss (FRG 143)	Quarry	Care and maintenance	110 km ENE of Norseman	51	489117	6462901	Fraser Range Granite NL/ Allied Granites Pty Ltd	E63/235 (dead)
Fantasia — mafic granulite (FRG 140)	Quarry	Care and maintenance	110 km ENE of Norseman	51	491259	6465548	Fraser Range Granite NL/ Allied Granites Pty Ltd	E63/284 (dead)
Garnet Ice — garnet–biotite gneiss	Quarry (FRG 145)	Care and maintenance	85 km ENE of Norseman	51	468771	6450802	Dimension Stone Group Australia Pty Ltd	M63/234
Horseshoe prospect — mafic granulite (FRG 138)	Prospect 1987–1993	Exploration	130 km ENE of Norseman	51	508108	6469457	Fraser Range Granite NL/ Allied Granites Pty Ltd	E69/267 (dead)
Phill's Prospect — mafic granulite (FRG 144)	Quarry	Care and maintenance	110 km ENE of Norseman	51	491037	6462228	Fraser Range Granite NL/ Allied Granites Pty Ltd	E63/284 (dead)
Verde Austral — gneissic granodiorite (FRG 135)	Quarry	Operating	100 km east of Norseman	51	485027	6435557	Dimension Stone Group Australia Pty Ltd	M63/235; M63/276
Yilgarn Craton–Eastern Goldfields Terrane								
Coolgardie								
Karramindie Soak — monzogranite	Prospect 1994–1995	Exploration	20 km ESE of Coolgardie	51	344562	6566460	Dodsley Pty Ltd	P15/3187 (dead); M15/1019 (dead)
Mungari Grey — monzogranite	Quarry 1	Abandoned	14 km NE of Coolgardie	51	332691	6582010	Stone Industries of Australia	M15/465 (dead)
Mungari Grey — monzogranite	Quarry 2	Care and maintenance	14 km NE of Coolgardie	51	332401	6585654	Red Emperor Developments	M15/644 (dead)
Yilgarn Craton–Southern Cross Terrane								
Boorabbin								
Boorabbin Rock — monzogranite	Quarry Prospect	Care and maintenance Exploration — 1994–1998	90 km WSW of Coolgardie	51	241831 241624	6544517 654495	Messrs Donnellan and Maynard	P15/3523
Koolyanobbing–Coolgardie								
Darrine Rock — monzogranite	Prospect	Exploration 1965	35 km ESE of Koolyanobbing	50	773191	6581768	No owner	

Yilgarn Craton–South West Terrane								
Jerramungup								
Albany Green — quartz syenite	Quarry	Care and maintenance	10 km WSW of Jerramungup	50	665181	6235626	Meloco Stone	EIL
Gairdner River Pink — quartz syenite	Quarry 1	Care and maintenance	8 km NE of Jerramungup	50	683912	6246599	No owner	EIL
	Quarry 2	Historic site	9 km ENE of Jerramungup	50	686414	6244131	No owner	
Laguna Green — quartz monzonite	Quarry	Care and maintenance	20 km SSE of Jerramungup	50	685224	6222767	Wales Quarries	EIL
Central western region								
Yilgarn Craton–Murchison Terrane								
Mount Magnet area								
Melangata Green — microdiorite	Prospect	Exploration 2005	100 km WNW of Mount Magnet	50	500848	6941198	H & J Jones and Sons Pty Ltd	E59/999
Boogardie — orbicular granite	Quarry	Care and maintenance	35 km west of Mount Magnet	50	547729	6895980	K Seivwright	M59/28
Boogardie — orbicular granite	North prospect	Exploration pre-2000	35 km west of Mount Magnet	50	547851	6896261	H & J Jones and Sons Pty Ltd	M59/493
Central prospect					547836	6896074	H & J Jones and Sons Pty Ltd	
Yalgoo								
Carlaminda Blue — lepidolite pegmatite	Quarry	Operating	16 km north of Yalgoo	50	470146	6880590	Oz Gem Pty Ltd	P59/1490 (dead)
							Zen Minerals Pty Ltd	M59/594
Northern region								
King Leopold Orogen								
Hooper Complex								
Wombarella Creek								
Kimberley Pearl — syenogranite gneiss	Quarry	Operating 1979–1992. 2008: care and maintenance	135 km ENE of Derby	51	702495	8094050	C Sim	M04/89
Kimberley Storm — syenogranite gneiss	Quarry	Operating 1980s. 2008: care and maintenance	135 km ENE of Derby	51	702480	8093701	Serenity Stone Pty Ltd	M04/202
Kimberley Ice — monzogranite gneiss	Prospect	Exploration 1996	140 km ENE of Derby	51	706911	8092894	Dodsley Pty Ltd, West Kimberley Black Granite Resources Pty Ltd	M04/301 (dead); M04/385 (dead)
Kimberley Ice — monzogranite gneiss	Quarry 1	Test quarries 1998	140 km ENE of Derby	51	708815	8091937	Dodsley Pty Ltd	M04/302 (dead)
	Quarry 2				708782	8091989	Dodsley Pty Ltd	M04/373 (dead)
BLACK GRANITE								
Southern region								
Albany–Fraser Orogen								
Fraser Range								
Fraser Range Black — metadolerite (FRG 106)	Quarry	Care and maintenance	115 km east of Norseman	51	500518	6447096	Fraser Range Granite NL/ Allied Granites Pty Ltd	E63/195 (dead)
Gold Leaf Black — ophitic dolerite (FRG 125)	Quarry 1	Care and maintenance	125 km ENE of Norseman	51	510393	6453930	Fraser Range Granite NL/ Allied Granites Pty Ltd	E69/283 (dead)
Gold Leaf Black — ophitic dolerite (FRG 142)	Quarry 2	Care and maintenance	115 km east of Norseman	51	502585	6447049	Raptor Exploration Pty Ltd	P63/1347
Central western region								
Edmund Basin								
Glen Florrie								
Glen Florrie Black — dolerite	Prospect	Exploration 1986–1997	48 km SSE of Nanutarra	50	369667	7465038	Pinniger/Australian Marble and Granite NL; Deacon, Dellar and Pember	E08/153 (dead) M08/51 (dead) M08/114
Maroonah area								
Maroonah Black — dolerite	Prospect	Exploration 2005–2007	25 km east of Maroonah Homestead	50	379100*	7402750*	R Pember and G Dellar	

Appendix 3 (continued)

Name	Operation	Status	Location	Zone	MGA values Easting	Northing	Owner/former owner	Tenement/licence
Gascoyne Province								
Maroonah area								
Chararoo Well — dolerite	Prospect	Exploration 1993–1994	25 km SSE of Maroonah Homestead	50	369368	7384496	Dodsley Pty Ltd	E09/603 (dead)
Manolini Well — dolerite	Prospect	Exploration 1994	10 km NE of Maroonah Homestead	*50*	*359432*	*7407567*	Dodsley Pty Ltd	E08/694 (dead)
Yilgarn Craton–Murchison Terrane								
Cue region								
Mindoolah — porphyritic dolerite	Prospect	Exploration 1999–2004	Mardoonganna Hill, 75 km NW of Cue	50	543334	7023786	D Caesar	M20/492 (dead) P20/1775 (pend.)
Mount Magnet region								
Boulder Well — gabbro	Prospect	Exploration 1996	65 km ESE of Mount Magnet	50	642800*	6861400*	Dodsley Pty Ltd	P58/950 (dead)
Mingyngura Hill — gabbro	Prospect	Exploration 1993–1994	Mingyngura Hill, 50 km ENE of Mount Magnet	50	634700*	6901800*	Dodsley Pty Ltd C Elkington	E58/133 (dead) P58/1381
Naluthanna Hill — gabbro	Prospect	Exploration 1993–1994	60 km ENE of Mount Magnet	50	642800*	6910200*	Dodsley Pty Ltd	E58/132 (dead) P58/949 (dead)
Palagea Rockholes — gabbro	Prospect	Exploration 1993–1994	85 km ESE of Mount Magnet	50	657391	6848064	Dodsley Pty Ltd	E58/135 (dead)
Pioneer Well — gabbro	Prospect	Exploration 1993–1994	75 km ENE of Mount Magnet	50	655148	6906557	Dodsley Pty Ltd	E58/134 (dead)
Paynes Find								
Doodhoowooroo — gabbro	Prospect	Exploration 1994	55 km ENE of Paynes Find	50	614800*	6786200*	Dodsley Pty Ltd	E59/498 (dead)
Yilgarn Craton–Narryer Terrane								
Erong Springs								
Erong Springs — dolerite	Prospect	Exploration 1994–1996	220 km NW of Meekatharra	50	455800*	7173000*	Marble and Granite Industries NL R W Thackwell	E09/692 (dead)
Yalbra								
Gum Creek Well — dolerite	Prospect	Exploration 1998–1999	265 km ESE of Carnarvon	50	416700*	7173000*	Foster Pty Ltd	E09/1030 (dead)
Northern region								
Halls Creek Orogen — Lamboo Complex								
Halls Creek								
McIntosh — gabbro	Prospect	Exploration 1994	Springvale Homestead, 50 km north of Halls Creek	52	360200*	8033800*	Clutha Minerals Ltd	E80/1553 (dead)
Kimberley Basin								
Inglis Gap								
Kimberley Jade — gabbro	Prospect	Exploration 1988–1991	160 km ENE of Derby	51	731372	8108678	C Sim	M04/90
Mount Hart								
Hart — dolerite	Prospects:	Exploration1991–1992						
	Mount Hart		160 km ENE of Derby	51	716900*	8125800*	Clutha Minerals Ltd	E04/713 (dead)
	Milliewindie		165 km east of Derby	51	746400*	8094400*	Clutha Minerals Ltd	E04/714 (dead)
King Leopold Orogen								
Hooper Complex								
West Kimberley								
Carpenter Gap — dolerite	Prospect	Exploration 1992–1994	150 km east of Derby	51	716445	8071747	Teedale Pty Ltd	E04/775 (dead)

Colemans Prospect — dolerite	Prospect	Exploration 1998–1999	80 km NNW of Fitzroy Crossing	51	751600*	8065800*	New Millennium Resources NL	M04/164 (dead)
Fairfield								
Fairfield 1 — metadolerite	Quarry	Operating 1998–1990. Care and maintenance	85 km NW of Fitzroy Crossing	51	729752	8061427	Kimberley Granite Resources Pty Ltd	M04/199 (dead 2008
Fairfield 2 — metadolerite	Quarry	Quarry abandoned	85 km NW of Fitzroy Crossing	51	730303	8061483	Kimberley Granite Resources Pty Ltd	M04/199 (dead)
Fairfield 3 — metadolerite	Quarry	Quarry abandoned	85 km NW of Fitzroy Crossing	51	730348	8061158	Kimberley Granite Resources Pty Ltd	M04/199 (dead)
Fairfield 4 — metadolerite	Quarry	Quarry abandoned	85 km NW of Fitzroy Crossing	51	730007	8061093	Kimberley Granite Resources Pty Ltd	M04/199 (dead)
Fairfield 5 — metadolerite	Quarry	Operating 1998–1990. Care and maintenance 2008	85 km NW of Fitzroy Crossing	51	729814	8061073	Kimberley Granite Resources Pty Ltd	M04/199 (dead)
Fairfield 28 — metadolerite	Prospect	Exploration 1998–1990	85 km NW of Fitzroy Crossing	51	729531	8061955	Kimberley Granite Resources Pty Ltd	M04/199 (dead)
Wombarella Creek and Quarry Camp								
Wombarella Creek								
Wombarella Creek — dolerite	Quarry	Operational 1989–1992			703455	8094998	C Sim	M04/87
	Prospect WC1	Exploration 1989–1992	135 km ENE of Derby	51	701200*	8094900*	C Sim	M04/84
	Prospect WC2				704000*	8094800*	C Sim	M04/85
	Prospect WC3				702200*	8095500*	C Sim	M04/86
	Prospect WC4				703000*	8095700	C Sim	M04/88
Quarry Camp								
Quarry Camp — dolerite	Quarry	Operating 1984–1990. Care and maintenance	145 km east of Derby	51	711934	8087319	McDonald Mining Pty Ltd Parry Corporation Ltd	M04/132 (dead) M04/49 (dead) and M04/74 (dead)
Quarry Camp south — dolerite	Quarries	Operating 1987	150 km east of Derby	51	715764	8085499	Black Granite Pty Ltd Parry Corporation Ltd	M04/154
New Quarry— dolerite	Quarry	Test mining 1985–1986	135 km east of Derby	51	702146	8088400	Parry Corporation Ltd McDonald Mining Pty Ltd	M04/227 (dead)
Quarry Camp — Prospects QC3 and 4 — dolerite	Prospects	Exploration 1985	145 km east of Derby	51	713017	8086482	Parry Corporation Ltd	M04/101 (dead)
Quarry Camp — Prospect QC6 — dolerite	Prospect	Exploration 1985	145 km east of Derby	51	713017	8086482	Parry Corporation Ltd	M04/100 (dead)
Quarry Camp — Prospect QC7 — dolerite	Prospect	Exploration 1985	145 km east of Derby	51	711331	8085171	Parry Corporation Ltd Norm Lowe Holdings Pty Ltd	M04/73 (dead) M04/377 (dead)
Quarry Camp — Prospect QC8 — dolerite	Prospect	Exploration 1985	150 km east of Derby	51	710806	8077598	McDonald Mining Pty Ltd Norm Lowe Holdings Pty Ltd	M04/62 (dead) M04/374 (dead)
Quarry Camp — Prospect QC9 — dolerite	Prospect	Exploration 1985	150 km east of Derby	51	708162	8085496	McDonald Mining Pty Ltd Norm Lowe Holdings Pty Ltd	M04/63 (dead) M04/375 (dead)
Quarry Camp — Prospect QC10 dolerite	Prospect	Exploration 1985	140 km east of Derby	51	705718	8084091	Parry Corporation Ltd McDonald Mining Pty Ltd West Kimberley Black Granite ` Resources Pty Ltd	M04/92 (dead) M04/376 (dead)
Wumburrul (QC5) — dolerite	Prospect and quarry	Exploration 1978–1985	145 km east of Derby	51	711447	8088315	D de Biasi	Unknown
	Prospect	1986–	145 km east of Derby	51	711447	8088315	C Sim	M04/119–122

Appendix 3 (continued)

Name	Operation	Status	Location	Zone	MGA values Easting	Northing	Owner/former owner	Tenement/licence
MARBLE								
Central western region								
Ashburton Basin								
Pannawonica								
White Gate Well — dolomitic marble	Prospect	Exploration early 2000s	25 km WSW of Pannawonica	50	403600*	7599500*	Locality discovered by B Kayes	
Wyloo–Ashburton Downs								
Cheela — calcitic marble	Quarry 1	Operating 1986–1987	60 km ESE of Wyloo	50	476150	7467187	Marbloc (WA) Pty Ltd (1986–1987)	E08/945 (dead)
	Quarry 2	2008: care and maintenance	Homestead	50	476089	7467180	Whitecrest Enterprises (1998)	E08/1272 (dead)
Wyloo — dolomitic marble	Quarry	Operating 1971–1975 2008: care and maintenance	17 km SE of Wyloo Homestesd	50	434293	7479022	Kinetic Mining Pty Ltd (1974–1975) Marbloc (WA) Pty Ltd (1986–1987) Stone Industries of Australia Pty Ltd	 M08/312
Success — dolomitic marble	Prospect	Exploration early 2000s	60 km WNW of Paraburdoo	50	509000*	7449900*	Locality discovered by B Kayes	
Beasley Pearl — marble	Prospect	Exploration 1986–1987	Cheela area	50	Location unknown		Marbloc (WA) Pty Ltd (1986–1987)	E08/89 (dead)
Cheela Grey — calcitic marble	Prospect	Exploration 1986–1987	Cheela area	50	Location unknown		Marbloc (WA) Pty Ltd (1986–1987)	E08/89 (dead)
Gala Mauve — ? dolomitic marble	Prospect	Exploration 1986–1987	Cheela area	50	Location unknown		Marbloc (WA) Pty Ltd (1986–1987)	E08/89 (dead)
Swan Black — ? dolomitic marble	Prospect	Exploration 1986–1987	Cheela area	50	Location unknown		Marbloc (WA) Pty Ltd (1986–1987)	E08/89 (dead)
Wonangara Rose — dolomitic marble	Prospect	Exploration 1986–1987	Cheela area	50	Location unknown		Marbloc (WA) Pty Ltd (1986–1987)	E08/89 (dead)
Kooline Opal — dolomitic marble	Prospect	Exploration 1986–1987	Wyloo area	50	Location unknown		Marbloc (WA) Pty Ltd (1986–1987)	E08/69 (dead)
Wyloo Smoky Pink — dolomitic marble	Prospect	Exploration 1986–1987	Wyloo area	50	Location unknown		Marbloc (WA) Pty Ltd (1986–1987)	E08/69 (dead)
Edmund Basin								
Glen Florrie								
Glen Florrie Black — dolomitic marble	Prospect	Exploration 2006	45 km SSE of Nanutarra	50	364400*	7464600*	Locality discovered by B Kayes	
Hooley Camp Hill — dolomitic marble	Prospect	Exploration 2003–2007	35 km SSE of Nanutarra	50	362000*	7474000*	Bambi Pty Ltd Deacon Nominees Tymor Pty Ltd GTI Resources Ltd	E08/1307 (dead) E08/1834 (pend.)
Minnie Springs Pink — dolomitic marble	Prospect	Exploration 1986–1993	65 km SSE of Nanutarra	50	365200*	7445600*	Australian marble and Granite NL Moonstone Resources NL	M08/56 (dead) EL08/650 (dead)
Minnie Springs White — dolomitic marble	Prospect	Exploration 1986–1990	55 km SSE of Nanutarra	50	359500*	7455500*	Australian marble and Granite NL	M08/131 (dead)
White Rocks — dolomitic marble	Prospect	Exploration 2004–2005	50 km SSE of Nanutarra	50	367538	7463612	B Kayes	E08/1486 (dead)
Maroonah								
Pilbara Green — dolomitic marble	Quarries:							
	Pilbara Green	Operating 2001–2005	25 km ESE of Maroonah	50	377262	7397522	Pilbara Stone Pty Ltd	M08/133 and
	Pilbara Green West	2008: care and	Homestead		376858	7397532	Pilbara Stone Pty Ltd	M08/175
	Pilbara Green Test	maintenance			377109	7397526	Pilbara Stone Pty Ltd	
Maroonah–Henry River — dolomitic marble	Exploration area	Exploration 2006–2008	From 16–26 km ENE to ESE of Maroonah Homestead		373000*	7404300*	Pilbara Stone Pty Ltd	E08/1888 (dead) E08/1963 (pend.)
	Prospects:							
	Bellotti			50	368742	7406894	Pilbara Stone Pty Ltd	P08/460 (dead)
	Pindanni				367605	7405846	Pilbara Stone Pty Ltd	P08/462 (dead)
	Sheela Bore North				375309	7399168	Pilbara Stone Pty Ltd	P08/461 (dead)
	Chain Pool				373517	7414373	Pilbara Stone Pty Ltd	P08/563
Maroonah Green — dolomitic marble	Prospect	Exploration about 2001–2005	30 km ESE of Maroonah Homestead	50	383466	7398826	Bambi Pty Ltd (R Pember) and Deacon Nominees	E08/1351
	Prospect	Exploration about 2001–2005	30 km ESE of Maroonah Homestead	50	383466	7397525	T Deacon and G Dellar	M08/82

Yarrie Pool — dolomitic marble	Prospect	Exploration 2005–2007	25 km ENE of Maroonah Homestead	50	375900*	7407700*	R Pember and G Dellar	
Nanutarra								
Bluff Well — dolomitic marble	Prospect	Exploration 2005–2007	20 km east of Nanutarra	50	365000*	7506700*	Pilbara Stone Pty Ltd	M08/315 (pend.)
Motin Bore — dolomitic marble	Prospect	Exploration 2006–2009	35 km SE of Nanutarra	50	373481	7489291	Pilbara Stone Pty Ltd	E08/1408
Nanutarra — dolomitic marble	Red quarry	Care and maintenance	30 km SE of Nanutarra	50	369303	7488285	Stone Dimensions of Australia	M08/149
	White quarry	since 2008	30 km SE of Nanutarra	50	369550	7488381	Stone Dimensions of Australia	M08/149
Parry Range — dolomitic marble	Quarry	Operating 1974–1975 2008: care and maintenance	25 km NNE of Nanutarra	50	350335	7531397	Kinetic Mining Pty Ltd G Robinson and W Rowe	M08/139
Ten Mile Well — dolomitic marble	Prospect	Exploration 2008	14 km ENE of Nanutarra	50	358083	7512670	Pilbara Stone Pty Ltd	E08/1544 (pend.)
Wadrah Bore — dolomitic marble	Prospect	Exploration 2006–2009	30 km SE of Nanutarra	50	369596	7489469	Pilbara Stone Pty Ltd	E08/1408
Paraburdoo								
Pingandy Grey — dolomitic marble	Prospect	Exploration early 2000s	90 km south of Paraburdoo	50	587300*	7342200*	Locality discovered by B Kayes	
Gascoyne Province								
Gascoyne Junction								
Weedarrah — dolomitic marble	Quarry	Exploration 1982 Operating 1991 2008: care and maintenance	60 km east of Gascoyne Junction	50	390376	7229440	Newmex Exploration Ltd Stone Enterprises Pty Ltd	M09/51
SANDSTONE								
Northern region								
Canning Basin								
Derby area								
Argyle White — quartz sandstone	Test quarry	Care and maintenance	70 km WSW of Derby	51	506281	8064675	Meteor Stone	M04/311
Kimberley Colourstone — quartz sandstone	Quarry 1	Care and maintenance	70 km WSW of Derby	51	503425	8068286	C Sim	M04/179
	Quarry 2	Care and maintenance	70 km WSW of Derby	51	503411	8068066	C Sim	M04/179
Nillibubbacca Quartzite — quartz sandstone	Quarry	Operating	70 km WSW of Derby	51	508407	8041334	Kimberley Quarries	M04/22
Kimberley Sandstone								
Kimberley Quartzite — quartz sandstone	Pale brown quarry	Operating	70 km WSW of Derby	51	503445	8067413	Meteor Stone	M04/357
Kimberley Sandstone — quartz sandstone	Multicoloured quarry	Operating	70 km WSW of Derby	51	503458	8067600	Meteor Stone	M04/357
Kimberley White — quartz sandstone	White quarry	Care and maintenance	70 km WSW of Derby	51	506069	8064603	Meteor Stone	M04/276
Hamersley Basin								
Karratha								
Karratha Stone — quartz sandstone	Quarry	Operating 2008	40 km SSE of Karratha	50	494639	7671332	N Bell	M47/1
	Prospect 1	Exploration 1987			495500*	7669800*	N Bell	M47/120
	Prospect 2	Exploration 2005			494300*	7669400*	D North	M47/637 (pend.)
Southern region								
Yilgarn Craton–Eastern Goldfields Terrane								
Bullabulling area								
Ashlar Pink Stone —	Quarry	Historic site	2 km WSW of Bullabulling	51	294921	6566644	No owner	
CONGLOMERATE and BRECCIA								
Central western region								
Ashburton Basin								
Wyloo area								
Three Corner Conglomerate	Prospect	Exploration 1980–1981	35 km ESE of Wyloo Homestead	50	456176	7478593	No owner for dimension stone	

