Department of
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Mineral Resources Bulletin 25

GEMSTONES OF WESTERN AUSTRALIA

SECOND EDITION

by J Michael Fetherston, Susan M Stocklmayer, and Vernon C Stocklmayer

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GAA
Gemmological Association of Australia

Gemstones of Western Australia

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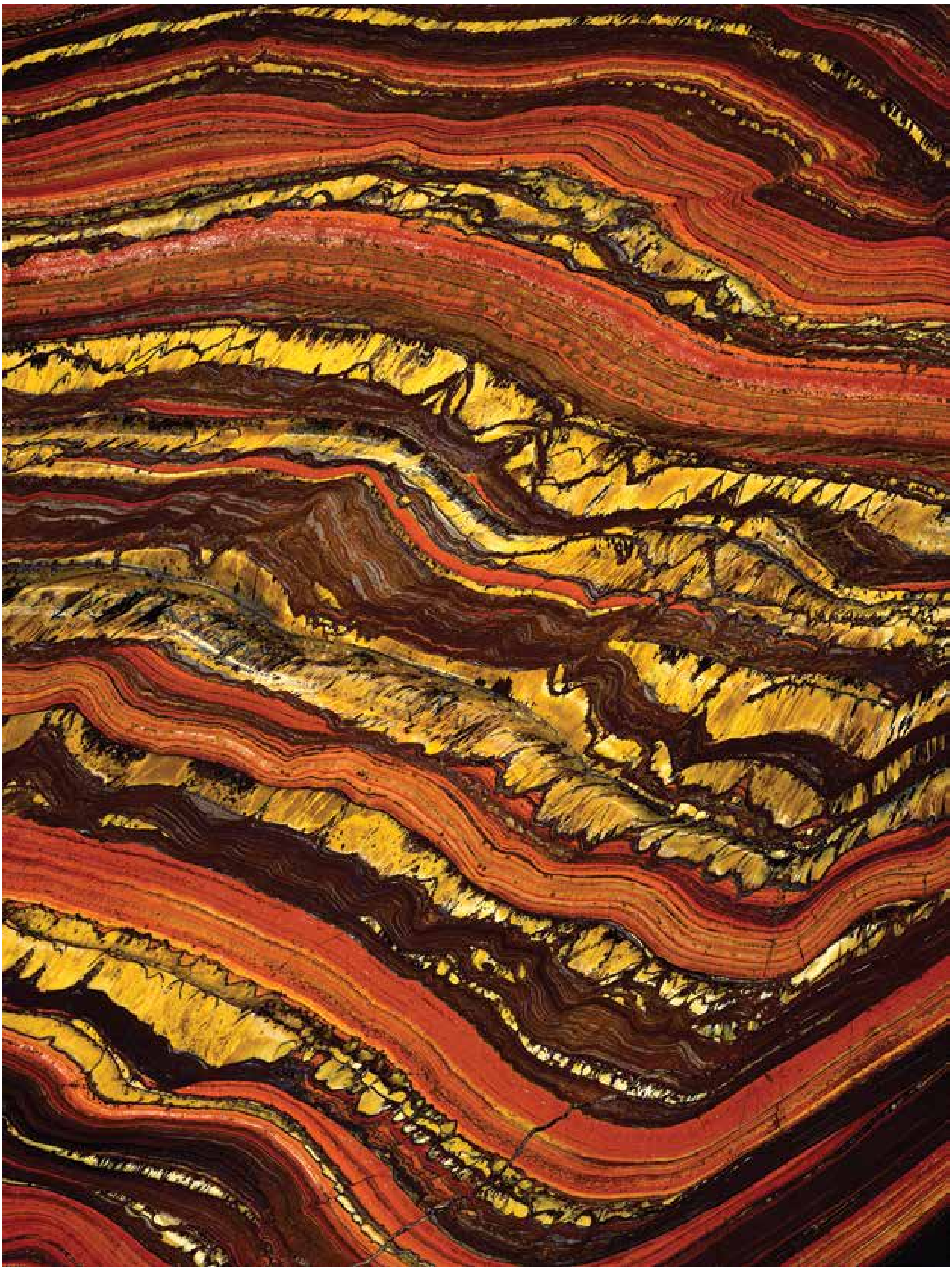

FRONTISPIECE

Tiger iron from the Ord Ranges, Pilbara region, displaying folded bands of dark brown hematite, cherty quartz, and golden tiger eye. Bands are up to 10 mm thick (courtesy Bill Atkinson and Glenn Archer, © Bill Atkinson Photography)

Government of **Western Australia**
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Front cover photograph: Argyle red, pink, and blue diamonds from the Argyle pink diamond tender in 2014 (© Rio Tinto 2014)

Back cover photograph: Polished sphere of Brockman tiger eye jasper from the Mount Brockman area, Pilbara region. The sphere, approximately 35 cm in diameter, contains a central lens of tiger eye up to 10 cm thick displaying vertical green and gold zones of tiger eye fibres. The tiger eye lens is set within irregular, horizontal bands of green, yellow, and red jasper (courtesy David Vaughan)

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Gemstones of Western Australia

SECOND EDITION

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J Michael Fetherston, Susan M Stocklmayer*, and Vernon C Stocklmayer*

Abstract

Since the discovery of diamonds in the Kimberley region of Western Australia, the mining and processing of these precious gems has developed into one of the State's major industries. Less well known is that Western Australia contains a plethora of other gemstones, decorative stones, and ornamental stone used for jewellery and sculptural purposes. This second edition of Bulletin 25 systematically organizes and discusses the history and quality of almost all known occurrences of these stones, together with chapters on precious metals and pearls. An extensive appendix lists precise geographical sites, where possible, for most materials mentioned, and references to earlier work and discoveries are numerous.

Additional information addresses the science of gemmology, and historical aspects of gemstones and their use in jewellery and ornamental objects from Paleolithic times. The history of mining for gemstones in Western Australia is discussed, as are legislative aspects of the *Mining Act 1978* (WA), and the obtaining of a Miner's Right and associated obligations. Notes on safety and survival in the bush complete this comprehensive work.

Although Mineral Resources Bulletin 25 is published by the Geological Survey of Western Australia, it is a collaborative enterprise between this organization and the Gemmological Association of Australia. The richly illustrated text therefore caters not only for geologists and professional gemmologists, but also for experienced fossickers and amateur rockhounds.

KEYWORDS: chemical analysis, gem cutting, gemstones, history, lapidary, mineral exploration, mining legislation, natural resources, ornamental stone

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Chapter 1

Introduction to gemstones in Western Australia

Object and scope

Mineral Resources Bulletin 25, the second edition of Gemstones of Western Australia, is produced by the Geological Survey of Western Australia in collaboration with gemmological specialists from the Gemmological Association of Australia (Western Australian Division). This second edition provides an update on gemstone occurrences in the State, enlarging existing chapters as required and adding information on new discoveries. A comprehensive index to gemstones, semiprecious and ornamental stones, and mineral locations has also been added.

Minerals, rocks and organic materials classified as gemstones or ornamental stones comprise an arbitrary and open-ended group ranging from high-value, facetable gemstones to attractive, lower value ornamental stones suitable for cutting and polishing as jewellery, ornaments, and sculptural works. Consequently, description of the eclectic range of gems and ornamental stones included in this publication has largely been guided by the demand for information by gemstone companies, prospectors, fossickers, and mineral collectors.

All of these materials have one or more interesting characteristic such as attractive colours or unusual textures. The skill of the gem or lapidary cutter is to cut, polish or facet a gemstone, mineral or rock as specified in order to produce a polished gem or *objet d'art* worthy of mounting or display in an item of jewellery or as a visually attractive ornamental stone. For these reasons many rare and unusual materials have been included in this volume, although it should be appreciated it is a work that can never be fully comprehensive. Where possible, for most materials mentioned, an extensive appendix lists precise geographical sites.

Western Australia has an established reputation as a producer of many varied ornamental stones (gemrocks), some of which are described in Geological Survey of Western Australia mineral resources bulletins covering dimension stone in the State (Fetherston, 2007, 2010). Dimension stones used in the building and ornamental stone industries may also be used as gemrocks. A selection of these rocks, such as orbicular granite and banded iron jasper (tiger iron), are included in this volume. The wide range of rock types used within the gemstone industry includes examples of igneous, sedimentary, and metamorphic rock types, spanning the State's geological history from the Archean to Cenozoic. In addition, native gold and silver and other rare materials such as tektites have been included. This edition also includes a discussion on organic gems that encompasses the production of cultured pearls (periculture), shells, and other organic gems.

Sources of information

Sources of information used in this Bulletin are both published and unpublished material, supplemented by data gathered from limited field inspections. Published information is derived from Geological Survey of Western Australia records, reports, bulletins, annual reports, and geological maps. Other sources include papers in geological and gemmological journals, conference papers, and articles published in newspapers. Of particular importance for pegmatite gemstones is the book entitled Guidebook to the pegmatites of Western Australia (Jacobson et al., 2007).

Unpublished information is obtained from open-file statutory reports submitted to the Department of Mines and Petroleum (DMP) in Western Australia by mineral exploration companies. This information is supplemented by unpublished data made available by gemstone and ornamental rock producers, amateur prospectors, and fossickers.

In this publication, gem and ornamental stones in Western Australia are described within the tectonic units in which they are found. Tectonic units are the broadest structural units relating to the geological evolution of the continent (Fig. 1.1). At a more regional level, the general location of every gem and ornamental stone is assigned to the 1:100 000 scale series map in which the deposit or prospect is located. An example of the name and number of each map would appear as (MUNDIWINDI, 2950) following each mine, mineral deposit, and prospect described in the text.

Most host rocks to gemstone localities listed in this publication have been assigned to a period in geological time, largely within the Archean or Proterozoic. A simplified geological time scale is given in Figure 1.2.

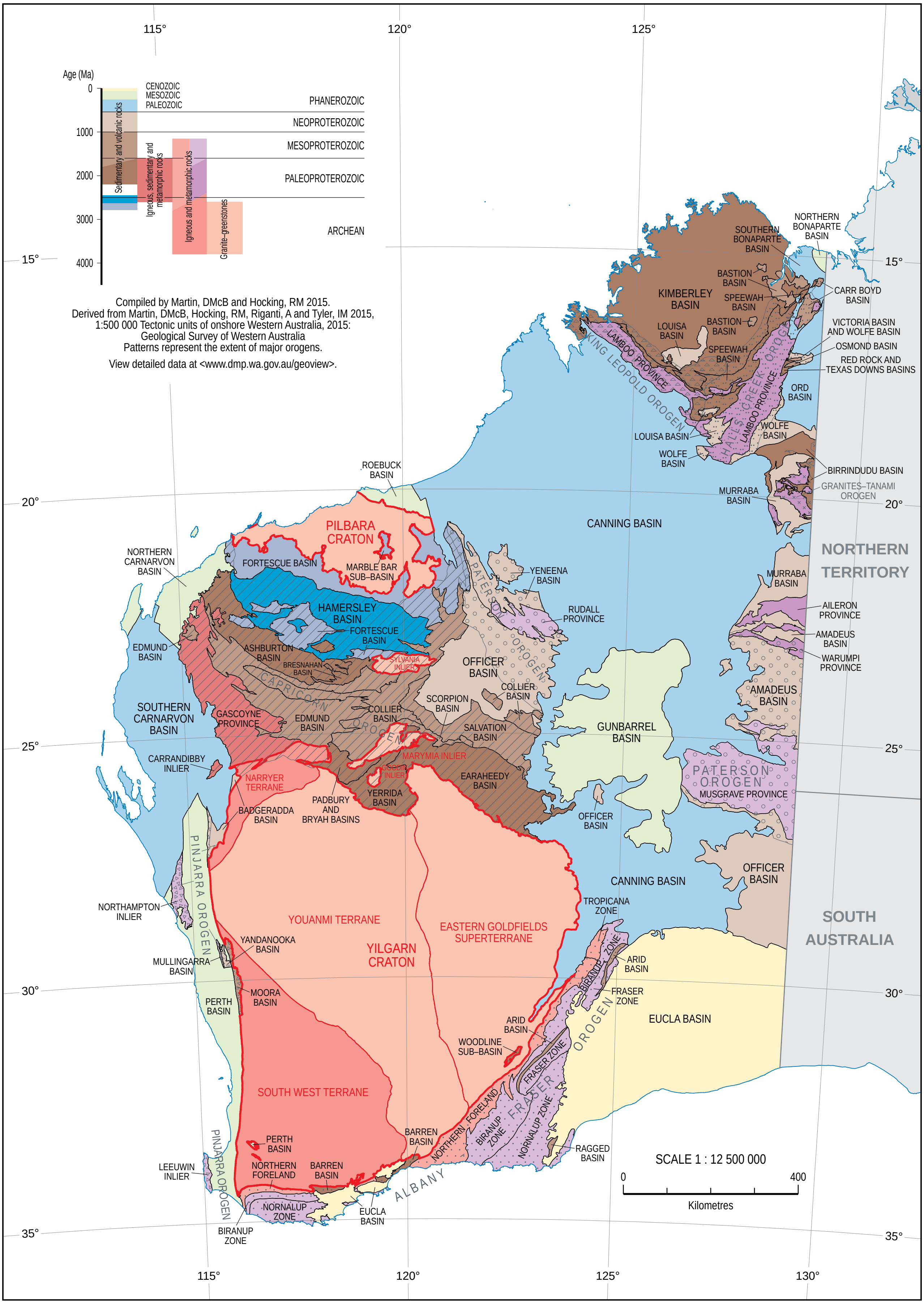

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Figure 1.1.　**Main tectonic units of Western Australia (modified after Martin and Hocking, 2015)**

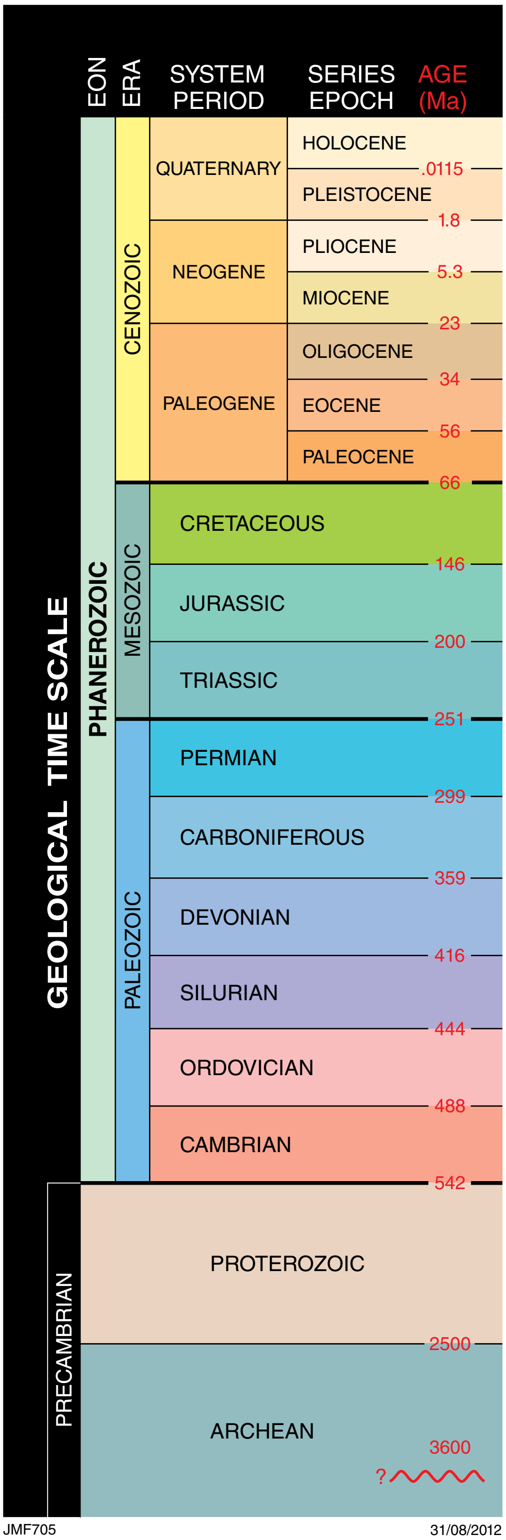

Figure 1.2. Simplified geological time scale

Gemstones in history

Archeological finds confirm a long association between Paleolithic humans and the deliberate collecting of natural objects. There are many examples that show some rocks, minerals, and organic materials including shells, amber, and jet were collected and were significant in some way to peoples of prehistory. Such early finds mark the beginnings of the history of jewellery. The recognition and appreciation of these special materials by early humans is regarded as an important cultural development.

Throughout history various cultural groups of people have created their own recognizable and specialized jewellery using whatever materials were available. Although many of the original early gem sources are now depleted, new sources have continued to be discovered, as have the jewellery arts and techniques that have evolved to make use of them.

Jewellery was not only created for aesthetic reasons although early in history gems were attributed talismatic or amulitic powers for the wearer. These were special powers; for example denoting protection from disease, endowing wisdom, preventing drunkenness, or making the wearer invulnerable. Similar superstitions have persisted throughout history, with an increased number of minerals and rocks added to those already chosen as having special powers. Even in this modern era, these superstitions are the basis for the burgeoning trade in crystals and minerals having a wide variety of metaphysical powers attributed to them.

History of gemstone mining in Western Australia

Ever since the first European settlement in Albany in 1826, the Western Australian gemstone industry has largely been the domain of prospectors, fossickers, and small syndicates rather than large mining companies. Major exceptions to this are in the pearling, diamond, and gold industries although gold also has a strong following of amateur and professional prospectors using metal detectors.

In general, gemstone deposits tend to be small and production somewhat restricted. In past years, much of the production was not recorded as it was extracted from small prospects on open ground, the location of which was commonly kept secret. The mining of ornamental rocks has tended to be on a larger scale, mainly using large earth-moving equipment in opencut quarries. Today mining tenements protect most of these deposits.

Australia's shell industry began long before European settlement of the northwest of the State. In these areas, coastal-dwelling Aboriginal people harvested abundant pearl shell from shallow waters to supply their well-established trading network for this material. Not long after Europeans settled in Western Australia, they were quick to see the value of the pearl fields, and pearling and pearl shell harvesting began in earnest in the 1850s at Shark Bay.

Around 1875–80 the pearling industry became established in Broome. The expansion of the pearl and pearl shell industry caused a major influx of immigrants into the

North West region including Chinese, Malay, and Japanese immigrants to work in the industry. In the 1890s, the production of cultured pearls (periculture) was first trialled unsuccessfully in Roebuck Bay at Broome. It was not until 1956 that periculture became commercially viable with the establishment of the Kuri Bay pearl farm off the West Kimberley coast north of Broome (Brown, 2005).

Major gold rushes in Western Australia were in Halls Creek in 1885, Southern Cross in 1887, Cue in 1891, Coolgardie in 1892, Kalgoorlie in 1893, and Norseman in 1894. While abundant gold in form of flakes, fragments, and nuggets would have been found in the early days, very little of this would have been used in jewellery, with the vast proportion melted down. The comparatively recent development of the modern metal detector has allowed the modern prospector to continue the search for surface and near-surface gold.

From the late 1800s to about 1915, gold and tin prospectors had discovered most of the major pegmatite deposits in the State mainly in the Pilbara region and in the south around Coolgardie, Greenbushes, and Ravensthorpe. These pegmatites were commonly notable for the inclusion of gem minerals of the beryl group including emerald and aquamarine. The Londonderry and Grosmont pegmatites, discovered in 1896 and 1909, respectively, are south of Coolgardie. Gem minerals from pegmatites at these sites included morganite and yellow beryl together with topaz and tourmaline. The first emerald discovery in Western Australia was at Poona, about 55 km northwest of Cue, in 1912 by a prospector known as AP (Paddy) Ryan (Jacobson et al., 2007).

The first recorded discovery of diamonds in Western Australia was in 1895 at Nullagine in the Pilbara where a few small stones were recovered from alluvial gold workings. Modern diamond exploration in Western Australia commenced in 1965 in the Nullagine area and new ground was not broken until exploration began in the Kimberley area in 1967. In August 1979, the Ashton Joint Venture laboratory in Perth reported that two diamonds had been discovered in a sample of gravel collected from Smoke Creek, a small creek draining into Lake Argyle. Further progressive sampling upstream led to the discovery of the Lower and Upper Smoke Creek alluvial diamond deposits, and ultimately, on 2 October 1979, geologists recognized the potentially diamondiferous Argyle Kimberlite No. 1 (AK1) olivine lamproite pipe (Chapman et al., 1996). Today, the Argyle AK1 diamond pipe is one of the world's largest producing diamond mines. The mine has been in production for 26 years and is famous for its coloured stones: yellow, brown, and the rare and extremely valuable pink diamonds.

Gemstone specifications

Gemstone quality

As a general rule, minerals and rocks classified as gemstones must share the important attributes of having visually attractive colours and textures, together with suitable durability so they may be cut and polished and thereby maintain that condition without being damaged excessively in wear or use.

In spite of this, comparatively softer materials are used as gemstones because their appeal is considered more important. Examples include variscite, a soft, attractive green phosphate mineral; opal, a brittle gemstone; and 'zebra rock', a siltstone with an attractive banded texture. Stabilizing treatments can be applied to softer materials to prolong the quality of finish.

In the past, an informal classification was developed to divide gems into precious and semiprecious groups largely based on their relative rarity. Historically, diamond, ruby, sapphire, emerald, precious opal, and alexandrite have been considered precious gems, with all others called semiprecious varieties. This grouping is no longer justified as each gemstone is assessed and appreciated on its individual merits, with its relative rarity determining its value.

Gemmological terminology

Most of the following chapters on gemstones and other ornamental materials contain highlighted boxes summarizing the gemmological properties of these materials. The boxes vary with each type of gemstone and ornamental stone and show the important identifying parameters and characteristic features of each. Detailed references to these terms used can be found in many standard gemmological and geological books. Brief explanations of some of these terms are given below.

Appearance describes common colours, recognizable patterns, and textures characteristic of the material.

Birefringence, also called **double refraction**, is a measure of the difference between the lowest and highest refractive indices of an optically anisotropic gem mineral (a mineral with a physical property that varies with crystallographic direction). Minerals with high birefringence, such as zircon, may display images of their internal features that appear doubled in specific orientations. Double refraction is only possible in minerals that belong to non-isometric crystal systems and only when viewed in specific crystallographic directions. Minerals of the isometric (cubic) system are singly refractive and show no birefringence.

Cleavage and **fracture** are terms used to describe splitting or breakage of both minerals and rocks caused by planes or zones of weakness along which breakages may preferentially occur.

Fracture is an uneven breakage in any direction other than that produced by regular cleavage planes. A common example in rocks is conchoidal fracture, which results in concave depressions similar to bottle glass fracture. Fracture is seldom used as a diagnostic property of a mineral.

Mineral cleavage describes where a mineral breaks along one or more well-defined, crystallographic planes. These planar surfaces are described according to the nature of the surface, such as perfect, good, fair, or poor. Mineral cleavage is a physical property of a mineral relating to its atomic bonding that reflects its crystal structure. For example, diamond has perfect cleavage along planes parallel to its octahedral symmetry.

Cleavages defining planar surfaces in fine-grained rocks may have resulted from a number of effects including the formation of thin sheets parallel to folding pressures in slate and phyllite where the planar surfaces do not relate to former bedding planes. Alternatively, rock cleavage may result from a tendency to break along parallel layers of mineral concentrations, such as mica and quartz, that may be aligned to bedding planes or other preferred directions.

Colour is an important guide in the identification of gem minerals and is a specific response of the eye to visible light (a range from 380 to 780 nm). Colour is perceived by the eye as a combination of both reflection and transmission of light as it interacts with a gem. The causes of colour in gems are complex. Some gems contain trace amounts of elements that generate colour change in an otherwise colourless gem, such as chromium and vanadium, that may result in green beryl known as emerald. The presence of trace elements affects the absorption of particular wavelengths in the gem and results in perceived colour differences. The majority of gem minerals, including quartz, diamond, beryl, tourmaline, topaz, and corundum, would be colourless (allochromatic) if they contained only the elements of their ideal chemical composition.

Other causes of colour include structural defects of the crystal lattice. Colour effects such as iridescence, where spectral colours are seen, result from diffraction and light interference effects caused by the physical structure of the material. Play-of-colour in precious opal and labradorescence displayed by some plagioclase feldspars results from the physical structures of these materials.

Crystal system refers to the symmetry group into which a mineral is classified based on its crystal structure. Each mineral can be classed into one of seven (previously six) crystal systems: isometric (cubic), tetragonal, orthorhombic, hexagonal, trigonal, monoclinic, and triclinic. Almost all minerals are crystalline. Non-crystalline minerals including glass and resins have no characteristic external form and are termed amorphous. An understanding of crystallography is important in gem identification and cutting as crystal structure influences many mineral properties.

Habit is the characteristic crystal form of a mineral, and may vary depending on the conditions of formation of the mineral. Habit is the easily observed expression of dominant crystal faces and is qualified by the appropriate form such as prismatic habit where describing columnar-shaped crystals of, for example, beryl or tourmaline.

Hardness is stated as a number or range of numbers according to Mohs scale. The numbers denote an order of relative hardness or resistance to scratching and have no quantitative significance. Thus, a mineral's hardness figure shows whether it can be scratched by a mineral harder than itself (i.e. it is of lower hardness), or whether it scratches a mineral of lower hardness on the scale (i.e. it is of greater hardness). The scale, first specified by the German mineralogist Friedrich Mohs, comprises 10 minerals in order of their comparative hardness from softest (1) to hardest (10):

Mohs hardness scale

1. talc
2. gypsum
3. calcite
4. fluorite
5. apatite
6. orthoclase feldspar
7. quartz
8. topaz
9. corundum
10. diamond.

Hardness test results establish some important distinctions between minerals of similar appearance such as beryl (hardness 7) and apatite (hardness 5). Hardness is a physical property that can be easily tested in the field on rough materials. Mineralogists also substitute other materials in the same way using a copper coin (hardness 3) or steel point (hardness 5.5)

Lustre is the brilliancy effect produced by light reflected from the surface of a gem. It is observed from a natural surface of a rock, mineral, or polished surface and its appearance is determined by the amount of incident light reflected from its surface. Gold and iron pyrite are both gem materials described as possessing a metallic lustre and many other gem minerals are described as having a vitreous (glass-like) lustre. Lustre is dependent on a combination of factors including the refractive index (RI) of the gem mineral and perfection of polish, which itself depends on the hardness of the material. Typically, minerals that are hard can be finished to a high polish and will retain the polish for longer because they are more resistant to abrasion. Diamond has the greatest hardness of any natural mineral, high RI, and an adamantine lustre. This lustre type is also displayed by other gems with high RI such as zircon and demantoid garnet. Several rock types containing minerals of low hardness, such as serpentinites, have a waxy or resinous lustre.

Pleochroism is a general term used to describe change of colour shown by some coloured gems when viewed in different orientations. Pleochroism is most easily detected with the aid of a dichroscope, which allows two colours to be viewed side by side. Dichroic minerals show two different colours (a hue change) or different intensities of colour when viewed by a dichroscope in directions other than parallel to an optical axis. Trichroic minerals can display a maximum of three colours or three changes of colour.

Dichroic minerals belong to the tetragonal, hexagonal, and trigonal crystal systems, and trichroic minerals to the orthorhombic, monoclinic, and triclinic systems. Minerals of the isometric (cubic) system cannot display pleochroism. Emerald and coloured tourmaline are examples of gem minerals that show strong dichroism. Cordierite (iolite) is an example of a trichroic gem showing three changes of colour from blue to violet-blue and yellow. Pleochroism (both dichroism and trichroism) can only be demonstrated in coloured gems.

Refractive index (RI) is shown as a number or range of numbers that express the optical density or refracting power of a mineral. For most minerals, refractive indices range from 1.35 to 2.42. RI is a ratio representing the velocity of light incident on a mineral (the velocity of light in air in practice is taken as a standard = 1.00) and its speed when transmitted through a mineral. RI is measured using a refractometer and standard models can detect a range of RI values between 1.4 and 1.8. In gem testing, an understanding of the behaviour of RI readings from a refractometer may be used to devise the optical character of a mineral. RI is probably the most important information used in gem mineral identification.

Specific gravity is the relative density of a material calculated as the mass or weight of a substance divided by the weight of an equal volume of pure water at 4°C. Specific gravity is a ratio without units. It can be determined by different methods; gemmologists commonly use a specialized balance with dual pans that permit weighing of the material in air and fully immersed in water. Calculation of specific gravity is derived using the formula: (weight of the material in air)/(weight of equivalent volume of water).

Transparency or **diaphaneity** expresses the degree to which light can be transmitted through a material. Terms include grades of transparency ranging from fully transparent, where objects can be viewed through the mineral, to partially transparent as in semitransparent to translucent, where some light is transmitted. No light is transmitted through opaque materials such as gold. Most minerals and rocks have some degree of translucency in thin section.

Ultraviolet (UV) light and **fluorescence**. Ultraviolet light responses to gemstones are uncommon although photoluminescence reactions shown by some gem minerals may provide a useful indication of a gem's identity. Fluorescence is the emission of visible light by certain minerals when exposed to UV light.

Ultraviolet light, also known as black light (because it is invisible), is commonly categorized as short or long wave, based on the wavelength range produced by filters or mercury discharge lamps. Long-wave UV has a range from 315 to 400 nm, and short-wave UV from 200 to 280 nm. Prospectors' UV lamps are likely to have filters specifically made for detecting UV responses of certain economic minerals such as scheelite (calcium tungstate) and may emit a mix of long- and short-wave UV. Gem minerals that commonly respond to UV light include diamonds, topaz, and some synthetic gem materials such as cubic zirconia and glass (paste). Ultraviolet light will commonly cause surface crusts of opaline silica to fluoresce white or green, and calcite pink. Gemmology books provide reference tables on UV responses and information on personal safety for using UV light.

Prospecting for gemstones

The rules and regulations governing prospecting and fossicking in Western Australia are set out in the *Mining Act 1978* (WA) (the Act) and subsequent amendments. This legislation is complex and any person intending to carry out a serious prospecting program including excavations or other disturbances to the environment should consult the Act and regulations and/or seek professional advice.

The Act provides for a Miner's Right that can be purchased for $25 from DMP at Mineral House in Perth or from any Mining Registrar's Office throughout the State. A Miner's Right remains valid for the lifetime of the holder. A list of Mining Registrars, addresses and telephone numbers is given on the Western Australian Department of Mines and Petroleum website at <www.dmp.wa.gov.au>.

A Miner's Right entitles the holder to prospect under prescribed conditions and to fossick for rocks and gemstones on Crown land, whether or not that land is held as an exploration licence, subject to the prior written consent of any occupier of that land and the exploration licence holder. For access to an exploration licence on Crown Land, a Section 40E permit is also required. Prospecting may be carried out for all minerals including gold, and a metal detector may be used (Department of Mines and Petroleum, 2009).

'Fossick' means to search for and remove rock, ore, or minerals (excluding gold or diamonds) not exceeding 20 kg for a mineral collection, lapidary work, or hobby interest by use of hand tools only (mechanized equipment and metal detectors may not be used in fossicking). Some local shires such as those at Carnarvon and Norseman have set aside special fossicking areas. Information on these areas can be obtained from the appropriate shire office, municipal centre, or tourist office.

Information for prospectors and fossickers in Western Australia is available from the Department of Mines and Petroleum (2009, 2016). Information is provided on the issue, regulations, and application for a Miner's Right, and also the requirements for a Section 40E permit for prospecting on a granted exploration licence on Crown land.

Be aware that Aboriginal Reserves and archeological sites are governed by other legislations. For example, damage to a site under the *Aboriginal Heritage Act 1980* (WA) carries a penalty of up to $2000 and one year imprisonment, and under the *Heritage of Western Australia Act 1990* (WA), a fine of up to $10 000 and two years imprisonment.

Maps and databases

Geological series maps of Western Australia at scales of 1:250 000 and 1:100 000 are available for perusal or purchase from DMP in Perth and Kalgoorlie. Digital versions of these maps may also be viewed or downloaded from the Geological Survey of Western Australia (GSWA) section of the DMP website at <www.dmp.wa.gov.au>. A limited number of geological maps at other scales are also available.

Several useful databases can be accessed online from DMP, which include the following:

- **GeoVIEW.WA** is an interactive, GIS-based mapping system for construction of geological maps that may incorporate mineral exploration datasets including mines, mineral deposits, and active leases.
- **WA Geology** is an online mapping app for mobile devices that allows the operator to query and view geoscience and resource information, and other datasets, to identify rocks and mineral resources at a given location.
- **Western Australian mineral exploration index (WAMEX)** is a searchable database of open-file reports

on exploration for minerals (excluding oil and gas), managed by GSWA Statutory Exploration Information Group. Open-file WAMEX mineral exploration reports may also be searched in GeoVIEW.WA.

- **Mines and mineral deposits (MINEDEX)** is a comprehensive database of mines, mineral deposits, and prospects along with their operational status, location, and ownership.
- **TENGRAPH** is a graphical database that displays the position of Western Australian exploration, prospecting and mining tenements, and petroleum titles in relation to other land information. It provides an easy means of determining land available for mineral exploration.

Note that online access to TENGRAPH requires the installation of client software from CITRIX Systems Inc.

Safety and survival in the bush

Western Australia is an extremely large State with an area in excess of 2.52 million km^2, making up approximately one-third of the Australian landmass. Outside of major urban centres, the State is mostly sparsely populated. Summer temperatures can be excessively high, especially in central and northern parts, and in the hotter time of year, typically November–March, tropical storms and cyclones may cause extensive flooding. Much of the State is either arid or semi-arid desert with little permanent water.

Most major roads are paved and there is a good network of surfaced gravel roads. However, away from these, access tracks are constructed by local landholders or by mining and exploration companies. These tend to be narrow gravel roads and tracks that may be rough, and difficult to follow. In many instances they are not shown on maps.

It is essential that fossickers are aware that travel in remoter regions of Western Australia remains potentially dangerous and that they take adequate precautions. Detailed information may be obtained from the many books on the subject that are available to the public. An outline of safe outback travel is available online from the Department of Regional Development and Lands (2011). Note that most rental vehicles, including four-wheel drives, are equipped with little else than a very basic tool kit and would almost certainly be unsuitable for outback travel.

For close-range communication between vehicles a citizen band (CB) or high-frequency (HF) radio may be used, and for long-range radio communication an HF radio is required and can be hired from communications suppliers. If using HF radios in the outback it is good practice to set up a communication schedule with the Royal Flying Doctor Service and contact them daily advising them who you are and your location. Today, the use of satellite phones (or 'satphones') is becoming increasingly common, replacing the need for an HF radio. Satphones allow the user to make a direct phone call from remote areas through a satellite system to anywhere in the world with no time delay. These are relatively expensive to purchase, although can be hired.

In an emergency, a personal emergency beacon should be activated. Two types of personal emergency beacons are available: an emergency position-indicating radio beacon (or 'EPIRB') and a personal locator beacon. Both instruments are relatively expensive although may be hired. Penalties apply for misuse of personal emergency beacons.

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Abbreviations

Abbreviations used throughout the book are given below.

Al	aluminium
Be	beryllium
B	boron
Ca	calcium
Co	cobalt
Cr	chromium
Cs	cesium
Cu	copper
ct	carat, a unit of weight for gemstones (equivalent to 0.2 g) and a measure of the purity of gold
ct/t	carats per tonne (or metric carats per tonne)
ct/ht	carats per hundred tonnes
Fe	iron
g	gram
g/t	grams per tonne
GSWA	Geological Survey of Western Australia (also a prefix for GSWA minerals in the Western Australian Museum collection)
ha	hectare
K	potassium
kg	kilogram
Li	lithium
km	kilometres
m	metres
Ma	million years (geological age)
Mct	million carats
MDC	Western Australian Museum mineral collection prefix
Mg	magnesium
mm	millimetre
µm	micrometre
Mn	manganese
oz	ounce (troy weight)
Moz	million ounces (troy weight)
nm	nanometre
Mt	million tonnes
N	nitrogen
Na	sodium
Ni	nickel
ppm	parts per million
t	tonne
S	Western Australian Museum mineral collection prefix
SEM	scanning electron microscopy
UV	ultraviolet
V	vanadium
XRD	X-ray diffraction

References

Brown, G 2005, The Australian pearling industry and its pearls: Gemmological Association of Australia, Australian Gem Gallery—A Rainbow of Gems, viewed 19 May 2015, <http://web.archive.org/20050406075226/www.gem.org.au/pearl.htm>.

Chapman, J, Brown, G and Sechos, B 1996, The typical gemmological characteristics of Argyle diamonds: The Australian Gemmologist, v. 19, no. 8, p. 339–346.

Department of Mines and Petroleum 2009, Prospecting in Western Australia: Department of Mines and Petroleum, Booklet, Edition 7, March 2009, 20p.

Department of Mines and Petroleum 2016, Prospectors & fossickers, viewed 19 May 2016, <www.dmp.wa.gov.au/Minerals/Prospectors-fossickers-1525.aspx>.

Department of Regional Development and Lands 2011, Travelling in outback Western Australia, viewed 19 May 2016, <www.lands.wa.gov.au/Publications/Documents/Travelling_in_Outback_Western_Australia.pdf>.

Fetherston, JM 2007, Dimension stone in Western Australia, volume 1 — Industry review and dimension stones of the southwest region: Geological Survey of Western Australia, Mineral Resources Bulletin 23, p. 124–127.

Fetherston, JM 2010, Dimension stone in Western Australia, volume 2 — Dimension stones of the southern, central western, and northern regions: Geological Survey of Western Australia, Mineral Resources Bulletin 24, p. 134–135.

Jacobson, MI, Calderwood, MA and Grguric, BA 2007, Guidebook to the pegmatites of Western Australia: Hesperian Press, Perth, Western Australia, 356p.

Martin, DMcB and Hocking, RM 2015, Main tectonic units of Western Australia: Geological Survey of Western Australia, 1:10 000 000 tectonic map.

1

Diamond

Fancy yellow diamonds from Ellendale (courtesy of Kimberley Diamond Company)

Diamond

Diamond properties

Diamond is composed of crystalline carbon and belongs to the isometric system. Its chemical stability and hardness arise from the covalent bonding of the carbon atoms within its structure. Diamond crystals commonly form as octahedra (pyramidal form) that are commonly twinned, resulting in flattened, triangular-shaped crystals termed macles. Other crystal forms including cubes, tetrahedra, hexoctahedra, and rhombic dodecahedra form more rarely. Natural surface features of crystal faces include octahedral faces characterized by equilateral triangular depressions (trigons) and rarer cubic faces by square, shallow depressions. Small hexagonal depressions of approximately 1 mm diameter, known as calderas, have been described from the surfaces of some Argyle diamonds and are interpreted as trigons with truncated corners.

The stone is the most important gem species within the gemstone and jewellery industry. All the processes of sawing, bruting, faceting, styling, and polishing of diamonds are based on its unique physical and optical properties. Diamond is faceted to particular and precise proportions to best demonstrate several characteristics: brilliance (internal and surface reflection of light related to total internal reflections from the base of the gem, high surface reflection resulting from high polish, and high lustre), and dispersion of light (resulting in spectral colours termed ‘fire’).

Diamond is the hardest of all natural minerals (10 on Mohs scale) and it can be polished to a very high finish. This property results in facets with sharp edges and high surface reflection due to its adamantine lustre. The hardness of diamond is not isotropic. Until recently, diamonds could only be sawn mechanically in specific crystallographic directions (parallel to a dodecahedral or cubic face). Laser sawing is a modern technique now used to overcome these problems and as a result many fancy shapes can be produced. Diamond facets can only be polished by diamond grits, as the random directions of the grains in the grit or polishing powder causes some of the ‘harder’ crystallographic planes to make contact with the ‘softer’ planes on the facets being polished. The perfect octahedral cleavage direction of diamond can be used on gem-quality crystal in the initial preparation for cutting, although today it is seldom applied.

Diamond	Crystalline carbon (C)

Physical properties of diamond

Crystal system	Isometric
Habit	Octahedral, also dodecahedra and combined forms
Surface growth features	Crystal faces commonly have triangular surface markings known as trigons. Square and hexagonal forms more rarely developed
Twinning	Common as spinel twins, resulting in flattened, triangular crystals termed ‘macles’
Colour range	Colourless, yellow, brown, orange, black and grey, rarely blue, green, pink, red or purple
Colour cause	Trace elements: nitrogen, aluminium, and boron; lattice structural plastic deformation; irradiation
Lustre	Adamantine
Diaphaneity	Transparent to opaque
Refractive index	2.417
Dispersion	0.044
Birefringence	Optically isotropic but commonly shows anomalous double refraction as light and dark first-order interference colour patterns under cross-polarized light
Hardness	10 (Mohs scale standard mineral)
Specific gravity	3.52
Fracture	Conchoidal
Cleavage	Perfect octahedral
Fluorescence	Commonly blue or yellow; blue fluorescence is followed by phosphorescence in ultraviolet (UV) light

Gem diamonds are classified either as Type I or Type II and both types are again divided into subtypes (a) and (b). This classification is largely based on the amount and aggregation of nitrogen within the crystal lattices. Type I diamonds, by far the most common group, contain nitrogen as aggregates or pairs in Type Ia, and in Type Ib nitrogen atoms are dispersed singly within the crystal lattices. The much rarer Type II diamonds (especially blue stones) contain low amounts of, or no, nitrogen. Type IIa are not electrically conductive although Type IIb will conduct electricity. Some diamonds are an admixture of both types (Oldershaw, 2003).

Most cut diamonds in the trade are colourless as they are typically esteemed more highly for their colourlessness. However, diamonds form naturally in all colours, most commonly with tints of yellow and brown, although also blue, green, pink, red, orange, purple, black, and grey. Intense colours are called ‘fancy’ colours. Although diamond is a pure form of carbon other trace elements in its structure are responsible for some of these colours, notably nitrogen, causing a pale yellow colour in Type 1a and intense ‘canary’ yellow in Type Ib diamonds, and boron, causing a blue colour in Type IIb diamonds. Browns and pinks are caused by a combination of plastic deformation and low nitrogen content in the crystal structure and green diamonds are the result of structural vacancies probably resulting from natural irradiation.

Diamonds host many minerals as inclusions and detailed studies have assisted in interpreting their conditions of formation. Common mineral inclusions are olivine, chrome diopside, enstatite and omphacite pyroxenes, pyrope and pyrope–almandine garnet, ilmenite and magnesian ilmenite, zircon, coesite, chromite and chrome spinel, diamond, ruby, rutile, kyanite, and sulfides. Inclusions, confirmed in Argyle diamonds, are orange garnet, clinopyroxene, omphacite, kyanite, rutile, coesite, mixtures of rutile–garnet, garnet–sulfide, garnet–clinopyroxene–sulfide, garnet–kyanite, kyanite–sulfide (eclogitic suite), and olivine, pyrope garnet, enstatite, mixtures of olivine–diopside, olivine–garnet, olivine–garnet–enstatite, and enstatite–garnet (peridotitic suite) with graphite lining cleavages and fractures (Chapman et al., 1996).

Although diamond is optically isotropic many stones show anomalous birefringence, displayed as patterns of light and dark zones with first-order interference colours when viewed under cross-polarized light.

Diamond exploration

Diamonds are formed in the mantle of the Earth at depths of 100–150 km and are brought to the surface by relatively small volcanic pipes or dykes. The principal primary source rock types for diamond are kimberlite and lamproite and less commonly rock types such as lamprophyre, picrite, and dolerite. Both kimberlite and lamproite are olivine-rich ultramafic rock types.

Volcanic pipes are typically wine glass in shape with a narrow ‘stem’ at depth opening out towards the surface as confining pressures decrease. At or near the surface, the pipe commonly contains considerable proportions of pyroclastic material and variable amounts of host rock. Kimberlite and lamproite intrusions are relatively common, although only a small proportion of these contain diamonds and only a very small proportion (less than 1% of pipes) contain diamonds in economic concentrations. Diamonds are extremely hard and resistant to erosion and thus are also commonly found in secondary alluvial diamond deposits such as river or beach gravels.

Exploration for diamonds is a long and expensive process. Exploration usually involves stream-sediment sampling on a regional basis and the use of heavy liquids to separate out heavy minerals that are then examined for indicator minerals. Diagnostic indicator minerals include chrome pyrope, chrome diopside, picroilmenite, magnesian chromite, and diamond itself. Other techniques used in conjunction with stream-sediment sampling include photogeology, aerial and ground magnetic surveys, airborne gravity surveys, and geochemistry. Once a suspected pipe has been discovered it is evaluated by means of extensive drilling, trenching, and processing of bulk samples. Diamonds recovered during exploration are initially classified according to grain size with stones larger than 0.5 mm (in the longest axial direction) called ‘macrodiamonds’ and stones less than 0.5 mm diameter ‘microdiamonds.’ Although microdiamonds are commonly of no economic value they are important indicator minerals.

With the exception of alluvial diamonds in known areas of occurrence, the rarity of diamond deposits together with the cost and complexity of diamond exploration would normally make it an extremely difficult mineral for the average fossicker to search for.

Diamond exploration in Western Australia

There are numerous references to the early discovery of diamonds in Western Australia and later exploration; three of the more recent ones used in this publication are by Jaques (1994), Jaques et al. (1986), and Downes and Bevan (2007).

The first recorded discovery of diamonds in Western Australia was in 1895 at Nullagine in the Pilbara where a few small stones were recovered from alluvial gold workings. In the early 1920s, RA Farqueson, a petrologist with the Geological Survey of Western Australia, sampled lamproites from the margin of the Kimberley Basin. Farqueson subsequently recognized these rocks as igneous in origin. Although other lamproite intrusions were noted and sampled, it was some 20 years later that Dr Rex Prider suggested a possible mantle origin for lamproites, along with a relationship to kimberlites, and the potential to host diamonds.

Modern diamond exploration in Western Australia commenced in 1965 in the Nullagine area although new ground was not broken until exploration began in the Kimberley area in 1967. Initial progress was slow and results rather disappointing. Extensive sampling at Mount Abbott yielded only five small diamonds and several microdiamonds, together with pyrope garnet and picroilmenite. In 1969, nine small diamonds were recovered from the Lennard River in the West Kimberley although the result was not repeatable.

In the mid-1970s, many companies became involved in the search, the most successful of which, the Kalumburu–Ashton Joint Venture, discovered kimberlite dykes and pipes in the north and east Kimberley and diamondiferous olivine lamproite in the Ellendale area of the west Kimberley. After the joint venture's discovery of two diamonds in Smoke Creek in the east Kimberley in 1979, a follow-up survey led to the discovery of the rich, diamondiferous, lamproite Argyle AK1 pipe, at that time the largest diamond deposit in the world (Hassan, 2004a).

Alluvial diamonds have been recovered in economic quantities from stream gravel deposits at Limestone and Smoke Creeks and Bow River, downstream of the Argyle AK1 pipe, and also from around Ellendale diamond pipes 4 and 9. Several companies have explored for alluvial diamonds in buried paleochannels of the Ord, Dunham, and Keep Rivers although with limited success. Elsewhere, small occurrences of alluvial diamonds are widespread throughout the Kimberley Basin although in subeconomic quantities. Similarly, exploration for marine and littoral placer diamond deposits, similar to those mined along the coasts of Namibia and South Africa, were undertaken along the coastline of Joseph Bonaparte Gulf although they produced little of economic interest.

Diamond deposits and prospects in Western Australia

Although many kimberlites and lamproites have been discovered in Western Australia, few contain diamonds and only two are of current economic significance. Additionally, alluvial deposits exist in the immediate vicinity of some pipes. The vast majority of these kimberlitic and lamproitic bodies in Western Australia are in, or adjacent to, the Kimberley Basin and form within three distinct regions. These are known as the East Kimberley, North Kimberley, and West Kimberley diamond provinces (Fig. 2.1).

The North Kimberley diamond province lies east of Kalumburu in the Paleoproterozoic Kimberley Basin. Here, diamondiferous kimberlites are found in a typical cratonic setting. The East and West Kimberley diamond provinces are mostly in, or near, the igneous and metamorphic rocks of the Paleoproterozoic Lamboo Province adjacent to the southeastern and southwestern margins of the Kimberley Basin (Fig. 1.1). The Lamboo Province contains diamond-bearing lamproite pipes although there are smaller numbers of diamondiferous kimberlitic dykes within the East Kimberley province (Bevan and Downes, 2004).

In other areas of the State, a group of small sills, dykes, and pipes of alkali picrite, carrying traces of diamond, are present in the Carnarvon Basin. Indicator minerals and rare diamonds have been identified from exploration within the East and West Pilbara, Earaheedy–Gascoyne, and Eastern Goldfields regions. Locations of notable diamond discoveries in the State are shown in Figure 2.1 and more detailed locational information on most of the State's diamond deposits and prospects is given in Appendix 1.

Halls Creek Orogen — Lamboo Province

East Kimberley diamond province

Within the Halls Creek Orogen, the East Kimberley diamond province in the Argyle area contains lamproites and associated alluvial diamond deposits within the igneous and metamorphic rocks of the Lamboo Province. The Argyle AK1 mine is currently Australia's largest source of colourless and fancy-coloured diamonds.

Argyle diamond mine *(Bow, 4564)*

The Argyle AK1 lamproite pipe was discovered in October 1979 and mining commenced in December 1985. The mine is about 50 km southwest of Lake Argyle and 110 km south-southwest of Kununurra (Figs 2.1 and 2.2). Access is via an all-weather road from the Great Northern Highway, although it is restricted and prior permission to enter must be obtained. Under the terms of the *Argyle Act 1979* (WA), entry into the designated areas of the Argyle and Ellendale mines is forbidden to the general public, prospectors, and fossickers.

The Argyle mine, owned and operated by Rio Tinto Ltd, has been in production for 30 years and is famous for its coloured stones: yellow, brown, and the rare and extremely valuable pink diamonds (Fig. 2.3). Other rare and valuable coloured diamonds include grey-blue-violet, purple-pink, and the visually spectacular fancy red stones (Fig. 2.4; van der Bogert et al., 2009; Rio Tinto, 2014).

During the Mesoproterozoic, the Argyle lamproite pipe intruded Paleoproterozoic to Mesoproterozoic successions overlying crystalline basement rocks of the Lamboo Province (1912–1788 Ma) near the margin of the Halls Creek Orogen (Jaques, 1994). At Argyle, the diatreme, containing both tuffaceous and magmatic varieties of lamproite, intruded sedimentary and volcanic country rocks along a pre-existing fault. The diatreme has an elongated, tadpole shape with the enlarged head at the northern end; the shape results from post-intrusional faulting and regional tilting. The width varies from 600 m at the head to 150 m along the tail. The body is also tilted northwards at approximately 30° (Fig. 2.5). Original proved ore reserves, estimated to 120 m depth, were 61 Mt at 6.8 ct/t, plus probable reserves of 14 Mt at 6.1 ct/t. The southern high-grade ore zone contained diamonds comprising about 5% (by weight) gemstones, 40% cheap gems, and 55% industrial diamonds (Jaques, 1994).

In 2009–10 the mine produced 10.91 Mct, a decrease from 14.72 Mct in the previous fiscal year arising from the global financial crisis in 2009, which had a serious effect on the demand for rough diamonds, which is largely dependent on the US economy (Abeysinghe and Flint, 2011).

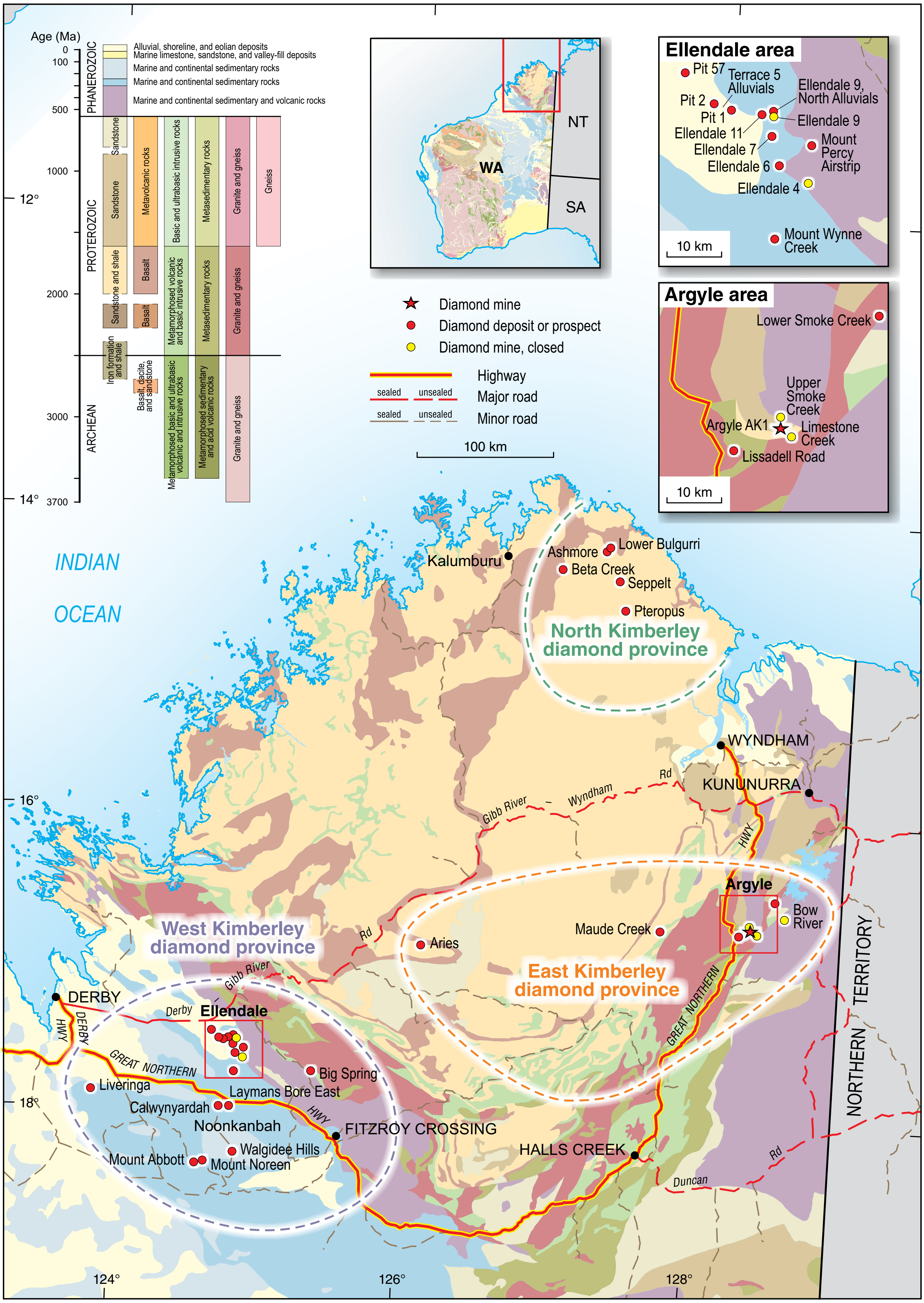

Figure 2.1. Diamond mines and principal diamond prospects in the Kimberley region, Western Australia

JMF951 29/03/2016

Figure 2.2. The extensive Argyle AK1 openpit completed in 2013 prior to transition to block cave underground mining (© Rio Tinto 2014)

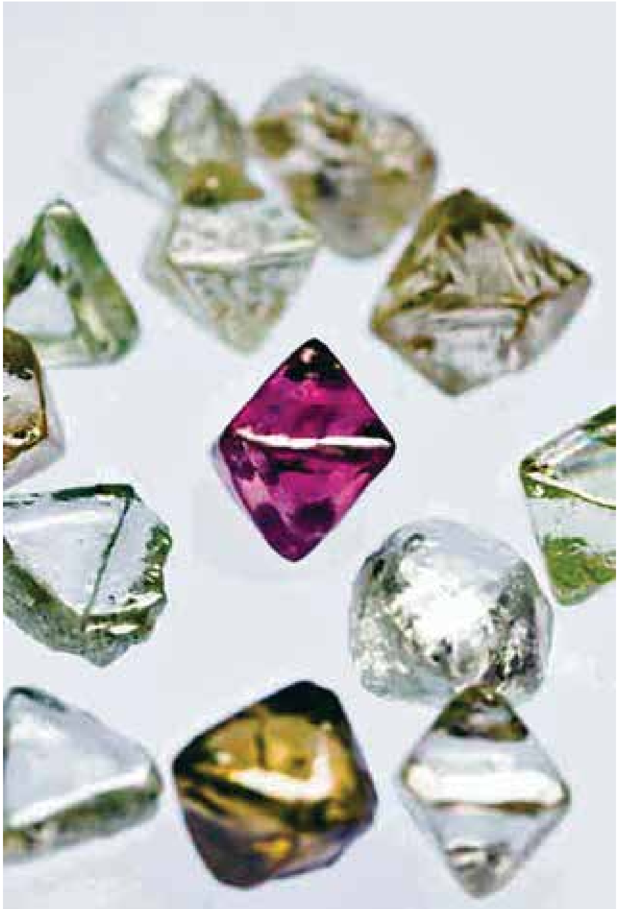

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Figure 2.3. Argyle diamond rough stones showing white, champagne, and very rare pink varieties (© Rio Tinto 2014)

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Figure 2.4. Faceted rare and valuable fancy red diamonds from the Argyle mine (© Rio Tinto 2014)

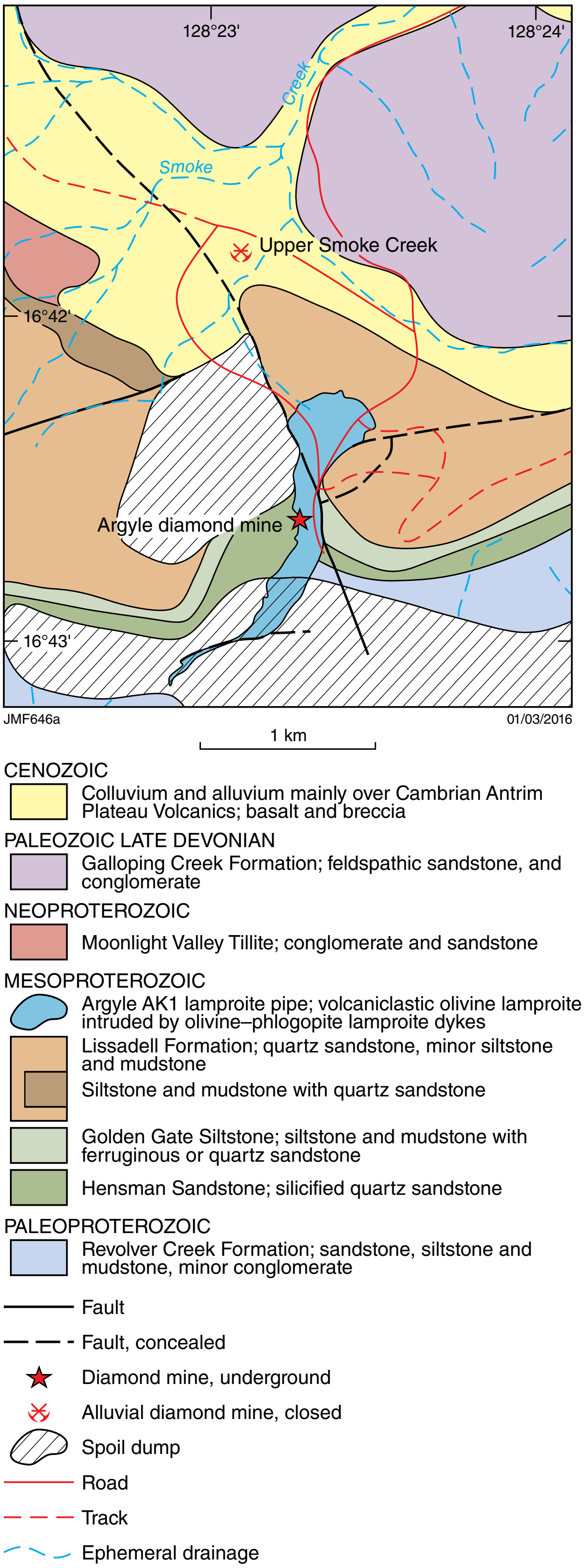

Figure 2.5. Geological sketch map of the Argyle AK1 lamproite pipe (modified after Sheppard et al., 1997; Shigley et al., 2001)

Mining continued in the openpit until early in 2013 when the new underground mine was commissioned (Fig. 2.6). In the same year the underground mine produced 11.4 Mct of diamonds, an increase of 57% over the previous year. At the end of 2013 updated resources of 42.1 Mt were announced comprising measured resources of 13 Mt at 3.4 ct/t, indicated resources of 23 Mt at 3.7 ct/t, and inferred resources of 6.1 Mt at 3.6 ct/t representing a 2.7% increase on resources estimated for the previous year (Rio Tinto, 2013a). Despite the new underground operating environment, production in 2014 continued to fall by about 20% to 9.2 Mct (Rio Tinto, 2015a). Nevertheless, it is expected that underground operations will soon be in full production and that mine life will be extended until at least 2020 with the block caving process expected to generate an average annual production of 20 Mct/y (Rio Tinto, 2015b).

Rare Argyle diamonds

In 2012, the company discovered Australia's largest rough pink diamond. The light pink diamond of 12.76 ct was recovered from the Argyle openpit and was named the 'Argyle Pink Jubilee' (Fig. 2.7). An expert diamond cutter began to cut and polish the stone but it was found that it would only yield a finished gem of 8.01 ct. Rio Tinto subsequently donated this rare pink stone for display at the museum in Melbourne (Museum Victoria, 2012).

Each year, Rio Tinto launches a collection of its very best diamonds for sale by tender with viewings in cities such as Perth, Sydney, Hong Kong, and New York. Each tender contains about 60 lots of rare, fancy pink, fancy red, blue and other diamonds. Often, all diamonds offered in a single tender are sold with prices reaching well above pre-tender estimates. A single stone reached a record price in 2013 in excess of US$2 million (Rio Tinto, 2013b).

In August 2014, 51 rare pink and purplish-red, and four fancy red diamonds were sold by tender. Stones from the collection included the most spectacular 1.21 ct radiant-cut fancy red diamond named the 'Argyle Cardinal'. Other valuable stones included a 2.17 ct fancy intense purple-pink emerald-cut diamond named 'Argyle Rosette' and a 1.59 ct fancy intense purplish-pink emerald-cut known as 'Argyle Toki' (Rio Tinto, 2014).

Lissadell Road *(Bow, 4564)*

The Lissadell Road lamproite dyke is about 10 km west-southwest of the Argyle AK1 pipe (Fig. 2.1). The dyke comprises a discontinuous set of small stringers up to 1 m wide that were intruded into the Lamboo Province. Sampling of the deposit recovered 6.4 ct of diamonds of similar appearance to the Argyle stones. The similarity of the diamonds and the proximity of the Argyle pipe suggest that the two occurrences may be related (Jaques, 1994).

Alluvial deposits in the Argyle area *(Bow, 4564; Dunham River, 4565)*

Several formerly economic alluvial diamond deposits are downstream of the Argyle AK1 pipe. With the exception of Kimberley Diamonds Lower Smoke Creek deposit all other deposits have been largely mined out and are either abandoned or in care and maintenance.

Figure 2.6. **Mining personnel inside the Argyle block cave mine, which commenced production in 2013 (© Rio Tinto 2014)**

Figure 2.7. **Australia's largest rough pink diamond, the 'Argyle Pink Jubilee'. Weighing 12.76 ct, the stone was recovered from the Argyle openpit in 2012 (© Rio Tinto 2014)**

Limestone Creek

The Limestone Creek alluvial deposits comprise several dissected piedmont fans at the foot of the range about 2.5 km south-southeast of the Argyle AK1 pipe (Fig. 2.1). The oldest fan gravels have been lateritized and are preserved as resistant ridge cappings. Mean stone sizes are larger than those from the AK1 pipe and diamond grade decreases rapidly downslope from the heads of the fans.

Upper Smoke Creek

The Upper Smoke Creek alluvial diamonds, 2 km north of the Argyle mine, are found in poorly sorted, ferruginized alluvial and colluvial gravels derived from the Argyle AK1 pipe and surrounding country rocks (Fig. 2.1). Diamond grades increase laterally from the high older terraces towards present stream channels and also decrease rapidly downstream.

Lower Smoke Creek

The Lower Smoke Creek diamond prospect, currently owned by Kimberley Diamonds Ltd, comprises 22 contiguous prospecting licences (P80/1712–1725 and 1734–1741) and a mining lease application (M80/621). The tenements, originally owned by Argyle Diamonds Ltd (now Rio Tinto Ltd), are aligned along Smoke Creek between 22 and 37 km north-northeast (downstream) of the Argyle AK1 diamond pipe (Fig. 2.1). In February 2014, Kimberley Diamonds purchased the tenements from Venus Metals Corporation Ltd, which had been the owner since the tenements were surrendered by Argyle Diamonds in 2008.

The prospect covers approximately 11 km of unmined diamondiferous gravels sited along the Smoke Creek stream channel and comprises several diamondiferous gravel terraces, ranging in age from Miocene to modern channel deposits, with each terrace displaying a characteristic diamond size distribution. The terraces are estimated to contain a JORC-compliant inferred resource of 21.5 Mt at an average grade of 28 ct/ht containing 6 Mct of diamonds at a cutoff grade of 10 ct/ht (Kimberley Diamonds, 2014).

An alluvial diamond processing plant was to be transported to the site as soon as all mining approvals were in place to allow Kimberley Diamonds to commence production. It was intended that diamond recovery from the Lower Smoke Creek prospect would increase Kimberley Diamonds' overall diamond production when combined with production from its Ellendale diamond mine in the west Kimberley region.

Bow River *(Lissadell, 4664)*

The Bow River alluvial deposit is on the lower reaches of Limestone Creek around 35 km east-northeast of the Argyle AK1 pipe and 96 km south of Kununurra (Figs 2.1 and 2.8). In comparison to the Argyle AK1 and Limestone Creek deposits, Bow River had a lower grade although the average stone size and proportion of gem diamonds was higher. At this site, diamonds were about 25% higher in quality than those from the Argyle pipe as it appears the 35 km transport tended to induce a quality upgrade. At Bow River, diamond ratios were 18–25% gem, 65–72% industrials, and 8–10% bort (diamond dust).

Kimberley Basin

East Kimberley diamond province

Within the Paleoproterozoic rocks of the Kimberley Basin, the East Kimberley diamond province, to the west and southwest of the Argyle area, contains numerous small kimberlite pipes and dykes. As elsewhere, very few of these pipes contain diamonds.

Maude Creek (Chamberlain, 4464)

At Maude Creek, approximately 150 km southwest of Kununurra, a 1.2 metre-wide kimberlite dyke intrudes the Hart Dolerite which itself is intrusive into the Speewah Group (Fig. 2.1). Small quantities of diamonds have been recovered from this occurrence including a 0.05 ct stone and several microdiamonds.

Figure 2.8. View looking north over the Bow River alluvial diamond mine processing plant and tailings dams

Phillips Range — Aries kimberlite (Barnett, 4164)

The Aries kimberlite is in the southern central Kimberley Basin about 150 km north-northeast of Fitzroy Crossing (Fig. 2.1). Covering an area of 18 ha, it is the largest kimberlite body discovered in Australia. This body comprises four north–south-trending lobes: the boomerang-shaped South lobe, the Central lobe and the North lobe intruded into the Paleoproterozoic King Leopold Sandstone, and the North lobe extended intruding the Carson Volcanics. The arcuate South lobe is made up of four smaller, diamondiferous kimberlite pipes named Helena, Athena, Persephone, and Niobe (Fig. 2.9; Ruddock, 2003).

The Aries pipe is composed of a micaceous kimberlite that has deeply weathered to stiff clay heavily contaminated with sandstone host rock to a depth of 6 m below surface. In the pipe, diamonds occur in subeconomic grades of between 2 and 5 ct/ht with the largest stone recovered weighing 3.51 ct. In total, bulk sampling yielded over 7000 diamonds. Small diamonds were also recovered in stream samples from the adjacent Hann River.

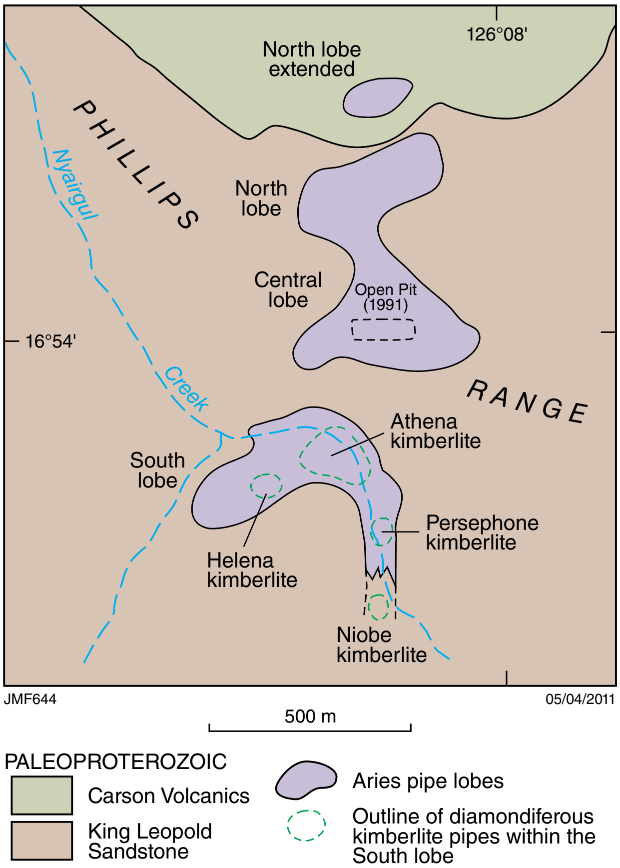

Figure 2.9. Geological map of the Aries kimberlite pipe (modified after Ruddock, 2003)

North Kimberley diamond province

Numerous small kimberlitic pipes and dykes are known from an area in the North Kimberley between the Berkeley and Drysdale Rivers. Of these, few have been found to contain diamonds although numerous small diamonds of unknown origin have been discovered in gravels in the King George River and other rivers (Ruddock, 2003). It is possible that further diamondiferous kimberlite bodies have yet to be discovered in this region.

Access to the area covered by the North Kimberley diamond province is difficult. It is reached via a track leaving the Gibb River Road near Gibb River Station Homestead and travelling north almost to Kalumburu about 310 km distant. Eighteen kilometres south of Kalumburu, the Carson River can be crossed and then along poorly maintained station tracks to the King George River. In this area numerous tracks of varying states of repair were constructed by exploration and mining companies in the 1990s. It should be noted that access to the Forrest River Aboriginal Reserve on the east bank of the King George River is restricted.

Beta Creek *(King George, 4369; Drysdale, 4269)*

The Beta Creek kimberlite prospects are between 40 and 70 km east to east-southeast of Kalumburu (Fig. 2.1). Bulk sampling of gravels from Beta Creek and associated tributaries produced numerous small diamonds. In this area, 17 sites were sampled and the majority were found to contain only a few small diamonds. It is probable that this work led to the discovery of the Lower Bulgurri kimberlite fissure and ultimately the Ashmore kimberlitic pipes.

Lower Bulgurri *(King George, 4369)*

The Lower Bulgurri kimberlite fissure, 3 km northeast of Ashmore prospect, was discovered in 1994. The prospect forms part of a fissure extending over 12 km and containing at least three en echelon kimberlitic dykes each up to 5 km in length and ranging from 0.5 to 2.0 m in width (Fig. 2.1). Drill testing of dykes to at least 80 m depth confirmed their kimberlitic affinity (Ramsay, 1999). A 9 t sample from the top 3 m of a costean yielded 208 diamonds totalling 8.78 ct. Bulk sampling along the fissure provided an initial estimated grade of 28 ct/ht.

Ashmore *(King George, 4369)*

The Ashmore diamond prospect comprises four separate small kimberlitic pipes (Ashmore 1–4), some 71 km east of Kalumburu (Fig. 2.1). Initial bulk sampling of the surface infill material from the upper portions of the pipes yielded an average grade of some 30 ct/ht with three stones weighing over 10 ct although later sampling of deeper, fresher material from the Ashmore 2 and 4 pipes produced lower grades of less than 10 ct/ht. The largest diamond recovered from bulk sampling at the Ashmore 2 pipe weighed 9.23 ct (Fetherston and Searston, 2004).

Seppelt *(King George, 4369)*

The Seppelt kimberlite pipes are about 80 km east-southeast of Kalumburu (Fig. 2.1). Seppelt 1 kimberlite consists of two lobes about 100 m apart with a combined area of about 0.7 ha. Grades were initially estimated at about 40 ct/ht although further work by North Australian Diamonds Limited identified an inferred resource of 1.7 Mt at an average grade of 38.7 ct/ht for the North and South lobes.

The Seppelt 2 kimberlite is about 5 km southwest of Seppelt 1. The pipe contains both weathered kimberlite and infill gravels. The gravels have a variable grade of approximately 50 ct/ht and persist to a depth of 36 m. Beneath the gravel layer, the weathered kimberlite has a grade of 211 ct/ht. The Seppelt 2 pipe has an inferred resource of 0.2 Mt to 200 m depth. Several large diamonds were recovered, including a clear colourless gem-quality stone of 8.5 ct (North Australian Diamonds Limited, 2010).

Seppelt 5 kimberlite was identified as a brecciated kimberlite fissure about 750 m in length with an average thickness of 1.4 m (maximum 3.0 m). A 70 t bulk sample yielded 15 ct of diamonds with the largest stone recovered a gem-quality octahedron of 1.1 ct (Striker Resources, 2004).

Pteropus *(Collison, 4368)*

The Pteropus breccia pipe is some 93 km east-southeast of Kalumburu (Fig. 2.1). At this site, a vertical pipe extending over approximately 2 ha is of possible kimberlite origin. It is filled with breccia mainly composed of angular fragments of siltstone and sandstone set in a tuffaceous matrix. Initially, only one fragment of diamond, 0.16 mm in diameter, was recovered from the breccia and 16 small diamonds were recovered from the adjacent Pteropus Creek. In later exploration nine diamonds were found in the pipe breccia from a bulk sample weighing 1 t (BHP Minerals, 1985).

Canning Basin — Lennard Shelf and Fitzroy Trough

West Kimberley diamond province

The first lamproite in the West Kimberley diamond province was discovered during an early expedition in 1905–06. Today, more than 100 lamproite bodies have been discovered in a broad belt extending south from the southern margin of the Paleoproterozoic Lamboo Province through sedimentary rocks of the northern Canning Basin covering discrete areas of the Paleozoic Lennard Shelf and Fitzroy Trough.

In 1969, the first diamonds were found in the West Kimberley diamond province where nine poor-quality diamonds with a total weight of 1.65 ct were obtained from five sites in the Lennard River. These sampling results were never repeated. The first diamonds found within lamproite pipes were from the Big Spring area and subsequently numerous additional bodies were discovered using indicator mineral sampling and geophysics.

In the West Kimberley province, lamproites form as pipes, plugs, sills, and rare dykes in three main fields: Ellendale, Calwynyardah, and Noonkanbah. These structures intrude Paleoproterozoic rocks of the King Leopold Orogen in the north, and Paleozoic and Mesozoic sedimentary rocks in the southern Lennard Shelf and Fitzroy Trough (Jaques, 1994).

Ellendale diamond field *(Ellendale, 3862; Lennard, 3863)*

The Ellendale diamond field is in an area approximately 140 km east-southeast of Derby (Fig. 2.1). Access is via the Gibb River Road and then by road along the Lennard River to the base of the Napier Range. From here access is by station and exploration tracks. This area contains the greatest concentration of Miocene (c. 22 Ma) lamproite intrusions in the West Kimberley diamond province with more than 50 discrete bodies intruding the Lennard Shelf, 38 of which are known to be diamondiferous. Of these diamondiferous pipes, approximately 70% are olivine-bearing lamproites and the remainder are leucite lamproites. It has been found that the older, olivine-rich lamproites are less fractionated, with a higher magnesium content, and tend to host higher grades of diamonds (Mining-technology.com, 2015). In the Ellendale area, about 60% of diamonds originally recovered from two intrusions (Ellendale 4 and 9) are of gem quality, although overall grades tend to be low and most deposits are considered subeconomic.