Appendix 3 (continued)

Name	Operation	Status	Location	Zone	MGA values Easting	Northing	Owner/former owner	Tenement/licence
Yilgarn Craton–Murchison Terrane								
Fields Find								
Asteroid Breccia	Prospect	Exploration 2006–2008	45 km NW of Paynes Find	50	529000*	6783500*	Royal Resources Ltd Australian Gem Resources	M59/727 (pend.)
Northern region								
Hamersley Basin								
Newman area								
Marillana Conglomerate	Prospect	Exploration 2001–2004	75 km NNW of Newman	50	770200*	7481300*	B Kayes	E47/1070 M47/1233 (pend.)
BANDED JASPER and TIGER IRON								
Central western region								
Yilgarn Craton–Murchison Terrane								
Fields Find								
Desert Sunset — banded jasper	Prospect	Exploration 2006–2008	50 km NW of Paynes Find	50	524857	6787660	Royal Resources Ltd Australian Gem Resources	M59/723 (pend.)
Northern region								
Hamersley Basin								
Mount Brockman								
Brockman Tiger Eye Jasper — banded jasper	Prospect	Exploration 2005	55 km NW of Tom Price	50	544356	7531082	D Vaughan G Archer	P47/1319 M47/487 (dead)
Pilbara Craton								
Ord Ranges								
Ord Ranges Tiger Iron — banded jaspilite	Quarry Prospect	Care and maintenance Exploration 2004	60 km east of Port Hedland	50	724651 724167	7754851 7755251	Zen Mining Pty Ltd T Kapitani & J Pas	M45/67 P45/2514 M45/1185 (pend.)
SPONGOLITE								
Southern region								
Bremer Basin								
Mount Barker								
Mount Barker Stone — spongolite	Quarry Prospect	Care and maintenance Exploration early 2000s	12 km east of Mount Barker	50	573218 573203	6167419 6167516	Mount Barker Stone Pty Ltd Mount Barker Stone Pty Ltd	M70/80 M70/80
Kamballup — spongolite	Prospect	Exploration 1988–1993	30 km ENE of Mount Barker	50	590600*	6173500*	B May and M Fong	M70/316 (dead)
Ravensthorpe								
Ravensthorpe — spongolite	Quarry Prospect	Operational 1970s–1980s ?Care and maintenance Exploration 2008	14 km SSW of Ravensthorpe	50	776108	6267414	Unknown C Gillis	 P74/320
Bremer Bay								
Twertup Creek — spongolite	Quarry	Historic site (Operational to mid-1980s)	41 km north of Bremer Bay	50	719400*	6232500*	Unknown Now situated in the Fitzgerald National Park	MC1062H (dead)

COQUINITE								
Central western region								
Southern Carnarvon Basin								
Hamelin Pool, Shark Bay								
Flagpole Landing — coquinite	Quarry	Historic site	85 km SE of Denham	50	217147	7077059	No owner	
Carbla Point — coquinite	Quarry	Historic site	10 km SW of Carbla Homestead	50	222000*	7092600*	No owner	
FELSIC VOLCANOGENIC ROCKS								
Central western region								
Yilgarn Craton–Murchison Terrane								
Cue historic stone Perth Porphyry kaolinized felsic volcanic	Shaft (collapsed)	Historic site	0.5 km north of Cue	50	589000*	6966800*	No owner	
Southern region								
Yilgarn Craton–Eastern Goldfields Terrane								
Kalgoorlie–Boulder								
White Cliff Ashlar Stone	Quarry	Historic site	9 km south of Kalgoorlie	51	355005	6588816	No owner	
OPALINE SILICA								
Northern region								
Pilbara Craton								
Wodgina								
Wodgina Opaline Silica	Prospect	Exploration 1999	95 km south of Port Hedland	50	671900^	7660300^	I Duggan and J Skeffington	P45/2389 M45/932 (pend.)

NOTES: All sites are listed in the Department of Industry and Resources online MINEDEX mines and mineral deposits database

* position approximate ^ location uncertain (pend.): pending issue of lease or licence

E: exploration licence P: prospecting licence M: mining lease

EIL: extractive industry licence

Appendix 4

Photo image gallery of dimension stones from the southern, central western, and northern regions of Western Australia

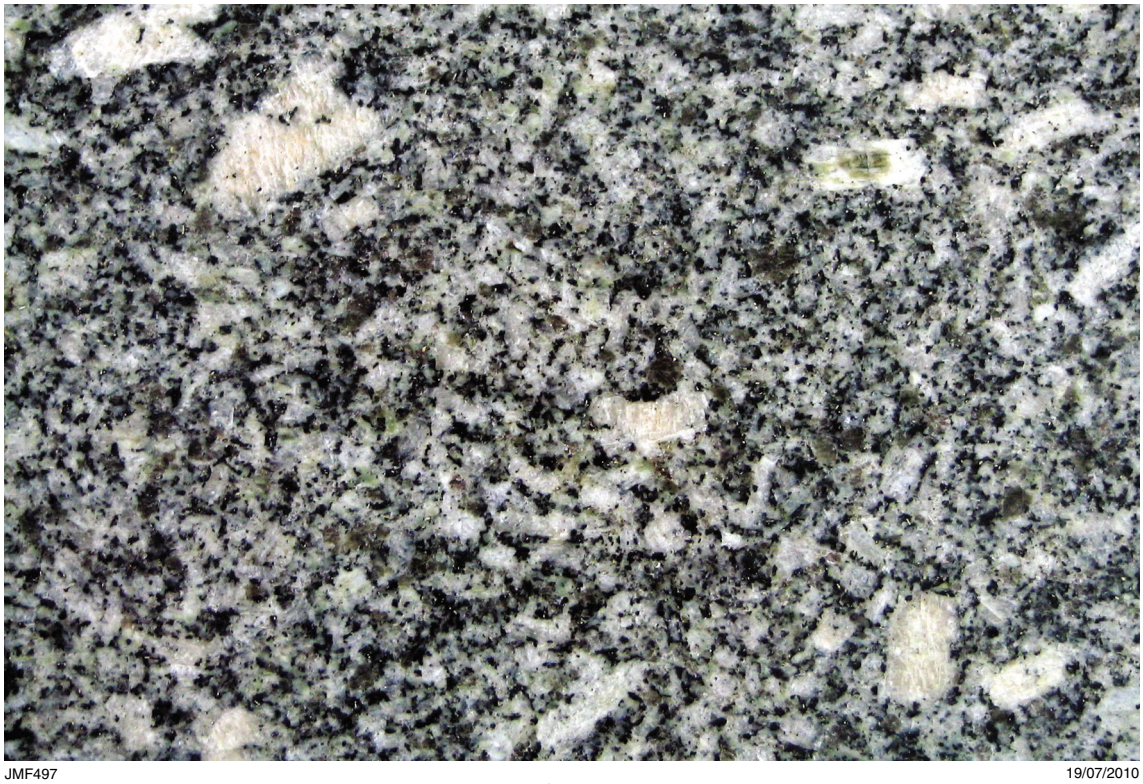


Figure 4.1. ***Albany Granite,*** **a megacrystic, grey syenogranite used in the monumental stone industry for many years. Mount Melville quarry, Albany.**

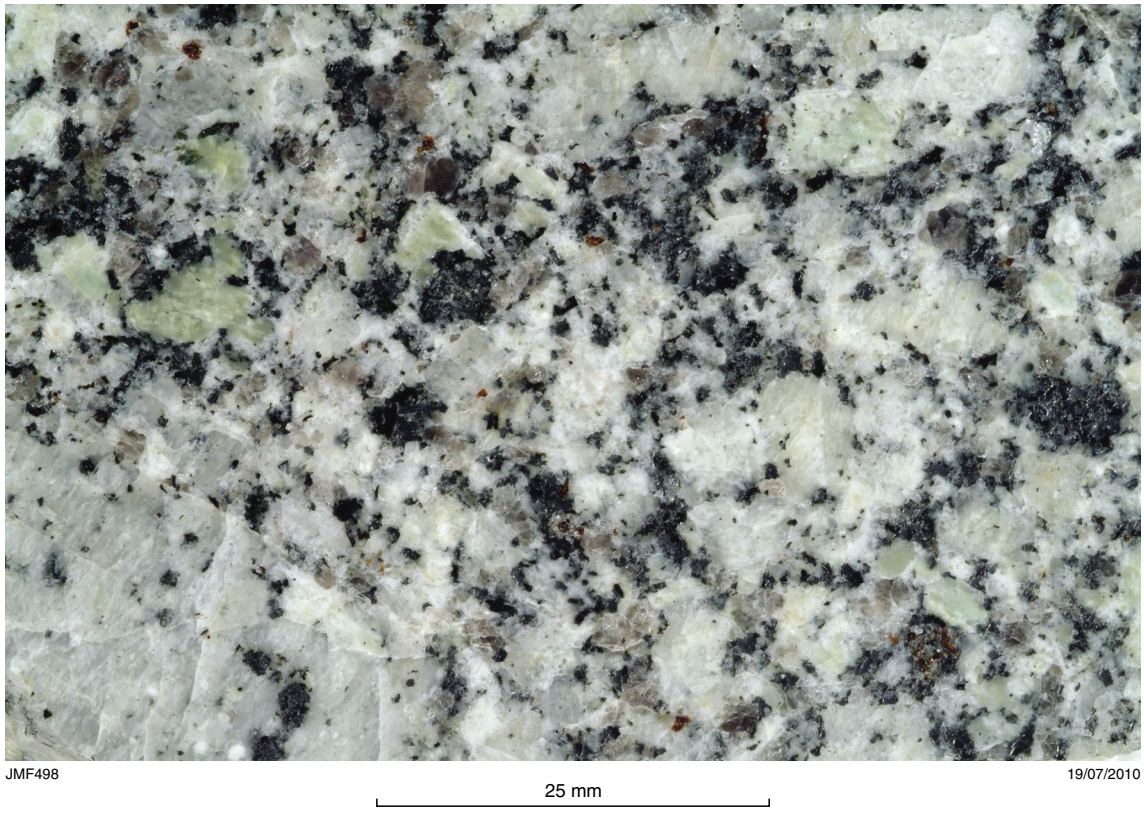


Figure 4.2. Willyung Hill leucocratic, biotite syenogranite containing K-feldspar megacrysts up to 50 mm length. Albany area.



Figure 4.3. *Desert Brown* syenogranite from the Merivale Road quarry at Mount Edward, Esperance area.

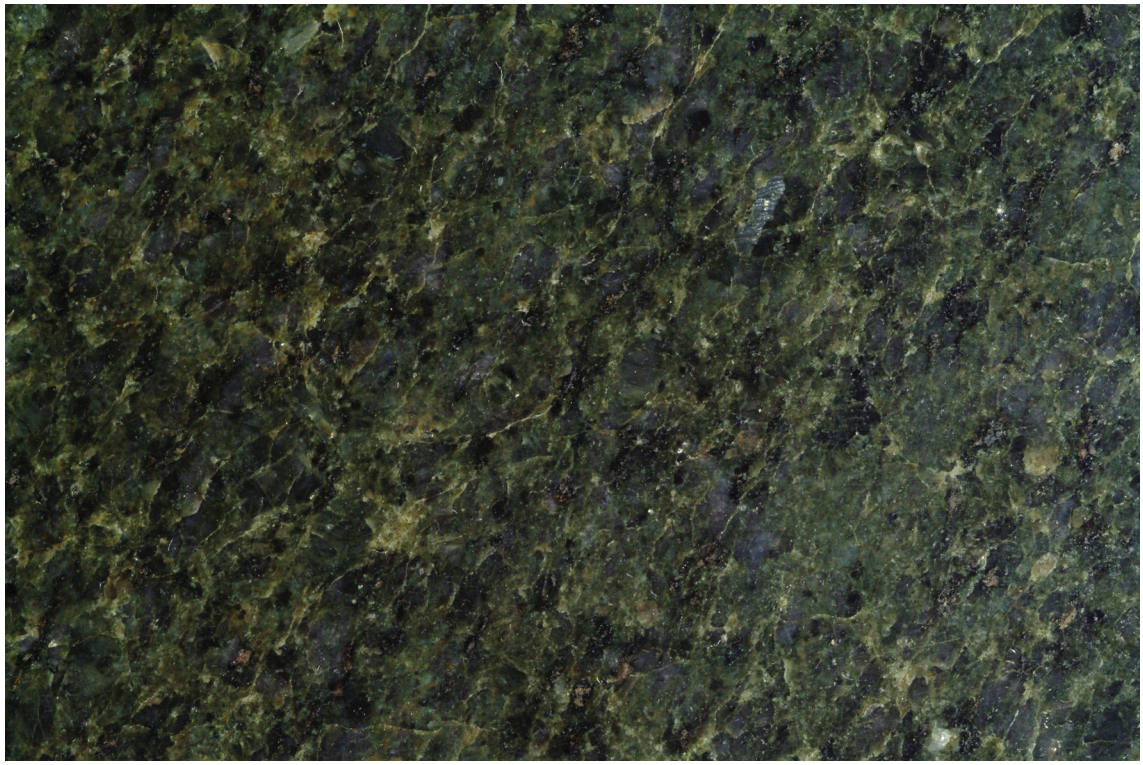


Figure 4.4. ***Verde Austral,*** **a charnockitic, gneissic granodiorite quarried at Mount Malcolm in the Fraser Range area.**

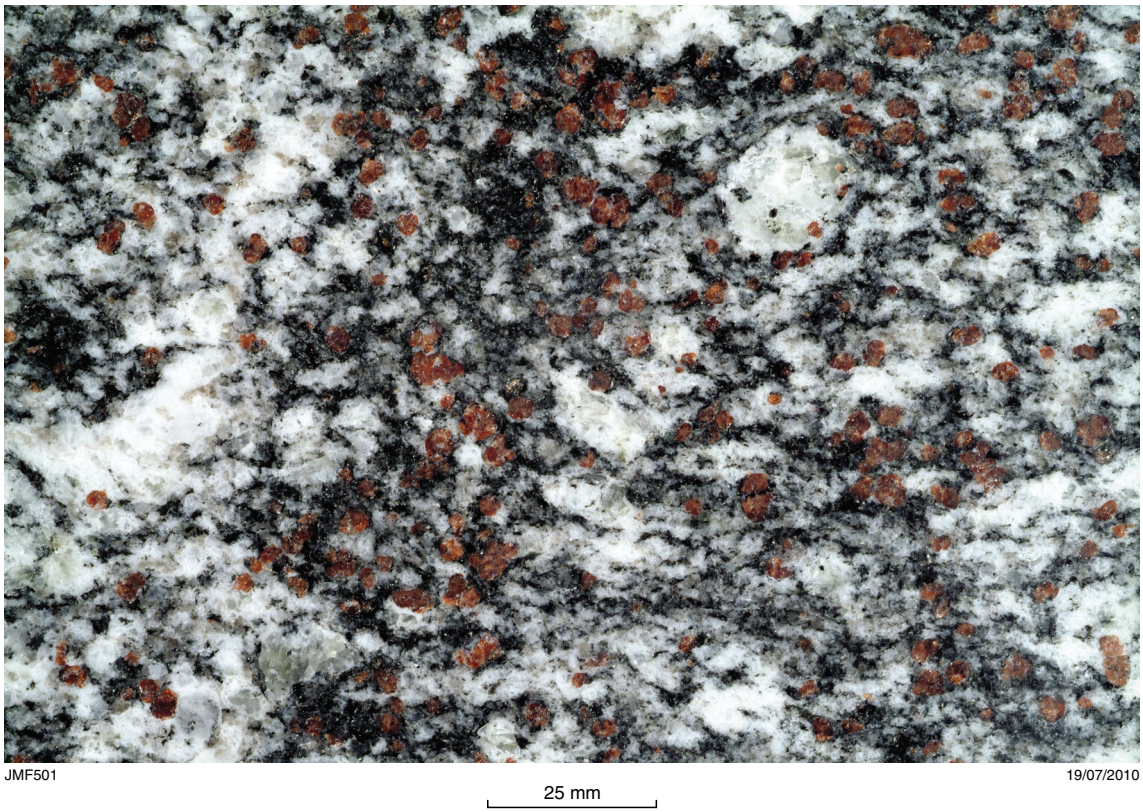


Figure 4.5. ***Garnet Ice,*** **a garnet–biotite gneiss from the Fraser Range area.**



Figure 4.6. Magenta-tinted pyroxene granulite from Phill's quarry, Fraser Range area.



Figure 4.7. A banded, dark grey pyroxene granulite from the American quarry, Fraser Range area.

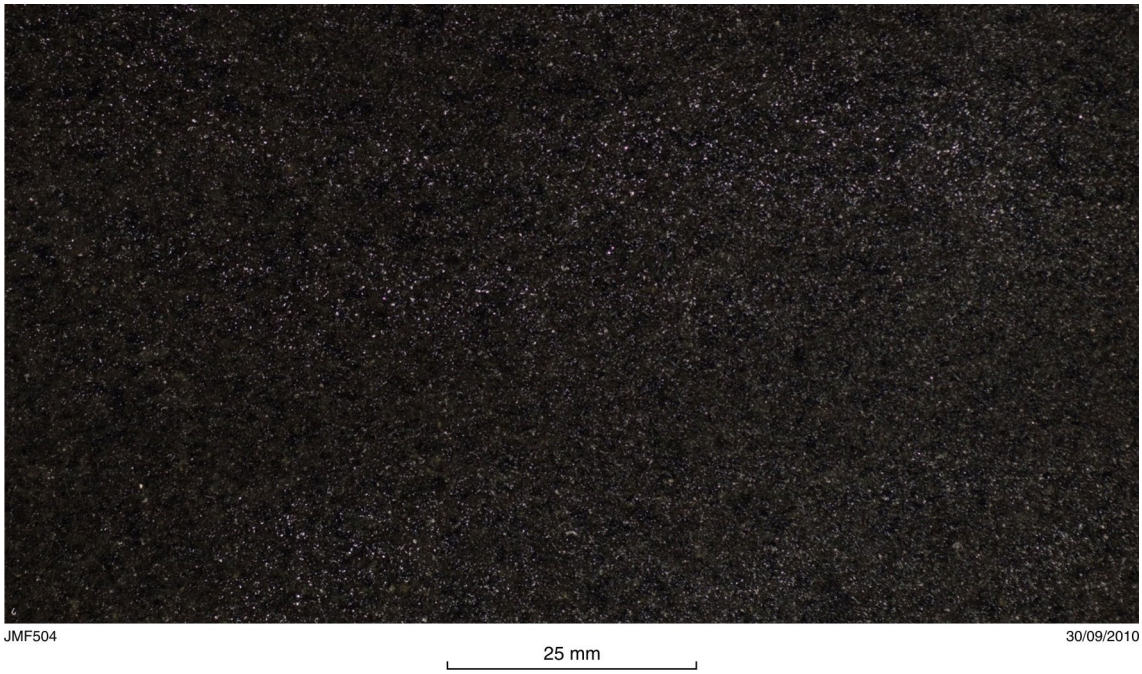


Figure 4.8. Dark grey, polished sample of Horseshoe pyroxene granulite, Fraser Range area.



Figure 4.9. Pink- to orange-banded, quartzofeldspathic, mylonitic, granitic gneiss, Fantasia quarry, Fraser Range area.



Figure 4.10. Pale grey, fine-grained Karramindie Monzogranite, Coolgardie area.



Figure 4.11. *Mungari Grey,* a fine-grained, pale grey, monzogranite, Coolgardie area.



Figure 4.12. Boorabbin Rock dimension stone, a pale grey, medium–coarse-grained monzogranite. Boorabbin area, Eastern Goldfields region.



Figure 4.13. ***Albany Green*** **granite, a megacrystic quartz syenite with large pink K-feldspar phenocrysts set in a green matrix. Jerramungup area.**



Figure 4.14. ***Gairdner River pink*****, a megacrystic quartz syenite with a black, mafic matrix. Jerramungup area.**



Figure 4.15. ***Laguna Green,*** **a megacrystic, biotite–hornblende, quartz monzonite. Jerramungup area.**



Figure 4.16. ***Melangata Green*** **microdiorite, Melangata Station, Mount Magnet region.**



Figure 4.17. A spectacular hornblende diorite orbicule of *Boogardie Orbicular* granite. Diameter of longest axis is about 150 mm.

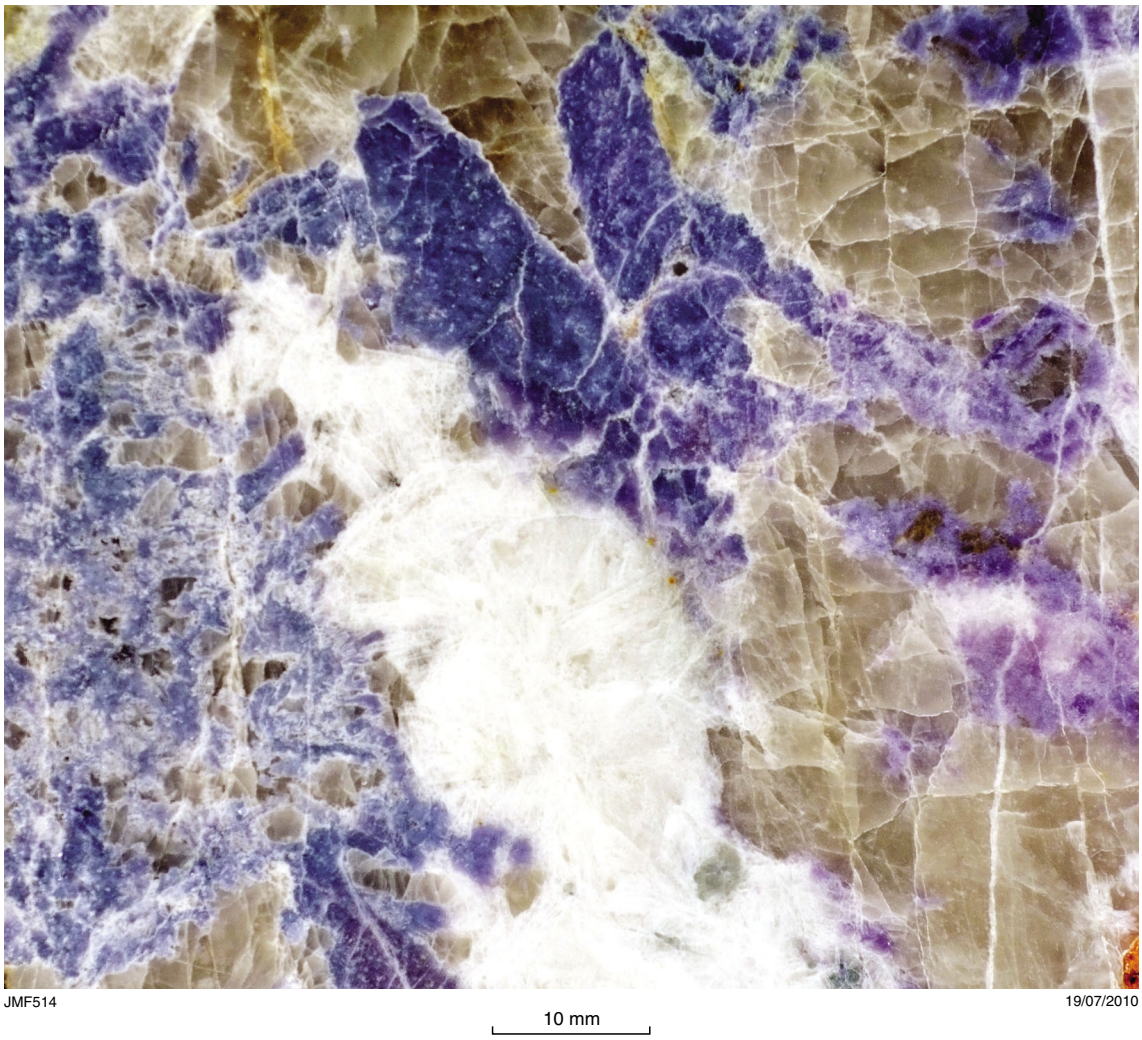


Figure 4.18. ***Carlaminda Blue*** **stone showing blue lepidolite mica interspersed with white albite feldspar and grey quartz.** ***Carlaminda Blue*** **quarry. Yalgoo area.**



Figure 4.19. ***Kimberley Pearl,*** **a megacrystic, biotite–hornblende syenogranite gneiss, being part of the Paleoproterozoic, Kongorow Granite, Wombarella Creek, West Kimberley region.**



Figure 4.20. ***Kimberley Storm,*** **a megacrystic, biotite–hornblende syenogranite augen gneiss, also part of the Paleoproterozoic, Kongorow Granite, Wombarella Creek, West Kimberley region.**



Figure 4.21. ***Kimberley Ice,*** **a megacrystic, leucocratic, monzogranitic gneiss forming part of the Paleoproterozoic Lennard Granite, Wombarella Creek, West Kimberley region.**

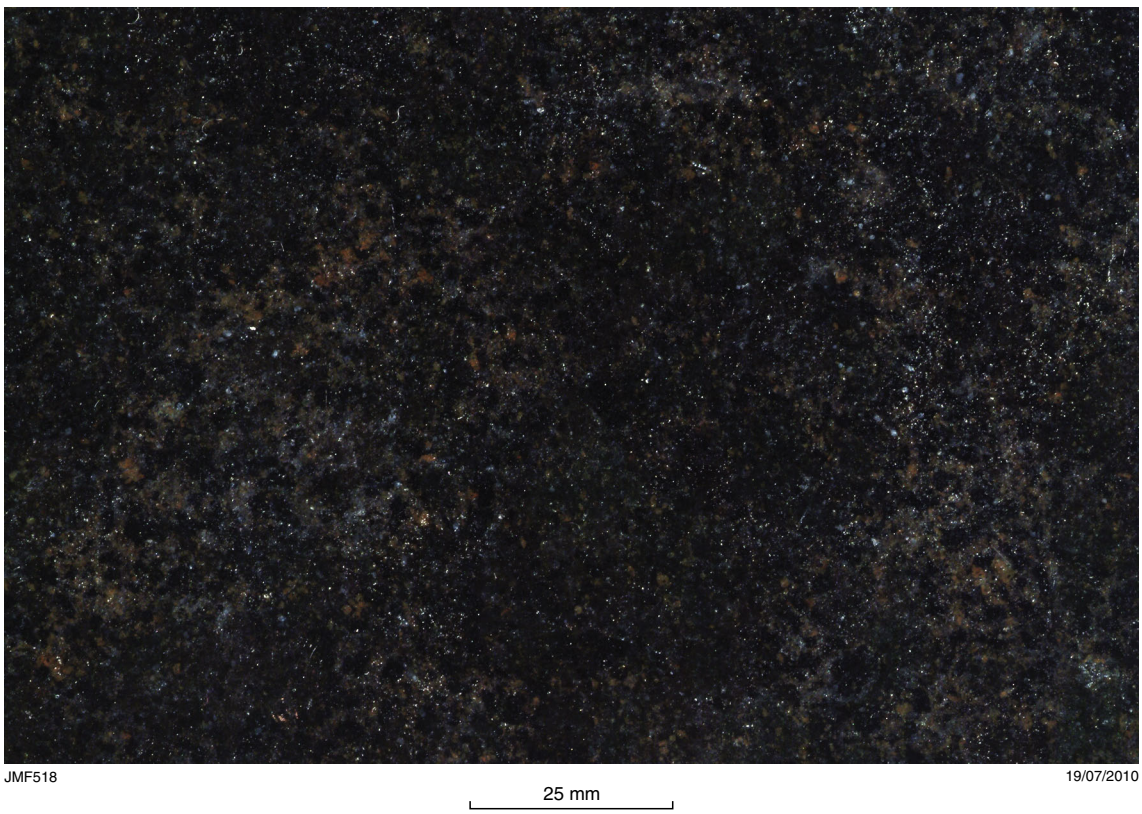


Figure 4.22. ***Fraser Range Black,*** **a fine-grained metadolerite from** ***Fraser Range Black*** **quarry.**

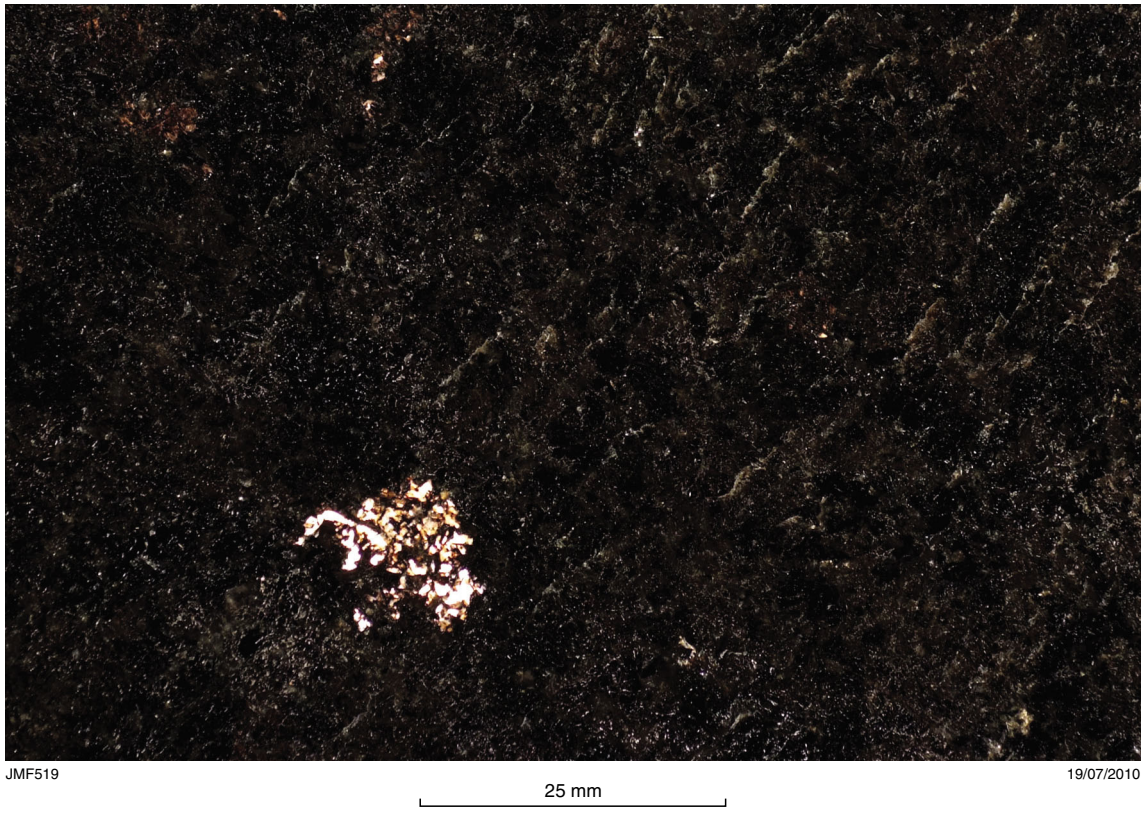


Figure 4.23. ***Gold Leaf Black*** **is an ophitic, olivine–orthopyroxene-bearing dolerite. The stone displays visually attractive plays of golden light (schillerization). This effect is caused by reflection mainly from plagioclase laths within ophitic pyroxene crystals. Quarry site FRG 142, Fraser Range area.**



Figure 4.24. ***Glen Florrie Black*** **granite, a very fine grained, olivine-bearing dolerite that polishes to a jet black, mirror-like finish. Located on Glen Florrie Station .**



Figure 4.25. Fine-grained, speckled Maroonah black granite from the Edmund Basin.

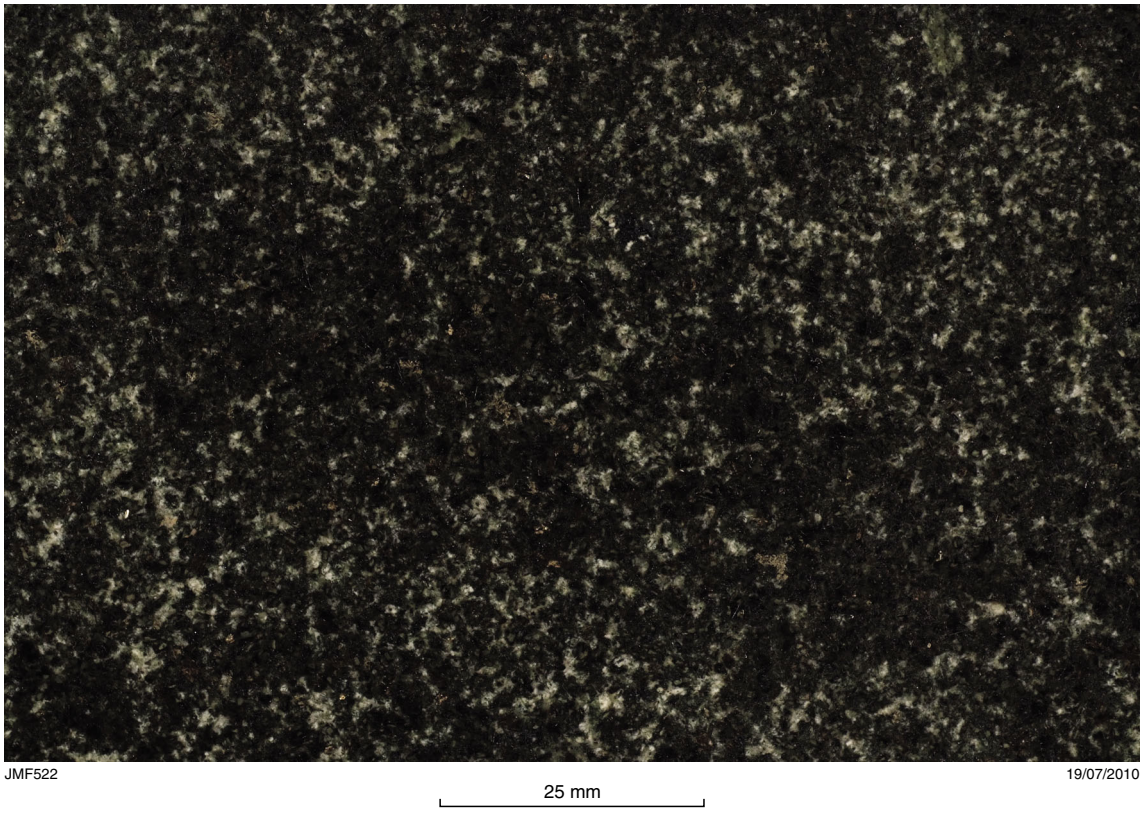


Figure 4.26. Chararoo Well black granite displaying white flecking due to the presence of medium-grained plagioclase feldspar laths.



Figure 4.27. Relatively fine, even-grained black granite from Manolini Well, Maroonah area.

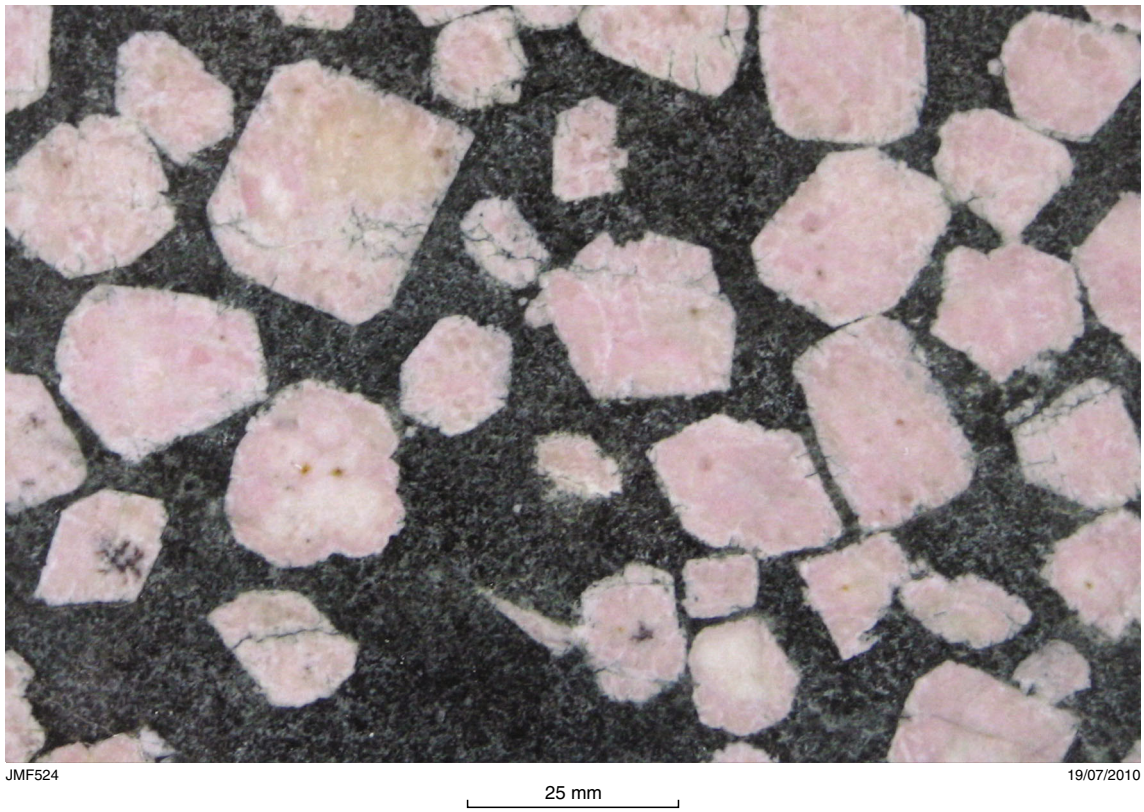


Figure 4.28. Mindoolah porphyritic dolerite displaying subhedral to anhedral clinozoisite megacrysts averaging 20 mm in diameter.

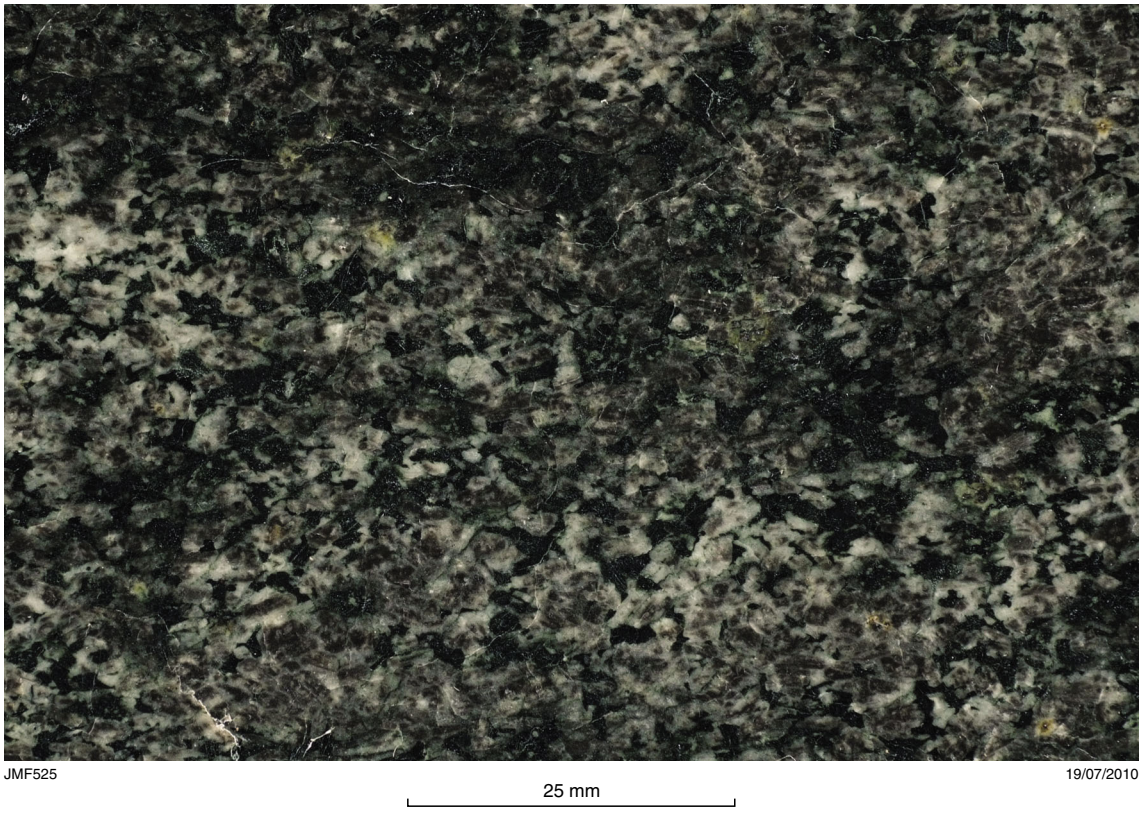


Figure 4.29. Dark grey–black, coarse-grained black granite from Palagea Rockholes gabbro prospect, Mount Magnet region.



Figure 4.30. Dark grey–black, coarse-grained black granite from Pioneer Well gabbro prospect, Mount Magnet region.