The Ellendale area also hosts several diamondiferous paleochannels that formerly drained the area surrounding the lamproite intrusion at Ellendale 9 (Terrace 5 Alluvials and Ellendale 9 North Alluvials). Also, paleochannels surrounding Ellendale 4 contain the northeast-trending A Channel Alluvials and the southwest-trending J Channel Alluvials (Fig. 2.1; Ahmat, 2012).

Kimberley Diamonds Ltd commenced mining at Ellendale in 2002. In 2007 the operation was acquired by Gem Diamonds Ltd whose operations were centred on extraction from the rich Ellendale 9 diamond pipe while operations at Ellendale 4 and 7 diamond pipes were put into care and maintenance in 2009. The Ellendale mine is well known internationally as a source of fancy yellow diamonds and until recently contributed an estimated 50% of the world supply (Fig 2.10). In 2007 a record-sized fancy yellow diamond weighing 18.5 ct was recovered. Around the same time, nine other large stones in excess of 6 ct and the first pink diamond of 1.58 ct were also recovered (Fetherston, 2008).

In 2008–09 the mine produced 0.443 Mct of diamonds. By 2009–10, production declined to 0.194 Mct, which was largely attributable to the placing of Ellendale 4 in care and maintenance and also to unseasonably bad weather conditions in the second quarter of 2010. This trend continued with production in 2013–14 falling to 0.109 Mct at an average grade of 2.59 ct/ht.

Prior to the end of the economic life of the mining operation in mid-2015, the company had a marketing agreement for the supply and sale of its yellow diamond production with Laurelton Diamonds Inc., a subsidiary of Tiffany & Co. (Abeysinghe and Flint, 2011). In July 2012, total diamond resources from Ellendale 4 and 9 were estimated at 3.98 Mct from 91.3 Mt of ore at 4.35 ct/ht. Also, fancy yellow diamonds offered for sale (about 14% of Ellendale 9 production) reached US$4315/ct (Ahmat, 2012).

In February 2013, the mine was acquired by Goodrich Resources through its wholly owned subsidiary, Kimberley Diamonds Ltd. The new company continued to mine the Ellendale 9 pipe until suspension of operations early in 2015. Following the Ellendale 9 pit closure, the company began processing low-grade ore stockpiles from Ellendale 9 with 1.74 Mt processed over six months to the end of March 2015 with an average recovery grade of 1.95 ct/ht. It was estimated this stockpile would be fully depleted by May 2015. Once depleted, the company had intended to access the run-of-mine stockpile at the Ellendale 4 pit, estimated to contain a probable reserve of 1.2 Mt grading 9.4 ct/ht. It was to be followed by processing of another low-grade stockpile (E9 Lights) at Ellendale 9 with a JORC-inferred resource of 11.23 Mt at an inferred grade of 1.1 ct/ht (Kimberley Diamonds, 2015).

Despite these contingency plans, on 1 July 2015 Kimberley Diamonds announced an immediate suspension of operations at Ellendale and that the mine would be put into voluntary administration. The company stated that despite the operation's strong performance over past months, revenues had decreased because of lower diamond grades and size distributions, resulting in a drop in prices received for their stones. This was evident in a sharp decline in prices achieved at an Antwerp diamond auction in June 2015 where prices were significantly lower than forecast (MiningNews.net, 2015).

Ellendale diamond collection

The Western Australian Museum has a spectacular collection of eight yellow and white Ellendale diamonds totalling 38.06 ct that were donated for display in the collection by the Kimberley Diamond Company and private benefactors in 2011. The diamonds from the Ellendale pits are predominantly resorbed with lustrous smooth surfaces and include dodecahedra, irregularly shaped stones and minor macles. The stones, weighing between 0.97 and 3.69 ct, range in colour from off-white to yellow and fancy yellow (Downes et al., 2012).

Ellendale 9 and 4 mining operations

In 2002, mining commenced at the Ellendale 9 pipe, which contained an estimated pre-mining resource of 31.92 Mt at 5.5 ct/ht and individual diamonds up to 11.47 ct (Hassan, 2004b). Mining operations continued for almost 13 years until the openpit was placed in care and maintenance in early 2015 (Fig. 2.11).

With an original surface area of 46.9 ha, the diamondiferous lamproite pipe comprised an oval Western lobe and larger elongated Central and Eastern lobes (Fig. 2.12). The Western lobe was a 'champagne-glass' shaped pipe that may have represented the upper portion of the original crater created by a violent phreatic explosion as the lamproitic magma came in contact with near-surface, water-saturated sediments (Ahmat, 2012).

Figure 2.10. Fancy yellow diamonds from Ellendale (courtesy Kimberley Diamond Company): a) fancy yellow, rough diamonds (average 2 ct), showing the typical smooth, resorption characteristics of the Ellendale deposit; b) cushion-cut, fancy yellow diamonds (each approximately 1 ct)

Figure 2.11. The Ellendale 9 openpit completed in 2015 (courtesy Kimberley Diamonds Ltd)

This lobe comprised a thick succession of tuffs with a central olivine lamproite core, and the Central and Eastern lobes were mainly composed of olivine lamproite with little tuffaceous material.

Discovered in 1976 and mined between 2002 and 2009, the Ellendale 4 deposit contained an estimated pre-mining resource of 40.7 Mt at 7 ct/ht with an additional 17.8 Mt at 5.7 ct/ht in the E4 satellite pipe (Hassan, 2004b).

Ellendale 4 is composed of a large, concealed lamproite intrusion of about 76 ha in surface area, together with the smaller E4 satellite pipe covering an area of 11 ha to the east of the main pipe. The intrusive structure consists of a complex suite of two coalescing eruptive centres each with a core of olivine lamproite and marginal zones of pyroclastics. The pyroclastics make up about 50% of the vent material and contain most of the diamonds. About 65% of the stones are yellow and the remainder are brown, colourless, and grey. To date, the E4 satellite pipe has not been mined.

Paleochannel exploration and mining

Prior to 2011, paleochannels surrounding Ellendale 9 were explored and mined. This process required the removal of up to 10 m of overburden to expose the diamondiferous channel gravels. These ancient watercourses were found to be irregular, undulating, and potholed.

The Terrace 5 alluvial channels, which extend up to 35 km west-northwest of Ellendale 9, were tested at two sites (Pits 1 and 2, at 8 and 11 km west-northwest of Ellendale 9, respectively). At each site, a large pit, up to 350 long, 80 m wide and 10 m deep, was excavated. The diamondiferous gravels with an average thickness of about 1 m were found to contain up to 11.1 ct/ht.

Limited mining carried out at two locations, 1 km north-northwest and north-northeast of Ellendale 9 in the irregularly shaped channels of the Ellendale 9 North (E9N) Alluvials, yielded approximately 0.2 Mt of diamondiferous gravels with an average grade of 14.4 ct/ht. In places, the gravels yielded diamonds up to 38 ct/ht (Ahmat, 2012).

Ellendale 7, 11, and 6 prospects

Ellendale 7 is some 34.7 ha in area and made up of a central core of olivine lamproite contained within an extensive pyroclastic succession that fills most of the vent. Bulk sampling indicated an average grade of a little over 1 ct/100 t.

Ellendale 11, a proposed future mining site, is 13.1 ha in area almost 1 km to the west of Ellendale 9. The pipe is composed predominantly of olivine lamproite with narrow marginal zones of pyroclastic rocks. Drilling during the exploration phase showed that the lamproite occurs as a cap over a pyroclastic-filled vent. Bulk samples produced an overall grade of 1.13 ct/100 t.

Ellendale 6 is the largest undeveloped lamproite intrusion in the Ellendale field with a surface area of 106 ha. The main body of the pipe comprises an olivine–leucite lamproite with a large tongue of pyroclastic material extending to the northwest. Bulk sampling produced 11 diamonds weighing 0.61 ct in total.

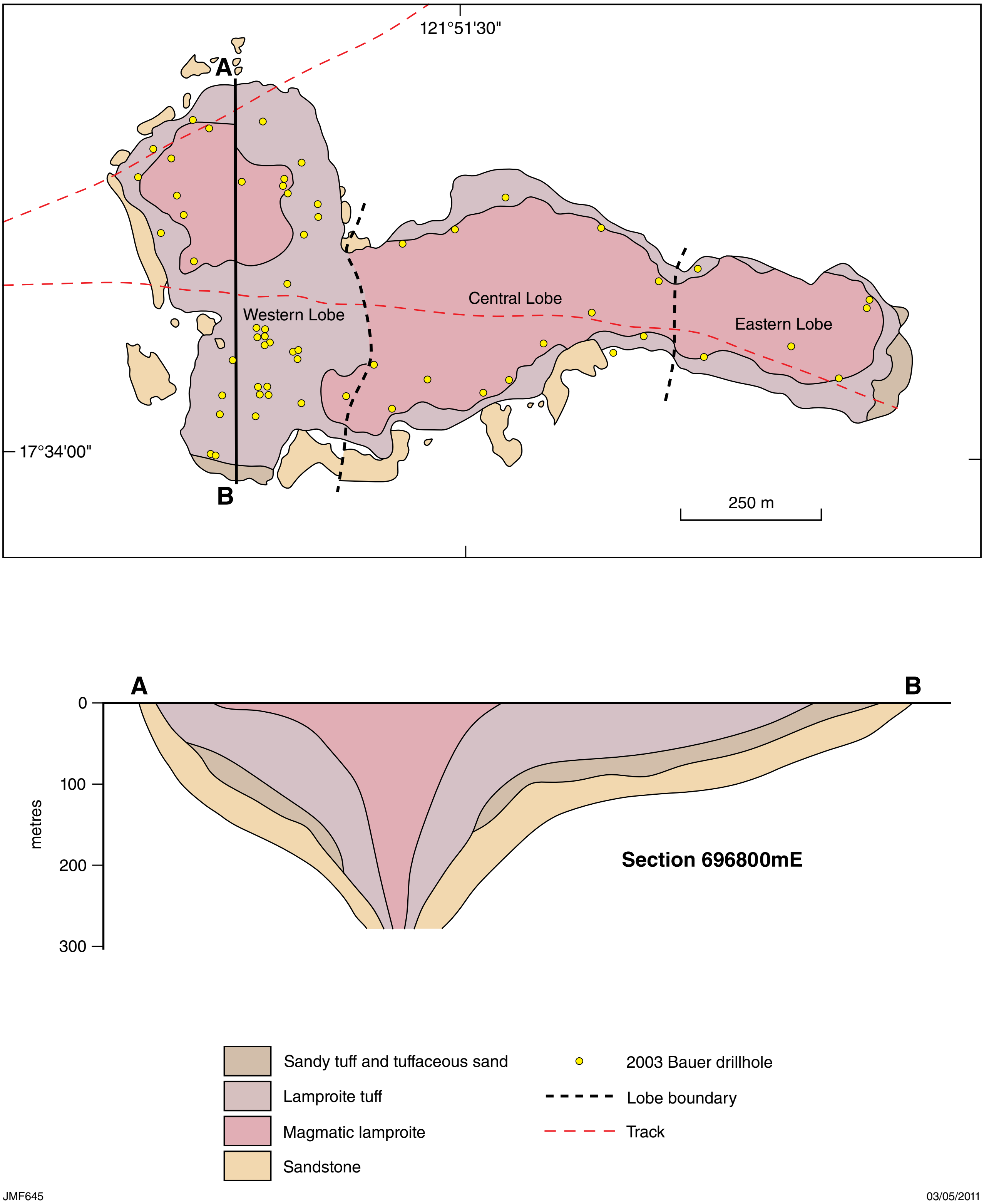

Figure 2.12. Geological map and cross-section of Ellendale 9 lamproite pipe (modified after Louthean, 2003)

Other Ellendale intrusions

Of the remaining lamproite intrusions at Ellendale a few diamonds were recovered from each of the following pipes: Ellendale 8, 10, 12–15, 17–19, 21, 22, 24, 25, 27, 33, 34, 39, 41 and 42.

Mount Wynne Creek *(Ellendale, 3862)*

Mount Wynne Creek is about 90 km west-northwest of Fitzroy Crossing (Fig. 2.1). The prospect comprises 1–2 m-thick gravel beds beneath 4–9 m of overburden, forming part of the J-channel paleodrainage system. Bulk sampling of the gravels found 10 small diamonds totalling 1.165 ct. These diamonds may have been derived from the weathering of the Ellendale 4 pipe (Romanoff, 1992).

Pit 57 *(Lennard, 3863)*

Pit 57 is in the Lennard Shelf about 117 km east of Derby (Fig. 2.1). A pit dug into a paleochannel contained 20 diamonds totalling 5.76 ct, with the largest stone weighing 1.47 ct.

Mount Percy Airstrip *(Ellendale, 3862)*

Located in the Lennard Shelf, this prospect is about 94 km northwest of Fitzroy Crossing (Fig. 2.1). Twenty-five diamonds totalling 2.23 ct were recovered from three pits dug into an olivine lamproite sill.

Laymans Bore East *(Ellendale, 3862)*

Laymans Bore East prospect, 83 km west-northwest of Fitzroy Crossing, comprises two vents contained within a pipe extending over 103 ha (Fig. 2.1). This pipe is of similar appearance to pipes in the nearby Calwynyardah field (see below) as it is composed almost entirely of pyroclastic material. Bulk sampling yielded four diamonds totalling 0.075 ct and numerous microdiamonds.

Calwynyardah diamond field *(Hardman, 3861)*

The Calwynyardah diamond field, covering an area of almost 50 km^2, is traversed by the Great Northern Highway 90 km west-northwest of Fitzroy Crossing (Fig. 2.1). The field, consisting of a small group of lamproite intrusions, is mostly within a few kilometres of Calwynyardah Homestead. Only one pipe is exposed at the surface.

The largest pipe, Calwynyardah 1, extends over 124 ha and is composed almost entirely of pyroclastic rocks intruded by thin lamproite sills and small plugs. Extensive bulk sampling yielded only one very small diamond and 34 microdiamonds.

Noonkanbah diamond field

This diamond field covers a large area in the central portion of the Fitzroy Trough approximately 175 km southeast of Derby (Fig. 2.1). Access is good with good gravel roads running south from the Great Northern Highway to the Noonkanbah Homestead and along the northern side of the Fitzroy River. Access from here is by station or exploration tracks.

Much of the Noonkanbah field is covered by the Noonkanbah Pastoral Lease, which is occupied by the Yungngora Aboriginal Community. Visitors should consult with community elders regarding their proposed itinerary.

The Noonkanbah field contains 17 exposed lamproite intrusions and a further 12 that are concealed. Several pipes were found to contain diamonds, although not in economic quantities.

Mount Abbott (Hardman, 3861)

The Mount Abbott prospect, 107 km west of Fitzroy Crossing, is a well-exposed, dumbbell-shaped lamproite and tuff pipe containing sandstone breccia (Fig. 2.1). Extensive sampling yielded five small diamonds and several microdiamonds together with indicator minerals.

Mount Noreen (Hardman, 3861)

This diamond prospect is about 100 km west-southwest of Fitzroy Crossing (Fig. 2.1). This small pipe, only 6.3 ha in area, is one of at least four lamproite pipes in the Mount Noreen area drilled by Ellendale Resources in 2003. The pipe is predominantly filled with pyroclastic material cut by veins and dykes of leucite lamproite. Samples of tuffaceous material and overlying loam yielded 37 small diamonds.

Walgidee Hills (Hardman, 3861)

The Walgidee Hills lamproite pipe, approximately 80 km west-southwest of Fitzroy Crossing, has a diameter of about 2.5 km covering about 490 ha (Fig. 2.1). Exploration in the 1990s yielded 891 microdiamonds and 62 macrodiamonds. More recent work recovered 11 macrodiamonds: six colourless, four brown, and one yellow (Graynic Metals Ltd, 2007).

Big Spring (Leopold Downs, 3962)

The first diamonds found in a lamproite pipe in the West Kimberley diamond field were discovered in the Big Spring lamproite pipes, 52 km north-northwest of Fitzroy Crossing (Fig. 2.1). Bulk sampling of two of the five olivine lamproite pipes at Big Spring produced 30 microdiamonds totalling 0.37 ct together with indicator minerals chromite, pyrope, and chrome diopside.

Liveringa (Yeeda, 3662)

The Liveringa prospect is in the Fitzroy Trough, 72 km south-southeast of Derby (Fig. 2.1). During a drilling operation in 1991, a single microdiamond (0.275 x 0.275 mm) was recovered from a probable lamproite pipe.

Southern Carnarvon Basin

Wandagee diamond province

The Wandagee diamond province is towards the northeastern edge of the South Carnarvon Basin, approximately 125 km northeast of the town of Carnarvon (Fig. 2.13). In 1975, small kimberlite-like diatremes were first discovered in the area and to date 16 diatremes and six dykes and sills have been discovered. These 22 intrusions are located within a belt approximately 50 km long by about 15 km wide mainly in the Hill Springs and Mardathuna pastoral leases. Access is via a good gravel road leading eastwards from the Great Northern Highway to Wandagee Station and then along the numerous station tracks that cover the area.

Wandagee pipes M92b, M154, and M142

(Barrabiddy, 1750; Mardathuna, 1849; Gooch Range, 1850)

Diatremes in the Wandagee diamond province tend to be steep-sided, pipe-shaped bodies filled with pyroclastic deposits with no recognized magmatic phases. The dykes and sills show mineralogical and chemical differences from true kimberlites and are called alkali picrites. As part of the exploration program, most of the diatremes, and gravel samples from the Minilya River and Barrabiddy Creek, were tested for diamonds. The program highlighted three sites of interest: Wandagee pipes M92b and M154, and a loam sample from over pipe M142 (Fig. 2.13). Sampling from these prospects yielded only three very small diamonds.

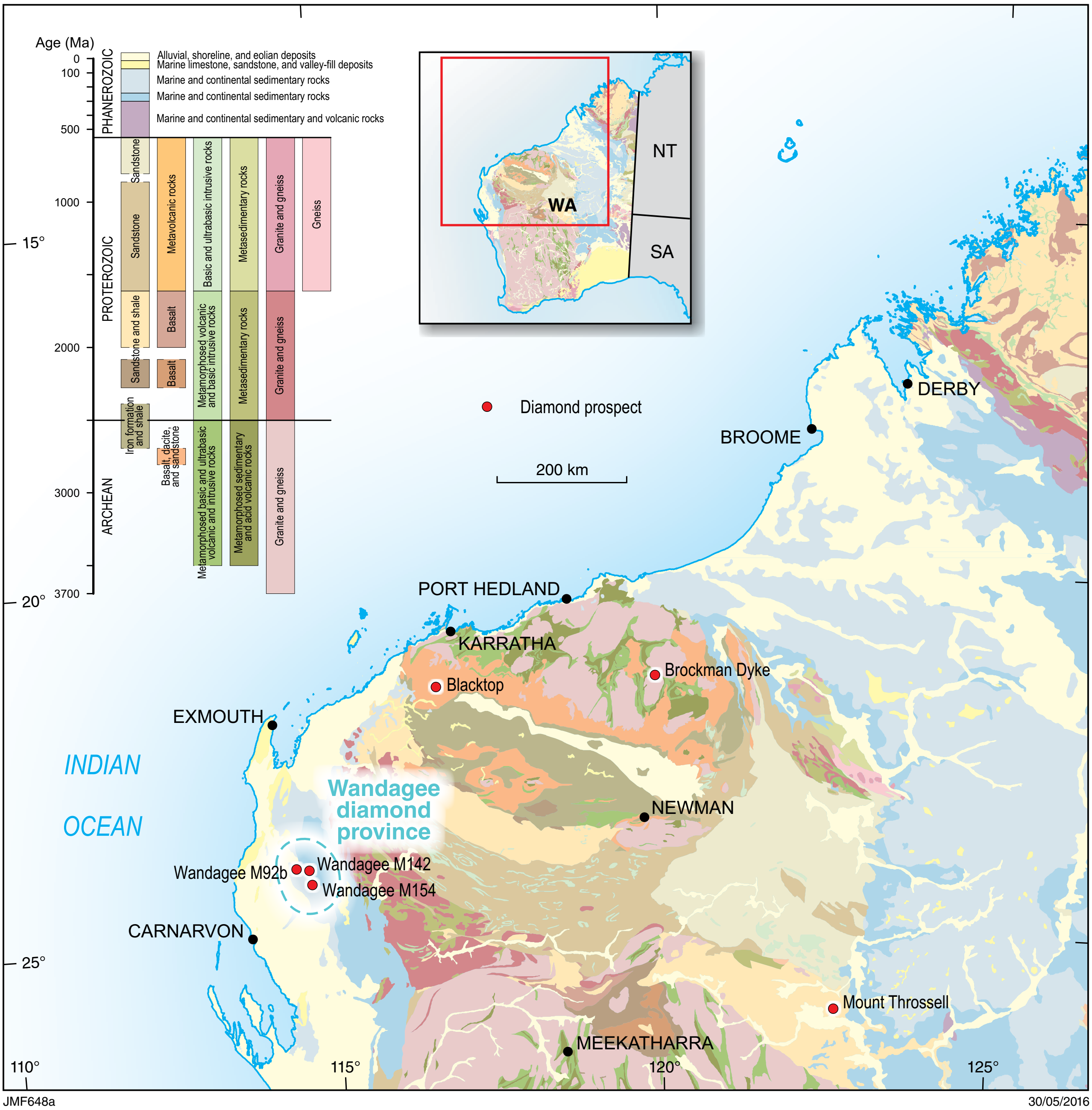

Figure 2.13. Principal diamond prospects in the central western region of Western Australia

Pilbara Craton

The first recorded diamond discovery in Western Australia was in 1895 when a few small stones were recovered from alluvial gold workings at Nullagine in the Pilbara. Over the years a few hundred small stones have been recovered from ancient river gravels. The largest stone was reported as 3.5 ct. Since 1998, two diamondiferous kimberlite dykes were explored at Brockman Dyke in the Marble Bar region, and east of Pannawonica at Blacktop although both deposits were found to be subeconomic (Fig. 2.13).

Brockman Dyke *(Marble Bar, 2855)*

The Brockman kimberlite dyke, discovered in 1998, is about 30 km southeast of the town of Marble Bar (Fig. 2.13). The dyke has a strike length of about 20 km and varies from 1 to 12 m in width. Possibly a fissure-style deposit, the kimberlite is diamondiferous, containing both macro- and microdiamonds and spinel and garnet indicator minerals, and is possibly the primary source of local alluvial stones (Wyatt et al., 2001). Testing of the prospect indicated grades to be subeconomic at around 1 ct/ht.

Blacktop Kimberlite 1 *(Pinderi Hills, 2255)*

The Blacktop Kimberlite 1 dyke, 34 km east-northeast of Pannawonica and 2 km southwest of Warla Pool on the Fortescue River, was first explored by Tawana Resources NL in August 2005 (Fig. 2.13). A 32.85 t bulk sample from the dyke yielded 130 diamonds larger than 0.82 mm totalling 4.1 ct, and a further 1.1 ct was recovered from retreating tailings from the bulk sample. In 2006, the –6 mm fraction from a second bulk sample of 215 t produced 263 diamonds weighing 20.89 ct (Tawana Resources, 2005, 2006). In 2007, the sampling programs were followed up by an airborne geophysical survey over the Blacktop area. Survey results indicated that while other kimberlitic intrusives were probably present in the area, it was considered unlikely that any substantial kimberlite pipes were present and the program was discontinued.

Earaheedy Basin

Mount Throssell area

Mount Throssell *(Carnegie, 3445)*

Also known as the Bulljah Pool prospect, the Mount Throssell diamond exploration area is about 250 km east-northeast of Wiluna, and 3 km northwest of Mount Throssell (Fig. 2.13). This site was originally identified by the discovery of diamond indicator minerals in local stream-sediment samples. Further exploration located five small pipe or sill-like intrusions (BJ 1–5). These structures, intruding Paleoproterozoic sedimentary rocks of the Earaheedy Basin, were provisionally identified as ultramafic lamprophyre. Despite the recovery of a single microdiamond from the BJ 1 sill and a full set of indicator minerals from BJ 5, nothing more of economic interest was found (Hamilton, 1990).

References

Abeysinghe, PB and Flint, DJ 2011, Overview of mineral exploration in Western Australia for 2009–10, *in* Annual Review 2009–10: Geological Survey of Western Australia, Annual Review, p. 13–42.

Ahmat, AL 2012, The Ellendale diamond field: exploration history, discovery, geology and mining: The Australian Gemmologist, v. 24, no. 12, p. 280–288.

Bevan, AWR and Downes, PJ 2004, In the Pink: Argyle's Diamond Gift to Western Australia, Australian Gemmologist, v. 22, no. 4, p. 150–155.

BHP Minerals 1985, M2140/8: Forrest River diamond exploration: BHP Minerals Pty Ltd, Annual Report, Geological Survey of Western Australia, Statutory mineral exploration report, A15299 (unpublished).

Chapman, J, Brown, G and Sechos, B 1996, The typical gemmological characteristics of Argyle diamonds: The Australian Gemmologist, v. 19, no. 8, p. 339–346.

Downes, PJ and Bevan, AWR 2007, Diamonds in Western Australia: Rocks and Minerals, v. 82, no. 1, p. 66–73.

Downes, PJ, Bevan, AWR and Deacon, GL 2012, The Kimberley Diamond Company Ellendale diamond collection at the Western Australian Museum: The Australian Gemmologist, v. 24, no. 12, p. 289–293.

Fetherston, JM 2008, Industrial minerals in Western Australia: the situation in 2008: Geological Survey of Western Australia, Record 2008/16, 70p.

Fetherston, JM and Searston, SM 2004, Industrial minerals in Western Australia: the situation in 2004: Geological Survey of Western Australia, Record 2004/21, 57p.

Graynic Metals Ltd 2007, Graynic concludes joint venture for Australian diamond tenements: Graynic Metals Ltd, Report to the Australian Securities Exchange, 10 December 2007, 3p.

Hamilton, R 1990, Bulljah Pool project, final surrender report, August 1990, E69/65, 71, 72, 74, 76, 83–85 & E38/118–119: Western Mining Corporation Ltd: Geological Survey of Western Australia, Statutory mineral exploration report, A31604 (unpublished).

Hassan, LY 2004a, Mineral occurrences and exploration of the east Kimberley: Geological Survey of Western Australia, Report 74, 83p.

Hassan, LY 2004b, Mineral occurrences and exploration of the west Kimberley: Geological Survey of Western Australia, Report 88, 88p.

Jaques, AL 1994, Diamonds in Australia, *in* The Geology and Origin of Australia's Mineral Deposits *edited by* M Solomon and DJ Groves: Oxford Monographs on Geology and Geophysics, no. 24, p. 787–820.

Jaques, AL, Lewis, JD and Smith, CB 1986, The kimberlites and lamproites of Western Australia: Geological Survey of Western Australia, Bulletin 132, 357p.

Kimberley Diamonds 2014, Kimberley Diamonds acquires Argyle Smoke Creek diamond project from Venus Metals Corporation: Kimberley Diamonds Ltd, Report to the Australian Securities Exchange, 18 January 2014, 42p.

Kimberley Diamonds 2015, Market update: Ellendale diamond mine to continue operating in FY2016: Kimberley Diamonds Ltd, Report to the Australian Securities Exchange, 1 April 2015, 4p.

Louthean, R 2003, Ellendale east stone values a healthy counterbalance: Australia's paydirt, November, p. 18.

MiningNews.net 2015, Kimberley suspends Ellendale: Kimberley Diamonds Ltd, press release, viewed 2 July 2015, <www.miningnews.net/storyview.asp?storyID=826951831&section=Final+Call&sectionsource=s191&aspdsc=yes>.

Mining-technology.com 2015, Ellendale diamond mine, West Kimberley, Australia: Mining–technology.com, viewed 8 April 2015, <www.mining-technology.com/projects/ellendale-diamond-mine-west-kimberly>.

Museum Victoria 2012, Australia’s largest pink diamond, viewed 24 June 2015, <http://museumvictoria.com.au/about/media-centre/media-releases/archive/australias-largest-pink-diamond/>.

North Australian Diamonds Limited 2010, Kimberley project, viewed 11 March 2011, <www.nadl.com.au/kimberley>.

Oldershaw, C 2003, Philip’s guide to gems: Octopus Publishing Group Ltd, p. 49.

Ramsay, RR 1999, Beta Creek Diamond Project–Combined 1999 Annual Report E80/1281–1282, 1296, 1560–1561, 1570, 1585–1586, 1644, 1672, E80/1705, 01/01/98–31/12/99: Striker Resources NL, Geological Survey of Western Australia, Statutory mineral exploration report, A57666 (unpublished).

Rio Tinto 2013a, Rio Tinto Ltd annual report: Report to Australian Securities Exchange, 17 March 2013, 248 p.

Rio Tinto 2013b, Rio Tinto’s Argyle pink diamonds tender sets new records, viewed 9 November 2015, <www.riotinto.com/media/media-releases-237_9278.aspx>.

Rio Tinto 2014, Rio Tinto showcases the world’s largest collection of rare red and pink diamonds, viewed 16 June 2015, <www.riotinto.com/media/media-releases-237_12222.aspx>.

Rio Tinto 2015a, Rio Tinto Ltd annual report 2014, viewed 23 June 2015, <www.riotinto.com/ar2014/>.

Rio Tinto 2015b, Mining and processing – Rio Tinto, viewed 23 June 2015, <www.riotinto.com/diamondsandminerals/argyle-4640.aspx>.

Romanoff, A 1992, M5427/3: Mount Wynne Creek diamond exploration: Auridam NL, Geological Survey of Western Australia, Statutory mineral exploration report, A35232 (unpublished).

Ruddock, I 2003, Mineral occurrences and exploration of the north Kimberley: Geological Survey of Western Australia, Report 85, 58p.

Sheppard, S, Thorne, AM, and Tyler, IM 1997, Bow, WA Sheet 4564: Geological Survey of Western Australia, 1:100 000 Geological Series.

Shigley, JE, Chapman, J and Ellison, RK 2001, Discovery and mining of the Argyle diamond deposit, Australia: Gems and Gemmology, v. 37, no. 1, p. 26–41.

Striker Resources NL 2004, December quarter activities report 2003: Report to the Australian Securities Exchange, 30 January 2004, 14p.

Tawana Resources 2005, Exploration report October 2005: Report to the Australian Securities Exchange, 14 October 2005, 2p.

Tawana Resources 2006, Exploration report October 2006: Report to the Australian Securities Exchange, 2 October 2006, 2p.

van der Bogert, CH, Smith, CP, Hainschwang, T and McClure, SF 2009, Gray-to-blue-to-violet hydrogen-rich diamonds from the Argyle Mine, Australia: Gems and Gemmology, v. 45, no. 1, p. 20–37.

Wyatt, BA, Mitchell, M, White, B, Shee, SR, Griffin, WL and Tomlinson, N 2001, The Brockman Creek Kimberlite, East Pilbara, Australia, *in* International Archaean Symposium *edited by* KF Cassidy, JM Dunphy and MJ Van Kranendonk: Extended Abstracts, AGSO–Geoscience Australia, Record 2001/37, p. 208–209.

2

Gemstones associated with pegmatites

Emeralds from the Curlew mine, Tambourah area, Pilbara region (courtesy Gemmological Association of Australia)

Chapter 3

Beryl group

Beryl properties

Beryl is a member of the hexagonal crystal system. It commonly occurs as well-formed crystals that are prismatic in habit and hexagonal in section, although 12-sided crystals are also found. Prisms are commonly terminated by basal planes, and more rarely, by small dipyramidal forms between prisms and basal planes.

The theoretical composition of beryl, $Be_3Al_2Si_6O_{18}$, is rarely substantiated by chemical analyses and most results show the presence of alkali metals (Na, Li, K, and Cs) and water. Colours and hues of beryl vary greatly according to traces of the chromophoric transition elements iron, chromium, manganese, and vanadium. Blue, green, and yellow beryl varieties typically contain divalent and/or trivalent iron (ferrous or Fe^{2+}, and ferric or Fe^{3+}, up to 1.5% FeO and 0.96% Fe_2O_3). Pink and red beryl contain manganese (Mn^{2+} and Mn^{3+} from trace amounts to <0.2%). Emerald analyses commonly show the presence of chromium (0.23% Cr_2O_3 from Poona, Western Australia), minor iron, and infrequently vanadium (0.12%); cobalt, nickel, and copper are rarely reported and only in trace amounts (Sinkankas and Read, 1986).

Beryl most commonly occurs in rare-element lithium–cesium–tantalum-bearing pegmatites formed at low to moderate pressures of 2.5 – 4.0 kb and temperatures of 500–650°C within andalusite to sillimanite metamorphic facies environments.

Beryl is a relatively abundant mineral in pegmatites throughout Western Australia, occurring as both crystals and disseminated material, and has been mined as a source of beryllium metal. Colours vary from milky white, pink, yellow, blue, and green although all material is opaque (Fig. 3.1). Where beryl exhibits translucence and clarity, it can typically be considered gem material.

Gem beryl has physical properties well suited for use as a gemstone with substantial hardness (7.5 – 8) and indistinct basal cleavage. Transparent beryl containing few inclusions and fractures is usually faceted and lower grade material is commonly cabochon cut or tumbled to produce beryl beads.

Beryl group

Beryllium aluminium silicates ($Be_3Al_2Si_6O_{18}$)

Several different coloured varieties of gem beryl are recognized: aquamarine (blue and blue-green), emerald (intense green), morganite (pink to orange pink), heliodor (yellow), goshenite (colourless), bixbite (red), and black. To date, the rare red and black beryls have not been recorded in Western Australia and only emerald and a small amount of aquamarine have been mined. Crystals of morganite, heliodor, and goshenite have been reported from various local pegmatites. Principal gem beryl minerals are shown in Figure 3.2 and localities of beryl group minerals in Western Australia are given in Figure 3.3.

More detailed locational information on most of the State's beryl group deposits and prospects is given in Appendix 1.

Emerald

Emerald is the name given to a green, transparent to translucent variety of beryl. Trace amounts of chromium, vanadium, and iron are mostly responsible for the colour, which ranges from blue-green and yellowish-green to deep green.

Physical properties of emerald

Crystal system	Hexagonal
Habit	Prismatic
Colour range	Light to dark green
Colour cause	Chromium, vanadium, and iron
Lustre	Vitreous or glassy
Diaphaneity	Transparent to translucent
Refractive index	1.560 – 1.602
Birefringence	0.005 – 0.009
Pleochroism	Yellow-green to blue-green
Hardness	7.5 – 8.0
Specific gravity	2.63 – 2.85
Fracture	Conchoidal

Figure 3.1. Pegmatite block (width 40 cm) containing large, pale green, euhedral beryl (aquamarine) crystals enclosed in a quartz–feldspar matrix from the Giles pegmatites in the Spargoville area (courtesy David Vaughan)

The defining chemistry of emerald is a matter of conjecture as some emeralds do not have detectable levels of chromium or vanadium and emerald merchants are guided by the intensity of green hue. Nevertheless, most emeralds contain sufficient chromium to be visible as absorption bands in the visible spectrum when examined by hand spectroscope. Coloured filters (Chelsea filters) can also be used to demonstrate the presence of chromium in emerald indicated by a red or pink response. Chemical analyses of gem beryls from Western Australia are not commonly available although an analysis of an emerald from Poona is given in Table 3.1.

According to Schwarz et al. (2002), emerald deposits can be classified into six main types:

- Pegmatites without schist — emerald in granite and pegmatite vugs
- Pegmatite and greisen with schist — emerald in pegmatites and phlogopite schists
- Schists without pegmatites — emerald in phlogopite schist
- Schists without pegmatites — emerald in carbonate–talc schists and quartz lenses
- Schists without pegmatites — emerald in phlogopite schists and carbonate–talc schists
- Black shales with veins and breccias — emerald in vugs with carbonates, pyrite, and albite.

Almost all of the Western Australian emerald deposits belong to the second type and are most commonly found in biotite–phlogopite schists directly adjacent to a variety of pegmatite veins or less commonly within the pegmatites. An example of emeralds from the Curlew mine at Tambourah in the Pilbara Craton is shown in Fig. 3.2a.

Yilgarn Craton — Murchison Domain

Cue region

Poona *(Noondie, 2343; Cue, 2443)*

The first emerald discovery in Western Australia was at Poona, about 55 km northwest of Cue (Fig. 3.3). In 1912, prospector AP (Paddy) Ryan showed two crystals of emerald that his son, LF (Fin) Ryan, had found to Government Geologist HP Woodward. Soon afterwards the first emerald lease, PA1042, was pegged at Poona in the name of HA (Henry) Ryan, the elder brother of Fin. This lease was converted to the Reward Claim mining lease ML45, also known as the Mount Ryan lease. HP Woodward reported on the occurrence of these emeralds in 1914.

Table 3.1. Chemical analysis[a] of an emerald from Poona, Western Australia

SiO_2	Al_2O_3	Fe_2O_3	BeO	MgO	CaO	Na_2O	K_2O	Cr_2O_3	MnO	Li_2O	H_2O	Total
64.40	18.03	0.50	14.28	0.52	0.16	0.48	0.14	0.23	0.19	trace	1.60	100.53

NOTE: (a) wt%
Source: Simpson (1948)

Figure 3.2. **Gem varieties of beryl from Western Australia: a) emeralds from the Curlew mine, Tambourah area, Pilbara region (courtesy Gemmological Association of Australia); b) aquamarine (1.49 ct) from Spargoville, Coolgardie region (photograph Carlo Benti, courtesy Australian Museum); c) yellow beryl, closely resembling heliodor, from Mullalyup, Donnybrook area (courtesy Western Australian Museum); d) morganite (3.59 ct) from Poona, Cue region (photo Carlo Benti, courtesy Australian Museum)**

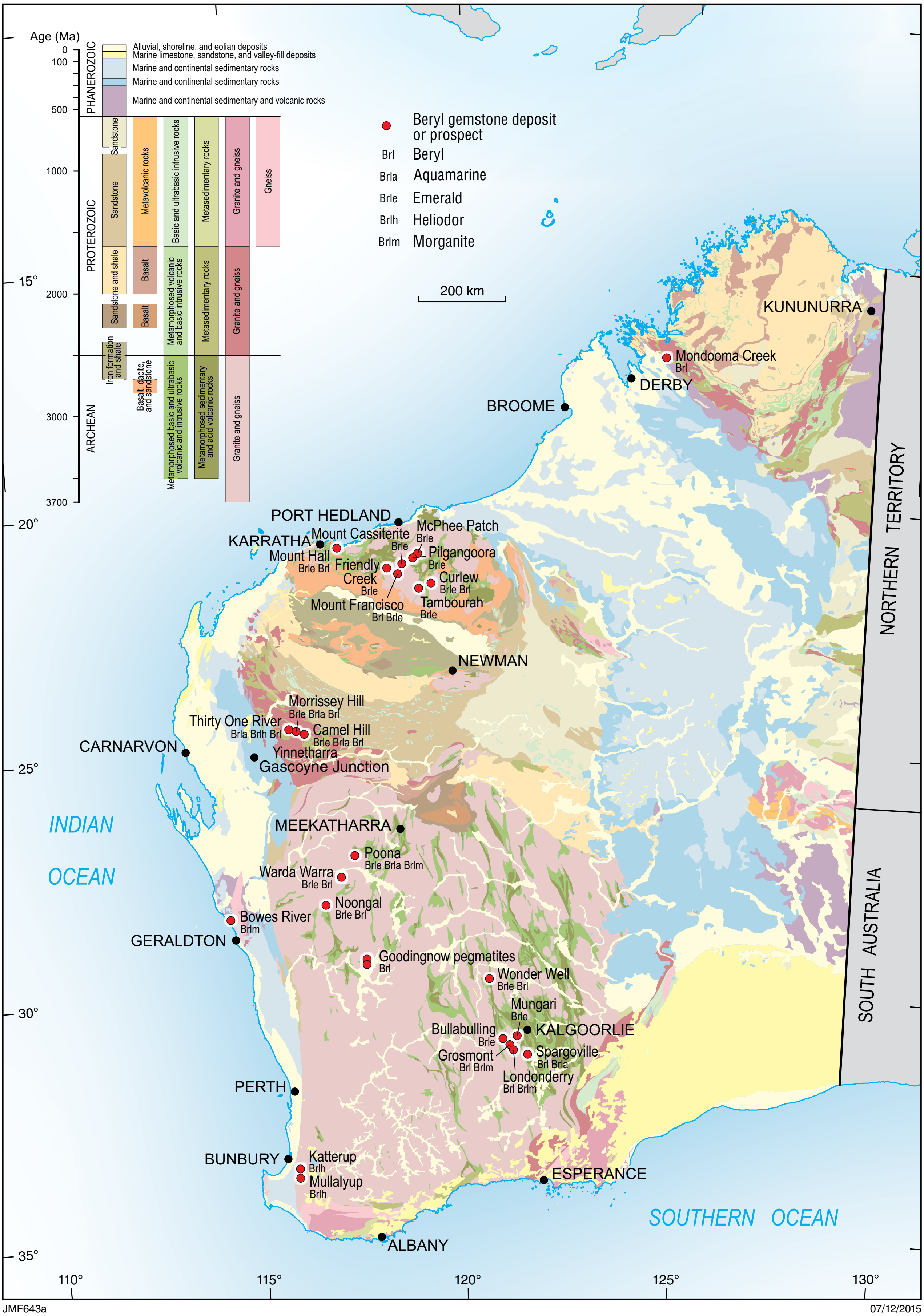

Figure 3.3. **Principal beryl group mineral localities in Western Australia**

The Poona area received considerable, albeit intermittent, attention from tin and emerald miners during the 20th century and there are numerous trenches, shafts, and small pits to mark this activity. The most significant of these are Aga Khan, Quartz Blow, Mid-section, Solomon, Reward, and Lee's Trench (Fig. 3.4).

In general, the emeralds at Poona were of low quality and limited value with dark green stones of some transparency being extremely rare. Because of this, mining emeralds at Poona was never a profitable exercise and, as a result, mining operations were small and of relatively short duration.

Geology of the Poona area

Poona lies in the north central area of the Murchison Domain forming part of the Yilgarn Craton, an extensive area of Archean granitic gneiss and greenstone rocks. The greenstone belts are surrounded by much more extensive granitic intrusions that contain enclaves of banded gneiss. These greenstone belts comprise metamorphosed volcanic, sedimentary, and intrusive rocks in which mafic rocks predominate. They are deformed by large-scale fold structures that are dissected by major faults (Watkins et al., 1987).

Emeralds at Poona are found within the greenstone belts in biotite–phlogopite schists adjacent to milky quartz lenses, quartz–feldspar pegmatites and margarite–quartz, quartz–muscovite, or beryl–quartz veins, or along the edges of these bodies (Jacobson et al., 2007).

According to Grundmann and Morteani (1998) there are three different types of emerald mineralization in the Poona area:

- Emeralds associated with margarite and topaz in quartz veins cutting dark brown biotite and phlogopite schists. Light to deep green emeralds as crystals up to 40 mm long can be found in both the margarite–quartz–topaz veins and directly adjacent phlogopite schists. Some of these are of gem quality. These are exposed at the Poona East emerald mine.
- Emeralds associated with ruby, sapphire, topaz, and alexandrite tend to be light green with crystal sizes ranging from 1 to 10 mm. Specimens of this size were collected from the dumps of a small exploration shaft near the Aga Khan Deep mine.
- Emeralds associated with quartz, feldspar, garnet, and muscovite are mostly colourless beryl although they can be light green and zoned and are always cloudy because of fractures and inclusions.

Many of the Poona emeralds are zoned with alternating bands of different shades of green. Inclusions are dominated by mica, ilmenite, apatite, and fluid.

Poona emerald deposits

In 1914, a syndicate mined an area close to the current Aga Khan workings (Fig. 3.4). The syndicate extracted many thousands of carats of poor-quality emeralds and two fine stones. The project was abandoned and the lease surrendered in 1916. All the Poona leases were forfeited by the end of World War I. Four leases over areas considered to have the best emerald potential were re-pegged in 1919 with small mining operations persisting for the next few years. Pegging resumed in earnest in 1926 and from this time to 1936, several syndicates mined the area obtaining abundant low-value stones although recovered nothing of significance (Palmer, 1990; Jacobson et al., 2007).

The first underground emerald mine, the Aga Khan Deep mine, was not established until 1975 and mining ended in 1977. The mine was opened again in 1980 although was finally closed in 1982 because of technical problems and low profits. Aga Khan Deep and adjacent mines were again mined on a part-time basis between 2001 and 2002.

The Reward opencut (Fig. 3.4) was established in 1963. A few stones of reasonable quality and poorer quality emeralds were obtained. The operation then passed to new owners in 1975 and continued until 1978 when the tenement expired. The Reward opencut operated briefly again between 1988 and 1990, but returns were inadequate and mining operations suspended.

In October 1971, newspaper publicity was given to the alleged finding of an emerald crystal, named the 'Mary B', weighing 138 ct from the Solomon opencut. Detailed examination of the two pieces subsequently recovered from the enclosing biotite schist indicated that the transparent parts of the larger piece were almost colourless with the apparent colour caused by reflection from dark green opaque material on the edges and near the centre of the crystal. Subsequent reports ascribed only specimen value to the crystal.

The Quartz Blow opencut (Fig. 3.4) was mined for six weeks in 1982 and 20 000 ct of low-quality emerald were dispatched to India but returns proved inadequate for operating at a profit (Mindat.org, 2015).

Other emerald mines in the Poona area

The Emerald Pool mine (formerly the Emerald Gem mine) is about 6.5 km northeast of Aga Khan. This mine supplied the emerald used for the production of synthetic emeralds by Equity Finance Ltd, owner of the Biron process, which produced hydrothermal emeralds in the laboratory. The stones were originally marketed under the name of Pool Emeralds. Equity Finance later terminated its contract to buy emeralds from the Emerald Pool mine and was renamed Biron Corporation Ltd. The company marketed the manufactured stones as Biron emeralds until May 2001 when its emerald production business was sold to its Russian competitors. Figure 3.5 is a photograph of a large, 120 ct hydrothermal emerald manufactured by Biron Corporation Ltd showing the thin seed plate in the centre.

The Poona East emerald mine lies about 10 km east of Poona (Grundmann and Morteani, 1998). No further information is available about this deposit.

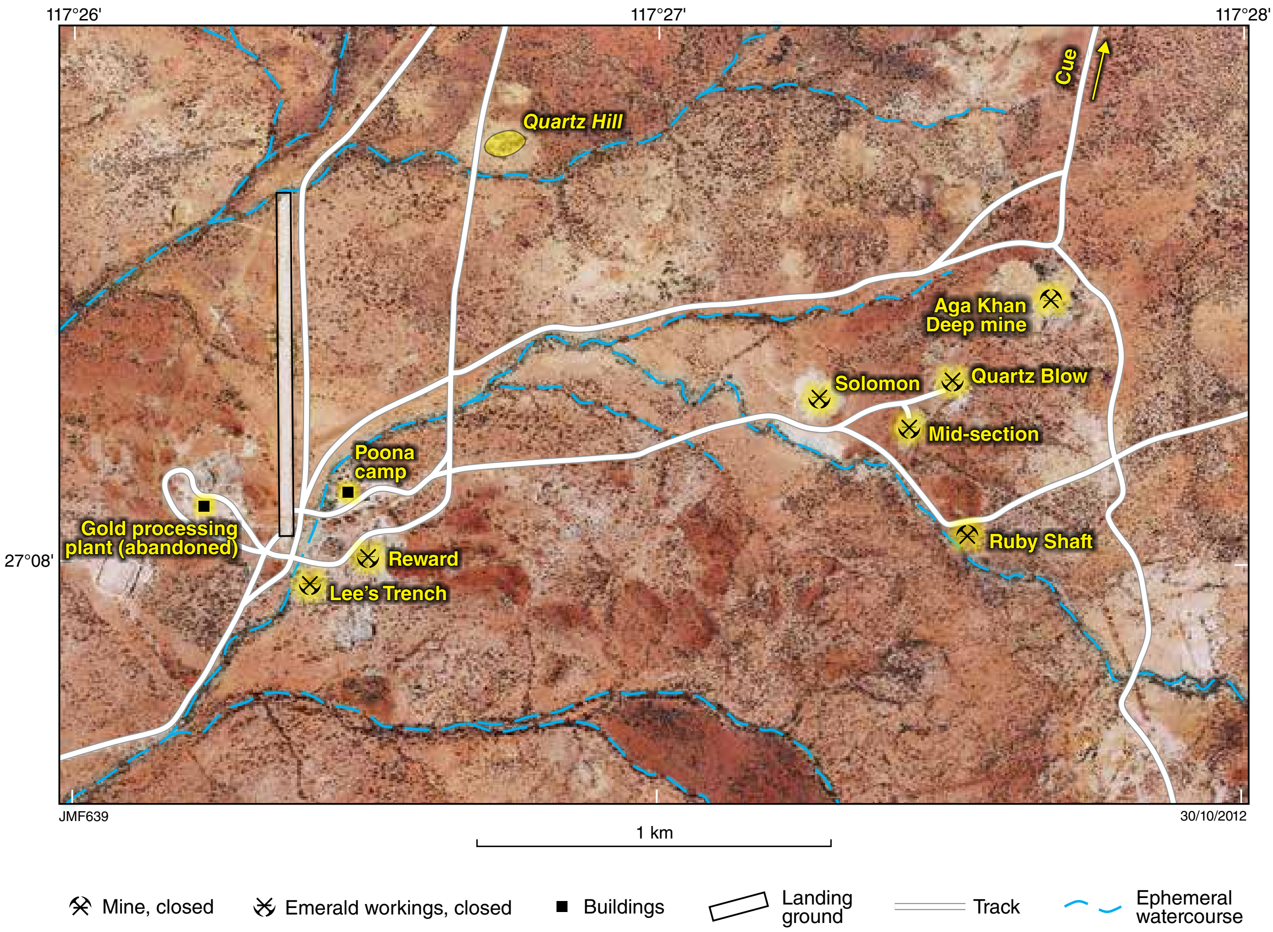

Figure 3.4. Locations of emerald mining operations at Poona, Cue region (after Grundmann and Morteani, 1998)

Yalgoo region

Noongal (*Yalgoo, 2241*)

Beryl and poor-quality emerald were discovered at Noongal (also called Melville), about 20 km north of Yalgoo and 4 km north of the old Melville townsite (Fig. 3.3). In this area, beryl-bearing pegmatites are found within the Melville pegmatite field, which occurs in a tightly folded anticlinal nose composed mostly of Archean metasedimentary rocks. The magmatic source of the pegmatites is thought to be one of the proximal, post-folding granites. Although beryl mineralization seems randomly scattered among the pegmatites, emerald is only recorded from two pegmatite groups (Jacobson et al., 2007).

The Emerald Show pegmatite (Drew's Emerald Show) comprises several small closely spaced pegmatites containing small beryl crystals in quartz within the pegmatite and in the adjacent biotite schist. Beryl colour varies from white through various green tints into dark green emerald. All emerald crystals that were mined were flawed. Associated minerals are topaz, albite, biotite, fluorite, microcline, muscovite, and scheelite.

The North Emerald Show is mentioned by Simpson (1948) as yielding emeralds of poor quality. The specific location of this pegmatite is unknown although it is almost certainly on the Yalgoo map sheet (2241).

No production figures are available for emeralds from Noongal although the amount is assumed to have been small.

Warda Warra (*Dalgaranga, 2342*)

The Warda Warra emerald occurrence is directly north of Warda Warra Hill about 95 km northeast of Yalgoo (Fig. 3.3). Access is via the Yalgoo–Cue dirt road and minor tracks leading to an abandoned gold mine prospect.

The beryl-bearing pegmatites occur as irregular pinch and swell veins cutting mafic–ultramafic rocks. Reaction zones on either side of the pegmatites contain phlogopite–biotite, actinolite–tremolite, chlorite, and talc. However, deposits are variable and the outer zones are commonly absent (Darragh and Hill, 1983).

The Warda Warra pegmatites are represented almost entirely by veins of white quartz. Pale to dark green emeralds are found within both the quartz and surrounding phlogopite–biotite schist. Many of the beryl crystals within the quartz are intergrown with and replaced by potash feldspar. Warda Warra emeralds have been described

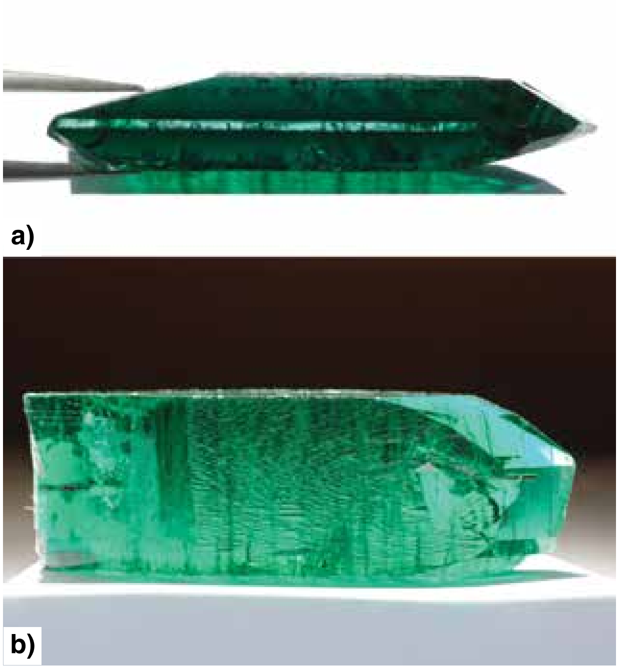

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Figure 3.5. Synthetic, 120 ct hydrothermal emerald manufactured by Biron Corporation Ltd (length 50 mm): a) crystal side view showing the thin horizontally aligned seed plate at the centre; b) the emerald-green, tabular form is the product of growth on the natural beryl seed plate with the broad face displaying geometric growth features (courtesy Susan Stocklmayer)

as being a beautiful green although they are small and fractured. There is no record of production.

Yilgarn Craton — Eastern Goldfields Superterrane

Menzies region

Wonder Well (*Riverina, 3038*)

The Wonder Well emerald-bearing pegmatites are on mining lease M30/8 astride the Riverina to Snake Hill road directly north of the Riverina Station Homestead, about 60 km west of Menzies (Fig. 3.3).

Emeralds were first discovered c. 1974 and mining commenced that year. Mining continued intermittently until 2003, producing both specimen- and facet-grade material. The largest opencut was 38 m long and up to 7 m deep (Garstone, 1981). During this period, North Kalgurli Mines Ltd conducted a complete geological evaluation of the emerald deposits including drilling and geological mapping. Metallurgical testwork was inconclusive and the project was never advanced (Mumme, 1982). In 2011 the mine was still active on a small scale, although it appeared that fossicker visits were not encouraged. In late 2015 ownership of the Wonder Well mining lease, M30/8, was transferred to new owners Australia Menzies Emerald Pty Ltd, which is currently refurbishing the mine in preparation for commercial production.

At Wonder Well, emerald-bearing pegmatites form within a north–south-trending greenstone belt composed predominantly of mafic lavas and sedimentary rocks with intercalated ultramafic bodies. The mafic lavas have been metamorphosed to chlorite–amphibole–plagioclase schist while the ultramafic bodies show a more varied mineralogy, changing from chlorite schist and talc schist close to surface to tremolite/actinolite–phlogopite/biotite schist at depth (Fig. 3.6).

At this site, the beryl-bearing pegmatites contain braided networks of plagioclase–quartz veins, which are concordant with the foliation of the enclosing Archean phlogopite and biotite schists and amphibolites. Metamorphism and metasomatism associated with the pegmatite emplacement has resulted in selvedges made predominantly of phlogopite schists. In the pegmatites most of the beryl occurs as milky blue-green euhedra in the albite, with fewer crystals in the quartz. The best emeralds are found in the phlogopite schists directly adjacent to the pegmatites and crystals up to 2 cm long have been found (Fig. 3.7a). Associated minerals are biotite, plagioclase, quartz, and topaz (Garstone, 1981). In 2015, new mine owners Australia Menzies Emerald faceted several spectacular emeralds sourced from the Wonder Well openpit (Fig. 3.7b).

Coolgardie region

Bullabulling (*Dunsville, 3036*)

The Bullabulling emerald deposit is directly north of the main Perth–Kalgoorlie highway, approximately 22 km west of Coolgardie (Fig. 3.3).

According to Sullivan (2000), beryl was discovered in 1987 within an area of biotite schists at the extreme western end of the Archean Norseman – Wiluna Greenstone belt composed of metamorphosed mafic and ultramafic successions overlain by felsic lithologies. Extensive Archean granite bodies surround the volcanic successions and smaller intrusives with associated pegmatites occur within them. The beryl mineralization at Bullabulling appears within two shear zones, which lie subparallel to the trend of the enclosing greenstone belt.

Following some cursory pitting and costeaning in 1992, a shallow opencut was excavated and a small parcel of emeralds was sent to South Africa for gemmological examination. The emeralds were found to have well-developed crystal symmetry and were not dissimilar to emeralds from Zambia. Apart from this comment, nothing is known about the size or quality of emeralds recovered from this deposit. It was concluded that gem-quality emeralds were not present in sufficient amounts to support a mining operation.

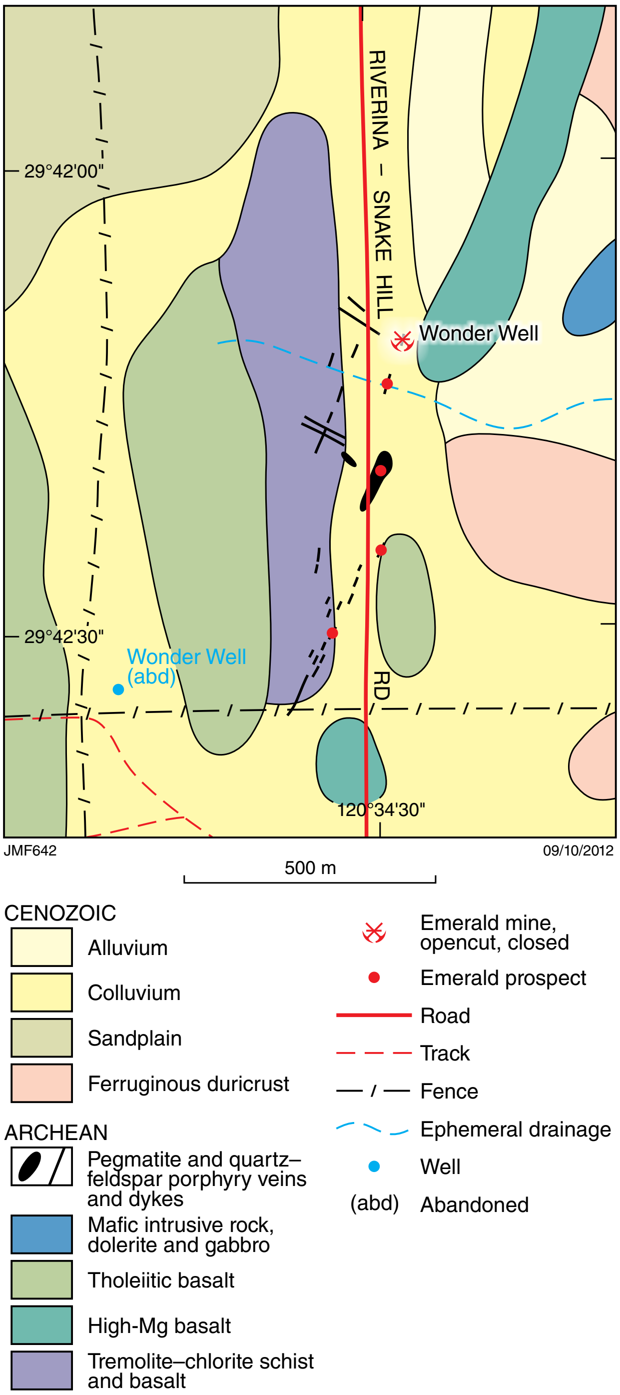

Figure 3.6. **Geology of the Wonder Well emerald-bearing pegmatites at Riverina, Menzies region (modified after Garstone, 1981; Wyche and Swager, 1996)**

Figure 3.7. **Emeralds from the Wonder Well deposit at Riverina in the Menzies region: a) emerald crystal in schist, (courtesy Australian Museum); b) three spectacular, faceted emerald gemstones; oval-shaped (left) 7.7 x 7.2 mm, oval-shaped (centre) 10.1 x 8.5 mm, octagonal (right) 7.05 x 6.2 mm (courtesy Australia Menzies Emerald Pty Ltd)**

Mungari (*Kalgoorlie, 3136*)

The small Mungari emerald deposit is approximately 11 km north-northeast of Coolgardie just off the Coolgardie to Kalgoorlie Highway. Just before the Mungari Industrial Park, a small road leads northwest for about 2 km to the reported emerald deposit on mining lease M15/1378 (Fig. 3.3).

At this location, the Kalgoorlie 1:100 000 geological map shows a narrow, northwest-striking band of Archean ultramafic schists and metamorphosed felsic, mafic, and ultramafic rocks intruded by the 2.6 Ga Mungari Monzogranite, a medium-grained biotite–muscovite monzogranite (Hunter, 1998). A short report by Wyche (1998) makes no mention of specific pegmatites in the area, although it does state that they are especially common near greenstone–granite contacts.

A sample of material from the deposit contains biotite–phlogopite schist crowded with numerous emerald crystals up to 25 mm in length. Most emeralds are fragmented, flawed, and included, although some do contain clear areas that may be suitable for faceting (Fig. 3.8). There are reports of some faceted stones from this deposit although no further information is available.

Figure 3.8. Emerald crystals in matrix, Mungari deposit, Coolgardie (courtesy of Ralph Bottrill)

Pilbara Craton

The names, locations, and general descriptions of the various emerald occurrences in the Pilbara Craton given by different authors can be confusing. Hickman (1983) reported an emerald prospect southwest of Calverts White Quartz Hill near the Shaw River, and emerald occurrences north of Lynas Find in the McPhees Hill area, at Pilgangoora to the north-northeast of Coffin Bore, and in the Mount Cassiterite area in the Wodgina district. Ellis (1962) and Hickman (2002) also recorded a beryl–emerald occurrence near Mount Hall, southeast of Roebourne. Ferguson and Ruddock (2001) recorded emeralds found at the emerald mine complex at Calverts White Quartz Hill in the McPhees Hill area, and around Mount Francisco.

Jacobson et al. (2007) reported emerald discoveries from at least seven localities: McPhees Hill, an unknown locality north of the main tantalite dyke at Wodgina; Friendly Creek, Tambourah, a site southeast of Roebourne; the Curlew deposit at Tambourah; and at Desert Rose near the Shaw River. Although some data are available for the Curlew deposit at Tambourah, little or no information is available for all other occurrences. Identified deposits are shown in Figure 3.3.

Tambourah region

Curlew emerald mine (Tambourah, 2754)

The Curlew emerald mine (also known as White Quartz Hill or Calverts) is on the western side of the Shaw River on Hillside Station, approximately 65 km southwest of Marble Bar (Fig. 3.3). Access from Marble Bar is via the graded road to Hillside and Woodstock Stations followed by relatively poor station tracks.

Emeralds were probably discovered at Curlew in the 1920s although no recorded mining activity occurred until 1976 and the first leases were pegged around 1967 (Laurie, 1982). At that time, a preliminary assessment of the site revealed the deposit contained about 2500 of emerald-bearing material (Jacobson et al., 2007). Mining commenced in 1977 by a small syndicate known as Aveiro Pty Ltd. Mining continued until the end of 1980, during which time several thousand carats of rough emerald and beryl were obtained from approximately 2000 t of material (Laurie, 1982). This production included a 600 ct emerald, which was later shown to be too flawed to be facetable. Mining operations included at least two shafts, one large opencut, and numerous pits and costeans. The main shaft was sunk to a depth of 14 m and the opencut was originally an area of underground mining where stoping took place from 14 m depth to the surface.

In January 1981, Aveiro Pty Ltd sold the Curlew emerald mine to Warren and Strang (Aust.) Ltd. Warren and Strang carried out a program of geological mapping over the deposit and collected a bulk sample for testwork. They estimated proven, probable, and possible ore reserves at 1700 t, 8050 t, and 12 420 t, respectively, at an emerald grade of 17.58 ct/t for all categories. Also, a percussion hole was drilled.

Laurie (1982) noted that when the mine was acquired by Warren and Strang (Aust.) Ltd, the purchase included:

- one 600 ct megacrystal specimen emerald
- 50.635 ct high-quality facetable emerald
- 5700 ct medium-quality emerald
- 20 000 ct low-quality emerald.

It is also stated that this parcel probably did not include all the mined material.

In 1985, Elders Resources Ltd purchased the mine, reviewed previous work and excavated three new costeans. Opinions expressed by consultants McGee (1986) and Herlihy (1987) were that the property would most likely be a more suitable operation for an individual or small syndicate. The tenements were relinquished in 1989. The mine is currently on prospecting licence P45/2735. It is worked in a small way and several quality stones have been recovered.

Geology of the Curlew mine area

Archean metavolcanic rocks of the Emerald Mine Greenstone Complex have been intruded by numerous quartz–feldspar pegmatites. Beryl mineralization is found along a fault marking the contact between amphibolites to the east and metasedimentary rocks and fragments of the Shaw batholith to the west (Van Kranendonk, 2003; Fig. 3.9).

The fault zone trends north–south and dips steeply to the west and narrow pegmatites and quartz veins, with the same strike direction, generally dip gently to the east. Within the fault zone the amphibolites to the west comprise a narrow zone, not exceeding 1.5 m wide and 250 m long, of biotite or phlogopite schists containing boudins of quartz and pegmatite. These mica schists contain gem-quality emerald and green beryl as medium- to coarse-grained crystals from less than 1 mm to large crystals up to several centimetres in diameter (Fig. 3.2).

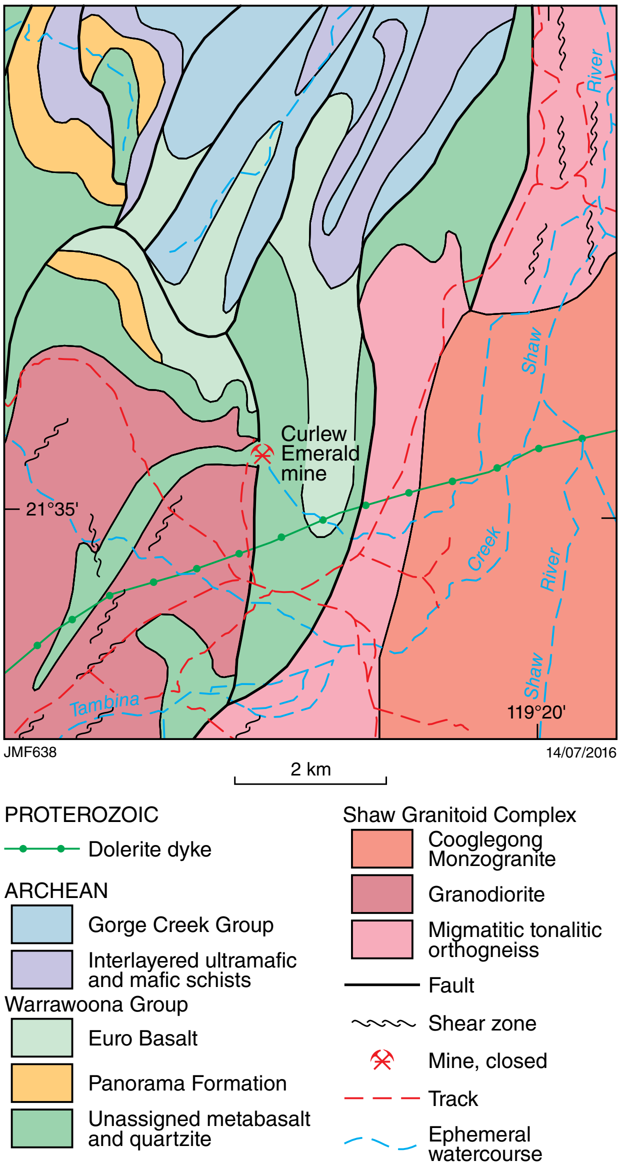

Figure 3.9. Geology of the area surrounding the Curlew emerald mine, Tambourah region (modified after Van Kranendonk, 2003)

Emeralds of good colour are also found within the quartz veins although they are crowded with inclusions and those from the pegmatites are always cloudy and paler in colour. Crystal zoning is apparent, with up to 16 zones recorded from some specimens (Laurie, 1982).

Minerals forming together with the emeralds include beryl, fluorite, molybdenite, scheelite, and topaz.

Tambourah pegmatite field *(Tambourah, 2754)*

Emeralds were reported by Jacobson et al. (2007) from the Tambourah pegmatite field about 90 km southwest of Marble Bar on the old road from Woodstock Station to Hillside (Fig. 3.3).

Wodgina region

Mount Cassiterite pegmatite field *(Wodgina, 2655)*

The Mount Cassiterite pegmatite field at Wodgina is about 100 km south of Port Hedland and is accessed via the Northwest Coastal Highway, the Great Northern Highway, and the Wodgina – Mount Cassiterite Road (Fig. 3.3).

In 1931, a prospector found a few emerald crystals in the Wodgina district about 3 km northwest of the Tantalite Lode. Simpson (1948) reported that at this locality the emeralds formed prisms embedded in feldspar, reaching up to 10 mm long and 5 mm wide. They were too turbid and badly flawed to be worth cutting.

Mount Francisco pegmatite field *(Wodgina, 2655)*

The Mount Francisco pegmatite field lies about 120 km south of Port Hedland within the Yandeyarra Aboriginal land (Fig. 3.3). Permission from the Aboriginal council is required for access.

Mount Francisco and the surrounding area contain ultramafic rocks with lesser amounts of amphibolite schist, metabasalt, and metasedimentary rocks. It forms a roof pendant in the Numbana Granite and the metamorphic rocks have been intruded by numerous pegmatites. Historically, beryl was mined from some of the pegmatites and it is assumed that these pegmatites also contained the reported emeralds. No further information is available.

Pilgangoora *(Wodgina, 2655)*

The Pilgangoora pegmatites are about 85 km south-southeast of Port Hedland. Access is via the Great Northern Highway, the Port Hedland railway access road, the Port Hedland – Wittenoom Road and station tracks (Fig. 3.3). Emeralds of variable quality have been found in pegmatites intruding ultramafic schists at a locality about 4 km north-northeast of Coffin Bore. No further information is available.

McPhee Patch *(Wodgina, 2655)*

The exact locality of the McPhee Patch (also called McPhee Hill) emerald occurrence is uncertain although it appears to be approximately 85 km south-southeast of Port Hedland and about 6–7 km north of Lynas Find (Fig. 3.3). The emerald-bearing pegmatites are part of the Pilgangoora pegmatite field. Little is known about the occurrence except that it was reported that 8.68 ct of emerald was cut from material obtained from pegmatite that intruded biotite schist and migmatite.

Friendly Creek *(Satirist, 2555)*

Emerald specimens in the Western Australian Museum (MDC 5349 and 5709) are recorded as sourced from Friendly Creek, approximately 110 km south-southwest of Port Hedland and 1 km from Bamboo Creek on Sherlock Station; however, the exact location is uncertain.

Roebourne region

Mount Hall pegmatites *(Roebourne, 2356)*

Emeralds have previously been reported from 9.6 km southeast of Roebourne near Mount Hall (Fig. 3.3). At this site, narrow prisms of flawed green beryl were mined from pegmatite dykes contained within the Archean Andover Intrusion (Ellis, 1962). Hickman (2002) also acknowledges the former mining of beryl from the same site.

Gascoyne Province

Gascoyne Junction region

Yinnetharra area *(Yinnetharra, 2148)*

Extensive beryl-rich pegmatite fields are present on Yinnetharra and Bidgemia Stations about 175 km to the east-northeast of Gascoyne Junction (Fig. 3.3). These pegmatites were mined on a small scale for beryl and columbite and they were also favoured as a source of gemstones such as amethyst and dravite. The pegmatites are of the beryl–columbite class and most are present within muscovite schists and migmatites of the Leake Spring Metamorphics. Emeralds have been recovered from unconsolidated stream sediments at Morrissey Hill, 12 km north of Yinnetharra Homestead, and from an opencut at Camel Hill. More detailed locational data relating to these deposits are given under Yinnetharra aquamarine.

Camel Hill *(Yinnetharra, 2148)*

Kenyon (1993) records two occurrences of poor-quality emeralds in pegmatites at Camel Hill, about 21 km east-northeast of Yinnetharra Homestead (Fig. 3.3). At one site in the Camel Hill pegmatite, emeralds of poor quality were found in a small pit in a black mica schist. Nothing further is known about this occurrence.

Aquamarine

Aquamarine is a greenish-blue gem variety of beryl used as a gemstone both in transparent or semitransparent form. Aquamarine, as a varietal name, was so named after the illusion of its colour to that of the sea.

The colour of aquamarine is attributed to divalent (ferrous, Fe^{2+}) and/or trivalent iron (ferric, Fe^{3+}; maximum 1.5% FeO and 0.96% Fe_2O_3). Iron in the two valence states occupies two different crystallographic sites in the beryl structure and the relative concentration of Fe^{2+} to Fe^{3+} determines whether yellow, blue, or green colours result. If iron does not occupy the correct crystallographic site, no colour results.

Commercially available aquamarine is commonly heat treated to remove the greenness from the gem. This treatment has a long history and is accepted in the trade without disclosure. Heat-treated aquamarine shows no tint of greenness. Blue can also be induced in beryl by heat treating yellow beryl. Heating between 250°C and 350°C results in reduction of Fe^{3+} to Fe^{2+} and removes the yellow and green tint, thereby bleaching the beryl. Further heating to approximately 430–475°C causes a change from pale to dark blue aquamarine. There is no tradition of heat treatment on locally produced gem-quality beryl varieties.

Physical properties of aquamarine

Crystal system	Hexagonal
Habit	Prismatic
Surface features	Crystal faces often exhibit etch pits and dissolution features
Colour range	Light to intense greenish-blue
Colour cause	Iron (Fe^{2+} and Fe^{3+})
Lustre	Vitreous or glassy
Diaphaneity	Transparent to translucent, and opaque
Refractive index	1.568 – 1.599
Birefringence	0.006
Pleochroism	Moderate to strong in intense colour varieties
Hardness	7.5 – 8.0
Specific gravity	2.63 – 2.92 (increases with alkali metal content, especially cesium)
Fracture	Conchoidal

Although facet-grade material can be cut in any style, aquamarine is commonly faceted as ‘emerald-cut’, which displays rectangular or square outlines commonly with truncated corners (to maximize weight recovery).

Total production of aquamarine from Western Australia is unknown although some gem-quality aquamarine suitable for cutting (and other high-quality pink, colourless, and yellow varieties of beryl) has been found; however, it appears production sites for these stones were not recorded. Occurrences of aquamarine have been reported from several pegmatites in Western Australia.

Gascoyne Province

Gascoyne Junction region

Yinnetharra area *(Yinnetharra, 2148; Mount Phillips, 2149)*

Extensive beryl-rich pegmatite fields are present on Yinnetharra and Bidgemia Stations about 175 km to the east-northeast of Gascoyne Junction (Fig. 3.3). Gem beryl including aquamarine, emerald, and heliodor has been located in at least three sites around Morrissey Hill, Camel Hill, and Thirty One River, 12 km north, 21 km east-northeast, and 21 km northwest of Yinnetharra Homestead, respectively (Figs 3.10 and 3.11).