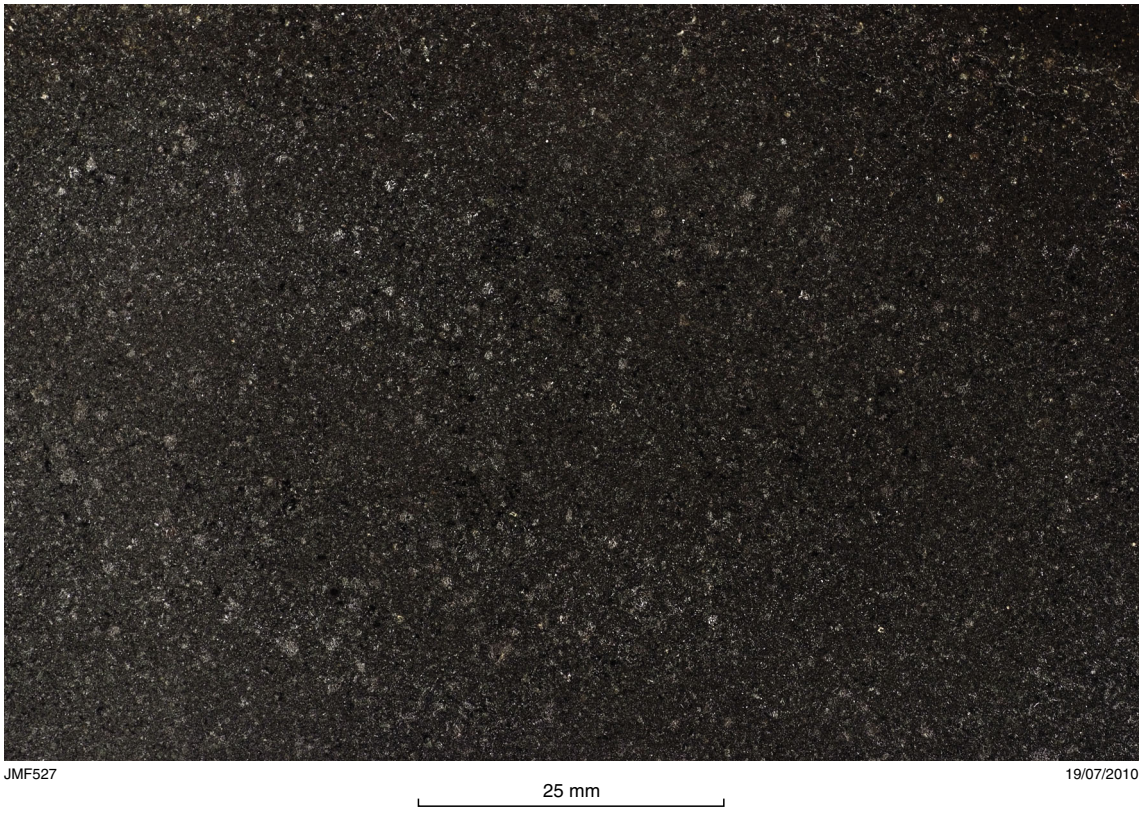


Figure 4.31. Fine-grained, slightly mottled black granite from Gum Creek Well prospect.



Figure 4.32. *Kimberley Jade* is a greenish black olivine gabbro. The stone displays an attractive checked pattern of white plagioclase laths, up to 6 mm in length, contrasting with a greenish black matrix.

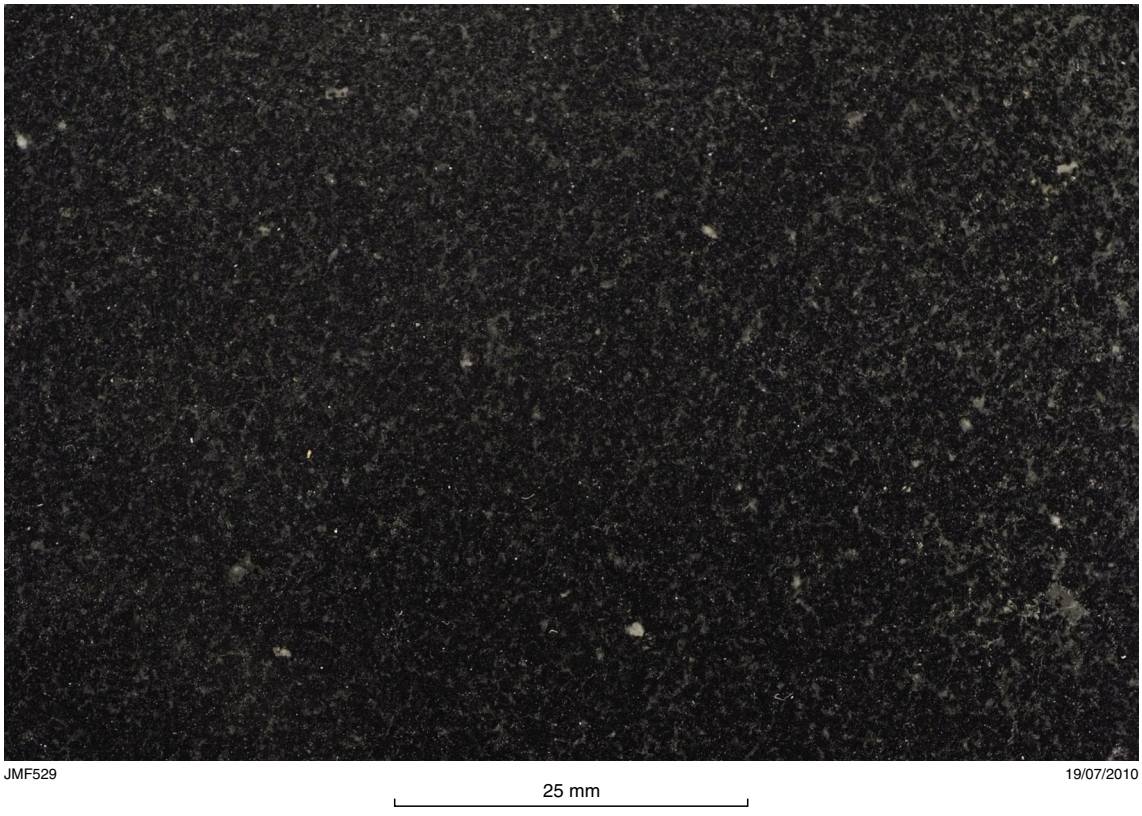


Figure 4.33. Medium-grained black granite from Fairfield 1 quarry.



Figure 4.34. Black, very fine grained *Kimberley Black* dimension stone from Wombarella Creek quarry.



Figure 4.35. High-quality *Kimberley Black* granite from Quarry Camp, Wombarella Creek area.



Figure 4.36. Very fine grained black granite from Quarry Camp prospect 7 (QC7).



Figure 4.37. Very fine grained black granite from Quarry Camp prospect 10 (QC10).



Figure 4.38. Pale grey *Cheela Marble* showing dark green veins and stylolites. Cheela Plains, Wyloo area.

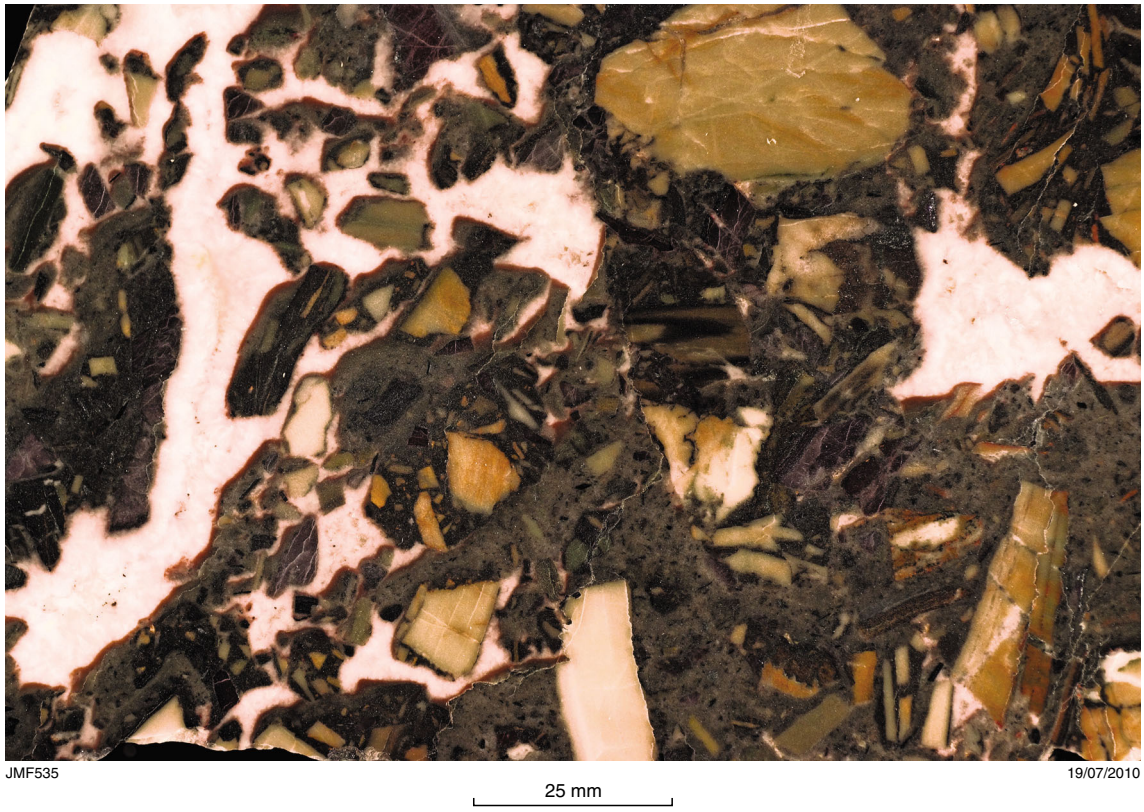


Figure 4.39. ***Wyloo Marble.*** **The stone comprises grey-green, brecciated, dolomitic marble together with blocky fragments of chert or fine-grained quartz subsequently recemented by pink veins of coarse-grained, sparry carbonate. Wyloo Homestead area.**



Figure 4.40. Glen Florrie black dolomitic marble, Glen Florrie Station.

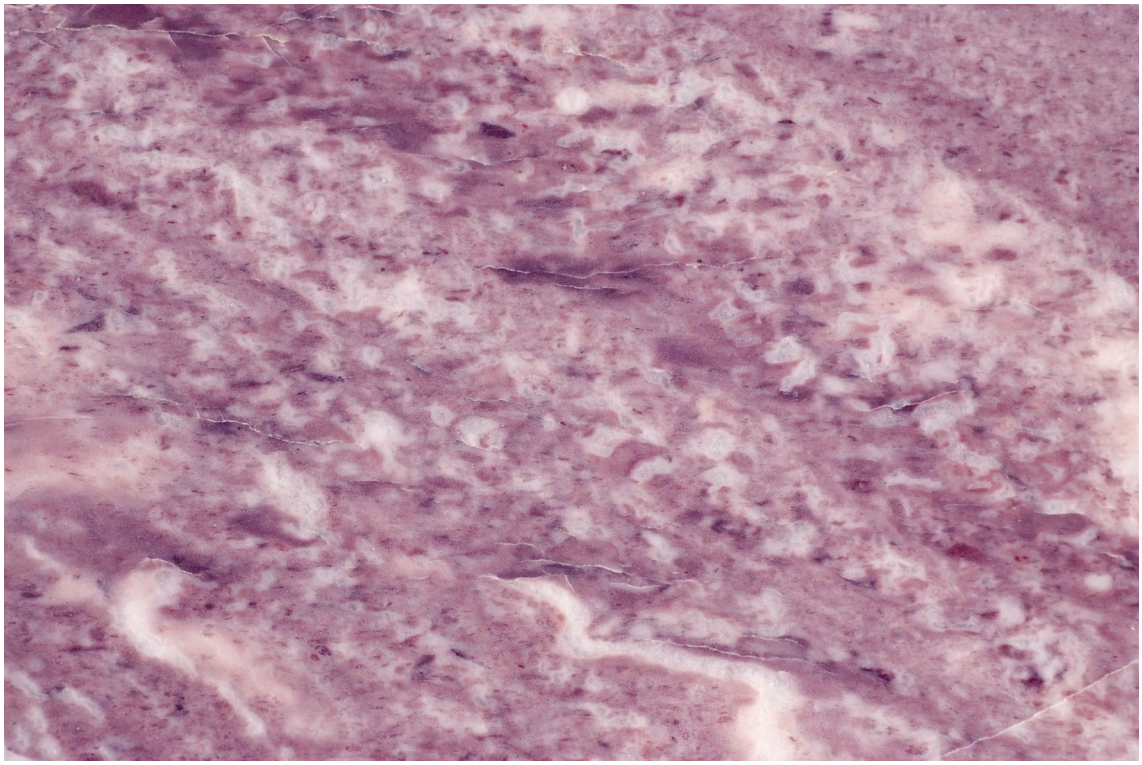


Figure 4.41. Mauve-coloured marble from Hooley Camp Hill, Glen Florrie area.



Figure 4.42. A sample of cream marble from Minnie Springs featuring an attractive pattern of light brown stylolites. Glen Florrie area.

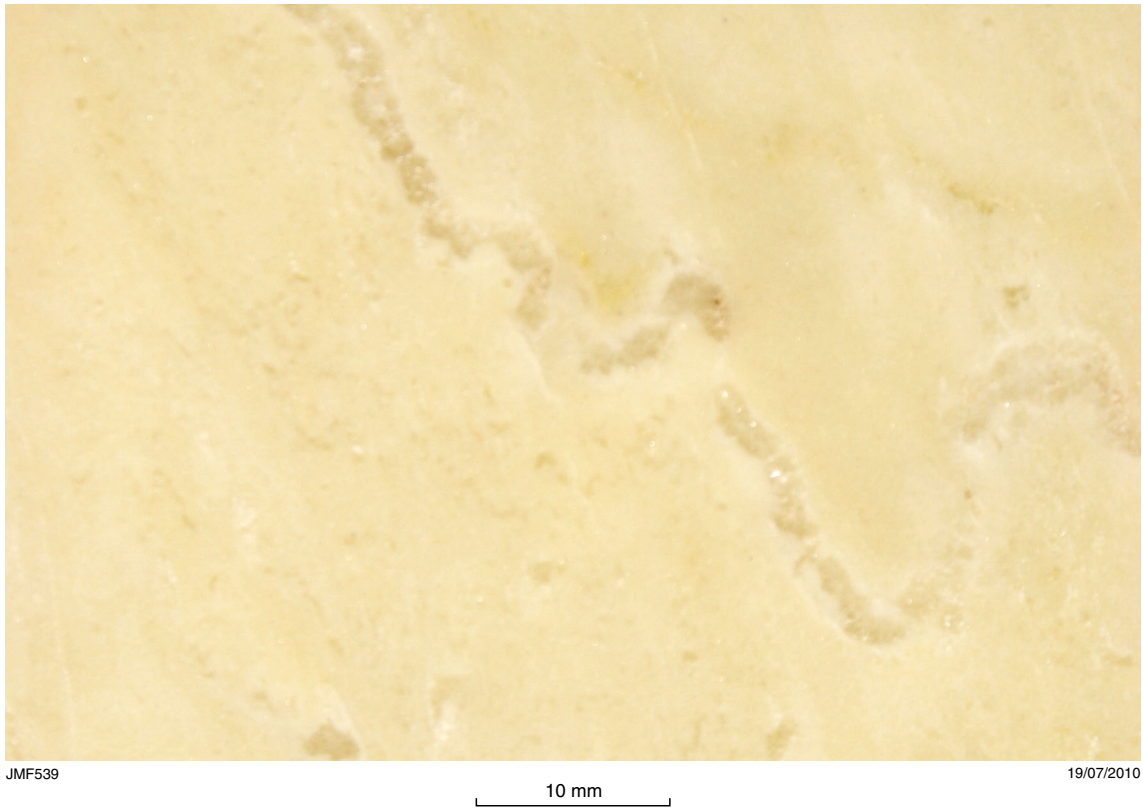


Figure 4.43. Cream-coloured White Rocks marble, Glen Florrie area .

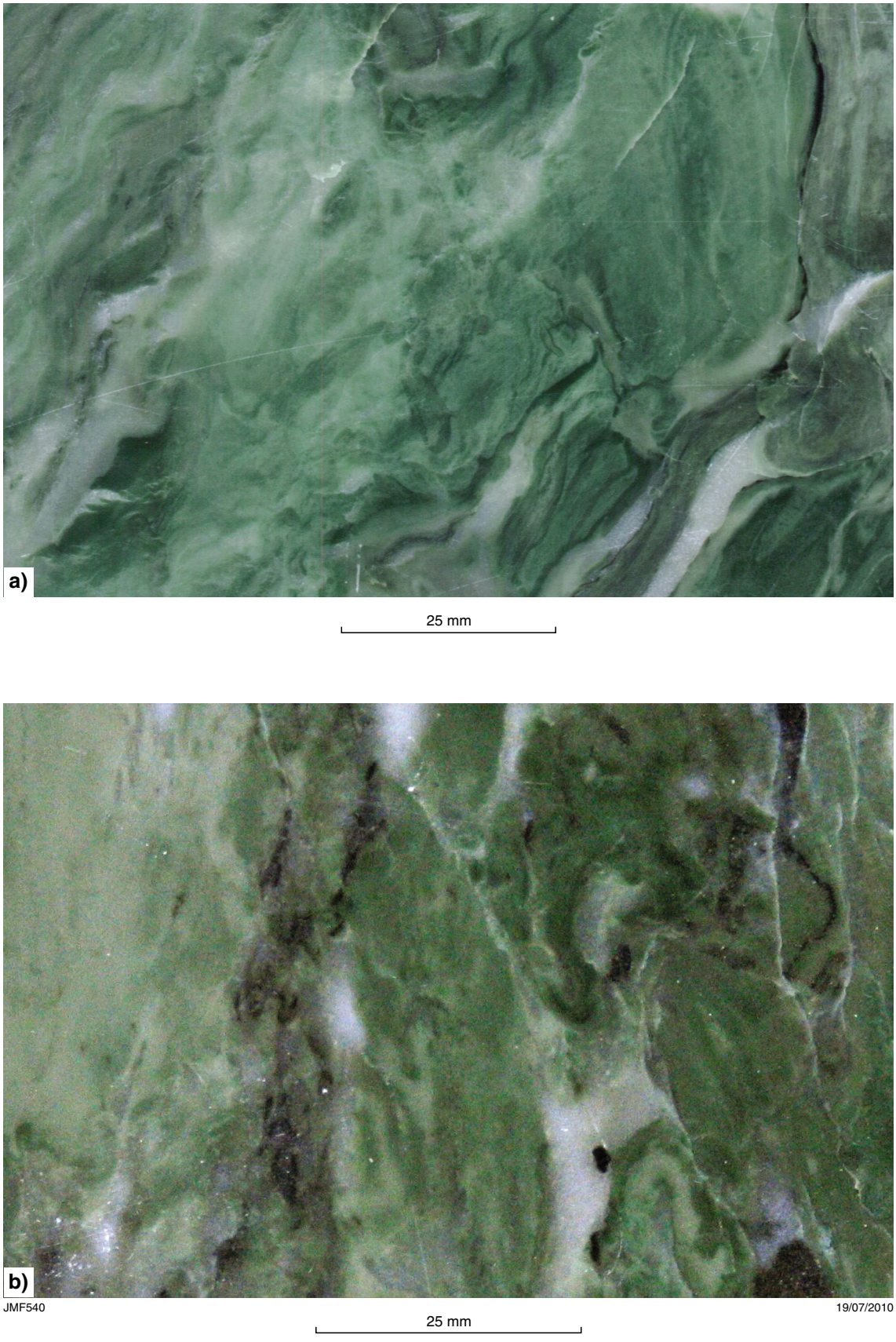


Figure 4.44. Two varieties of *Pilbara Green* marble: a) banded, mid-green ; b) grey-green variety.



Figure 4.45. Green marbles from Bellotti and Pindanni prospects, Maroonah area: a) polished core splits showing pale green Bellotti marble; b) folded, irregularly banded, mid- to dark green Pindanni marble.

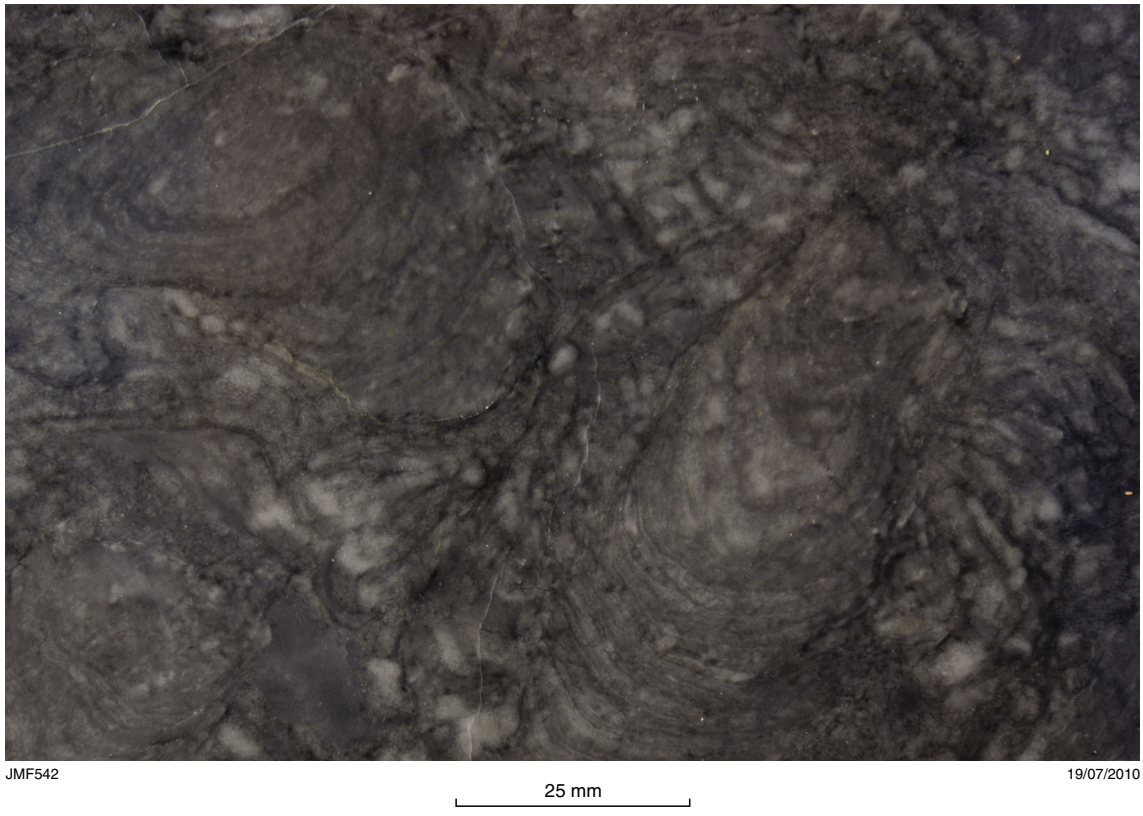


Figure 4.46. Grey, stromatolitic marble from Chain Pool, Maroonah area.



Figure 4.47. *Maroonah Green* dolomitic marble, Maroonah Station area.

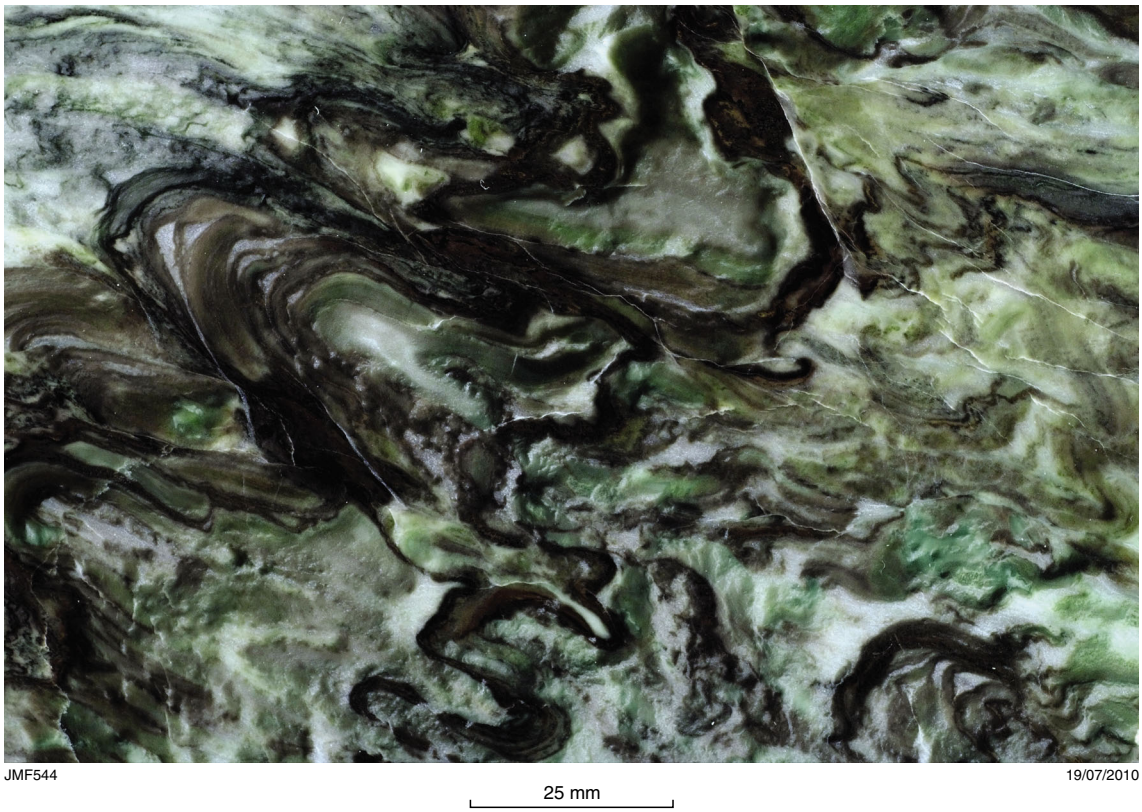


Figure 4.48. Yarrie Pool stromatolitic, green-grey, dolomitic marble, Maroonah area.

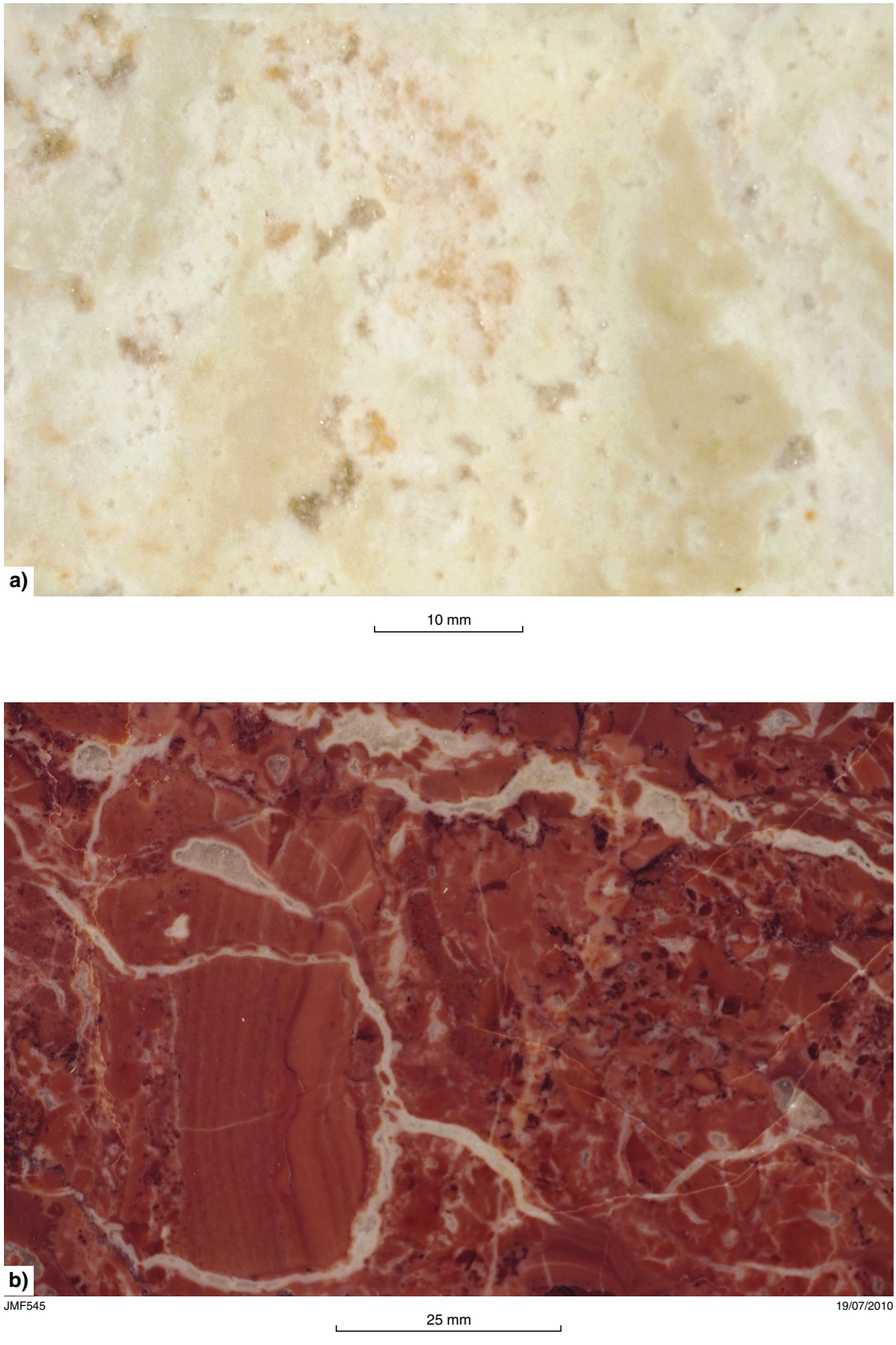


Figure 4.49. Marbles from Motin Bore, Nanutarra area: a) core split of the overlying mottled cream marble; b) red, brecciated, basal marble unit.

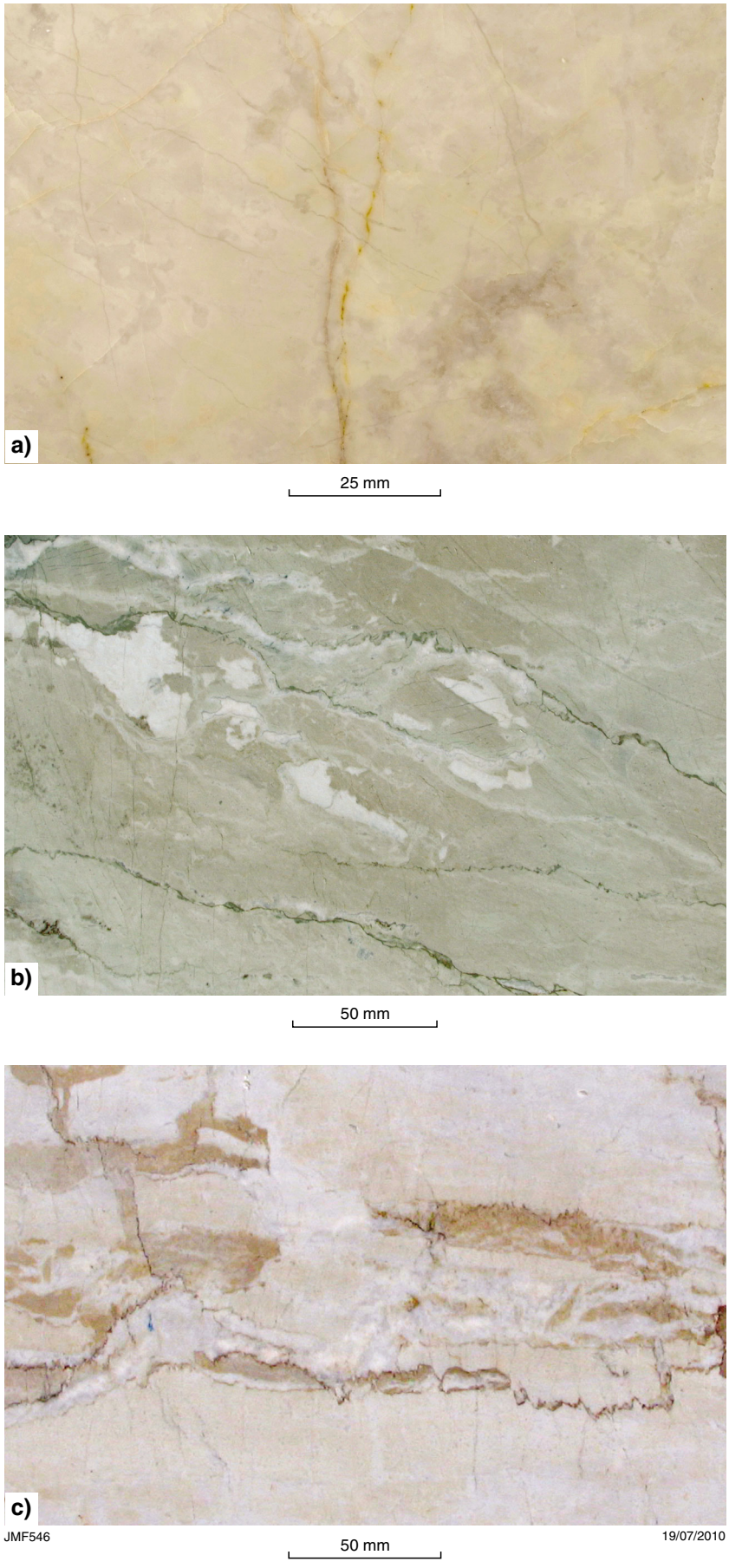


Figure 4.50. Marbles from the upper Nanutarra white quarry: a) *Austral Pearl;* b) *Austral Dream;* c) *Austral Brown* .

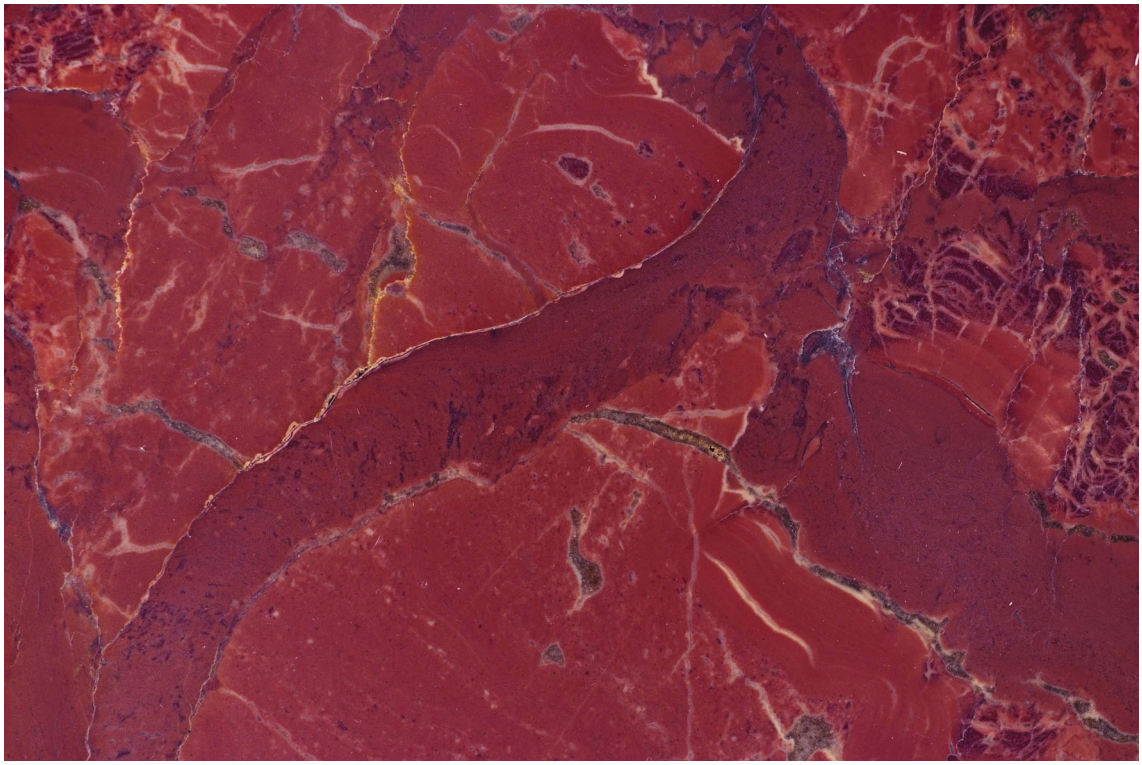


Figure 4.51. *Rosso Venezia,* brecciated, mahogany-red marble from the lower Nanutarra quarry.

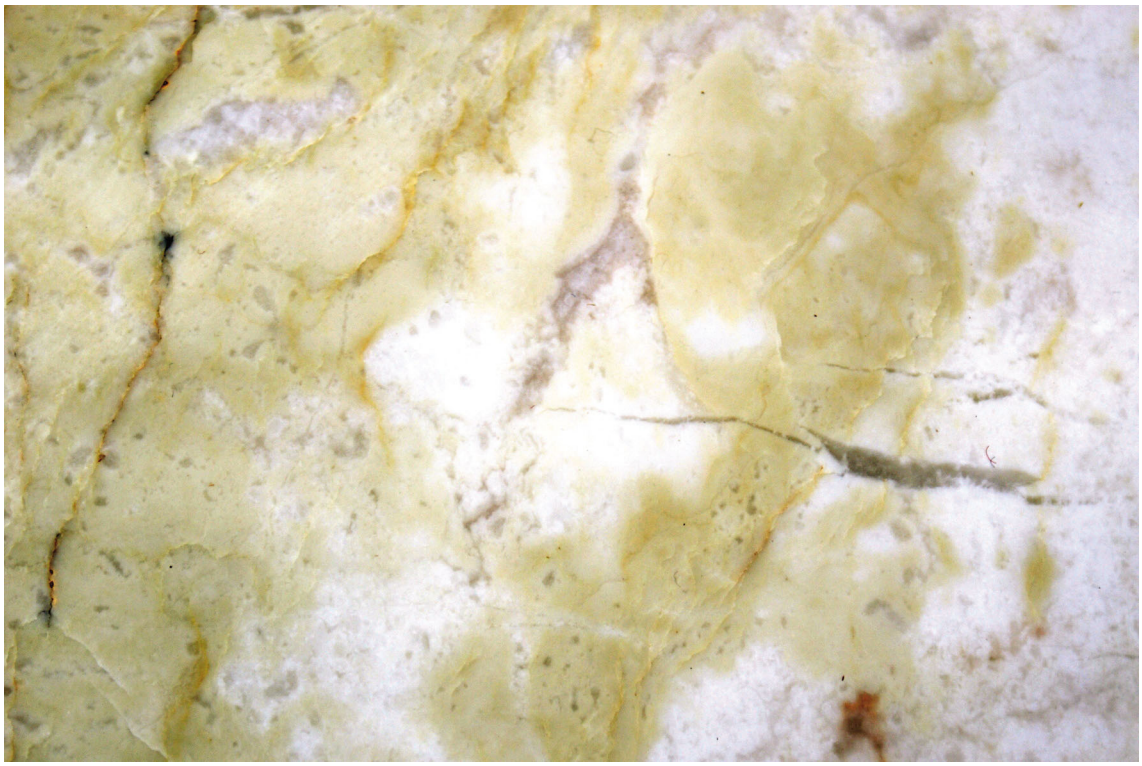


Figure 4.52. Cream–white marble from Parry Range quarry, Nanutarra area.

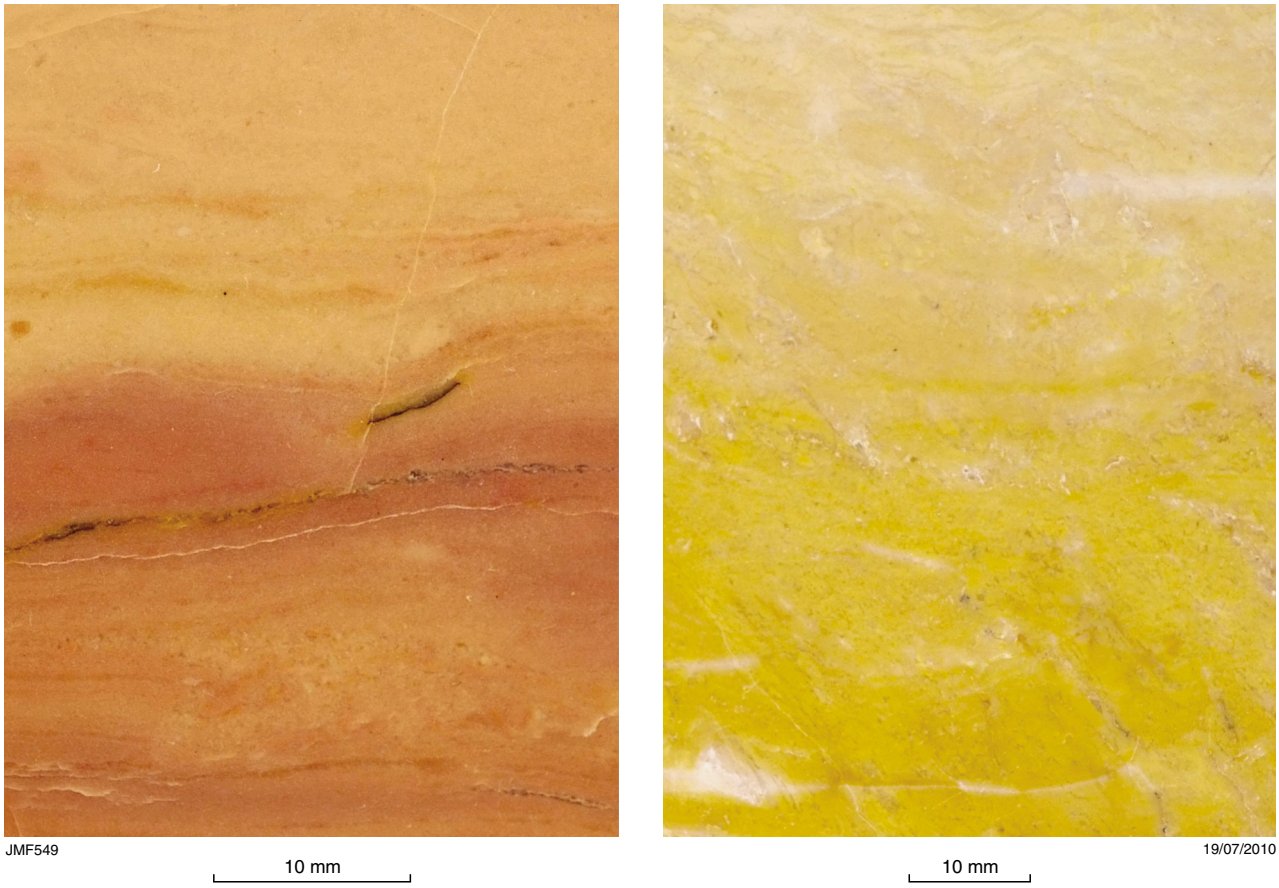


Figure 4.53. Pink and yellow marbles from Ten Mile Well, Parry Range, Nanutarra area.