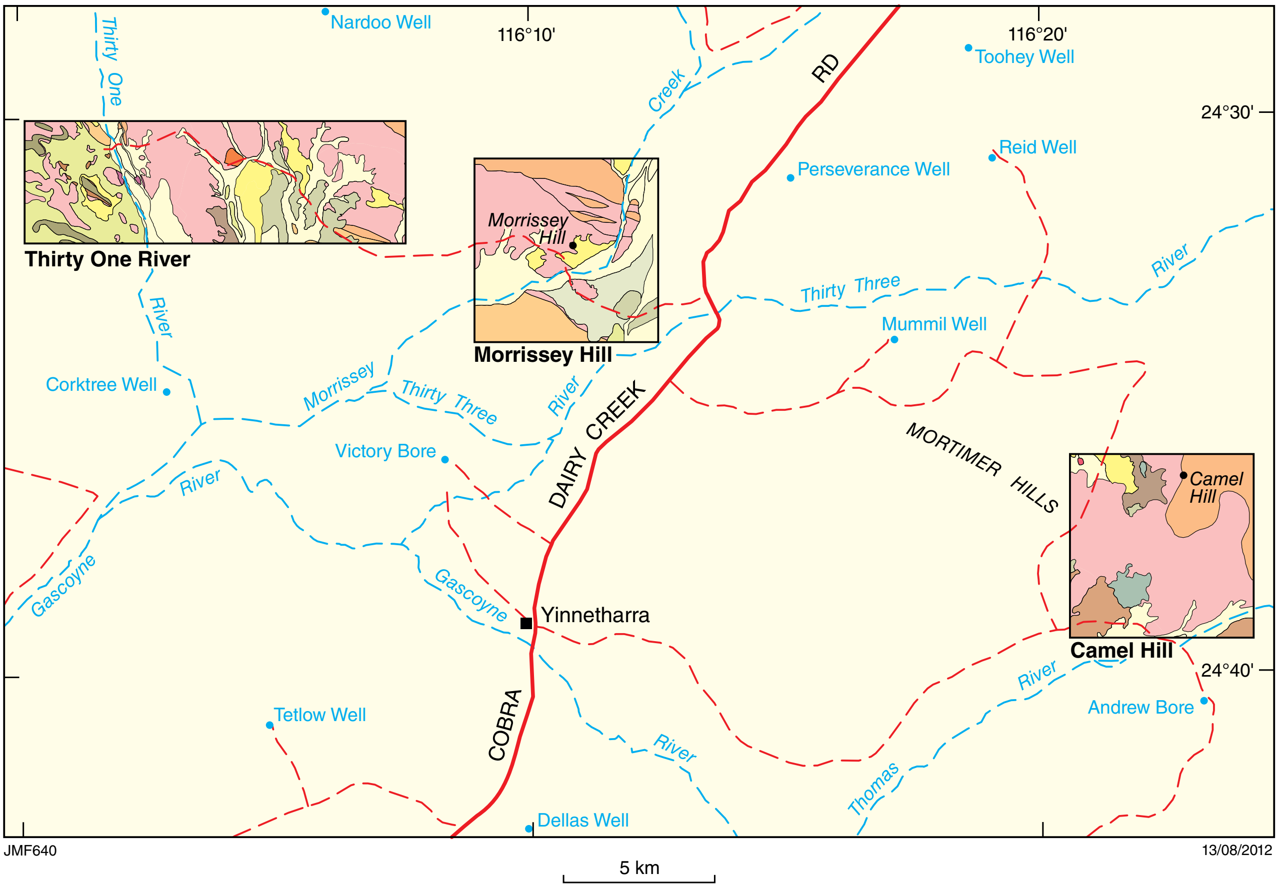

Figure 3.10. Locations of gem beryl mining areas at Yinnetharra, Gascoyne Junction region; legend as in Figure 3.11

These pegmatites were mined on a small scale for beryl and columbite and they were also favoured as a source of gemstones such as amethyst and dravite. The pegmatites are of the beryl–columbite class and most form within muscovite schists and migmatites of the Leake Spring Metamorphics together with adjoining, foliated to schistose metamonzogranite units of the Durlacher Supersuite. Jacobson et al. (2007) record several specific pegmatites containing aquamarine, although not necessarily of facetable size or clarity:

- In the Thirty One River pegmatite field, Williamsons beryl mine (possibly the same as the Lake Moore pegmatite) forms a conspicuous conical hill on the west bank of the Thirty One River (Fig. 3.11a). Among the reported minerals recovered, which include manganocolumbite, uranpyrochlore, uranmicrolite, and chrysoberyl, were aquamarine and heliodor (yellow beryl). A 10.2 ct light-coloured aquamarine reportedly originates from the Williamsons beryl mine (Fig. 3.12).
- In the Morrissey Hill pegmatite field, the Roe and Hassell pegmatite workings are on the east bank of Morrissey Creek, approximately 2 km southeast of Mica Well (Fig. 3.11b). An aquamarine fragment from here was reported to be of excellent colour.
- The prospective April pegmatite is probably the most northerly pegmatite found in the Morrissey Hill pegmatite field, about 9 km north of Morrissey Hill.
- Kenyon (1993) recorded the common occurrence of blue-green aquamarine in the Camel Hill pegmatite field approximately 1.5 km southwest of Camel Hill (Mount Camel) (Fig. 3.11c). He commented that the distribution of aquamarine in the pegmatites was erratic although any mine in the region could be expected to produce some. Before this time, it appears aquamarine was included with the rest of the beryl for sale. This site may be the same occurrence mentioned in Geological Survey of Western Australia (1994), which records that during production of beryl at Yinnetharra in 1943 and 1944, a small amount of clear pale to deeper blue-green aquamarine was obtained from broken beryl ore although 'water-clear' and colourless stones were more plentiful than the pale bluish-green.

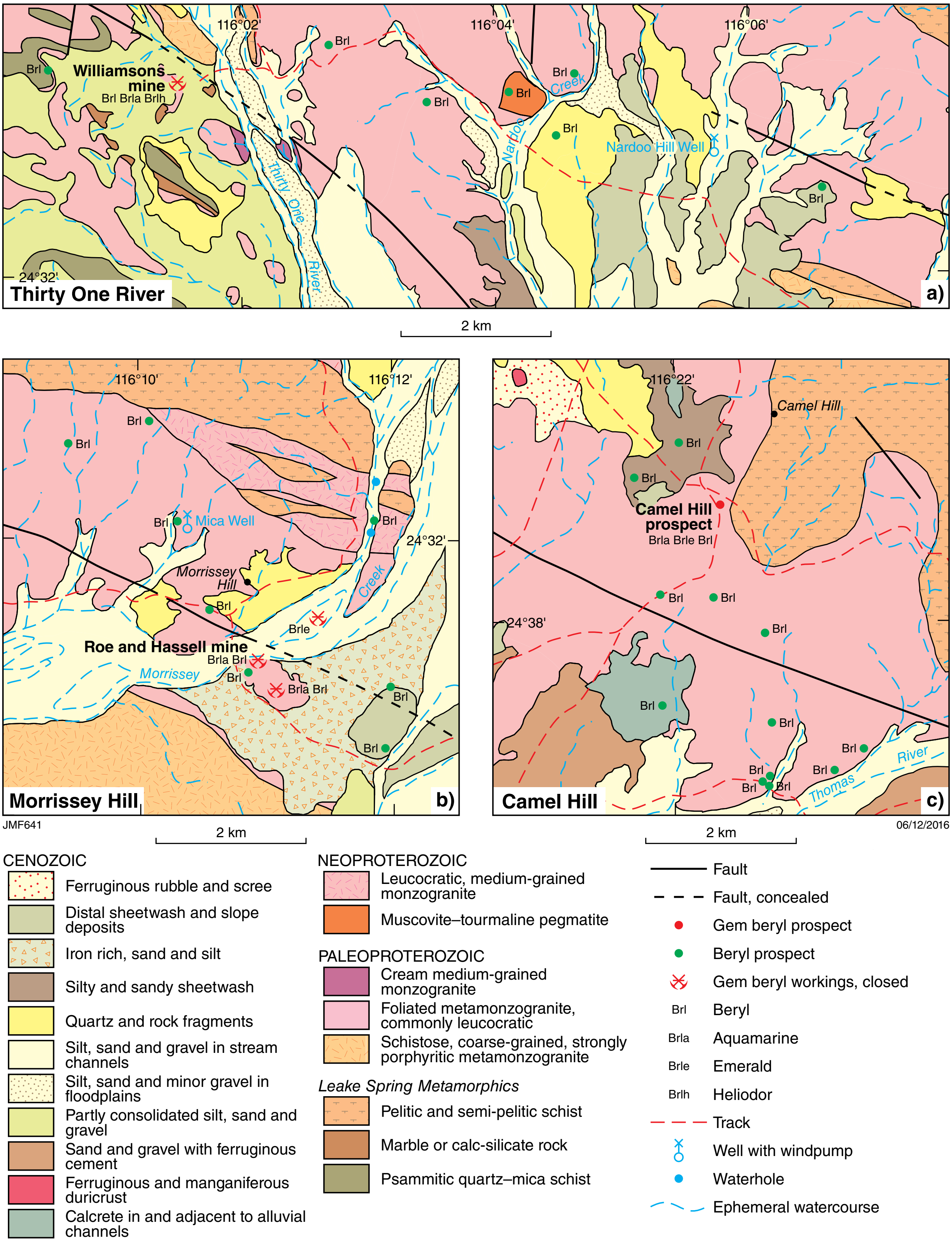

Figure 3.11. Geology of gem beryl mining areas at Yinnetharra (modified after Sheppard et al., 2008)

Figure 3.12. **Gem beryl stones from Williamson's beryl mine in the Yinnetharra area. Large, uncut, pale green aquamarine (left); smaller, uncut, yellow heliodor (right); and a 10.2 ct, pale green, emerald-cut aquamarine (below) (courtesy Gemrock Enterprises)**

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Giles pegmatites at Spargoville (*Yilmia, 3135*)

The Giles columbite–beryl pegmatites are about 3 km southeast of Spargoville and 45 km southeast of Coolgardie. They are about 600 m west of the Norseman–Coolgardie Road and are accessed by dirt roads (Fig. 3.3).

In 1931, prospector AS Giles commenced mining eluvial ferrocolumbite fragments from a pegmatite and by 1951 had shipped more than one tonne of columbite to London. Mining continued and nearly 4 t of columbite was shipped between 1952 and 1955. Beryl was also recovered during this period. In 1983, the Giles and associated pegmatites were pegged for their ferrocolumbite crystals and have produced what are probably the best columbite crystals in Australia.

The main Giles pegmatite appears to have been intruded mostly concordantly into the local Archean greenstones. It is at least 330 m long and up to 45 m wide. All pegmatites are zoned, although the zonation is asymmetric with segmented quartz cores located irregularly within the pegmatite (Jacobson et al., 2007).

In this area, white to pale green beryl may form single crystals greater than 15 cm in diameter and some greenish to dark green euhedral crystals up to 10 cm in diameter have been discovered (Fig. 3.1). Glassy, green zones are present within the interiors of some of these crystals, which might be facetable. It has been reported that facetable blue to blue-green beryl can be found on dumps (Reeve, 1973). The Australian Museum in Sydney houses a 1.49 ct round brilliant cut aquamarine from Spargoville (Fig. 3.2b).

Yilgarn Craton — Murchison Domain

Cue region

Poona (*Noondie, 2343*)

There are reports of small aquamarine crystals have been found in the old dumps at Poona about 55 km northwest of Cue (Fig. 3.4) although there are no records of precise locations.

Morganite

Morganite is a transparent or translucent pink gem variety of beryl. The colour is attributed to manganese (Mn^{2+} and Mn^{3+}). Pink beryl tends to form as tabular habit crystals and commonly contains elevated amounts of alkali metal elements, especially cesium.

The gem is named after JP Morgan, a prominent American banker and mineral collector of the early 20th century.

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry (*Yilmia, 3135*)

The Londonderry pegmatite is 19 km south-southwest of Coolgardie. Access from Coolgardie is via the Nepean Road and then west along a prominent dirt road (Fig. 3.3).

The pegmatite was discovered in 1909 and intermittently mined for microcline, petalite, columbite–tantalite, and beryl until the last production in 1987. The Londonderry pegmatite is about 1000 m long and 200–280 m wide. It is an ovoid-shaped body tapering off to the south. Eight asymmetrical zones have been recognized in the pegmatite, with each zone defined by a specific set of mineral assemblages.

This pegmatite is known as a popular fossicking site for its lepidolite and gem minerals including petalite, feldspar, and a variety of coloured beryls including pink morganite. A morganite specimen weighing about 2 kg from Londonderry was reported as being part of a private collection. A detailed description of the Londonderry pegmatites is given in Fetherston et al. (1999).

Grosmont (*Yilmia, 3135*)

The Grosmont pegmatite is about 15 km southwest of Coolgardie and 7 km north-northwest of Londonderry.

Access from Coolgardie is southwestward along the Victoria Rocks Road for nearly 15 km and then north along a dirt road (Fig. 3.3).

The pegmatite, discovered in 1896, is narrow, averaging 3–4 m in width. It is concordantly intruded into fine- to medium-grained amphibolites and strikes north-northeast, dipping steeply to the west.

The Grosmont pegmatite has been a popular collecting locality for lustrous blue topaz masses and relatively large plates of lepidolite crystals. Morganite and colourless beryl are recorded with topaz.

Yilgarn Craton — Murchison Domain

Cue region

Poona (Noondie, 2343)

There are reports of small morganite specimens found in the old dumps at Poona in the area shown in Figure 3.4 although there are no details of exact locations. The Australian Museum has a 3.5 ct cushion-cut morganite from Poona (Fig. 3.2d).

Northampton Inlier

Northampton region

Bowes River (Northampton, 1841)

A few samples of morganite have been reported from a conglomerate at Bowes River. The exact location of this site is unknown and is recorded as 'position doubtful' (Fig. 3.3).

Heliodor and goshenite

Heliodor is a variety first named in 1910 for the golden-yellow beryl found in granitic pegmatites near Klein Spitzkoppe in Namibia. The original finds were stated to be weakly radioactive and other yellow beryls have also been reported to contain trace amounts of uranium. It appears that nearby sources of uraninite and other minerals such as columbite–tantalite and zircon, which commonly contain small amounts of radioactive elements, can induce a yellow colour by ionizing the iron in beryl and changing Fe^{2+} to Fe^{3+}. This causes a colour change from blue to green to yellow.

Goshenite was initially named after a locality for alkali-rich colourless beryl in Massachusetts, US, although the term is now applied to any variety of beryl that has a light colour.

Small amounts of heliodor and goshenite have been reported in Western Australia although there are few records concerning any specific production or quality.

Gascoyne Province

Gascoyne Junction region

Yinnetharra area (Yinnetharra, 2148)

In addition to the aquamarine, the Williamsons beryl mine in the Thirty One River pegmatite field was reported to contain the golden-yellow beryl, heliodor (Fig. 3.10).

Yilgarn Craton — South West Terrane

Donnybrook region

Katterup area (Donnybrook, 2030)

The Katterup pegmatite is approximately 10 km east-northeast of Donnybrook. It appears the site may be reached from the Donnybrook – Boyup Brook Road at Katterup via a track leading 1.9 km south, and then by walking 600 m west (Fig. 3.3). The location is on freehold land and requires permission for access. It is reported that a portion of a crystal of about 13 mm in diameter of transparent yellow beryl (heliodor) was found here.

Mullalyup (Donnybrook, 2030)

Oliver's pegmatite, one of the Mullalyup group of pegmatites, is approximately 22 km south-southeast of Donnybrook and 800 m west of the former Mullalyup railway station (Fig. 3.3). In this vicinity a narrow pegmatite, 1.3 m in width, is intruded into Archean quartz–feldspar–biotite gneiss. One visually attractive, terminated yellow beryl (heliodor) 2.5 cm long and 1 cm in diameter is reported from this location (Fig. 3.2c).

Other beryl occurrences

King Leopold Orogen

Derby region

Mondooma Creek (Tarraji, 3764)

The Mondooma Creek mica–beryl pegmatite at Stewarts East prospect is directly west of the Kimberley Downs to Mondooma Road, approximately 6.5 km south of Mondooma and 95 km northeast of Derby (Fig. 3.3). Initial access is via the Gibb River Road from Derby.

The pegmatite was concordantly emplaced in northwest-trending amphibolite and quartz–mica schists of the Paleoproterozoic Hooper Complex. The pegmatite contains two zones: a quartz zone with accessory muscovite and a quartz–microcline zone with accessory muscovite, schorl, and beryl. Beryl crystals up to 15 cm in diameter were noted, some of which were semitransparent, and it was suggested that better crystals from this deposit might yield gem-quality stones (Harms, 1959, in Jacobson et al., 2007).

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry (Yilmia, 3135)

The Londonderry pegmatite, 19 km south-southwest of Coolgardie, already discussed under morganite, is also reported to contain dark green, yellow, and colourless beryls. These beryls are commonly massive and were found mostly near the western edge of the main quarry. Also, a beryl mass of about 2 t was reported from the northeastern corner of the same quarry (Fetherston et al., 1999; Fig. 3.3).

Grosmont (Yilmia, 3135)

The Grosmont pegmatite (Fig. 3.3) described above is also reported to carry colourless beryl and pink morganite.

Yilgarn Craton — Murchison Domain

Paynes Find area

Goodingnow pegmatites (Maranalgo, 2439)

The Goodingnow pegmatite prospects are in the Mount Edon pegmatite field in the Paynes Find area. Spaced about 400 m apart, the two pegmatite pits (northern and southern) are about 400 m northeast of Mount Edon on former prospecting licence P59/7104 (Fig. 3.3).

These simple K-feldspar–beryl pegmatites were mined between 1975 and the late 1980s for beryl and high-grade microcline–perthite feldspar. It is reported that up to 1987, the Goodingnow pegmatites produced 5.85 t of beryl, mostly from the northern pit, and included a beryl crystal cluster of at least 5 t. The southern pit also yielded smaller quantities of well-crystallized, yellow and green, euhedral beryl masses within quartz (Jacobson et al., 2007).

References

Darragh, PJ and Hill, RET 1983, The mineralogy and genesis of an emerald occurrence at Warda Warra near Yalgoo, Western Australia, Australia: CSIRO Division of Mineralogy, Research Review, p. 134–136.

Ellis, HA 1962, Report on a pegmatite locality 6 miles SE of Roebourne: Geological Survey of Western Australia, Annual Report for 1961, p. 6–7.

Ferguson, KM and Ruddock, I 2001, Mineral occurrences and exploration potential of the East Pilbara: Geological Survey of Western Australia, Report 81, 1140p.

Fetherston, JM, Abeysinghe, PB, Jiang, S-Q and Wang, G-W 1999, Six industrial minerals of significance in Western Australia—bentonite, feldspar, kaolin, micaceous iron oxide, and tourmaline: Geological Survey of Western Australia, Report 67, p. 15–25.

Garstone, JD 1981, The geological setting and origin of emerald deposits at Menzies Western Australia: Journal of the Royal Society of Western Australia, v. 64, part 2, p. 53–64.

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, Perth, Western Australia, 52p.

Grundmann, G and Morteani, G 1998, Alexandrite, emerald, ruby, sapphire and topaz in a biotite–phlogopite fels from Poona, Cue District, Western Australia: Australian Gemmologist, v. 20, no. 4, p. 159–167.

Herlihy, JH 1987, Inspection of the Curlew emerald mine for Elders Resources Ltd, progress report for ML45/517: Geological Survey of Western Australia, Statutory mineral exploration report, A22468 (unpublished).

Hickman, AH 1983, Geology of the Pilbara Block and its environs: Geological Survey of Western Australia Bulletin 127, 283p.

Hickman, AH 2002, Geology of the Roebourne 1:100 000 sheet: Geological Survey of Western Australia Explanatory Notes, p. 31.

Hunter, WM 1998, Kalgoorlie, WA Sheet 3136: Geological Survey of Western Australia, 1:100 000 Geological Series.

Kenyon, A 1993, Annual Report 10 September 1992 to 9 September 1993, E09/534, Camel Hill: Geological Survey of Western Australia, Statutory mineral exploration report, A41594 (unpublished).

Jacobson, MI, Calderwood, MA and Grguric, BA 2007, Guidebook to the pegmatites of Western Australia: Hesperian Press, Perth, Western Australia, 356p.

Laurie, J 1982, Annual report on mineral claim 45/9076 for Warren and Strang (Aust.) Ltd: Geological Survey of Western Australia, Statutory mineral exploration report, A37066 (unpublished).

McGee, WA 1986, Report on the Curlew emerald mine, Pilbara region, Western Australia for Elders Resources Limited: Geological Survey of Western Australia, Statutory mineral exploration report, A19268 (unpublished).

Mindat.org 2015, Aga Khan Mine, Poona, Cue Shire, Western Australia, Australia, viewed 28 October 2015, <www.mindat.org/loc-18834.html>.

Mumme, IA 1982, The emerald, its occurrence, discrimination and valuation: Mumme Publications, Port Hacking, New South Wales, 135p.

Palmer, A 1990, Poona WA, and the seekers of its emeralds: Lap Industries, Perth, Western Australia, 97p.

Reeve, RJ 1973, Some gem-bearing pegmatites near Coolgardie, Western Australia: Australian Gemmologist, v. 11:12, p. 21–22.

Schwarz, D, Giuliani, G, Grundmann, G and Glas, M 2002, The origin of emerald, in Emeralds of the world: ExtraLapis v. 2, Lapis International LLC, East Hampton, NY.

Sheppard, S, Johnson, SP, Groenewald, PB and Farrell, TR 2008, Yinnetharra, WA Sheet 2148: Geological Survey of Western Australia, 1:100 000 Geological Series.

Simpson, ES 1948, Minerals of Western Australia, volume 1: Government Printer, Perth, Western Australia, 466p.

Sinkankas, J and Read, PG 1986, Beryl: Butterworths Gem Books, London, 225p.

Sullivan, M 2000, Bullabulling emerald mine, M15/467: Geological Survey of Western Australia, Statutory mineral exploration report, A59691.

Van Kranendonk, MJ 2003, Geology of the Tambourah 1:100 000 sheet: Geological Survey of Western Australia Explanatory Notes, 57p.

Watkins, KP, Tyler, IM and Hickman, AH 1987, Cue, Western Australia: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 52p.

Wyche, S 1998, Kalgoorlie, Western Australia: Kalgoorlie, Western Australia: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 31p.

Wyche, S and Swager, CP 1996, Riverina, WA Sheet 3038: Geological Survey of Western Australia, 1:100 000 Geological Series.

Chapter 4

Tourmaline group

Tourmaline properties

Tourmalines are complex aluminium borosilicates with a constant chemical composition in their general structure although variable in regard to replacements by substitutional elements. Accordingly, the general aluminium borosilicate composition may be substituted by magnesium, iron, and alkali metals (Ca, Na, K, and Li). Several isomorphous series occur within the group, and minor elements include transition elements such as Cu, Mn, Cr, V, and Fe, which are responsible for colour variations. Because of the widely variable chemical composition, the tourmaline group has the largest range of colours of any gem mineral.

Although a few colour varieties of tourmaline are known by commercial names, such as rubellite, indicolite, and verdelite for red, blue, and green types, respectively, tourmaline is more correctly and commonly referred to with a simple colour prefix, such as 'yellow tourmaline'. Positive identification of coloured tourmaline varieties can only be determined from chemical analyses because tourmalines of similar colour from different sources may belong to different end member series.

Gem varieties of tourmaline found in Western Australia include the following series:

- Elbaite $Na(Al,Li)_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$ is the most common variety of transparent gem tourmaline and is associated with granitic pegmatites. Alkali-rich elbaites commonly contain Na and Li, may be colourless 'achroite', red, green, or blue, and are commonly colour zoned both parallel to the length of crystals and concentrically. Rubellite, a relatively rare gemstone member of the elbaite group noted for its pink to intense red colour, has been mined in the Southern Cross region of the State.
- Schorl (or schorlite) $NaFe^{+2}_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$ is a ferrous iron-rich tourmaline, commonly black, dark blue, or bluish-green. Schorl forms commonly in the wall zones and contact margins of granitic pegmatites where sufficient iron has been sourced from host rocks. Schorl has been collected as specimen crystals in Western Australia.

Tourmaline group
Complex aluminium borosilicates

- Dravite $NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$ is magnesium rich and commonly isomorphous with schorl where ferrous iron (Fe^{+2}) substitutes for Mg. Dravite minerals are commonly colourless, yellow-brown, brown, or brownish-black. Dravite has been produced in Western Australia as specimen-grade euhedral crystals, and as a gemrock material used for carving and ornamental stones.

Crystals of tourmaline are commonly recognized by their stout columnar habit commonly with striated and rounded prismatic faces. Prisms are mainly triangular in section and terminated by a combination of pyramids (rhombohedra) or pedions. Terminations may also appear convex and rounded. These forms are common in tourmaline sourced from granitic pegmatites. Dravite crystals, notably from the Yinnetharra (formerly 'Yinnietharra') area in the Gascoyne region, are almost equidimensional with the development of short prisms resulting in crystals with a squat or equant habit.

Tourmaline minerals are classified as hemimorphic–rhombohedral in the trigonal crystal system and have crystallographic polar asymmetry resulting from the development of different faces and forms on opposite crystal terminations. Polarity is also demonstrated by the significant pyroelectric and piezoelectric properties caused by heat and pressure, respectively, which induce electrical charges in crystals. Electrical polarity is likely a contributing factor in the formation of different colour bands that develop across tourmaline prisms as ions responsible for colour variations are attracted by different electrical charges to one or other termination of a growing crystal.

Concentric colour zoning is also common in tourmaline. A variety known as 'watermelon' displays a pink core with green outer zones or many concentric zones displaying repeated colours. Some crystals, termed 'parti-coloured', display colour zoning seen as horizontal colour bands across the prismatic zone. Tourmaline crystals originating from Spargoville in the Kambalda region display this duality of colours (Fig. 4.1).

Although the principal hosts of all tourmaline gemstones are pegmatite and quartz veins directly or indirectly related to granitic intrusions, tourmaline also forms as an accessory mineral in many other rocks including greenstones, mafic rocks, schists, and some sedimentary rocks. Tourmaline may also form within pre-existing rocks following boron metasomatism, an example of which is given in Chapter 5 on tourmalite and warrierite, a massive variety of tourmaline from Warriedar Station in the Lake Mongers region.

Transparent forms of gem-quality tourmaline crystals are commonly cut and faceted in elongated rectangular step-cuts that maximize the weight recovered from prismatic crystals. Colour-zoned varieties are commonly cut to emphasize colour banding, especially in high-quality material. Translucent or heavily included forms may be carved or manufactured into beads. The Warriedar tourmalite, a massive, black, fine-grained variety of tourmaline, has been used as a gemrock and the material carved and polished.

Physical properties of tourmaline

Crystal system	Trigonal
Habit	Prismatic
Surface features	Prism faces vertically striated and may appear rounded to barrel-shaped
Lustre	Vitreous
Hardness	7 – 7.5
Fracture	Subconchoidal
Fluorescence	Inert in ultraviolet (UV) light

Properties of some Western Australian tourmaline

	Spargoville elbaite	*Forrestania rubellite*
Colour	Green-blue	Purplish-red
Diochroism	Green-blue, dark blue, blue-black	
Colour zoning	Along prisms — strong blue; at crystal core — light blue	
Diaphaneity	Transparent	Transparent
Refractive index	1.622 – 1.642	1.62 – 1.64
Birefringence	0.020	0.020
Pleochroism	Light bluish-green to dark brownish-green	Light pinkish-orange to dark purplish-pink
Specific gravity	3.07	3.09
Absorption spectrum	Band in far red, line at 498 nm; violet adsorption	Narrow band in far red, lines and bands at 454, 462, 482–518, and 530 nm; violet adsorption
Inclusions	Growth tubules	Growth tubules and trichites

Source: Darby (1991)

Although there are hundreds of recorded occurrences of tourmaline from Western Australia only a few sites have produced gem-quality material. Over many years, tourmaline has been mined in small quantities in the State. In the 1990s there was renewed interest at two prospects: at Spargoville in the Coolgardie region where blue-green elbaite forms, and a deposit of pink to intense red rubellite south of Southern Cross. Locations for the main tourmaline group mineral deposits in Western Australia are given in Figure 4.2 and more accurate locations are given in Appendix 1.

Tourmaline in Western Australia

Yilgarn Craton — Eastern Goldfields Superterrane

Kambalda region — Spargoville

Giles elbaite pegmatite *(Yilmia, 3135)*

The Giles elbaite pegmatite, 6 km south of Spargoville in the Kambalda region, is the most important source of tourmaline in the local area (Fig. 4.2). In 1938, green, gem-quality tourmaline was discovered at this site. The discovery is recorded as loose float material containing many terminated, euhedral tourmaline crystals up to 25 mm long and 10 mm diameter. From this initial find, other specimen crystals around 30–40 mm long were found and from which many faceted gems were cut. Today, these gems form part of private collections (Henry, 2004). Pink tourmaline was also discovered in a lithium-rich pegmatite nearby. Crystals of unknown quality from this site measured up to 75 mm long × 12 mm diameter and many were concentrically zoned in pink and blue with up to 11 colour zones present.

Other excavations in the local area produced blue and pink, opaque tourmaline specimens. One specimen, described as having a hollow central core, provides evidence that the tourmaline possibly crystallized as secondary overgrowths (Darby, 1991). Also, the euhedral form of many of the tourmaline crystals indicates they may have originated from clay-filled vugs or pockets.

In the 1960s, the Giles elbaite pegmatite was found again and pegged. It was worked to about 1966 with pink, green, blue, and watermelon elbaite taken from an area known as the western pit. The steeply dipping pegmatite trends in an east–west direction over a length of at least 200 m with a thickness of 1–2 m and intrudes Archean greenstones comprising metasedimentary rocks, komatiite, and basalt. Outcrop is mostly cleavelandite and fine-grained, purple lepidolite. The pegmatite is zoned asymmetrically with aplitic wallrock on one side, and quartz–microcline–albite–quartz on the other. The central core contains cleavelandite, quartz, elbaite, fine-grained lepidolite, minor beryl, and schorl.

Figure 4.1. **Green, blue, and pink watermelon tourmaline from Spargoville in the Kambalda region. The smaller crystal measures 6 mm in diameter (courtesy Vernan Potter)**

After 1966, several costeans were cut across the Giles and other local pegmatites and the old mining area has since found favour with fossickers and lapidary associations. More detailed information on the Giles pegmatites is given in Jacobson et al. (2007).

North Moriarty elbaite pegmatite (*Yilmia, 3135*)

Approximately 150 m north of the Giles elbaite pegmatite is the North Moriarty elbaite and lithium-bearing pegmatite (Fig. 4.2). It is reported that this pegmatite was prospected from pits and excavated during the 1970s by the owners of the Giles elbaite pegmatite. The Moriarty pegmatite also appears to be a vertically dipping dyke of about 1 m thickness. The excavated dyke is contained within the weathered zone and pegmatite fragments are coated with silica crusts. The waste rock contains opaque green, blue, and pink elbaite (Jacobson et al., 2007).

Dalglish prospect (*Yilmia, 3135*)

Another elbaite tourmaline prospect in the same area that has produced green and blue gem-quality elbaite is the Dalglish prospect, about 6 km south-southwest of Spargoville on prospecting licence P15/4783 (Fig. 4.2).

The prospect consists of a shallow pit about 1.6 m deep and up to 12 m in diameter (Fig. 4.3). At this site, tourmaline is found as prismatic crystals with rounded faces, striated prismatically with rare crystal terminations. Many specimens have a transparent core covered with a dark skin. Some specimens are bi-coloured green and blue when viewed perpendicular to the principal axis, and concentrically zoned in shades of blue. Colours in the bi-coloured gems tend to merge gradually. In some specimens, a ‘pin fire’ appearance has been observed. This effect is an iridescent response caused by reflections from numerous internal cracks (Payette and Klemm, 2011).

Chemical analysis of five specimens indicates that tourmalines from this site are predominantly elbaite (60–73%), with the subordinate bluish-black tourmaline, foitite (17–23%), and minor amounts of pink tourmaline, olenite (0–14%), and schorl (0–10%). Tourmaline crystals recovered from the pit vary in diameter from 1 mm to 55 mm, with the largest weighing 3120 ct (Fig. 4.4).

Yilgarn Craton — Southern Cross Domain

Mount Holland area

Forrestania rubellite pegmatite (*Holland, 2833*)

The Forrestania rubellite pegmatite deposit (also known as the Southern Cross rubellite deposit) is in the Mount Holland pegmatite field about 112 km south-southeast of the town of Southern Cross and 6 km east-southeast of Mount Holland (Fig. 4.2).

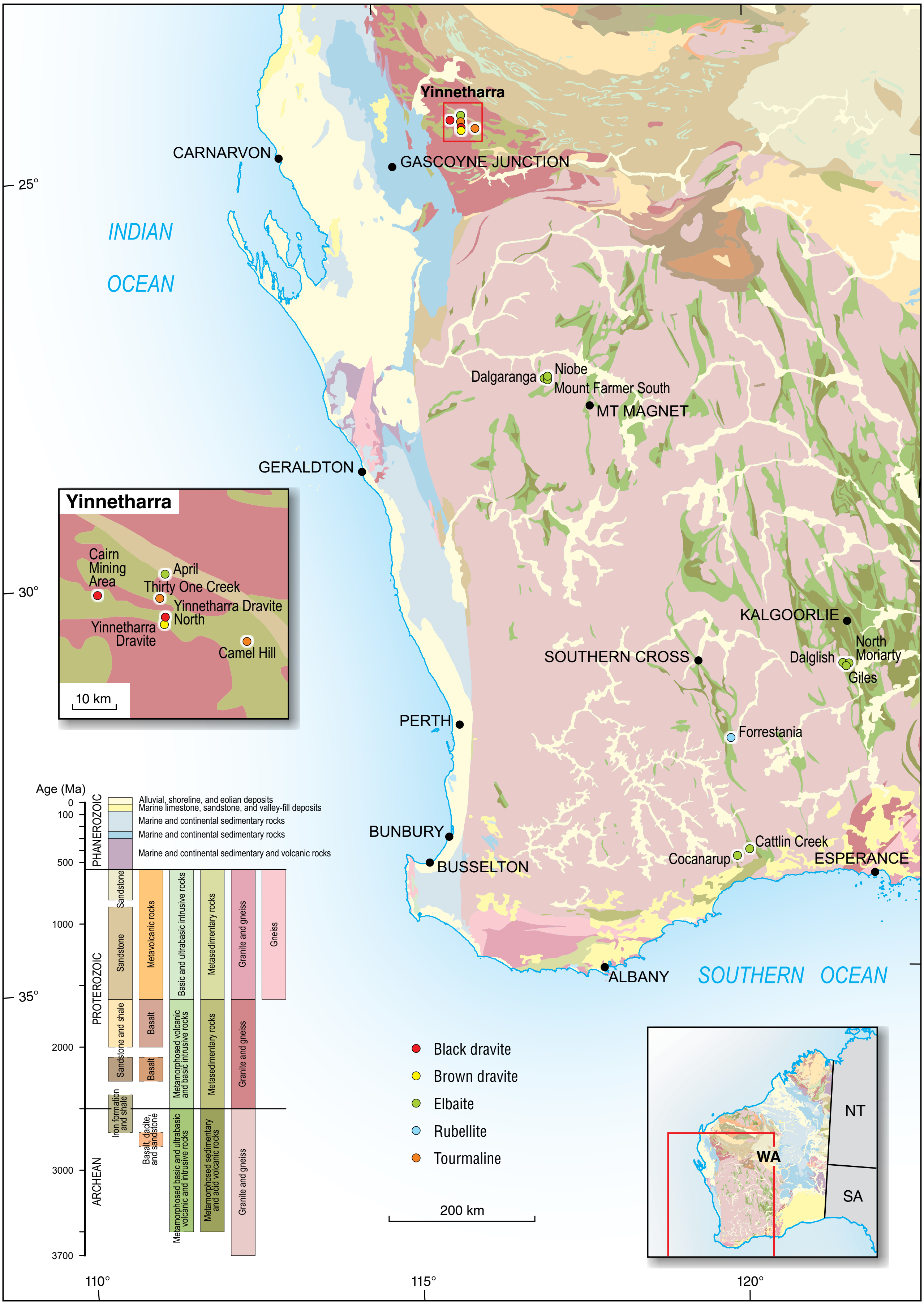

Figure 4.2. **Locations of tourmaline group minerals in Western Australia**

JMF718 31/08/2012

Figure 4.3. The Dalglish prospect in the Spargoville area has produced green and blue gem-quality elbaite. The exploration pit is approximately 12 m in diameter and 1.6 m deep (courtesy Francine Payette)

JMF719 31/08/2012

Figure 4.4. Faceted, 2.39 ct blue-green elbaite gemstone from the Dalglish prospect near Spargoville in the Kambalda region

The discovery of tourmaline on the periphery of a narrow belt of north–south trending Archean greenstones was made by Kim Robinson and Associates in the 1970s during an exploration drilling traverse for nickel when fragments of red tourmaline were found in drill cuttings. The pegmatite was mined in the 1980s for tantalum ore and rubellite. The pink to intense red rubellite was obtained from veins within the pegmatite.

By 1991, 1400 ct of gem-grade rubellite had been produced. At that time the largest sample of rubellite rough recovered was 120 ct, which when cut yielded six high-quality gems, with the largest faceted stone weighing 38 ct (Darby, 1991). Also, an uncut gem-quality crystal from this deposit, measuring 75 mm in length, is known to form part of a private collection.

Sometime in the late 1990s, pegmatite mining ceased and apart from visits by fossickers the mine remained in care and maintenance for some years. In 2001, mining lease M77/549 was reactivated by Messrs L Bell and F Rose. Since that time, pink tourmaline has been produced from a gem shaft on the northwest side of the east–west openpit.

The Forrestania pegmatite has been intensely weathered to a clay-like material. It appears likely the rubellite tourmaline crystallized within gem pockets in a central pegmatite zone, as specimens of euhedral quartz together with a terminated crystal of elbaite are among samples collected from this zone. Significant wall zones of the pegmatite contain microcline–quartz and quartz–lepidolite–cleavelandite.

Several other pegmatites have been recorded in this area. These have all produced some green, yellow, and multicoloured tourmaline stones although there is no record relating to their quality.

Ravensthorpe area

Cattlin Creek pegmatites (*Ravensthorpe, 2930*)

The Cattlin Creek pegmatites are about 2 km north of the town of Ravensthorpe in the far south of the State (Fig. 4.2). In this area a swarm of pegmatites has intruded a unit of the Archean Ravensthorpe greenstone belt, the Annabelle Volcanics, comprising metamorphosed ultramafic, mafic, and felsic volcanic rocks, and several granitic bodies ranging from quartz diorite to tonalite. The Cattlin Creek pegmatites comprise several large, flat-lying tabular sheets up to 800 m long by 400 m wide and at least 25 m thick, dipping gently to the east. The pegmatites intrude amphibolite rock on the western side of the Ravensthorpe greenstone belt close to the contact between the Annabelle Volcanics and the Ravensthorpe Quartz Diorite (Witt, 1992).

In 1900, spodumene, an ore of lithium sourced from pegmatites, was first recorded in the Ravensthorpe area. Until recently, the Cattlin Creek pegmatite produced only small quantities of microlite, stibiotantalite (ores of tantalum), and bismuth. Since the 1960s several feasibility studies for tantalum and lithium were carried out on this pegmatite-rich area although no mining resulted until 2009 when Galaxy Resources Ltd began construction of its new mine and lithium concentration plant. Known as the Mount Cattlin lithium mine, the operation commenced production of lithium ore early in 2011 with an expected output of 137 000 t/year of spodumene concentrate.

In past years, tourmaline in the form of pink, green, and watermelon elbaite and also black tourmaline were recorded from minor pit excavations in pegmatite where it was found associated with lepidolite, cleavelandite, quartz, spodumene, and other pegmatite minerals. The elbaite tourmalines are commonly zoned with pink cores and green margins. Minor colour variations occur although the general change in colours within crystals from core to margin is pink – darker pink – colourless – light green – dark green. Colour variations are explained by the relative distribution of Fe^{2+} and total manganese within crystals. Higher refractive indices and specific gravity are correlated with increased Fe^{2+} concentrations present in the rich green elbaite as shown in the Cattlin Creek elbaite properties box below. A more detailed description of the colour changes in the elbaite tourmaline at Cattlin Creek is given in Grubb and Donnelly (1969).

Significant physical properties of elbaite from Cattlin Creek

	Green elbaite (green margin)	*Pink elbaite (core zone)*
Refractive index	1.621 – 1.641	1.619 – 1.635
Birefringence	0.020	0.016
Specific gravity	3.04	2.99

Tourmaline specimens found on dumps associated with fine-grained masses of lepidolite–cleavelandite–quartz are recorded as exceeding 70 mm in length (Jacobson et al., 2007). Nevertheless, there is no record of any facet-quality tourmaline from the Cattlin Creek pegmatites.

Cocanarup pegmatite field (*Cocanarup, 2830*)

The Cocanarup pegmatite field is in hilly country, about 16 km west-southwest of Ravensthorpe (Fig. 4.2). Also discovered in 1900, the field is made up of four flat-lying sheets, each several metres in thickness, named Quarry, Horseshoe, Crescent, and Eastern, as well as several other smaller sheets. These pegmatites have intruded Archean rocks comprising amphibolite gneiss of the Annabelle Volcanics, and amphibolite and metadolerite greenstones. The pegmatites consist mainly of quartz, K-feldspar, albite, muscovite, and lepidolite together with zinnwaldite, tourmaline, beryl, columbite, and amblygonite (Witt, 1992).

Over the years, the pegmatites have yielded small amounts of economic minerals including 13.3 t of beryl during 1960–63, 0.75 t of columbite–tantalite, and lithium minerals amblygonite, lithiophilite, and lepidolite.

Blue, green, and pink elbaite have been observed in some pegmatite outcrops. Witt (1992) records locally abundant black, and less commonly blue, tourmaline in pockets up to 0.5 m in diameter of euhedrally terminated, equant prisms up to 3 × 10 cm in size together with quartz and occasional feldspar.

Yilgarn Craton — Murchison Domain

Dalgaranga area

Dalgaranga pegmatites (Dalgaranga, 2342)

The closed Dalgaranga pegmatite opencut is about 80 km northwest of Mount Magnet (Fig. 4.2). The mine, on mining lease M59/106, was operated as a tantalum mine by Tantalum Australia NL until 2002 when it was closed due to the near-exhaustion of the mineralized pegmatite.

In addition, there are two other former tantalum pegmatite opencuts east of the Dalgaranga mine: the Niobe prospect (formerly the Mount Farmer opencut mined in 1995) is 5 km east-northeast, and the Mount Farmer South pit is 5 km east-southeast, of the mine. These pegmatites form part of a northeasterly trending swarm of moderately dipping, zoned pegmatites intruding mainly Archean metasedimentary rocks. A more detailed description of the Dalgaranga and Niobe pegmatites is given in Fetherston (2004).

In past years, elbaite tourmaline was recorded from pegmatites from all of the Dalgaranga operations listed above although there are no records relating to the gem quality of the tourmaline.

Gascoyne Province

Yinnetharra area

Morrissey Hill, Cairn mining area, and Camel Hill (Yinnetharra, 2148; Mount Phillips, 2149)

Extensive dravite-rich pegmatite fields are present in the Yinnetharra area about 175 km to the east-northeast of Gascoyne Junction (Fig. 4.2). In this area, tourmaline is mainly found in the area around Morrissey Hill, and the Cairn mining area at Nardoo Creek about 12 km north and 19 km north-northwest, respectively, of Yinnetharra Homestead. In the Camel Hill area, approximately 20 km east-southeast of Morrissey Hill, a quartz–tourmaline prospect is about 2 km west-southwest of Camel Hill although no information about this site is available. Green elbaite has also been recorded from the April pegmatite, 9 km north of Morrissey Hill (Fig. 4.5).

In past years, the Yinnetharra area was notable for rare tantalum–niobium minerals and potential gem minerals such as beryl, emerald, and aquamarine (see Chapter 3 on the beryl group), chrysoberyl, corundum, variscite, amethyst, rose quartz, garnet, and diopside. Simpson (1951) states that brown dravite tourmaline crystals were first collected near Morrissey Hill in 1918, and numerous small to large prismatic crystals of black schorl (now demonstrated to be black dravite) were found in pegmatite veins on Morrissey Hill. The area was a small, intermittent producer of muscovite, tantalum–niobium minerals, beryl, and tourmaline mined between 1939 and 1971.

In the Yinnetharra area, host rocks for the majority of Gascoyne Province tourmaline-bearing pegmatites are schists of the Paleoproterozoic Leake Spring Metamorphics together with adjoining, foliated to schistose metamonzogranite units of the Durlacher Supersuite. Also, smaller numbers of tourmaline pegmatites, including the April pegmatite to the north and in a small area at Morrissey Hill, are hosted by a younger Neoproterozoic muscovite–tourmaline monzogranite.

Morrissey Hill pegmatites

In the Yinnetharra area, dravite is found enclosed in phlogopite–plagioclase greisens and schists varying from massive phlogopite to subparallel veins of calcic plagioclase feldspar up to 1 m in width intruded into tourmalinized augen gneisses (Fig. 4.5). Between January 1969 and January 1971, the Soklich Trading Company mined the tourmaline from the Yinnetharra dravite openpit on mineral claim MC09/82, about 4 km south of Morrissey Hill. Over the period, the mine produced about 12 t of dravite of which about 75% were high-quality, euhedral, doubly terminated crystals. These crystals were mostly sold to collectors on the international market fetching a total of $16 000 (value of the day). Dravite crystals ranged from less than 1 cm in length with numerous crystals reaching 15 cm. The maximum weight of a single crystal was recorded at around 11.5 kg (Bridge et al., 1977).

At the Yinnetharra dravite openpit, mining was carried out using front end loaders following limited blasting used to loosen the mica to ease crystal extraction. Dravite crystals were found to occur sporadically within pockets and production was unpredictable. Also, near-surface crystals were typically poor quality due to fracturing and the main excavation zones were located between 3 and 6 m below surface. Crystals are brown in colour, mostly appearing opaque although translucent in thin section; they have vitreous lustre with surfaces commonly indented by small booklets of mica. They form single and twinned crystals or may be grouped.

In all but the smallest crystals of dravite, plagioclase commonly occurs as poikilitic inclusions that are aligned as flattened laths subparallel to the principal axes of the dravite crystals. Other minerals occurring as inclusions are phlogopite, subhedral rutile, apatite, zircon, and fluorite. The surfaces of the brown dravite crystals have a vitreous lustre. They are commonly pockmarked by phlogopite and plagioclase, and in the upper levels of deposits are commonly encrusted by secondary opal and carbonates formed by weathering. At the Yinnetharra openpit, crystal habits of dravite are varied although many are almost equidimensional or equant, with short prismatic zones terminated by rhombohedra, superficially resembling the dodecahedral morphology of garnets, which initially

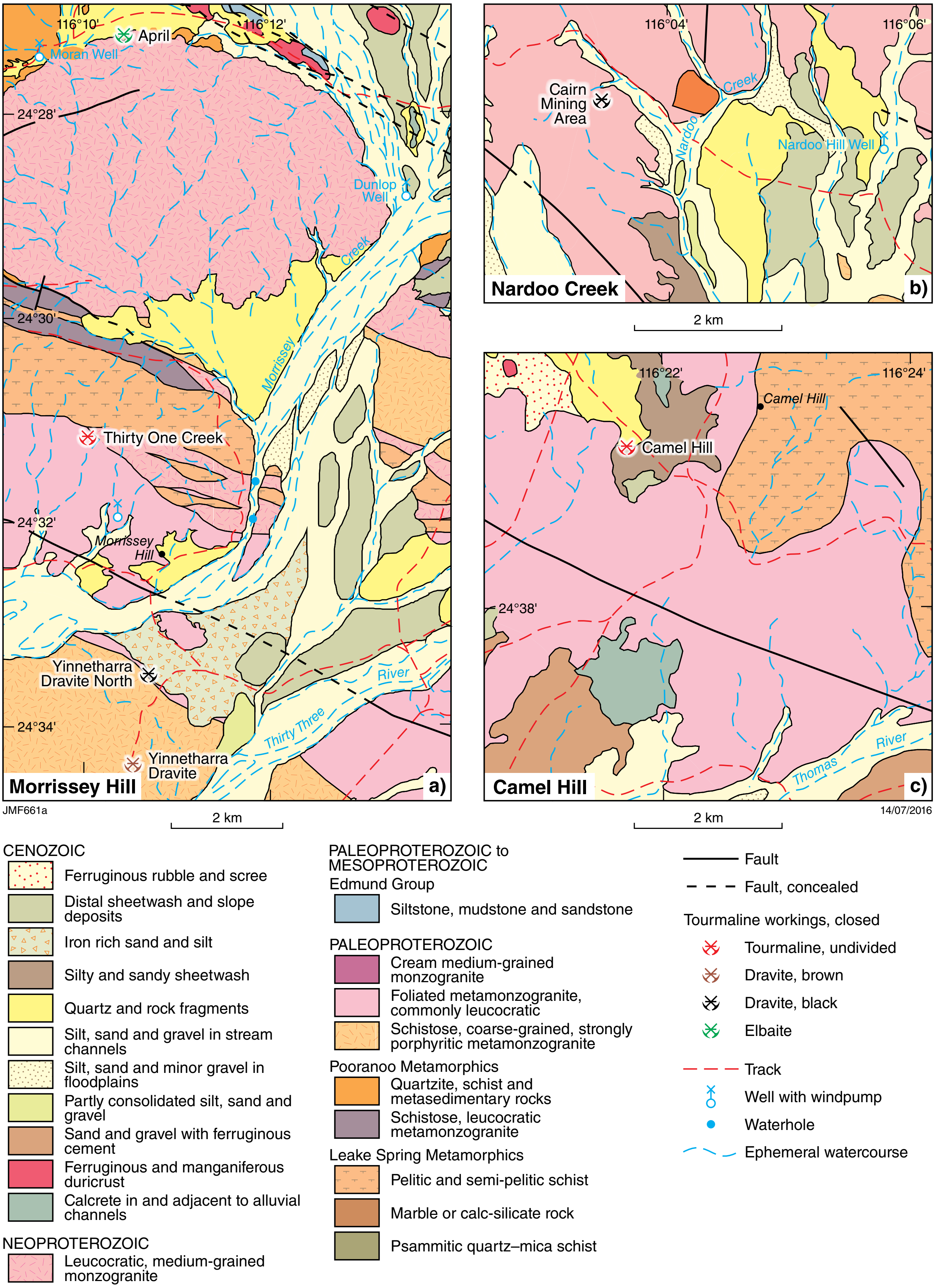

Figure 4.5. Geology of the gem tourmaline mining areas at Yinnetharra: a) Morrissey Hill; b) Nardoo Creek; c) Camel Hill (modified after Sheppard et al., 2008)

caused confusion among collectors. Crystal forms present include the hexagonal prism, trigonal prism, and rhombohedral terminations.

At the Yinnetharra North deposit, 1.5 km to the north of the Yinnetharra dravite openpit, schorl or black tourmaline was originally reported. In more recent years, it has been established that all tourmaline in this area is black dravite, with an MgO content of 9.85%. The Yinnetharra North deposit, on former mineral claim MC09/215, is in a black phlogopite schist containing large, euhedral black dravite rhombohedra, many with double terminations and internal zoning visible in thin section. Maximum crystal size is recorded as 60 mm in diameter and 23 cm in length (Fig. 4.6). Dravite production from this deposit was about 1.3 t (Bridge et al., 1977).

Although the area containing the Yinnetharra dravite deposits listed above was previously recognized as an excellent fossicking area by collectors, since early 2010 the area has been incorporated in mining lease M09/101 owned by Mr T Kapitany. The lease owner should now be contacted for permission to fossick.

Another tourmaline site, 2.5 km north-northwest of Morrissey Hill, is an old shallow pit known as Thirty One Creek (Fig. 4.5). The prospect is known for the presence of tourmaline, bismuth, and beryl although no other details are available.

Cairn mining area

The Cairn mining area at Nardoo Creek is about 13 km west-northwest of Morrissey Hill (Fig. 4.5). In this area, Proterozoic monzogranites have been intruded by muscovite-bearing pegmatites containing black tourmaline (probably black dravite), beryl, and garnet. These pegmatites were mined up until the 1970s from several closely spaced pits. The main tourmaline pit appears to have been the Cairn 2 mine. Total recorded tourmaline production from the Cairn mining area was 827 kg (Williams et al., 1983).

April pegmatite

The lithium-bearing April pegmatite is 9 km north of Morrissey Hill (Fig. 4.5). This pegmatite is a recorded site for elbaite tourmaline, lepidolite, and beryl. Crystals of green tourmaline were found on the surface close to the pegmatite dyke, although these were too fractured to be classified as gem quality. A set of specimens held by the Western Australian Museum shows the opaque green elbaite crystals, up to 30 mm long × 10 mm in diameter, enclosed in albite and associated with milky quartz and fine-grained lepidolite (sample number MDC4968).

JMF959 30/03/2016

Figure 4.6. Euhedral black dravite crystals from Yinnetharra. Set in a black phlogopite schist, these rhombohedral crystals, many doubly terminated, average 14 cm long x 4 cm in diameter (courtesy Mark Creasey and David Vaughan)

References

Bridge, PJ, Daniels, JL and Pryce, MW 1977, The dravite crystal bonanza of Yinnietharra, Western Australia: The Mineralogical Record, March–April, p. 109–110.

Darby, BJ 1991, Tourmalines from Western Australia: The Australian Gemmologist, May, v. 17, no. 10, p. 405–408.

Fetherston, JM 2004, Tantalum in Western Australia: Geological Survey of Western Australia, Mineral Resources Bulletin 22, p. 125–130.

Grubb, PLC and Donnelly, TH 1969, Colour changes in elbaite tourmaline from Ravensthorpe, Western Australia: The Australian Gemmologist, November, p. 15–18.

Henry, D 2004, What's new in Australia: Australian Journal of Mineralogy, v. 10, no. 1, p. 35.

Jacobson, MI, Calderwood, MA and Grguric, BA 2007, Guidebook to the pegmatites of Western Australia: Hesperian Press, Perth, Western Australia, p. 283–297.

Payette, F and Klemm, L 2011, Gem-quality green and blue tourmaline from a Coolgardie pegmatite, Western Australia: The Australian Gemmologist, v. 24, no. 7, p. 171–175.

Sheppard, S, Johnson, SP, Groenewald, PB and Farrell, TR 2008, Yinnetharra, WA Sheet 2148: Geological Survey of Western Australia, 1:100 000 Geological Series.

Simpson, ES 1951, Minerals of Western Australia, volume 2: Government Printer, Perth, Western Australia, p. 187–203.

Williams, SJ, Williams, IR, Chin, RJ, Muhling, PC and Hocking, RM 1983, Mount Phillips, WA, Sheet SG/50-2: Geological Survey of Western Australia, Explanatory Notes, p. 23–24.

Witt, WK 1992, Heavy-mineral characteristics, structural settings, and parental granites of pegmatites in Archaean rocks of the eastern Yilgarn Craton: Geological Survey of Western Australia, Record 1992/10, p. 21–23.

Chapter 5

Tourmalite and warrierite

Tourmalite

Tourmalite is a tourmaline-rich rock defined as 'a rock composed almost entirely of tourmaline and quartz, with a mottled appearance and a texture ranging from dense to granular to schistose. It is of secondary origin, resulting from metasomatic and pneumatolytic effects along the margins of igneous intrusions' (Neuendorf et al., 2005).

Warrierite

Yilgarn Craton — Murchison Domain

Lake Mongers tourmalite island

Warriedar tourmalite *(Ninghan, 2339)*

The Warriedar tourmalite deposit is on an island in the centre of Lake Mongers, about 45 km west-northwest of Paynes Find and 7 km east-northeast of the abandoned Warriedar Homestead (Fig. 5.1). The island is approximately 300 m in diameter and rises to a height of 30 m above the surface of the gypsum salt lake.

Although the presence of tourmaline in the Warriedar area was reported by Simpson (1951), the discovery of tourmalite on the island in Lake Mongers was made in 1962 by a prospector, Gerry Knorreck, who recognized the lapidary potential of the massive, fine-grained tourmalite.

In September 1986, a prospecting licence was applied for and 2.5 t of material was stockpiled for testing in Perth. During 1987–93, chemical analysis and physical testing were carried out. The tests indicated the lapidary-grade tourmalite rocks from the island were either an opaque, black microcrystalline schorl, or a black and white, finely mottled schorl and quartz rock. Samples were also submitted for testing for lapidary suitability; high-quality polished cabochons were cut, and polished animals were carved.

Tourmalite and warrierite

Mg–Fe-rich tourmaline (dravite–schorl series)

$Na(Mg,Fe)_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$

Subsequent trace element analysis confirmed that the Mg–Fe-rich tourmaline mineralization is part of the dravite–schorl series.

In February 1994, mining lease M59/302 over the island in Lake Mongers was granted to Diamond Mine Holdings Pty Ltd (Fig. 5.1). Throughout 1994, mineralogical analysis of specimens was carried out and a system for grading the ore samples was devised. Further lapidary testing was carried out with the carving and polishing of figurines and spheres using different grades of material. During the second half of the 1990s the Warriedar tourmalite deposit was examined in relation to the geology, possible origin of the deposit, and the rock's potential as a high-quality lapidary rock. These investigations are discussed in some detail in Olliver and Thompson (1995) and Fetherston et al. (1999).

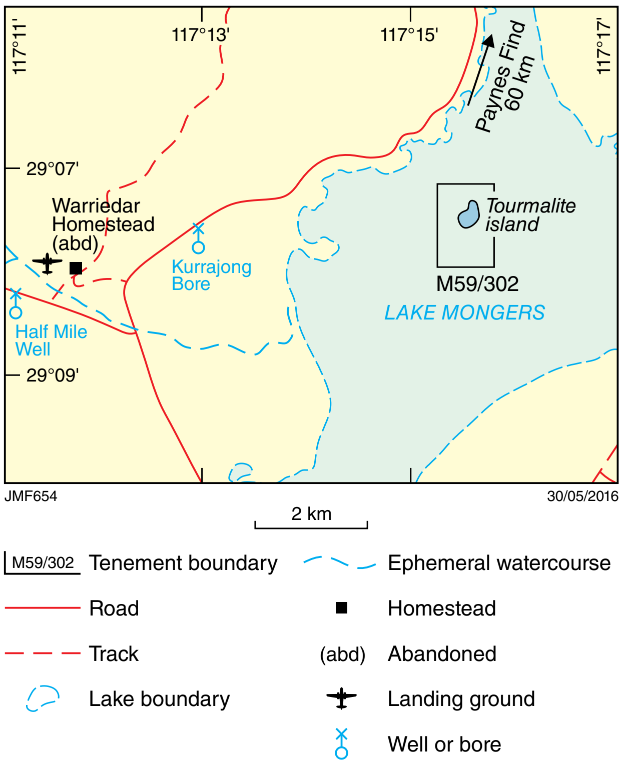

Figure 5.1. **Location of the tourmalite island and mining lease M59/302 in Lake Mongers**

In 2002–03, approximately 34 t of massive, black, microcrystalline dravite–schorl was extracted for test manufacture of high-quality ornamental jewellery and carved artwork such as statuettes. The tests demonstrated the material's extreme hardness, durability, ultrafine-grained texture, uniform black colour, and ability to polish to a high lustre. Thus, the name 'warrierite' was devised for marketing purposes. Today, mining lease M59/302 is owned by Aradon Pty Ltd.

More detailed locational information on the Warriedar tourmaline deposit is given in Appendix 1. The Warriedar tourmaline deposit is discussed in much greater detail in Olliver and Thompson (1995) and Fetherston et al. (1999).

Regional geology

A suite of folded, Archean greenstone rocks of the Warriedar Fold Belt is present in the area directly north of Warriedar Homestead, and west of Lake Mongers (Fig. 5.2). These rocks consist of a mafic volcanic association comprising rhythmically layered metagabbro, thin metabasaltic flows, thick differentiated flows, metadolerite sills and flows in places separated by thin banded iron-formations, and a thin basal pyroxenite. The nearest greenstone outcrop to the tourmalite island is approximately 2 km to the west-southwest. In this area, adjacent to Kurrajong Bore, a metabasalt has been intruded by a late Archean porphyritic quartz monzonite.

At the northern end of Lake Mongers, the Archean greenstone succession has been truncated by a postulated fault that appears to trend along the northeast–southwest axis of the lake playa, possibly passing through, or close by, the tourmalite island.

Tourmalite island geology

The island, which lies about 1.4 km from the western shore of Lake Mongers, rises to the peak of a small hill about 30 m above lake level. The hill, together with a lower rise at the northern end, forms the island's rocky spine, which exhibits a distinct northeast–southwest trend (Fig. 5.2). This may be significant in that it may match the trend of the postulated fault beneath the lake and may be related to the mineralization processes. Away from the central rock outcrop, the eastern and western slopes are composed of a scree of large to small boulders, and other finer grained colluvial material.

Rocks on the island are made up of three main types:

1. Warrierite is a very hard (7 – 7.5 Mohs scale), black, well-jointed, massive, microcrystalline tourmaline with a distinctive conchoidal fracture. This rock appears to have relict features of a thick-bedded metabasalt, particularly in relation to its ultrafine grain size and the presence of multiple smooth joint surfaces commonly at obtuse angles to each other, which form large prismatic or tabular boulders similar to columnar jointing. High-quality material of this type was classified as 'A-grade black' (Olliver and Thompson, 1995; Fig. 5.3a).

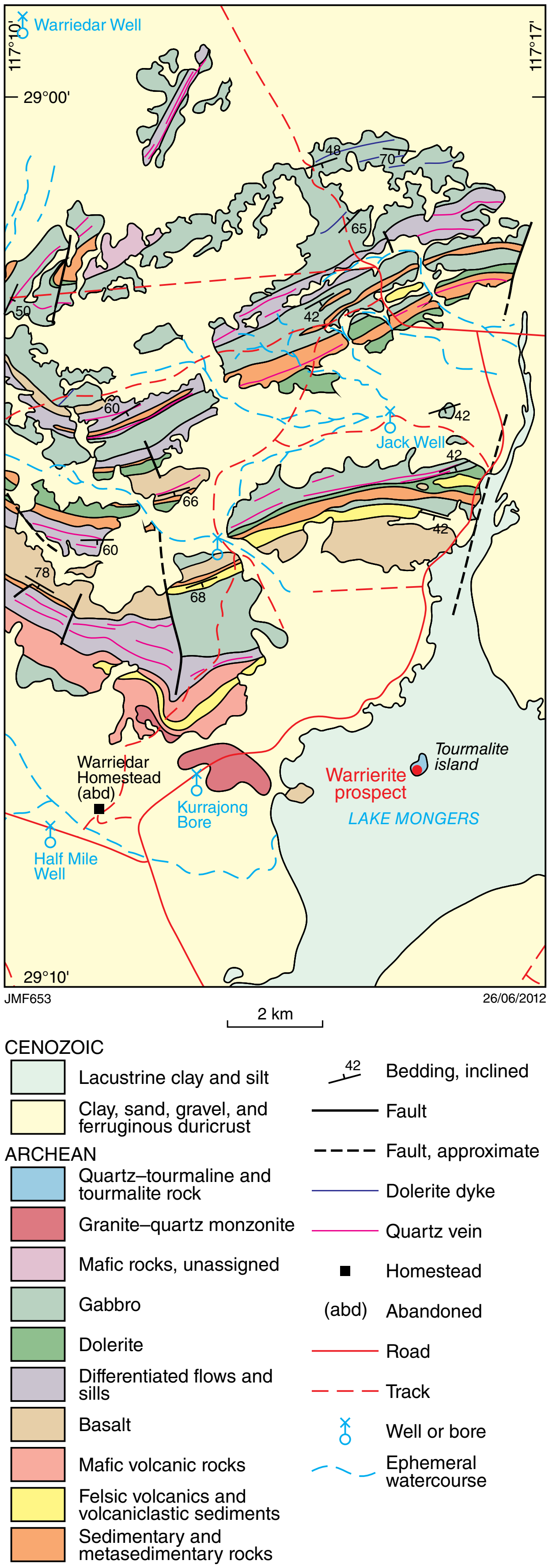

Figure 5.2. Geology of the Warriedar area (modified after Lipple et al., 1982; Baxter, 1991)

2. Tourmalite is a hard, mid- to dark grey, mottled quartz–tourmaline rock with varying proportions of each mineral, which determine the rock's colour. Tourmalite is the dominant rock type. The rock is notable for its distinctive ragged blebs, veins, and boxworks of black tourmaline, many of which are distinctly elongate and almost linear, whereas the remainder have an ovoid or subrounded appearance. This material was classified as 'M-grade mottled' (Olliver and Thompson, 1995; Fig. 5.3b).

3. White, massive quartz veins have intruded the tourmaline rock in the centre of the island. The intrusion of this material has caused extensive brecciation of both quartz–tourmaline rocks and microcrystalline, black tourmaline rocks. Composite veins may be up to 1 m thick (Fig. 5.3c).

It is suggested that the warrierite mineralization may have formed by boron-metasomatic replacement of Archean volcanic rocks, the boron fluids having pervaded the local area through a shear zone related to the postulated fault. Later intrusion of vein quartz resulted in the formation of the hybrid mottled tourmaline–quartz rock and rocks constituted largely of vein quartz.

Warrierite properties

Because few physical properties are available for the warrierite rock at Lake Mongers, the group properties of the dravite–schorl tourmaline series are provided here as general guidelines.

Physical properties of dravite–schorl series

Crystal system	Trigonal
Habit	Prismatic
Colour range	Light to dark brown and black
Lustre	Vitreous
Diaphaneity	Opaque to transparent
Refractive index	1.62 – 1.68
Birefringence	0.014 – 0.024
Pleochroism	Strong
Hardness	7 – 7.5
Tenacity	Brittle
Specific gravity	3.08 – 3.25
Fracture	Uneven to conchoidal
Processing display (warrierite)	Cabochon cut and highly polished, carved artwork

In hand specimen, warrierite (massive microcrystalline tourmaline) appears black and homogeneous, is extremely compact with no visible evidence of crystallinity, and breaks with a subconchoidal fracture. Microscopically it is composed of acicular and fibrous tourmaline crystals typically less than 100 µm in length, loosely packed in subradiating crystal groups as rounded to ovoid spherulites typically 0.1 – 0.2 mm in diameter. Colour within these more regular-size spherulites ranges from almost colourless to pale greenish-blue.

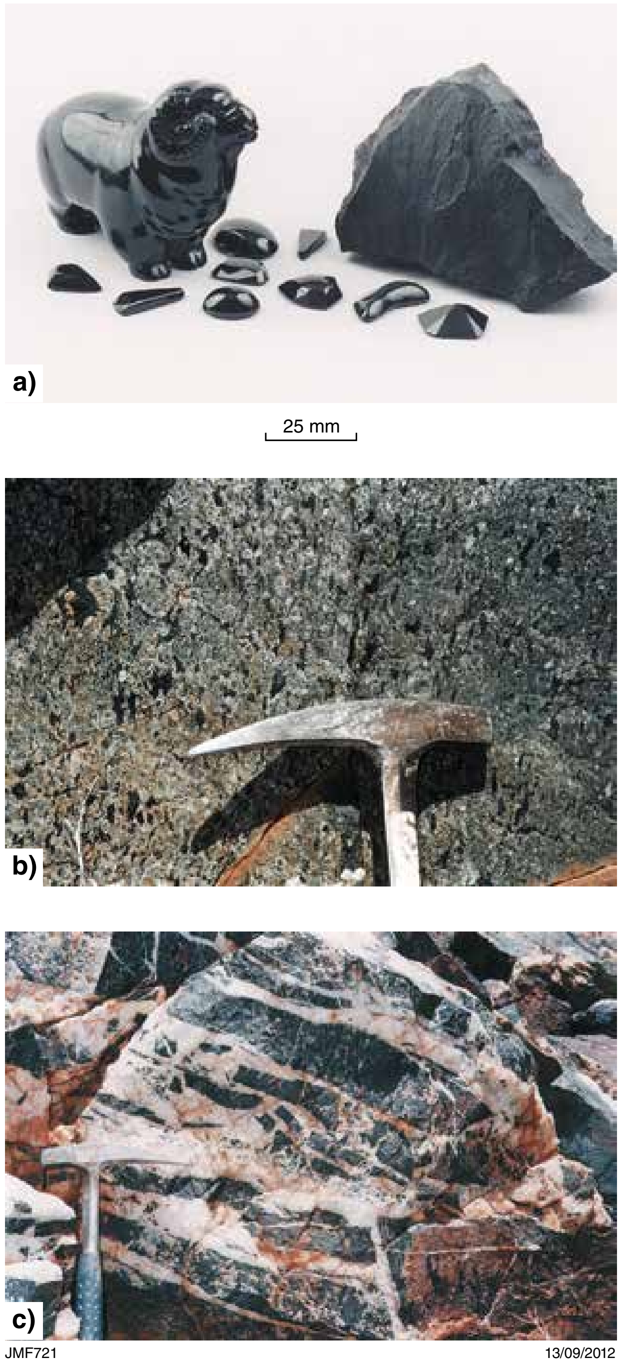

Figure 5.3. Tourmalite island rock types: a) warrierite, a massive, microcrystalline tourmaline rock (at right) showing its distinctive conchoidal fracture; the cabochons and carved merino ram show the superb polish that may be achieved; b) tourmalite, a hard, mid to dark grey, mottled quartz–tourmaline rock; c) black tourmaline breccia in a massive, white quartz vein (after Fetherston et al., 1999)

In places, the texture degenerates into a fine chert-like mass of disordered tourmaline containing scattered spherulites up to 0.5 mm in diameter, with a more erratic grain size and a less well-developed spherulitic shape. In this less-homogenous tourmaline together with the aphanitic tourmaline matrix, colours vary from colourless, through khaki to deep blue.

The radiating structure of the spherulites can be clearly seen in scanning electron micrographs from Olliver and Thompson (1995). These images show randomly orientated and interlocking tourmaline rosettes of 50–200 µm diameter, each displaying a broad fabric of bunches of subradiating crystals, commonly less than 100 µm long (Fig. 5.4a). Individual subradiating prismatic to columnar crystals, showing prominent terminations, can be seen at higher magnification (Fig. 5.4b).

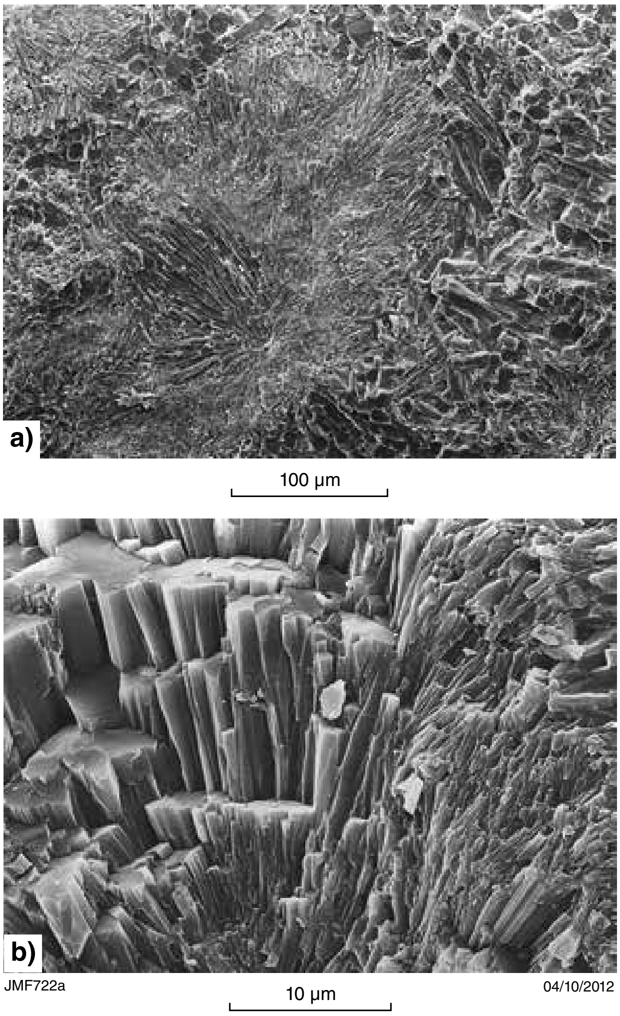

Figure 5.4. Scanning electron photomicrographs of warrierite spherulites: a) tourmaline rosettes displaying subradiating crystals commonly less than 100 µm in length; b) higher magnification of individual prismatic to columnar tourmaline crystals showing prominent terminations (after Olliver and Thompson, 1995)

Lapidary assessment

In lapidary trials it has been found that the warrierite (A-grade black tourmaline) is a tough, durable, massive rock with a jade-like texture and without foliation of any type. It is also extremely hard and capable of producing a superb polish, and is therefore ideal for jewellery and carvings. The characteristics of this rock can be clearly seen in a highly polished sphere (Fig. 5.5a).

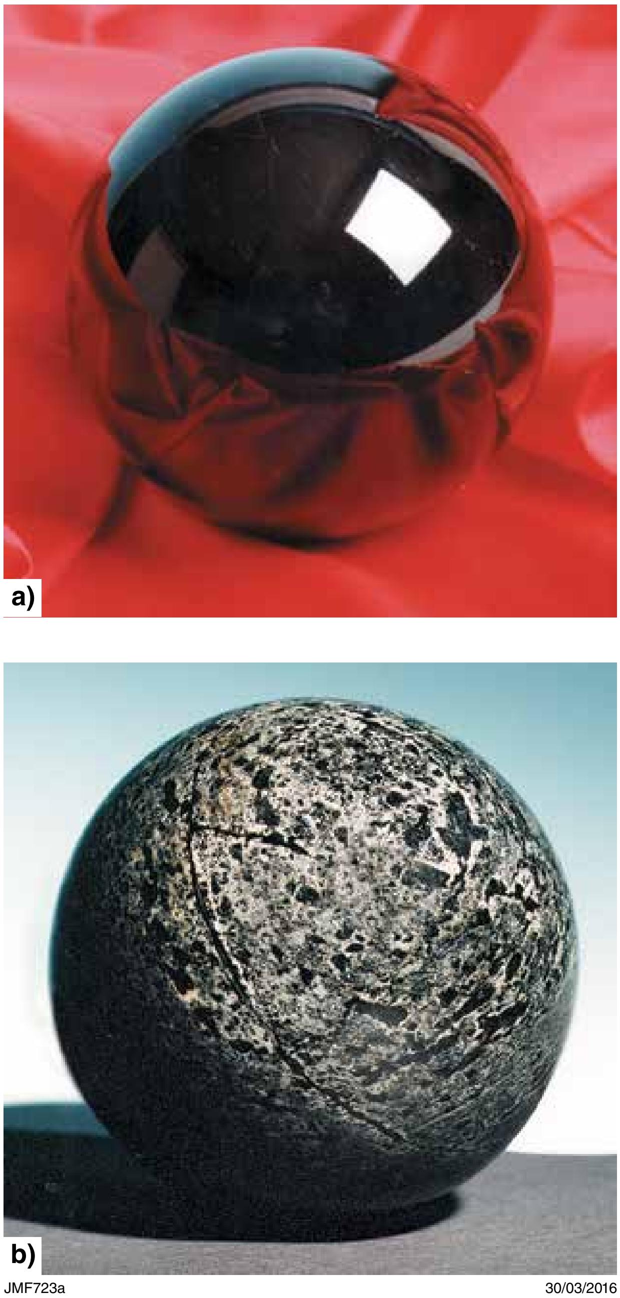

Figure 5.5. Polished spheres of lapidary-grade warrierite and tourmalite each approximately 13 cm in diameter: a) highly polished sphere of A-grade black warrierite; b) polished sphere of M-grade mottled quartz–tourmaline rock (tourmalite) (after Olliver and Thompson, 1995)

The M-grade mottled tourmalite is a black and white rock of variable hardness that can also be polished to a high lustre. Minor defects on polished surfaces are masked by its mottled texture. Care is required to select pieces with attractive patterns for carving. An example of a carved and polished sphere produced from this rock is shown in Figure 5.5b.

References

Baxter, JL 1991, Geology of the Warriedar Fold Belt: Geological Survey of Western Australia, 1:100 000 scale.

Fetherston, JM, Abeysinghe, PB, Jiang, S-Q and Wang, G-W 1999, Six industrial minerals of significance in Western Australia—bentonite, feldspar, kaolin, micaceous iron oxide, talc, and tourmaline: Geological Survey of Western Australia, Report 67, p. 69–80.

Lipple, SL, Baxter, JL and Marston, RJ 1982, Ninghan, Western Australia Sheet SH 50-7: Geological Survey of Western Australia, 1:250 000 Geological Series.