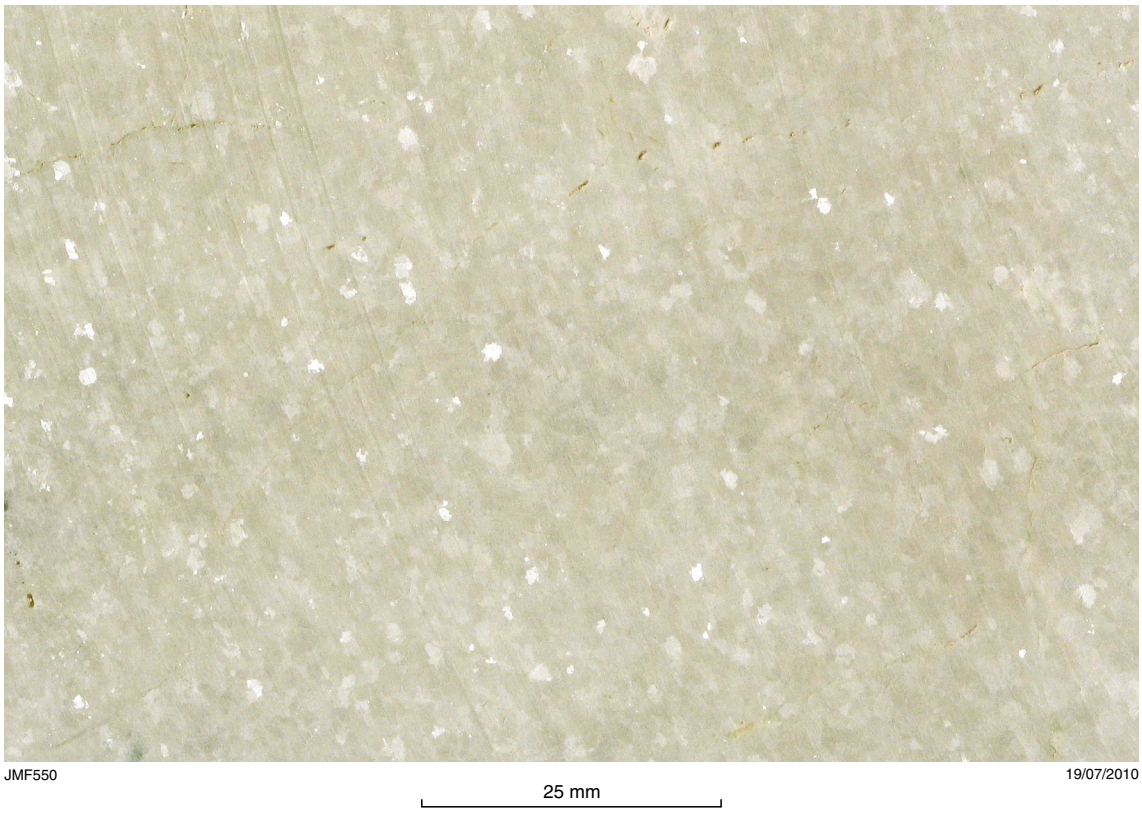


Figure 4.54. Coarsely crystalline, white *Weedarrah Marble*, Weedarrah Station area.



Figure 4.55. Fine-grained, beige *Kimberley Sandstone*, Meteor Stone quarry 1, Mount Jowlaenga area.



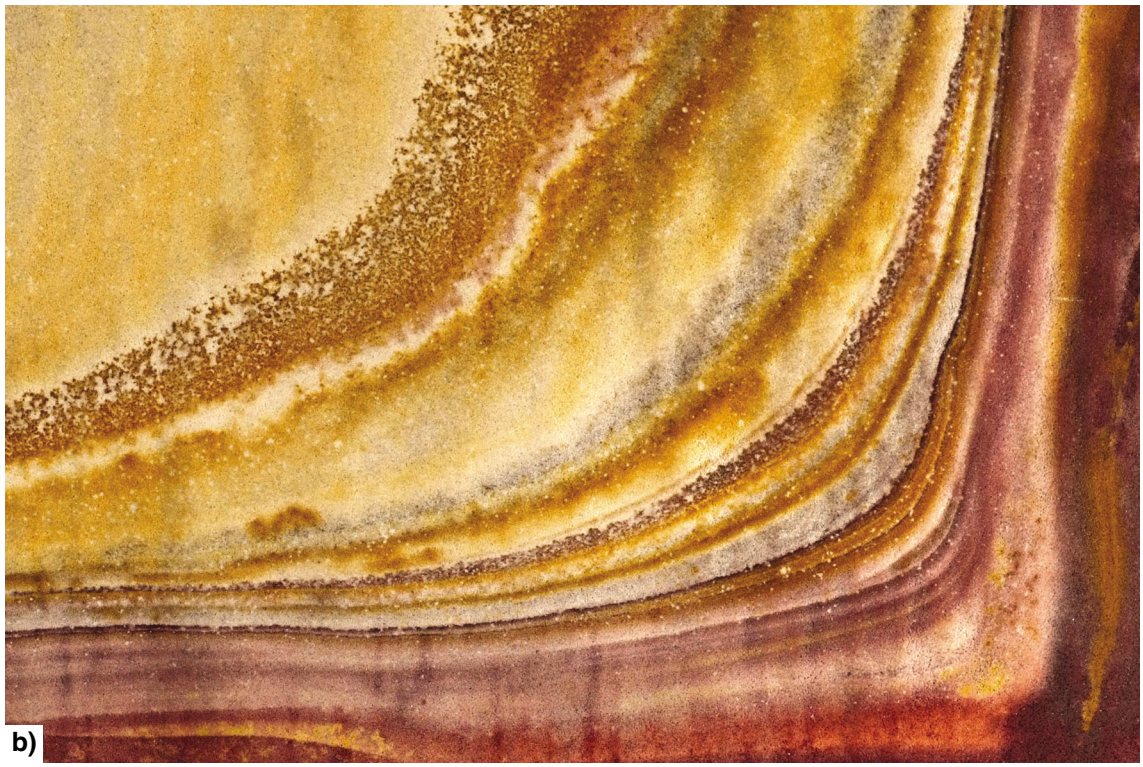


Figure 4.56. Examples of spectacularly banded *Kimberley Sandstone* from Meteor Stone multicolour quarry 2, near Dampier Hill, Mount Jowlaenga area (photo (a) courtesy Meteor Stone).

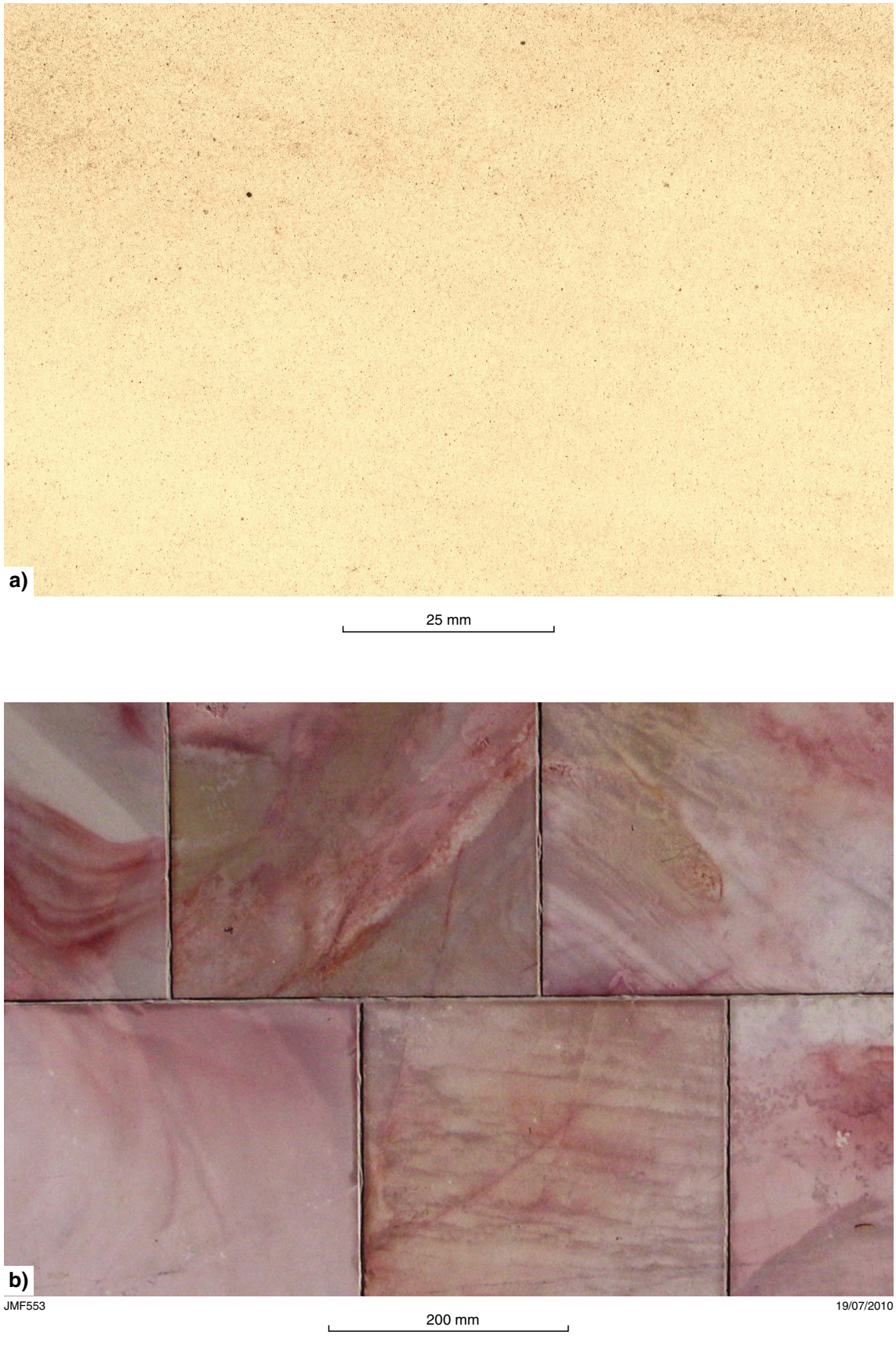


Figure 4.57. Two varieties of *Kimberley Quartzite* from the Mount Jowlaenga area: a) beige (unpolished, rubbed finish); b) salmon pink (partially polished, honed finish).

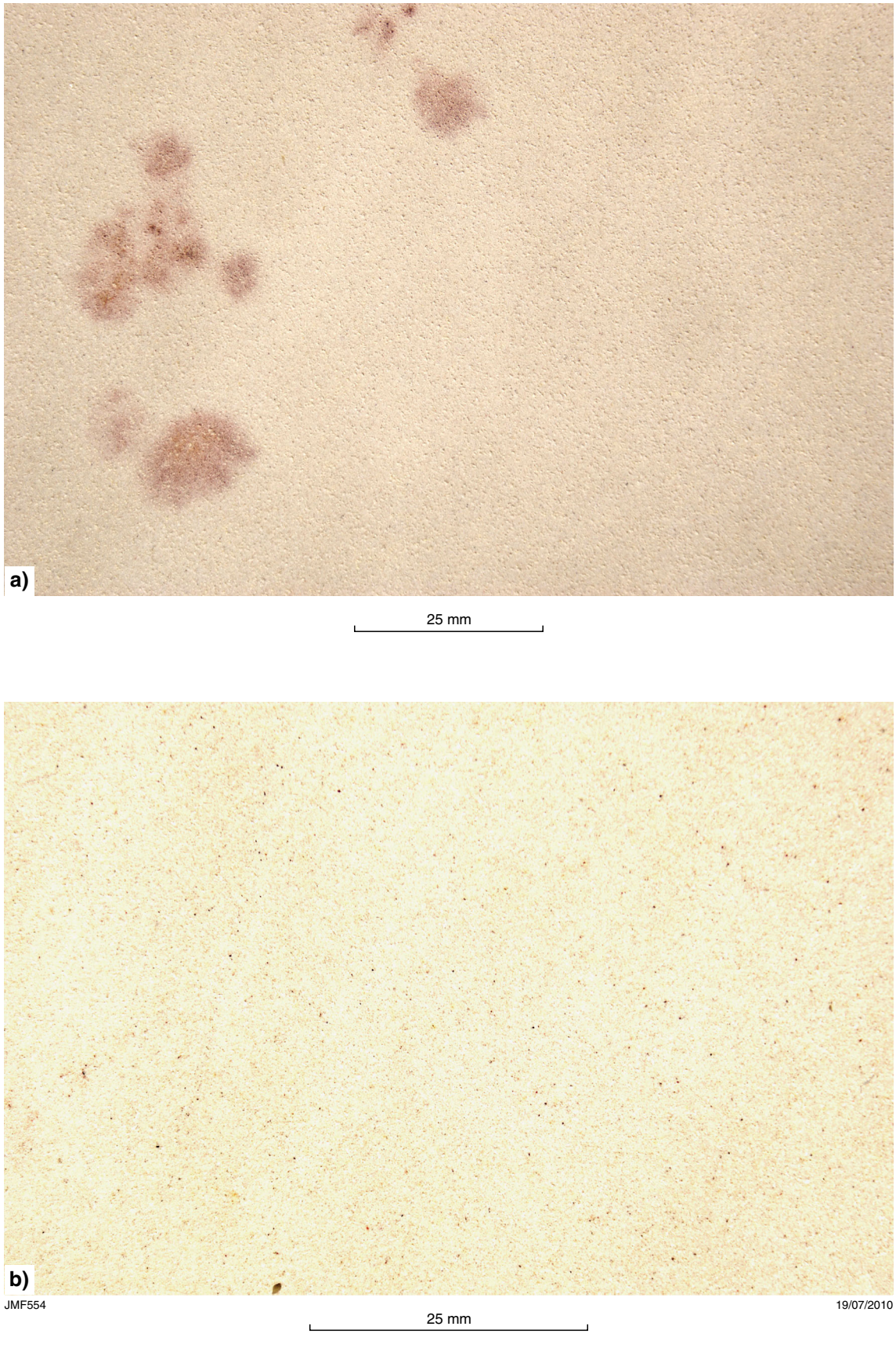


Figure 4.58. Two varieties of fine-grained *Argyle White* sandstone: a) commercial beige variety from lower in the sandstone section; b) white to cream variety from the upper sandstone horizon.

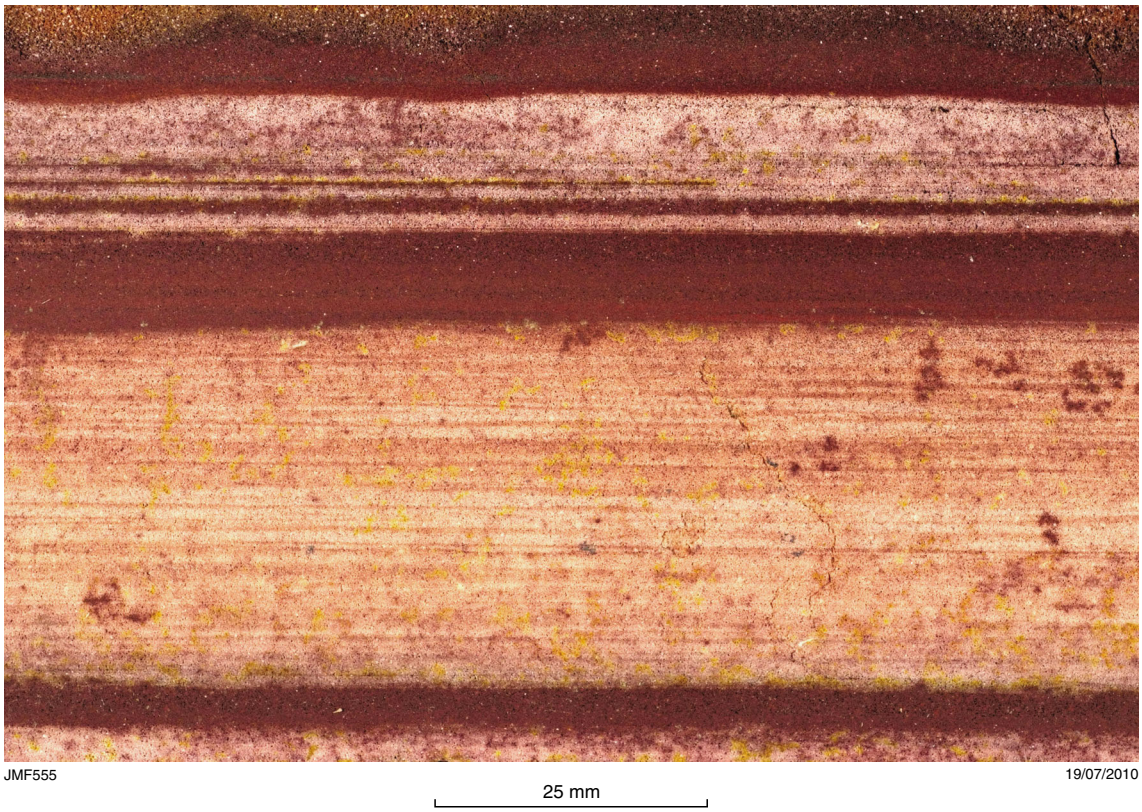


Figure 4.59. Fine-grained, laminated, red-brown and cream *Kimberley Colourstone*.



Figure 4.60. Visually attractive *Nillibubbacca Quartzite* from the Nillibubbacca aggregate quarry, Derby region. The stone displays a medium–high polish.



Figure 4.61. Wall of *Karratha Stone* blocks showing the diversity of colours and banding displayed in the stone. Kings Park, Perth.



Figure 4.62. Weathered metasandstone from the historic *Ashlar Pink Stone* quarry near Bullabulling.

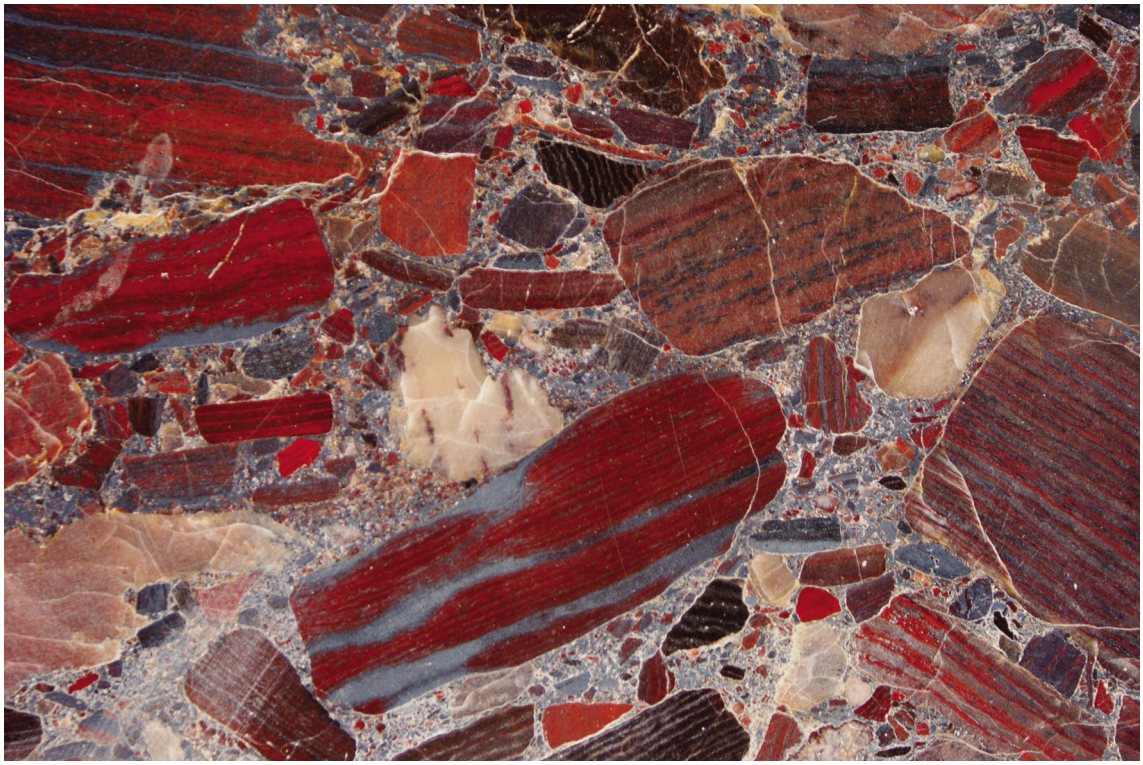


Figure 4.63. The Three Corner Conglomerate consists largely of laminated BIF fragments, ranging from around 20 to >100 mm in length, cemented by microcrystalline cherty quartz set in a sand of angular BIF particles.

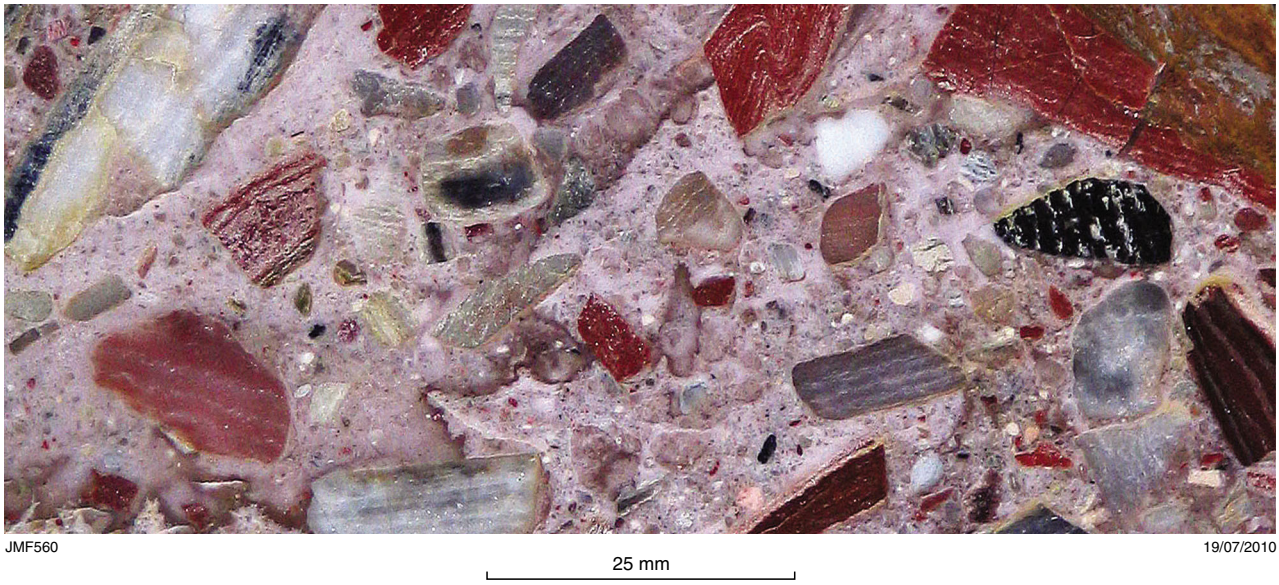


Figure 4.64. *Asteroid Breccia* from the Fields Find area. The stone comprises subrounded to angular pebbles, mainly chert and banded jasper, set in a hard, cherty matrix.