Olliver, JG and Thompson, M 1995, Warrierite — a new black tourmalinite gemstone from Western Australia: The Australian Gemmologist v. 19, no. 5, p. 210–214.

Neuendorf, KKE, Mehl, Jr, JP and Jackson, JA (eds) 2005, Glossary of geology: American Geological Institute, Alexandria, VA, 667p.

Simpson, ES 1951, Minerals of Western Australia, volume 2: Government Printer, Perth, Western Australia, p. 179–224.

Chapter 6

Feldspar group

Feldspar properties and occurrence

Feldspar is a group name for several varieties of alkali aluminium silicates, many of which feature as gemstones worldwide although few from Western Australia have the requisite qualities. Feldspars are the most common minerals of the lithosphere, making up the most abundant constituent minerals of igneous rocks, gneisses, schists, and granitic pegmatites. Although susceptible to alteration and weathering, they are second in abundance to quartz in arenaceous sediments although are rare in argillaceous sediments and carbonate rocks.

Feldspars occur in rock types that were formed under different physical conditions (high and low temperatures) although they form a closely allied group in form and habit. Like quartz, feldspars are found as gigantic crystals especially from granitic pegmatite sources. One crystal of feldspar in a quarry north of Kristiansand, Norway, was reported as about 9 × 4 × 2 m in size. Feldspars are important minerals in many ornamental rocks used as dimension stone, as the commonly large crystal sizes with broad tabular crystal faces and well-developed cleavage provide surfaces for light reflection (Fig. 6.1).

All feldspar group members crystallize in either the monoclinic or triclinic systems and have closely related physical and optical properties. In appearance, they are typically light coloured with tabular habit. Most feldspars show complex twinning, sometimes observable in hand specimen. Feldspars' blocky habit, combination of twinning patterns, well-developed cleavages and pearly lustre assist to distinguish feldspar from quartz as in testing both have low ranges of refractive indices and specific gravity. Within lithium pegmatites, feldspars can be mistaken as petalite.

The majority of feldspars are classified into two major chemically isomorphous groups, alkali feldspars and plagioclase.

Feldspar group

Alkali feldspars: orthoclase, microcline, sanidine, and anorthoclase (K, Na)Al Si_3 O_8
Plagioclase feldspars: isomorphous series from albite to anorthite $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$

Physical properties of feldspars

Crystal system	Monoclinic and triclinic varieties
Habit	Blocky, tabular, and prismatic
Twinning	Multiple lamellar, repeated and simple twins commonplace, often observable
Colour range	Colourless greyish-white, rarely pink, yellow, green, and red
Lustre	Vitreous or pearly
Diaphaneity	Transparent to translucent
Refractive index	1.514 – 1.534 (sodium–potassium series) 1.527 – 1.590 (sodium–calcium series)
Optical phenomena	Many varieties of feldspar display sheen, a spangled appearance, and iridescence
Birefringence	0.007 – 0.013 (calcic members show higher birefringence)
Hardness	6 – 6.5
Specific gravity	2.56 – 2.76
Cleavage	Perfect basal (001) and good (011) and (010)

NOTE: barium feldspars are not included

Figure 6.1. Rough crystal fragment of amazonite feldspar from Paynes Find

Alkali feldspars

This group includes orthoclase, microcline, sanidine, and anorthoclase. Gem minerals of this group include:

- moonstone, which is translucent orthoclase with a white or bluish billowing opalescence
- orthoclase, which can occur as yellow transparent crystals suitable for faceting
- amazonite, a green to bluish-green microcline that has a spangled sheen and a colour range similar to that of turquoise
- graphic granite, an ornamental material comprising an intergrowth of microcline and quartz.

Plagioclase feldspars

This group forms an isomorphous series ranging from the sodic albite to the calcic anorthite. Within this group several feldspar varieties of potential gem interest include:

- sunstone, which shows a spangled sheen (aventurescence) caused by inclusions of hematite, goethite, and rarely copper
- labradorite, which can display iridescent bright colour flashes, especially blue, caused by light interference. Madagascar currently supplies much of the labradorite available for sale in local outlets
- other plagioclase group members, which all have been found in transparent crystals suitable for faceting. Recent finds of red plagioclase, coloured by inclusions of native copper, provide a new and valuable gem.

With the exception of a few references to labradorite, plagioclase is not an important gemstone in Western Australia.

Optical effects

Some of the unique optical effects seen in feldspar include:

- shimmer, a silver sheen effect caused by reflections from cleavage planes, commonly seen in blue-green amazonite
- aventurescence, a spangled effect caused by light reflection from a regular pattern of inclusions
- adularescence (also termed opalescence), a silvery effect caused by light scattering from exsolved compositional layering
- labradorescence and similar interference phenomena, which result in iridescent play-of-colour from the lamellar compositional structure of feldspar.

Graphic granite

Also known as runic granite, graphic granite is an intergrowth of feldspar and quartz. The feldspar component is commonly microcline feldspar and the enclosed quartz forms a polygonal pattern of tapering rods within the feldspar groundmass. The patterns shown by the enclosed quartz are commonly geometric and regular, and polished slabs of graphic granite are both interesting and attractive.

Feldspar in Western Australia

Simpson (1952) described many occurrences of feldspars from Western Australia. While there are numerous occurrences (such as the Londonderry pegmatite) of commercially important feldspar, gem material is almost absent. Only those occurrences providing specimens of gem interest are described below.

Microcline (amazonite)

Yilgarn Terrane — Murchison Domain

Paynes Find (Maranalgo, 2439)

Simpson (1952) described amazonite from Paynes Find. More recent attempts to locate this occurrence were unsuccessful and it was concluded that the original amazonite pegmatite may have been completely removed during mining operations at the adjacent Carnation Gold mine (Jacobson et al., 2007). However, Geological Survey of Western Australia (1994) reported that the best quality amazonite is found by travelling north along the highway from Paynes Find for just over 2 km and, where the highway sweeps to the east, taking a track to the west. Turn right through the ruins of an old house and after travelling for 0.7 km from the highway the dumps and a shallow shaft can be seen on the right (Fig. 6.2). Simpson mentions pegmatite dykes typically striking in a northwesterly direction cutting greenstones and hornblende gneisses. The contained feldspar consists of microcline, or in some cases amazonstone (amazonite). Garnetiferous albite pegmatites also occur. Specimens of amazonite in the collection of the Western Australian Museum include S1685A and S4286 from the Daphne gold mine and S1685C from Carnation gold mine, both in the general area (Fig. 6.3).

Warda Warra area (Dalgaranga, 2342)

A specimen of amazonite from the collection of the Western Australian Museum (4278) is recorded as originating 1.8 km northeast of Warda Warra (Fig. 6.2). No further details are on record.

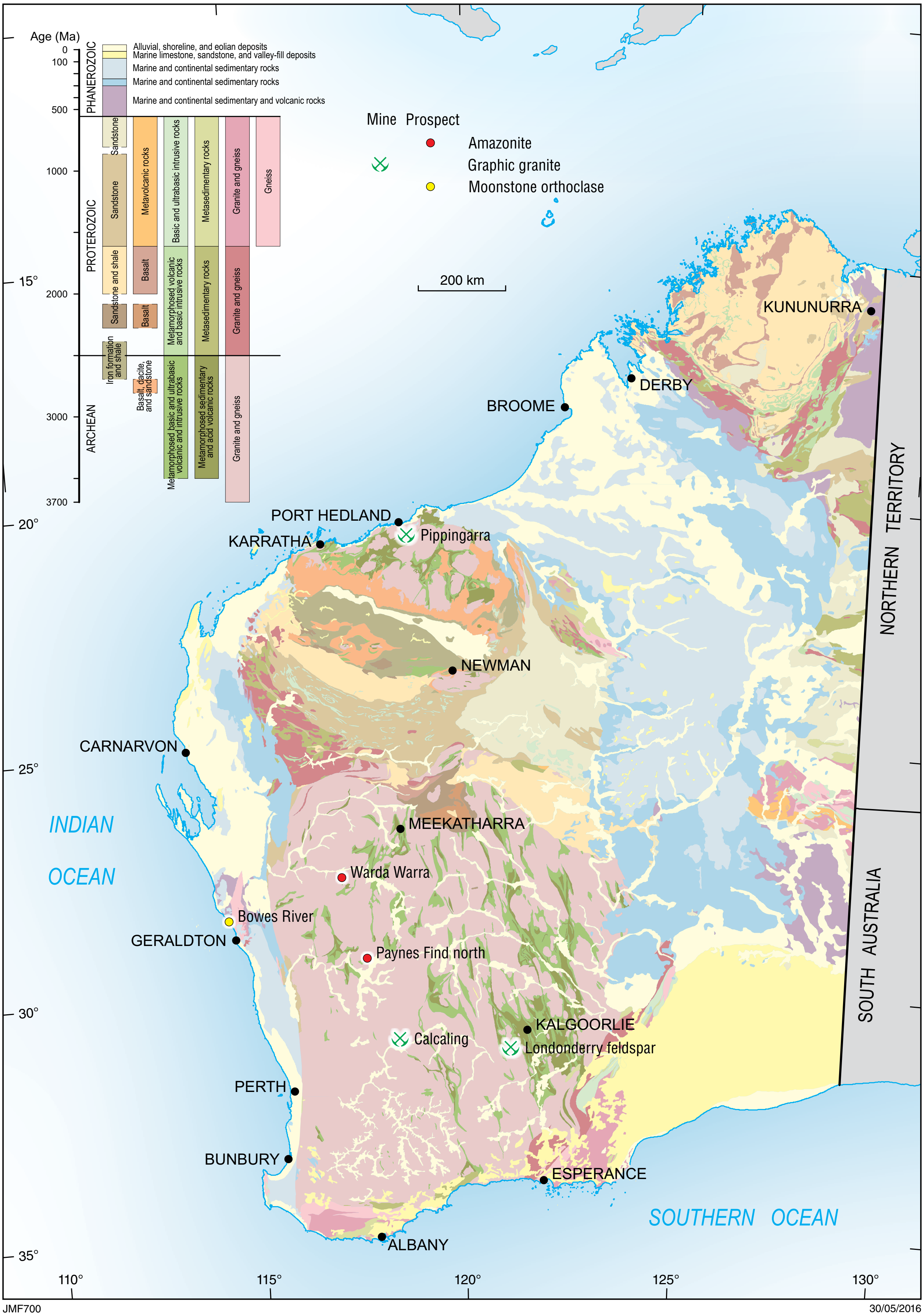

Figure 6.2. **Locations of lapidary-grade feldspar minerals in Western Australia**

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Figure 6.3. Cabochons of amazonite from Melville in the Yalgoo district. Freeform amazonite measures 38 x 42 mm and oval stone 26 x 36 mm (cut and polished by Maria Isaacs)

Orthoclase feldspar

Northampton Inlier

Bowes River moonstone (Northampton, 1841; Butt, 1741)

A specimen of moonstone orthoclase in the collection of the Western Australian Museum (S4331) shown in Figure 6.4 is recorded as originating from the 'mouth of the Bowes River' (Fig. 6.2). Other orthoclase moonstone is coloured silver-grey, light green, and light brown (or peach) (Fig. 6.5). The specimens are uncut, tabular cleavage fragments, and all show the requisite silvery schiller effects of moonstone. Unconfirmed information on their source is that it is the same as the museum specimen.

JMF726 03/09/2012

Figure 6.4. Naturally tumbled specimen of moonstone from the collection of the Western Australian Museum

Graphic granite

Pilbara Craton

Pippingarra (Wallaringa, 2656)

The Pippingarra pegmatite, at least 1500 m long by 200 m wide, is entirely within an Archean porphyritic quartz monzonite that is part of the Carlindi batholith (Fig. 6.2). The contact between the pegmatite and the biotite–quartz monzonite is gradational, progressing from the biotite–quartz monzonite to a graphic granite pegmatite with a biotite-enriched band in direct contact with the quartz monzonite (Jacobson et al., 2007).

Yilgarn Craton — Murchison Domain

Calcaling mine (Barbalin, 2536)

The Calcaling pegmatite is a small microcline-rich pegmatite intruded into biotite–quartz monzonite in the Mukinbudin area (Fig. 6.2). The wall zone is described as discontinuous with irregular fingers of graphic granite and quartz fracture fillings projecting from the main pegmatite into the biotite adamellite (Jacobson et al., 2007).

Yilgarn Craton — Eastern Goldfields Superterrane

Londonderry (Yilmia, 3135)

The Londonderry feldspar pegmatite has been an important producer of commercial-grade feldspar (Fig. 6.2). Graphic granite occurs in sections of the pegmatite and was photographed in the area of the quartz core in the small quarry (Fig. 6.6).

Northampton Inlier

East Bowes area (Northampton, 1841)

Specimens of graphic granite are from an undisclosed site, reportedly in the East Bowes area. A large polished specimen of graphic granite is displayed in the Geological Museum of the University of Western Australia (Figs 6.7 and 6.8). It is purported to be from the vicinity of Moonyoonooka in the Geraldton area. No further details are available.

Figure 6.5. **Four pieces of uncut green, white, and peach-coloured moonstone (courtesy Maria Isaacs and the Lapidary Club of Geraldton)**

Figure 6.6. **Slab of graphic granite, an intergrowth of feldspar and quartz, from the Londonderry feldspar pegmatite quarry**

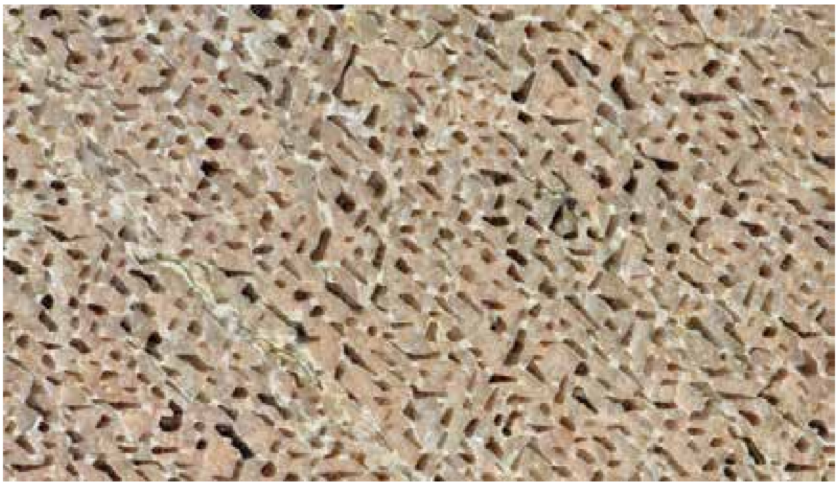

Figure 6.7. Polished specimen of graphic granite from Northampton (courtesy Ken Brussola)

Figure 6.8. Cabochon of graphic granite from Northampton (cut and polished by Maria Isaacs)

References

Jacobson, MI, Calderwood, MA and Grguric, BA 2007, Guidebook to the pegmatites of Western Australia: Hesperian Press, Perth, Western Australia, 356p.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, 714p.

Chapter 7

Topaz

Topaz properties

Topaz is a relatively hard mineral and is the reference standard for 8 on Mohs hardness scale. It has perfect basal (001) cleavage and commonly the table facet of a cut gem is positioned at a small angle to this plane in order to assist polishing and avoid accidental breakage. Iridescence in the form of planar, rainbow-like inclusions in cut topaz gems may indicate incipient cleavage. Topaz takes a high polish and has a brighter vitreous lustre compared with quartz gems with similar colours. Yellow quartz (citrine) is at times incorrectly described as topaz in the jewellery trade.

Although topaz forms naturally in a wide variety of colours it most commonly appears as blue (Fig. 7.1a) or colourless. Most valuable colours are pink, red, and purple although yellow, orange, and brown-coloured stones are typically more common; natural green topaz is rare. Cut colourless topaz is commonly marketed as 'silver topaz'. The diaphaneity of topaz can range from transparent to opaque. In the jewellery industry, transparent gem material is faceted and lower grades are used for beads, cabochons, and carvings. Massive and non-transparent grades have potential for use as an industrial mineral. When topaz is heated fluorine is lost and the mineral becomes high-quality refractory mullite and the fluorine produced may be used for the production of fluoride chemicals.

In the chemistry of topaz, fluoride (F^-) and hydroxyl (OH^-) ions are interchangeable and form an isomorphous series with variations in colour. Accordingly, refractive index (RI) and specific gravity (SG) values are not assigned to a particular colour. There is a small range of values for both RI and SG, as increased F raises the SG and lowers RI, whereas increased OH^- may cause the opposite effect. Therefore, the crystallographic, optical, and chemical properties of topaz may vary with chemical composition, which reflects the petrogenesis of rocks in which individual crystals formed.

The causes of colour in topaz are complex and involve different processes. For example, blue, yellow, reddish-brown, and orange colours are caused by colour centres, which involve a vacancy or defect in the crystal lattice that absorbs light. Colour centres may be natural or can be induced with treatment involving irradiation (Fig. 7.1b). Colour centres can also be stable or unstable and colour fading may result. Much natural topaz fades in sunlight; for example, yellow-to-brown material from Utah and from some Mexican locations commonly loses colour a few days after being mined (Nassau, 1980). Colourless, light yellow, and blue topaz specimens obtained from mining operations are commonly colour-enhanced for use in jewellery by irradiation treatment usually followed by annealing involving heating to 200–300°C. This treatment results in the range of light to dark blue colours in stones commonly seen in the gem market.

Topaz

Hydrous aluminium silicate $Al_2SiO_4(F,OH)_2$

Physical properties of topaz

Crystal system	Orthorhombic
Habit	Prismatic
Colour range	Blue, colourless, yellow, orange, brown, pink, red, violet, purple, and green
Colour cause	Pink, red and violet colours result from Cr^{3+}, and blue, yellow, reddish-brown, and orange result from colour centres
Lustre	Vitreous
Diaphaneity	Transparent to translucent
Refractive index	1.609 – 1.639
Birefringence	0.009
Pleochroism	Trichroism; distinct for coloured topaz
Hardness	8 (Mohs scale standard mineral)
Specific gravity	3.513 – 3.563
Fracture	Conchoidal
Cleavage	Perfect basal (001)
Fluorescence	Varied response, mostly inert, although some topaz shows yellow and green fluorescence in long- and short-wave ultraviolet (UV) light. Topaz with high OH^- content may show strong orange fluorescence in long-wave UV, and white in short-wave UV
Absorption spectrum	Weak doublet at 682 nm in Cr^{3+}-bearing topaz

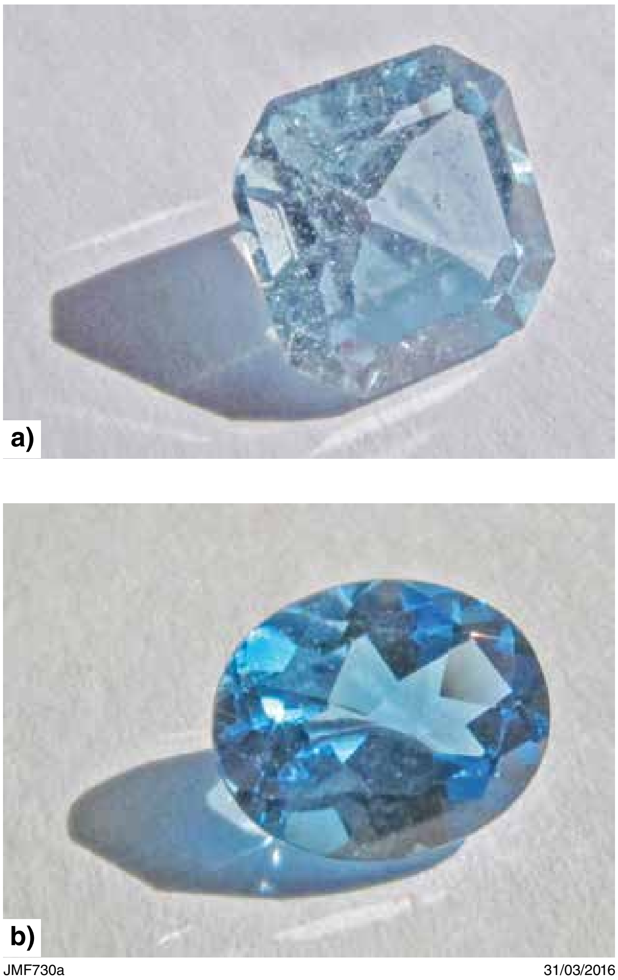

Figure 7.1. **Faceted blue topaz gemstones: a) natural blue topaz from Saint Ann's mine, Zimbabwe, dimensions are 10 mm square, weight approximately 5 ct; b) artificially irradiated, colour-enhanced blue topaz, dimensions are 7 x 5 mm (courtesy Gemrock Enterprises)**

Other current colour treatments for topaz, dating from the mid-1990s, involve coatings or surface diffusion treatments that result in a broad range of colours. Many of the colours produced have no natural counterpart and appear both obvious and artificial to the trained observer. Other colours produced are more subtle and can mimic natural topaz colours.

Brazil and Pakistan are sources of natural pink-coloured topaz. Chromium causes pink, violet, and red colours. If the original pink colour also has a brownish hue, heat treatment may successfully remove the brown colouration, resulting in a stable colour unaffected by further heating. This response is the basis of a common heat treatment known as 'pinking' where the gem is heated in a test tube over an alcohol burner so that colour change can be observed and stopped at the correct point (Nassau, 1980).

Topaz is present as an accessory mineral in siliceous igneous rocks including granites, pegmatites, and quartz veins commonly within miarolitic cavities, and greisens and associated hydrothermally altered rocks. Topaz also occurs in rhyolites and aluminous igneous rocks. At Torrington in New South Wales, numerous intrusions of silexite, a quartz–topaz rock containing 15–20% topaz, form near margins of granitic bodies and have been assessed as a potential source of industrial topaz. Because of its hardness, topaz commonly pervades as a residual mineral in placer and other alluvial deposits.

At Schneckenstein in Germany, yellow crystals of gem-quality topaz have been mined since the early 18th century. Other important sources from Minas Gerais State in Brazil were discovered around the same time and today Minas Gerais remains an important world source of gem-grade topaz. Numerous other topaz localities around the world include significant sites in the US, Mexico, Sri Lanka, Nigeria, Madagascar, Pakistan, and Russia.

Topaz in Western Australia

In Western Australia, topaz is present in many pegmatites throughout the State, although no jewellery-grade material has yet been found. Some finds of partially transparent, white and light blue crystals, and some very large specimens of topaz pseudomorphs (particularly muscovite after topaz forms) have been reported and have been of interest to gemmologists and fossickers.

Locations of topaz prospects in the State are shown in Figure 7.2 and more detailed locational information on these sites together with Western Australian Museum specimen numbers are given in Appendix 1.

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Grosmont *(Yilmia, 3135)*

The Grosmont pegmatite is about 15 km southwest of Coolgardie and 7 km north-northwest of Londonderry (Fig. 7.2). Access from Coolgardie is southwestwards along the Victoria Rocks Road for nearly 15 km and then north along a dirt road. In recent years, the Grosmont opencut has been a popular collecting site for opaque blue topaz masses and large plates of lepidolite mica.

Prospectors first accessed this 3–4 m-thick pegmatite in 1896 and after a succession of developments over the years it was abandoned in 1953. In the 1800s the pegmatite was known as the General Foch on mining lease 68 and a specimen from this minesite is in the Western Australian Museum (specimen WAM 7073). In 2001 the abandoned workings were described as an opencut, approximately 65 m long, 2 m wide, and 2–3 m deep.

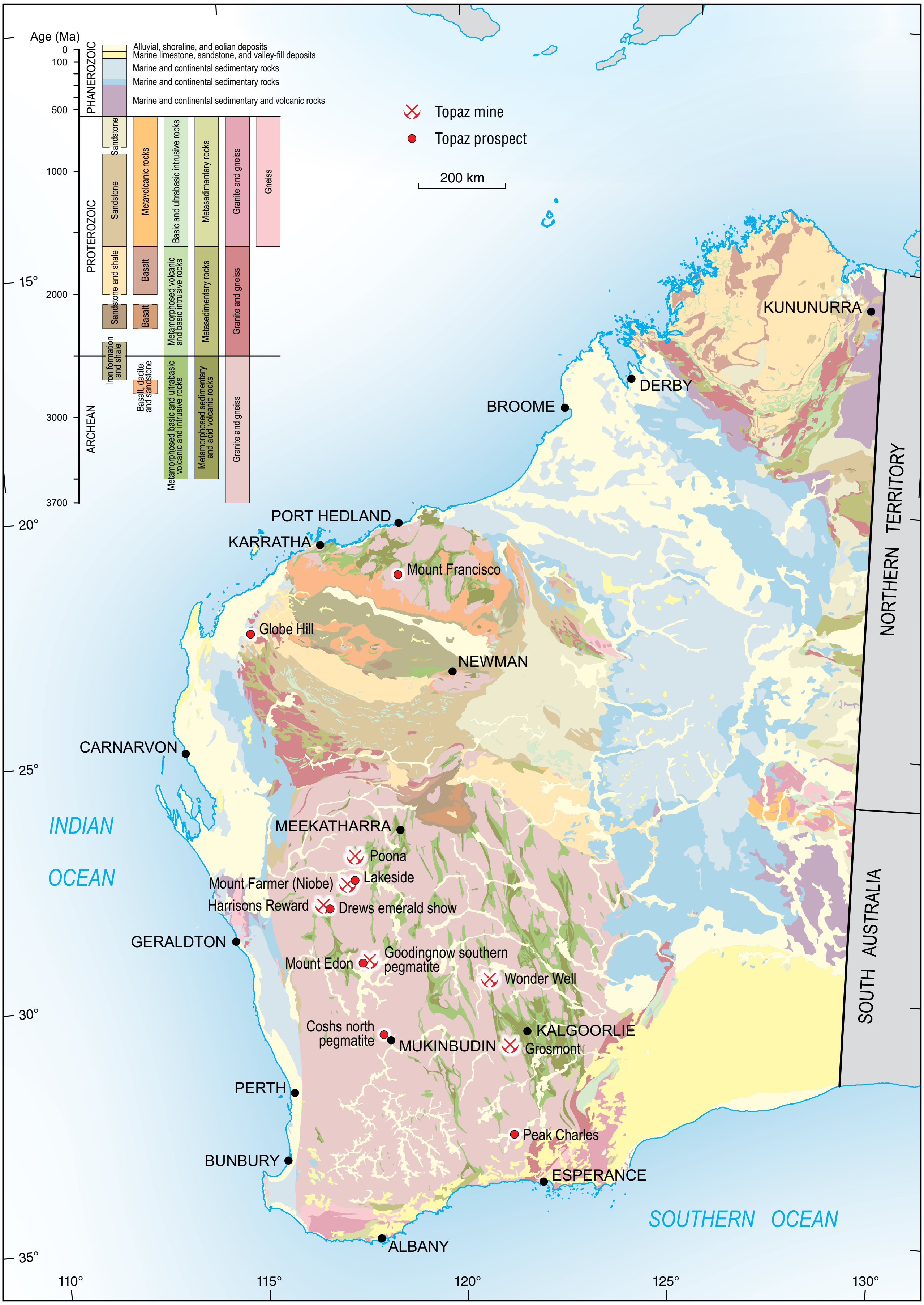

Figure 7.2. **Principal topaz localities in Western Australia**

The pegmatite was only visible in a few places along the walls where slumping had occurred and the mullock heaps showed signs of digging, the result of visits by fossickers (Jacobsen et al., 2007).

The Grosmont pegmatite was concordantly intruded into Archean, fine- to medium-grained amphibolites striking north-northeast and dipping 80–85° to the west. Poor exposure of the structure has for the most part precluded attempts to describe pegmatite zoning or mineral associations although Reeve (1973) reported that the topaz was found as massive pieces of a visually attractive blue stone almost everywhere enveloped by lepidolite.

Minerals reported from the site include albite (cleavelandite), microcline (white to light green), quartz, muscovite, common opal (light blue), massive topaz, damourite (a purple hydromica formed by topaz alteration), and lepidolite as fine-grained pink, curved plates, as overgrowths on muscovite, and as flat coarse-grained plates up to 30–40 cm long. Morganite (pink beryl) was reported as a minor mineral (Reeve, 1973).

The massive, semitransparent topaz is present in colours ranging from light blue to white, and pale sky-blue. An analysis of the clear blue portion of topaz is given by Simpson (1952) as a high F-type topaz containing 17.86% F.

Menzies region

Wonder Well (Riverina, 3038)

The Wonder Well pegmatites outcrop astride the Riverina – Snake Hill Road directly north of the Riverina Station Homestead about 60 km west of Menzies (Fig. 7.2).

The beryl-bearing pegmatites are found in the north-trending Riverina – Mount Ida greenstone belt. Emeralds have been found in phlogopite and adjacent plagioclase pegmatites. Topaz described as glassy clear although with frosted faces, euhedral, and terminated in biotite schist was recovered from the emerald deposit. The terminated crystal was 8 cm long x 5 cm wide.

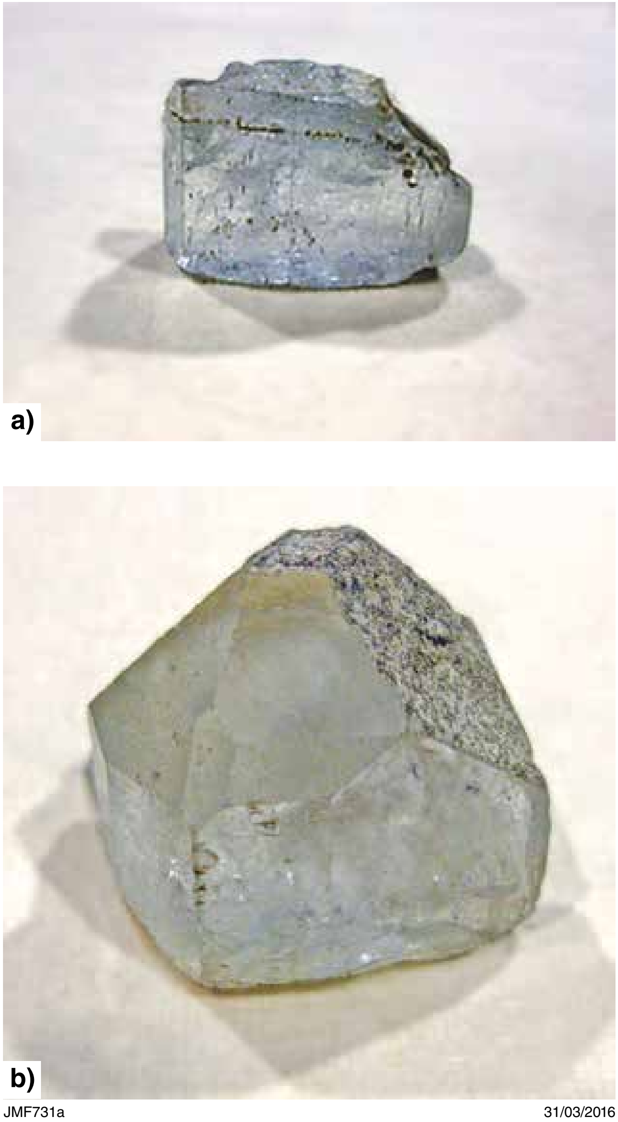

Figure 7.3. Examples of gem-quality topaz from the Peak Charles area, Norseman region: a) semitransparent topaz (Western Australian Museum specimen M594); b) terminated, euhedral, colourless topaz (Western Australian Museum specimen M11)

Yilgarn Craton — Southern Cross Domain

Norseman region

Peak Charles area (Peak Charles, 3132)

Two specimens of semitransparent, colourless topaz were collected from an unknown site in the Peak Charles area, approximately 95 km south-southwest of Norseman (Fig. 7.2). These specimens (WAMM11 and M594) are part of the collection of the Western Australian Museum. Both crystals are semitransparent (almost clear) and show good prismatic crystal form; one crystal has a completed termination (Fig. 7.3).

The area surrounding the peak is now part of the Peak Charles National Park and accordingly no prospecting or fossicking is permitted within its boundaries. No additional information relating to this site is available.

Yilgarn Craton — Murchison Domain

The Murchison Domain has a varied assortment of pegmatites ranging from simple beryl–columbite pegmatites to both niobium–yttrium–fluorine (NYF) and lithium–cesium–tantalum (LCT) rare-metal pegmatites. Some of these pegmatites have been exploited for feldspar, tantalum, emeralds, beryl, and topaz (Jacobson et al., 2007).

Around the town of Mukinbudin, an abundance of quartz-cored pegmatites have intruded post-tectonic, Archean, quartz monzonite bodies surrounding local greenstone belts (Fig. 7.2). The pegmatites belong to the allanite–

monazite NYF rare element class. Topaz is recorded from some of these pegmatites, commonly as white, non-gemstone varieties.

Cue region

Lakeside pegmatite *(Dalgaranga, 2342)*

The Lakeside pegmatite is about 50 km west-southwest of Cue, and 5 km west-northwest of Lakeside Homestead (Fig. 7.2). At this location the pegmatite has intruded a north-northeast-trending, Archean, fine- to medium-grained amphibolite.

De la Hunty (1973) recorded that 3.2 kg of blue topaz and 90.7 kg of coloured beryl were at some time in the past sold out of Lakeside Station. This gemstone material was probably sourced from the nearby Lakeside pegmatite. Western Australian Museum Specimen MDC 4180 appears to have been sourced from this site.

Dalgaranga pegmatite field *(Dalgaranga, 2342)*

The Dalgaranga pegmatite field, including the Mount Farmer pegmatites, is a small group of lithium and tantalum-bearing pegmatites that were mined for beryl, tantalum, and cassiterite between 1960 and 1980. The Mount Farmer pegmatite (Niobe prospect) is 70 km northwest of Mount Magnet and 24 km northeast of Dalgaranga Homestead (Fig. 7.2).

The zoned pegmatite has a surface width of approximately 50 m, dips 30–40° to the northwest and was traced along a northeast-trending strike for at least 400 m. Topaz is recorded commonly in the zinnwaldite–quartz–albite zone as euhedral, white, and bluish crystals up to 0.35 m in length. Most crystals had a sharp contact with 1–2 cm-thick coatings of white hydromica alteration containing fibres radial to crystal faces.

Poona *(Noondie, 2343)*

The Poona mineral field is about 55 km northwest of Cue (Fig. 7.2). In this area, a pegmatite sited on the Reward Claim (ML45) contains several imperfect topaz crystals. They are described as up to 25 mm in length, colourless to very light blue, transparent with a basal parting (Simpson, 1952). The topaz is associated with muscovite, quartz, and beryl. Also, detrital pebbles of topaz, up to 5 cm in diameter, containing several parallel, colourless, and iron-stained crystals were found at the western end of the field (Fig. 3.4, Chapter 3 on the beryl group).

Topaz is also described as a minor mineral from dumps near the Aga Khan Deep mine, occurring within altered quartz–topaz–fluorite greisen that also contains ruby, alexandrite, and a quartz–emerald layer. An unusual observation revealed that the topaz is light red in colour because of many tabular inclusions of ruby (Grundmann and Morteani, 1998).

Paynes Find area

Mount Edon pegmatite field *(Maranalgo, 2439)*

The Mount Edon pegmatite field is between 5 and 9 km south of Paynes Find where numerous, irregularly shaped pegmatites for the most part concordantly intrude a northeast-trending succession of Archean greenstones comprising mafic, ultramafic, and metasedimentary rocks (Fig. 7.2). The Mount Edon pegmatite field is described in detail in Jacobsen et al. (2007).

The Western Australian Museum collection includes a few non-gem-grade topaz specimens from unknown locations in the Mount Edon pegmatite field. Specimen MDC 3787 is listed as from southwest of Paynes Find, and MDC 5918 as Paynes Find. No further details are available.

Goodingnow southern pegmatite *(Maranaglo, 2439)*

The Goodingnow feldspar pegmatites are within the Mount Edon pegmatite field about 5 km south of Paynes Find (Fig. 7.2). This area has been mined from a series of openpits found to contain considerable quantities of feldspar and smaller quantities of beryl, and tantalite–columbite together with numerous minor pegmatite minerals including topaz. During 1975–81, Universal Milling mined the Goodingnow southern pegmatite, recovering 2416 t of high-grade K-feldspar (Flint et al., 2000). During the early 1980s well-crystallized yellow and green beryl was also mined from this openpit (Jacobsen et al., 2007). The Western Australian Museum holds a non-gem-grade topaz specimen from this site (MDC 1087).

Yalgoo region

Noongal area

Harrisons Reward (Yalgoo, 2241)

The Noongal pegmatite field (Melville) is on Carlaminda and Noongal Stations about 20 km north of Yalgoo and 5 km north-northwest of the old Melville townsite. The field contains numerous pegmatites including Harrisons Reward pegmatite on former mining lease ML26, about 3 km northeast of Bottom Well (Fig. 7.2). Harrisons Reward is a highly siliceous pegmatite composed mostly of quartz and biotite. It trends southeast, parallel to the foliation of its host metapyroxenite, which is a xenolith within a fine-grained granitic rock.

The prospect was worked in 1913 to recover ores of bismutite and scheelite together with quartz and minor feldspar. Topaz was discovered in 1932 and subsequently further discoveries were made in pegmatites approximately 2 km to the northwest and 200 m south of the original find. In all cases the topaz is associated with pseudomorphs of muscovite after topaz. Simpson (1952) described the topaz as colourless, or milk-white, and in masses up to ‘several pounds in weight' (possibly up to 1.5 kg). Each mass represented a single crystal with some parts completely colourless and transparent to a thickness of 5 mm, with the translucency extending to a thickness of 10 mm. Analysis of a specimen of the cleanest and most colourless topaz shows it is a high F-type containing 18.55% F, 0.87% H_2O^+, and 0.05% H_2O^-.

Drews Emerald Show (Yalgoo, 2241)

Also in the Noongal area, Drews Emerald Show, comprising several small, closely spaced pegmatites, has been reported by Simpson (1952) to contain topaz and small emerald crystals in quartzitic veins. No further information is available about the topaz contained in this pegmatite (Fig. 7.2).

Mukinbudin area

Coshs north pegmatite *(Barbalin, 2536)*

Coshs north pegmatite (also known as Whytes south) is approximately 20 km northwest of the town of Mukinbudin (Fig. 7.2). Access from Mukinbudin is westwards along the Koorda–Bullfinch Road for about 18 km and then northwards for about 5 km. The pegmatite lies between two properties with the southern end on the Cosh farm on former mining lease M70/1069 and the northern end on the Whyte farm.

At this location, a medium- to coarse-grained Archean quartz monzonite has been intruded by a north-trending quartz–feldspar pegmatite also containing biotite, muscovite, and topaz. The pegmatite displays a crude form of zoning in the form of large books of biotite together with fine-grained muscovite along the edge of quartz cores containing embedded, large masses of iron-stained yellow to white glassy topaz. This material has a fine-grained texture and is completely unaltered (Jacobson et al., 2007).

Coshs north pegmatite has produced the largest euhedral crystal fragments of topaz found in Western Australia to date, with some fragments more than 40 kg. Crystal faces are found on most fragments recovered from several sites on both the Whyte and Cosh farms. Subsequently, a 45 kg single crystal fragment was cleaned and restored to a white mass displaying at least one well-formed crystal face. Another fractured topaz mass, held in a private collection, weighs about 1 kg and contains small clear gem areas.

Gascoyne Province

Nanutarra area

Globe Hill pegmatite *(Uaroo, 1952)*

The Globe Hill pegmatite is on the south side of the Ashburton River, approximately 27 km west of Nanutarra Homestead and 11 km north-northeast of Globe Hill (Fig. 7.2). This site is in an area of amphibolitic and quartzofeldspathic gneisses forming part of the Paleoproterozoic Gascoyne Province. The exact location of the pegmatite is uncertain although according to Simpson (1952), alluvial topaz, associated with tin, occurs at the site as angular, colourless fragments 2–5 mm in diameter.

Pilbara Craton

Wodgina area

Mount Francisco *(Wodgina, 2655)*

Gemstones in Western Australia (Geological Survey of Western Australia, 1994) records white translucent topaz in a pegmatite at Mount Francisco about 120 km south-southwest of Port Hedland (Fig. 7.2). No further information is available for this deposit although Simpson (1952) records one or two specimens of topaz without site location from the Wodgina district. Note that the Mount Francisco pegmatite field lies within the Yandeyarra Aboriginal land and permission from the relevant Aboriginal council is required for access.

Roebourne area *(Roebourne, 2356)*

The Western Australian Museum holds three topaz specimens reportedly from the Roebourne area. Specimens MDC 2567 and 2567A are given as from 23 and 29 km west-southwest of Roebourne, respectively. Specimen WAM M 976 has no locality given. These specimens are of massive, white topaz of non-gemmological quality. No further information is available.

References

De la Hunty, LE 1973, Cue Western Australia Sheet SG 50-15: Geological Survey of Western Australia 1:250 000 Geological Series, Explanatory Notes, p. 29.

Flint, DJ, Abeysinghe, PB, Gao, M, Pagel, J, Townsend, DB, Vanderhor, F and Jockel, F 2000, Geology and mineral resources of the Mid West Region: Geological Survey of Western Australia, Record 2000/14, p. 100.

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, Perth, Western Australia, 52p.

Grundmann, G and Morteani, G 1998, Alexandrite, emerald, ruby, sapphire and topaz in a biotite–phlogopite fels from Poona, Cue District, Western Australia: Australian Gemmologist, v. 20, no. 4, p. 159–167.

Jacobson, MI, Calderwood, MA and Grguric, BA 2007, Guidebook to the pegmatites of Western Australia: Hesperian Press, Perth, Western Australia, 356p.

Nassau, K 1980, Gems made by man: Chilton Book Company, Radnor, Pennsylvania, 364p.

Reeve, RJ 1973, Some gem-bearing pegmatites near Coolgardie, Western Australia: Australian Gemmologist, v. 11, no. 12, p. 21–22.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 668–670.

Chapter 8

Minor pegmatite gemstones

Lepidolite

Lepidolite, a hydrated lithium aluminium silicate, is included in the mica group of minerals. It is the most common lithium-bearing mineral in lithium-rich, granitic pegmatites in which it is commonly associated with petalite, amblygonite, and spodumene. Lepidolite is most commonly violet, bluish-violet, or pink. Lepidolite from Western Australia is found in many shades of purple and, less commonly, blue from the Carlaminda Blue quarry north of Yalgoo (Fig. 8.1).

Lepidolite may form as large tabular crystals although it is more commonly found in aggregates, and in places as botryoidal, scaly flakes. It derives its name from this scaly appearance. The fine-grained, massive variety is most sought after by lapidarists for carving into *objets d'art* (Fig. 8.2).

Lepidolite in Western Australia

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry pegmatite field *(Yilmia, 3135)*

The Londonderry pegmatite field is about 20 km south-southwest of Coolgardie via the Nepean Road (Fig. 8.3). Londonderry has been a fossicking site for many years as a source of gem materials including colourful lepidolite masses. Tantalite, beryl, lepidolite, and petalite have all been recovered from the pegmatites and quarrying operations for microcline feldspar, which was the economic focus from 1929 to 1983.

Minor pegmatite minerals

Lepidolite — hydrated lithium aluminium silicate $K(Li, Al)_3(Si,Al)_4O_{10}(F,OH)_2$
Petalite — lithium aluminium silicate $LiAlSi_4O_{10}$
Spodumene — lithium aluminium silicate $LiAlSi_2O_6$
Phenakite — beryllium silicate Be_2SiO_4

Londonderry feldspar pegmatite

The Londonderry feldspar-bearing pegmatite is a north-trending structure shaped like a flattened tadpole with the 'head' at the northern end. The pegmatite is about 1000 m long and 200–280 m wide, and is asymmetrically zoned. Eight zones have been recognized, each defined by specific mineral assemblages. For example, purple-coloured lepidolite mica occurs in the quartz–albite–microcline–lithium mica zone where it is found in association with lithium muscovite and zinnwaldite. Lepidolite is also found as several other crystal forms including light purple ball-shaped structures up to 6 cm in diameter, and more commonly as fine-grained, randomly orientated flakes (Fig. 8.4; Jacobson et al., 2007). A geological map of the area surrounding the Londonderry pegmatite field is shown in Figure 8.5.

Lepidolite Hill pegmatite

The Lepidolite Hill pegmatite is 1.6 km north of the Londonderry feldspar quarry and 400 m southeast of the Tantalite Hill pegmatite. The site may be accessed 1.5 km along a track leading from the Nepean–Coolgardie Road (Fig. 8.5).

Physical properties of lepidolite

Crystal system	Monoclinic
Habit	Foliated, tabular, and fine-grained massive
Colour range	Colourless, violet, blue, and pink
Lustre	Vitreous or pearly
Diaphaneity	Semitransparent to translucent
Refractive index	1.530 – 1.556
Birefringence	0.026
Hardness	3.5
Specific gravity	2.8 – 3.3
Fracture	Irregular, uneven
Cleavage	Perfect (001)

JMF961 02/08/2016

25 mm

Figure 8.1. **Blue lepidolite mica interspersed with white albite feldspar and grey quartz, Carlaminda Blue quarry, Yalgoo area (courtesy Glenn Archer)**

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Figure 8.2. **Ornamental bowl featuring lepidolite, 13 cm in diameter, fashioned on a gem lathe. The rock was sourced from the Kathleen Valley pegmatite field about 45 km north of Leinster, Western Australia (courtesy Bill Moriarty)**

The pegmatite at Lepidolite Hill is present as two bodies within Archean greenstones of the Yilgarn Craton, with the larger, northeastern pegmatite slightly over 200 m long and 24–90 m wide. The smaller southwestern pegmatite forms a south-pointing, L-shaped outcrop.

Zones in the Lepidolite Hill pegmatites include an albite–quartz–spessartine border zone, a quartz–albite–microcline–muscovite wall zone, up to two intermediate zones, a fine-grained lepidolite–quartz core margin, and a central quartz core. The discontinuous, fine-grained lepidolite–quartz-core margin may reach 2 m in thickness along the footwall of the quartz core. The quartz core in the northeast pegmatite is 60 m long with an average thickness of 8 m whereas the core in the southwest pegmatite is thin and discontinuous and reaches only about 2 m in thickness (Jacobson et al., 2007).

Lepidolite Hill has been a favourite area for collectors searching for large masses of bright purple, fine-grained lepidolite.

Yilgarn Craton — Murchison Domain

Noongal area

Carlaminda Blue pegmatite (*Yalgoo, 2241*)

The Carlaminda Blue pegmatite quarry (otherwise known as Johnson Well or Dollar Well) within the Melville pegmatite field is developed on a blue lepidolite-bearing pegmatite, approximately 20 km north of the town of Yalgoo (Fig. 8.3).

At this site, the Carlaminda Blue pegmatite has intruded a suite of mostly Archean metasedimentary rocks arranged in a tightly folded anticlinal nose. The northwest-striking pegmatite extends for about 1 km, although it has been fragmented by faulting into at least four major segments. The central portion of the pegmatite is composed of albite – lithium mica with an albite–quartz–microcline border zone (Jacobson et al., 2007).

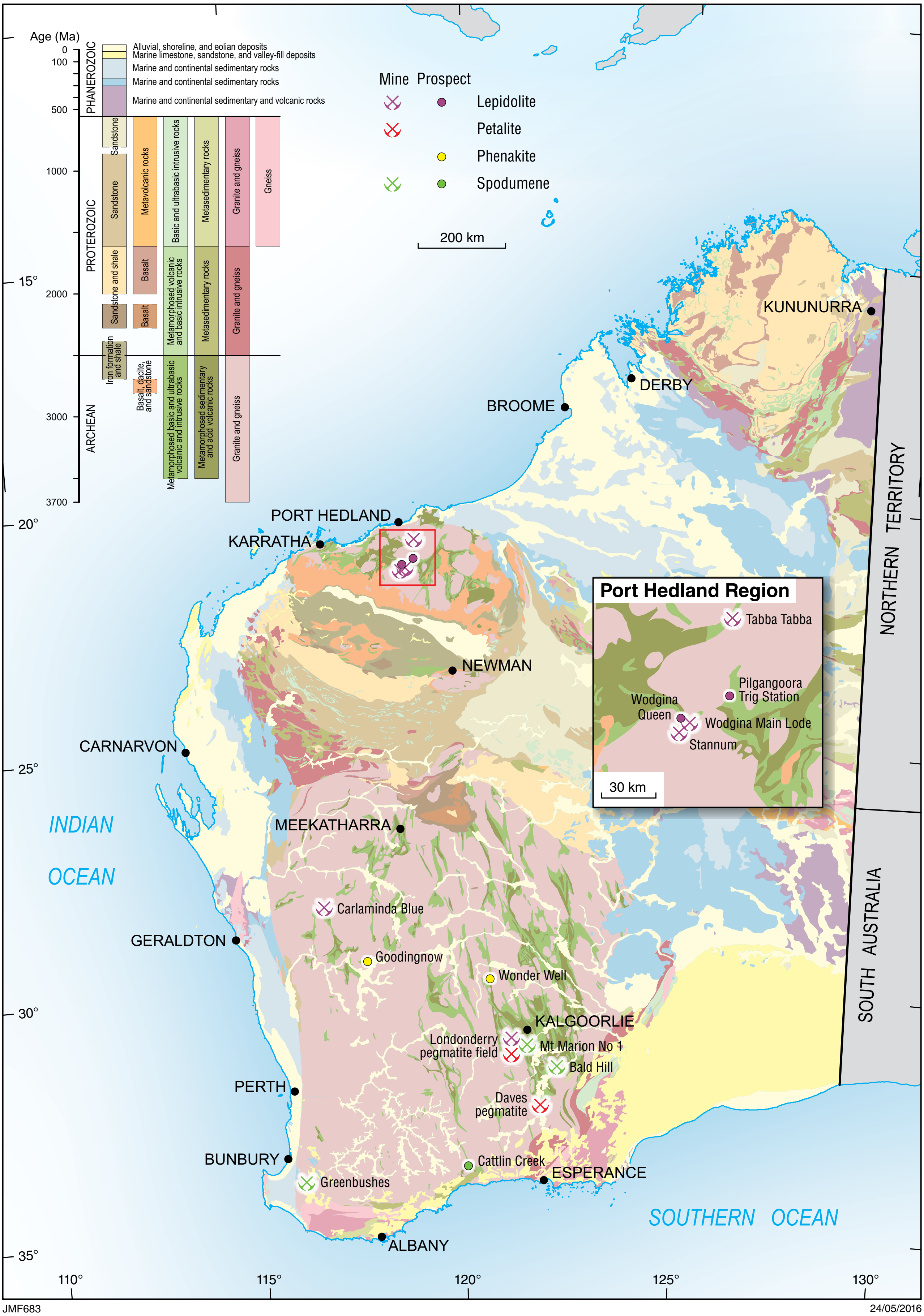

Figure 8.3. **Locations of minor pegmatite gemstones in Western Australia**

Figure 8.4. Botryoidal lepidolite, cut and polished section, 16 cm diameter, from the Londonderry feldspar pegmatite (courtesy Peter Bridge)

In the quarry, fine-grained, bright purple to blue lepidolite masses in sugary albite are common together with ball lepidolite structures 1–2 cm in diameter. The fine-grained, blue lepidolite was originally thought to be lapis lazuli although in 2002 it was identified as lepidolite with the blue colouration probably caused by manganese in concentrations up to 6050 ppm (Ross, 2003; Fig. 8.1).

Rough and slabbed blue lepidolite is sold by rock and lapidary shops and is commonly used for *objets d'art* (Fig. 8.6).

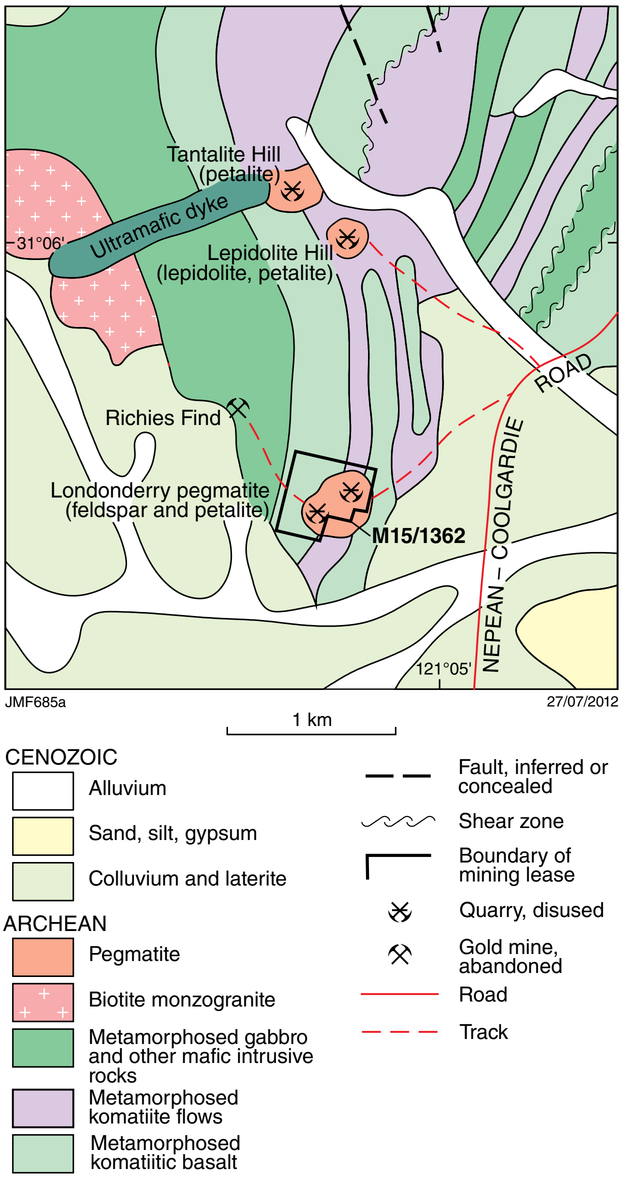

Figure 8.5. Geology of the area surrounding the pegmatites at Londonderry (modified after Fetherston et al., 1999)

Pilbara Craton

Wodgina area

Wodgina greenstone belt (WODGINA, 2655)

Wodgina Main Lode

The Wodgina Main Lode or Tantalite Lode is in the Wodgina tantalum mining area about 100 km south of Port Hedland mainly along the Great Northern Highway (Fig. 8.3).

The Wodgina Main Lode is a northerly striking pegmatite vein 3–10 m wide that dips 40° east over about 700 m. The pegmatite has a granitic-textured core with marginal and crosscutting veins of almost pure albite, and contains irregularly distributed pods of quartz, microcline, lepidolite, and mica. Manganotantalite is present throughout the pegmatite although it is primarily concentrated in the feldspathic portions (Ferguson and Ruddock, 2001).

Wodgina Queen

The Wodgina Queen prospect is about 2.6 km west-northwest of the Wodgina Main Lode (Fig. 8.3). This prospect forms part of the West Wodgina pegmatite group and contains simple and zoned pegmatites containing dense, fine-grained masses of lepidolite together with cassiterite and quartz. Other pegmatites in this area are also reported to contain lepidolite (Jacobson et al., 2007).

Stannum pegmatite

The Stannum mine is in an old tin mining area about 8 km south-southwest of the Wodgina Main Lode (Fig. 8.3). The mine is sited on a pegmatite containing cassiterite together with columbite, lepidolite, blue tourmaline, and topaz. No further information is available on this site.

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Figure 8.6. Lepidolite from the Carlaminda Blue deposit carved as a pod of dolphins, 30 cm high x 25 cm wide (courtesy Glenn Archer)

Pilgangoora area

Pilgangoora pegmatite field (*Wodgina, 2655*)

The Pilgangoora pegmatite field on Wallareenya Station is about 90 km south-southeast of Port Hedland and contains swarms of lepidolite–spodumene-bearing pegmatites (Fig. 8.3). This area can be accessed from Port Hedland via the Great Northern Highway, the Port Hedland – Wittenoom Road, and other dirt roads.

The area surrounding the Pilgangoora trig station contains numerous pegmatites intruding Archean mafic and ultramafic schists close to the western margin of the Pilgangoora greenstone belt. This northerly trending zone extends for about 5 km and includes pegmatites up to 600 m long and 300 m wide. Small areas of these pegmatites are mineralized where quartz–microcline–biotite pegmatite has been altered to quartz, albite, and spessartine, with varying amounts of lepidolite, spodumene, tantalite, columbite, and cassiterite, together with traces of microlite, tapiolite, and beryl. Spodumene and lepidolite tend to be associated with cleavelandite zones (Ferguson and Ruddock, 2001).

Tabba Tabba area (*Wallaringa, 2656*)

Pegmatites in the old Tabba Tabba tantalite mining area about 60 km south-southeast of Port Hedland are well-known sources of the tantalum mineral simpsonite (Fig. 8.3).

Also at Tabba Tabba, crystals, plates, and mammilated masses of lepidolite are recorded in Geological Survey of Western Australia (1994). Jacobson et al. (2007) show the location of a discrete lepidolite zone within the Tabba Tabba main tantalite pegmatite workings in mining lease M45/376.

Petalite

Petalite is a granitic pegmatite mineral commonly associated with other lithium minerals such as spodumene, amblygonite, eucryptite, and lepidolite, and common pegmatite minerals including alkali feldspars, quartz, tourmaline, topaz, pollucite, and tantalite. Petalite is an uncommon gem mineral with a tabular habit and light-coloured appearance similar to feldspar. It may be faceted if it is transparent, quality material (Fig. 8.7).

The host pegmatite group for petalite is the lithium–cesium–tantalum (LCT)-type pegmatite that forms at low to moderate pressures (2.5 – 4 kb) and temperatures of 500–650°C. Petalite forms in a subclass of LCT-type pegmatites in a group containing lithium-bearing minerals (Jacobsen et al., 2007). Several mineral assemblages form as pseudomorphs after petalite, including spodumene–quartz, prehnite–quartz, albite–quartz, cookeite–quartz, and eucryptite–quartz. Eucryptite was first recognized at Londonderry in 1963, and is typically intergrown with quartz. Hard, white albite pseudomorphs after petalite from both Londonderry and the nearby pegmatite at Lepidolite Hill have been termed ‘hornstone’.

Petalite commonly crystallizes as large, cleavable blocks, although transparent facetable-grade petalite crystals are uncommon and cut gemstones are considered a rarity. Recent sources of faceted petalite originating from Brazil indicate that gems of over 40 ct may still be found. As cut stones, petalite has a glassy appearance and an unusual slippery feel compared with other colourless gems of similar appearance such as quartz. Although cut specimens of petalite are commonly without inclusions, generally incipient cleavages are present. Internal features of gems show distinct doubling as the birefringence of petalite is high relative to other colourless gems such as quartz. Translucent, quality petalite, petalite pseudomorphs, and altered pink petalite and eucryptite host rocks may all be cut as cabochons. Also, petalite is an important industrial mineral used as a source of lithium.

Physical properties of petalite

Crystal system	Monoclinic
Habit	Often massive, blocky, or tabular; crystals are rare
Colour range	Greyish-white, white, colourless, rarely pink, yellow, and green
Lustre	Vitreous or pearly
Diaphaneity	Transparent to translucent
Refractive index	1.505 – 1.523
Birefringence	0.011 – 0.017
Hardness	6 – 6.5
Specific gravity	2.390 – 2.422
Cleavage	Perfect basal (001) and good (021) faces

Petalite in Western Australia

Petalite has been recorded from several Western Australian pegmatites although the only occurrences of any significance are within pegmatites of the Londonderry pegmatite field. At the time of its discovery in the late 1920s, the Londonderry feldspar deposit was one of the few significant petalite localities in the world (Jacobsen et al., 2007).

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry pegmatite field *(Yilmia, 3135)*

Londonderry feldspar pegmatite

The Londonderry feldspar pegmatite is about 20 km south-southwest of Coolgardie via the Nepean Road (Figs 8.3 and 8.5). The pegmatite was first discovered in 1909 and the first quarrying operations for feldspar commenced in 1929 with petalite production starting in 1947. Mining continued at irregular intervals until 1987, and currently the extensive pegmatite mullock heaps are being crushed for road gravel.

The Londonderry pegmatite is about 1000 m long and 200–280 m wide; it is an ovoid-shaped body tapering off to the south. Eight asymmetrical zones have been recognized in the pegmatite with each zone defined by a specific set of mineral assemblages. The petalite–quartz and petalite–quartz–albite–muscovite zones occupy the central portion of the main pegmatite exposed in the southwest quarry. Here the petalite-bearing zones were extensively altered and much of the original petalite has been altered to eucryptite–quartz, prehnite–quartz, albite–quartz, and cookeite–quartz assemblages (Fig. 8.8).

Petalite found in this deposit displays large platy crystals with a distinct (001) cleavage and ranges in colour from pearly white to colourless. It is recorded that rare, transparent pieces suitable for faceting were found and some of these are on display in the museum of the Western Australian School of Mines in Kalgoorlie (Reeve, 1973). More recently, mining activities appear to have removed most of the unaltered petalite.

Tantalite Hill pegmatite

The Tantalite Hill pegmatite is about 2 km north-northwest of the Londonderry feldspar pegmatite quarries (Fig. 8.5). Tantalite Hill consists of a zoned pegmatite containing a discontinuous, intermediate zone of quartz–microcline–petalite among others. The pegmatite has been mined in several small, shallow pits resulting in many mullock heaps. Small masses of grey to white petalite are exposed in a pit within the quartz–microcline–petalite zone and small, gemmy, clear fragments can be found on the heaps surrounding the pits. The alteration of the pegmatite is similar to that at the Londonderry feldspar and Lepidolite Hill pegmatite bodies.

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Figure 8.7. **Faceted petalite gemstones from Londonderry: left, 5.91 ct; right, 6.07 ct (courtesy Bill Moriarty)**

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Figure 8.8. **Pink, altered petalite and eucryptite rock from the Londonderry feldspar pegmatite quarry. Specimen is about 80 mm wide (courtesy Western Australian School of Mines, Kalgoorlie, sample 9536)**

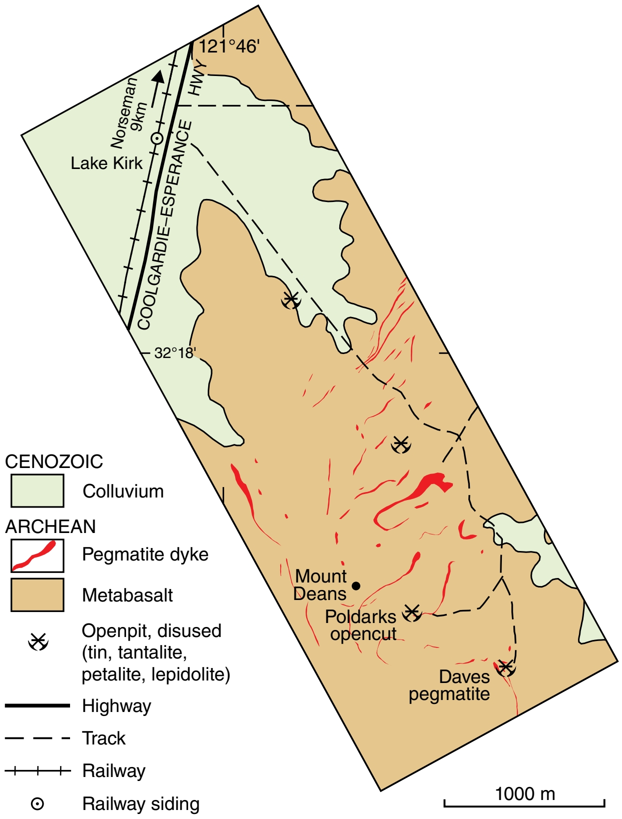

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Figure 8.9. **Geology of the Mount Deans area showing the location of Daves pegmatite opencut (modified after Fetherston, 2004)**

Lepidolite Hill pegmatite

Four-hundred metres southeast of the Tantalite Hill pegmatite prospect, the Lepidolite Hill pegmatite outcrops as two bodies within the Archean greenstones of the Eastern Goldfields Superterrane (Fig. 8.5). These pegmatites are distinctly zoned and the petalite–quartz–microcline zone is up to 14 m thick in the northeast pegmatite. Petalite appears as grey to pearly white masses with single crystal fragments averaging 20 × 8 cm. Some of the petalite has been altered to albite–quartz, and quartz–cookeite. There are no records of any transparent, facetable-grade petalite from this prospect.

Norseman region

Daves pegmatite *(Norseman, 3233)*

Daves pegmatite mine (also known as Daves claim) is in the Mount Deans pegmatite field about 13 km south of Norseman and 3 km east of the Coolgardie–Esperance Highway (Figs 8.3 and 8.9). At the openpit, workings have exposed several thin, steeply dipping pegmatites that are very strongly weathered. At Daves pegmatite, small crystals of petalite together with cassiterite and lepidolite were found (Johnson et al., 2007).

Spodumene

Spodumene is a pyroxene group mineral and one of a few gems that compositionally contain lithium. It is best known from its coloured gem varieties: kunzite (pink and violet), hiddenite (green), and a yellow variety. Both kunzite and hiddenite are eponymous varieties first recognized in the US in the late 19th century. Originally, the term hiddenite was used specifically for the bright green, chromium-bearing spodumene from the US. Today, it is customary to market green spodumene as hiddenite irrespective of the cause of colour. Although gem spodumene is still sourced from the US, other important world sources now are Afghanistan, Pakistan, Brazil, Madagascar, and Burma.

Physical properties of spodumene

Crystal system	Monoclinic
Habit	Prismatic, commonly flattened, striated, and etched
Colour range	White, grey, yellow, pink, violet, purple, blue, and green
Colour cause	Traces of manganese, iron, or chromium
Lustre	Vitreous
Diaphaneity	Transparent to opaque
Refractive index	1.660 – 1.675
Birefringence	0.015
Hardness	7
Specific gravity	3.17 – 3.19
Fracture	Uneven
Cleavage	Two well-developed cleavages parallel to the prism faces
Fluorescence	Pink, white, and yellow varieties commonly fluoresce under long-wave UV light and may display temporary changes of colour

Spodumene is a characteristic mineral of lithium-rich, granitic pegmatites, commonly known as lithium–cesium–tantalum (LCT)-type pegmatites from which it is mined as a source of lithium ore. Spodumene is typically associated with quartz, feldspar (albite), lepidolite, beryl, and tourmaline.

The chemical composition of spodumene shows only minor elemental substitution although it is commonly found as ‘rotten’ crystals pseudomorphed by a variety of minerals including clays, feldspars, and mica. Detailed studies of examples of altered spodumene show that included minerals such as mica may show specific orientation with the original prisms of the host spodumene. Spodumene also commonly contains micro-inclusions, which may account for some minor element chemical anomalies.

Spodumene in Western Australia

Pink, white, grey, and light green spodumene is found in Western Australia although rarely as facetable-quality crystals. Transparent-quality gem spodumene requires particular cutting skill during faceting, as it shows inherent perfect cleavages. Pink spodumene–quartz rock from Western Australia is used by lapidaries as a decorative material and is cut and polished to make items such as bookends. Small amounts of spodumene can be found in numerous LCT-type pegmatites in many areas of the State; the more significant deposits are described below.

Yilgarn Craton — Eastern Goldfields Superterrane

Kambalda region

Mount Marion *(Yilmia, 3135)*

Numerous spodumene-bearing pegmatites are present at Mount Marion, 26 km northwest of Kambalda (Fig. 8.3). These pegmatites are of unzoned quartz–spodumene type intruding Archean greenstones of the Eastern Goldfields Superterrane. The pegmatites contain substantial spodumene resources although there is no record of any gem-quality material. One pegmatite contains pale green to white spodumene crystals up to 30 cm long with the long axis of the crystals orientated perpendicular to the pegmatite contact (Jacobson et al., 2007).

Binneringie area

Bald Hill *(Yardina, 3334)*

The Bald Hill pegmatite group, a subset of the Binneringie pegmatites, are in and around the Bald Hill tantalite mine on Binneringie Station about 60 km southeast of Kambalda (Fig. 8.3). At this site, pegmatites outcrop as gently dipping sheets and steeply dipping veins that are aligned in a northerly direction, parallel to regional foliation. Pegmatites range in thickness from a few metres to around 30 m, and in some instances are multiple, parallel dykes separated by a few metres of sheared metasedimentary rocks.

At the Bald Hill mine, spodumene is incorporated in a quartz–albite–spodumene unit. During mining in 2002, spodumene was found to make up 30–50% of the rock with white to grey crystals up to 5 cm thick, 10 cm wide, and 1 m long. Vugs up to 2 cm in diameter are found in places in the albite zones of the spodumene-bearing unit. These mostly contain albite and microquartz crystals and may also contain other secondary minerals (Jacobson et al., 2007).

Yilgarn Craton — Southern Cross Domain

Ravensthorpe area

Cattlin Creek (Ravensthorpe, 2930)

Discovered in 1900, the Cattlin Creek pegmatite was the first spodumene to have been discovered in Western Australia. The pegmatite is along the old Newdegate Road, 1.9 km north of the town of Ravensthorpe where pits cut into the pegmatite can be seen to the east of the road (Fig. 8.3).

Despite extensive exploration and evaluation by various companies, only minor, intermittent mining of tantalum and bismuth ores was carried out until the current owners, Galaxy Resources Limited, commenced mining for lithium and tantalum in 2010. Cattlin Creek was once a popular local fossicking site although since mining commenced, access is no longer permitted.

The Cattlin Creek pegmatite outcrops on the western side of the Archean Ravensthorpe greenstone belt close to the contact between the mafic Annabelle Volcanics and the Ravensthorpe Quartz Diorite (Jacobson et al., 2007). The pegmatite is zoned and forms a flat-lying tabular body that is at least 800 m long × 400 m wide and approximately 25 m thick.

Spodumene crystals from this site ranging up to 0.7 × 0.15 × 0.1 m have been described by Simpson (1952). Some crystals were vertically striated and many were lamellar in habit with colour varying from almost colourless to greenish-white, and an apple-green. Despite this there are no records of any gem-quality spodumene from this pegmatite.

Also, detailed studies of the so-called ‘rotten’ spodumene from Ravensthorpe showed that it consisted of muscovite with the orientation of its sheet structure parallel to the prismatic faces of the original spodumene (Graham, 1975).

South West Terrane

Greenbushes area

Greenbushes mine (Bridgetown, 2130)

The extensive Greenbushes pegmatite is 80 km southeast of Bunbury and just south of the small town of Greenbushes on the Southwestern Highway (Fig. 8.3).

Cassiterite (tin ore) was discovered in this pegmatite in the 1880s. In 2002, the deposit was recognized for its large resources of tantalite and spodumene. Mining was carried out in two discrete pits and the mine subsequently became the largest Australian producer of tantalite and spodumene concentrates for industrial applications. Currently, spodumene mining continues from the southern openpit.

The 2.5 billion-year-old Greenbushes pegmatite was intruded into the Donnybrook–Bridgetown shear zone during a period of metamorphism and deformation. The main Greenbushes pegmatite and associated smaller pegmatites cover an area of about 7 km^2. The pegmatite trends north-northwest for about 2.5 km with a width of 61–244 m and an average dip of 65° to the southwest.

Greenbushes pegmatite is a relatively fine-grained, LCT-type containing mineralogical and compositional zones including a spodumene–quartz zone, a microcline–quartz zone, an albite–quartz zone, and a border zone (Fig. 8.10). Other lithium minerals recorded at Greenbushes include lithiophilite and amblygonite (lithium phosphates), lepidolite (lithium mica), and holmquistite (lithium amphibole) (Freeman and Donaldson, 2004).

The spodumene–quartz zone is composed of up to 60–80% sucrose to coarse-grained spodumene in which anhedral spodumene crystals have been found up to 70 mm in length. Also, in some areas albite, microcline, and muscovite form a minor part of the zone and accessory minerals include apatite, schorl, and tantalite.

There are no records describing any gem-quality spodumene from the Greenbushes deposit although a spodumene–quartz rock makes an attractive variegated pink and grey ornamental stone (Fig. 8.11). In hand specimen, the rock consists of anhedral, prismatic, pink-coloured spodumene intergrown with glassy, transparent, greyish quartz. Microcline, albite, apatite, and tourmaline were all identified as accessory minerals. Grain boundaries between spodumene and quartz are clearly visible and spodumene prism faces noticeably reflect light. The specific gravity of the rock was determined as 2.81, ‘spot’ refractive indices gave results of 1.54 for quartz and 1.66 for spodumene, and fluorescence was not detected (Brown and Bracewell, 1989).

At Greenbushes, mineral collecting by amateur groups and individuals is not permitted in the mining areas or dumps. By special arrangement with the owners, Talison Lithium Ltd, academic and amateur groups may be permitted to inspect the dumps and quarry pits.

Pilbara Craton

Pilgangoora area

Pilgangoora pegmatite field (Wodgina, 2655)

The Pilgangoora pegmatite field on Wallareenya Station is about 90 km south-southeast of Port Hedland and contains a large lepidolite–spodumene resource (Fig. 8.3).

First known in 1905, the Pilgangoora pegmatite field contains swarms of lepidolite–spodumene-bearing pegmatites with accessory columbite–tantalite (Jacobson et al., 2007). A description of the Pilgangoora pegmatite field is given earlier in this chapter under the section on lepidolite in Western Australia.

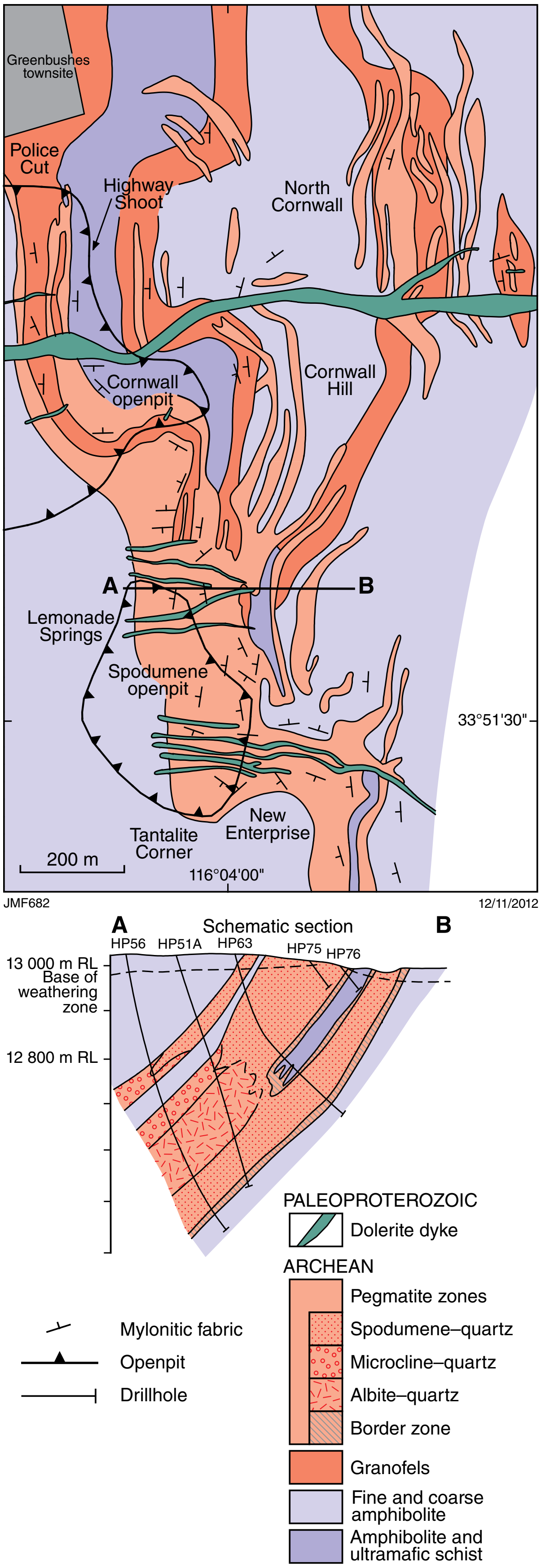


Figure 8.10 **Geological map of the Greenbushes pegmatite, with schematic cross-section showing the pegmatite zonation pattern (modified after Partington et al., 1995)**

Figure 8.11 **Polished tile of decorative pink spodumene–quartz rock from Greenbushes; tile is 40 mm wide**

Phenakite

Phenakite is a beryllium silicate mineral first identified in 1833 by the Finnish mineralogist Nils von Nordenskiöld from samples from the recently discovered emerald occurrences in the Ural Mountains. Phenakite (also phenacite) is commonly associated with other beryllium minerals, particularly emerald and chrysoberyl.