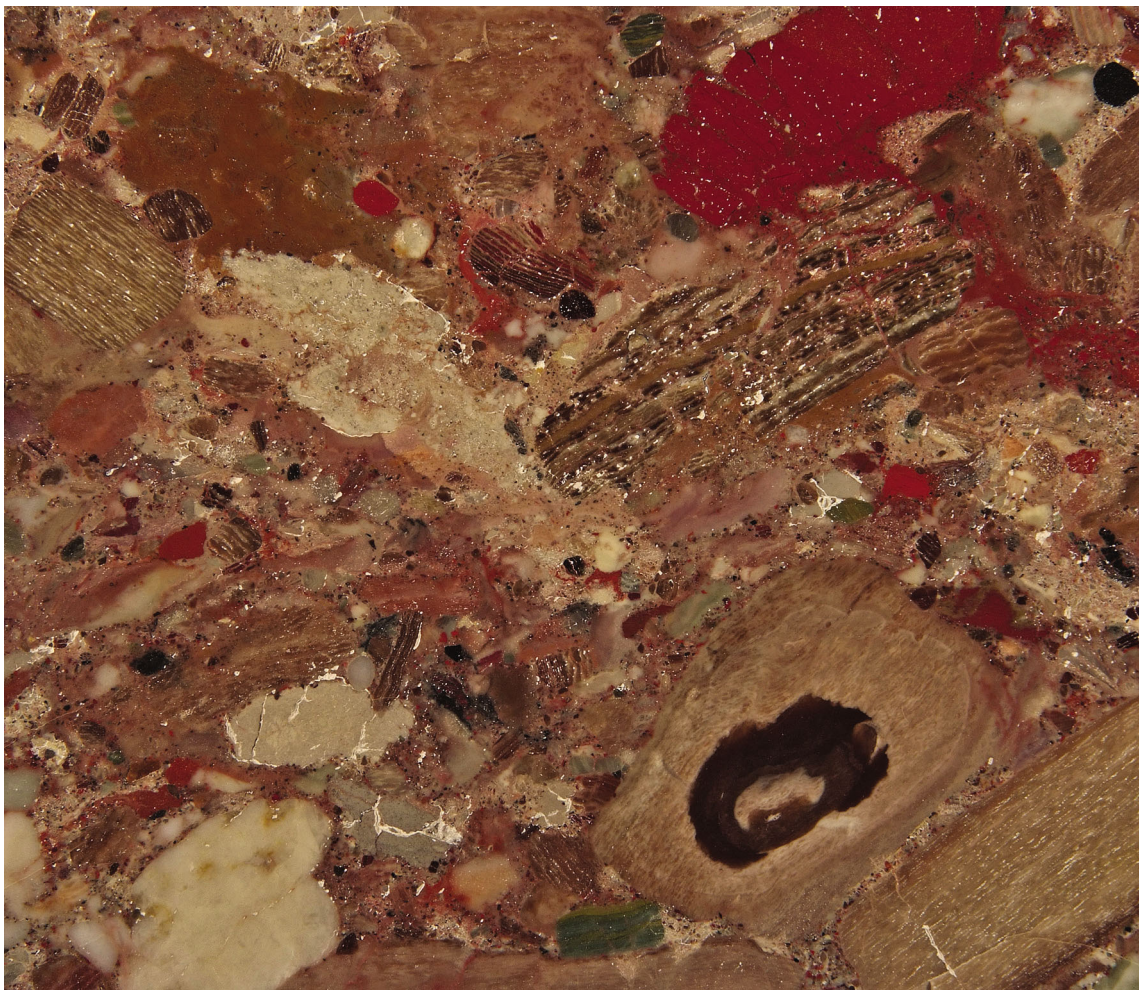


Figure 4.65. The Marillana conglomerate. This stone is a conglomeratic/brecciated admixture of hematite-, quartz-, and carbonate-rich fragments set in a hard matrix of sandy siltstone.

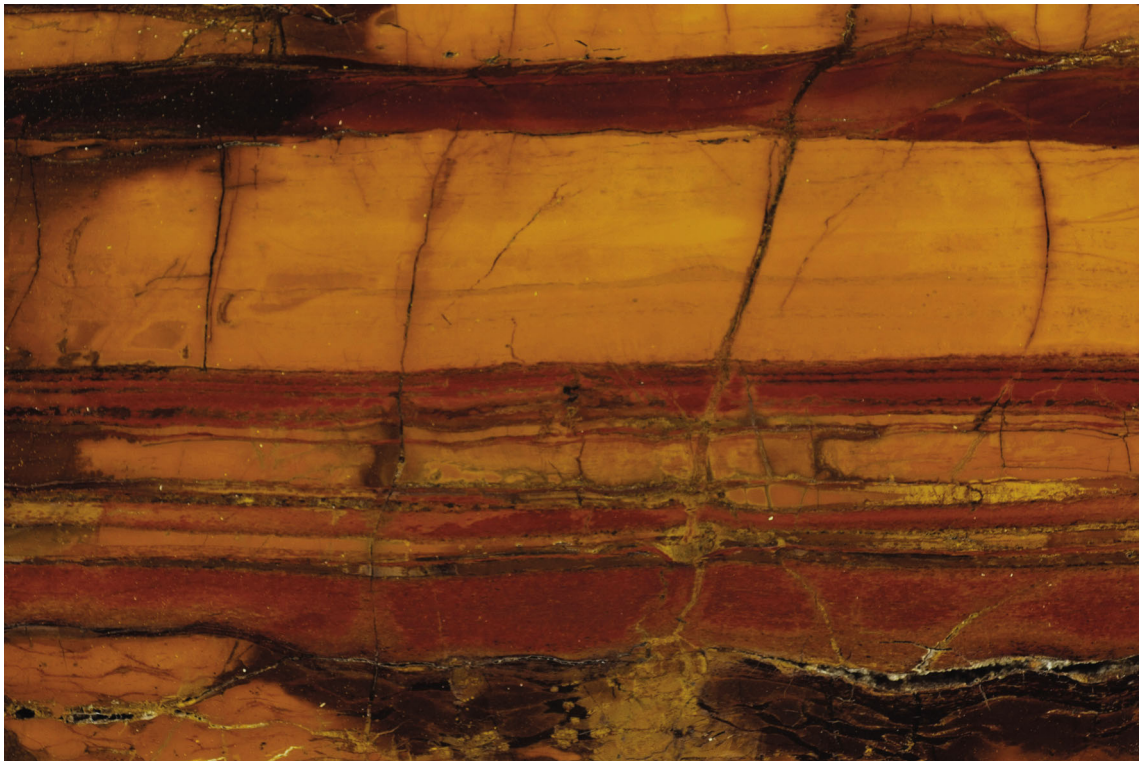


Figure 4.66. *Desert Sunset* is an extremely hard, massive banded jasper that takes a high polish.



Figure 4.67. A section of a large slab of Brockman tiger eye jasper. Section shows multiple bands of green, blue, red, and orange jasper interspersed with bands and triangular blebs of golden tiger eye.

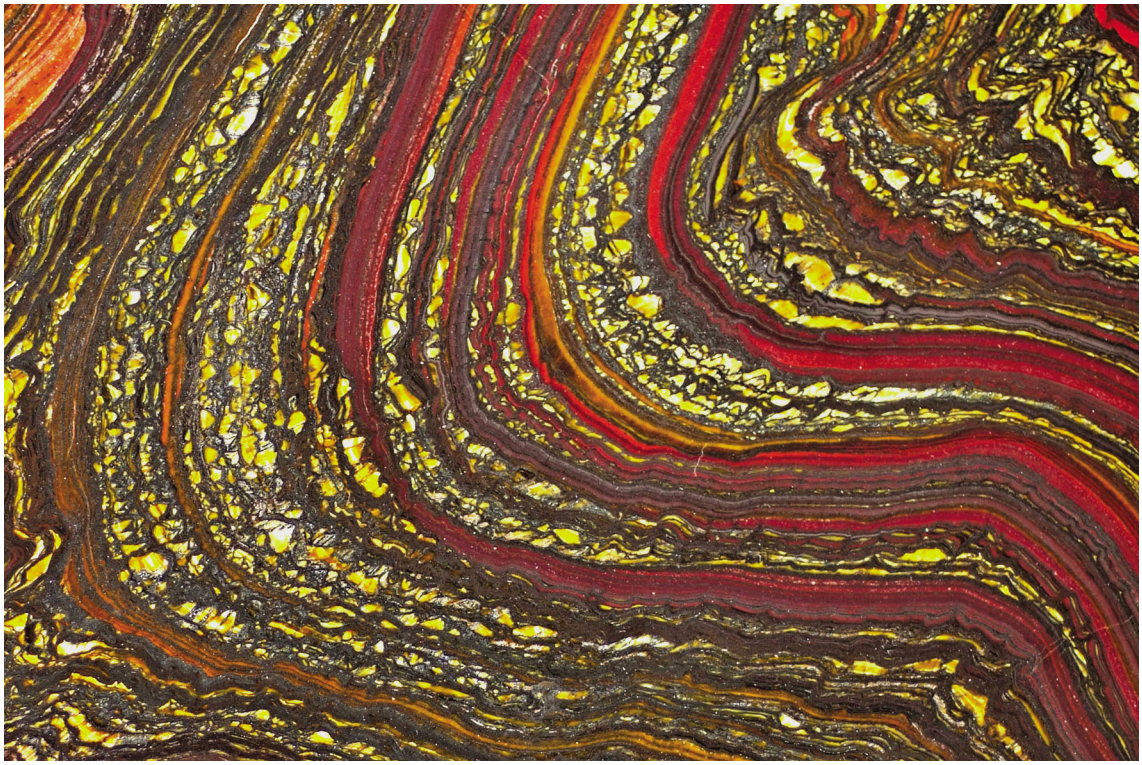


Figure 4.68. Ord Ranges tiger iron comprising folded bands of oxidized BIF alternately rich in microcrystalline, red hematite, and cherty quartz, as well as lenses and laminae of golden tiger eye up to 5 mm wide.



Figure 4.69. *Mount Barker Stone* is a very fine grained spongolite from the Mount Barker area.



Figure 4.70. Detail of a coquinite shell block from Shark Bay.

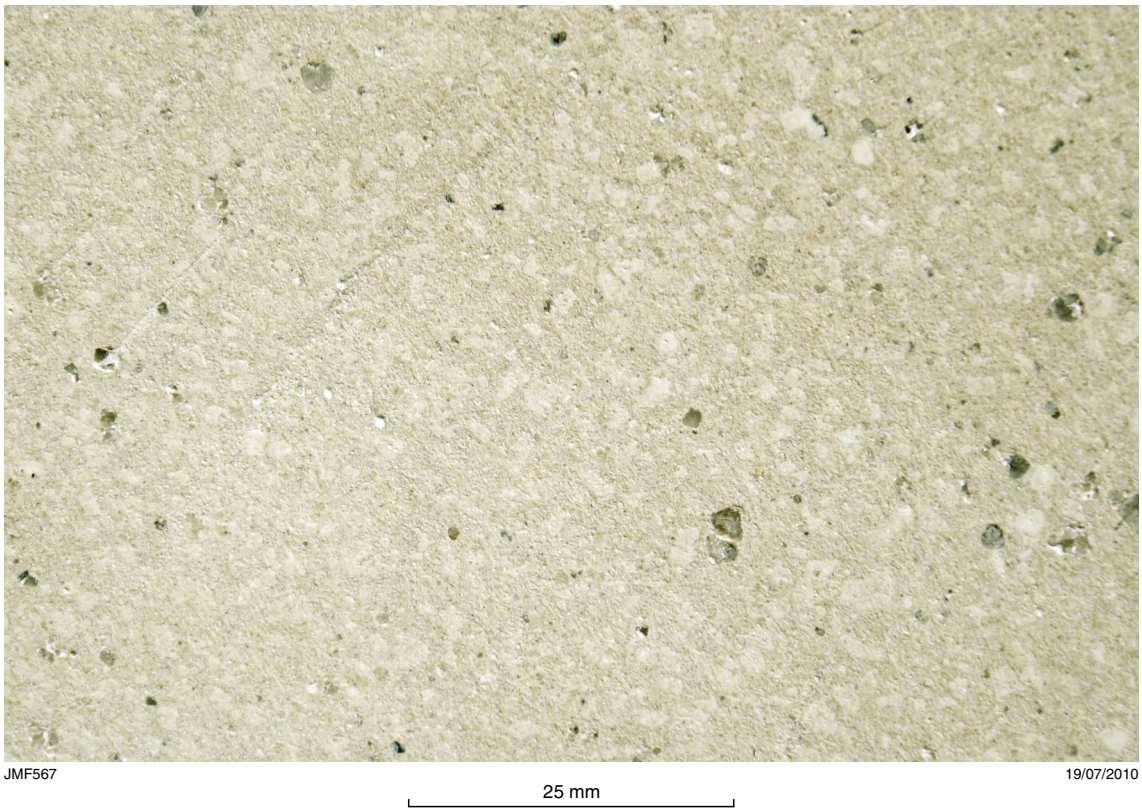
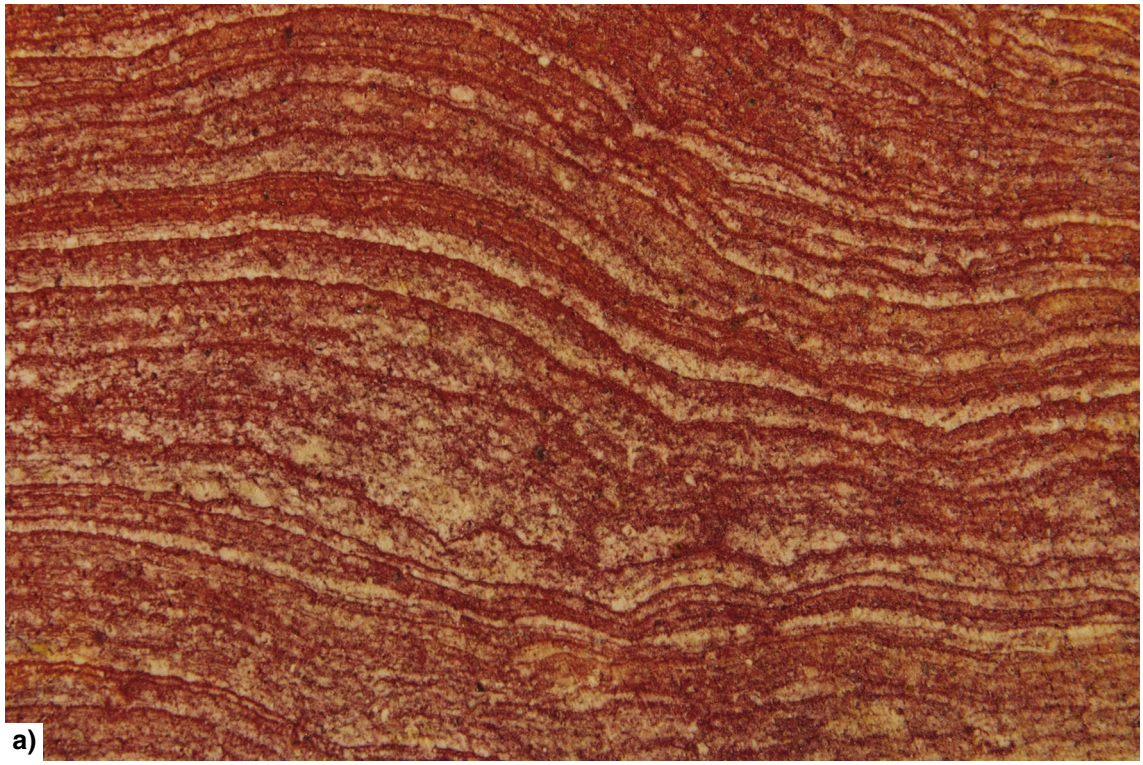


Figure 4.71. Cue historic building stone. An altered felsic volcanic rock largely composed of kaolinite–illite clay, and quartz.



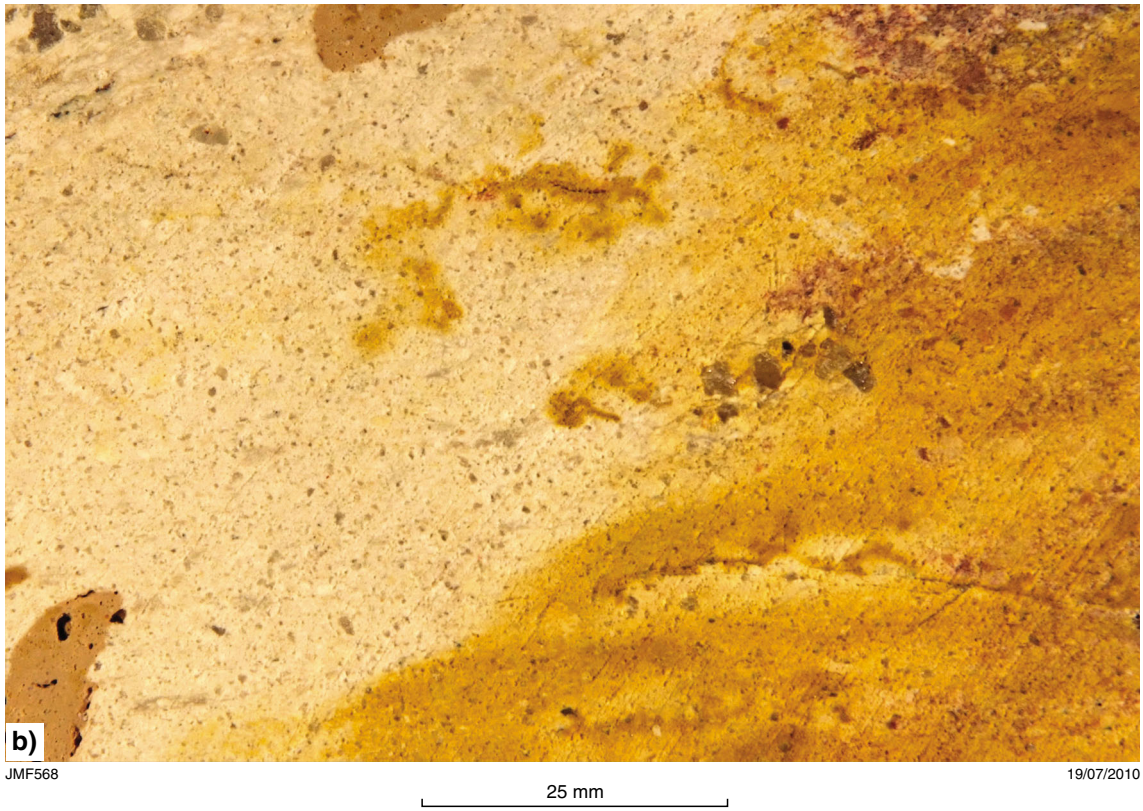


Figure 4.72. Colour and textural variations in *White Cliff Ashlar Stone* from White Cliff quarry. These weathered rocks were probably derived from felsic, volcaniclastic rocks: a) red-banded, quartz–sericite–clay; b) cream to yellow, clay-rich, pebbly volcanic–lithic sedimentary rock or tuff.

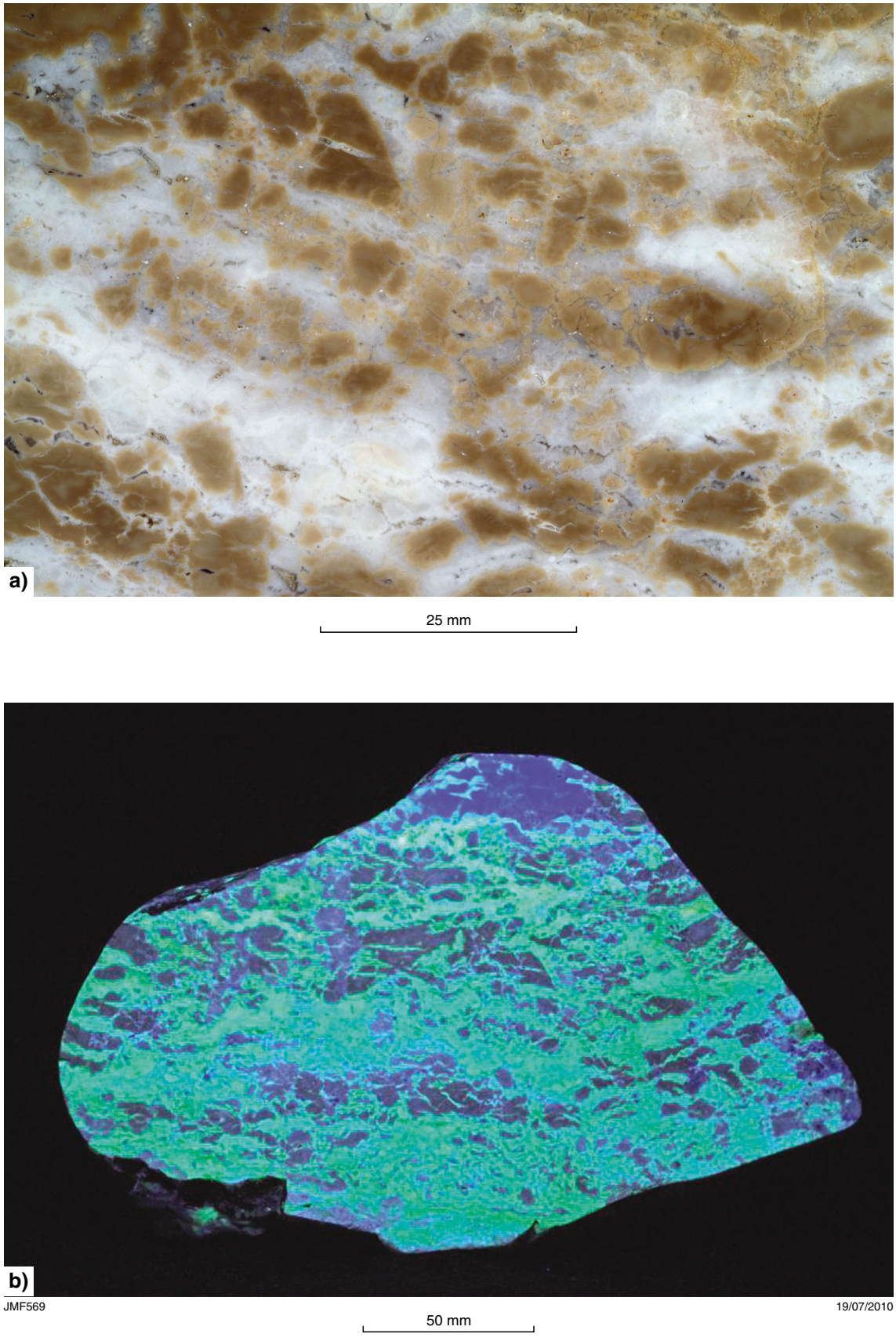


Figure 4.73. Wodgina opaline silica: a) the polished stone in natural light; b) spectacular green and blue fluorescence generated on exposure to short-wave UV light.