Phenakite is a rare beryllium mineral and a collector's gem. It is commonly colourless, although yellow, brown, and pink varieties also exist. The name phenakite derives from a Greek word alluding to deception and as a colourless mineral was mistaken by prospectors for both quartz and topaz. Phenakite has been found as large-sized crystals, particularly from Brazil, from where large faceted gems of around 100 ct have been fashioned.

Phenakite forms in granitic and miarolitic pegmatites and also in greisens and hydrothermal veins. It forms part of the emerald–chrysoberyl–phenakite mineralogical association in black schist-type emerald deposits. In this environment it is present as corroded relics within emerald porphyroblasts and is a precursor mineral of beryl (Franz and Morteani, 2002). Both phenakite and alexandrite (a variety of chrysoberyl with trace amounts of chromium) were first identified as minerals associated with emerald deposits in the Ural Mountains of northern Russia (Schmetzer, 2010).

Beryl is the most common beryllium mineral and is associated with less-common beryllium minerals euclase, chrysoberyl, and phenakite. Both euclase (a beryllium aluminium silicate) and phenakite (a beryllium silicate) are alteration and replacement products of beryl. Phenakite forms in a wider range of deposits than euclase although it appears restricted to environments with medium to low aluminium availability. It can be a precursor to emerald and may be replaced if aluminium and alkali metals become available. Intergrowths of chrysoberyl (alexandrite), emerald, and in places phenakite are locally found in or near desilicated pegmatites. Intergrowths of these beryllium minerals have also been produced synthetically by Russian researchers (Hainschwang, 2003).

Brazil is an established source of fine collectors' specimens and gem-quality phenakite from deposits such as the Talho Aberto granitic pegmatite in Minas Gerais State, and the Socoto deposit in Bahia State where phenakite is associated with emerald. At the Socoto emerald deposit, phenakite is rare with small quantities of brittle, milky to translucent specimens up to 10 cm in length recovered. These crystals have a short prismatic habit, commonly terminated by two rhombohedra (Cassedanne, 1985; Chaves et al., 1998).

Because of rarity and identification difficulties, both phenakite and euclase are not target minerals for prospectors. Production and availability of both minerals are strictly byproducts of exploration and mining of other gems such as aquamarine, emerald, diamond, and topaz.

Physical properties of phenakite

Crystal system	Trigonal, rhombohedral
Habit	Tabular rhombohedral crystals; also massive as intergrowths within beryl
Colour range	Most commonly colourless, also yellow, pink, and brown
Lustre	Vitreous; crystals may have a waxy appearance
Diaphaneity	Transparent to translucent
Refractive index	1.65 – 1.67
Birefringence	0.016
Hardness	7.5 – 8
Specific gravity	2.9 – 3.0
Cleavage	Distinct
Fluorescence	Inert in ultraviolet (UV) light

Phenakite in Western Australia

Phenakite has been recorded from two discrete occurrences in Western Australia. It was first recorded at the Mount Edon pegmatite field near Paynes Find, where it was found in massive form intergrown with beryl within a granitic pegmatite (Jacobson et al., 2007). A second occurrence is at the Wonder Well emerald deposit on Riverina Station in the Menzies region where colourless phenakite crystal specimens, including gem-quality material, have been collected.

Phenakite is easily distinguished from quartz by its optical character and higher specific gravity. As a gemstone, phenakite is faceted to display its moderate light dispersion. Some faceted gems of several carats have been produced from Western Australian specimens.

Yilgarn Craton — Murchison Domain

Paynes Find area

Goodingnow pegmatites *(Maranalgo, 2439)*

The Goodingnow pegmatite field is in the Mount Edon pegmatite field in the Paynes Find area. Spaced about 400 m apart, the two pegmatites (northern and southern) are about 400 m northeast of Mount Edon on former prospecting licence P59/7104 (Fig. 8.3). The pegmatite field is composed of a small group of columbite–tantalite-bearing pegmatites with minor amounts of lithium and other minerals.

The pegmatite in the northern pit contains zones composed of microcline–quartz–muscovite, albite, and several quartz segments. At its eastern end a 15 × 4 × 1.5 m pit is cut into the pegmatite, and about 10 m southeast of this pit, the pegmatite was found to contain mostly cleavelandite (a white, lamellar form of albite), zinnwaldite, and very fine-grained purple lepidolite. Other minerals present included beryl, allanite, manganotantalite, uranophane, and phenakite.

Phenakite from the northern pegmatite pit was identified as a minor intergrowth with beryl by the Western Australian Government Chemical Laboratories (Government Chemical Laboratories, 1965) and was the first record of the identification of phenakite in the State. Also, the Western Australian Museum has a specimen consisting of 2–4 cm-long, greyish-white masses provisionally identified as phenakite (specimen MDC 3648).

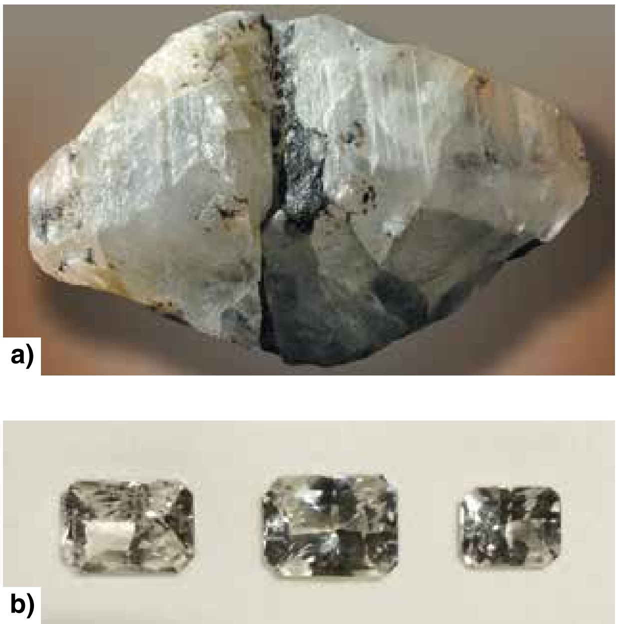
Yilgarn Craton — Eastern Goldfields Superterrane

Menzies region

Wonder Well *(Riverina, 3038)*

Wonder Well emerald pegmatites on Riverina Station are described in detail in Chapter 3 on the beryl group. At Wonder Well, emerald-bearing pegmatites are on mining lease M30/8 astride the Riverina – Snake Hill Road directly north of the Riverina Station Homestead about 60 km west of Menzies (Fig. 3.3).

In the late 1970s, a large crystal of white-grey, twinned phenakite was discovered by prospector Mr David Vaughan. The crystal was found within the black–brown biotite or phlogopite micaceous lens zones. Mica is attached to the crystal and also between the two components forming the twin. The crystal measures 75 × 56 mm and is well formed with slightly worn faces displaying a waxy appearance. It is also partly transparent although it has many fine fractures (D Vaughan, 2010, written comm.; Fig. 8.12a). More recently, three phenakite crystals from Wonder Well have been faceted as radiant-cut gemstones (Fig. 8.12b).



JMF739b 31/03/2016

Figure 8.12 Phenakite crystals from Wonder Well emerald mine on Riverina Station: a) white-grey, twinned crystal measuring 75 x 56 mm (courtesy David Vaughan); b) three radiant-cut phenakite gems weighing (left to right) 2.27 ct, 2.68 ct, and 1.33 ct (courtesy Murray Thompson)

References

Brown, G and Bracewell, H 1989, Greenbushes spodumene–quartz (a new Australian lapidary material): The Australian Gemmologist, v. 17 no. 1, p. 14–17.

Cassedanne, JP 1985, Recent discoveries of phenakite in Brazil: The Mineralogical Record, v. 16, March–April, p. 107–109.

Chaves, MLSC, Karfunkel, J and Hoover, DB 1998, Rare gems from Brazil part 1: euclase and phenakite: The Australian Gemmologist v. 20, no. 2, p. 80–86.

Ferguson, KM and Ruddock, I 2001, Mineral occurrences and exploration potential of the East Pilbara: Geological Survey of Western Australia, Report 81, 114p.

Fetherston, JM 2004, Tantalum in Western Australia: Geological Survey of Western Australia, Mineral Resources Bulletin 22, p. 135–140.

Fetherston, JM, Abeysinghe, PB, Jiang, S-Q and Wang, G-W 1999, Six industrial minerals of significance in Western Australia—bentonite, feldspar, kaolin, micaceous iron oxide, talc, and tourmaline: Geological Survey of Western Australia, Report 67, p. 15–25.

Freeman, MJ and Donaldson, MJ 2004, Major mineral deposits of southwestern Western Australia—a field guide: Department of Industry and Resources, Geological Survey of Western Australia, Record 2004/17, 38p.

Franz, G and Morteani, G 2002, Be-minerals: stability and occurrence in metamorphic rocks, *in* Beryllium: mineralogy, petrology, and geochemistry, Reviews in mineralogy and geochemistry volume 50 *edited by* ES Grew: Mineralogical Society of America and Geochemical Society, p. 551–588.

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, Perth, Western Australia, 52p.

Government Chemical Laboratories 1965, Government Chemical Laboratories annual report—1965 in Report of the Department of Mines for the year 1965, p. 184.

Graham, J 1975, Mineralogical notes: some notes on α-spodumene, $LiAlSi_2O_6$: The American Mineralogist, v. 60, p. 919–923.

Hainschwang, T 2003, Gem News International: Gems and Gemology, Fall, p. 227.

Jacobson, MI, Calderwood, MA and Grguric, BA 2007, Guidebook to the pegmatites of Western Australia: Hesperian Press, Perth, Western Australia, 356p.

Partington, GA, McNaughton, NJ and Williams, IS 1995, A review of the geology, mineralization, and geochronology of the Greenbushes pegmatite, Western Australia: Economic Geology, v. 90, no. 3, p. 616–635.

Reeve, J 1973, Some gem-bearing pegmatites near Coolgardie, Western Australia: The Australian Gemmologist, v. 11, no. 12, p. 21–22.

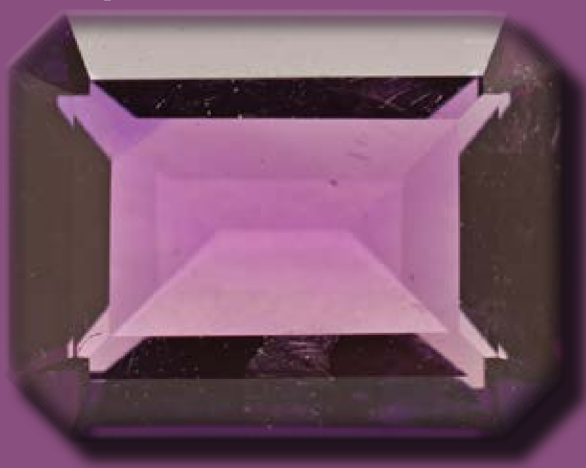
Ross, A 2003, The world's only deposit of 'arossonite'?: Australian Gem and Treasure, March, p. 18–19.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, 714p.

Schmetzer, K 2010, Russian alexandrites: Schweizerbart Science Publishers, Stuttgart, 141p.

3

Siliceous gemstones



Rectangular, step-cut, 1.71 ct amethyst from Wyloo (courtesy Australian Museum, Sydney)

Chapter 9

Quartz group

Gem-quality quartz

Quartz is a silicon dioxide (silica) mineral and a common constituent of many rock types. Quartz exists as two polymorphs: a low-temperature form termed common or α-quartz (alpha-quartz), and the high-temperature form, β-quartz (beta-quartz). Common α-quartz forms as trigonal crystals at temperatures below 573°C and forms within rocks in vugs and pockets. At 573–870°C, β-quartz forms, with a symmetry change in which the high-temperature quartz crystallizes in the hexagonal system. Beta-quartz constitutes quartz grains found in igneous rocks such as granites and volcanic lavas.

Gem quartz is sourced from a wide variety of geological environments where the most attractive crystals and crystal clusters are found as fracture fillings and veins where gashes and rock cavities (known as vugs and geodes) and amygdales (gas cavities in rocks such as basalt) have provided space for their development. Granitic pegmatites are an important source of gem-quality quartz crystal especially where miarolitic cavities or clay-filled pockets provided space and a suitably soft matrix in which euhedral (near perfectly formed) crystals may develop unimpeded. Quartz crystals that develop within vugs and geodes are commonly colourless, transparent, and euhedral, with lustrous crystal faces (Fig. 9.1). Coloured varieties from this environment include citrine (yellow), smoky quartz (brown), and amethyst (purple). By contrast, massive polycrystalline milky quartz displays no crystal form, and commonly forms as a major component of granitic pegmatites and as vein quartz. Milky quartz is typically translucent to opaque white because of evenly distributed gas and/or fluid inclusions.

Quartz has a hardness of 7 and is a standard used on Mohs scale of relative hardness. Quartz has no cleavage, and fractures to produce irregular, conchoidal shards resembling broken glass. It is a durable mineral so that quartz grains weathered from rocks may survive many cycles of weathering and erosion to commonly accumulate as almost pure sand and ultimately as sandstone.

JMF740 03/09/2012

Figure 9.1. Doubly terminated, colourless, 8 mm quartz crystal with prismatic habit from Yinnetharra in the Gascoyne region

Quartz crystals may attain gigantic size; for example, one such aggregate measuring 4.4 × 2.4 × 1.2 m is displayed in the Kristal Galerie, Swakopmund, Namibia. This crystal mass was recovered from a zoned, rare-metal pegmatite on Farm Otjua 37 in the Erongo region, Namibia. Crystal clusters of gem-quality quartz with perfect form and lustrous surfaces make aesthetic display specimens. Several examples of attractive crystal aggregations are displayed in public collections of the Western Australian Museums in Perth and Kalgoorlie.

Transparent colourless and coloured varieties of quartz are commonly cut and polished as faceted gems. Translucent quartz is commonly cut as cabochons, made into beads, or carved and fashioned as sculptural *objets d'art*. Quartz is also used as a medium for practising lapidary skills as it is both inexpensive and commonly available.

Quartz group

Macrocrystalline silica SiO_2

Physical properties of quartz

Crystal system	Trigonal (trapezohedral)
Habit	Prismatic with mostly short hexagonal prisms (commonly horizontally striated), and rhombohedra (+, –) usually unequally developed
Colour range	Quartz rock crystal — colourless Varieties: • amethyst — purple • smoky and cairngorm — brown and grey • morion — black • citrine — yellow • prasiolite — green • rose — pink • other colours from mineral inclusions
Colour cause	Colour variants may result from: • traces of iron (green quartz also from inclusions) • colour centres and inclusions (rose quartz from pink inclusions; white quartz from liquid inclusions and light scattering) • ionic state of iron (amethyst, Fe^{4+}; citrine, Fe^{3+}) • irradiation of quartz containing traces of aluminium (smoky)
Lustre	Vitreous (glassy)
Diaphaneity	Transparent to translucent
Refractive index	1.553 (ε) and 1.544 (ω)
Birefringence	0.009
Pleochroism	Weak in coloured varieties
Hardness	7 (Mohs scale standard mineral)
Specific gravity	2.650
Fracture	Conchoidal
Cleavage	None
Fluorescence	Inert in ultraviolet (UV) light
Absorption spectrum	Weak iron absorption bands

NOTE: ε and ω: extreme values for uniaxial minerals

In Western Australia, quartz deposits are widespread and Simpson (1952) and Jacobsen et al. (2007) detail numerous records of their occurrence. Quartz gems found in the State have been sourced from many geological environments. A selection of these environments is described in this chapter, including gem quartz derived from granitic pegmatites, veins, and cavity infillings.

Crystal structure

Quartz crystals are commonly found with a single termination at one end with the other termination being the point of attachment to the rock surface where the crystal commenced development. Doubly terminated quartz crystals can be found where favourable conditions existed such as where the enclosing matrix minerals were soft relative to the developing quartz crystal. Calcite, weathered feldspar, and clay zones may provide favourable environments for the development of doubly terminated quartz euhedra (Fig. 9.2).

Forms exhibited by quartz crystals and the nature of their crystal structure have several exceptional characteristics not found in other gem materials. Quartz crystallizes in the trigonal trapezohedral class of the rhombohedral subsystem of the trigonal system. Its common habit is as short, six-sided hexagonal prisms. Each prism termination comprises six rhombohedra (known as + and – rhombohedra), commonly of different sizes. Unequal development of crystal faces results from differential speed of growth of particular faces, which results in crystals that appear misshapen. Hexagonal prism faces are commonly striated parallel to the plane of the horizontal axes. These striations are formed by oscillatory development of prism and rhombohedra faces. Quartz that has undergone equal development of the rhombohedra may form bi-pyramidal crystals, and in the absence of the prism faces may develop as a six-sided pyramid, base to base, termed a quartzoid crystal.

Twinning (an intergrowth of two or more individual crystals) is common in quartz although it is not always obvious unless individual crystals are in contact. Twins commonly develop in quartz during crystal growth. Crystal twins are classified according to their twinning symmetry defined in relationships such as Dauphine and Brazil laws. For example, a Japan-law twin, comprising two quartz crystals, is in contact with the *c*-axes of the crystals inclined at 84°33´. Examples of this form of twinning for amethyst and citrine crystals are described in O'Donoghue (1987; Fig. 9.3). Twinning may be readily observed by microscopic examination under cross-polarized light where various complex patterns of extinction can be viewed.

Under the microscope, quartz is unique in having a spiral crystal structure that causes circular polarization, rather than plane polarization, of light. Single crystals of quartz commonly display a distinctive optical interference figure (a bullseye figure) and a gemmologist noting this optical figure can confirm the identity of the gem as quartz (Fig. 9.4).

Quartz mineral varieties

Colourless quartz is known as 'rock crystal', and *objets d'art* and gems fashioned from colourless quartz are commonly called 'crystal'. Note that the term crystal is also used to describe objects made from manufactured lead glass. Simpson (1952) makes reference to clear quartz as 'water-clear'. Quartz also occurs naturally as many coloured mineral varieties; for example, amethyst (purple), smoky and cairngorm (brown to brownish-grey), morion (black), citrine (yellow), prasiolite (green), rose (pink), and ametrine (distinct colour zones of purple and yellow in a single crystal). Aventurine quartz shows a glistening effect caused by fuchsite inclusions.

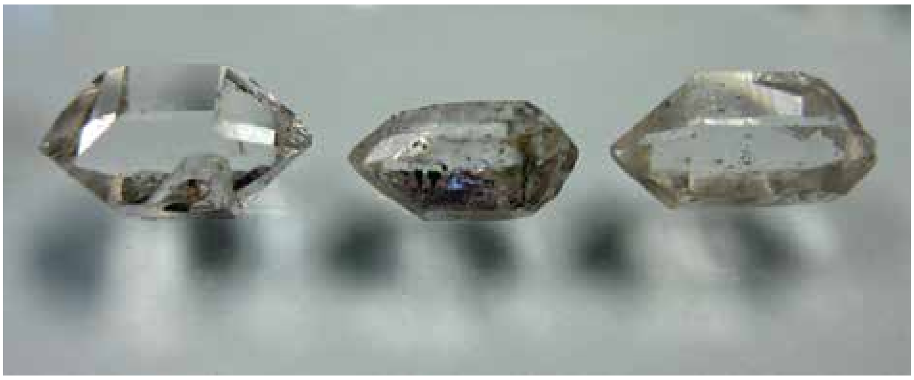


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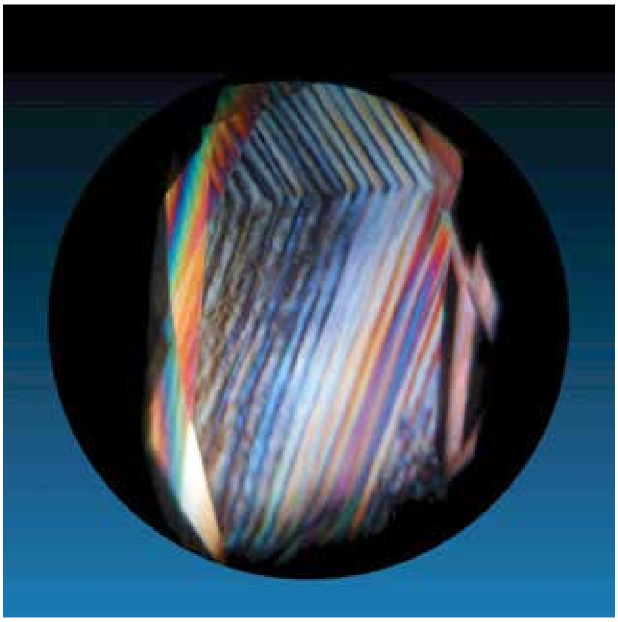
Figure 9.2. Euhedral, transparent quartz crystals each approximately 10 mm in length, recovered from surface deposits at Yinnetharra (courtesy Gemrock Enterprises)



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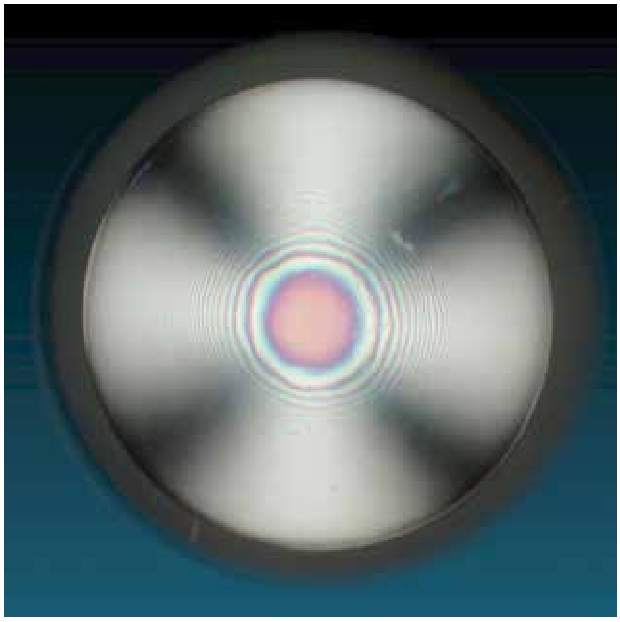
3 mm

Figure 9.3. Micrograph of amethyst crystal showing multiple twin planes viewed in cross-polarized light (courtesy John Harris)



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10 mm

Figure 9.4. Unique bullseye uniaxial quartz figure (courtesy John Harris)

Colour banding is common, especially in amethyst and citrine as chevron-style banding commonly parallel to directions of the rhombohedra faces. Quartz crystals commonly contain other minerals as inclusions, which can impart colour variations and optical phenomena to the host crystal to form, for example, asteriated and chatoyant varieties.

'Phantom quartz' is a term given a common growth feature of crystals that shows the shape of smaller crystals developed inside larger quartz crystals. Sometimes the shape inside the crystal is outlined by the deposition of included microscopic minerals (commonly iron oxide) that mark a stage in the growth of the parent crystal (Fig. 9.5). A succession of growth stages can sometimes be recognized as repeated and parallel shapes. Growth stages may also be marked by a change in the chemistry of solutions at the developing crystal faces visible as different colour zones. This effect is common in amethyst and citrine quartz.

Figure 9.5. **Zoned growth of an amethyst quartz crystal, which displays a sharply delineated, colourless border with contact planes marked by mineral inclusions; Wyloo area, Ashburton region (Western Australian Museum, specimen 888)**

Artificial treatments

Although quartz in all its colour variants forms naturally, quartz gems are routinely treated to improve or change colour. Heat treatment and mineral irradiation are two long-used methods. For example, amethyst heated to 250°C may lose its purple colour and change to yellow or yellow-brown to form artificially coloured citrine. Although citrine quartz occurs naturally, it is also supplied to the market from treated material. Heat-induced colour change results from a change in the valance state of iron within the quartz from Fe^{4+} to Fe^{3+}. Heat-induced colour change starting with amethyst can also produce green quartz as a substitute for the rare, naturally occurring prasiolite.

Brown and black quartz (commercially termed smoky, cairngorm, or morion) occurs naturally although it is also supplied to the market from quartz that has been irradiated. This process is effected using colourless quartz that in places contains small amounts of aluminium, which is irradiated to produce the smoky colour. Irradiation of quartz containing trace amounts of iron may also produce the purple colour of amethyst. Quartz colours may also be produced artificially using surface coatings.

Geological occurrence

Of most interest to collectors are locations where quality crystals can be readily found. These places include cavities and fracture zones where quartz has crystallized as druses infilling spaces that have provided for the growth of good crystal form. In Western Australia, quartz crystals are sourced from crystal pockets (‘blows’) within quartz veins and granitic pegmatites, fracture zones within dolomite and other sedimentary rocks, and from amygdale fillings associated with basalts.

Quartz in pegmatites

In Western Australia, most pegmatites show some mineral zonation or segregation although only a few are concentrically zoned. White quartz cores or large masses of quartz within pegmatites are common and provide the source of some quartz used by lapidaries. These are described from pegmatites such as Spargoville, Ubini, Paynes Find, and Cocanarup (Jacobson et al., 2007).

Crystal vugs, also known as miarolitic cavities, are rare within all forms of pegmatites in the State. Cavities that are present may be primary or replacement related. These cavities, also known as blows, are well known as potential sources of euhedral crystals especially if clay filled (Fig. 9.6).

Examples of gem crystals including quartz sourced from cavities in pegmatites recorded from Western Australia include green gem tourmalines from the Giles elbaite pegmatite at Spargoville, black quartz crystals from the Calcaling pegmatite at Mukinbudin, and red tourmaline and quartz crystals from the Forrestania rubellite pegmatite. Quartz crystal vugs within quartz cores are present in some deposits such as at the Kangan Station pegmatites, Mukinbudin feldspar pegmatites, and Oakdale Estate pegmatites. Quartz vugs in the Mukinbudin feldspar pegmatite formed as both primary vugs and in secondary fractures (Jacobson et al., 2007). Euhedral smoky and colourless quartz crystals found in topsoil and at shallow depths are reported as fairly widespread in granite cratonic areas in the State and are likely to have weathered from pegmatite sources.

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Figure 9.6. Amethyst quartz crystals lining the cavity of a slightly flattened vug (Western Australian Museum, specimen 5076)

Quartz in amygdales

Amygdales or gas cavities that develop within igneous rocks, especially basalts, are a source of quartz crystals commonly occurring as infillings with chalcedony. Quartz crystals are reportedly widespread from amygdales of the Archean Maddina basalt (Thorne and Tyler, 1997; Fig. 9.7) and from basalts in the Cambrian Antrim Plateau Volcanics (Gemuts and Smith, 1968).

Quartz in hydrothermal reefs and blows

Attractive specimens of clustered quartz crystals have been found in druses infilling cavities or blows that are widespread in gold mines and other metalliferous hydrothermal vein deposits in Western Australia.

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Figure 9.7. Cluster of quartz crystals from an amygdale in basalt from the Maddina Formation, Gregory Gorge, Western Australia. Crystals are euhedral and transparent with well-formed single terminations where space was available for their growth. The largest crystal measures 4 cm across (courtesy Glenn Archer)

JMF747a 31/03/2016

Figure 9.8. Spectacular quartz crystal cluster or ‘quartz blow’ from the Pilbara region on display at the Western Australian Museum

Simpson (1952) noted that where blows occur within quartz veins they are typically barren of gold. Vein quartz is a common gangue mineral of metalliferous veins and is commonly white, translucent, and massive (amorphous). Where vugs occur within veins, quartz may be found as crystals.

Quartz crystal specimens

Spectacular specimens of quartz crystal clusters from localities such as Northampton, Kalgoorlie, and the Pilbara region are displayed at the School of Mines Museum in Kalgoorlie and the Western Australian Museum in Perth (Fig. 9.8).

Gem-quality rock crystal, citrine, and smoky quartz in Western Australia

Yilgarn Craton — Eastern Goldfields Superterrane

Binneringie area

Binneringie pegmatite field (*Mount Belches, 3335*)

The Binneringie pegmatite field is in a north-trending zone about 50 km east-southeast of Widgiemooltha and 8 km northeast of Binneringie Homestead. The field extends over 8 km from the northeast corner of Lake Cowan in the south to Mount Belches in the north, encompassing the Dawn View and adjacent pegmatites, the Saint John pegmatites, and Mount Belches tantalum prospect (Fig. 9.9).

The Binneringie area comprises Archean quartz–biotite metasedimentary rocks and amphibolites of the Eastern Goldfields Superterrane. These north-trending metasedimentary rocks have been conformably intruded by pegmatites that appear as steeply dipping, elongate sheets and veins trending parallel to the regional foliation.

In this area, pegmatites range in thickness from a few metres to approximately 30 m and in some instances as multiple, parallel dykes separated by a few metres of metasedimentary rock. Binneringie pegmatite mineralogy is similar to pegmatites immediately east at Bald Hill where the mineralogy contains a quartz–spodumene–albite zone in which cassiterite, tantalite, and amblygonite are present together with a quartz–microcline–muscovite–albite zone. In addition to this zonation, the Binneringie pegmatites contain beryl and black tourmaline.

Saint John pegmatites

The Saint John pegmatites, part of the Binneringie pegmatite field, are poorly exposed, tantalum-bearing pegmatites on adjoining mining leases M15/1305 and 1308, about 10 km northeast of Binneringie Homestead (Fig. 9.9).

Prior to 2002, the area was worked for weathered pegmatite material in the colluvial layer up to 1.5 m thick adjacent to subcropping pegmatites. Processing of weathered pegmatite material yielded water-rounded columbite–tantalite crystal fragments including a large mass about 20 cm long and weighing 5 kg, and several 2–3 kg masses of water-rounded citrine. Smoky and clear quartz masses were also recovered.

From the crystalline quartz recovered, large yellow citrine stones (20–35 ct) were cut and polished (Fig. 9.10). Also, some of the large smoky, citrine, and clear quartz masses have yielded single euhedral crystals, originally formed in vugs, whose crystal faces have been water-rounded during transportation processes.

Spargoville area

Giles and South Spargoville pegmatites (*Yilmia, 3135*)

About 6 km south of Spargoville in the Kambalda region, the Giles and South Spargoville pegmatites are sited only 400 m apart (Fig. 9.9). At these localities, the Giles columbite–beryl and the South Spargoville columbite pegmatites have been recorded as containing gem-quality quartz crystals including a 7 cm-long, doubly terminated milky white quartz crystal encrusted with green elbaite tourmaline crystals (Jacobson et al., 2007).

Edjudina area

Local Lady mine (*Lake Carey, 3339*)

The Local Lady gold mine is about 180 km north-northeast of Kalgoorlie and about 1.5 km south of the old Linden townsite (Fig. 9.9). It is recorded that about 40 kg of clear, doubly terminated single quartz crystals, up to 140 mm long, were collected from a clay-filled vug at the top of a quartz blow on the northeastern side of the Local Lady gold mine (WR Moriarty, 2012, written comm.).

Yilgarn Craton — Southern Cross Domain

Mount Holland area

Forrestania rubellite pegmatite (*Holland, 2833*)

The Forrestania rubellite pegmatite deposit (also known as the Southern Cross rubellite deposit) is in the Mount Holland pegmatite field about 112 km south-southeast of the town of Southern Cross and 6 km east-southeast of Mount Holland (Fig. 9.9).

This pegmatite, described in Chapter 4 on the tourmaline group, lies within the north-trending greenstone belt of the Southern Cross Domain. The pegmatite has been intensely weathered to a clay-like material. It appears likely that crystallization within gem pockets in a central pegmatite zone yielded specimens of euhedral quartz together with rubellite tourmaline, and a terminated crystal of elbaite. Significant wall zones of the pegmatite contain microcline–quartz and quartz–lepidolite–cleavelandite.

Opencut mining in the early 1980s resulted in a pit 10–18 m deep, 30–50 m wide, and 75–150 m long. The pegmatite was worked for tantalite (manganotantalite and microlite) and for gem pink tourmaline (rubellite). During mining, two rare tantalum minerals, stibiotantalite and kimrobinsonite, were found associated with the quartz–cleavelandite–lepidolite pegmatite.

Tantalite mining ceased by the late 1980s although the pegmatite has remained a site visited by prospectors and fossickers. The mullock heaps have been picked over for pink gem tourmaline and more recently for pink gem beryl.

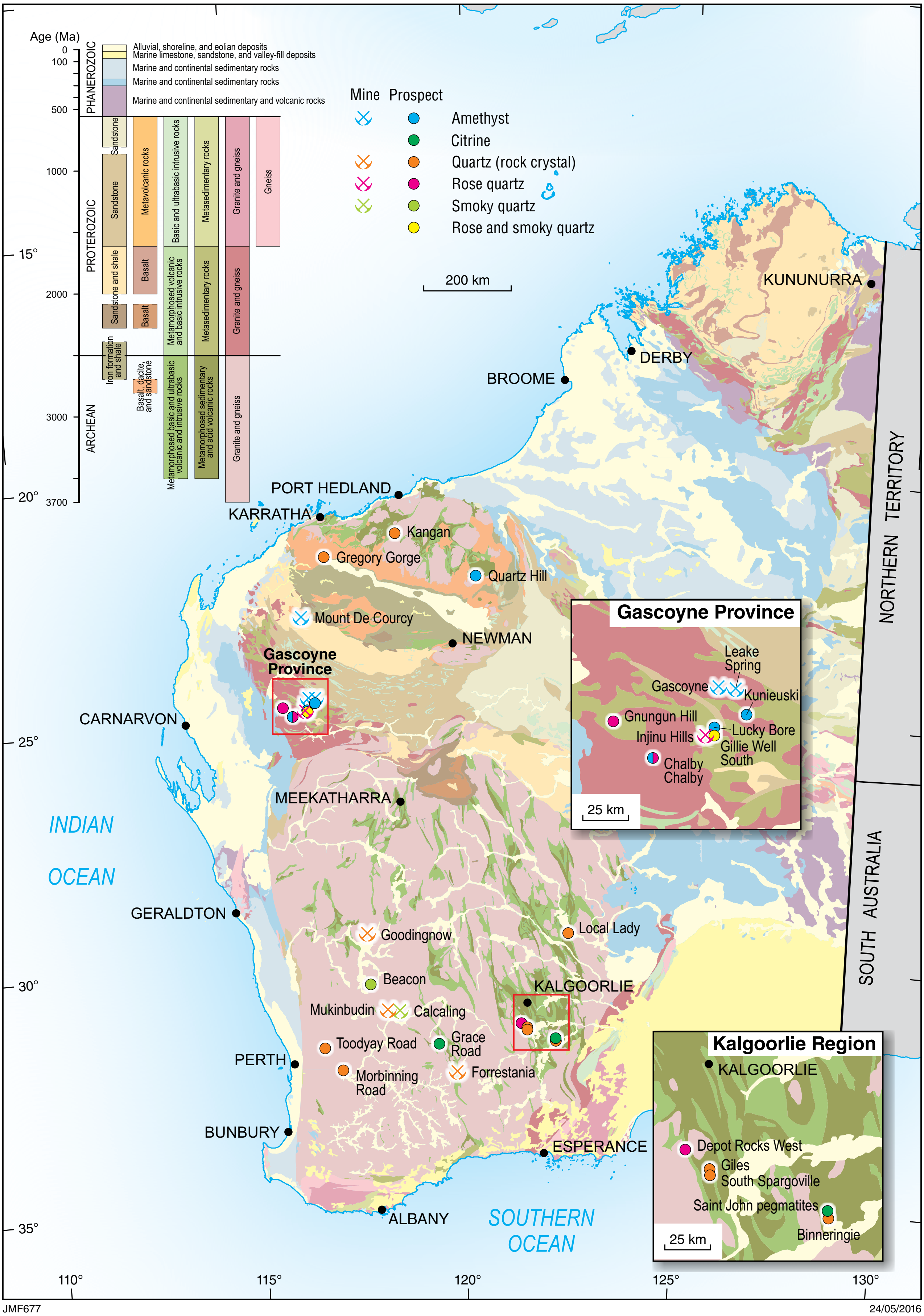

Figure 9.9. Locations of gem-quality quartz minerals in Western Australia

Figure 9.10. **Cut and polished citrine quartz gemstone, 35 mm in diameter, from the Saint John pegmatites (courtesy Bill Moriarty)**

The pegmatite is currently worked and the owners have continued to mine pink tourmaline in a tunnel extending northeast from the small gem shaft on the northwest side of the east–west openpit.

The pegmatite is extremely weathered and most of the original microcline and albite feldspars have been altered to clay. The remaining residual minerals are mostly fractured and brecciated where quartz masses do not exceed 15 cm in diameter. In exposed pegmatite, the presence of clear colourless quartz and gem tourmaline crystals suggests that the pegmatite is probably mineralogically layered and gem pockets with vugs may be contained within the central core zone. Quartz crystals are reported to reach up to 2 cm in length (Jacobson et al., 2007).

Yilgarn Craton — Murchison Domain

Mukinbudin area

Mukinbudin feldspar mine (Barbalin, 2536)

The Mukinbudin feldspar mine (also called the Snowstone quarry) is adjacent to the Koorda–Bullfinch Road, about 7 km west-northwest of the town of Mukinbudin in the central Wheatbelt region (Fig. 9.9).

The deposit is on a rare-element pegmatite of the niobium–yttrium–fluorine (NYF) type and was developed between 1970 and 1999 as three quarries originally for high-purity white quartz, known as ‘snowstone’, and in later years for high-grade K-feldspar. The quarries, currently in care and maintenance, are contained within mining lease M70/118 owned by Sibelco Australia Ltd.

Initial exploration indicated the pegmatite mass contained a large quartz core, estimated to be 750 m long × 20 m wide. From the commencement of mining until 1975, the mine had produced and sold 29 111 t of white quartz. By the late 1980s the mine had been acquired for mining K-feldspar and at peak production in 1992 the mine was the second-largest feldspar producer in Western Australia.

The mine comprises three quarries, none of which is currently being worked. With the occurrence of euhedral quartz crystals, the mine has become an important site for mineral collectors and fossickers (with permission from the mining lease owners). Other minerals of special interest include fergusonite, allanite, monazite, and zircon.

The southeastern quarry at Mukinbudin is the smallest of the three quarries at about 50 m wide × 75 m long × 7 m deep. At this site, it was reported that it was possible to observe zonation from the massive white quartz core to the adjacent pure microcline zone, and the zone of intergrown quartz–microcline–plagioclase with scattered metre-sized biotite crystals near the contact with the granitic wallrock. The remains of several smoky quartz – microcline vugs are present along the eastern wall. Lustrous, grey to black quartz crystals up to 30 cm long were found in these vugs. Well-crystallized albite and microcline feldspars are reportedly still found in these vugs.

The quartz vugs formed as both primary vugs with later secondary fractures within the microcline–quartz zone, and in the quartz core. It was noted that single crystals may reach 25 × 15 cm, and that groups of parallel-growth crystals lining fractures may exceed 30 cm and 10 kg. Crystals vary from white, clear, clear with hematite inclusions, to dark, smoky quartz crystals. The smoky quartz crystals are highly lustrous and in places display overgrowth phantoms. All the quartz crystal vugs and fragments are described as being noticeably darker and clearer compared with the opaque white quartz of the core (Jacobson et al., 2007).

Calcaling pegmatite (Barbalin, 2536)

The Calcaling pegmatite is on farmland about 21 km east of Mukinbudin (Fig. 9.9). The pegmatite, outlined by a low quartz hill, was first investigated in about 1994. Mining operations followed initial exploration and an oval-shaped quarry was developed from which feldspar was exported during 1995–97. The mining lease was relinquished in late 1997 and by 1999 was under a new mining project with interest centred on the production of quartz from rock waste in the old quarry and from the surface quartz stockpile. The mining lease covering this project was surrendered in 2004.

In the Calcaling area, a granitic rock (biotite–quartz monzonite) has been intruded by swarms of quartz–feldspar–mica pegmatites. The white quartz surface outcrop indicates the pegmatite remains largely unexcavated. Prior to mining, the pegmatite in the quarry had no surface expression and was discovered by drilling. The pegmatite is zoned and of a highly irregular form within strongly weathered and foliated biotite–quartz monzonite.

The irregular shape of the pegmatite may result because its formation is related to fracture jointing and the presence of a large, vertically foliated greenstone mass in the southeast corner of the pegmatite. The composite quartz core appears to comprise large milky quartz masses intermixed with masses of microcline feldspar. A large mass of albite feldspar occupies the western part of the quarry floor and contains a few smoky quartz masses. One miarolitic cavity containing euhedral microcline, albite, and smoky quartz crystals was found within the albite.

The albite also contains thin plates of ilmenite with intergrown crystals of euxenite (a rare earth, niobium–tantalum mineral) and ilmenorutile. The wall zone is discontinuous with irregular fingers of graphic granite and quartz fracture fillings projecting from the pegmatite into the biotite–quartz monzonite. Monazite and beryl were also reported from albite in the mullock debris.

During mining in 2001, the quarry operator opened a primary smoky quartz–albite–microcline pocket in the albitic unit in the quarry wall. The pocket was about 0.6 m high × 0.6 m wide and extended at least 1.2 m into the quarry wall. The largest black smoky quartz crystal from this pocket was 40 cm long × 15 cm in base diameter, tapering to 7 cm at the top. Many other lustrous black, euhedral crystals are now in private collections. A few specimens of smoky quartz on an etched white albite matrix were also recovered. Most crystals were 10–18 cm long × 2–8 cm diameter (Fig. 9.11). Additional crystals have since been removed from this pocket.

Figure 9.11. Smoky quartz crystal cluster from the Calcaling pegmatite, Mukinbudin area (courtesy Stewart Cole)

Paynes Find area

Mount Edon pegmatite field (Maranalgo, 2439)

The Mount Edon pegmatite field (also known as Paynes Find or Goodingnow) is a small group of columbite–tantalite-bearing pegmatites with minor amounts of lithium minerals. The centre of the area is 7 km south-southwest of Paynes Find (Fig. 9.9).

The Paynes Find greenstone belt comprises a northeast-trending succession of ultramafic and mafic greenstones and metasedimentary rocks intruded by largely concordant although irregularly shaped bodies of felsic pegmatite and aplite. Pegmatites in the area are simple quartz–microcline–muscovite pegmatites although several have small core–margin zones of cleavelandite (a variety of albite). Quartz in small vugs within pegmatites has been noted from several pegmatites in the area.

Mining and exploration took place in the pegmatite field at Mount Edon during 1965–90. At the southern pegmatite, the Goodingnow feldspar and beryl quarries contained euhedral white microcline crystals up to 15 cm long together with small, 10 cm vugs containing quartz and gem-quality albite crystals along the edges of quartz masses.

The Mount Edon lepidolite–tantalite pegmatites are about 5 km to the south-southwest of the Goodingnow quarries. At this site, on old mineral claim MC59/5799, a group of three pegmatites has yielded small, glassy, clear quartz crystals and fragments of tantalite found in local debris piles.

Simpson (1952) recorded descriptions of quartz crystals that were clear and colourless sourced from the Orchid gold mining lease (GML 613) in the Paynes Find area. Clarke (1925) described these crystals with missing rhombohedra as originating in a vug from the main shaft. Quartz crystals have also been collected from the dump at this mine (Miles, 1944).

Bencubbin region

Beacon prospect (Beacon, 2437)

Gem-quality smoky quartz, citrine, and crystal quartz were reported by Blight et al. (1984) from the property of Mr F Ayres, about 17 km northwest of Beacon township (Fig. 9.9). The crystals were found in soil formed over quartz-infilled easterly trending fractures, parallel to dolerite dykes intruding local granitic rocks.

Southern Cross region

Grace Road prospect (Holleton, 2734)

Citrine is reported at the Grace Road prospect approximately 38 km south of Southern Cross (Fig. 9.9). The crystals occur as a quartz blow (not in a vein or a pegmatite) and have been exposed over 2 m in the floor of a gravel pit (Frank, 1974). No further information on this site is available.

Yilgarn Craton — South West Terrane

Northam area

Toodyay Road prospect (*Northam, 2234*)

Simpson (1952) described an occurrence of quartz crystals ranging up to 4.5 × 2.2 cm in topsoil on the Northam–Toodyay Road in the former Oakfield Estate about 5.6 km from Northam (Fig. 9.9).

Some of the crystals are described as perfectly clear and colourless, some contain phantom structures, and some have alternate prism faces corroded. Although the quartz crystals may originate from a pegmatite possibly on the south side of the Avon River, a search conducted in 2002 could not confirm this occurrence and the location of the prospect remains doubtful (Jacobson et al., 2007).

Beverley area

Morbinning Road prospect (*Brookton, 2333*)

Chin (1986) recorded an occurrence of clear, colourless to pale, smoky-brown quartz at the Morbinning Road prospect about 10 km east of Beverley (Fig. 9.9). The quartz prisms and pyramids are typically well formed although some crystals are slightly distorted. Growth of the crystals as phantoms is marked by inclusions of fine dust-like, reddish material, possibly hematite inclusions. The overall size of the crystals is not recorded although it is noted that only a few were of the minimum size (approximately 12 mm) that could be cut for optical purposes (Simpson, 1952).

A quartz crystal specimen from the Morbinning Road prospect is held in the mineral collection of the Western Australian Museum (S 3849).

Wickepin area

Hopes Farm prospect (*Yealering, 2432*)

Small, clear, phantom quartz crystals, mainly displaying pyramidal faces, were obtained from an unknown locality on a property known as Hopes Farm in the Wickepin area. Phantom crystals with iron staining suggested they originated from a vug in material containing iron (Simpson, 1952).

Pilbara Craton

Wodgina area

Kangan quartz prospect (*Wodgina, 2655*)

The Kangan quartz prospect is approximately 20 km west-northwest of the Wodgina tantalite mine and about 1.6 km west-northwest of Kangan Station Homestead (Fig. 9.9).

In 1944, quartz was investigated from pegmatites in an area of Archean greenstone rocks within the Wodgina pegmatite field. At the Kangan quartz prospect, in old prospecting area 2096, quartz crystal deposits are associated with pegmatites and quartz reefs that have intruded a series of quartzites and schistose amphibolites. Ellis (1945) reported two separate quartz deposits 200 m apart.

At the first pegmatite, quartz crystals were found on the surface extending to a depth of about 1 m over a width of 0.5 m on either side of a narrow central quartz core of a deeply weathered pegmatite, 60 m in length, from which eluvial tantalite was being worked. At this site, a red clay loam infilled open spaces in which the quartz crystals had originally formed. Crystals are described as up to 30 mm in length and terminated at one end, although others were flattened forms of hexagonal, prismatic crystals with one or both ends terminated by pyramids. Crystal sizes varied from about 6 mm wide × 25 mm long up to 100 × 30 mm. Intergrown crystals were also common.

The second pegmatite intrudes the same host rock. At the western end, a mass of quartz crystals was located in a shallow surface excavation in a narrow lens of weathered feldspar and kaolin. It was noted that the development of quartz with minor amounts of kaolin and decomposed feldspar appeared to have formed in an original open space at the very end of the pegmatite (Ellis, 1945).

Excavation at this site yielded many hundreds of quartz crystals showing a wide range of crystalline development and varying lengths up to around 280 mm. Many crystals showed obvious pyramidal development at both ends and all crystals showed extensive twinning, intergrowth, and cloudy inclusions although some smaller crystals were clear, glassy, and free from flaws. At the time of that report, quartz crystals were sent for testing for industrial purposes.

A doubly terminated quartz crystal from the Kangan deposit is held in the mineral collection of the Western Australian Museum (specimen 211).

Pilbara Craton — Hamersley Basin

Millstream area

Gregory Gorge (*Elvire, 2254*)

It is reported in Geological Survey of Western Australia (1994) that magnificent clusters of quartz crystals have been found in vugs in amygdaloidal basalt within the Maddina Formation, part of the Archean Fortescue Group (Fig. 9.7). This site is at an unknown location in the Gregory Gorge area on the Fortescue River, approximately 18 km west-northwest of Millstream (Fig. 9.9). No further information is available.

Amethyst in Western Australia

Amethyst is the visually attractive, purple form of quartz. The purple colour is commonly unevenly distributed and banded. The colour of amethyst is caused by iron colour centres, and iron inclusions, particularly goethite (FeOOH) or hematite (Fe_2O_3; Fig. 9.12).

Where amethyst colour is concentrated in zones parallel to crystal faces it produces a phantom-like appearance. Colour developed at crystal terminations can be more intense parallel to one set of rhombohedra (the *r*-faces) compared with that at the other set (*z*-faces). Colour patterns are also complicated by crystal twinning. The colour varies from dark blue-violet to a pale pinkish-violet with red and grey, and in some instances is of smoky appearance. Amethyst shows weak dichroism, displaying a colour change from grey-violet to purple. Colour may fade with exposure to sunlight and it is well known by prospectors that the purple colour may improve and intensify with depth in an excavation.

'Amethystine quartz' is a term describing colour-zoned amethyst and white or colourless quartz crystals grown together in a serrated and banded manner (commonly a feature of vein fillings; Fig. 9.13).

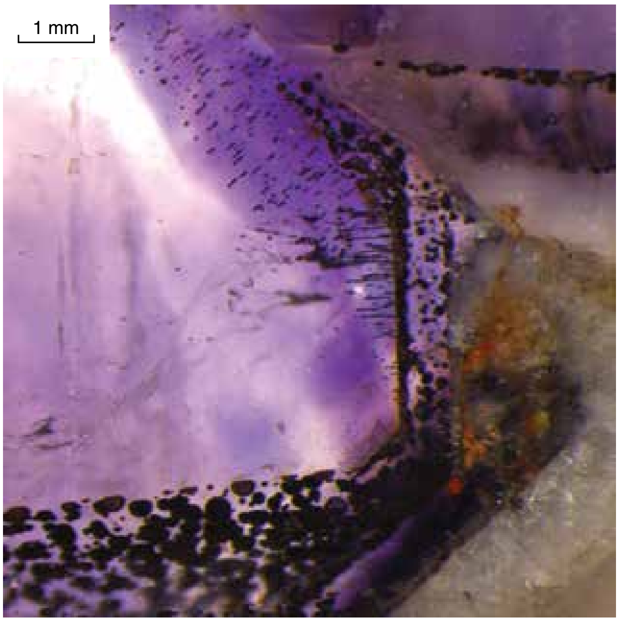

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Figure 9.12. Polished section of variably coloured, intergrown amethyst crystals with opaque iron oxide inclusions concentrated along crystal planes. The inclusions, up to 0.5 mm in length, are commonly dome shaped although others are spindle shaped

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Figure 9.13. Group of polished amethyst and amethystine quartz of various shapes including two pendants. The group displays the varicoloured nature of amethyst. In the upper row are specimens displaying chevron bands highlighted by dark inclusions (courtesy Dorothy Netherway)

Gascoyne Province

Mount Phillips area

Gascoyne amethyst field (Mount Phillips, 2149)

Amethyst was mined intermittently between 1970 and 1990 from the Gascoyne amethyst field in the Mount Phillips area, about 42 km west-southwest of Mount Augustus (Fig. 9.9). The amethyst mining operation is on mining lease M09/28 currently owned by Mr B Kayes. The operation was formerly known as the Mount Phillip amethyst mine, Soklich amethyst mine, and Gascoyne amethyst deposit. In this area, amethyst was mined from sites called Main Pit and No. 2 Pit. Over the mining period, production amounted to 360 t.

The Gascoyne field is a non-pegmatitic source of amethyst and is present in quartz segregations near calc-silicate and marble metamorphosed host rocks (Fig. 9.14). In zones of mineralization exposed in Main Pit and No. 2 Pit are breccia pipes, several metres wide, that contain a complex open-space filling assemblage of minerals including gem-quality amethyst (Fig. 9.15). The breccia pipes cut a tremolite-rich rock that appears to have been a metamorphosed, impure dolomite. These breccia pipes and their associated dilational amethyst veins are considered of epithermal, post-metamorphic origin intruding massive Paleoproterozoic, porphyritic to pegmatitic granitic rocks considered the youngest rocks exposed in the area. The textures of minerals within the pipes, their mineralogy, and the nature of fluid inclusions within amethyst crystals suggest an epithermal origin for these pipes (Johnson, 1995).

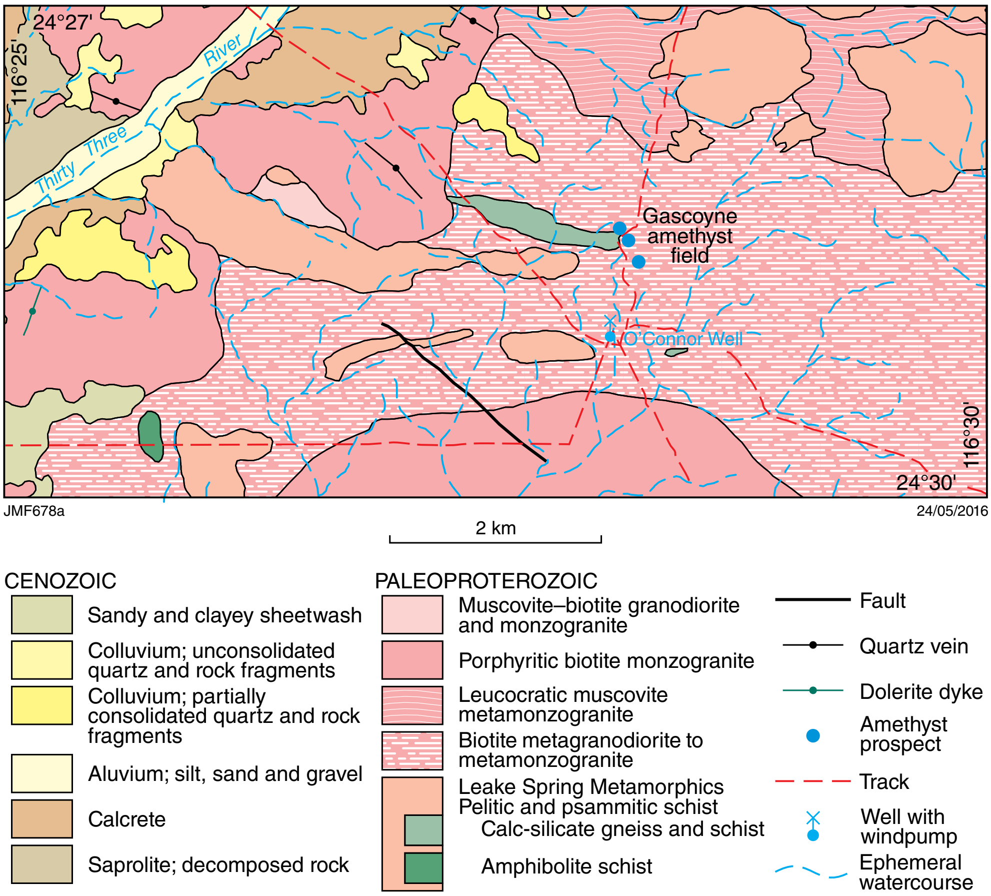

Figure 9.14. Geological map of the area surrounding the Gascoyne amethyst field (modified after Sheppard et al., 2008)

Figure 9.15. Detail of gem-quality, pale mauve to purple amethyst crystals developed in an open-space filling within large breccia pipes in the Gascoyne amethyst field (courtesy Bill Atkinson and Glenn Archer, © Bill Atkinson Photography)

The source of the pipes' hydrothermal fluid is unknown although fluid inclusions suggest an alkaline source possibly from post-metamorphic alkaline intrusions near Gifford Creek north of the Mount Phillips area. A feature of some of the pipe and vein quartz is a bladed texture after calcite, suggesting that the fluids were boiling at the time of the pipe formation. This interpretation is consistent with the brecciated nature of the pipes. Although sulfides are typically rare to absent, minor copper sulfide mineralization appears at the bottom of the Main Pit.

Up to eight textural vein styles have been recognized in the deposit, mostly relating to quartz although also to stilbite and calcite. Comb texture is a feature of most veins where large quartz and amethyst crystals have grown from opposite sides of a fracture. Growth zoning is also a characteristic of these crystals. Colloform banding is a common vein texture associated with chalcedony. Lattice-bladed calcite is commonly recognized in drillcore as an intersecting network of calcite blades. Rare, pseudo-bladed quartz after calcite is noted in vugs in veins, indicating a late-stage of deposition for calcite.

The extent of wallrock alteration is restricted to 2–3 m around the main structures. Main alteration types are argillization and silicification. Argillic alteration comprises green clays with lesser amounts of kaolinite and sericite. Silicification results in chertification and extreme toughening of the rock. Fluid inclusion studies show that total homogenization temperatures were around 200–220°C. Vein paragenesis studies indicate that the bladed calcite was formed later than the amethyst.

During the exploration phase, two holes were drilled, one in the near Mount Phillips, and one beneath Breccia Hill. Samples from the top 16 m from the hole at Breccia Hill revealed a continuation of quartz breccia including a clay-rich band extending 9–16 m. The remainder of the hole to a depth of 47 m was composed of coarse leucocratic granite (Johnson, 1995).

In 1995, amethyst was being exported to Germany. This amethyst was cobbed and heat treated to lighten the colour where the natural crystals were too dark. It was also noted that amethyst exposed at the surface for several years in the area around the mine site had turned a pale green colour (Bracewell, 1996).

Leake Spring amethyst mine (Mount Augustus, 2249)

The abandoned Leake Spring amethyst mine is adjacent to former mineral claim MC09/444 on Mount Phillips Station, about 24 km east-northeast of Camel Hill, and 13 km south of Leake Spring (Fig. 9.9). In total, 4163 kg of amethyst was produced from this openpit during 1971–72 (Connolly, 1980).

At this site, amethyst was found in quartz segregations in zoned pegmatite adjacent to relatively unaltered calc-silicate and marble within migmatitic zones of metamorphosed granitic rocks.

Kunieuski amethyst pits (Pink Hills, 2248)

About 4 km southeast of the Leake Spring amethyst mine and 16 km south-southeast of Leake Spring, the Kunieuski amethyst pits are on mining lease M09/72 (Fig. 9.9). At this site are two large openpits that were prospected for amethyst around 1975. It is known that amethyst samples from this site were submitted to overseas buyers although no other information is available.

Yinnetharra region

Lucky Bore prospect (Yinnetharra, 2148)

Poor-quality amethyst has been recorded at the Lucky Bore alluvial tantalite prospect, 3 km south-southwest of Gillie Well (bore) in the Camel Hill area (Williams et al., 1983; Fig. 9.9).

Chalby Chalby prospect (Yinnetharra, 2148)

The Chalby Chalby amethyst and rose quartz prospect (also known as Jackson Well) is 19 km south-southwest of Yinnetharra Homestead (Fig. 9.9).

In 1997, five costeans were trenched across an amethyst and rose quartz outcrop on prospecting licence P09/376 (now P09/458). Four costeans to 4 m depth exposed amethyst and rose quartz along two en echelon veins. Each vein varied in thickness 5–35 cm with approximate lengths of 120 m. The veins appeared to merge and increase in thickness with depth. The quartz exhibited a cockscomb vein texture with the purple colour increasing towards vein centres. Only amethyst and rose quartz were reported (Jacobson, et al., 2007).

Ashburton Basin

Wyloo area

Mount De Courcy amethyst mine (Wyloo, 2152)

The deposit at Mount De Courcy, on mining lease M08/7, about 18 km southeast of Wyloo Homestead and adjacent to the Wyloo marble mine, has been an important mining area for the production of amethyst (Fig. 9.9).

In this area, amethyst is found in late-stage quartz-cavity infillings in faulted, slope-facies breccia in the Paleoproterozoic Duck Creek Dolomite. In the area, the dolomite is a thin to thickly bedded unit, locally stromatolitic with minor chert and mudstone horizons (Fig. 9.16). Amethyst found in the area has been described as mainly inferior in colour although some good-quality material is reported (Thorne and Seymour, 1991). Despite various reports, some large crystal display specimens have been sourced from the claims (Figs 9.17 and 9.18).

The amethyst mineral claims on Wyloo Station were originally known as 'The Great Australian Amethyst mine' and have had a long history of exploration and mining.

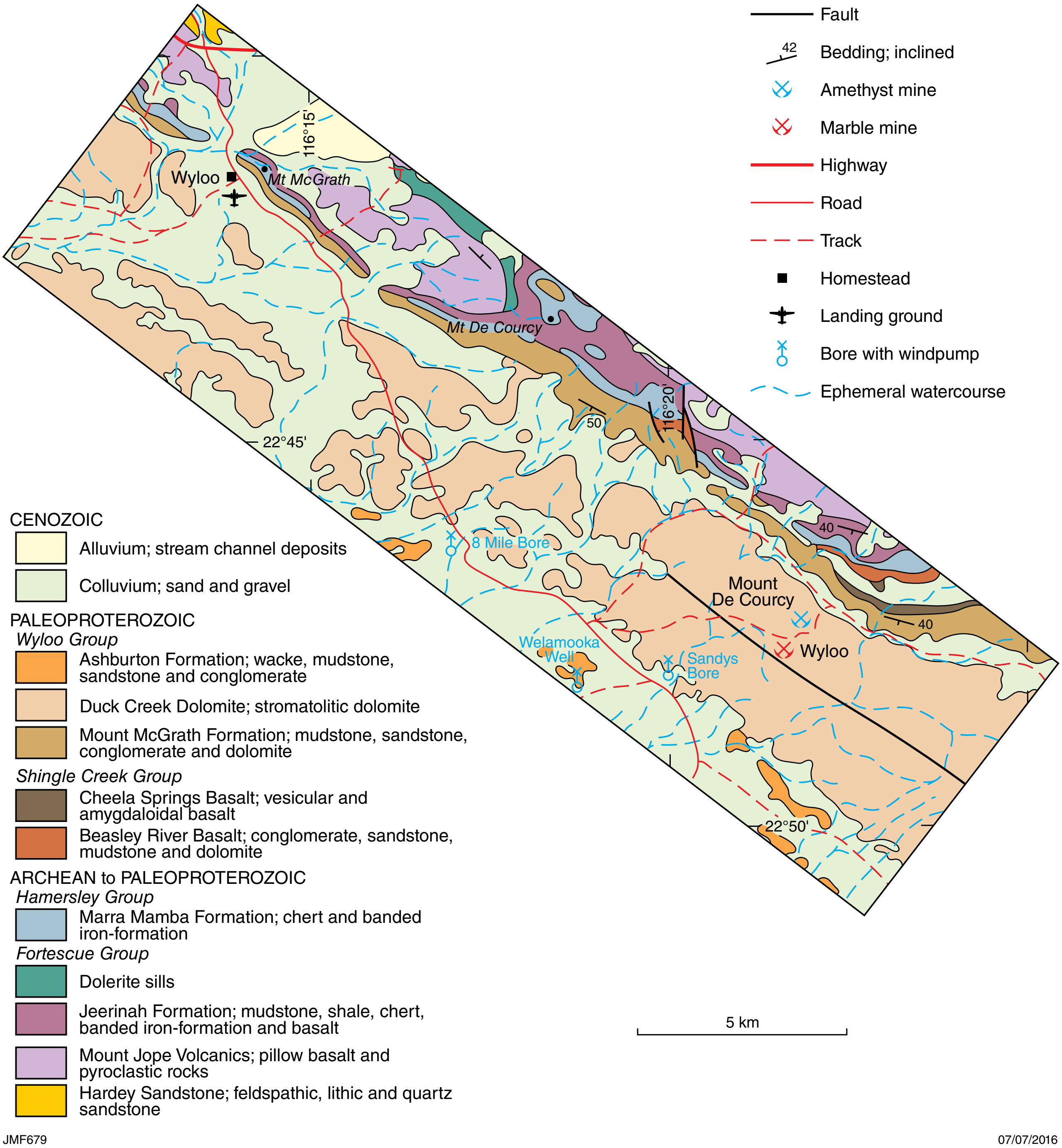

Figure 9.16. Geological map of the area surrounding the Mount De Courcy amethyst mine (modified after Blight et al., 1986)

Figure 9.17. Amethyst quartz crystal terminations from the Mount De Courcy mine at Wyloo (courtesy Murray Thompson)

Figure 9.18. **Rectangular, step-cut, 1.71 ct amethyst from Wyloo (courtesy Australian Museum, Sydney)**

The discovery of amethyst was originally made by prospectors searching for gold in the early 1900s. Simpson (1926) described amethyst from an undefined source not far from Survey Station 71 on the Hardey River and it is possible that this source is the same as for the current mining area on Wyloo Station. A test sample of amethyst crystals from the Wyloo claims was taken to Onslow by camel. From there it was shipped to Fremantle and then to England for assessment. A report dated 1906 from J Cohen and Co. of Hatton Garden London stated, ‘We have had them carefully examined and find them without any commercial value whatever. None of the specimens would yield a clean stone of any size or sufficient depth of colour to make it worthwhile to pay the cost of cutting’ (Simpson, 1926).

Following this early period, the claims were taken over although remained unworked until 1966 when the Soklich family, gem merchants from Perth, commenced mining amethyst. During 1967–78, around 18.8 t of amethyst was produced from various pits in the area. At this time, the deposit was described as a dyke consisting of decomposed feldspar in which perfect amethystine crystals had formed. An estimate of the dyke’s dimensions was given as 1.5 – 2.75 m wide and extending for approximately 1.1 km across the top of the hill. A drillhole showed amethyst present in cores spaced at intervals of 0.75 m to a depth of 18.3 m.

Amethyst present at the surface is described ‘sun bleached’ and it is known the colour intensifies with depth. Some crystals are described as doubly terminated and suitable for faceting with higher quality material most common at crystal terminations (Bracewell, 1995). Also, several single crystals had diameters of 12–15 cm without twinning or fractures (Leiper, 1967), and Cronstedt (1969) noted the abundance and size of perfectly terminated clusters and doubly terminated crystals, stating that these forms were ‘not scarce’.

Pilbara Craton

Nullagine area

Quartz Hill amethyst prospect *(Nullagine, 2954)*

At the Quartz Hill amethyst prospect, about 21 km southeast of Nullagine in the east Pilbara region, two openpits for amethyst exploration were established on mining lease M46/122 (Fig. 9.9). These openpits, spaced about 650 m apart, are currently inactive. The northern pit is known as the Soklich Quartz Hill amethyst prospect.

This amethyst prospect was reported by Simpson (1952), who described fragments of worn amethyst attached to the upper half of roughly crystallized quartz that may have been derived from a pegmatite. No other information is available in relation to these prospects.

Rose quartz in Western Australia

Rose-coloured quartz in Western Australia is light pink with semitranslucent diaphaneity. Several mechanisms involving mineral inclusions may result in the pink colour in quartz. An important mechanism is the presence of nanofibrous mineral inclusions. Rose quartz deposits in Western Australia have been rarely reported apart from a small number of pegmatite localities where the rose quartz is commonly massive and without crystal form.

Yilgarn Craton — Eastern Goldfields Superterrane

Spargoville area

Spargoville *(Yilmia, 3135)*

Specimens of rose quartz have been collected from pegmatites at unrecorded sites in the Spargoville area; however, photographs still exist showing faceted rose quartz gemstones from this area (Fig. 9.19).

Kambalda region

Depot Rocks West prospect *(Yilmia, 3135)*

A prospector reported the pegmatite prospect at Depot Rocks West containing rose quartz, mica, and feldspar in its outer rim (Fig. 9.20). The pegmatite is hosted by andalusite-rich metamorphosed rocks. This prospect is on former prospecting licence P15/5337, about 17 km southwest of Mount Marion in the Kambalda region (Fig. 9.9). No other information is available on this site.

Figure 9.19. Faceted, light pink, translucent rose quartz gemstones from the Spargoville area (courtesy Bill Moriarty)

Gascoyne Province

Yinnetharra region

Bracewell (1996) reported a deposit containing masses of 'coconut ice'-coloured rose quartz at an unspecified locality in the area of Yinnetharra Station although no faceting-quality material was found. Kenyon (1993) reported numerous pegmatites in the area containing quartz cores, some of which were in the form of rose quartz. It was noted that exposure to sunlight caused fading of the coloured quartz minerals. It was also reported that several sites in the area had been severely damaged by blasting.

Injinu Hills (Yinnetharra, 2148)

The Injinu Hills rose quartz mine is on mining lease M09/58 about 8 km southwest of Gillie Well in the Camel Hill area (Fig. 9.9). All that is known about this mining operation is that it is owned by Soklich Holdings Pty Ltd and rose quartz and high-quality quartz crystals have previously been mined from quartz segregations in a zoned pegmatite.

Another rose quartz occurrence, known as Lucky Bore 2, has also been reported in this area. In 1984, the area was prospected by Mr Alex Kenyon on former exploration licence E09/590. It is reported that additional rose quartz could be expected at other sites within the central band of local pegmatites (Kenyon, 1994). The location of Kenyon's exploration site is doubtful although it may be in a disturbed area approximately 250 m north-northeast of the Injinu Hills mine.

Gillie Well South prospect (Yinnetharra, 2148)

The Gillie Well South prospect is approximately 5 km south-southwest of Gillie Well in the Camel Hill area (Fig. 9.9). Rose and smoky quartz have been sourced from quartz segregations in a zoned pegmatite at this site.

Gnungun Hill (Lockier, 2048)

Simpson (1926) records highly translucent, pale rose-pink quartz in masses weighing several kilograms from an unknown site in the Gnungun Hill area, between the Lockier Range and Pyramid Hill on Bidgemia Station, approximately 30 km west-northwest of Yinnetharra Homestead (Fig. 9.9). A specimen from this site (S 3739) is held in the mineral collection of the Western Australian Museum.

Other gem-quality quartz sites in Western Australia

There are many other sites for gem-quality quartz minerals in Western Australia, as indicated by many attractive stones that form part of the Western Australian Museum's mineral collection. Many of these specimens are from sites whose locality is uncertain or unknown. Some of these are listed in Table 9.1.

Table 9.1. Other gem-quality quartz sites in Western Australia

Mineral	*Locality (approximate)*	*Specimen no.*
Quartz (perfect doubly terminated crystals)	Brisi Farm, 0.8 km north of Walpole	S 3846 and S 3019
Quartz	Orchid gold mine, Paynes Find area	S 3844
Quartz	Bird in Hand gold mine, Coolgardie	S 3855
Quartz	Lake View gold mine, Kalgoorlie, 1400 ft (approximately 425 m) level	S 3859
Rose quartz	Cairn Mining Centre, Yinnetharra area	688
Smoky quartz (cluster)	Baddera lead mine, Northampton	S 3448

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Figure 9.20. Rose quartz site at Depot Rocks West prospect in the Kambalda region. The exposure is about 4 m in diameter (courtesy Francine Payette)

References

Blight, DF, Chin, RJ and Smith, RA 1984, Bencubbin, Western Australia: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, p. 9.

Blight, DF, Seymour, DB and Thorne, AM 1986, Wyloo, WA Sheet SF 50-10, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series.

Bracewell, H 1995, Gems around Australia, part 11: The Australian Gemmologist v. 19, no. 4, p. 182–184.

Bracewell, H 1996, Gems around Australia, part 12: The Australian Gemmologist v. 19, no. 6, p. 252–254.

Chin, RJ 1986, Corrigin, Western Australia: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, p. 17.

Connolly, RR 1980, Mineral Resources of Western Australia: Department of Mines, Perth, Western Australia, p. 70.

Cronstedt, K 1969, The Great Australian Amethyst mine: The Australian Gemmologist, August, p. 23.

Clarke, E de C 1925, The geology and mineral resources of the Yalgoo goldfield: Geological Survey of Western Australia, Bulletin 86, p. 14–38.

Ellis, HA 1945, Report on quartz crystal deposits on PA 2096, Pilbara goldfield, Kangan Station, North West Division: Geological Survey of Western Australia, Annual Report for 1944, p. 10–12.

Frank, PH 1974, Geological assessment report on Southern Cross citrine prospect: Geological Survey of Western Australia, Statutory exploration report, A6629 (unpublished).

Gemuts, I and Smith, JW 1968, Gordon Downs: Commonwealth of Australia, 1:250 000 Geological Series Explanatory Notes, 23p.

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, Perth, Western Australia, 52p.

Jacobson, MI, Calderwood, MA and Grguric, BA 2007, Guidebook to the pegmatites of Western Australia: Hesperian Press, Perth, Western Australia, 356p.

Johnson, G 1995, Annual Report on Exploration Licence 9/627, Mount Phillips, WA: Geological Survey of Western Australia, Statutory exploration report, A44063 (unpublished).

Kenyon, A 1993, Annual report 10 September 1992 to 9 September 1993, E09/534, Camel Hill: Geological Survey of Western Australia, Statutory exploration report, A41594 (unpublished).

Kenyon, A 1994, Annual report 21 January 1993 to 20 January 1994, E09/590, Lucky Bore: Geological Survey of Western Australia, Statutory exploration report, A41595 (unpublished).

Leiper, H 1967, Possibly the world's largest deposit of amethyst found in Western Australia: The Lapidary Journal, v. 21, p. 18–36.

Miles, KR 1944, Notes on an inspection of quartz crystal deposits, Goomalling, Morowa and Payne's Find: Geological Survey of Western Australia, Annual Report, p. 50.

O'Donoghue, M 1987, Quartz: Butterworths Gem Books, London, 110p.

Sheppard, S, Farrell, TR, Martin, DMcB, Thorne, AM and Bagas, L 2008, Mount Phillips, WA Sheet 2149: Geological Survey of Western Australia, 1:100 000 Geological Series.

Simpson, ES 1926, A geological reconnaissance of part of the Ashburton drainage basin with notes on the country southwards to Meekatharra: Geological Survey of Western Australia, Bulletin 85, p. 82–83.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 460–470.

Thorne, AM and Seymour, DB 1991, Geology of the Ashburton Basin Western Australia: Geological Survey of Western Australia, Bulletin 139, p. 123.

Thorne, AM and Tyler, IM 1997, Roy Hill Western Australia, 2nd edition, Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 22p.

Williams, SJ, Williams, IR, Chin, RJ, Muhling, PC and Hocking, RM 1983, Mount Phillips, Western Australia: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, p. 24.

Chapter 10

Opal

Opal properties

Opal is a form of hydrated silica (silicon dioxide) and is either amorphous or poorly crystalline. It is commonly found within the regolith as a secondary material where it formed at low temperatures from silica-rich solutions.

Visually, two distinct types are recognized: precious opal and common opal. Precious opal, also known as noble or true opal, shows play-of-colour, a phenomenon that is a display of iridescent colours against the background of light to dark body colour tones. Precious opal can be translucent or opaque in diaphaneity. Common opal exists in a varied range of body colours and can also be opaque or translucent although it shows no play-of-colour. While deposits of common opal are widespread in Western Australia, precious opal deposits are typically small and little known.

The distinction between precious and common opal results from differences in their paracrystalline structures and mineralogy. All opal is composed of micrometre-sized silica particles chemically combined with variable amounts of water. Thus, opal is expressed as a formula $SiO_2.nH_2O$ although its full characterization can only be established by X-ray diffraction techniques.

The submicroscopic structure of precious opal is demonstrable only by electron microscopy. These investigations show the constituent silica particles are in the form of microspheres of regular dimensions that may be aggregated in domains of orderly three-dimensional arrays. Where these spheroids have diameters of 150–300 nm and are aggregated in blocks, they can act as diffraction gratings. When light diffracts and interferes as it passes through the voids in the blocks, iridescent colours, known as play-of-colour, result.

Colours appear in patches, and the colour in each patch changes with the orientation of the opal, the viewing angle, and the lighting source. The colours seen in a particular colour patch are restricted to a very narrow wavelength of the visible spectrum and each patch is seen as a distinct display of red, green, or blue primary colours.

Opal
Hydrated silicon dioxide $SiO_2.nH_2O$

These colours depend on the sizes of the nanometre-scale silica spheres (150–300 nm), precision of their stacking arrangements, size of the gaps or voids between spheroids, and refractive index differences between the spheroids and cementing silica matrix (Smallwood, 2011; Fig. 10.1).

Physical properties of opal

Crystal structure	Amorphous or poorly crystalline
Colour range	Colourless, white, yellow, yellowish-green, red, brown, and black
Colour cause	Common opal — opalescence resulting from light scattering, inclusions of host rock minerals, and chromium, nickel, copper, and iron Precious opal — diffraction and interference of light reflected from submicroscopic, orderly 3D arrays of silica spheres
Lustre	Waxy and subvitreous
Diaphaneity	Opaque to translucent
Refractive index (distant vision)	1.37 – 1.47 (commonly 1.43 – 1.44)
Optical characteristics	Isotropic; also fibrous and birefringent
Hardness	5 – 6.5
Tenacity	Brittle, subject to dehydration and cracking
Specific gravity	1.95 – 2.25
Fluorescence	Common opal — variable responses but generally inert in ultraviolet (UV) light Precious opal — bluish-white under long- and short-wave UV light with phosphorescence
Textures and patterns	Dendritic mineral inclusions and brecciated textures
Replacement habit	Replacement after tiger eye, chrysotile, and wood pseudomorphs
Processing and display	Commonly freeform or cabochon cut; translucent and transparent specimens may be faceted; some specimens are cut and displayed with host rock matrix attached

Potch opal is a form of common opal that does not show play-of-colour although it commonly appears with precious opal. Changes in the type of opal from precious to potch within a deposit or vein are not unusual and may result from changes in the viscosity of the gel from which the opal precipitated. Although potch opal has a structure of silica spheres, spheres are irregular in size and randomly aggregated and as a result no play-of-colour is displayed.

With no play-of-colour, constituent silica particles in common opal may crystallize as ultrafine fibrous masses. Scanning electron microscopy (SEM) has identified the silica polymorphs cristobalite and tridymite and this type of opal is termed 'opal-CT'. Mineralogy of common opal determined by petrological microscope demonstrates that the fibres are anisotropic and have low birefringence. Precious opal is optically isotropic and is termed 'opal-AG' (amorphous gem opal; Frazier and Frazier, 2007).

The water content of opals, expressed as a percentage by weight, can vary from 1 to 21%. Chemical analysis of the combined water (both bonded and free water within the crystal structure) of selected common opals from Western Australia shows a range from 4.8 to 12.2% H_2O (Simpson, 1952).

Opaque and semitranslucent common opals are commonly cabochon cut or carved; fire opal can also be faceted. Some of the thin seam precious opal from Kalgoorlie is also mounted as slivers in composite cabochons.

Opal terminology

Opals have an uncommon set of terms used for their description. Most of these are reproduced in the following glossary of opal terminology.

Precious opal in Western Australia

Precious opal is universally rare and the most valuable type of opal. In Western Australia, only two deposits, Three Mile Hill and Cowarna, both in the Kalgoorlie Mining District, have been mined by opencut methods (Fig. 10.2). Both deposits have formed as a network of narrow veins associated with common opal (potch) and chalcedony within Archean graphitic shales and tuffs. Precious opal deposits at these sites differ from the usual geological environments present at the major sources of precious opal in other Australian states. In these areas precious opals are found in supergene-enriched vein and cavity fillings in sedimentary rocks. Despite the difference in deposit types, SEM examination of Western Australian precious opals has shown structural similarities with opals occurring in mainly Cretaceous sedimentary rocks in New South Wales, South Australia, and Queensland (Fig. 10.1). Opal formation in these rocks is considered to have occurred during periods of deep weathering in the mid-Cenozoic.

Glossary of opal terminology

Chloropal	Former name for prase opal; also a mix of nontronite clay and opal-CT
Chromopal	Common opal coloured green by chromium
Chrysopal	Former name for prase opal
Composite opal	Finished gemstones that are manufactured from more than one piece of material, commonly comprising two or three components such as a thin slice of precious opal mounted on or between a transparent capping and/or an opaque base
Common opal	Synonym for opal, or a generic term for opal lacking play-of-colour
Fire (flame) opal	Translucent or transparent red-brown common opal variety
Honey opal	Translucent red or orange-yellow common opal
Hyalite	Colourless, transparent variety of opal
Moss (dendritic) opal	Common opal with dendritic or arborescent inclusions, usually green silicate minerals
Nobby opal	Nodule of opal
Opal	Form of hydrated silica
Opal-AG	Amorphous form of gem opal, optically isotropic, opal-AG displays play-of-colour if ordered silica spheres are 150–300 nm in diameter; irregularities of structure result in potch
Opal-CT	Low-ordered form of potch opal shown by X-ray diffraction to comprise silica polymorphs cristobalite and tridymite, microscopically fibrous and birefringent
Opaline silica	Field term describing surface silica of unknown character
Opalite	Misnomer to describe imitations of opal, common opal, and impure opal
Opalized wood	Wood that has a preserved natural structure after silica (opal) permineralization
Play-of-colour	Iridescent spectral colours resulting from the diffraction and interference of light passing through gratings of silica spheres; an optical effect
Potch	Term originating in Australia describing common opal found together with precious opal; it does not display play-of-colour
Prase opal (or prasopal)	Common opal with nickel chromophores; nickel-bearing phyllosilicates; also a green variety of opal
Precious opal	Opal that displays iridescent spectral colours resulting from diffraction and interference of light because of its structure; also termed noble or true opal
Siliciophite	Mixture of chrysotile and opal, or serpentine and opal
Siliciophitic	Term describing opalized chrysotile fibres displaying chatoyancy when cut as cabochons
Tiger eye and cats eye opal	Chatoyant varieties of common opal composed of tiger eye or silicified chrysotile fibres within a matrix of common opal

More detailed locational information on most of Western Australia's precious opal deposits and prospects is given in Appendix 1.

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie area

Three Mile Hill opal mine (Kalgoorlie, 3136)

In the Coolgardie area, precious opal has been produced intermittently since its discovery in the early 20th century.

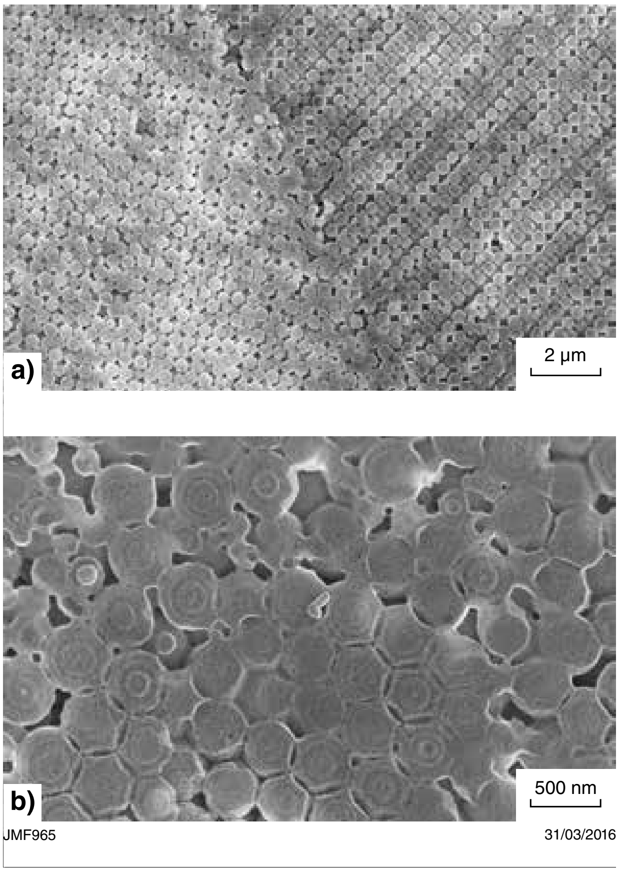

Figure 10.1. Scanning electron micrographs of precious opal from Coober Pedy, South Australia: a) image showing approximately 250 nm-sized silica spheres in precious opal; the right-hand side shows well-ordered and well-packed spheres in a suitable array resulting in a predominantly red play-of-colour and the left hand portion of the micrograph shows 250 nm spheres which are in a random stacking arrangement that would result in no play-of-colour; 20 000x; b) a scanning electron micrograph of concentric growth structures in silica spheres (images courtesy Anthony Smallwood, Microstructural Analysis Unit, University of Technology Sydney)

The opal mining site is within an area of gold mines known as the Three Mile group, about 5 km north-northeast of Coolgardie Railway Station, close to the Coolgardie–Kalgoorlie railway and main road (Fig. 10.3).

The Three Mile Hill opal mine is within mining lease M15/1456 covering an area of 4.9 ha. The mining lease is within an area of Archean metamorphosed, interbedded mafic lavas, and ultramafic and metasedimentary rocks. The opal is confined to a shear zone, about 9 m wide, within graphitic slate horizons that grade across-strike in places into thin arkosic beds with a steep southerly dip. These horizons lie at or near the boundary with adjoining greenstone rocks, where they outcrop as thin, discontinuous, and probably highly folded, laminated beds of sedimentary rock. In this situation, the beds have been silicified and in one locality thin seams of precious opal have developed along cleavage and joint planes.

The siliceous matrix is a relatively hard, black or dark grey, fine-grained rock that is jointed and foliated. The rock is intruded by a series of quartz veins and both rocks are cut by a series of minute cracks filled with precious opal, some of which is of gem quality, although the remainder is of no commercial value. The largest veins were about 2.5 mm thick although thicker veins were reported by miners, and locally good specimens exhibiting a brilliant display of colours were found (Fig. 10.4).

History of mining operations

In 1904 a claim was applied for at Three Mile Hill for the purpose of producing precious opal. At that time the operation, known as Williams opal mine, yielded insufficient quantities of opal to warrant continuation of mining operations and the workings were abandoned. The deposit was considered depleted and was later described as 'inaccessible' in a 1953 report by the Coolgardie Bulletin.

Since that time there have been two renewed opal mining ventures on the site. In the 1960s an opencut was made over the old workings. It was reported that during this period several blob-like concretions (nobbies) containing precious opal of a few centimetres diameter were discovered. Following this activity, the site remained abandoned until renewed mining operations took place in 1989 and the mine worked profitably for a several years by prospector P Milic. In September 1991, a large, visually spectacular piece of gem-quality black opal was recovered. The uncut opal weighed 16.5 kg and was reportedly valued at $5–6 million (1991 A$ value). Subsequently, two smaller gem-quality black opals were found weighing 2.5 kg and 170 g (Wattone, 1992). Currently, the Three Mile Hill opal deposit is on mining lease M15/1456 owned by Mr A Stehn.

Most of the opal from this deposit is of the thin seam type and thin slivers were cut and mounted on-site as composite gems. The original workings were extended to depths of 10–12 m. Gem-quality opal produced was black and grey with crystal and light qualities displaying red, orange, green, and blue play-of-colour. The surrounding potch veins were typically much wider than the precious opal and were glassy and bluish in colour.

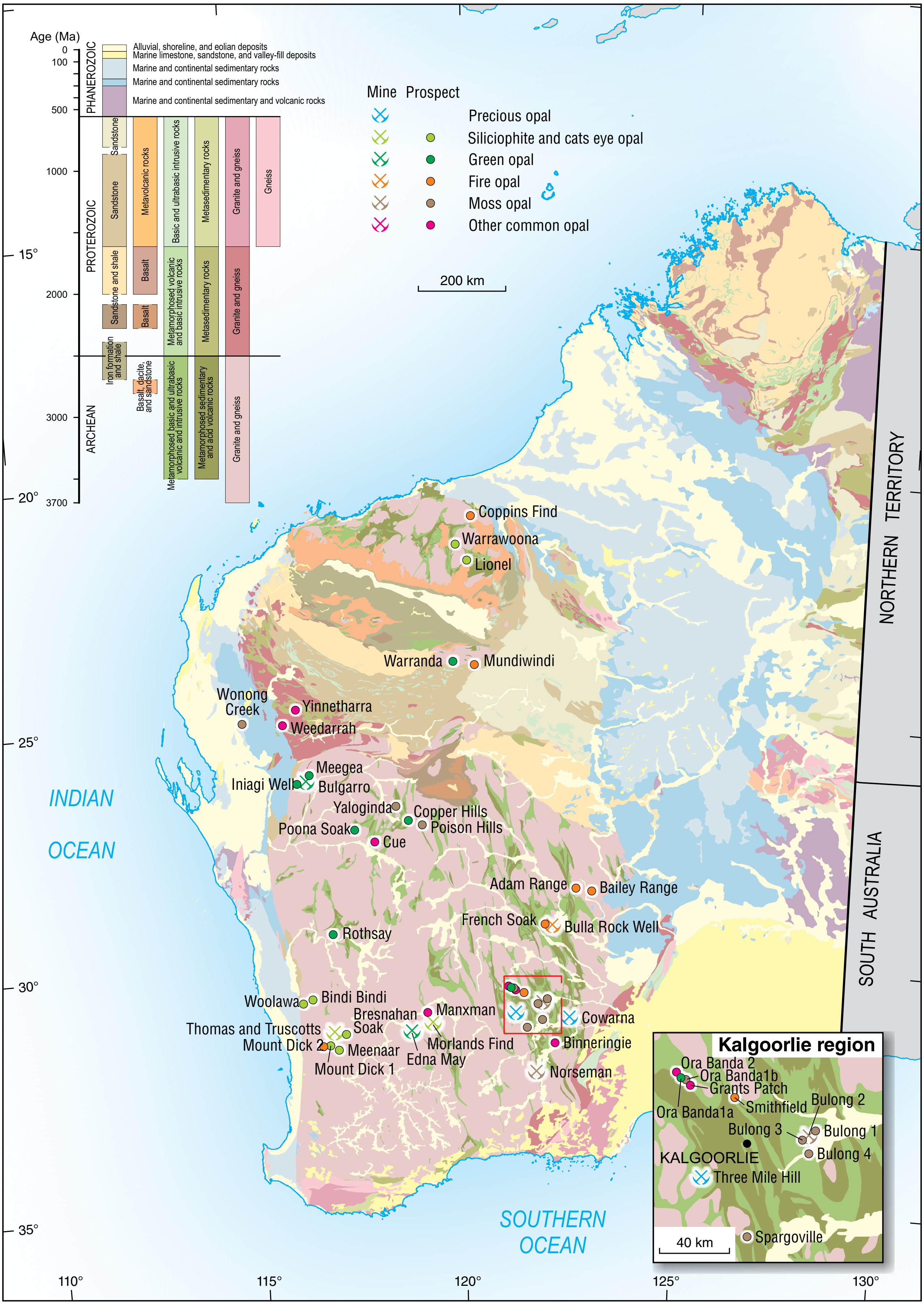

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Figure 10.2. Opal mines and prospects in Western Australia

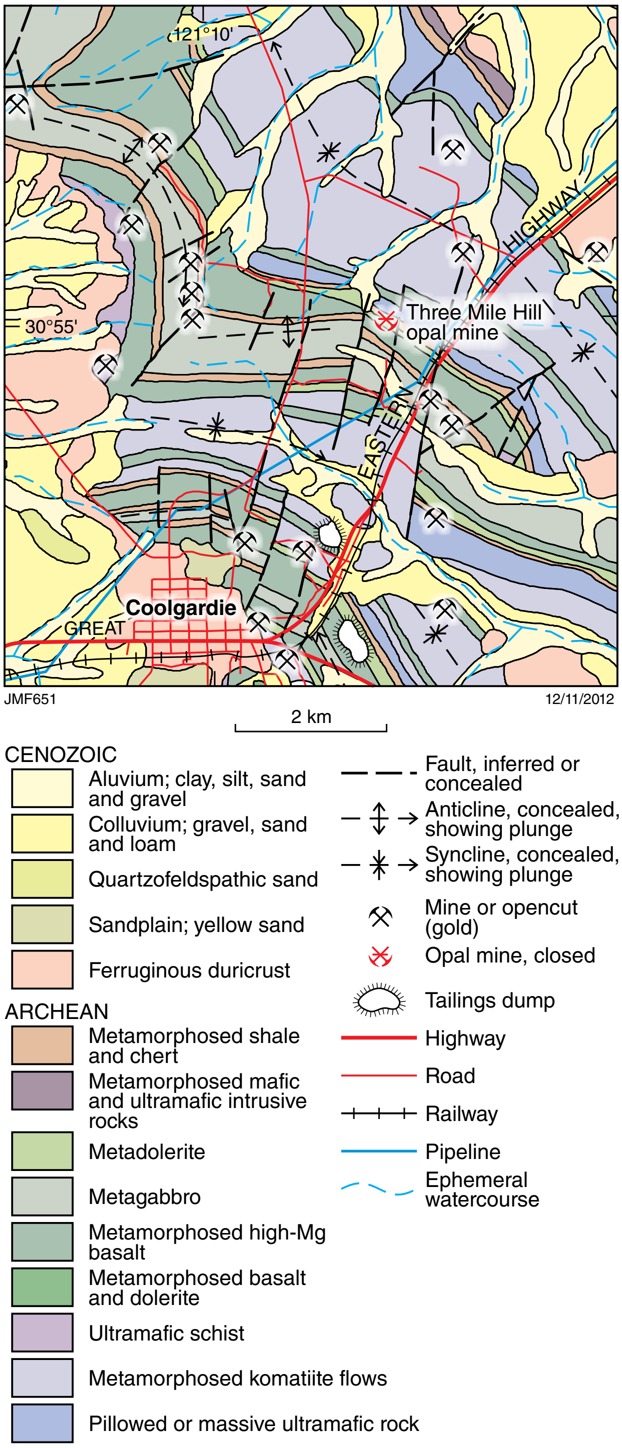

Figure 10.3. Geological map of the Coolgardie area showing the location of the Three Mile Hill opal mine (modified after Hunter, 1985)

Figure 10.4. Precious opal with play-of-colour on graphitic schist from Three Mile Hill opal mine, Coolgardie

Cowarna Downs Homestead area

Cowarna opal mine (MOUNT BELCHES, 3335)

The Cowarna opal mine is about 100 km east-southeast of Kalgoorlie, and 11 km east-southeast of Cowarna Downs Homestead (Fig. 10.2). Between September 1972 and May 1973 the deposit was explored and test mining carried out by Russgar Minerals NL on mineral claim K392. During this period, costeaning and test pitting were carried out on-site followed by the construction of three shafts to a maximum depth of 11.6 m. This operation was followed by the drilling of 14 large-diameter (0.9 m) Caldwell drillholes to a maximum depth of 15.2 m. Later, the main shaft was connected by a drive at the 12.2 m level to Caldwell holes directly to the north and south. During investigations of shafts, Caldwell holes, and drives, many traces, veinlets, and pockets of precious and common opal were found although none were assessed of commercial significance (Russgar Minerals, 1973).The operation resulted in the removal of 1500 t of waste rock. About 500 t of this material, considered host rock, yielded about 15.6 kg of precious opal of varying grade and size with the high-grade material displaying green, blue, yellow, and blood-red colour flashes. A few dozen stones of unknown value, including solids, doublets, and triplets are known to have been cut and polished (Fig. 10.5; Connolly, 1976).

Currently, the Cowarna deposit is held under mining lease M28/372 by Bullabulling Pty Ltd and Mr V Potter.

Geology of the deposit

The Cowarna opal deposit is within a north-trending zone of thinly bedded, Archean graphitic quartz schist and tuff beds within an amphibolitic succession that appears to extend north and possibly south of the exploration area for several kilometres, indicated by sparse outcrop and subsurface material (Fig. 10.6).

In the exploration area, a mineralized strike length of 220 m has been demonstrated. The host rocks strike at 348° and the prevailing dip is 70° west or steeper. In this area, subhorizontal and vertical networks of silica veins are present in a 5 m-wide belt of thinly bedded, graphitic quartz schist and tuff beds within amphibolites that have been intruded by quartz porphyry dykes, which have caused extensive kaolinization of the host rocks.

Quartz, opaline silica, and common and precious opal are present as veinlets and stringers in quartz–kaolinite rocks within the shale and an adjoining, black, glassy, silicified unit. In these rocks the opal appears to represent a late-stage mineralized phase. Precious opal veinlets are up to 1.2 cm thick whereas potch veins are up to 7.5 cm thick. Quartz is also common in these veinlets and transitions from quartz to common opal and precious opal within 2.5 – 5 cm in the same vein have been observed (Connolly, 1976).

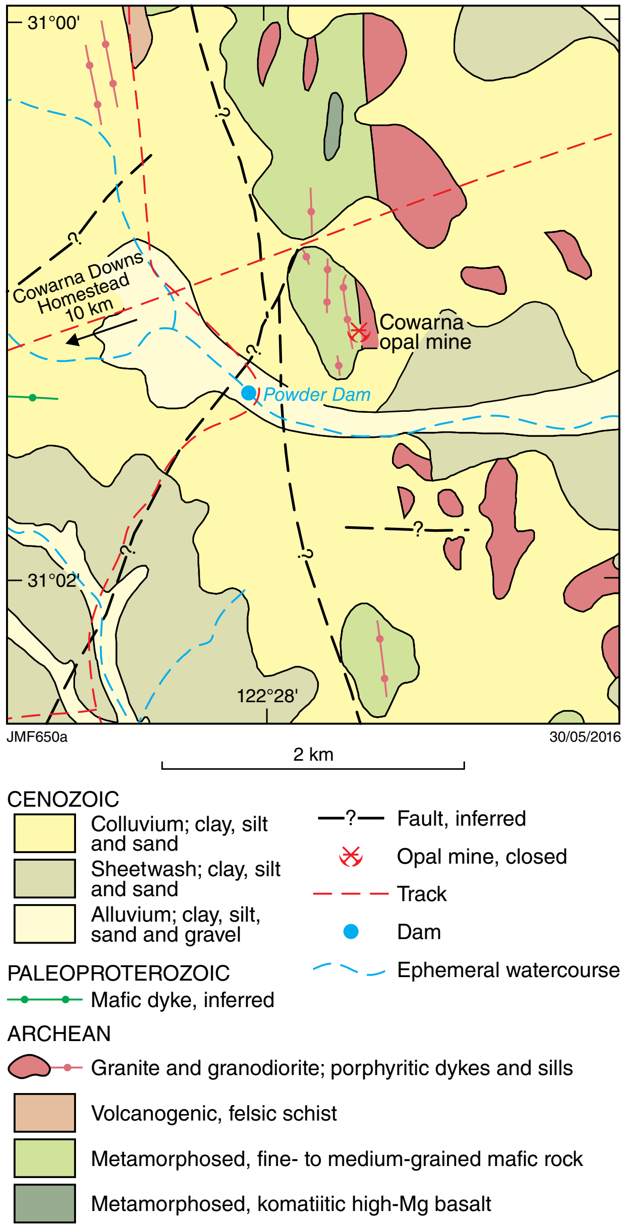

Figure 10.6. Geological map of the area surrounding the Cowarna opal mine (modified after Painter and Groenewald, 2000)

Figure 10.5. Polished specimen of Cowarna opal showing play-of-colour (courtesy Bill Moriarty)

Common opal

To date, common opals have been less well studied than precious opal. As a group, opals contain many attractive varieties including cats eye and siliciophite, fire (or flame) opal, green opal (including prase opal, chromopal, and Cu-bearing opal), moss (or dendritic) opal, and other common opal forms.

Common opal may be present as colourless masses or in a variety of colours including green, white, cream, red, brown, and black. Some common opals, notably green varieties, are coloured by the presence of nickel, chromium, and copper. 'Prase opal' and 'prasopal' are informal terms used to describe green common opal coloured by nickel-bearing inclusions, and 'chromopal' describes green opal coloured by chromium-bearing inclusions. Although chemical analyses may show the presence of chromophores their nature is rarely reported or confirmed. Other causes of colour within common opal include inclusions of minerals such as clays, phyllosilicates, and hydrated iron minerals. White opal results from light scattered from microfissures within the opal. Cats eye and siliciophite opals display chatoyancy (cats eye effect) from fibrous inclusions within the opal; fire (or flame) opal contains coloured nodules ranging from red to orange and yellow; and moss (or dendritic) opal contains visually attractive dendritic inclusions.

Common opal in Western Australia

Common opal is widespread in Western Australia and is commonly associated with magnesite and/or other forms of silica, especially chalcedony. There are numerous locations where visually attractive material is present (Fig. 10.2). Common opal from these sites may be coloured, patterned, or translucent, or may display attractive inclusions. Many of these opals are collected for cutting and polishing. More detailed locational information on most of State's common opal deposits and prospects is given in Appendix 1.

Extensive areas of ferruginous duricrust (laterite) with opal horizons are present in greenstone belts of Western Australia. Most common opal forms as narrow veins, thin coatings, and nodular aggregations on rocks at or near the current land surface. In this environment, opal is commonly a byproduct of the chemical degradation of ultramafic and mafic rocks. Many opal sites are associated with these rocks, especially serpentinites, where common opal is commonly accompanied by magnesite. Textural evidence from some opaline horizons that contain fibrous networks and residual grains of magnetite or chromite indicates that some common opal is formed by mineral or rock replacement in situ.

Also, in many sites in the State opal is associated with siliceous sedimentary rocks, especially spongolite (a fossil sponge spicule-bearing sedimentary rock) found in the Eocene rocks of the Eucla Basin along the south coast, and the Cretaceous rocks of the Carnarvon Basin in the central west coast region. These opals are not gem grade. In a few sites opal is also found as pseudomorphs of fossil wood.

Many documented occurrences of the more interesting forms of common opal found in the State are listed in the following sections. Selected sites are referenced to specimens held at the Western Australian Museum (numbered and prefixed S, MDC, or GSWA) and are given in Appendix 1.

Cats eye

Cats eye opal describes common opal displaying chatoyancy or cats eye effect. The reflection is a silky sheen displayed as a moveable bright band resulting from fibrous inclusions within the opal. Cats eye opals are mainly formed by secondary replacement of asbestiform minerals especially dense, fibrous chrysotile with cross-fibre seams preserved within an opalized matrix. Other asbestiform mineral inclusions may include anthophyllite and tremolite. Cabochon-cut gems orientated with the fibre inclusions parallel to the base of the stone can produce a cats eye effect as a bright light band across the gem when viewed by reflected light.

Cats eye

Yilgarn Craton — Narryer Terrane

Byro area

Bulgarro opal mine *(Byro, 2145)*

Tiger eye opal (a variety of cats eye) from the Byro Station area was discovered in 1899 associated with asbestiform minerals at a site somewhere along Yarra Yarra Creek. The deposit was originally opened up by prospectors under the name of Bulgarro (or Bulgaroo) opal mine, although little work was done. This deposit is probably the same as the opal mine 20 km east-southeast of Byro Station Homestead (Fig. 10.2). The mine was recorded to have produced 54.4 kg of tiger eye opal in 1960 (Williams et al., 1983).

Tiger eye opal mainly forms by replacement of massive, fibrous chrysotile present in both wide and narrow veins throughout the rock prior to silicification. Tiger eye is translucent with a minutely fibrous structure and forms as single veins 1–15 mm in width or as a series of anastomizing veins each about 1 mm wide and separated by layers of massive opal. Tiger eye opal displays a visually attractive, brilliant chatoyance ranging from golden-yellow to grass-green and olive-green commonly highlighted by a slightly mottled, mid-brown matrix (Simpson, 1952).

Siliciophite

A variety of cats eye is siliciophite, a gemstone term referring to chrysotile asbestiform fibre inclusions encapsulated by common opaline silica (Brown, 1989).

It is worth noting that Simpson (1952) also includes the asbestiform mineral anthophyllite in some of his descriptions of siliciophite. There are several recorded sites containing siliciophite opal.

Physical properties of siliciophite

Colour range	Yellowish-green, yellowish-brown, and brown
Lustre	Resinous, silky appearance of fibres
Refractive index	1.455
Hardness	6
Specific gravity	2.13
Fluorescence	Inert in ultraviolet (UV) light
Inclusions	Chrysotile fibre inclusions, healed fissures, black octahedra (possibly chromite), brown platy inclusions (possibly chlorite)

Pilbara Craton

Nullagine area

Lionel prospect *(Nullagine, 2954)*

Approximately 26 km north of the town of Nullagine, there are numerous sites where the asbestiform mineral chrysotile is present in an area of Archean ultramafic rocks containing serpentinite (Fig. 10.2). At one of these sites, the Lionel cats eye siliciophite prospect, the chrysotile lode has been silicified and completely converted into pseudomorphs after chrysotile displaying chatoyant cats eye properties and ranging in colour from golden-yellow to greenish-yellow (Fig. 10.7; Simpson, 1951).

Marble Bar area

Warrawoona *(Marble Bar, 2855)*

Cats eye siliciophite is recorded near Warrawoona, 19 km south-southeast of Marble Bar at a site 45 m east of the road (Fig. 10.2).

Yilgarn Craton — Southern Cross Domain

Bullfinch area

Morlands Find *(Southern Cross, 2735)*

Pale green siliciophite is present in serpentine and talc at Morlands Find, 19 km south-southeast of Bullfinch (Fig. 10.2; Simpson, 1952).

Yilgarn Craton — South West Terrane

Goomalling and Goomalling area

Thomas and Truscotts mine *(Goomalling, 2235)*

Common opal and siliciophite are recorded from the former Thomas and Truscotts anthophyllite mine at Goomalling. Irregular masses of opal were recorded as common in weathered serpentine, in the anthophyllite workings on the east and west sides of Slate Street, 0.8 km southeast of Goomalling railway Station (Fig. 10.2). Some of the opal was siliciophite, although other forms of common opal were white, brown, and black; mottled specimens showed bright green, violet, and grey colours (Simpson, 1952).

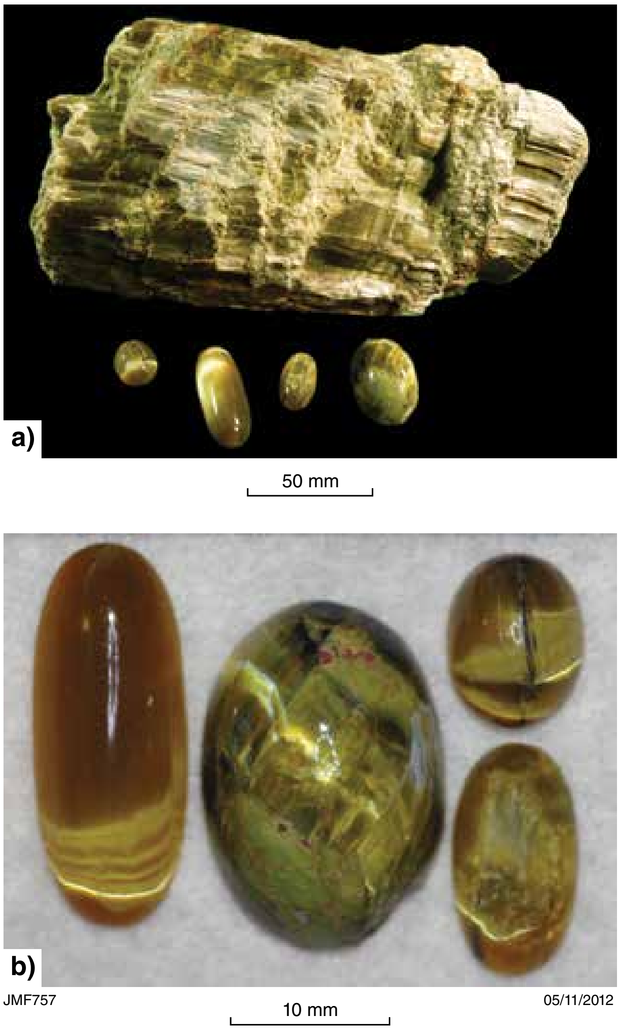

Figure 10.7. Cats eye siliciophite from Lionel in the Nullagine area. These specimens have been described as chatoyant opal pseudomorphs after chrysotile: a) fibrous, greenish-yellow form (upper) and cats eye cabochons (below); b) detail of golden-yellow to greenish-yellow, polished cats eye cabochons (courtesy Western Australian Museum)

Bresnahan Soak *(Goomalling, 2235)*

Numerous, large masses of siliciophite are recorded over serpentinite rocks near Bresnahan Soak in the Ucarty area, approximately 25 km east-southeast of Goomalling (Fig. 10.2; Simpson, 1952).

Moora area

Woolawa *(Moora, 2136)*

Abundant green and brown siliciophite was recorded in an area of Archean migmatite rocks on Woolawa (formerly Wandera) Station, about 14 km east-southeast of Moora (Fig. 10.2; Simpson, 1952).

Bindi Bindi *(Moora, 2136)*

Approximately 32 km east of Moora and 2 km west-southwest of Bindi Bindi, a north-trending belt of serpentinite was found to contain simple or brecciated veins of finely fibrous anthophyllite (Fig. 10.2). This material contains semitransparent, light to dark olive-green siliciophite pseudomorphs after serpentine and anthophyllite, commonly containing perfectly preserved fibre inclusions (Simpson, 1952).

Northam area

Mount Dick 1 *(Northam, 2234)*

Mount Dick is about 7 km north-northeast of Northam (Fig. 10.2). Dark green and intense yellow-green opalized serpentine (siliciophite) is recorded as widely distributed in an intrusive mass of serpentine adjacent to Mount Dick. The siliciophite texture varies in proportion to the amount of unaltered serpentine present and may be subtranslucent or nearly opaque. A microscopic examination showed a replacement texture of the original serpentine with a transparent glassy groundmass containing minute black grains, probably magnetite, picotite, or chromite (Simpson, 1952).

Meenaar *(Northam, 2234)*

Simpson (1952) states that mottled green siliciophite as well as brown and hyalite common opal are abundant in the Meenaar area, 20 km east of Northam, about 2.5 km south-southwest of Meenaar (Fig. 10.2; Simpson, 1952).

Fire or flame opal properties

Fire or flame opal is one of the more unusual forms of common opal. It is transparent to translucent, occurring as nodules commonly with chalcedony, and is red, orange-red, orange, or yellow in colour.

Studies of fire opals from sources worldwide indicate that compositionally the silica spherules form as random aggregates averaging 20 nm in size and that the red to orange body colours originate from light absorption by Fe^{3+} in iron oxide nanoparticles (Fritsch et al., 2006).

Physical properties of fire opal

Colour range	Yellow to orange, red, and red-brown
Lustre	Resinous
Diaphaneity	Translucent to transparent
Refractive index	1.42
Hardness	5 – 5.5
Specific gravity	1.98 – 2.0
Fracture	Conchoidal
Fluorescence	Inert in ultraviolet (UV) light
Inclusions	Flow structures, dark dendritic inclusions, random discoidal inclusions, clusters of white mineral material, tiny spherical white inclusions, red particles, and internal veins

Source: Brown and Bracewell (1989) and Pardieu (2011)

Collier Basin

Mundiwindi area

Mundiwindi *(Mundiwindi, 2950)*

Red-brown translucent fire opal is found in nodules at an unknown locality near the Mundiwindi Aboriginal Community about 70 km southeast of Newman (Fig. 10.2). The opal nodules are reported up to 20 mm or more in diameter.

Pilbara Craton

Yarrie Station area

Coppins Find *(Muccan, 2956)*

Intense yellow opaque nodular opal is recorded from an unknown locality near Coppins Find about 65 km northeast of Marble Bar (Fig. 10.2).

Yilgarn Craton — Eastern Goldfields Superterrane

Kalgoorlie region

Smithfield *(Kalgoorlie, 3136)*

Simpson (1952) recorded a specimen of fire opal forming irregular masses and veinlets in auriferous quartz from an unknown location at Smithfield about 26 km north of Kalgoorlie (Fig. 10.2).

Yundamindra area

French Soak *(Yerilla, 3239)*

Opal, including nodular fire opal, occurs along narrow fault planes in kaolinized granitic rock about 6 km northeast of French Soak on Yundamindra Station (Fig. 10.2). Opals are embedded in the weathered host rock or in a chalcedonic matrix and are commonly in excess of 2.5 cm in diameter. Many of the opalized nodules are colourless or faintly milky whereas others are a deep reddish-amber colour (Simpson, 1952).

Bulla Rock Well opal mine *(Yerilla, 3239)*

Reddish-brown, transparent common or possibly fire opal is recorded approximately 4 km northeast of Bulla Rock Well in deeply weathered granite breakaways (Fig. 10.2). Nodules of this opal are contained in epigenetic, chalcedonic vein fillings and vein-like structures that infill narrow fault planes in strongly kaolinized granite. Larger nodules of deep reddish-amber fire opal, mainly 2.5 cm or more in diameter, are commonly fractured and fissured. Fire opal was intermittently hand mined during the 20th century from several vertical pits hand sunk into the granite (Brown and Bracewell, 1989).

Leonora area

Leonora *(Leonora, 3140)*

Translucent, clear, and red-orange fire opal is recorded by the Western Australian Museum from an unknown location in the Leonora (Gwalia) District (MDC 3439).

Laverton region

Adam Range and Bailey Range *(McMillan, 3441)*

In this area, red-brown, translucent flame opal was found originally in an area of monzogranite in the Adam Range area adjacent to Deeba Rockhole, approximately 34 km northeast of Laverton (Fig. 10.2). A flawless 4 ct red flame opal was cut from this material (Fig. 10.8; Simpson, 1952).

More recently, Holdfast Exploration Pty Ltd prospected the southern side of the Adam Range for fire opal although subsequently mining activities were relocated approximately 35 km east to the Bailey Range to exploration licence E38/2904 on White Cliff Station (Fig. 10.2). In this area the company identified several grades of common opal including high-quality red fire opal from excavations on the southern side of the Bailey Range. At these sites, opal occurs at shallow depths of less than 1 m along veins within kaolinized biotite monzogranite (Fig. 10.9). Because of the brittle nature of opal, mining is carried out principally with hand tools. Current production has included several grades of near-transparent opal including colourless, red, and orange fire opal of facetable grade. The opal is marketed by Mr P Piromanski as ‘Piroman opal’.

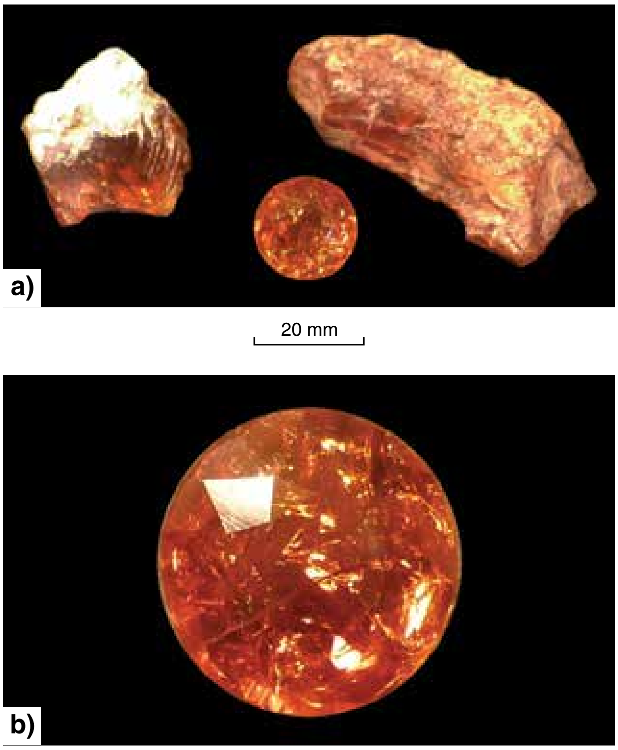

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Figure 10.8. Red-brown, translucent fire opal from the Bailey Range area, Laverton region: a) rough pieces of fire opal and a 4 ct red-brown gem; b) detail of the 4 ct red-brown gem (courtesy Western Australian Museum)

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Figure 10.9. Monzogranite from the Bailey Range area with an opal vein that is approximately 1 m in length (courtesy of Holdfast Pty Ltd)

From physical properties and Raman spectroscopy the opal has been confirmed as opal-CT (opal with silica as cristobalite and tridymite) as defined in the glossary of opal terminology. In the past, fire opal gems have exhibited a problem with the development of fractures. However, a small proportion of the Piroman opals did not require stabilizing treatment after a selection of this material was observed at the Gemological Institute of America Laboratory in Bangkok over a six-month trial and was subsequently shown to have developed no observable cracking (Pardieu, 2011). Some gems faceted from this rare grade of red common opal are currently commercially available without treatment (Fig. 10.10).

Yilgarn Craton — South West Terrane

Northam area

Mount Dick 2 *(Northam, 2234)*

Approximately 8 km north of Northam and a few kilometres north-northwest of Mount Dick, veins of fire opal were found in outcrops of limonite (Fig. 10.2). Apparently this material included dark green and brown opal, and hyalite common opal (Simpson, 1952).

Green opal — prase opal, chromopal, and Cu-bearing opal

Green common opals are commonly coloured by the presence of nickel, chromium, and copper. Prase opal and prasopal are informal terms to describe green opal coloured by nickel-bearing inclusions, and chromopal is coloured by chromium-bearing inclusions.

Yilgarn Craton — Eastern Goldfields Superterrane

Laverton area

Laverton *(Laverton, 3340)*

A white and light green chromiferous banded opal was collected from an unknown locality east of Laverton (Fig. 10.11; S 3799).

Ora Banda area

Ora Banda 1a *(Bardoc, 3137)*

A bright, almost emerald-green opal forming small irregular masses in brown opal occurs close to the Ora Banda pipeline, approximately 5 km south-southeast of the town and adjacent to a serpentinite outcrop (Fig. 10.2). This green opal contains 1.2% Cr_2O_3 (Simpson, 1952).

Yilgarn Craton — Murchison Domain

Gabanintha area

Copper Hills prospect *(Gabanintha, 2644)*

At Copper Hills prospect, approximately 45 km south-southeast of Meekatharra and 4.8 km southeast of Gabanintha, specimens of quartz with irregular lenses and masses of bright emerald-green opal were recorded (Fig. 10.2). The colour is caused by the presence of copper silicate (Simpson, 1952).

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Figure 10.10. Common opal from the Bailey Range area: a) faceted opals displaying a range of colours. Pear-cut centre gem is 20 mm in length and weighs 4.35 ct; b) 9 ct gold pendant set with faceted central fire opal (12 x 11 mm) bordered by five oval cut colourless opals (6 x 4 mm) (courtesy of Holdfast Pty Ltd)

Figure 10.11. **Green chromium-rich opal collected east of Laverton (courtesy Western Australian Museum)**

Belele area

Belele Station *(Tieraco, 2545)*

Simpson (1952) reported a green chromiferous opal collected from an unknown locality on Belele Station. Analyses show no copper or nickel content (S 3805).

Poona area

Poona Soak *(Noondie, 2343)*

Bright green chromiferous opal occurs in a glassy quartz vein on historic mining lease ML94 at Poona Soak about 53 km northwest of Cue (Fig. 10.2). At this locality, opaline masses reach 2–3 cm long and 1 cm thick, and are distinctly platy in structure. The surfaces of the plates and parallel partings are slightly undulating. The opal is translucent in chips 0.5 mm in thickness and contains possible chromium-rich fuchsite and other minerals. Chemical analysis revealed a 6.41% Cr_2O_3 content. Other specimens from this area are white, green, and brown and are replacements after serpentine (Simpson, 1952).

Perenjori region

Rothsay *(Rothsay, 2239)*

Large masses of deep green, chromium-rich common opal were obtained from a mine dump at Rothsay, 60 km east-northeast of Perenjori (Fig. 10.2). The opal, placed on the dump from the main lode of the old Rothsay gold mine 1 km north of the main shaft, contained 3.28% Cr_2O_3 and trace amounts of nickel (Simpson, 1952).

Westonia region

Edna May mine *(Westonia, 2635)*

Simpson (1952) records that irregular masses of opal associated with quartz, serpentine, and other minerals were found in ultramafic wallrock at the 90 m level of the Edna May gold mine at Westonia (Fig. 10.2). The opal, described as transparent and deep sea-green in colour, provided an analysis of 0.14% Cr_2O_3. Yellow common opal is also present.

Westonia region *(Westonia, 2635)*

Chromiferous green opal is reported from an unknown locality north of the Trans-Australian Railway line between Merredin and Southern Cross, a distance in excess of 100 km.

Yilgarn Craton — Narryer Terrane

Byro area

Bulgarro opal mine *(Byro, 2145)*

Green opal is recorded at the Bulgarro (or Bulgaroo) opal mine. This deposit is probably the same as the opal mine 20 km east-southeast of Byro Station Homestead. The deposit also contains brown and white opalized serpentine, which is also termed 'scenic opal' (Fig. 10.2; Simpson, 1952; Williams et al., 1983).

Iniagi Well *(Byro, 2145)*

At Iniagi Well, 13 km south-southeast of Byro Station Homestead, potential gem-quality green opal is found in small quantities together with jasperoidal chalcedony within silica caprock overlying ultramafic rocks containing iron-rich chromite layers (Fig. 10.2; Williams et al., 1983).

Meegea *(Byro, 2145)*

Approximately 11 km north-northwest of Meegea Hill and 24 km east-northeast of Byro Station Homestead, green opaline silica and jasperoidal chalcedony are contained within silica-rich caprock overlying nickeliferous schist (Fig. 10.2). According to Williams et al. (1983), the caprock contains small amounts of potentially gem-quality opaline silica.

Sylvania Inlier

Newman region

Newman *(Warrawanda, 2850)*

Several different qualities and colours of green common opal have been sourced from unknown sites within ultramafic bodies in the Sylvania Inlier. Yellow-green chromium opal and a light green opal are currently marketed by Mr G Archer (Fig. 10.12).

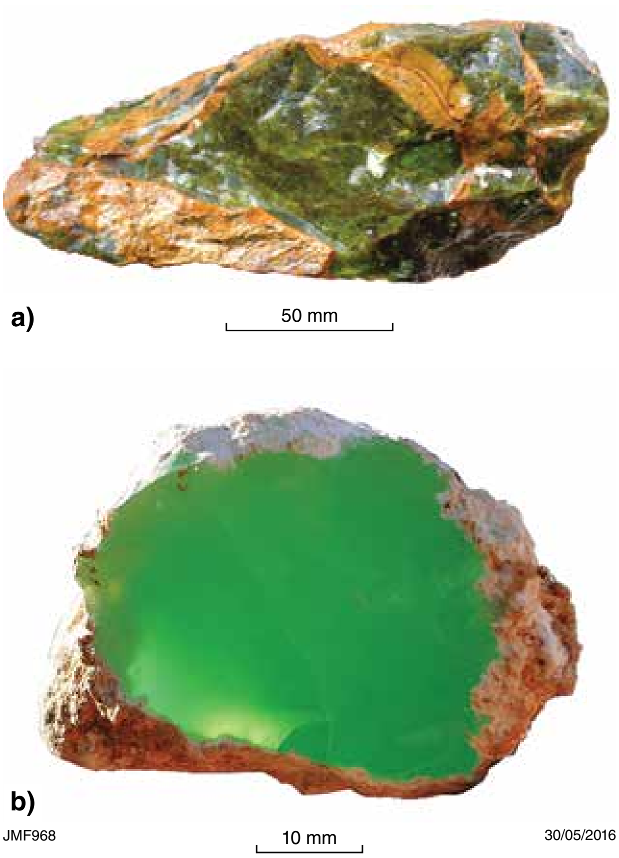

Figure 10.12. Green opal material from the Newman region: a) boulder-sized specimen showing green chromium common opal; b) light green, gem-quality opal nodule encased within white clay-like material (images courtesy Glenn Archer)

Moss or dendritic opal

'Moss opal' and 'dendritic opal' are terms that describe varieties of common opal characterized by inclusions forming arborescent (dendritic), commonly fern-like patterns of a very naturalistic appearance within the opal. Specimens displaying these fern-like dark patterns are sometimes called pseudofossils.

Dendritic inclusions are commonly dark green, brown, or black whereas the matrix opal may be any colour with any degree of diaphaneity. The secondary minerals forming the dendritic patterns are seldom identified although they include chlorite, iron and manganese oxides, and clay (Fig. 10.13). Dendrites are typically considered to have developed later than the host opal, forming from solution action along fractures and may show two- and three-dimensional patterns.

Yilgarn Craton — Eastern Goldfields Superterrane

Bulong area

***Bulong 1–4** (Kanowna, 3236)*

Moss opal and common yellow-brown opal are recorded at several localities (Bulong 1–4 and others) between Bulong and Lake Yindarlgooda, approximately 40 km east of Kalgoorlie (Fig. 10.2). In this area a deeply weathered, north-trending belt of serpentinite is capped with silcrete and magnesite containing common opal veins (Simpson, 1952).

In former years, some opaline material from the Bulong area was slabbed, faceted, or tumbled for marketing as moss and 'lace' opal in the Goldfields area (Williams, 1973). At Bulong 2 opal mine, approximately 6 km northeast of Bulong, veins of chrysoprase and green common opal are present. This area produced 11.3 kg of opaline silica and 2268 kg of chrysoprase.

Norseman area

***Norseman opal mine** (Norseman, 3233)*

Moss opal, common opal, and chalcedony have been mined from a series of small workings in a narrow, north-trending band of ultramafic rocks about 11 km northwest of Norseman (Fig. 10.2). Various colours of moss or dendritic opal, including opaque 'golden lace', translucent green (including chromiferous opal), brown, and white opal are all found in the area (Fig. 10.14). Since 1967, 0.15 t of moss opal and chalcedony has been mined in this area.

Spargoville area

***Spargoville** (Yilmia, 3135)*

Golden and yellow moss opals occur at an unknown locality in the Spargoville area (Fig. 10.2).

Ora Banda area

***Ora Banda 1b prospect** (Bardoc, 3137)*

Common opal of many colours and qualities has been produced from this area (Fig. 10.2). Currently, dendritic types include yellow and white varieties. Golden lace opal with black thread-like dendrites has been sourced from an area about 6 km south-southeast of Ora Banda on prospecting licence P24/4836 owned by Mr G Archer.

Also produced from this area is a white dendritic opal with the black dendrites displaying attractive thread-like and plumose patterns (Fig. 10.13b).

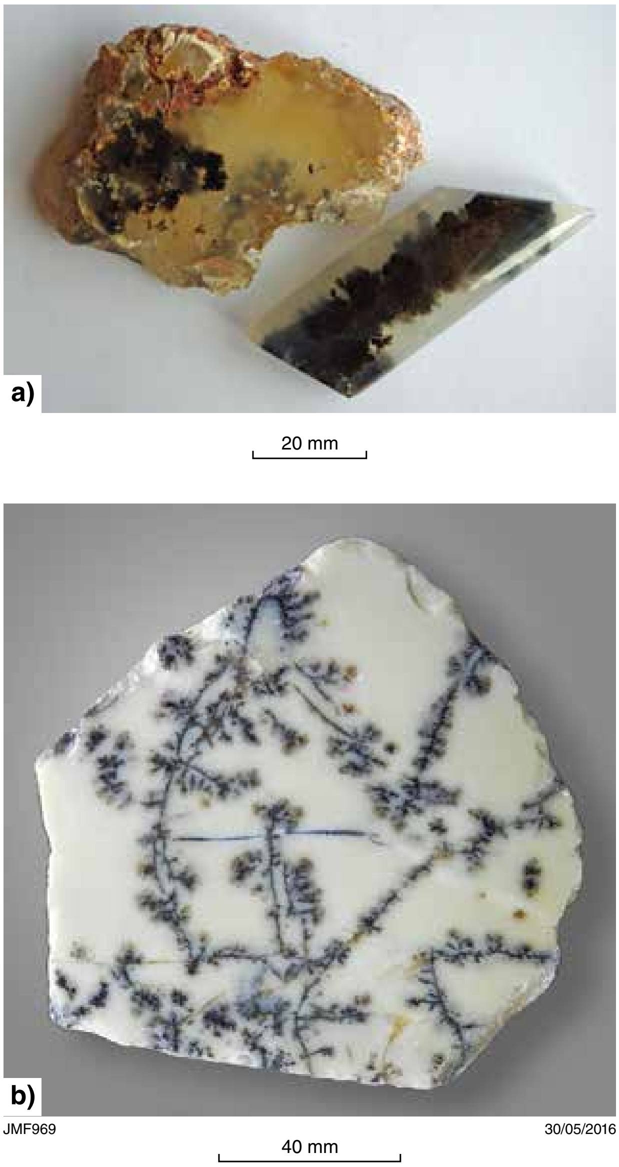

Figure 10.13. Specimens of moss opal also known as dendritic opal: a) rough dendritic opal with cabochon gemstone (length 50 mm) cut from the same material; the gemstone displays three-dimensional plumose dendrites in a colourless opal matrix (courtesy Murray Thompson); b) white dendritic opal from the Ora Banda area with the black dendrites displaying spectacular thread-like and plumose patterns (courtesy Glenn Archer)

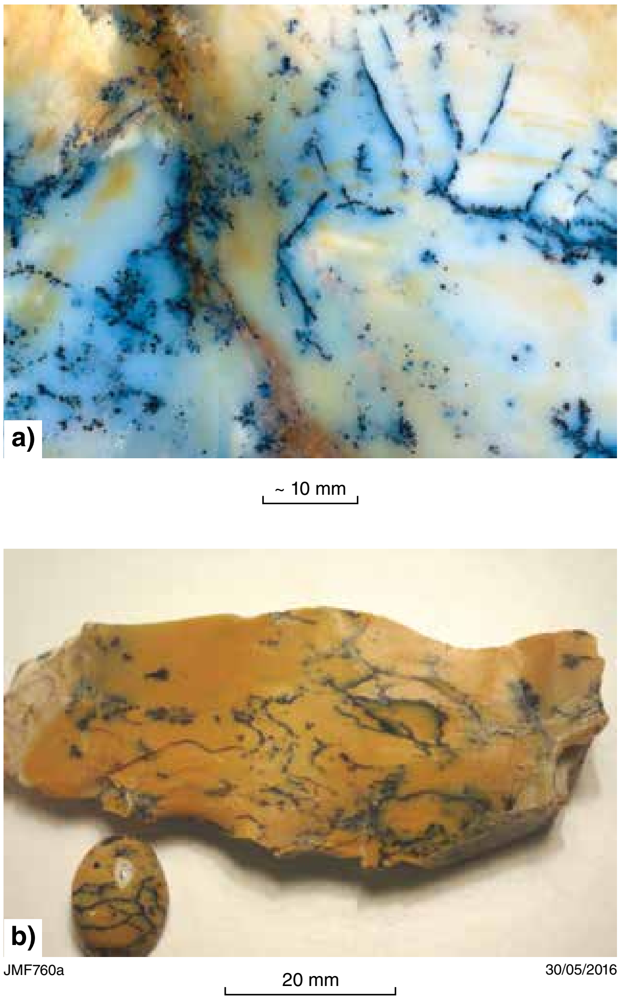

Figure 10.14. Forms of moss opal from the Norseman area: a) magnified image of white opal tinted blue and golden-yellow displaying black dendrites (courtesy Bill Atkinson and Glenn Archer, © Bill Atkinson Photography); b) golden lace opal displaying black, dendritic patterns in a yellow-brown opaque matrix

Yilgarn Craton — Murchison Domain

Yaloginda–Chunderloo area

Yaloginda (*Meekatharra, 2544*)

Approximately 12 km southwest of Meekatharra, in the Yaloginda–Chunderloo area, white opal with black dendrites and moss opal have been found at an unknown site in an area of north-northeasterly-trending schistose ultramafic rocks (Fig. 10.2)

Yilgarn Craton — Southern Cross Domain

Poison Hills area

Poison Hills *(Youno Downs, 2743)*

White opal with black dendrites and moss opal have been found at an unknown locality in the Poison Hills area approximately 70 km southeast of Meekatharra (Fig. 10.2).

Southern Carnarvon Basin

Upper Gascoyne region

Wonong Creek prospect *(Binthalya, 1848)*

Recently, common opal with black plumose inclusions within a light brown-pink, semitranslucent matrix has been found in the Wonong Creek prospect on exploration licence E09/1617 owned by Mr G Archer (Figs 10.2 and 10.15). This opal discovery is in the same local area as the pink opalized porcellanite at Binthalya Pool on Mooka Creek, which is described in Chapter 33 on mookaite and other decorative porcellanites.

Figure 10.15. Dendritic opal specimen from Wonong Creek in the upper Gascoyne region. The opal displays decorative black plumose dendrites set in an orange-brown, translucent matrix (courtesy Glenn Archer)

Other common opal

Gascoyne Province

Weedarrah and Yinnetharra areas
(Yinnetharra, 2148)

In the southern area of the Gascoyne Province, brown-coloured common opal is found at an unknown locality on Weedarrah Station (Fig. 10.2).

Further north, a green and honey-coloured common opal is present at an unknown site on Yinnetharra Station (Fig. 10.2).

Yilgarn Craton — Eastern Goldfields Superterrane

Lake Cowan area

Binneringie *(Yardina, 3334)*

Massive yellow to mauve, variegated, opaque opal has been reported on former mineral claim MC15/37, close to the edge of Lake Cowan and about 4 km east of Binneringie Station Homestead (Fig. 10.2).

Ora Banda area

Grants Patch *(Bardoc, 3137)*

Variably coloured common opal is found at Grants Patch 10 km southeast of Ora Banda (Fig. 10.2). Opal colours vary considerably and include white, red and brown, yellow, and green (Fig. 10.16).

Ora Banda 2 *(Bardoc, 3137)*

Small angular pieces of common opal of similar colours to those from Grants Patch are found scattered on the surface on the western side of the Black Flag Road, about 2 km west-southwest of Ora Banda (Fig. 10.2; Simpson, 1952).

Widgiemooltha area

Widgiemooltha *(Lake Lefroy, 3235)*

Bright red to black, streaky common opal and moss opal have been collected from an unknown location east of Widgiemooltha (Simpson, 1952; red opal S 3706, and S 3814, and moss opal MDC 4779).

Yilgarn Craton — Murchison Domain

Cue area

Cue *(Cue, 2443)*

Red and black, banded common opal has been found 3.2 km north of Cue (Fig. 10.2).

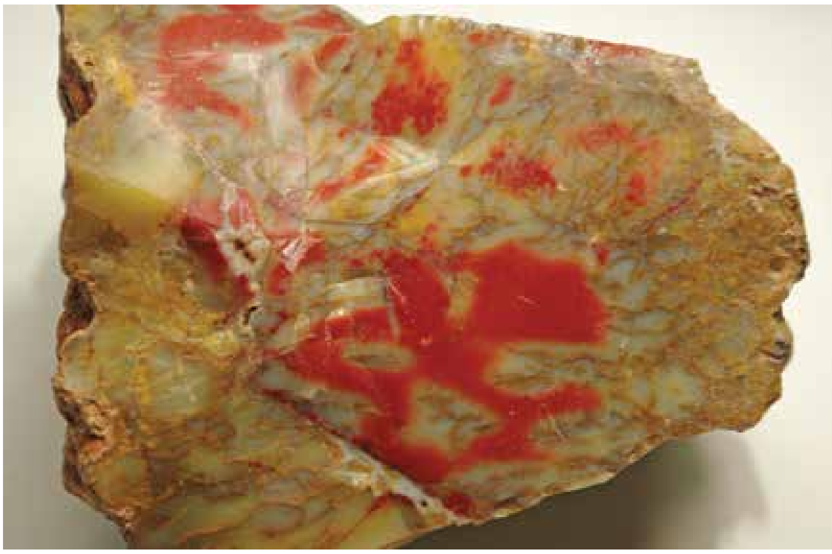

Figure 10.16. Variably coloured common opal from Grants Patch

Yilgarn Craton — Southern Cross Domain

Bullfinch area

Manxman (Bullfinch, 2736)

Massive white opal, known locally as 'enamel', has been collected from Manxman, 8 km northwest of Bullfinch (Fig. 10.2; Simpson, 1952).

Yilgarn Craton — Southwest Terrane

Northam area

Mount Dick 2 (Northam, 2234)

Dark green, brown, and hyalite common opal are recorded 8 km north of Northam (Fig. 10.2; Simpson, 1952).

Opaline chalcedony

Extensive deposits of opaline chalcedony have been reported from the Southern Carnarvon Basin around Winning Station in the central west of the State, and along the 'Eagle Highway' (a four-wheel drive track) in the remote Gunbarrel Basin that forms part of the Gibson Desert in the central east of the State. In both areas, opaline chalcedony is a common weathering feature overlying siliceous radiolarite units (R Hocking, 2012, written comm., November).

References

Brown, G 1989, Siliciophite: Australian 'cat's-eye opal': The Australian Gemmologist, v. 17, no. 2, p. 48–51.

Brown, G and Bracewell, H 1989, Yundamindera 'fire' opal: The Australian Gemmologist, v. 17, no. 3, p. 101–103.

Connolly, RR 1976, Precious opal—Western Australia, *in* Economic geology of Australia and Papua New Guinea *edited by* CL Knight: The Australasian Institute of Mining and Metallurgy, Monograph 8, volume 4, Industrial minerals and rocks, Melbourne, p. 323–324.

Fritsch, E, Gaillou, E, Rondeau, B, Barreau, A, Albertini, D and Ostroumov, M 2006, The nanostructure of fire opal: Journal of Non-Crystalline Solids, v. 352, p. 3957–3960.

Frazier, S and Frazier, A 2007, An opal—glossary of terms, *in* Opal the phenomenal gemstone: ExtraLapis no. 10 Opal: Christian Weise Verlag, East Hampton, CT, p. 58–63.

Hunter, WM 1985, Kalgoorlie, WA Sheet 3136: Geological Survey of Western Australia, 1:100 000 Geological Series.

Painter, MGM and Groenewald, PB 2000, Mount Belches, WA Sheet 3335: Geological Survey of Western Australia, 1:100 000 Geological Series.

Pardieu, V 2011, Common opal from Western Australia: Gems and Gemology, Gem News International, v. 47, no. 4, p. 319–320.

Russgar Minerals 1973, Cowarna opal prospect: Russgar Minerals NL: Geological Survey of Western Australia, Statutory mineral exploration report, A3819 (unpublished).

Smallwood, A 2011, The unique attributes of Australian precious opal: The Australian Gemmologist, v. 25, no. 6–7, April–July, p. 207–230.

Simpson, ES 1951, Minerals of Western Australia, volume 2: Government Printer, Perth, p. 25–26.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, p. 310–332.

Wattone, M 1992, Opal mining, *in* Way to the gold II: Contralind Press, Innaloo, Western Australia, p. 125–126.

Williams, IR 1973, Kurnalpi WA Sheet SH/51–10: Geological Survey of Western Australia, Explanatory Notes, p. 33.

Williams, IR, Walker, IM, Hocking, RM and Williams, SJ 1983, Byro Western Australia Sheet SG 50-10: Geological Survey of Western Australia 1:250 000 Geological Series, Explanatory Notes, p. 22.

Chapter 11

Chalcedony group

This chapter describes microcrystalline quartz gems including agate, carnelian, onyx, chrysoprase, and chrome chalcedony. These gem materials are all forms of chalcedony and are discussed under two groups:

- Agate, carnelian, and onyx. These varieties are coloured by iron (pink, red, and orange-red) and are commonly formed as amygdales within a variety of igneous rocks (especially basalts and rhyolites), and as fracture fillings in other rocks.
- Chrome chalcedony and chrysoprase. These varieties commonly form as veins and irregular nodular forms, as fracture fillings within weathered ultramafic rocks, particularly serpentinites, and as part of the siliceous caprock. In some occurrences they can be as zones of replacement of the host rock. Chalcedony varieties are commonly coloured green where found associated with ultramafic rocks; the colour can be caused by nickel or chrome.

Chalcedony occurrence and properties

Chalcedony is a fine-grained (microscopic or submicroscopic) form of quartz with a compact fibrous texture. Individual quartz grains (crystallites) are of variable thickness and range from only a few micrometres in diameter up to several hundred micrometres in length. Crystallites can also reach sizes visible under a hand lens or to the unaided eye (Frondel, 1962). Individual fibres are not physically separable and coarser fibres can be viewed under high magnification by optical microscope (microcrystalline). Chalcedony has a conchoidal fracture, sometimes with a splintery appearance, and waxy or subvitreous lustre.

Chalcedony is mostly translucent or semitransparent in thin pieces, although not transparent. It is commonly opaque particularly where intergrown with other minerals. Opaque chalcedonic silica is termed chert and/or jasper and some gem varieties (jasper and jaspilite) are described in Chapter 35 on siliceous decorative stones.

Chalcedony group

Microcrystalline quartz SiO_2 — chalcedony (agate, carnelian, and onyx), chrome chalcedony, and chrysoprase

Natural colours of chalcedony are many but mainly various shades of grey and light blue, with white and colourless varieties resulting from light scattering. Other colour varieties of chalcedony have different mineral inclusions, iron being the most common, and can be described under a wide glossary of variety terms; however, there are also wide differences of opinion on how these terms are applied.

Chalcedony has physical properties that differ from quartz, with notably lower refractive indices and specific gravity. Specific gravity covers a small range of values mainly caused by differences in texture, compositional homogeneity, and porosity.

Microscopic examination under cross-polarized light demonstrates that chalcedony is optically anisotropic; textures commonly produce spherulitic and/or wavy extinction patterns where viewed in thin section under crossed polarization. These extinction patterns denote a high degree of alignment and orderliness of the microscopic quartz crystals.

Chalcedony occurs mainly as nodules with domed and spherulitic shapes and is commonly growth banded as seen in agate and onyx. However, chalcedony can assume a wide variety of shapes as it is a common replacement material and takes on the form of the material or mineral that it replaced.

Colours and varieties

Chalcedony coloured by iron oxide and iron hydroxides can be pink, red, yellow, orange-red, and brown. The presence of minerals such as chlorite or clay can also be responsible for colour variants.

Varieties include the brown-coloured sard, and orange and red carnelian. Agate is a form of chalcedony showing growth banding. When varicoloured, it is common for agate to display coloured and non-coloured bands within a single specimen. If carnelian and sard are cut from portions of agate, the banding may only be noticed in transmitted light.

Green chalcedony, a group that exhibits a range of green colours, is described under the terms chrysoprase and chrome chalcedony. Chrysoprase is a translucent light to medium green and bluish-green chalcedony and it has been demonstrated that nickel minerals are the cause of the green colour. Chrome chalcedony is a translucent, medium to mostly dark green variety with colour caused by the presence of chromium.

Glossary of chalcedony terminology

Agate	Banded chalcedony with colour banding in parallel layers. Colour bands may be straight or curved and commonly show differences in diaphaneity. Agate colours are commonly white, grey, brown, pink, red, and light blue
Blow	Portion of a hydrothermal vein, commonly a quartz vein, that has widened and is in places the site for large crystals
Carnelian	Reddish-brown or yellow translucent chalcedony that may be uniformly coloured or, more rarely, shows the banded structure of agate. Its colour is caused by varying concentrations of microgranular iron oxide inclusions, commonly hematite and goethite
Chalcedony	Microcrystalline quartz with a compact structure comprising quartz microfibres of only a few micrometres in diameter and up to a few hundred micrometres in length. These microfibres may form as parallel, subparallel, and radiating bundles and are seen in patterns of extinction and birefringent zones under polarized light microscopy. Chalcedony is commonly not a pure material but includes other forms of silica such as morganite, with some water and iron and aluminium oxide impurities. It has a waxy lustre and refractive index range lower than that of quartz
Chert	Opaque, compact, tough rock composed of microcrystalline quartz, chalcedony, and opal. It may be any colour although is commonly white, black, or grey
Chertification	Secondary silicification process especially by fine-grained or cryptocrystalline quartz
Chrome chalcedony	Medium to dark green chalcedony coloured by chromium that shows a positive response with a Chelsea colour filter, appearing red or pink. It may also contain relict chromite, magnetite, and serpentine. Although it occurs naturally it is also imitated by dye-treated agate
Chrysoprase	Term used specifically to describe light to medium green translucent chalcedony coloured by inclusions of nickel minerals, such as kerolite. Although chrysoprase occurs naturally it is commonly imitated by dye-treated chalcedony and agate
Crazy lace agate	Trade name for vein agate currently produced from Marillana Station, Western Australia
Level-banded agate	Term synonymous with onyx; an agate material with straight bands
Moganite	Monoclinic polymorph of microcrystalline silica (SiO_2) first described from Mogán, Grand Canary Island, in 1976, and first termed ‘silica-G’
Moss agate	Term for chalcedony with dendritic or arborescent mineral inclusions that are commonly green or black and contained within a light-coloured chalcedony groundmass matrix. The secondary minerals forming these dendritic patterns are seldom mineralogically specified although they include chlorite (commonly celadonite), iron and manganese oxides, and clay
Onyx	Straight-banded variety of agate coloured red, black, and brown alternating with white. Although red, brown, and white onyx occur naturally the black and white form is rare, and the so-called ‘black onyx’ described in jewellery is commonly the result of treatment
Opaline chert	Compact, hard rock commonly containing >80% silica
Prase	Green translucent variety of chalcedony or macrocrystalline quartz with unspecified cause of colour
Sard	Brown or brownish-red translucent variety of chalcedony
Silcrete	Commonly used field term for siliceous duricrust and hard surface deposits of sand and gravel cemented by opal, chalcedony, and microquartz. It precipitates following chemical weathering and water evaporation in a semi-arid climate. Extensive deposits developed in Australia especially during the Cenozoic
Silica	Silicon dioxide (SiO_2) that occurs in a great variety of crystalline and microcrystalline forms including quartz, opal, and chalcedony
Silicification	Introduction of, or replacement by, silica, particularly fine-grained quartz, chalcedony, and opal
Vein agate	Agate formed along fissures, joints, and fractures of host rocks. Western Australian crazy lace agate is formed as a vein agate material
Wall-banded agate	Descriptive term that describes the growth bands of the agate as typically following the shape of the cavity in which it has developed. Agate developed in vesicles is typically wall banded

Source: MacDonald et al. (2006); Pabian et al. (2006); Mindat.org (2016)

The colours of chalcedony cover a range similar to those of common opal and these two forms of silica commonly are found together. A variety of names is given to chalcedony based on colour and patterning. Additional information relating to the chalcedony group minerals is available on The Quartz Page (2012).

Physical properties of chalcedony

Chemistry	SiO_2 (90–99%) with water and impurities including including Fe_2O_3 and Al_2O_3
Habit	Commonly nodular, botryoidal, stalactitic lining or infilling cavities, also as concretions, interstitial cement, and veins
Colour range	Commonly colourless, white; also yellow, pink, brown, red, orange, and blue
Colour causes	Iron oxide and hydroxides, and mineral inclusions; also and optical effects
Lustre	Subvitreous and waxy
Diaphaneity	Translucent to opaque
Refractive index	1.526 – 1.543
Birefringence	0.005 – 0.008
Hardness	6.5
Specific gravity	2.57 – 2.64
Fracture	Conchoidal
Fluorescence	Inert, although green fluorescence is common under short-wave ultraviolet (UV) light because of uranyl oxide $(UO_2)^{2+}$ at concentrations in parts per million

Formation of chalcedony

Many occurrences of chalcedony (including common opal) in Western Australia are associated with the regolith as siliceous caprock and formed under ambient temperature (40–60°C). Research suggests that the formation temperature is typically less than 100°C (Moxon, 2009). Chalcedony forms as a secondary material and commonly lines or infills various types of cavities and may or may not have a direct relationship with the rock type in which it occurs.

Agate, onyx, and carnelian

Agate, onyx, and carnelian can be found together. Agate is growth-banded chalcedony of any colour, with the banding typically parallel and curved. Onyx describes horizontally banded agate and carnelian describes orange-red chalcedony that may display growth banding.

Principal types of agate are wall-banded and vein agate, which infill vesicles, cavities, and veins, and develop growth rings following the approximate outline of the cavity, and level-banded agate, commonly termed onyx, where bands form gravity-controlled horizontal parallel layers (Pabian et al., 2006). Wall-banded agate typically develops within cavities such as vesicles and is commonly found as amygdales formed within various lavas. Most Western Australian agate is the wall-banded type. Vein agate develops as a vein, or breccia infilling material within a particular contact horizon. One principal source of vein agate from Western Australia is marketed as ‘crazy lace’.

Moss or dendritic agate is a variety name for non-banded chalcedony, usually describing a matrix of light-coloured chalcedony with contrasting dendritic or plumose, dark-coloured mineral inclusions. The included minerals are commonly green or black and have a naturalistic moss- or fern-like appearance. Moss agate has a similar appearance to moss opal (common opal) although moss agate is differentiated by its higher density and higher refractive index.

Formation of banded agate

Although agates have been appreciated as a gem material over a long history many aspects about their formation remain the subject of conjecture. The sequence of formation of banded agate within vesicles and cavities commonly follows a similar pattern of development and mineralogy.

The first-formed layers of agate within cavities and vesicles are those at the perimeter, the zone that originally would have been in contact with the host rock (if found in situ) and the younging direction is inwards towards the centre of cavities. Agates may develop as many as 200 individual growth bands of chalcedony per centimetre, such as some fine-banded agates from Agate Creek in Queensland (Moxon, 2009). The central portion of amygdales commonly contains coarse quartz crystals, many of which are well formed.

Age of agates

Agates that were formed as vesicle fillings within igneous rocks, such as those of basaltic and rhyolitic lavas, are considered as having an age similar to, or within a few million years of, the time of formation of the host rock.

Recent work has shown differences in the mineralogy of silica between younger and older agates over geological time. Among these differences are a decrease in the content of the silica polymorph, moganite, an increase in the crystallinity of quartz, and an increase in specific gravity in older agates (Moxon, 2009).

In Western Australia agates are derived from lavas from Archean to Early Cretaceous host rocks and include some that are possibly the oldest in the world (Moxon, 2009).

Glossary of rock-cavity terms

Vesicles are vacant cavities formed in igneous rocks by the expansion of gas bubbles during solidification of the rock. They occur particularly in the upper parts of lava flows, or in dykes close to the surface. Vesicles are typically less than 20 mm in diameter although they coalesce to form larger cavities. They tend to be spherical if formed in stationary lava of low viscosity and elongate in the direction of flow if formed in moving viscous lava. Vesicles are typically larger in basaltic lava than felsic to intermediate lavas. Rocks containing vesicles have a texture described as vesicular.

Amygdales are secondary mineral-filled gas cavities (vesicles) in igneous rocks, especially basalt. They can be any shape although are commonly rounded and elongated with sizes from millimetres to one metre in diameter. Minerals commonly found as amygdales include quartz, carbonates, prehnite, and zeolites. Lavas containing amygdales are described as amygdaloidal. Agate, onyx, and chalcedony are commonly found as amygdales.

Geodes are hollow, globular mineral bodies that can develop in limestone and lavas. Although their shape is commonly nearly spherical, tubular or irregularly shaped geodes also form. They commonly have a lining of chalcedony or agate and a hollow centre where crystals may grow unimpeded from the cavity wall towards the centre. Geodes may contain crystals with well-formed terminations towards the centre, some doubly terminated.

Druse is a crust of crystals that develops along the walls of a cavity or mineral vein. The crystals are euhedral and commonly of the same minerals as those of the enclosing rock.

Vug (also vugh or vugg) is a cavity in a rock or mineral vein and may be open or infilled by secondary minerals. Vugs can provide space where crystals may develop and thus may be lined with minerals. Vugs are the source of many gem materials such as crazy lace agate and the amethyst form of quartz.

Applications of agates

Agate has had a long history of use for both gemmological and scientific purposes. Named from the River Achates in Sicily, it is a hard and durable material that is relatively chemically unreactive and resistant to acid corrosion. Agate has both colour and textural pattern visual appeal and can be fashioned to display these attributes for many decorative items such as beads, cabochons, carvings, and small vessels (Fig. 11.1). As a chemically stable material, agate has been fashioned for items such as mortars and pestles, and instrument balance pivots.

Agate is a porous material that is commonly dye-treated and sold in a wide range of colours, many vivid and obviously artificial. Colour variations between growth bands are the result of differences in the porosity between layers, which are accented by dye treatment. Brighter brownish or yellowish agates can be heat treated, converting hydrous iron oxides into simple oxides that are red, to produce a colour that is regarded as more popular.

Agate in Western Australia

Agate has been collected from many locations within the State and sourced from various geological situations (Fig. 11.2).

Agate, onyx, and carnelian amygdales that have weathered from their host rocks are collected as loose entities. These are rounded, irregular forms, commonly with geometrically shaped imprints of mineral casts over the outer surface derived from when the agate was enclosed within its host rocks. Kriewaldt and Ryan (1967) described agate from the Mount Roe Basalt, for example, as eroded out to form plentiful deposits on the slopes and plains near outcrops.

Some weathered agates have been transported from their host rocks and incorporated as clasts within conglomerates such as those that are found in the conglomerates of the Coondoon and Lilian Formations. Agates are also found in unconsolidated sedimentary material within some river channels and terrace deposits. Agate may be also found in association with caprock material, formed in recent geological time as a silicification feature during the Cenozoic. Crazy lace vein agate at Marillana Station is an example of this type (Fig. 11.3).