Appendix 5

Addendum to Volume 1

Since 2007, when Volume 1 of the dimension stone series was published by Fetherston (2007), new information has been reported relating to two prospects located adjacent to the Great Southern Highway in the Wambyn area, about 20 km west of York and close to Mount Observation. The first of these relates to the correct location of the original drillsite of the Wambyn black granite. The second report highlights the discovery of a decorative stone known as the Hurricane Hill saprolite, with some potential as paving material in the landscaping industry.

Black granite

Southern Region

Yilgarn Craton – South West Terrane

Wambyn

The Wambyn black granite drillsite reported by Lipple (1988) is located in a forested area on Allawuna property at MGA 461228E 6470949N (Zone 50), approximately 200 m west of the original sample site (Appendix 5.1). At the drillsite, a relatively massive north-northwesterly trending dolerite dyke, about 40 m wide, has intruded an Archean, fine-grained, grey granite, identified in thin section as an altered biotite granodiorite (Appendix 5.2).

In 1988, three diamond coreholes were drilled to a maximum depth of 95 m at a variety of angles to ascertain the attitude and frequency of joint sets as well as the quality of the black granite. Information obtained from these holes indicated that at least two zones, within a potential quarry area, could yield marketable, fine- to medium-grained black granite blocks with dimensions of 1.0 m × 1.0 m × 3.0 m of monument-grade stone estimated at about 0.252 Mm^3 (Lipple, 1988).

Massive black granite drillcores still remaining on site and up to 1.25 m in length, tend to confirm the availability of large black granite blocks from this prospect. The high quality of the stone contained in drillcore is shown in Appendix 5.3.

The discovery of commercial-grade, fine-grained black granite at this site indicates that with additional exploration, similar dolerite dykes may be located in the Darling Ranges that also contain commercial quantities of similar high-quality stone. Given the relatively short distance to the Perth metropolitan area, reduced transportation costs may assist in the establishment of a black granite industry supplying both domestic and overseas markets in future years.

Petrographic description

Weakly metamorphosed, weakly granophyric, fine-grained dolerite with minor actinolite, sericite, clinozoisite, titanite, and possible chlorite.

This fine-grained, weakly metamorphosed dolerite has a visually estimated mineralogy with 52% plagioclase, 38% clinopyroxene, 8% opaque oxide, and 2% granophyre with granular late magmatic quartz plus apatite. Minor actinolite replacing small grains is also present. Plagioclase laths to 2 mm long are commonly microfissured and contain possible chlorite as well as sericite and clinozoisite (saussurite). The pyroxene is mostly granular to prismatic and rimmed and veined by green amphibole, but the green amphibole has also replaced separate grains to 1 mm in diameter of possible orthopyroxene or pigeonite. Opaque oxide has been partly replaced by titanite. Minor late magmatic quartz and granophyre contain apatite as well as sparse sericite or amphibole.

Saprolite

Southern Region

Yilgarn Craton – South West Terrane

Hurricane Hill

This saprolite prospect is located in the northeastern portion of Hurricane Hill property on Boyercutty Road, at MGA 462598E 6477463N (Zone 50), about 5 km north of the Great Southern Highway in the Wambyn area (Appendix 5.1).

The saprolite is of variable appearance and appears to be the weathering product of an underlying, southwesterly trending metadolerite dyke. The weathered stone is in the form of an aggregate largely composed of kaolinite together with lesser amounts of leucoxene, hematite, and illite. The extremely fine grained material is relatively hard and appears to be insoluble in water. Attractive colours range from pink to orange, red, brown, and mauve, and textures may be mottled or extensively banded with fine liesegang rings. The surface polishes to a fine, silky lustre (Appendix 5.4).

It has been suggested that this material could be value-added by cutting into smooth, decorative slabs for application as spectacular paving stones in landscaping projects.

Petrographic description

Kaolinite–leucoxene–hematite–illite saprolite aggregate probably derived from crenulated metadolerite.

This sample appears to be composed mainly of kaolinite and possible leucoxene and very minor illite as well as liesegang bands rich in earthy hematite in over 65% of the thin section. The entire rock seems to have a coherent fabric suggesting that the protolith had a crenulated foliation defined by lamellae of possible leucoxene. There are also suggestions of fractures and shears. Small leucoxene-free patches to 3–4 mm long may indicate former feldspar phenocrysts, although this is uncertain. This sample may represent saprolite derived from metadolerite. The mineralogy may require confirmation by X-ray diffraction analysis.

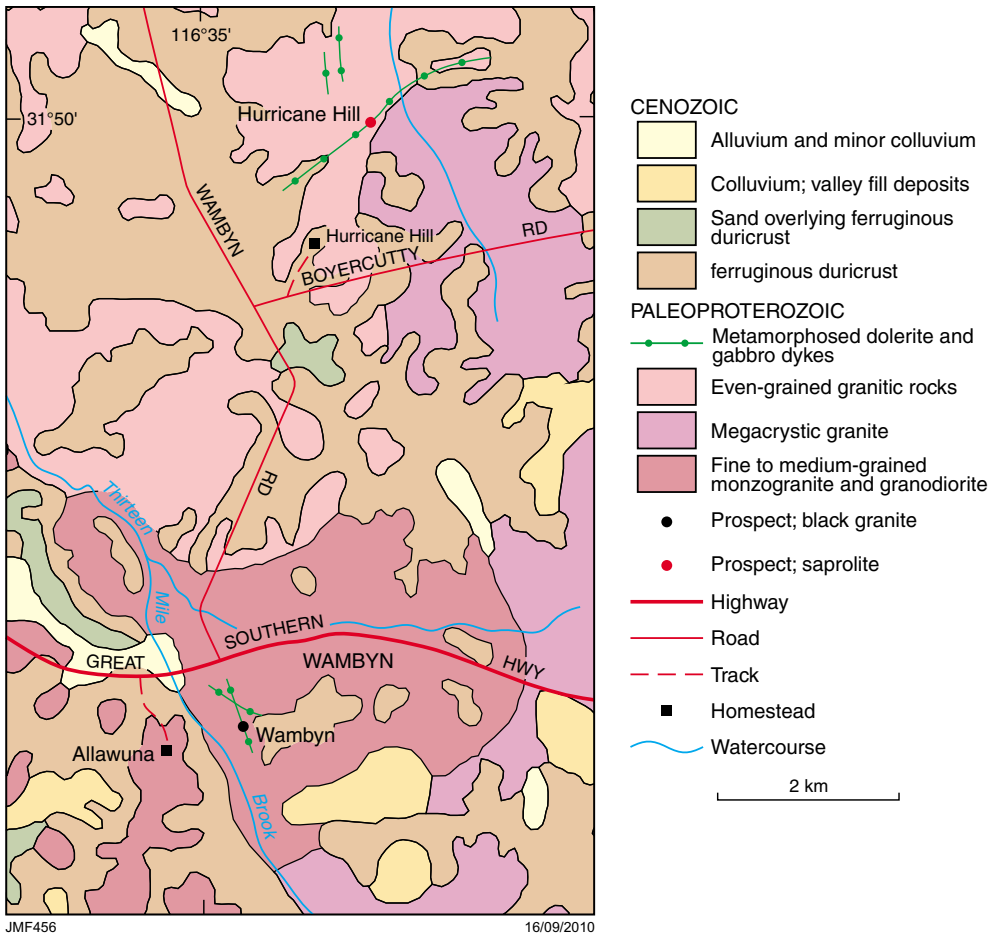


Figure 5.1 Geology of the Wambyn area (modified after Low et al., 1978).



JMF632 29/07/2010

Figure 5.2 Wambyn black granite exploratory drillsite (1988) showing massive dolerite outcrop (up to 40 m wide).



JMF633 29/07/2010

Figure 5.3 Drill core split of fine-grained black granite from the 1998 Wambyn drilling program.

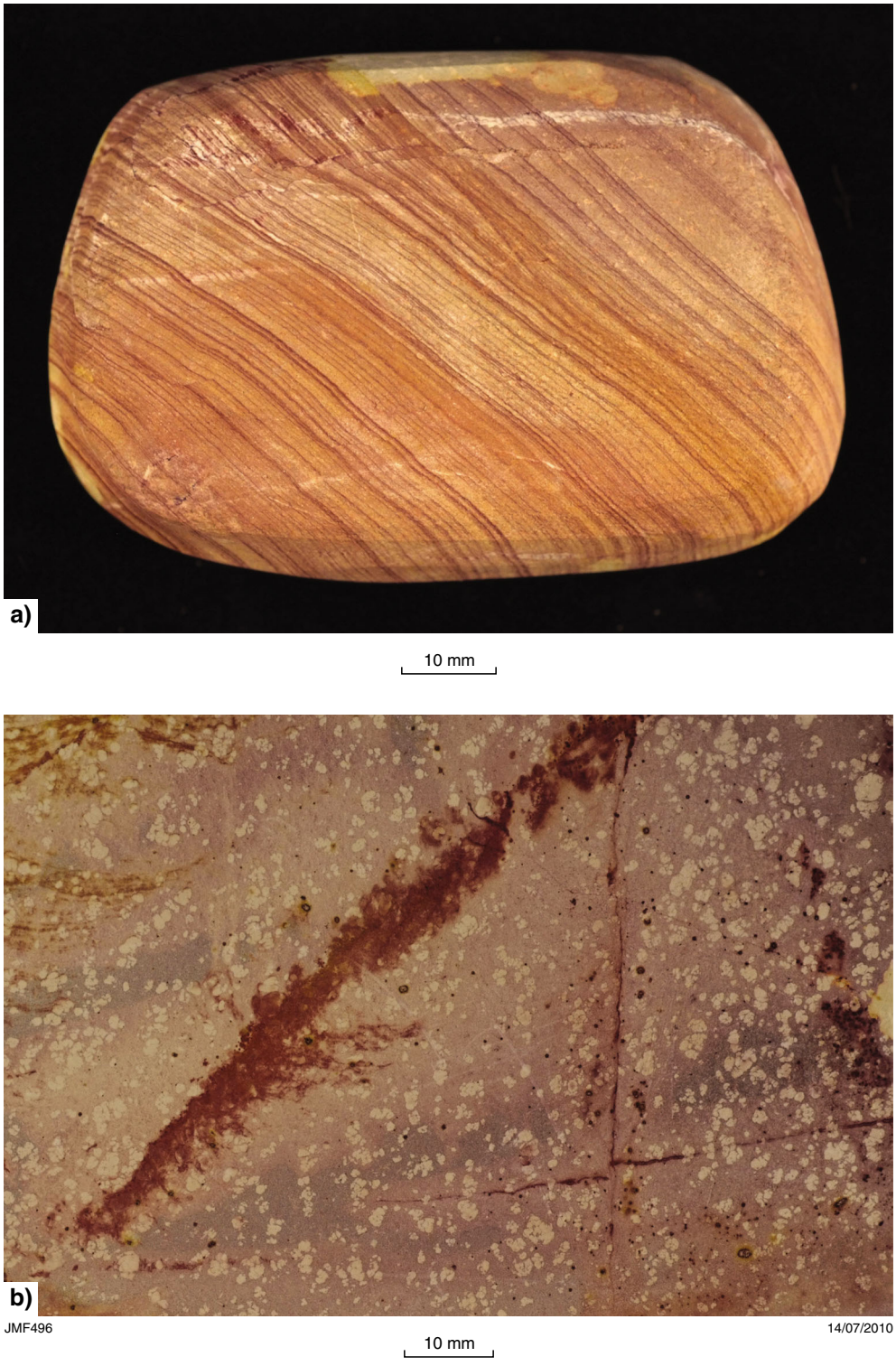


Figure 5.4 **Visually attractive, saprolitic stone from the Hurricane Hill prospect at Wambyn: the samples demonstrate the variablility of this stone with (a) displaying fine, light brown liesegang rings, and (b) a mottled texture set in a mauve-coloured matrix.**

Mineral Resources Bulletin 24 constitutes the second volume of the work presented previously in Mineral Resources Bulletin 23 as Volume 1.

Volume 2 covers much of the published and unpublished data on dimension stone quarries, prospects, and historical sites in the southern, central western, and northern regions of Western Australia. Almost 120 sites have been investigated for inclusion in this publication.

Major dimension stone rock types include granite and metamorphic rocks, black granite, marble, and sandstone, together with a variety of minor stones comprising conglomerate and breccia, banded jasper, spongolite, coquinite, felsic volcanogenic rocks, and silica.

This detailed study is intended to highlight for future developers the extensive resources of high-quality dimension stones available in accessible areas of the State.



Further details of geological publications and maps produced by the Geological Survey of Western Australia are available from:
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100 Plain Street
East Perth WA 6004
Phone: (08) 9222 3459 Fax: (08) 9222 3444
www.dmp.wa.gov.au/GSWApublications

FETHERSTON
Dimension stone in Western Australia Volume 2
MINERAL RESOURCES BULLETIN 24

116° 120° 124° 128°

16° 20° 24° 28° 32° 36°

Parry Range
Ten Mile Well
Bluff Well
Wadrah Bore
Nanutarra
Motin Bore
Hooley Camp Hill
Glen Florrie
Glen Florrie Black
White Rocks
Minnie Springs White
Minnie Springs Pink
Chain Pool
Bellotti
Manolini Well
Yarrie Pool
Pindanni
Maroonah
Sheela Bore North
Maroonah Green
Pilbara Green
Chararoo Well

Edmund Basin Inset (marble)

Mount Hart
Kimberley Jade
Wombarella Creek
Kimberley Pearl
Kimberley Storm
Kimberley Black
Kimberley Ice
Milliewindie
New Quarry
Wumburrul
Quarry Camp
Quarry Camp 10
Quarry Camp south
Quarry Camp 9
Quarry Camp 3 & 4
Quarry Camp 6
Quarry Camp 8
Quarry Camp 7
Carpenter Gap
Colemans Prospect
Fairfield

West Kimberley Inset (granitic gneiss and black granite)

Kimberley Colourstone
Argyle White
Kimberley White
Kimberley Sandstone and Quartzite
Nillibubbacca Quartzite

Mount Jowlaenga Inset (sandstone)

INDIAN OCEAN

KING LEOPOLD OROGEN
Kimberley and Speewah Basins
Bonaparte Basin
Wyndham
Kununurra
Hooper
West Kimberley
Complex
Derby
Broome
Mount Jowlaenga
McIntosh
Ord Basin
Fitzroy Crossing
Halls Creek
HALLS CREEK OROGEN
Birrindudu Basin
Lamboo Complex
Granites–Tanami Complex
NORTHERN REGION
Northern Carnarvon Basin
Canning Basin
Port Hedland
Ord Ranges Tiger Iron
Dampier
Karratha
Roebourne
Karratha Stone
Wodgina
Marble Bar
Yeneena Basin
PATERSON OROGEN
CENTRALIAN SUPERBASIN
Onslow
White Gate Well
Hamersley Basin
Exmouth
Edmund Basin
Brockman Tiger Eye Jasper
Learmonth
Nanutarra
PILBARA CRATON
Three Corner Cheela
Tom Price
Marillana
Wyloo
Stuckess
Paraburdoo
Newman
Rudall Complex
ARUNTA OROGEN
Ashburton Basin
Officer Basin
Pingandi Grey
CAPRICORN OROGEN
Amadeus Basin
Southern Carnarvon Basin
Edmund Basin
Collier Basin
Marymia Inlier
Carnarvon
Gascoyne Junction
Weedarrah
Shark Bay
Gascoyne Province
Gum Creek Well
Erong Springs
OROGEN
Earaheedy Basin
Denham
Bryah and Padbury Basins
Yerrida Basin
Warburton
Musgrave Province
Badgerada Group
CENTRAL WESTERN REGION
Carbla Point
Jundee
Meekatharra
Wiluna
Flag Pole Landing
Mindoolah
Cue
Perth Porphyry
Officer Basin
Melangata Green
Kalbarri
Naluthanna Hill
Boogardie
Pioneer Well
Mount Magnet
Mingyngura Hill
Carlaminda blue
Yalgoo
Boulder Well
Palagea Rockholes
Gunbarrel Basin
Leinster
Northampton
Mullewa
Laverton
Northampton Complex
PINJARRA OROGEN
Desert Sunset
Asteroid
Doodhoowooroo
Leonora
Geraldton
Paynes Find
Dongara
Menzies
Perth Basin
YILGARN CRATON
Wubin
Eucla Basin
Darrine Rock
Mungari Grey
Kalgoorlie–Boulder
Bullabulling
White Cliff
Moora
Coolgardie
Karamindie Soak
DIMENSION STONE IN WESTERN AUSTRALIA VOLUME 1, PLATE 1
Southern Cross
Boorabbin Rock
Londonderry
Kambalda
Merredin
Fraser Range
SOUTHERN REGION
Northam
Wambyn Saprolite
York
Norseman
PERTH
Wambyn Black
Brookton
Mandurah
Pinjarra
Narrogin
Bremer Basin
OROGEN
Bunbury
Collie
Capel
Wagin
Ravensthorpe
Busselton
Donnybrook
Gairdner River Pink
Desert Brown
Kojonup
Katanning
Margaret River
Bridgetown
Albany Green
Laguna Green
Twertup Creek
Esperance
PINJARRA OROGEN
Leeuwin Complex
Manjimup
Mount Barker Stone
Kamballup
Biranup and Nornalup Complexes
Augusta
Mount Barker
FRASER
ALBANY
Willyung Hill
Albany
Denmark

SOUTHERN OCEAN

Fraser Range Inset (gneiss, granulite and black granite)

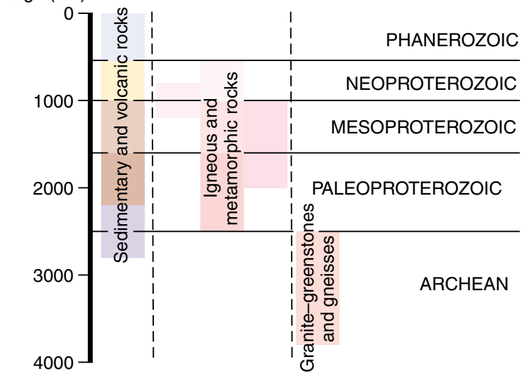
Horseshoe
Fantasia
American
Phill's
Gold Leaf Black 1
Garnet Ice
Fraser Range Black
Gold Leaf Black 2
Verde Austral

JMF398 15/05/2010

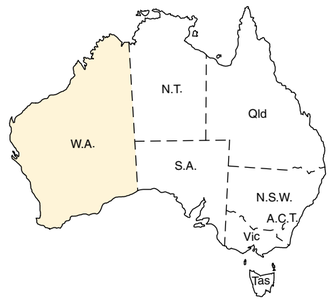
REFERENCE

Deposit style	Quarry	Prospect	Historic
Granite and metamorphic rocks	▼	▽	●
Black granite (dolerite and gabbro)	▼	▽	
Sandstone	▼	▽	●
Conglomerate and breccia		▽	
Marble	▼	▽	
Banded jasper and tiger iron	▼	▽	
Spongolite	▼	▽	●
Coquinite			●
Opaline silica		▽	
Felsic volcanic rocks			●
Saprolite		▽	

Age (Ma)



Collie City or town
Highway
Major road
Track
Railway



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MINISTER FOR MINES AND PETROLEUM

Geological Survey of Western Australia
RICK ROGERSON
ACTING EXECUTIVE DIRECTOR

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
MINERAL RESOURCES BULLETIN 24, PLATE 1

DIMENSION STONE IN SOUTHERN, CENTRAL WESTERN, AND NORTHERN WESTERN AUSTRALIA

SCALE 1: 5 000 000

0 50 100 150 200
Kilometres

Compiled by JM Fetherston 2009

Geology by IM Tyler and RM Hocking, 2002, A revision of the tectonic units of Western Australia: Western Australia Geological Survey, Annual Review 2000–01, p. 33–44.

Edited by N Tetlaw

Cartography by M Prause

Further information on mineral localilties in WA can be obtained from MINEDEX database, Department of Mines and Petroleum

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Plotted by the Geological Survey of Western Australia

The recommended reference for the map is:
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