Agate occurrences are widespread in the State. A few sites are described although many additional sites are known to prospectors, fossickers, and lapidary club members. Some of these sites may also be sourced in Simpson (1952) and various Geological Survey of Western Australia publications. Host lavas that feature as sources of agate include the Maddina and Kylena Formations, the Nymerina, Mount Roe, and Bunbury Basalts, and the Bamboo Creek dacitic lavas and Antrim Plateau Volcanics. Other sources include conglomerates of the Coondoon and Lilian Formations.

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Figure 11.1. Agate fashioned for use as an instrument handle; length 40 mm

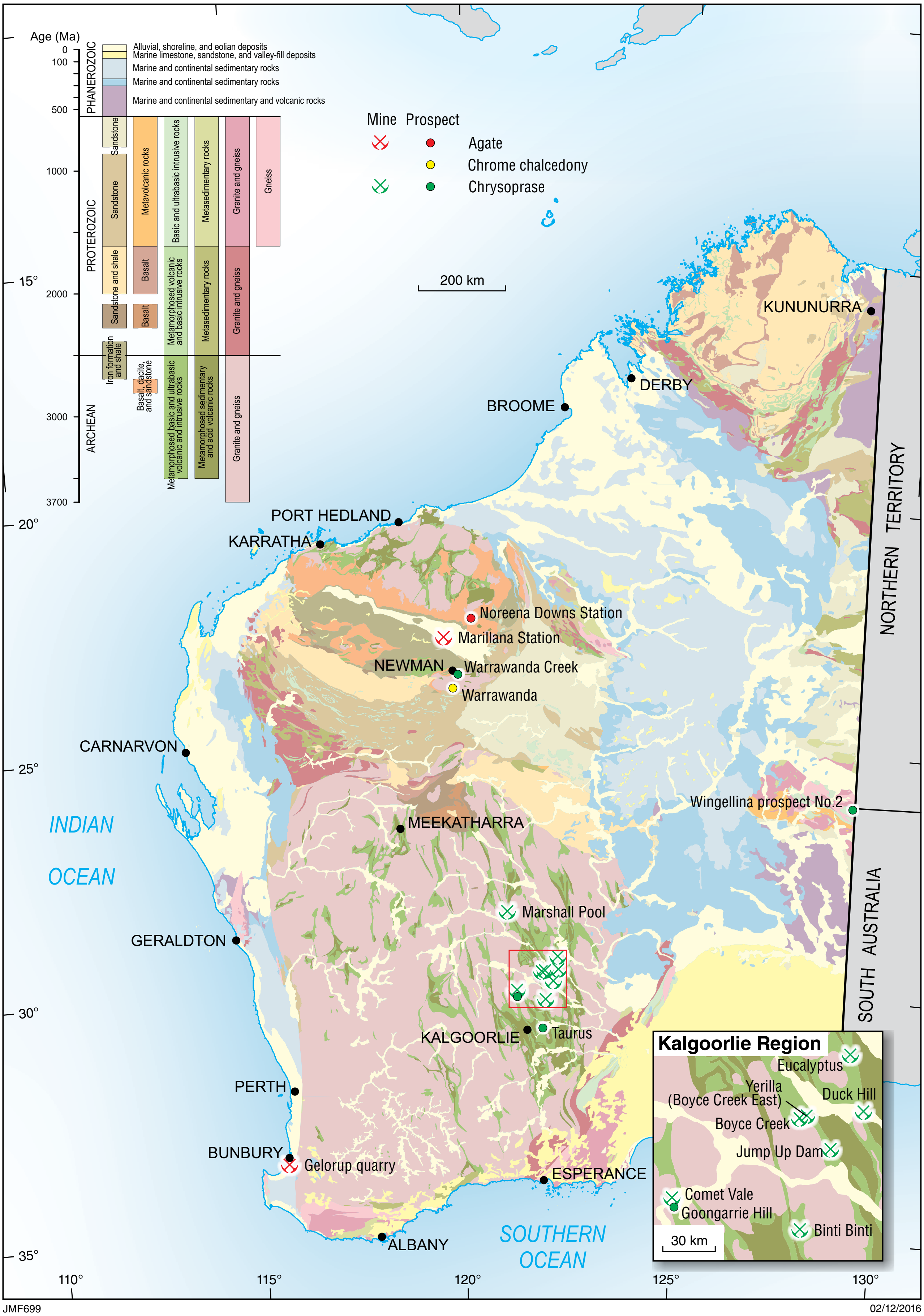

Figure 11.2. Locations of chalcedony group gems and decorative stones in Western Australia

Figure 11.3. **Polished slab of crazy lace vein agate from the Archer mine, Marillana Station, Pilbara region (courtesy Glenn Archer)**

Pilbara Craton

Occurrences of agate are widespread and cover extensive areas within the Pilbara Craton especially in areas where basalts and other lavas are present.

Fortescue and Hamersley Basins — Balfour Downs region

Noreena Downs Station *(Balfour Downs, 3052)*

Noreena Downs Station is about 125 km north-northeast of Newman (Fig. 11.2). Various agate–carnelian fossicking sites are also known by lapidary club members on this station. Agate and carnelian are reportedly abundant in the upper parts of the Kylena Formation and Nymerina Basalt throughout Balfour Downs, although specific sites are not stated (Fig. 11.4).

The Kylena and Maddina Formations are part of the Archean Fortescue Basin. The Maddina Formation contains a dark green to grey massive vesicular and amygdaloidal metabasalt that is the dominant basaltic unit of the Fortescue Group on Balfour Downs. The prominent feature of the upper part of the unit is the presence of very large amygdales (up to 50 cm across) mainly infilled with pink to red carnelian-bearing agate. Amygdales also contain chlorite, carbonates, quartz, and stilpnomelane.

Northern Pilbara region

SF 51-1 *(Yarrie 1:250 000)*

Agate is recorded from several basalts and rhyolites in this general area. Within the Maddina Formation massive, amygdaloidal, and vesicular basalts and andesites contain amygdales filled with quartz, agate including carnelian, chlorite, calcite, and epidote (Fig. 11.5). The Bamboo Creek Member, part of the Hardy Group, consists of porphyritic, amygdaloidal, massive fine-grained and flow-banded rhyolites, rhyodacites, and dacitic flows that are reported to contain quartz and agate-filled amygdales (Williams, 2003).

Nullagine region *(Mount Edgar, 2955)*

Agates, carnelian, and onyx are described by Williams and Bagas (2007) in several lavas from this area. From within the Wyman Formation, part of the Kelly Group, in the McPhee greenstone belt, black hydrothermal chert veins, many carrying open vugs lined with banded chalcedony (agate), intrude the entire felsic volcanic succession. Within the Mount Roe Basalt, amygdale-rich individual flows contain calcite, chalcedony (some banded agate), and chlorite. From the Bamboo Creek Member of the Hardy Formation of the Fortescue Group, vesicular rhyodacite and dacitic lavas contain amygdales with carbonate, quartz, and banded chalcedony (agate). Within the upper successions of the Kylena Formation of the Fortescue Group, amygdales are reported to contain quartz, carbonate, and banded chalcedony. Within the Maddina Formation of the Fortescue Group are amygdales up to 30 mm diameter containing red-brown to red carnelian-bearing agate.

Chichester Range *(Mount Bilroth, 2454; Mount Marsh, 2753)*

The Maddina Formation, part of the Archean Fortescue Group, is a scoriaceous and amygdaloidal basalt containing amygdales up to 60 cm diameter with some containing agate, calcite, epidote, chlorite, iron oxides, and quartz. Agates are also common in amygdales of the Kylena Formation in this area, although specific localities are not recorded (Kriewaldt and Ryan, 1967).

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Figure 11.4. Carnelian-coloured (orange-red) agates from Noreena Downs Station in the east Pilbara region. Centre agate is 40 mm in width (courtesy Ken Brussola)

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Figure 11.5. Cut specimen of agate derived from the Maddina Formation. Specimen is 70 mm from top to bottom (courtesy Glenn Archer)

Marillana Station

Archer mine (Roy Hill, 2852)

Agate production from this area was first reported from the Archer mine on Marillana Station on mining lease M47/514 owned by Mr Glenn Archer where 68 t of ore was processed up to 1992 (Thorn and Tyler, 1997; Fig. 11.2). At this site, multicoloured vein agate, marketed as ‘crazy lace agate’, is associated with siliceous caprock and calcrete overlying part of the Wittenoom Formation in the Fortescue Valley.

The agate is mined from surface outcrop exposed in the Fortescue Valley floodplain. The deposit covers about 0.4 ha although only small areas of agate display good colour and are attractively banded. At a depth of about 1.5 m the quality decreases and material becomes more friable and porous.

Examination of large boulders of this material show that in its cavernous structure some zones are infilled by coarse quartz crystals and quartz-filled vugs between irregular zones of banded agate of mixed colours from colourless to red, yellow, and grey (Figs 11.3 and 11.6).

Kayes mine (Roy Hill, 2852)

More recently, a second agate deposit in the Fortescue Valley floodplain has come into production. About 10 km southeast of the Archer mine, the Kayes mine on Marillana Station is on mining lease M47/1233 (Fig. 11.2). The mine, owned and operated by Mr Barry Kayes, has the same geological setting as for the Archer deposit.

This deposit contains both crazy lace vein agate and amygdaloidal wall-banded agate of variable colour and quality. Some good-quality material exists at the surface and to depths of 5–10 m in places. Rounded boulders in

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Figure 11.6. **Crazy lace vein agate cabochon cut and polished from the Archer mine on Marillana Station; pendant measures 75 x 45 mm (courtesy Kayley Usher)**

the near-surface environment may contain a mixture of variable-quality agate and small quartz crystals derived from vugs and found among the boulders (Fig. 11.7). This mine has produced an assortment of semiprecious stones made into jewellery such as polished spheres, eggs, hearts, and button-shaped ornaments (Fig. 11.8).

Other Hamersley Basin occurrences

Large amygdales are reported in the Maddina Formation. Many contain quartz with carbonate and chlorite although there is no mention to indicate the quartz type. Geological Survey of Western Australia (1994) described some other agate from this general area. Quartzite and basalt rocks near Bamboo Springs contain veins of chalcedony and opaline silica. Good-quality red- and white-banded agates are found as nodules in sedimentary rocks near Wandagee Station.

Oakover Basin

Agate is also present in the Coondoon Formation, a poorly sorted boulder conglomerate containing clasts of chalcedonic silica and agate (Williams, 1989). The Coondoon Formation is of the Mesoproterozoic Mangan Group. In the Davis River area (BALFOUR DOWNS and NULLAGINE 1:250 000 map sheets) brown and white agate is abundant in gravels of the Davis–Oakover – De Grey River system (Geological Survey of Western Australia, 1994).

Collier Basin

***Bulloo Downs Station** (ILGARARI, 2849)*

Onyx and carnelian are found in the Mesoproterozoic Collier Basin around Ilgarari outstation on Bulloo Downs Station about 120 km south-southwest of Newman (Geological Survey of Western Australia, 1994). The exact location is uncertain. A specimen from the collection of the Western Australian Museum (S 3713) is of straight-banded onyx.

Paterson Orogen

Warburton area

***Ainslie Hill** (WARBURTON RANGE, 4245)*

Poor-quality brown and white agates up to 45 cm in diameter are common in conglomerates of the Lilian Formation, 5–10 km northwest of Ainslie Hill in the Warburton Range. The quality of the agate is described as fractured and commonly cracked. Onyx specimens WAM 6696 and 669 from this locality are in the collection of the Western Australian Museum.

In this area, the Lilian Formation consists principally of shale with minor intercalated thin basic lavas, minor dolomitic shale, and several polymictic conglomerates. These conglomerate horizons carry abundant agate and rounded pebbles of rhyolite (Daniels, 1974).

Ord Basin

***Flora Valley region** (HALLS CREEK, 4461)*

In this area amethyst quartz and chalcedony form in amygdales and geodes of the Cambrian Antrim Plateau Volcanics northeast of Halls Creek in the east Kimberley region.

Perth Basin

***Gelorup quarry** (BUNBURY, 2031)*

The early Cretaceous Bunbury Basalt in the Perth Basin consists of two flows of porphyritic tholeiitic basalt (high in Mg and Fe), which have a total thickness of 130 m.

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Figure 11.7. Mining crazy lace agate boulders, Marillana Station, Pilbara region (courtesy Barry Kayes)

The basalts are locally vesicular and outcrop can be seen along the foreshore at Bunbury and is exposed as dramatic columnar or pillar-like cliffs about 7 m high at Gelorup quarry, 8 km south of Bunbury (Freeman and Donaldson, 2006; Fig. 11.2). Agates have been collected from this basalt, particularly in the 1970s during land reclamation and deepening of the harbour. Most agates are now in private collections. These agates are commonly grey and nodular with sections of moss agate, and others are similar to nodules of green jasper (Fig. 11.9). During the reclamation operations, vertebrate fossils, fossil wood, chalcedony nodules, and jasper were collected from this locality (K Mortley, 2016, written comm., 15 January).

Chrome chalcedony

In the third century CE, chrome chalcedony was sourced possibly from Anatolia in Turkey by the Romans who carved the green stone as intaglios. Green chrome chalcedony is relatively rare worldwide as most green chalcedonies are related to the nickel-rich mineral chrysoprase or the green mineral prase commonly coloured by associated or included green minerals. Recently, chrome chalcedony was identified in Zimbabwe where it is known commercially as mtorolite. In Zimbabwe, chrome chalcedony forms as narrow veins within ultramafic horizons of the Great Dyke. Chrome chalcedony is also recorded from Bolivia where it is commercially termed chiquitanite.

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Figure 11.8. Selection of crazy lace agate polished hearts from material from the Kayes mine, Marillana Station (courtesy Barry Kayes)

Green, chrome-rich chalcedony, an ornamental stone new to Australia, was first discovered about 30 years ago in the Sylvania Inlier (Fig. 1.1) in the Newman region of Western Australia.

a)

b)

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Figure 11.9. Agates sourced from the Bunbury Basalt: a) grey, nodular chalcedony and moss agate geode; the interior of the 120 mm-wide geode displays mammillary growth of chalcedony (courtesy Ken Brussola); b) agate specimen from a collection of Bunbury foreshore materials. The specimen displays an outer border of radiating groups of acicular chalcedony, and the central portion comprises grey-blue agate and a small quartz crystal-lined vug; specimen is 12.5 x 7.5 cm (courtesy Tom Kapitany)

Chrome chalcedony in Western Australia

Sylvania Inlier

Newman region

Warrawanda chrome chalcedony prospect
(WARRAWANDA, 2850)

The Warrawanda chrome chalcedony prospect is on Sylvania Station about 40 km south of Newman and approximately 3 km east of the Great Northern Highway (Fig. 11.2).

The prospect is in the Sylvania Inlier, an Archean granite–greenstone body adjacent to the southeastern boundary of the Hamersley Basin. The site is within a relatively narrow, intrusive serpentinite body known locally as the Southern Ultramafic Intrusion, which trends east–west for about 30 km.

The quarry site is on a small hill of massive silica capping over weathered, ultramafic serpentinite rock. The chrome chalcedony mostly forms irregular masses of dark green material within subordinate areas of light green, relict host serpentine. It is thought to have formed by pervasive silicification of the serpentinite at or near the paleowatertable during the early Cenozoic. The green colour of the stone is caused by the presence of chromium (0.24% Cr_2O_3) derived from chromite grains contained in the ultramafic body (Fig. 11.10).

Mineralogically, the massive chrome chalcedony contains about 90% microcrystalline silica with a grain size characteristic of chalcedony. Localized rosettes and microfans of subradiating chalcedony up to 0.6 mm in diameter occur within the groundmass and numerous grains of the opaque minerals hematite, magnetite, and chromite. X-ray diffraction shows quartz as the major mineral component with traces of talc and moganite, a monoclinic polymorph of microcrystalline silica (Willing and Stocklmayer, 2003).

Chrome chalcedony is a robust rock, breaking with a conchoidal fracture and exposing fresh surfaces with a waxy appearance. Transmitted light shows the usual deep green colour to exhibit considerable variation commonly with a speckled appearance caused by finely disseminated grains of an opaque mineral. The hardness, intense green colour and high translucency make the massive chrome chalcedony an excellent medium for fashioning into cabochons or carved objects.

Figure 11.10. Highly siliceous, deep-green Warrawanda chrome chalcedony from the Newman region (courtesy Australian Outback Mining)

Chrysoprase

Chrysoprase is a light to medium green and bluish-green coloured chalcedony and is the most valuable variety. Historically, chrysoprase was known particularly from Szklary in the Breslau area of southwestern Poland. It was first investigated from this source in the late 18th century for the cause of its green colour and it was found that the colour was probably related to inclusions of nickel compounds (Heflik et al., 1989).

Chrysoprase has been sourced from India, Brazil, the Urals of Russia (from nickel ochre at Revdinsk), and the US, especially the nickel mine on Nickel Mount in Oregon. Australia has been an important source of chrysoprase since the 1960s, particularly Queensland, and Western Australia produces chrysoprase from many small workings throughout the State.

Chrysoprase develops in weathered nickeliferous mafic and ultramafic rocks, and is commonly associated with serpentinites. There are few reports detailing the identification of the nickel minerals within chrysoprase. However, recent work on chrysoprase specimens from the Newman area has identified the presence of kerolite, a talc-like nickeliferous mineral (Nagase et al., 1997).

Chrysoprase is an impure siliceous material. Specimens typically show a non-homogenous texture with a dominant groundmass of cryptocrystalline granular or fibrous quartz, commonly with zones and patches of embedded idiomorphic quartz microcrystals lining minute cavities, common opal and amphibole, chlorite, and clay minerals from the host rock. The best quality is selected for uniformity of colour and textural homogeneity.

Chrysoprase is commonly a byproduct of magnesite mining and once sorted from magnesite it is graded and sold. The colour of chrysoprase varies with locality.

Translucent chrysoprase is a durable gem material that is commonly fashioned into cabochons and beads; high-grade material is also set into finely crafted jewellery. Chrysoprase is marketed by price per kilogram for larger pieces, or by gram or carat weight for high-grade material. Chrysoprase is commonly artistically carved together with adherent matrix material, providing both colour and textural contrast in the finished sculptural works.

A high proportion of chrysoprase mined in Western Australia is marketed in Hong Kong, Taiwan, China, and Thailand and it is traded at international gem and mineral fairs.

Chrysoprase in Western Australia

In Western Australia chrysoprase from Yerilla has the following gemmological properties: refractive index of 1.54 (spot), and specific gravity of 2.60 (Gems and Gemology, 1994). A specimen from Comet Vale in the Western Australian Museum was analysed and found to contain 1.43% NiO. Some chrysoprase specimens from the Western Australian Museum collection are shown in Table 11.1.

Polished sections of chrysoprase will commonly produce two shadow edges on a refractometer, with a difference in readings of about 0.006. This effect is caused by quartz fibres embedded in opaline silica and the refractive indices of the two materials are slightly different. A faint absorption band at 632 nm is seen in places in a spectroscopic examination.

The colour of chrysoprase fades when subjected to heating, possibly the result of dehydration; in jewellery, a chrysoprase intaglio seal was recorded as losing its colour after use (Bauer, 1904). Similar decolouration has been observed when chrysoprase is exposed to sunlight.

Chrysoprase, prase, various coloured chalcedonies, and common opal are widespread throughout the State, especially in the main Eastern Goldfields nickel province between Wiluna and Norseman.

There have been two main areas of production for chrysoprase, with a pre-1973 recorded production of 122 202 kg (Connolly, 1976). These areas are the Wingellina centre in the far east of the State, and the Taurus group in the Bulong district, although many other production localities in the Eastern Goldfields have also been recorded. At these localities, secondary magnesitic concretionary cappings contain chrysoprase as thin subhorizontal irregular layers and nodules with deposition related to an earlier weathering profile. Typical of such occurrences are those at Comet Vale, Yerilla, Grants Patch, Lake Rebecca, and Yundamindra Station Homestead. At Wingellina, the chrysoprase exists in a nickeliferous laterite. Chalcedonic material also present is commonly impure and diaphaneity may vary from opaque to semitranslucent.

There are many occurrences of green chalcedony within the State. Many have been called chrysoprase, and some are chrome chalcedony, although few have been investigated for detailed mineralogical study and analysis. A selection of chrysoprase specimens is shown in Table 11.1.

Table 11.1. Selection of chrysoprase specimens in the collection of the Western Australian Museum

1:100 000 sheet no.	Specimen no.	Locality
2136	S 3724	Koojan
2136	6280	Cairn Hill, 8 km north of Moora
2850	5716	MC717, 44 km south-southeast of Mount Whaleback
2950	6068	Sylvania Station
2741	6281	5 km south of Sandstone
3137	3910	Goongarrie
3138	S 3796	Comet Vale
3235	4163	Mount Monger
3239	7654	Yerilla
3239	7655	Yundamindra
3239	7662	Yerilla
3239	3843	Kookynie
3239	S 3725	Mount Catherine, Yerilla
3338	4035	Lake Rebecca
3339	4162	Just north of Mount Florence
3339	4349	Eucalyptus
3339	4620	Pyke Hill
3339	4927	Yundamindra, 3.5 km southeast of Eucalyptus
3340	3958	16 km southeast of Mount Margaret Mission
3340	4682	24 km south of Mount Margaret Mission
4245	4655	Warburton Range
4645	4709	Wingellina Lease 501P

Sylvania Inlier

Newman region

Warrawanda Creek (*Newman*, 2851)

Warrawanda Creek is 44 km south-southeast of Mount Whaleback and 18 km east-southeast of Newman (Fig. 11.2). This chrysoprase is marketed as Murramunda chrysoprase.

In this area, chrysoprase is found within and near the contact of serpentinites of the Sylvania Inlier and granitic rocks; both rock types are strongly weathered to a brownish colour and both have been silicified near the contact zones. The chrysoprase deposit lies along this contact border and attains a few tens of metres in thickness and about 160 m in length. Chrysoprase forms as a vein network in granite or as irregular lens-like nodules in the serpentinite. High-quality chrysoprase shows a homogenous bright green colour and is mainly associated with the serpentinites in the granite contact areas. Research into the chrysoprase nodules in the serpentinites has revealed the presence of kerolite, which infills small cavities in the chrysoprase. Kerolite also forms cotton-like aggregates of very fine crystals at the boundaries of quartz grains and in quartz crystals of the chrysoprase.

The nickel oxide content of the chrysoprase increases with the degree of silicification of the surrounding serpentinite. It is inferred that the nickel-bearing kerolite is the likely cause of the green colour of the chrysoprase (Nagase et al., 1997). An example of green siliceous nodules from this area is shown in Figure 11.11. The rock material contains siliceous minerals chrysoprase, green chalcedony, and probably opal.

Recent prospecting within the Sylvania Inlier (Fig. 1.1) has located another decorative chalcedony associated with ultramafic rocks. A slab of purple and white, dendritic chalcedony from this area is shown in Figure 11.12.

Yilgarn Craton — Eastern Goldfields Superterrane

Duck Hill and Jump Up Dam (*Edjudina*, 3338)

Chrysoprase as part of widespread Cenozoic silicification is derived from weathering of ultramafic rocks and is locally associated with silica caprock (Chen, 1999). It has been mined from several small openpits west of Jump Up Dam and at Duck Hill. Although chrysoprase is mined from several openpits at Boyce Creek, west of Jump Up Dam, at Duck Hill, and 1 km southeast of Eucalyptus Bore, there is no recorded production (Fig. 11.2).

Simpson (1952) recorded various colours of chalcedony from just east of Comet Vale township as nodules and veins in the laterite overlying serpentine. The colours vary through colourless, grey, milky white, yellow, and bright green. The green chalcedony forms as veins 15–22 mm wide. Analysis of a portion of this green chalcedony contained 1.43% NiO and no chromium; specific gravity was 2.60. Microscopic examination showed that it is a mixture of granular quartz, fibrous chalcedony, and opal.

Chrysoprase has been worked by openpit mining on Yerilla and Yundamindra Stations at several sites in areas covered by the Yerilla (3239), Lake Carey (3339), Edjudina (3338), Boyce (3238), and Gindalbie (3237) 1:100 000 map sheets.

Yerilla (Boyce Creek East) (*Yerilla*, 3239)

The Yerilla chrysoprase mine, on mining leases M31/104 and M31/112, is approximately 160 km north of Kalgoorlie and 13 km south of the Yerilla Homestead (Fig. 11.2). The mine area can be best accessed by the well-maintained Kookynie–Yarrie gravel road and is directly north of the Cranky Jack Road intersection.

Figure 11.11. Green siliceous nodules of mixed green chalcedony and chrysoprase from the Warrawanda area. Width 20 cm (courtesy Glenn Archer)

Figure 11.12. Polished slab of decorative purple and white dendritic chalcedony from the Sylvania Inlier (courtesy Glenn Archer)

Apart from chrysoprase, the deposit is stated to contain significant potential for the recovery of highly siliceous magnesite of varying colours. The Yerilla tenements have had a long history of citron, lemon prase, or lime prase magnesite mining for the carving or ornamental markets (Bellmount Holdings, 2009).

Chrysoprase has also been investigated in an opencut operation at a prospect 5 km east-southeast of Mount Catherine on Yerilla Station. It was worked in a small way prior to 1992 although since then has been operated by Gembank Group.

Chrysoprase is collected within the weathered profile by bulldozer where it appears as swarms of green veins throughout a jasperized ironstone caprock overlying a hill of ultramafic rock. Fragmental chunks of less than 25–100 mm in thickness consist of veins of white to grey chalcedony, nodules of white magnesite, and bright green veins of chrysoprase. They form elliptical pods a few centimetres across, long stringers of a metre or more long, and angular masses of various sizes depending on the crack and joint system in the original ironstone cap.

Chrysoprase is sensitive to heat and will fade when heated or exposed to sunlight. The largest piece mined weighed 165 kg (Fig. 11.13).

Gemmological investigations of this chrysoprase-on-matrix jasperized ironstone revealed quartz (chalcedony or jasper) and a serpentine-group mineral, probably antigorite. The brown colour was attributed to amorphous to poorly crystalline iron oxides (Gems and Gemology, 1994).

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Figure 11.13. Polished chrysoprase specimens and cabochons from the Yerilla mine, Boyce Creek area. Centre cabochon measures 50 x 30 mm (cut and polished by Murray Thompson)

Boyce Creek (*Boyce*, 3238)

Chrysoprase and magnesite have been worked from openpits at Boyce Creek about 50 km northwest of Edjudina (Fig. 11.2).

Eucalyptus mine (*Lake Carey*, 3339)

Eucalyptus mine is on Yundamindra Station about 95 km east-southeast of Leonora (Fig. 11.2). At this site, chrysoprase and magnesite are mined from mining lease M39/289 operated by Mr Glenn Archer.

The chrysoprase from these occurrences is called 'Eucalyptus', named after an early gold mining location. It exists as nodules of all sizes and shapes, with one specimen reportedly weighing 35 kg (Fig. 11.14). The site was worked in the late 1960s and although there are no official records one shipment of 10 000 kg was produced at the time (Palmer, 2006). In more recent times the area has been covered by gold mining tenements. Moganite has been detected in green chalcedonic chrysoprase from Eucalyptus (Willing and Stocklmayer, 2003).

Other sites are recorded from Western Australian Museum specimens that have been sourced from an opencut prospect 5 km south-southeast of Eucalyptus on Yundamindra Station and at Pyke Hill, 9.6 km east-northeast of Yundamindra Homestead.

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Figure 11.14. Chrysoprase from the Eucalyptus mine, Leonora region. Oblong cabochon measures 50 x 30 mm (cut and polished by Murray Thompson)

Binti Binti (*Gindalbie*, 3237)

The Binti Binti chrysoprase project is recorded as an active project involving shallow workings, 56 km southwest of Edjudina (Fig. 11.2).

Taurus chrysoprase (*Kanowna*, 3236; *Mulgabbie*, 3337)

Taurus chrysoprase forms part of the Bulong complex, a large, discordant, layered intrusive body ranging in composition from peridotite to gabbro between Bulong and Lake Yindarlgooda (Fig. 11.2). It forms a broad, almost north–south striking zone of mafic and ultramafic lithologies with a total strike length of more than 70 km (Ahmat, 1995). The centre of the complex lies approximately 35 km east of Kalgoorlie in an area containing numerous gold and nickel mines.

Goongarrie Hill chrysoprase (*Bardoc*, 3137)

Citron magnesite is reported at Goongarrie approximately 100 km to the north of Kalgoorlie (Fig. 11.2). The 1:100 000 Bardoc geological map (Witt and Swager, 1989) shows a north-striking belt of ultramafic rocks lying between Goongarrie Hill and the main bitumen Kalgoorlie–Leonora Road. Chrysoprase is reported about 40 km and 41 km north-northeast of Ora Banda.

Comet Vale mine (*Menzies*, 3138)

Chrysoprase is described from the now abandoned township of Comet Vale gold mining centre, comprising a group of workings, later known as Lake View, near the western edge of Lake Goongarrie, about 70 km north of Kalgoorlie on the main Goldfields Highway (Fig. 11.2).

The Happy Jack mine, part of this group, was the most significant source of fine crocoite specimens in Australia (not including Tasmania), some associated with coarse gold. Good-quality chrysoprase is known from the weathering of the ultramafic units of the Walter Williams Formation to the east of the Happy Jack mine. Veins of chrysoprase from Blue Speck Creek area, 1.5 km southeast of the Happy Jack mine, are described as gem quality (Grguric et al., 2006). In this area, chrysoprase is reportedly formed in the silica caprock over ultramafic rocks and has been extracted locally (Wyche, 2003).

Leonora area

Marshall Pool deposit (Wildara, 3041)

Deep weathering over ultramafic rocks has produced widespread occurrences of chrysoprase within silica caprock (Fig. 11.15). The chrysoprase lies approximately 70 km north-northwest of Leonora and 5.5 km to the east of Marshall Pool (Fig. 11.2). Reference to the occurrence of chrysoprase at this site is made in Chapter 28 on the carbonate group, where nickeliferous magnesite is described. Australian Outback Mining reported that in this area nickeliferous magnesite exists in a belt of serpentine–talc and talc–chlorite schists.

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Figure 11.15. Chrysoprase specimen displaying a magnesite centre from Marshall Pool deposit, Leonora area (courtesy Glenn Archer)

Musgrave Province

Wingellina area

Wingellina prospect (Bell Rock, 4645)

The Wingellina chrysoprase prospect is in the Wingellina area, approximately 240 km east of Warburton (Fig. 11.2). In this area, deep weathering of folded interbanded mafic and ultramafic rocks of the Giles Complex has produced a nickeliferous ochre (see Chapter 28 on the carbonate group). Associated with the deposit are chromite, chrysoprase, moss agate, and nickeliferous magnesite. It has been reported that the chrysoprase included dark apple-green material and that some specimens have faded in colour when exposed to light, becoming milky and opaque. A Western Australian Museum specimen of this material (MDC 4709) analysed for nickel gave a 0.8 – 2.1% Ni result.

The deposit has been mined by various individuals and companies since 1967. As the prospect is currently within Aboriginal lands, entry permits are required for entry and fossicking (Parker, 1995).

References

Ahmat, AL 1995, Geology of the Kanowna 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 28p.

Bellmount Holdings 2009, Yerilla mining project–Combined annual mineral exploration report, tenements M31/104 and M31/112: Bellmount Holdings Pty Ltd: Geological Survey of Western Australia, Statutory exploration report, A82264 (unpublished).

Bauer, M 1904, Precious stones: Charles Griffin and Company Ltd, London, 627p.

Chen, SF 1999, Edjudina, WA, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 32p.

Connolly, RR 1976, Semi-precious stones — Western Australia, *in* Economic Geology of Australia and Papua New Guinea, Volume 4, Industrial Minerals and Rocks *edited by* CL Knight: The Australasian Institute of Mining and Metallurgy, Parkville, p. 354–355.

Daniels, JL 1974, The geology of the Blackstone region of Western Australia: Geological Survey of Western Australia, Bulletin 123, p. 81.

Freeman, MJ and Donaldson, MJ 2006, Geology of the southern Perth Basin and Margaret River wine district, South Western, Western Australia: Geological Survey of Western Australia, Record 2006/20, p. 12–13.

Frondel, C 1962, The System of Mineralogy, 7th edition, volume III: John Wiley and Sons, New York and London, 334p.

Gems and Gemology 1994, Chrysoprase chalcedony matrix carving: Gem News, *in* Gems and Gemology, Fall, p. 193–194.

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, Perth, Western Australia, 52p.

Grguric, BA, Pring, A, Bevan, AWR and Downes, PJ 2006, The minerals of Comet Vale, Western Australia: Australian Journal of Mineralogy, v. 12, no. 1, p. 9–23.

Heflik, W, Kwiecinska, B and Natkaniec-Nowak, L 1989, Colour of chrysoprase in the light of mineralogical studies: The Australian Gemmologist, v. 17, no. 2, p. 43–46, 58–59.

Kriewaldt, M and Ryan, GR 1967, Pyramid, WA: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 39p.

MacDonald, J, Burton, C and Winstanley, I 2006, Geology: Collins internet-linked dictionary of geology: Harper Collins, London, 480p.

Mindat.org 2016, Agate mineral information and data, viewed 4 January 2016, <www.mindat.org/min-51.html>.

Moxon, T 2009, Studies on agate: microscopy, spectroscope, growth, high temperature and possible origin: Terra Publications, CPI Anthony Rowe, Eastbourne, England, p. 96.

Nagase, T, Akizuki, M, Onoda, M and Sato, M 1997, Chrysoprase of Warrawanda, West Australia: Neues Jahrbuch fur Mineralogie, Monatshefte, v. 7, p. 289–300.

Pabian, R, Jackson, B, Tandy, P and Cromartie, J 2006, Agates, treasures of the earth: Natural History Museum, London, 184p.

Palmer, A 2006, Yundamindra—its town, mines, people and station: Hesperian Press, Carlisle, Western Australia, p. 9–22.

Parker, F 1995, Gemstones of Western Australia: The Australian Gemmologist, v. 19, no. 3, p. 139–142.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 470–477.

The Quartz Page 2012, The quartz page, viewed 21 August 2012, <www.quartzpage.de>.

Thorne, AM and Tyler, IM 1997, Roy Hill, Western Australia, second edition: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 22p.

Williams, IR 1989, Balfour Downs, Western Australia, second edition: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 38p.

Williams, IR 2003, Yarrie, Western Australia, 3rd edition: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 84p.

Williams, IR and Bagas, L 2007, Geology of the Mount Edgar 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 62p.

Willing, MJ and Stocklmayer, SM 2003, A new chrome chalcedony occurrence from Western Australia: Journal of Gemmology, v. 28, no. 5, p. 265–279.

Witt, WK and Swager, CP 1989, Bardoc: Geological Survey of Western Australia, 1:100 000 Geological Series, Sheet 3137.

Wyche, S 2003, Menzies, Western Australia, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 32p.

Chapter 12

Fossil wood

Fossil wood in Western Australia

Western Australia has fossil wood sites in many areas throughout the State in the major sedimentary basins including the Canning, Carnarvon, Perth, and Eucla Basins, and major Cenozoic paleodrainage channels in the Coolgardie–Norseman area and other areas of the southwest and south of the State. These fossil wood sites cover a broad geological time span of about 300 million years ranging from the early Permian to the late Quaternary and were established in different ecological zones under changing paleoclimates.

Western Australian fossil wood specimens with well-preserved cellular detail have been studied by examination of thin sections. In the absence of other significant anatomical features it has been possible to name or taxonomically assign only relatively few species. Some woods have been identified as gymnosperms (conifers), and various angiosperms (flowering and seed producing species) are found within younger woods from the Cenozoic (Fig. 12.1).

Western Australia's oldest petrified logs are of early Permian age. These examples are probably fragments derived from glossopterids, the dominant plants of that time, and reach 40 cm in diameter. These fossil log specimens are unsuitable for lapidary use.

The Jurassic and Cretaceous petrified woods (200–66 Ma) show structural anatomies characteristic of evergreen podocarpacean and araucarian conifers; these findings are corroborated by studies of foliage preserved within terrestrial strata. Several sites in the Southern Carnarvon Basin produce lapidary-grade fossil wood specimens from these geological periods.

Fossil woods from the Cenozoic (66 Ma to the present) include both conifers and angiosperms although they have not been researched in great detail. Conifers of the Podocarpaceae, Araucariaceae, and Cupressaceae have all been identified from their leaf imprints in Eocene deposits at Kojonup whereas angiosperm woods have been confirmed from distinctive cellular evidence. Some of the angiosperms resemble modern Casuarinaceae (sheoaks of the casuarina family) and others have affinities to the Protoeaceae, Fagaceae, and Myrtaceae (banksia, beech, and eucalypt families, respectively; McLoughlin and Worth, 1994). Some of these Cenozoic woods and specimens of opalized peat are suitable as lapidary-grade specimens and can be cut and polished. Specimens exhibiting fossil leaf impressions may make visually attractive display materials.

Fossil wood

Wood preserved by minerals, commonly silica SiO_2

Preservation of wood

Petrified wood is preserved by cellular permineralization processes that involve the precipitation of minerals in the interstices of organic tissues, but not replacement of the original organic material. Permineralization is not selective and plant parts and woods of any type may be preserved. Mineral-charged waters may infiltrate and permeate plant tissues impregnating, coating, and infilling open spaces. Original organic matter may be retained although it is commonly lost by alteration and weathering. Preserving processes may be improved by good porosity of the enclosing sediments, which allows for the constant flow of mineralizing solutions over time to permeate driftwood incorporated in the matrix.

Silica is a common permineralizer forming as opal, chalcedony, and microquartz, and all of these forms may exist within a single specimen. Many specimens of petrified woods also contain open fractures and cavities that may become infilled by small quartz crystals. In the Stirling Ranges in the southwest of the State, specimens of silicified peat are recorded with plant parts including roots replaced by white opaline silica (McLoughlin and Worth, 1994). Silicified woods mineralized by opal and chalcedony are typically the most suited and robust for cutting and polishing. Fossil wood is also preserved by other minerals including calcite, aragonite, apatite and clays, and the iron minerals goethite, hematite, and siderite.

Fossil wood for lapidary applications

For lapidary use, silica-preserved specimens of chalcedony, quartz, and opal are the most durable. However not all silicified wood is lapidary grade and many specimens, particularly from the southwest of the State, are coated by drusy quartz crystals and are useful only as display specimens (Fig. 12.2). Fine-grained silica in the form of chalcedony or opal can be polished to a high-quality finish. As tumble-polished stones, and slabbed and polished sections, silicified woods make attractively coloured specimens with distinctive naturalistic textures.

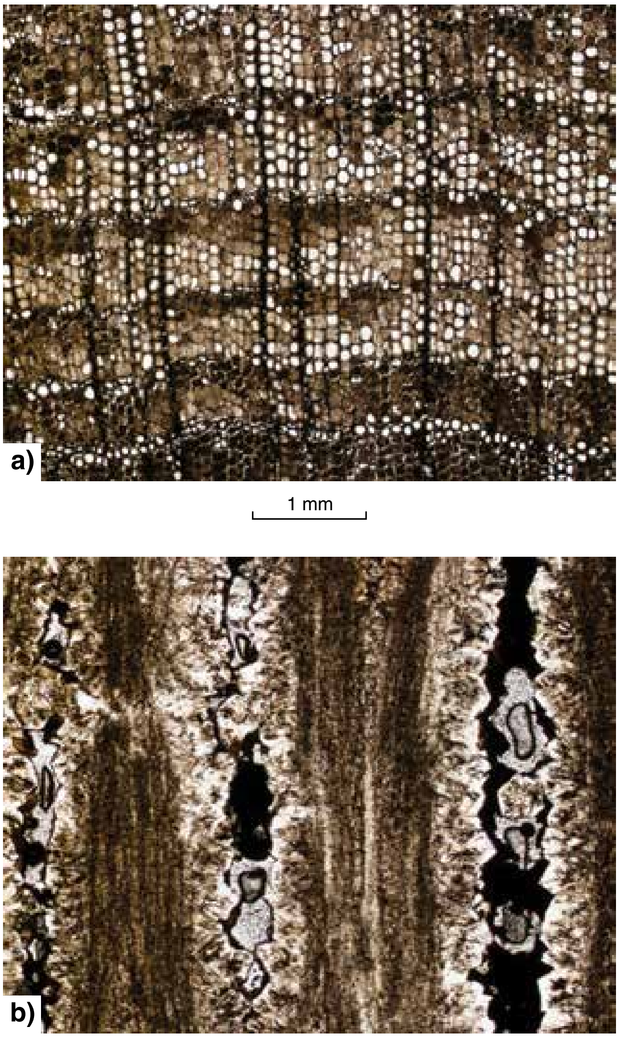

Figure 12.1. **Photomicrographs of Western Australian fossil woods: a) permineralized conifer wood from the North Stirling Ranges showing cellular structure with growth rings; b) permineralized angiosperm wood showing open cavities infilled with microcrystalline quartz displaying good crystal form (courtesy Stephen McLoughlin)**

Figure 12.2. **Lattice pattern coating of drusy quartz on fossil casuarina from southwest Western Australia. This type of silicified wood is unsuitable for cutting and polishing (courtesy Western Australian Museum)**

Lapidary-grade fossil wood sites

Southern Carnarvon Basin

Several Cretaceous formations in the Southern Carnarvon Basin contain detrital petrified wood. This material is abundant near Kalbarri, north of Geraldton, in areas west of the Kennedy Range including Merlinleigh Station and Mooka Creek, and in the Giralia Range, east of Coral Bay (Fig. 12.3). Some fossil woods from these areas show prominent growth rings and anatomical features typical of podocarp conifers and are assigned to the genus *Podocarpoxylon* (McLoughlin and McNamara, 2001).

West of the Kennedy Range, fossickers have collected fossil wood specimens from surface outcrops over an extensive area in several pastoral stations covering the central area of the 1:250 000 Kennedy Range map, which incorporates the Mardathuna (1849), Mount Sandiman (1949), Binthalya (1848), and Lyons River (1948) 1:100 000 map sheets.

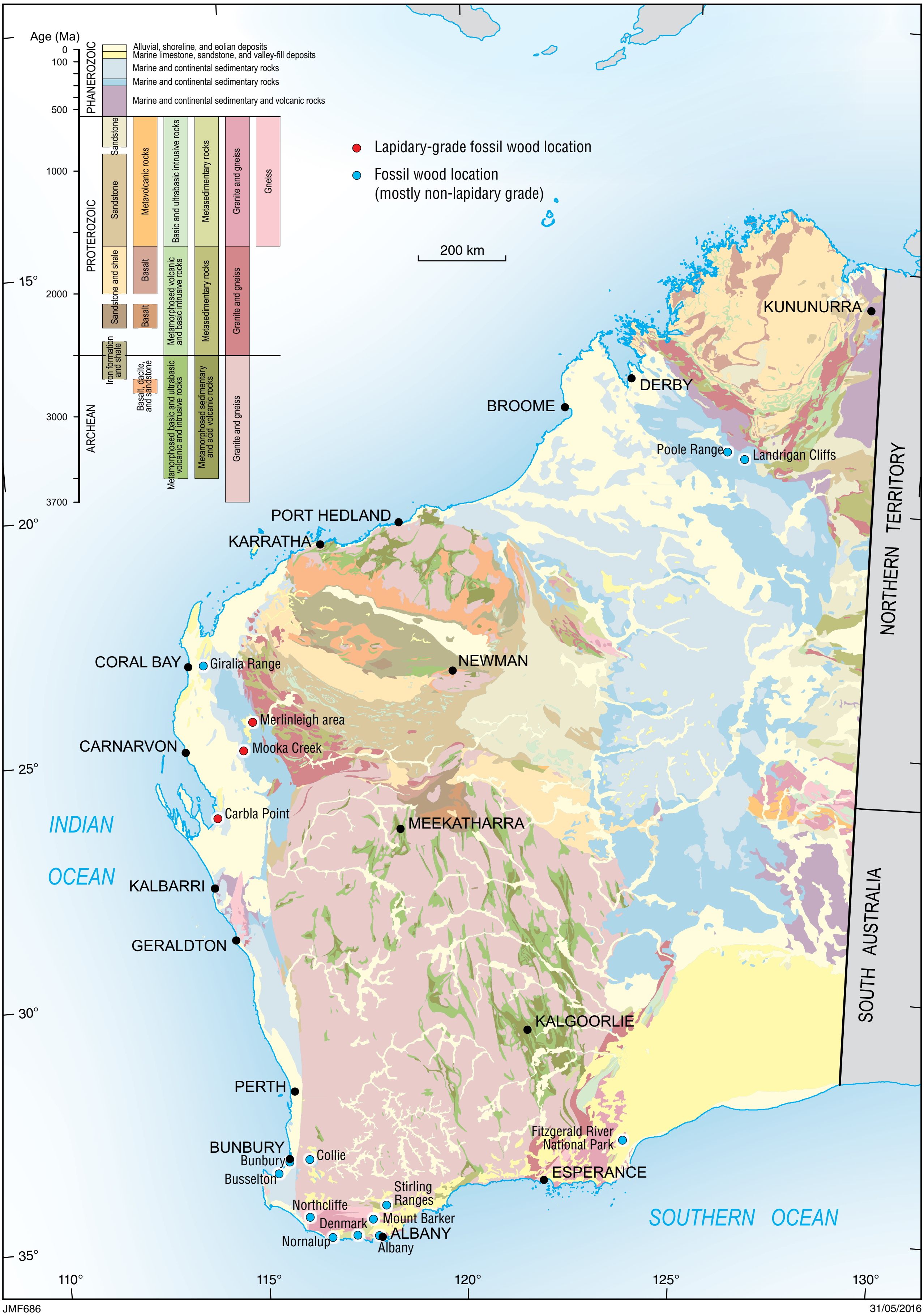

Figure 12.3. Approximate locations of fossil wood sites in Western Australia

Fossil woods from the Southern Carnarvon Basin include some of the best-quality lapidary-grade material. Different woods species can be recognized although not all types are suitable for polishing. The most common petrified wood from these areas is marketed as 'peanut wood' (Fig. 12.4).

Peanut wood

Mooka Creek *(Binthalya, 1848)*

Peanut wood is associated with silicified Cretaceous Windalia Radiolarite. It appears sporadically as angular to subrounded pebbles, cobbles, and boulders. At Mooka Creek, 32 km northwest of Gascoyne Junction, peanut wood detritus lies on the surface at various sites around the mookaite workings (Fig. 12.3, and Fig. 33.3 in Chapter 33 on mookaite and other decorative porcellanites).

Peanut wood is petrified wood that has been formed by chalcedonic and opaline silica replacement after burial in fine-grained, marine sedimentary rocks. It has a distinctive light brown colour, commonly displaying growth banding and original cellular structure that has been identified as conifer wood. The permineralized cellular structure is clearly visible as compact, parallel trains of individual, relict cells each about 50 µm in length (Fig. 12.5).

Prior to silicification, wood-boring bivalve molluscs (also termed shipworms) of the families *Teredinidae* or *Pholadidae* made numerous burrows in the wood that were subsequently infilled by a white, radiolarian-rich mud and silt, which constitutes the Windalia Radiolarite (Hocking et al., 1987). In transverse section, the burrows are round or oval, 0.5 – 22 mm in diameter with some attaining lengths of several centimetres. Burrows have a clavate (club-shaped) form and they may be straight or more commonly sinuous and seldom intersect. Cut sections commonly show both transverse and longitudinal burrows, and in some specimens burrows are concentrated within particular sections of the original wood. The infilled burrows contain fossiliferous, white- to cream-coloured siliceous mudstone contrasting with the translucent dark brown, near-black, or carnelian red-banded wood in between (Fig. 12.6).

The hard, siliceous, permineralized replacement of the cellular structure of peanut wood makes it very suitable for cutting and polishing as high-grade lapidary material. Examples of polished peanut wood include tumble-polished stones, polished slabs, and jewellery items including pendants (Fig. 12.7).

Cardabia region

Giralia Range *(Giralia, 1752; Mia Mia, 1751)*

The Giralia Range, about 35 km east of Cardabia Homestead near Coral Bay, consists of Cretaceous sedimentary rocks forming the north-trending Giralia Anticline (Fig. 12.3).

In this area, fossil wood specimens (podocarpian or araucarian conifers) permineralized by silica and phosphates are preserved within glauconite-rich beds of the Cretaceous Birdrong Sandstone. In the outcropping sandstone, abundant fossil wood specimens are present as randomly orientated fragments, seldom larger than 50 cm in length and 17 cm in diameter. Specimens collected at various locations from surface and near-surface sites are strongly weathered and contain iron oxide and clay minerals. Lapidary-grade material from this area is uncommon.

The Giralia Range fossil wood contains fractures caused by compaction, and cavities produced by molluscan borers have been filled with glauconite, quartz sand, chalcedony, or calcite (McLoughlin et al., 1995). The wood's cellular structure is infilled with cryptocrystalline silica and fluorapatite. Prominent growth banding is evident although important cellular detail is commonly either poorly defined or absent.

In some fossil woods from the Birdrong Sandstone, small cavities arranged along the growth rings are considered to have been caused by fungi. Microscopic evidence has shown the development of fungal hyphae within these pockets, representing the first examples of fossilized saprophytic fungi recorded from Western Australia (McLoughlin, 1996).

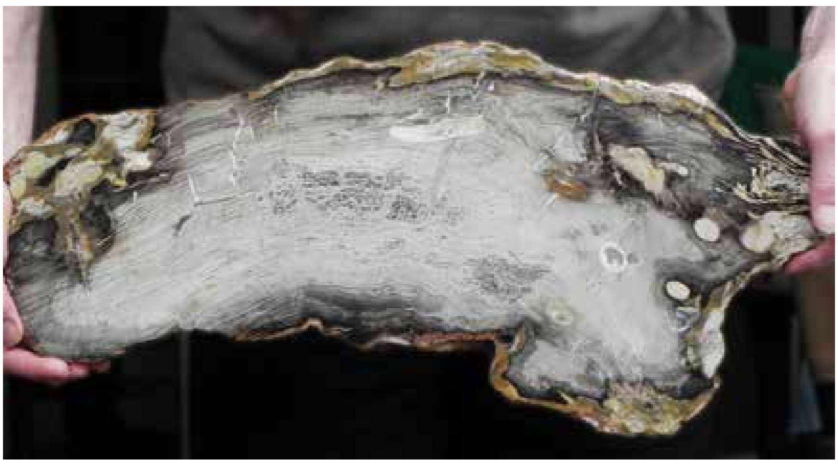

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Figure 12.4. Polished slab of peanut wood from Binthalya Station, Gascoyne Junction region; width 55 cm (courtesy Barry Kayes)

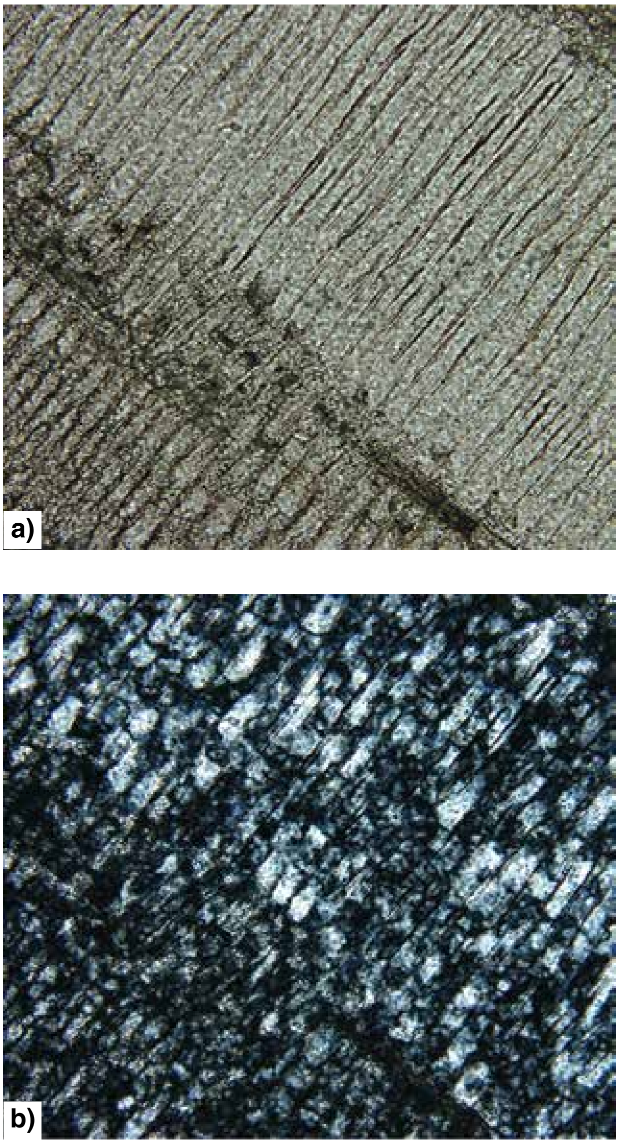

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Figure 12.5. Photomicrographs of peanut wood (200x) showing the preserved, permineralized cellular structure: a) photomicrograph in plane-polarized light showing the compact, linear trains of fossil plant cells; b) photomicrograph of same view in cross-polarized light showing parallel trains of individual relict cells about 50 µm in length (Pontifex, 2011)

Minnie Creek and Williambury Stations

Merlinleigh Station area (Mount Sandiman, 1949)

Fossil wood specimens have been collected from various locations on the former Merlinleigh Station (currently part of Minnie Creek and Williambury Stations), approximately 80 km north of Gascoyne Junction (Fig. 12.3). These fossils were derived from the Eocene Merlinleigh Sandstone present in the northeastern part of the Kennedy Ranges close to the eastern margin of the Southern Carnarvon Basin.

The Merlinleigh Sandstone is a thin succession (typically <10 m) of coarse- to fine-grained quartz sandstone with subordinate conglomerate and siltstone that accumulated in both fluvial and marine environments. The formation contains a varied fauna of molluscs, gastropods, corals, bryozoans, and foraminifers, and abundant fossil wood (Hocking et al., 1987). The sandstone underlies much of the high-level sandplain on top of the Kennedy Range and has its type section near the abandoned Merlinleigh Homestead.

Fossil wood specimens are of variable quality as lapidary material because the fossil wood is commonly of a species displaying a finely striated texture in longitudinal sections. Precise specimen localities are not available although the Western Australian Museum has recorded several sites on Mount Sandiman, and the former Moogoorie and Merlinleigh Stations.

Southwest Western Australia

Many specimens of fossil wood in the collections of the Western Australian Museum and The University of Western Australia derive from numerous sites covering an extensive area in the southwest of the State. There are many sites in the Fitzgerald National Park, and bordering the Stirling Ranges, and other locations from around Northcliffe, Albany, Mount Barker, Denmark, Nornalup, Collie, Bunbury, and Busselton (Fig. 12.3). Several of these sites contain accumulations of driftwoods associated with paleodrainage channels of ancient river systems, active prior to the Late Eocene. The drainage channels were broad and had low gradients, and modern inland lakes can be remnants of these systems. Also, swamps and freshwater lakes were sites of peat and driftwood accumulation (Hocking and Cockbain, 1990).

In general, fossil wood specimens from the southwest of the State mostly form collectors' items, as they are unsuitable for cutting and polishing. Despite this, there are a few sites of unknown location around the Stirling Ranges and extending south towards Albany where suitable lapidary-grade silicified wood and opalized peat have been found.

Other fossil wood sites

In the northern Canning Basin in the northwest of the State, several fossil wood sites form part of sedimentary rocks ranging from Permian to Cenozoic age. In particular, at the southern end of the Landrigan Cliffs there is a deposit of large silicified fossil logs, some up to 4 m in length, and further west in the Poole Range is another area of silicified wood (Fig. 12.3). Precise locations for these sites are not available and the fossil wood from these areas is unsuitable for lapidary purposes.

Silicified wood of polishable grade has been reported from Carbla Point on the eastern side of Hamelin Pool at Shark Bay where it has washed out of exposures of Miocene Lamont Sandstone (R Hocking, 2012, written comm., 1 November).

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Figure 12.6. Peanut wood displaying irregular, white borings of molluscs of the Teredinidae family enclosed in a dark, siliceous, fossil wood matrix, set in pale pink resilicified Windalia Radiolarite (courtesy Judy Brewster)

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Figure 12.7. Peanut wood applications: a) selection of tumble-polished pebbles (courtesy Judy Brewster); b) slabbed and polished pendant (courtesy Soklich Trading)

References

Hocking, RM and Cockbain, AE 1990, Regolith, *in* Memoir 3, Geology and Mineral Resources of Western Australia *edited by* AF Trendall: Geological Survey of Western Australia, Perth, Western Australia, p. 591–597.

Hocking, RM, Moors, HT and van de Graaff, WJE 1987, Geology of the Carnarvon Basin, Western Australia: Geological Survey of Western Australia, Bulletin 133, p. 150–152.

McLoughlin, S 1996, Early Cretaceous macrofloras of Western Australia: Records of the Western Australian Museum, v. 18, p. 19–65.

McLoughlin, S, Haig, DW, Backhouse, J, Holmes, MA, Ellis, G, Long, JA and McNamara, KJ 1995, Oldest Cretaceous sequence, Giralia Anticline, Carnarvon Basin, Western Australia: Late Hauterivian–Barremanian: AGSO Journal of Australian Geology and Geophysics, v. 15, no. 4, p. 445–468.

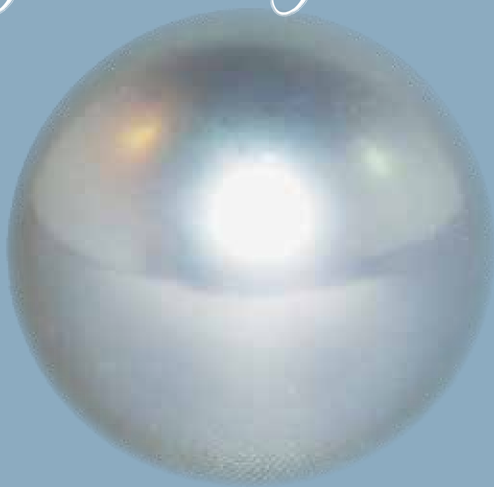
McLoughlin, S and McNamara, K 2001, Ancient floras of Western Australia: Western Australian Museum, Perth, Western Australia, 42p.

McLoughlin, S and Worth, M 1994, Petrified (permineralized) wood in Western Australia: The Fossil Collector, v. 42, p. 5–17.

Pontifex, IR 2011, Mineralogical Report No. 10016: Pontifex and Associates Pty Ltd, (unpublished).

4

Organic gems



High-quality, silver-white, South Sea cultured pearl from Western Australia (courtesy Nash Pearls)

Chapter 13

Pearls, shells, and other organic gems

Early history of pearling

Natural pearls have been appreciated and desired through history, although they have been little preserved from antiquity because of their soft nature and chemically sensitive composition. The oldest surviving natural marine pearl was found in at a Neolithic grave at Uum Al-Quwain in the United Arab Emirates (UAE) and has been carbon dated at approximately 5500 BCE (Chandour Sampson et al., 2013). A recent find in 2011 of a single pearl from Western Australia is estimated at 2000 years old. Known as the Brremangurey pearl, it is 5.9 mm in diameter and weighs 0.25 g. It was discovered in the Admiralty Gulf area, 80 km east of Kalumburu, in a midden containing *Pinctada albina* shells about 70 m from the current coastline (Szabo et al., 2015).

In the sixth century BCE the Persians introduced pearls into Egypt. Pearls became a desired asset of royalty and have been found buried with the dead. Mother-of-pearl (nacre) inlay work was part of Egyptian artistic culture. In China records about pearls date from 2300 BCE. From the 13th century CE, Chinese people had discovered the means of coating images, some made of wood and/or lead, with mother-of-pearl by inserting the images between the shell and mantle tissue of the Chinese freshwater mussel, *Cristaria plicata*.

The finest and historically best known natural marine pearls, termed 'oriental pearls', are produced by the pearl oyster *Pinctada radiata*. Since 300 BCE these pearls, commonly less than 8 mm in diameter, were harvested from the coastlines surrounding the Persian Gulf and Arabian Sea, especially around the island of Bahrain. Important oyster beds stretched along the gulf coast from Kuwait south to the UAE, particularly between Al-Qatif in Saudi Arabia and Dubai in the UAE. Pearl diving continued for hundreds of years in the main centres of Manama (Bahrain), Doha (Qatar), and the island of Dalma (off Abu Dhabi). Early pearl trade routes centred on Basra (Iraq) and passed through the Arabian Gulf to China. Arab merchants travelled across the Indian Ocean, trading at several ports along the coast of India, especially Bombay (Mumbai). By the eighth century CE, these merchants had settled in Sri Lanka.

Pearls, shells, and other organic gems
Calcium carbonate polymorphs $CaCO_3$

Pearl banks in the Gulf of Mannar between India and the northwest coast of Sri Lanka have been worked for about 2500 years. Until recently they were an important source of pearls, including seed pearls (<2 mm diameter), much in vogue in jewellery in the late 19th and early 20th centuries (Mahroof, 1997).

Although there has been a gradual depletion of traditional oyster beds harvested in Arabia and other centres for hundreds of years, the most significant factor relating to the collapse of the oriental (natural) pearl harvesting industry was the appearance on world markets of Japanese cultured pearls from the 1920s. Natural pearls continue to be marketed from old stocks and any pearls of special size and quality still discovered are both rare and highly valued. Natural pearls continue to be found in Western Australia.

Pearls and pearl shell

Nomenclature, structure, and natural properties

Pearls are solid calcium carbonate concretions that develop naturally within living molluscs with saltwater oysters and freshwater mussels the most important hosts. Pearls develop in various forms, commonly spherical or near spherical, although other bizarre forms may develop with highly irregular shapes termed 'baroque pearls'. Pearls that are not attached to the shell but develop freely within the host's tissues are termed 'cyst pearls'. By contrast, 'blister pearls' develop on the inside of the host's shell where they form convex protuberances that are harvested from the shell by sawing. All pearls become larger by incremental, seasonal growth. After harvesting, pearls may be used in jewellery with no treatment required to reveal their beauty (Fig. 13.1).

Although pearls can be formed within many species of molluscs, pearls that possess a lustrous quality, termed 'nacreous pearls', are of commercial importance in the cultured pearl industry. Nacre is the hard, smooth, iridescent coating on the inner surface of specific mollusc shells. It is a composite material of microscopic layers of aragonite (a calcium carbonate polymorph) and conchiolin, an intergranular protein, which acts as a framework and cement (Kennedy, 1998). Accordingly, nacreous pearls are the product of shells with a nacreous inner shell lining, and both the nacre of the shell and that of the pearl are composed of the same material produced by the mollusc's soft tissue, known as the mantle.

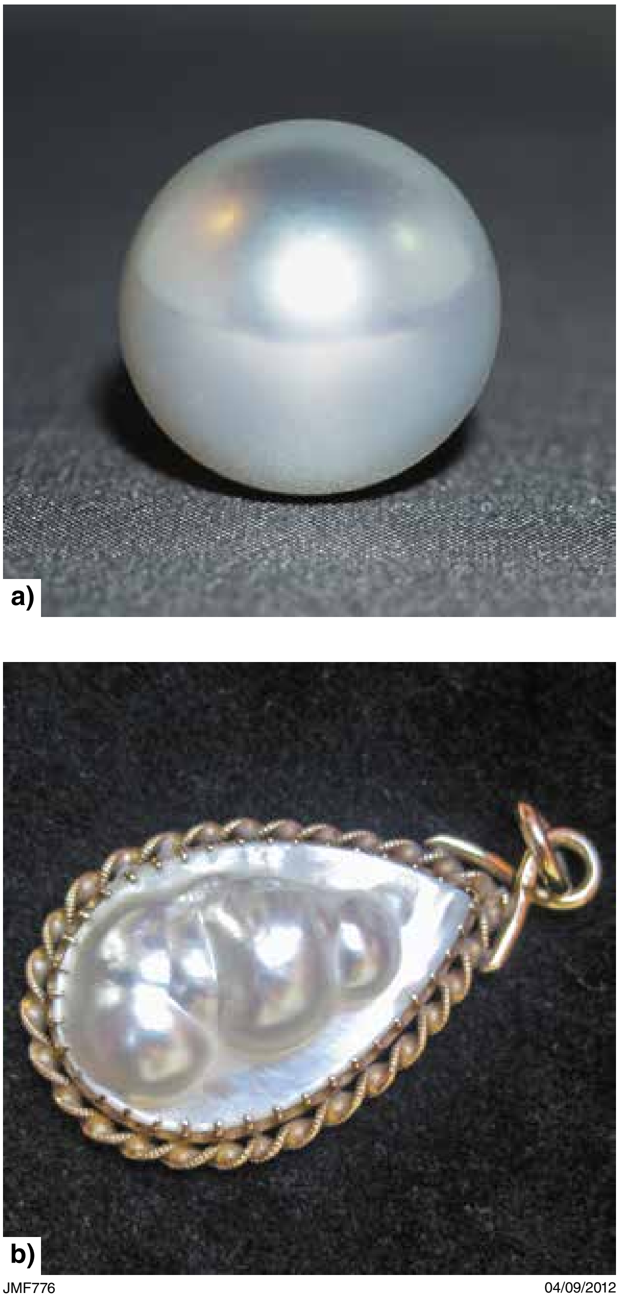


Figure 13.1. Pearls used in jewellery: a) high-quality, silver-white, South Sea cultured pearl from Western Australia, diameter 16.3 mm, weight 6.5 g (courtesy Nash Pearls); b) blister pearl, mounted as a pendant with a gold rope-motif border. The blister pearl cluster has been cut from the shell host with a narrow mother-of-pearl border. The pendant is 40 mm in length (courtesy Joy Rogers)

As mentioned above, a pearl develops by incremental and seasonal growth of successive layers of aragonite and conchiolin around a nucleation site. Natural pearls develop under natural conditions, whereas in cultured pearls the process is initiated artificially. Although the mineral portion of the pearl is dominantly in the form of aragonite, recent research has demonstrated that vaterite and amorphous calcium carbonate (other polymorphs of calcite) may also be present (Wehrmeister et al., 2007).

The special lustre of nacreous pearls and mother-of-pearl is the result of optical effects involving diffraction and interference of light produced by surface reflection and iridescence from the mineralized layers of their structures. These optical effects are known as the 'orient' of a pearl. Nacre is formed by the accretion of successive layers of crystallographically aligned aragonite platelets and it is this precision of the structure that causes diffraction and interference of light, resulting in the iridescence, or orient, of shell linings and their pearls. Disruption to the orderliness of the structure, or changes to the alignment of crystals, result in a non-nacreous lustre.

Marine pearls from oysters, mussels, and gastropods

Pearl-producing oysters and mussels belong to a subgroup of molluscs known as Lamellibranchia or bivalves in which the shell consists of two hinged parts. Pearls can also form in gastropods (with a non-hinged shell) such as the non-nacreous baler shell, *Melo amphora*, present in Shark Bay. Pearl oysters most important to the pearling industry in Western Australia are *Pteria penguin* and four species from the genus *Pinctada* found in the tropical coastal waters in northern Australia: *P. maxima*, *P. albina*, *P. imbricata fucata*, and *P. margaritifera*.

The silver-lipped pearl oyster, also termed the gold-lipped oyster, *P. maxima*, is the largest living species of this genus. It can measure up to 40 cm in diameter and has a maximum life span of about 40 years. It is harvested for mother-of-pearl, and produces Australian silver and white pearls and gold-coloured pearls from the Philippines and Japan. The large pearls produced by this species are commonly 10–20 mm, with the largest recorded diameter of 24 mm. Large cultured pearls of varied colours produced from *P. maxima* are collectively termed 'South Sea pearls'.

Black-lipped pearl oysters, *P. margaritifera*, produce pearls in a large range of colours and overtones of iridescent colours that include bronze, grey, black, greens, and purples with varieties from Tahiti termed 'Tahitian black' cultured pearls. This oyster is a host species used for culturing pearls off the northwest coast of Western Australia.

Pinctada fucata, *P. martensi*, and *P. imbricata* are important hosts for the Japanese cultured pearl industry, producing pearls known collectively as 'akoya pearls'. These pearls are commonly white, yellow, pink, and cream, with overtones in many shades. The white-rose and pink-rose pearls are the most highly prized.

Periculture

Nucleated cultured marine pearls

Pearl culturing, or periculture, as practised today did not develop until the turn of the 20th century when the world's first scientifically induced gem-quality pearls were produced in Japan. In 1893, after years of experimentation, Kokichi Mikimoto achieved the culturing of the first blister pearl (half-pearl). There were other experimenters at this time and eventually patents were granted in 1916 covering the development of spherical pearls. Japanese periculturists mostly use the mother-of-pearl nuclei fashioned from the Mississippian pig-toe mussels and other varieties from the Ohio, Tennessee, and Mississippi Rivers and their tributaries.

Seeding and growth of cultured marine pearls

Today, pearls are cultivated in many locations including Japan, China, Australia, the Philippines, Indonesia, Burma, Tahiti, the islands of Polynesia, and Venezuela. Farming techniques are improving steadily.

Cultured pearls grown commercially are produced by the same molluscs that produce natural pearls, although they are developed on implanted, pre-formed nuclei. The culturing process is a surgical procedure that is performed under sterile conditions. It commonly involves grafting of a section of mantle tissue ('saibo') from a sacrificial or donor oyster together with a pearl nucleus into a recipient oyster. Several incisions are made in the body of the host oyster, into each of which a piece of the sacrificial mantle tissue is placed. The pre-formed bead nucleus is then inserted into the incision next to the grafted-in piece of mantle tissue. In ideal conditions the mantle tissue of the host oyster forms a sac around the implanted nucleus, which then becomes coated by nacre. The donor mantle tissue plays an important part in determining pearl quality and the nacre that develops will be the same colour as that of the host animal.

Despite the care taken in all aspects of the implantation operations, mortality rates of the host oyster can be high and other problems including rejection of the nuclei are common. The Australian industry estimates that its mortality rate for seeded shell, over the two-year cultivation period, is about 5%. Most of the technology and procedures used in the cultured pearl industry are performed by experienced Japanese technicians.

The cultured pearl industry produces pearls of various shapes from spherical to irregularly shaped baroque pearls, half-round blister or 'mabe' pearls, and irregularly shaped and bizarre pearl concretions termed 'keshi' pearls. Keshi pearls develop as a byproduct of the cultured pearl process, forming without an artificial bead nucleus with nacre built up over a section of tissue. These pearls, estimated to constitute at least 15% of Australian pearl exports, look attractive and are desirable for individually designed jewellery.

It takes approximately two years from the time of implantation for a farmed pearl oyster to produce a pearl of commercial value and size. Producers expect to seed an oyster four times in its life, the first at about two years old for spherical pearls; in its last year the oyster may be used for mabe pearl production (Fig. 13.2).

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Figure 13.2. Shells of black-lipped oyster, *Pinctada margaritifera*. Iridescent colours of mother-of-pearl are displayed at the shell edges and a cultured half-pearl ('mabe' pearl) is exposed at the shell rim. Pearl size is approximately 15 mm in diameter (courtesy Maggie Campbell Pedersen)

Natural freshwater pearls

Natural pearls from the freshwater mollusc, *Margaritifera margaritifera*, and mussels, *Unio* spp., termed 'river pearls', have been harvested and appreciated for some 2000 years. Especially well known in the jewellery trade are pearls from the Scottish rivers Spey, Earn, Teith, and Tay. River pearls were also sourced from Scandinavia, Germany, and Russia although most sources are now strictly controlled or no longer in production. The best of the river or freshwater pearls are found in the mussel *Unio* spp. In North America, river pearls and shell, commonly from Mississippian pig-toe mussels, formed the basis of an important industry from the time of colonization. Today, much of the cultured pearl industry uses mother-of-pearl shell nuclei made from the shells of these mussels.

Nucleated and non-nucleated freshwater pearls

Mussel species are the hosts used in freshwater cultured pearls. Most suitable is the species *Hyriopsis schlegeli*, used in pearl farms in lakes, rivers, and streams in Japan and China. Freshwater cultured pearls form the basis of a large industry rivalling marine cultured pearls in their lustre and colour. In Japan, freshwater cultured pearls are produced in Lake Kasumigaura using bead nucleated production to yield pearls of 13–14 mm in diameter produced from a hybrid of *H. schlegeli* and *H. cumingi* (Dillenburger, 2004). The Chinese freshwater pearl industry dominates the industry today with production of over 1500 t/year in 2005 (Hui and Beili, 2005).

Cultured pearl quality

Gem-quality pearls are initially assessed by growers and sorted into groups based on whether they are unmarked, have one major blemish, or have more than one major blemish. They are then graded using a series of quality criteria (see inset box below).

Pearls and shells in Western Australia

History of the Western Australian pearling industry

Although pearl shell was first reported at Shark Bay by William Dampier in 1699, it was not until the mid-19th century that the resource was actively used.

The first recorded operations of the pearling industry in Western Australia were in 1850 when 3 t of pearl shell was shipped from Shark Bay. This early date makes pearling one of the first gem industries in the State. The Shark Bay pearling industry centred on Wilya Mia (formerly Wilyah Miah), along an 8 km stretch of the northeastern shore of Useless Inlet (Fig. 13.3). During this time, pearling activities were largely confined to a bank extending about 16 km north from the mouth of the inlet where pearl shell was bagged and taken ashore for processing. The shell species collected at Shark Bay were the subspecies *P. albina albina*, *Avicula* (*meleagrina*) *fucata*, and *P. cacharium* (Streeter, 1886). These shells were smaller and of lower value than the silver-lipped or gold-lipped pearl oyster *P. maxima*, which lived further north in the Broome area.

At this time, pearl shell was recovered by dredges and no pearl diving was undertaken. Following recovery, the landed shell was heated in 'pogey pots' until the pearls fell from the shells. From an 1890 report from a pearling camp on Dirk Hartog Island it can be established that camps of pearlers were in the area around Notch Point on the eastern side of the island from the early 1870s until 1896 (Western Australian Museum, 2011). Although dredges were cheap and efficient they destroyed juvenile shells and there were concerns for the environmental sustainability of the industry. As a result, by 1892 pearl shell dredging was banned.

Quality criteria for cultured pearls

Nacre thickness is largely determined by the length of time the nucleus remains in the host animal. Mostly, the thicker the nacre, the higher the value and better the lustre. South Sea pearls from *Pinctada maxima* are expected to have much thicker nacre than the accepted minimum thickness (0.6 – 1.0 mm) and it is more likely to be about 3.5 mm thick.

Lustre is the result of reflected and refracted light from the inner layers of nacre and the surface although it cannot be measured quantitatively. It is also known as the orient of a pearl and the most beautiful lustre displays the sharpest image of a light source.

Size is the smallest diameter measured in millimetres. For pearls of equivalent type and quality, the larger the pearl, the greater its value. Cultured pearl diameters are about 6–22 mm and seedless pearls may be smaller than 1 mm diameter.

Shape includes round, near round, oval, drop, or button. Pearls are categorized by their shape. The most valuable and desirable high-quality pearls are spherical although there is also a market for subrounded and irregularly formed pearls, especially in custom-made jewellery items.

Surface perfection refers to dimples, spots, circular markings, and other pinpoint imperfections that are common on the surface of pearls. Categories of imperfection are typically classed between clean and spotted, with various grades in between.

Colour of the most valuable pearls is white or pink, although different colours such as white, silver, cream, gold, and shades of colour are acceptable and appreciated in different markets. Different designations of primary colour and tones are relevant to different host species used in culturing pearls. The orient or iridescent rainbow-like colours that change as a pearl is rotated relate to the nature of the nacre.

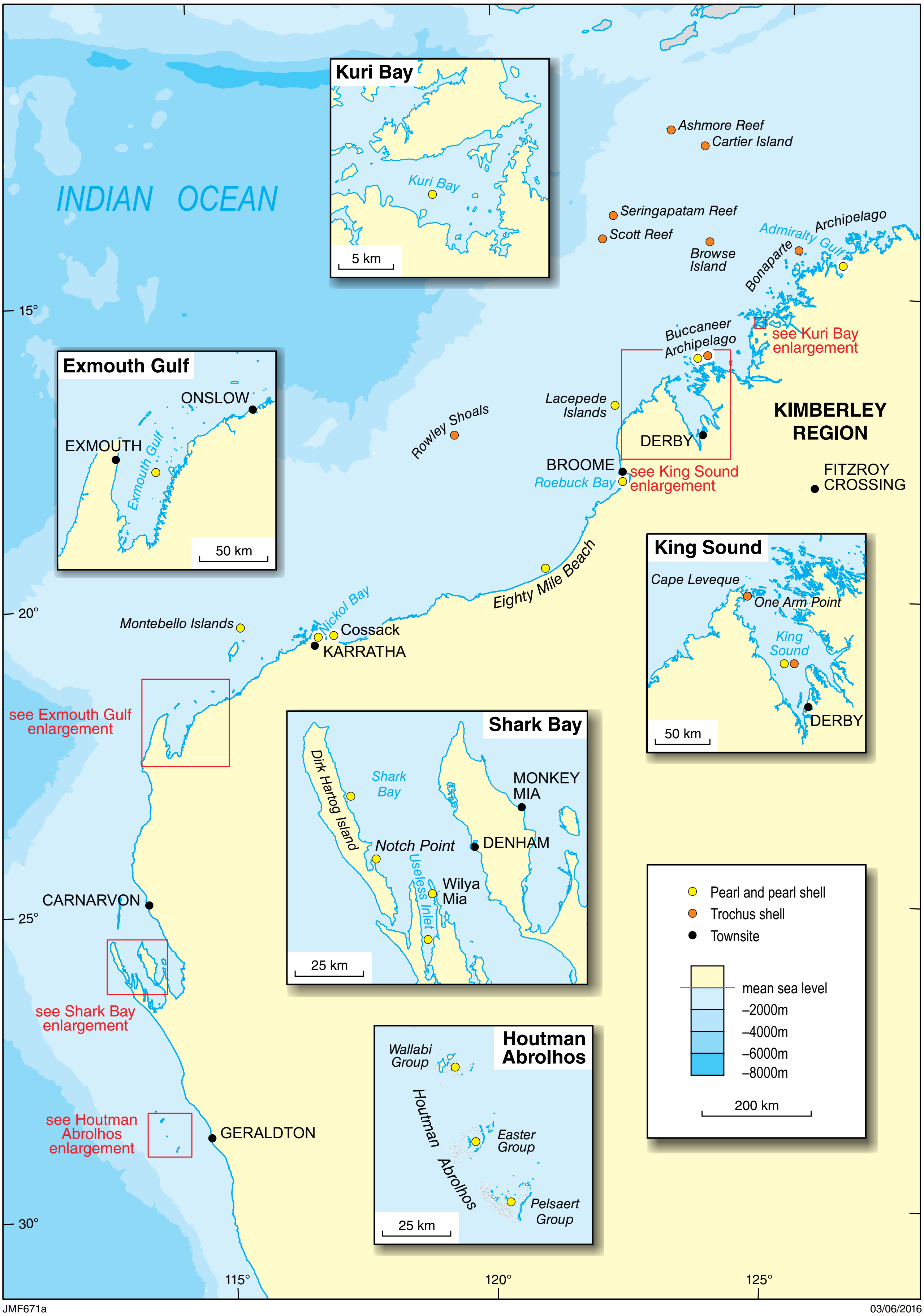

Figure 13.3. **Locations of pearl, pearl shell, and trochus shell sites in Western Australia**

Pearling had a large impact on the jewellery and associated industries of the late 19th and early 20th centuries as it provided a local and important raw material to a growing State when it would have been quite expensive to import other gemstones. Jewellery using pearls, blister pearls, and mother-of-pearl were fashioned into brooches, pendants, bangles, and other items to form the basis of an industry that was unique in style and content to Western Australia (Figs 13.4 and 13.5). Accordingly, blister pearls that appear to have been considered semiworthless formed the basis of this interesting genre of jewellery. In addition to the pearl fishing aspects of the industry, many different workshop skills evolved from pearling activities including pearl skinning, carving, and piercing work on mother-of-pearl as well as jewellery skills. Several pastoralist pearlers marketed their pearls in London using shipping contacts involved in the transport of mother-of-pearl (Erickson, 2010).

In Shark Bay, shell was taken as a byproduct of pearling from areas where pearls of about 3 mm were fished. The town of Denham was the centre of the Shark Bay fishery and employed workers included Aboriginal, Chinese, Japanese, Filipino, and Malay people. Shells were collected by hand at low tide or by trawling with metal-framed wire baskets towed by sailing ships (luggers). The catch was shelled, pearls were removed, and the empty shells stacked and dried.

When larger and better quality *P. maxima* shell was discovered further north, pearl fishing became centred in Nickol Bay in the Karratha area, close to where commercial pearling began in 1861 (Erickson, 2010; Fig. 13.3). This soon extended eastward to the area around Cossack. Here, *P. maxima* shell and pearls were harvested in shallow waters by both Indigenous and non-Indigenous divers. Pearl shelling continued to spread along the coast and at certain times both Onslow and Cossack became the focus of the industry. In his book, *Pearls and pearling life*, published in 1886, Streeter gives an account of local history of the pearling industry in Western Australia in the early days. He reported that in the season 1882–83 there were 19 operating vessels crewed by 539 divers, with production stated as £30 300 for the value of shells and £6000 as pearl value. By 1910, Broome had become the world's largest centre for the pearling industry with nearly 400 pearling luggers and more than 3500 people fishing for pearl shells in the area (Department of Fisheries and Wildlife, 1985).

Among reports of several large natural pearls in the early history of pearling in Western Australia was the discovery of the 'Southern Cross' pearl in 1883. This unusual object consists of an agglomeration of nine natural baroque pearls attached in a cruciform arrangement. Seven pearls form a linear row with the 'branches' of the cross formed by two additional pearls. Its discovery in Baldwin Creek, off the coast between Broome and Derby, was reportedly made by an employee of James WS Kelly, a master pearler. The Southern Cross pearl was exhibited in London at the Colonial and Indian exhibition in 1886 and later in 1889 in Paris. This pearl has been intensively investigated and described (Scarratt, 1986; Scarratt et al., 2012). The pearls within the Southern Cross have been substantiated as natural and the object's length is 37.2 mm, width 18.3 mm, and weight 27.3 ct. The Southern Cross pearl is part of the Western Australia Museum collection on permanent loan from Chris Peto-Bennett. In recent times, the aggregation has been artificially re-cemented at two sites where the natural union between pearls would have been very fragile (Fig. 13.6).

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Figure 13.4. Delicately carved pearl shell paperknife. It was made around 1880 for William Shakespeare Hall, a pastoralist and pearler who lived at the historic Cossack settlement in the Karratha area. The paperknife is made in two sections bound by a silver band and is 220 mm in length (courtesy Western Australian Museum, CH 1970.972)

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Figure 13.5. Natural pearl and gold bangle. The centre section has a double peak mounted with three fine natural cream pearls from Broome (or possibly Shark Bay) in claw settings. Two matching cream pearls alternate lengthwise, between four small darker coloured pearls. Seventeen applied gold beads decorate the centre section. The bracelet was made in 1890 by Fremantle jeweller William Hooper for John Slade Durlacher from gold and pearls he had acquired in the north of the State (courtesy Western Australian Museum, H 1995.1371)

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Figure 13.6. The Southern Cross pearl is a natural, baroque pearl cluster, arranged in a formation of nine pearls roughly in the shape of a cross. It was found off Baldwin Creek in Western Australia in 1883. The cross measures 37.2 mm in length and 18.3 mm in width (courtesy Western Australian Museum Collection)

Periculture was introduced to Australia in 1956 when the pearl farm of Pearls Proprietary Ltd was established at Kuri Bay, 420 km north of Broome (Malone et al., 1988). Today, some of the world's most valuable cultured pearls including the largest, whitest, and most lustrous together with half-pearls and baroque pearls are produced in Western Australia. Broome is now the centre for the pearl industry and Paspaley Pearls has the largest operation. In 2001, black pearl production began near Dirk Hartog Island at Shark Bay, and at the Houtman Abrolhos Islands, 60 km west of Geraldton (Sutherland, 2006).

Current pearling operations

Pearl-farming areas and hatcheries

The pearl industry in Western Australia currently uses several mollusc species although most production is of large South Sea pearls in sites along the northern coastline using *P. maxima*. Off the west coast of the State other species used on pearl farms include *P. margaritifera*, the winged oyster *Pteria penguin* used to produce mabe (blister) pearls, the akoya oyster *P. fucata martensi* for white pearls, and *P. albina albina* for small yellow pearls (Department of Fisheries, 2012).

Western Australian black pearls are currently produced from the Houtman Abrolhos Islands comprising the Wallabi, Easter, and Pelsaert island groups, 60 km west of Geraldton on the mainland, which is the commercial centre (Fig. 13.3). Pearls produced from this area using *P. margaritifera* show a range of colours including silver, green, peacock, and aubergine.

In the waters off Monkey Mia in Shark Bay, one commercial operation is producing a form of cultured blister pearl that encloses either a precious opal or a native gold nugget inserted against the shell of a host oyster. The operation, trading under the name Blue Lagoon Pearls, uses *Pinctada* spp. as the host oysters. Once the pearls are harvested, the pearl is prepared and polished to reveal the enclosed gem (either opal or gold). These gem-included cultured pearls have been fashioned mostly as pendants and earrings for sale locally in Denham.

In Western Australia, host oysters are either captured in the wild as young oysters before they can seed and cultivate pearls, or are taken as young oysters from hatcheries. Wild pearl oysters are collected by divers in waters off the coast between Cape Leveque and Exmouth including the fishing grounds off Eighty Mile Beach near Broome and around the Lacepede Islands. Off the northern coast mainly *P. maxima* is collected. The industry has been restricted in the State by a quota system for shell collection to prevent overfishing and currently recent catches have been below the quota levels because of low market demand. Researchers set the quota at a level to ensure that stocks of oysters are sustained over the years (Malone et al., 1988). Also, major oyster hatcheries operate at Broome and King Sound.

Pearl farms are sited mainly along the Kimberley coast, particularly in the Buccaneer Archipelago, Roebuck Bay near Broome, and further south around the Montebello Islands (Fig. 13.3). Further south, hatchery production of oysters is of critical importance in the Gascoyne region because of unreliable supplies of wild oysters. Hatcheries in Carnarvon and Exmouth supply significant quantities of *P. maxima* spat (juvenile stock) to pearl farms in Exmouth Gulf and the Montebello Islands, and several hatcheries supply spat of the black-lipped pearl oyster *P. margaritifera* from a small number of wild Shark Bay brood stock oysters to the black pearl farms in the region (Fig. 13.3).

Periculture research and operations

Research has led to advances in genetic engineering, mollusc nutrition, and marine management. Also, selective breeding and artificial spawning has produced hardier oysters that mature to produce more oysters available for culturing (Joyce and Addison, 1992).

Recent studies have established that the Houtman Abrolhos Islands also contain good culture sites for the development of a viable akoya cultured pearl industry. This research is centred on the feasibility of developing a pearl industry based on *P. imbricata* and followed work conducted in New South Wales that established that quality cultured pearls using this oyster species could be produced in Australian waters (Cropp et al., 2011).

In Western Australia, periculture operates under aquaculture pearling licences from the Department of Fisheries where each licensee holds an approved quota for shell, and licenses are restricted to the zones from which individual licensees can take shell. In addition to their livestock quotas, each licensee has a hatchery quota. After collection, shells are cleaned, sized, and seeded. Technicians from the pearling companies surgically implant a nucleus and mantle tissue into the shell (seed) from the host pearl shell at the collecting grounds before transporting them to their farm leases. The seeding process on the fishing grounds uses large vessels that hold shells in tanks. The oysters are then allowed to recover for several months from the seeding process in specially designed net panels tied onto longlines that sit on the bottom of the seabed in locations known as ‘dumps’.

The seeded oysters are transported to sheltered waters at pearl farms where net panels are suspended on a floating line from the sea surface on which the oysters mature. The oysters feed naturally with no artificial feeding or chemicals. Within the shell, encystation of the implanted nuclei (commonly one per shell) by the host mantle tissue deposits nacre on the nucleus and this process continues throughout the development time of the pearl, normally about two years (Brown, 2000).

Pearls cultured using *P. maxima* hosts have a nacre thickness of more than 2 mm. Colours include silver, white, yellow to golden, and grey to bluish-grey. Currently, the 8–14 mm-diameter nuclei used include those made from the Mississippian pig-toe mussel, although a new artificial nucleus, ‘Bironite’, is undergoing trials. This product, replacing the increasingly scarce freshwater mussel material, is manufactured from natural dolomite that has been modified by a proprietary process. Bironite is uniformly coloured white, is uniformly hard, takes an acceptable polish once converted into a bead, and can be safely drilled with traditional pearl drills as it does not have directional properties. To date, trials indicate that the product is well tolerated as an implant by host pearl oysters (Brown, 2002).

The Western Australian pearl industry has withstood setbacks including severe weather conditions, changes in shell wildstock quotas, and fluctuations in world demand for cultured pearls. In spite of these factors, it remains the most important aquaculture industry in the State. The environmental impacts of pearl farms are considered negligible and Western Australia is currently the world’s largest producer of white and silver South Sea cultured pearls, with the industry contributing $96 million in 2012–13 (Department of Fisheries, 2015).

Shells

Mother-of-pearl

Mother-of-pearl is produced from pearl shell of the same species that are hosts to nacreous pearls, with the large shells of *P. maxima* particularly important. Western Australia established a profitable mother-of-pearl shell industry in the mid-19th century and the ready market for mother-of-pearl initiated additional pearling ventures. Expert shell graders categorized pearl shell according to size, lustre, and blemishes. At that time, most shells were exported to Europe and used to make mother-of-pearl buttons. Button manufacturing grew into large enterprises with centres in Birmingham in England, and Meru in France.

A small portion of the pearl shell industry was retained in the State, especially in Broome, where mother-of-pearl and pearl jewellery were manufactured. Items of jewellery featuring mother-of-pearl were commonly carved and pierced with fretwork and many were either mounted in gold or were gold backed. By the early 20th century Broome supplied 80% of the world's shell, which at that time was used for buttons, mother-of-pearl cutlery (dessert flatware), hair combs, decorative items, and inlay work (Fig. 13.7).

The large shells of the gold-lipped oyster, *P. maxima*, have a long history of many specialized uses within Aboriginal communities. These shells were mostly used as trimmed oval plates, either uncarved, termed 'guwan', or decoratively etched and coloured, termed 'riji' or 'jakuli'. These traditional ornaments were worn suspended from either the waist or around the neck. Riji are particularly associated with Aboriginal peoples of the Kimberley and Cape York regions and many examples are featured in local museum collections. Shell ornaments have been traded through an extensive network of routes over great distances as far as the south coast of South Australia and central Australia (Akerman and Stanton, 1994). Riji were elaborately decorated with incised designs that include geometric, figural, and maze patterns, and may be coloured by ochres and charcoal.

Large pearl shells continue to be used by local craftspeople as an important artists medium. Artisans in Japan carve shells to very high standards.

Trochus

Trochus, *Trochus niloticus*, shells currently provide a small export commodity to serve the fashion industry with raw materials for buttons (Fig. 13.8). Trochus shells are found on the coral reefs of the Buccaneer and Bonaparte Archipelagos along the Kimberley west coast, and offshore at Rowley Shoals, Browse Island, Scott Reef, Seringapatam Reef, Ashmore Reef, and Cartier Island (Fig. 13.3).

Trochus shells from inshore reefs along the Kimberley coast are brought to One Arm Point and other places along King Sound. Several other shell types are collected, including nautilus and trigonia. In this area, shell collection is the preserve of local Indigenous communities as a source of income. It is expected that a multi-species hatchery to be established in Broome will reduce the problem of overfishing of trochus shell in the region, which is indicated by a decline in annual production. This decline has been highlighted in recent years with less than 15 t/year of shell reported compared with 135 t produced in 1980.

Tusk shell

Beads made from tusk shells are sourced from a marine scaphopod mollusc. The delicate shells, coloured brown and white, are about 0.5 – 15 cm in length and are of a tapering cylindrical form open at both ends. Sections of the shells were simply threaded together. A group of nine tusk shell beads, dated at 30 000 years, was part of an archaeological find from an excavation at Riwi near Fitzroy Crossing in the Kimberley region (Fig. 13.3). It is thought that the tusk shell beads were highly valued by Indigenous peoples as they were transported up to 500 km inland from the coast.

Opercula

Opercula are unusual gemmological materials that are parts of the armour of certain marine shells. Western Australia has long been a source of this material, especially in the 19th century. Opercula are the calcified 'doors' of the turban and other marine snail shells and seal the shell to function as a defensive structure against predators. Opercula are composed of aragonite (a calcium carbonate polymorph). They have a spiralling or whorled pattern on one surface and a convex and coloured surface on the other.

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Figure 13.7. Butterfly ornament made c. 1890 with silver body and featuring *Pinctada maxima* shell 'wings'. The ornament measures 100 mm in height, 297 mm in width, and 172 mm in depth (courtesy Western Australian Museum Collection, CH 1970.1016b)

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Figure 13.8. Trochus shell sourced from the northwest coast, offshore islands, and reefs of Western Australia: a) shells displaying the natural outer coating and application as shell buttons (courtesy Maggie Campbell Pedersen); b) decorative shell where polishing has removed the shell's outer coating revealing the beautifully smooth, iridescent nacre coating beneath. Measuring 85 mm in height, the shell is from One Arm Point at Cape Leveque

When first collected, opercula are an intense blue colour caused by a natural pigment, although over time the colour fades. Opercula found in Western Australia originate from the mollusc *Astraea stellare*, which grows along the northern coastline from Exmouth Gulf and around the northern continental coast as far as north Queensland. As with pearls, opercula are natural objects used 'as-found' in jewellery without requiring any fashioning although they can be polished to remove natural surface imperfections.

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Figure 13.9. Examples of opercula-mounted jewellery: a) drop earrings in saw-tooth claw settings on gold backplates with hook fittings. The opercula are typical of those collected from the Shark Bay area and were probably set into earrings in the late 19th century. The subtle pink and blue colours shown by the opercula would have been more vivid when originally collected. Opercula are approximately 12 mm in length; b) early 20th century silver-mounted bar brooch featuring a single turban sea snail operculum displaying its natural colours. Operculum is 15 mm in diameter (images courtesy Trevor Hancock, Trinity Antiques)

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Figure 13.10. Four items of gold-mounted tiger shark tooth jewellery, manufactured in Western Australia in the early 20th century. The brooch (at top) was mounted in 15 ct gold by Fremantle Jewellers Doig and Horn, c. 1920 (courtesy Trinity Antiques)

Opercula vary in size according to the variety of host shell; *Astraea* spp. shells produce small oval opercula whereas the larger turban sea snail shells (*Turbo* spp.) provide the larger and more or less circular opercula with a green-brown colour. Opercula-mounted jewellery, especially from the 19th century, mainly used the larger opercula and items were individually designed and crafted. Jewellery featuring small opercula form part of a small but unique collection of jewellery characteristic of Western Australia and its pearling industry of the day (Fig. 13.9).

Shark teeth

Shark teeth are unusual and distinctive items that are sometimes mounted as jewellery. Items of Australian colonial jewellery have featured shark teeth with pieces crafted and set in decorative gold settings by professional goldsmiths. This genre of trophy jewellery probably has its origins in using locally available quirky objects at a time when coloured gemstones were not readily available in Western Australia and would have been comparatively expensive to import.

Shark teeth from both extinct and extant shark species are commonly found within the State. Figure 13.10 shows a collection of gold jewellery manufactured in the early 20th century, each mounted with a single tiger shark tooth. In contemporary jewellery, shark teeth are commonly displayed pierced and are suspended as necklets or bracelets.

References

Akerman, K and Stanton, J 1994, Riji and jakuli: Kimberley shell in Aboriginal Australia: Northern Territory Museum of Arts and Sciences, Monograph series no. 4, 73p.

Brown, G 2000, Australia's gemstone resources and their markets: The Australian Gemmologist, v. 20, no. 12, p. 534–539.

Brown, G 2002, Update of Australia's gemstone and pearl resources: The Australian Gemmologist, v. 21, no. 8, p. 273–277.

Chandour Sampson, B and Bari, H 2013, Pearls: V&A Publishing, Victoria and Albert Museum, London, 158p.

Cropp, D, Koltasz, C, Boschetti, P and Davidson, M 2011, Develop the non-maxima pearl industry at the Abrolhos Islands (Pinctada imbricata): FRDC Project No: 2007/216, Final Report, 181p.

Department of Fisheries and Wildlife 1985, The pearling industry of Western Australia 1850–1895, Fisheries Education publication, no. 3 *edited by* ML Taylor: Department of Fisheries and Wildlife, Perth, Western Australia, 30p.

Department of Fisheries 2012, Aquaculture Regions, West Coast Bioregion, viewed 6 November 2015, <www.fish.wa.gov.au/Fishing-and-Aquaculture/Aquaculture/Aquaculture-Regions/Pages/default.aspx>.

Department of Fisheries 2015, Aquaculture in Western Australia, industry overview, viewed 8 June 2016, <www.fish.wa.gov.au/Documents/Aquaculture/aquaculture_position_paper.pdf>.

Dillenburger, B 2004, The Kasumigaura pearl: The Australian Gemmologist, v. 22, no. 4 p. 156–161.

Erickson, D 2010, Gold and silver smithing in Western Australia, a history: UWA Publishing, Perth, Western Australia, 479p.

Hui, Z and Beili, Z 2005, Pearl resources of China: The Australian Gemmologist, v. 22, no. 5, p. 196–209.

Joyce, K and Addison, S 1992, Pearls, ornament and obsession: Thames and Hudson Limited, London, 253p.

Kennedy, SJ 1998, Pearl identification: The Australian Gemmologist, v. 20, no. 1, p. 2–19.

Malone, FJ, Hancock, DA and Jeffriess, B 1988, Final report of the Pearling Industry Review Committee: Fisheries Department of Western Australia, Fisheries Management Paper no.17.

Mahroof, MMM 1997, The pearl fisheries of Sri Lanka: The Australian Gemmologist, v. 19, no. 10, p. 405–412.

Scarratt, K 1986, The Southern Cross: notes from the laboratory: Journal of Gemmology, v. 20, no. 3, p. 145–146.

Scarratt, K, Bracher, P, Bracher, M, Attawi, A, Safar, A, Saeseaw, S, Homkrajae, A and Sturman, N 2012, Natural pearls from Australian Pinctada maxima: Gems and Gemology, v. 48, no. 4, p. 236–261.

Sutherland, F 2006, Gemstone mining and exploration in Australia: The Australian Gemmologist, v. 22, no. 11, p. 496–502.

Streeter, EW 1886, Pearls and pearling life: George Bell and Sons, York Street, Covent Garden, 329p.

Szabo, K, Koppel, B, Moore, M, Young, I, Tighe, M and Morwood, M 2015, The Brremangurey pearl: a 2000 year old archaeological find from the coastal Kimberley, Western Australia: Australian Archaeology, v. 80, p. 212–215.

Western Australian Museum 2011, Notch Point history–Shark Bay pearling, viewed 13 January 2012, <www.museum.wa.gov.au/maritime-archaeology-web/content/notch-point>.

Wehrmeister, U, Jacab, DE, Soldati, AL, Hager, T and Hofmeister, W 2007, Vaterite in freshwater cultured pearls from China and Japan: The Journal of Gemmology, v. 30, no. 7–8, p. 399–412.

5

Precious metals

An example of a gold nugget (126 g) found using a metal detector in the Kalgoorlie region

Chapter 14

Gold and silver in jewellery

Gold

Pure gold is a soft, dense, yellow metal with a specific gravity of 19.32 and a melting point of 1063°C. It is the most malleable and ductile of all metals and resists tarnishing, is insoluble in most acids, and amalgamates readily with mercury.

In the natural environment, gold is invariably alloyed with silver or copper. Native gold commonly contains approximately 85–95% gold with the balance typically as silver. Gold containing at least 20% silver is called electrum. Gold is also associated with tellurides. Gold tellurides were discovered in Kalgoorlie in June 1896, an event recorded on a plaque at the KCGM superpit lookout (Glover and Bevan, 2010).

Vein gold is commonly associated with sulfides. Detailed studies indicate that vein gold exists most commonly in direct contact with the following sulfide minerals in the order listed: pyrite, arsenopyrite, galena, sphalerite, chalcopyrite, bismuth sulfides, pyrrhotite, and tetrahedrite–tennantite. The most common gangue minerals containing gold are quartz, carbonates, chlorite, graphite and other carbonaceous material, and tourmaline (Schwartz, 1944).

Primary gold deposits are most commonly associated with quartz veins where gold forms as relatively large masses, veins, stockworks, and tiny grains intergrown with other sulfides. Crystalline gold is extremely rare. Primary gold ores fall into two groups. The first is free-milling gold, which is recovered by simple crushing and extraction, and the second is refractory gold associated with telluride and sulfide ores, and which require complex extraction processes.

Placer gold deposits contain gold that has weathered out of primary deposits and been deposited in suitable trap sites. These deposits may be very old and can be lithified to form hard rock deposits or as comparatively recent, unconsolidated, alluvial deposits.

Gold may also be remobilized through near-surface weathering processes as it can be dissolved by saline groundwater and deposited at the watertable to form zones of gold enrichment. The larger nuggets are primary, in situ gold in which the quartz matrix has been removed, leaving the gold behind (Hough et al., 2007).

In January 1931, the Golden Eagle, Western Australia's largest nugget, was found buried only 0.45 m below surface by James Larcombe and his son at Larkinville, about 60 km southeast of Coolgardie. The original nugget, weighing 35.287 kg (1134.62 oz), was bought by the Western Australian State Government. After a period of display throughout Australia it was melted down by the Royal Mint in Perth into 29.461 kg (947.3 oz) of fine gold (Fig. 14.1).

In Western Australia in 2010, by far the greatest gold production was derived from the Eastern Goldfields (63% comprising 132.8 Moz), largely from areas of Archean granite–greenstones of the Yilgarn Craton. The remainder was sourced from the Murchison – Southern Cross Domains (25% at 52.9 Moz), the Pilbara, Kimberley, Peak Hill, and Gascoyne gold mining areas (9% at 18.9 Moz), and the Southwest Yilgarn Terrane (3% at 7.0 Moz). This resulted in a total gold production of 212 Moz for Western Australia in 2010 (Department of Mines and Petroleum, 2011).

Precious metals
Gold (Au) Silver (Ag)

Gold in Western Australia

In February 1862, the Western Australian Government offered a reward of £5000 for the discovery of a workable gold field within a radius of 150 miles (240 km) from the Public Offices in the City of Perth on, or before, 31 December 1862 (Spillman, 1993).

Although there were several applications for the reward, it was never paid out. Despite these claims, discoveries of gold at several locations in the State caused large influxes of prospectors from interstate and overseas. Over the years, significant finds included:

Halls Creek (1885) Traces of gold were first found in the East Kimberley area in August–September 1882, but this find was not progressed. A follow-up expedition in 1884 also found traces of gold although there is no record of payable amounts. Finally, in July 1885 a party led by Charles Hall found payable gold in an area subsequently named Halls Creek. This discovery led to the first Western Australian gold rush.

Figure 14.1. Replica of the Golden Eagle, Western Australia's largest gold nugget, measuring approximately 630 mm in width and 260 mm in height and weighing 35.287 kg. It was found in 1931 by James Larcombe and his son at Larkinville about 60 km southeast of Coolgardie

Southern Cross (1887) Thomas Risely and Mick Toomey discovered gold in the Yilgarn Hills area, north of Southern Cross, in 1887–88. They claimed they had been led to their discovery by the Southern Cross so they named the goldfield after the star constellation.

Cue (1891) Michael John Fitzgerald and Edward Heffernan began prospecting in the Cue area in 1891. Within a week they had found about 260 oz of gold in what is now the main street of Cue. The town was subsequently named after Tom Cue, a friend of Fitzgerald.

Coolgardie (1892) Arthur Bayley and his party discovered 554 oz of gold at Coolgardie in 1892. This discovery marked the acceleration of the Western Australian gold rush in earnest, leading to a substantial influx of people from all over the world to this remote and arid region.

Kalgoorlie (1893) In January 1893, prospectors Patrick (Paddy) Hannan, Tom Flanagan, and Dan O'Shea noticed signs of gold near Mount Charlotte in the Kalgoorlie area. On 17 June 1893 they filed a reward claim at what became known as Hannans Find.

Norseman (1894) In 1894, gold was first discovered in the region at Dundas, 22 km south of present-day Norseman. This find was quickly followed by a gold discovery near the future town of Norseman by prospector Laurie Sinclair, who named the gold deposit after his horse, 'Hardy Norseman'.

Australian gold rushes

Gold was discovered in the eastern states much earlier than in the west with the earliest verified discovery in 1823 at Bathurst, New South Wales. In 1851, Edward Hargraves discovered the first payable gold at Ophir, near Bathurst, leading to Australia's first gold rush. Gold was found in Victoria in the same year and subsequently in Queensland in 1858, and Tasmania in 1852.

Gold in jewellery

History of gold in jewellery

Gold has been used for jewellery manufacture for many thousands of years. Gold artefacts from the Paleolithic period (c. 40 000–10 000 years BCE) have been found in Spanish caves.

The earliest gold jewellery that has been found dates from around 3000 BCE from the Sumerian civilization that flourished between the Tigris and Euphrates Rivers in southern Iraq. From about 2600 BCE in Ancient Egypt, large resources of alluvial gold were extensively exploited. Egyptian goldsmiths demonstrated exceptional skills in fire assaying, alloying, and lost-wax casting of gold to produce golden treasures such as those found in the tombs of pharaohs.

The Minoan, Mycenaean, and Etruscan civilizations all produced extensive and unique gold jewellery. Although the Romans favoured the use of coloured gemstones over gold they did introduce the use of gold coins throughout the Roman Empire.

Gold purity and alloys

The purity or fineness of gold is measured in carats (also spelled 'karats'), with pure gold called '24 carat'. In addition to pure 24 ct gold, the most common gold grades are 22 ct (91.6% pure), 18 ct (75.0% pure), 14 ct (58.3% pure), and 9 ct (37.5% pure).

Gold can be readily alloyed with other metals to produce a variety of colours and hardness. The ratio of gold to other metals in the alloy determines the carat value. For example, an alloy containing 14 parts gold to 10 parts alloy metals would create a 14 ct gold product. This carat value may also be expressed as the result of the ratio 14:24, which equals a purity of 58.3% gold. Although the carat scale is used in jewellery, an alternative scale is used in mining to measure the 'fineness' of gold, where a value of 1000 corresponds to pure or 24 ct gold.

Although gold can be included in hundreds of possible alloys, in general the addition of metallic silver colours gold white, and copper metal colours gold red. A mixture of around 50% gold to 50% copper and silver results in a range of yellow-gold alloys commonly seen in the marketplace (Fig. 14.2). In addition, a small amount of zinc (about 0.2%) may be added to harden the alloy.

Gold alloy colours

White gold — alloy of gold and at least one white metal, commonly nickel, manganese, or palladium

Rose, pink, or red gold — gold and copper alloy also known as Russian gold

Green gold — made by omitting copper from the alloy and only using gold and silver (electrum is a naturally occurring alloy of silver and gold)

Grey gold — alloys made by adding silver, manganese, and copper in specific ratios to the gold

Purple gold — alloy of gold and aluminium, also called amethyst gold or violet gold

Blue gold — alloy of gold and indium

Examples of gold jewellery and coins

Apart from gold being melted, alloyed, and fabricated into items of jewellery, small natural gold nuggets are commonly mounted as pendants and earrings, and gold-in-quartz can be cut and fashioned as cabochons to make attractive items of jewellery (Fig. 14.3).

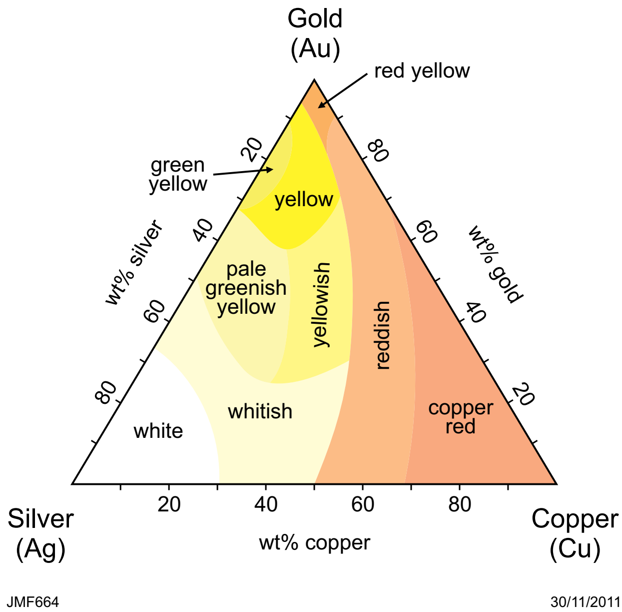

Figure 14.2. Ternary plot of the different colours of Ag–Au–Cu alloys (modified after Cretu and Van Der Lingen, 1999)

The Perth Mint purchases and refines gold, and sells gold jewellery, bullion, and commemorative gold coins. Registered jewellers are permitted to buy and sell gold.

Prospecting for gold in Western Australia

Early prospectors used panning and dry blowing methods to locate surface and near-surface gold. These techniques have now been mostly replaced by the hand-held metal detector (Fig. 14.4).

Small gold flakes, pieces of spongy gold, and more rarely, larger gold nuggets may be found by using a metal detector in prospective areas throughout Western Australia especially within the Yilgarn and Pilbara Cratons (Fig. 14.5). Almost certainly, the best chance of finding these forms of gold would be near known gold deposits. Figure 14.6 locates the principal gold mining areas of Western Australia. More detailed information may be obtained from 1:250 000 or 1:100 000-scale geological maps, explanatory notes, and other publications produced by the Geological Survey of Western Australia.

Fossickers should remember that carrying out metal detecting for gold in Western Australia requires a Miner's Right, as described in Chapter 1 on the introduction to gemstones in Western Australia, and it is necessary to be aware of the relevant sections of the *Mining Act 1978* (WA). Also, most gold mining areas in the State are almost completely covered by mining and/or exploration tenements and it is necessary for people wishing to carry out fossicking in tenement areas, with or without a metal detector, to obtain the consent of the owner of every tenement they intend to prospect on.

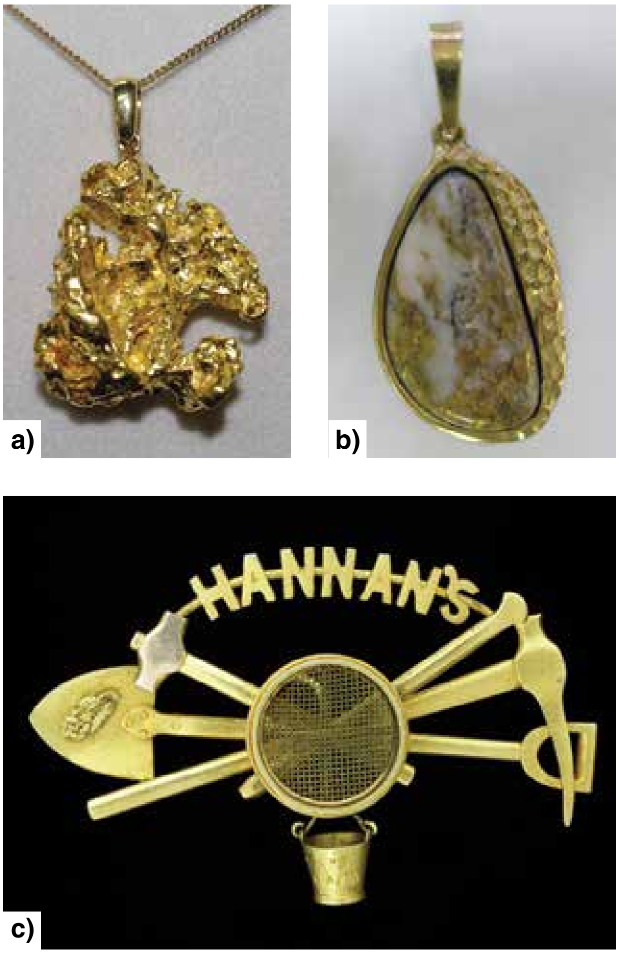

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Figure 14.3. Three examples of gold jewellery: a) 33.28 g gold nugget pendant (courtesy Perth Mint); b) gold shell pendant encasing a gold–quartz cabochon; c) gold prospectors' brooch, made in Kalgoorlie by GR Addis in about 1894, Western Australian Museum no. CH 1970.772

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Figure 14.4. Prospecting for gold and precious metals using a hand-held metal detector

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Figure 14.5. Example of a gold nugget (126 g) from the Kalgoorlie region found using a metal detector

In Western Australia, there are several metal detecting clubs in Perth, Mandurah, Coolgardie, and Kalgoorlie–Boulder. Also, prospecting equipment may be hired from prospecting stores in Perth and Kalgoorlie.

Silver

Metallic silver is a soft, white, lustrous metal with the highest electrical conductivity of any element and the highest thermal conductivity of any metal. It has a specific gravity of 9.32 and melts at 962°C. Silver is stable in pure air and water, although it tarnishes when exposed to air or water containing ozone or hydrogen sulfide.

As with gold, silver has long been valued as a precious metal and has been used in artefacts, jewellery, high-value tableware, and coins. As early as 700 BCE, electrum coins were used as money and, later, silver was refined and coined in its pure form. Over time, the use of silver in circulating coins has gradually diminished and today silver has been mostly replaced by various metal alloys, although pure silver commemorative coins are still produced (Fig. 14.7). In 2001, 20% of total silver produced was used in jewellery and 3.5% in coins and medals.

Silver forms naturally as native silver, as an alloy with gold (electrum) and other metals, and in silver ore minerals such as argentite and chlorargyrite. Most silver is produced as a byproduct of copper, gold, lead, and zinc refining. Currently, the principal sources of silver are Central and South America, Australia, China, and Poland.

Silver in Western Australia

There is only one recorded silver deposit in Western Australia with the potential to supply suitable specimens of native silver in a matrix form that may be used for fashioning into cabochons for jewellery.

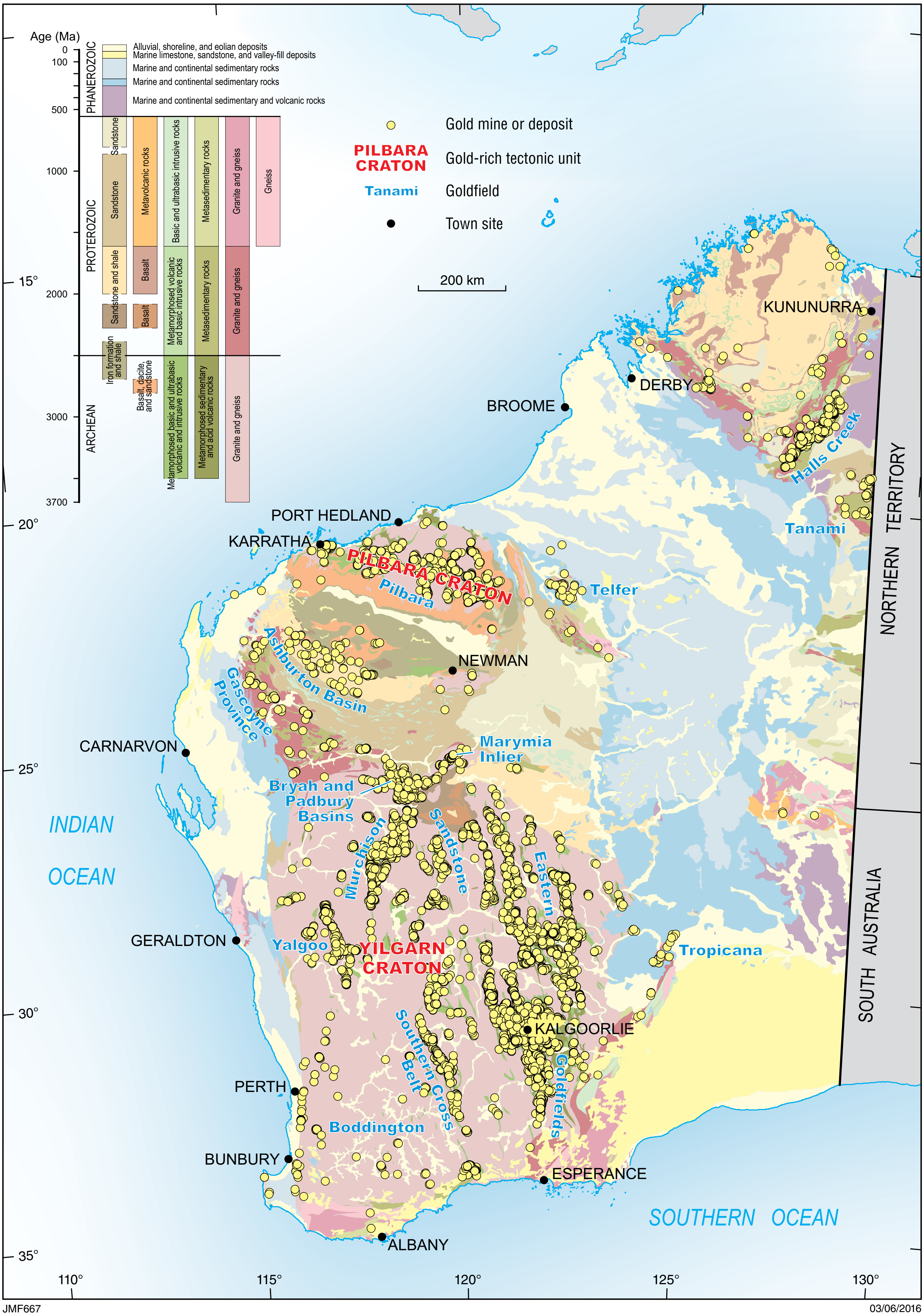

Figure 14.6. Principal gold mining areas of Western Australia

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Figure 14.7. Pure silver kookaburra commemorative coin produced by the Perth Mint in 1993 (10 oz, 311.03 g)

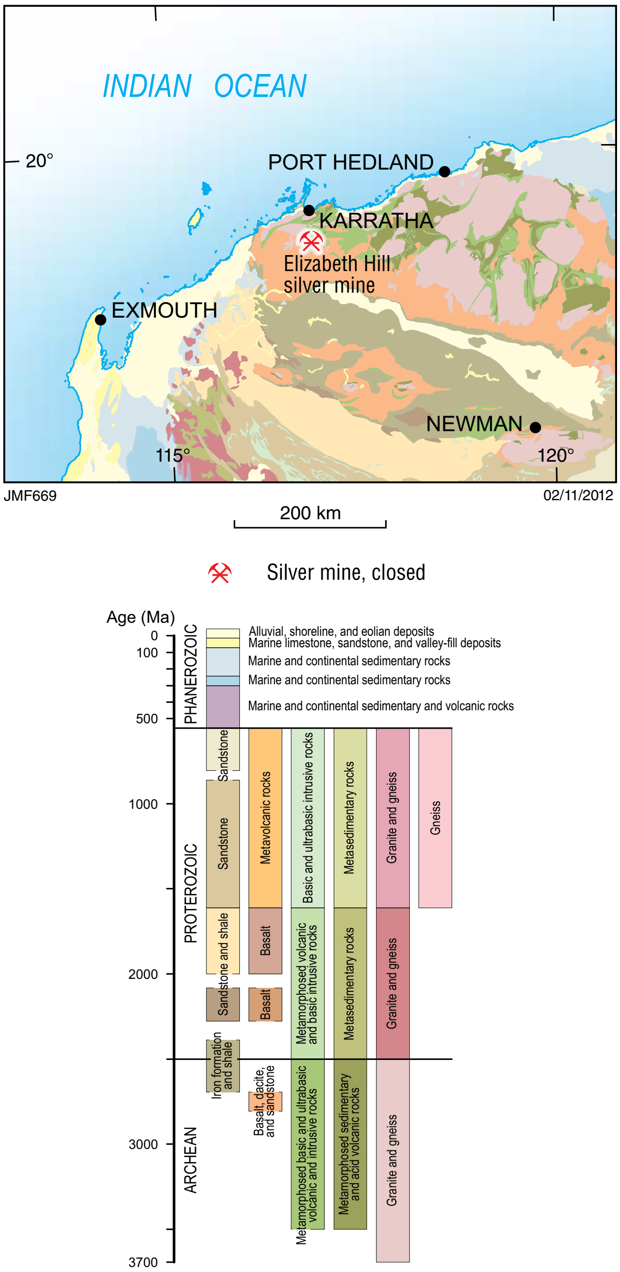

Figure 14.8. Map of the Karratha region showing the location of the Elizabeth Hill silver mine in the Pinderi Hills area

Pilbara Craton

Pinderi Hills area

Elizabeth Hill (Pinderi Hills, 2255)

The Elizabeth Hill mine was a small underground mine in the Pinderi Hills area about 40 km south of Karratha (Fig. 14.8). The mine is west of the Maitland River and is best accessed via the Tom Price Railway Road, which runs from Karratha to Tom Price. A more accurate location is given in Appendix 1. The area around the Elizabeth Hill mine is currently controlled by East Coast Minerals under mining leases M47/342 and M47/343.

In 1987, high-grade silver was discovered by AGIP in the northern part of the Archean Munni Munni Intrusion, comprising metamorphosed mafic and ultramafic rocks. In 1996, East Coast Minerals and Legend Mining commenced drilling, and trial mining commenced in 1998. In total 1.17 Moz of silver was produced from 16 800 t of ore (at 70 oz Ag/t) until the mine was closed in 2000. In 2010, East Coast Minerals carried out a drilling program of 17 drillholes targeting magnetic and electromagnetic anomalies. Unfortunately, assay results achieved a maximum grade of only 6.8 g/t over 4 m, which did not match the tenor of ore from the previous underground mining operation, and the project has remained under assessment. A description of the mine and illustrations of silver ore specimens from the site are given in Mindat.org (2015).

The Elizabeth Hill mineralization comprises a series of southerly plunging pods or shoots within the shear system of the Munni Munni Fault at a point where it intersects the contact between the Munni Munni Intrusion and the Cherratta Granitic Complex. The silver mineralization lies within a 10–15 m-wide, almost vertical vein system, and occurs as native silver veinlets, crystals, sheets, globules, and dendrites in a carbonate–quartz breccia or as silver sulfides and sulfosalts within a coarse-grained calcite matrix (Hickman and Kojan, 2003; Fig. 14.9).

Figure 14.9. Polished cabochons and an unpolished specimen displaying native silver enclosed in a calcium carbonate matrix from the Elizabeth Hill silver mine

When the mine was in operation, there was opportunity to collect native silver specimens from the dumps and the lease owners permitted certain collectors to do this for a fee (Crystal World, 2002). Large masses weighing more than 10 kg were commonly encountered as masses of thin wires or thicker ropy silver up to 60 mm long (Henry, 2007). The current situation relating to fossicking on the mine dumps is unknown.

References

Department of Mines and Petroleum 2011, Investment opportunities—gold: Geological Survey of Western Australia, Mineral information pamphlet, August.

Cretu, C and Van Der Lingen, E 1999, Coloured gold alloys: The Ganoskin Project, viewed 11 July 2016, <www.ganoksin.com/borisat/nenam/colored_gold_alloys.htm>.

Crystal World 2002, Elizabeth, viewed 22 November 2011, <www.crystal-world.com/html/mining/australian/elizabeth.htm>.

Henry, DA 2007, Silver from the Elizabeth Hill mine Western Australia: Rocks and Minerals, January–February, v. 82, no. 1, p. 26–27.

Hickman, AH and Kojan, CJ 2003, Geology of the Pinderi Hills 1:100 000 Sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 36p.

Hough, RM, Butt, CRM, Reddy, SM and Verrall, M 2007, Gold nuggets: supergene or hypogene?: Australian Journal of Earth Sciences, v. 54, no. 7, p. 959–964.

Glover, JJE and Bevan, JC 2010, The forgotten explorers: pioneer geologists of Western Australia, 1826–1926: Hesperian Press, Carlisle, Western Australia, 231p.

Mindat.org 2015, Elizabeth Hill mine (Elizabeth Hills mine, Elizabeth Hill silver mine), Karratha, Roebourne Shire, Western Australia, Australia, viewed 1 June 2016, <www.mindat.org/loc-212254.html>.

Schwartz, GM 1944, The host minerals of native gold: Economic Geology, v. 39, no. 6, p. 371–411.

Spillman, K 1993, A Rich Endowment — Government and Mining in Western Australia 1829–1994: University of Western Australia Press, Perth, Western Australia, p. 29.

6

Other gemstones

Copper matrix cabochon containing chrysocolla, native copper, tenorite, and iron minerals (courtesy Sandfire Resources NL)

Chapter 15

Andalusite and chiastolite

Andalusite minerals

Andalusite, first described in the mid-18th century, was named after the Andalusia region of southern Spain, the assumed location of the original samples. However, the first occurrence and type locality are in the province of Guadalajara (Minerales y Minas de España, 2012).

Andalusite is typically a metamorphic mineral and commonly forms as well-defined prismatic porphyroblasts (large crystals). More rarely, it crystallizes as a primary mineral in granites, aplites, and pegmatites. Andalusite can be formed in low- to medium-grade contact metamorphic hornfelses in argillaceous rocks in aureoles around igneous intrusions. In schists, its development results from regional metamorphism of fine-grained, aluminous sedimentary rocks.

Andalusite is commonly associated with other aluminous minerals including mica and cordierite. Crystals can be partially or completely pseudomorphed by fine-grained aggregates of the white micaceous minerals sericite, pinite, and margarite.

Andalusite polymorphs

Andalusite, sillimanite, and kyanite are aluminium silicate allotropes that exist as different mineral species with the same chemical formula. Although all three polymorphs can co-exist within rocks of the same metamorphic grade, kyanite and sillimanite are commonly found in rocks formed under higher regional metamorphic grades. Their physical and optical properties are summarized on the following page.

Andalusite crystals of cylindrical form are described as 'cigar-shaped', and are square or rhomboid in section. Other varieties of andalusite include chiastolite, and a manganiferous type termed viridine.

All three minerals contribute gemmological quality material. Kyanite is faceted in attractive, intense blue, green, and orange transparent colour varieties. Sillimanite is commonly cut to demonstrate chatoyant qualities although is also faceted in its violet, purple, and grey transparent coloured varieties. Andalusite can be faceted in its transparent light brown and green colour varieties and chiastolite can be cabochon cut to show its distinctive cross forms.

Neither kyanite nor sillimanite has been found in gem quality in Western Australia. In a few sites, andalusite has been found as small, transparent crystals suitable for faceting (Fig. 15.1).

Andalusite and chiastolite
Aluminium silicate polymorphs Al_2SiO_5

Chiastolite

When viewed down the length of a crystal, chiastolite shows distinctive light and dark-coloured mineral zones that form tessellated patterns. Chiastolite is sectioned specifically for use in jewellery to display these cross-form patterns. It is fashioned as cabochons or beads, which have featured traditionally in rosaries and religious emblem jewellery, particularly in Europe.

Physical properties of andalusite

Crystal system	Orthorhombic
Habit	Prismatic crystals, vertically striated, square in section
Colour range	Light green to reddish-green, pink, and yellowish-brown; commonly bicoloured pink and green
Colour cause	Trace iron and manganese
Lustre	Vitreous
Diaphaneity	Transparent to translucent and opaque
Refractive index	1.63 – 1.64
Birefringence	0.007 – 0.013
Pleochroism	Strong in transparent varieties
Hardness	7.5
Specific gravity	3.15 – 3.20
Fracture	Subconchoidal
Cleavage	Distinct prismatic
Varieties	Chiastolite displays a cross-form pattern of inclusions in transverse crystal sections; viridine is manganiferous andalusite
Processing and display	Resin-impregnated and oiled to conceal fractures and improve durability

Physical and optical properties of andalusite, kyanite, and sillimanite

	Andalusite	*Kyanite*	*Sillimanite*
Crystal system	Orthorhombic	Triclinic	Orthorhombic
Hardness	7.5	4–7 (strongly directional)	6–7
Specific gravity	3.15 – 3.2	3.6	3.23
Colour range	Pink, red, grey, green, brown	Blue, green, white, orange	Grey, brown, yellow, violet
Habit	Stout prismatic crystals	Bladed, elongated, tabular crystals	Acicular, fibrous, silky
Refractive index	1.63 – 1.64	1.712 – 1.729	1.657 – 1.684
Varieties	Transparent and chatoyant, also opaque chiastolite	Transparent and chatoyant	Transparent and chatoyant

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Figure 15.1. Faceted andalusite gems; largest stone is 6 mm wide (courtesy Bill Moriarty)

The dark and light zones of chiastolite are the result of aggregated carbon, graphite, and dark mica grains between zones that are either transparent-quality andalusite or a fine-grained opaque cream-grey mix of micas and clays. The zones formed against the prism faces as the crystals developed. The name chiastolite is a descriptive term from the Greek word ‘khiastos’, alluding to its tessellated patterns (Fig. 15.2).

Viridine

Viridine is a manganiferous variety of andalusite and has been recorded in the Russell Range region in the far south of the State in schists from areas around Mount Ragged, Mica Hill, and Mount Dean. The viridine forms as porphyroblasts (large crystals) up to 20 mm long in quartz–muscovite schists, where the muscovite is also reported as an unusual pink to violet colour. The crystals are described as heavily included with other minerals (quartz and iron oxides) although they are interesting in displaying strong pleochroism from golden-yellow, yellow-green, to emerald-green. Refractive indices are greater than those for the normal range of andalusite (1.649 – 1.661) because of the presence of Mn^{3+} and Fe^{3+} (Prider, 1960). A specimen of viridine (8615) is displayed in the School of Mines Museum, Kalgoorlie.

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Figure 15.2. Specimen of uncut, facet-quality chiastolite approximately 15 mm wide (courtesy Bill Moriarty)

Andalusite in Western Australia

Andalusite is recorded by Simpson (1948) from many locations within Western Australia, and at the time of that publication, no material of gemmological interest had been documented with the exception of descriptions of chiastolite crystals from the Toodyay area. Facet-grade andalusite and chiastolite have recently been recorded in the Kalgoorlie area.

Yilgarn Craton — Eastern Goldfields Superterrane

Kambalda region

Spargoville (*Yilmia*, 3135)

There are many pegmatites within the Spargoville area south of Coolgardie; some are currently worked for gem minerals (Fig. 15.3). Rose quartz is currently exploited from the core of a pegmatite a few kilometres south of Spargoville on prospecting licence P15/5630 where chiastolite crystals are found within the mica rock aureole of this pegmatite (Fig. 15.4). The site is of local interest to lapidarists. Some of these crystals attain lengths of 100 mm with sections of approximately 30 mm. A specimen at the School of Mines Museum, Kalgoorlie (8390) displays an incomplete crystal of andalusite-in-matrix with a length of 325 mm.

Staurolite, a red-brown to black orthorhombic silicate mineral, and garnets, are found within the same schists and have also been collected from this area. The staurolite is commonly dark red with an orange hue, a colour too dark for faceting. The fragments tend to be angular broken crystal pieces, are heavily included with dark iron oxide-stained fractures, and only rare pieces of the typical foxy-red colour can be found clean enough to facet small gems from it. Well-crystallized, although weathered, staurolite can be found in situ in some of the outcropping andalusite schist and is also found on hillslopes as eluvial material.

Ora Banda area

Credo Station (*Davyhurst*, 3037)

An unpublished report about andalusite from Credo Station covers an investigation to use andalusite as a refractory ore (Fig. 15.3). The area was investigated under exploration license E16/26 (Trask, 1987) and referred to three projects titled Rock Dam, Reptile Dam, and West Reptile Dam. The prospect was not progressed although of interest is some facet-grade quality andalusite crystals, including chiastolite.

In one part of the project, scattered eluvial andalusite crystals extend over an area of approximately 600 × 200 m in a weathered rock described as fine-grained whitestone schist. In another area of the project, andalusite exists within a silicified laterite with crystals averaging 10 × 35 mm. West of the main occurrence (West Reptile Dam area) a large number of ferruginous andalusite crystals were collected on a laterite surface at the time of the investigation (Trask, 1987).

At the Credo Station site, eluvial andalusite and chiastolite, some with adherent matrix, were recently collected. The crystal fragments are typically less than 15 mm in length although finds include transparent-quality material (Fig. 15.5).

South West Terrane

Toodyay area

Lovers Lane prospect (*Wooroloo*, 2134)

Andalusite and chiastolite occur within schists of the Jimperding Metamorphic belt, which is formed dominantly of metasedimentary rocks with subordinate mafic rocks (Fig. 15.3). The belt extends north-northwest for more than 120 km and varies in width from 15 to 65 km, forming part of the Yilgarn Block west of the Darling Fault. The rocks show a progressive eastward increase in metamorphic grade from lower amphibolite to granulite facies (metamorphic grades), with andalusite, sillimanite, and cordierite indicator minerals present.

The andalusite schist is composed of large bluish porphyroblasts of andalusite up to 20 mm in length, set in a reddish matrix of mica, quartz, minor feldspar, and sillimanite, and is associated with units of quartzite and banded iron-formation (Wilde, 2001).

Simpson (1952) described the andalusite schists within the Jimperding Metamorphic belt as one of the best localities in the State for andalusite and chiastolite. The Jimperding Valley, a few kilometres southwest of Toodyay, runs along a belt of Precambrian mica schist about 800 m wide, in which crystals of andalusite are abundant at several points over a distance of at least 16 km from Gabardine Hill in the southeast to the head of Julimar Brook in the northwest.

The schist is weathered, and imperfect prisms of andalusite project from the surface forming as much as 5–10% of the exposed surface. The crystals vary from 10 × 5 × 5 mm to 40 × 40 × 40 mm or 60 × 25 × 20 mm. Their form is that of a fairly sharply outlined prism with imperfectly defined terminations. The ends taper off indefinitely, or are terminated by single faces (a dome). The colour is almost invariably dark grey because of included carbon dust; many crystals exhibit a typical chiastolite structure. Some 2.4 km east-southeast of this site, on the same belt, is another andalusite zone. Here individual crystals reach larger sizes, up to 60 × 30 × 30 mm. A distinct feature is the coating of coarse mica on the surfaces, which is integral to the crystal and not part of the host mica schist. Simpson (1952) described other localities within this metamorphic belt.

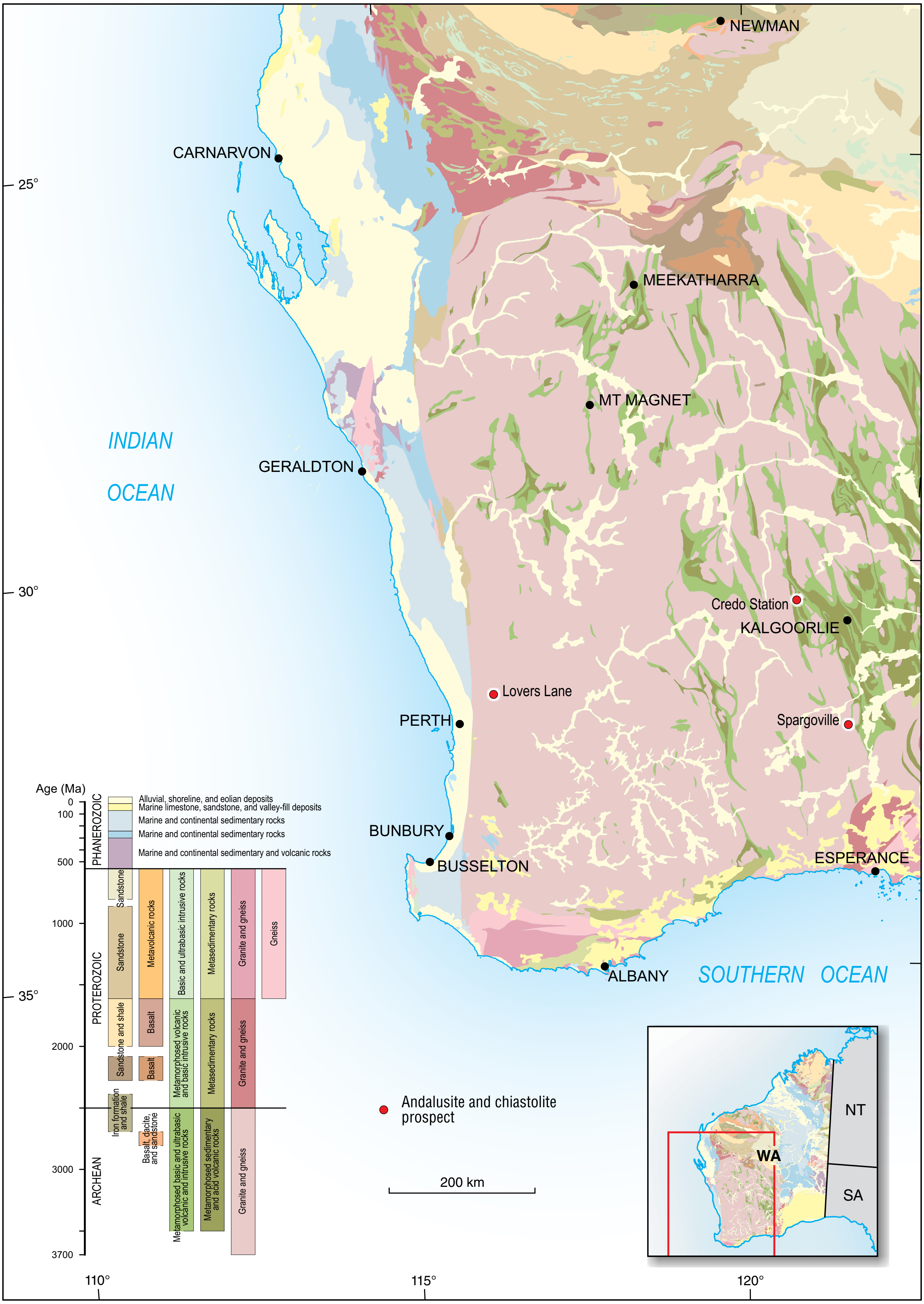

Figure 15.3. Locations of andalusite and chiastolite prospects in Western Australia

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Figure 15.4. **Chiastolite crystal in greenstone schist south of Spargoville (courtesy Francine Payette)**

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Figure 15.5. **Rough crystal fragments of andalusite from Credo Station. Maximum crystal length is 16 mm (courtesy Bill Moriarty)**

References

Minerales y Minas de España 2012, viewed 29 August 2012, <http://milksci.unizar.es/miner/mineralesp/tipo.html>.

Prider, R 1960, Viridine from Mount Ragged, Western Australia: Reprinted from The Indian Mineralogist, v. 1, no. 1, p. 42–47.

Simpson, ES 1948, Minerals of Western Australia, volume 1: Hesperian Press, Perth, Western Australia, p. 71–82.

Trask, F 1987, Report on the Credo andalusite project A22987 M4665 item 8526: Geological Survey of Western Australia, Statutory mineral exploration report (WAMEX unpublished report).

Wilde, SA 2001, Jimperding and Chittering Metamorphic Belts, southwestern Yilgarn Craton, Western Australia – a field guide: Geological Survey of Western Australia, Record 2001/12, 24p.

Chapter 16

Chrysoberyl and alexandrite

Chrysoberyl minerals

Chrysoberyl

Chrysoberyl, a hard, beryllium mineral, commonly forms gemstones that are predominantly yellow, golden-yellow, yellow-green, green, or brown and, rarely, colourless. Cats eye and alexandrite are recognized as two rarer and more valuable varieties of chrysoberyl.

Chrysoberyl crystals are typically tabular in form and are commonly twinned with two conjoined crystals producing a divergent or chevron form. Three crystals may intersect cyclically in a regular pattern appearing as a pseudohexagonal form. Transparent, high-quality chrysoberyl is commonly faceted to form a hard, durable gemstone with a vitreous lustre.

Cats eye

Chrysoberyl may also exhibit chatoyancy. Chrysoberyl exhibiting this property is called 'cats eye' (Fig. 16.1). This optical property is a phenomenon caused by light reflection from prolific needle-like inclusions developed parallel to the principal crystal axis (*c*-axis). These inclusions are most commonly hollow tubules that develop on a microscopic scale. Cabochon-cut gemstones are commonly cut as oval-shaped, biconvex forms from chrysoberyl containing these inclusions and may exhibit a single bright ray of light across the gem. It is essential that the inclusions are parallel to the stone's base in order to produce a gemstone with a well-centred ray. Note that the name 'cats eye' is also applied to a chatoyant form of opal discussed in Chapter 10 on opal.

Alexandrite

Alexandrite is the variety name given to chrysoberyl that displays a change of colour from green in daylight (or fluorescent light) to red or purplish-red under incandescent tungsten light. The cause of this effect is trace amounts of chromium, which has substituted for aluminium in the crystal lattice. Alexandrite displaying this change-of-colour phenomenon is rare and highly valued as a gemstone. Principal sources include the Ural Mountains in Russia, where the variety was first identified in 1833, and more recently from Sri Lanka and Brazil. Other known sources of alexandrite include Tanzania and Zimbabwe although gem-quality material is rarely found (Schmetzer et al., 2011). Alexandrite is reported from many occurrences worldwide in association with emerald, as both are beryllium minerals with trace amounts of chromium as the cause of colour. Alexandrite at Poona in Western Australia is an example of this mineralogical association.

Chrysoberyl and alexandrite
Beryllium aluminium oxide $BeAl_2O_4$

Physical properties of chrysoberyl

Crystal system	Orthorhombic
Habit	Tabular; commonly twinned
Colour range	Brown, yellow, golden-yellow, yellow-green, green, and colourless
Colour cause	Yellow — iron Yellow to green — chromium
Lustre	Vitreous
Diaphaneity	Transparent to translucent
Refractive index	1.742 – 1.757
Birefringence	0.009
Pleochroism	Strong
Hardness	8.5
Specific gravity	3.68 – 3.78
Fracture	Conchoidal
Cleavage	Moderate

Source: Thomas (2008)

Chrysoberyl in Western Australia

Although there are several occurrences of chrysoberyl in pegmatites in Western Australia, and specimens exist in the Western Australian Museum mineral collection, there are few records of specimens from the State that have been fashioned as gems. Locations for chrysoberyl and alexandrite openpits and prospects in Western Australia are shown in Figure 16.2 and more accurate sites are given in Appendix 1.

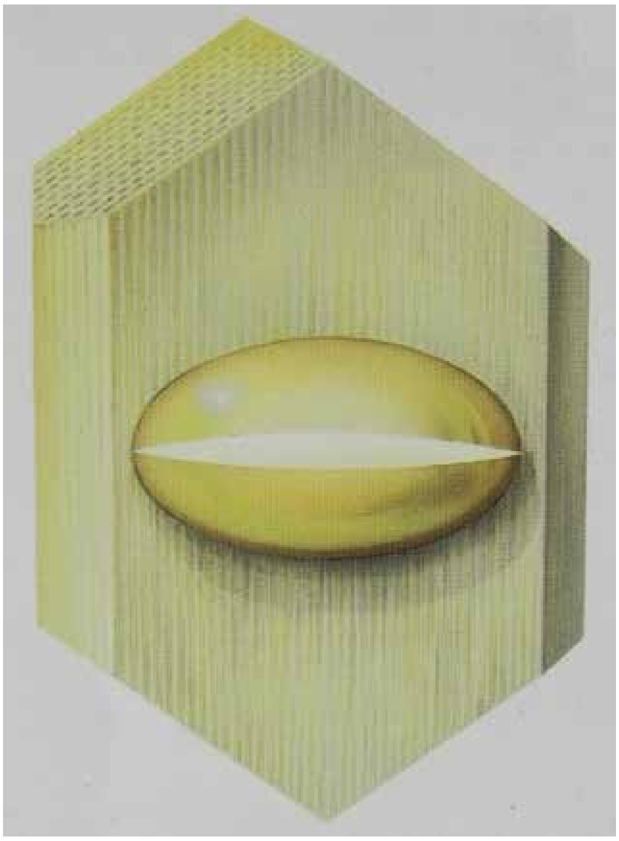

Figure 16.1. Cats eye effect in chrysoberyl (after The Natural History Museum, 1993)

Gascoyne Province

Yinnetharra area

Williamsons beryl mine (*Yinnetharra, 2148*)

Williamsons beryl mine (possibly the same as Lake Moore pegmatite mine), 21 km northwest of Yinnetharra Homestead, forms a conspicuous conical hill on the west bank of the Thirty One River in the Thirty One River pegmatite field (Fig. 16.2). This location has already been described in Chapter 3 on the beryl group. The mine has also yielded chrysoberyl crystals. Specimens MDC 4988 and 5632 in the Western Australian Museum collection come from this pegmatite. Other chrysoberyl specimens from this site are recorded as being in private collections (Jacobson et al., 2007).

Pilbara Craton

Wodgina region (*Wodgina, 2655*)

The Western Australian Museum has a specimen of chrysoberyl (MDC 2515) purportedly from the Wodgina area. Nothing further is known about this occurrence.

Yilgarn Craton — South West Terrane

Bridgetown area

Donovans Find (*Manjimup, 2129*)

Situated on the Smithfield pegmatite, Donovans Find is an old tin mine 16 km west-southwest of Bridgetown (Fig. 16.2). The deposit may be accessed via Tin Mines Road, which intersects the Brockman Highway some 18 km west of Bridgetown.

In this area, mineralized pegmatites were intruded into Archean quartz–feldspar–biotite schist and granofels rocks. These kaolinized albite–quartz–microcline–muscovite pegmatites contain tin, tantalum, and lithium mineralization. Chrysoberyl is also recorded as present in the pegmatite, although no further details are known (MDC 5778).

Dowerin

Dowerin pegmatite (*Dowerin, 2335*)

The Dowerin pegmatite is about 1.6 km southeast of Dowerin township and about 200 m west of the Dowerin–Meckering Road (Fig. 16.2). The openpit workings form part of mining lease M70/956 currently owned by Mr M Anderson of Dowerin. It is reported that permission to enter the workings is only available from the owner to bona fide mineralogical researchers (Jacobson et al., 2007).

In 1930, the first chrysoberyl discovered at Dowerin was contained in a loose boulder. This find was followed up by tracing subcrop material to a pegmatite in a wheat field (Simpson, 1932). The Dowerin pegmatite was prospected for about three years before it was abandoned in 1933 because all of the clear crystals recovered were assessed as too small to be worth cutting. In 1991–92, the Department of Mines provided assistance to Dowerin land owner Murray Anderson in the preparation of a feasibility study to assess the commercial viability of the alexandrite variety of chrysoberyl found on his property (Department of Mines, 1992). Subsequently, detailed examinations of the deposit were carried out in 1995 by Bevan and Downes (1997), and later by Downes and Bevan (2002).

In the area south of Dowerin, an Archean quartzofeldspathic gneiss is intruded by pegmatitic veins during granulite facies metamorphism. At the chrysoberyl openpit, the exposed rocks contain pegmatite veins hosting varying amounts of biotite, andesine, quartz, schorl, and almandine together with intensely folded lenses of cummingtonite–actinolite–biotite schist. The schist contains bands of small bright green crystals of actinolite, which contain trace amounts of nickel (Bevan and Downes, 1997).

In the Dowerin deposit, crystals of chrysoberyl are found most commonly, although not exclusively, in the biotite-rich zones in the pegmatite, particularly in association with almandine garnet. Simpson (1932) described crystals

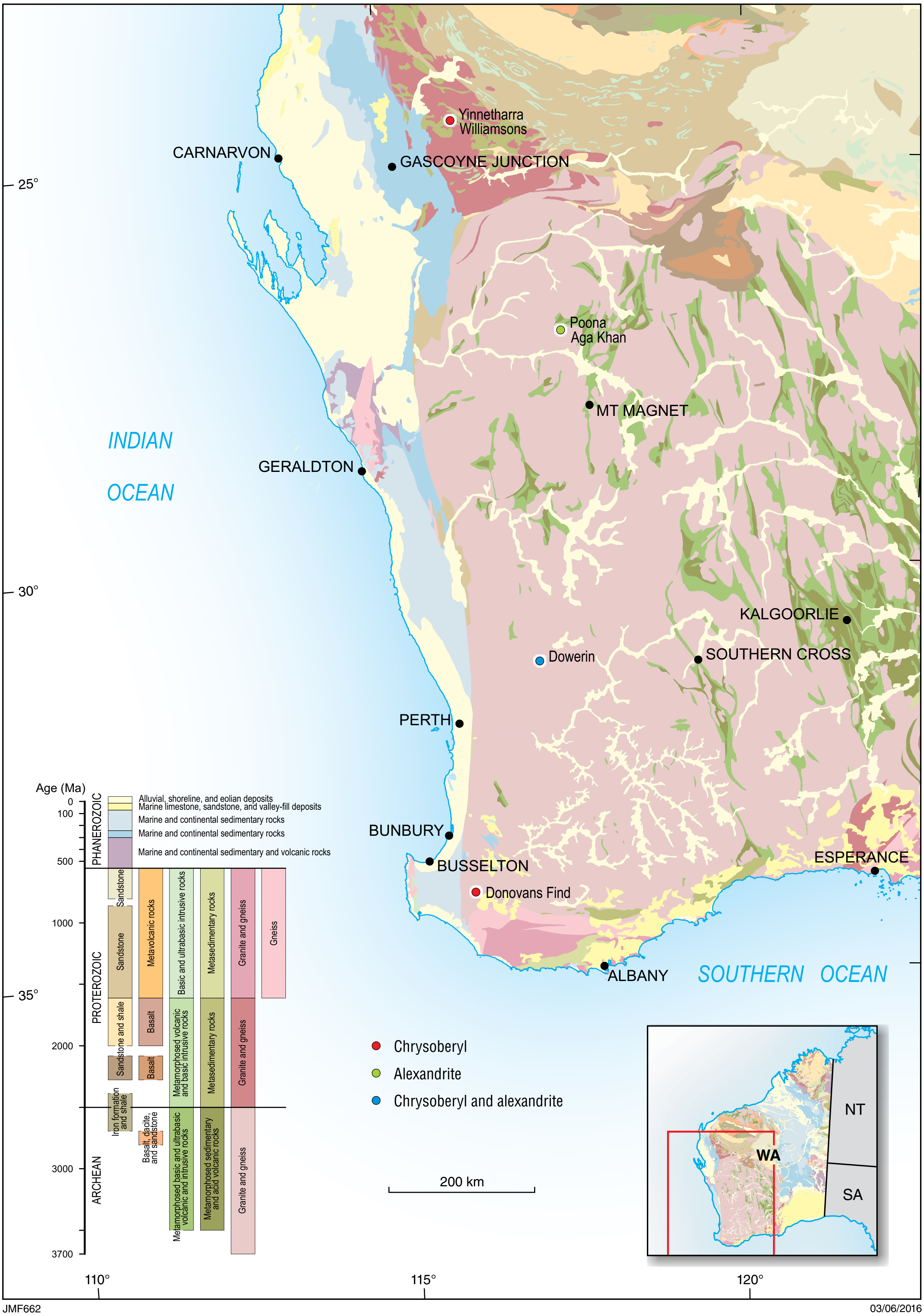

Figure 16.2. Locations of chrysoberyl and alexandrite prospects in Western Australia

of chrysoberyl ranging from less than 1 mm to more than 1 cm across and varying from colourless to yellow, through pale green to deep emerald-green. Most of the smaller crystals were typically transparent and a few of the deeper green crystals show the characteristic alexandrite colour change described in more detail above.

Common crystal forms of chrysoberyl present include tabular, striated, and elongate crystals with some small cyclically twinned (trilled) crystals. The largest chrysoberyl crystals are typically poorly developed and translucent, and contain inclusions of other minerals. Some crystals are bright yellow. The largest crystal found in recent times is a broken trilled crystal measuring 8.5 mm in diameter (Bevan and Downes, 1997). Available records indicate that one small yellow chrysoberyl was faceted.

Alexandrite in Western Australia

Yilgarn Craton — Murchison Terrane

Cue region

Poona *(Noondie, 2343; Cue, 2443)*

The Poona pegmatites are approximately 55 km northwest of Cue (Fig. 16.2). These pegmatites have been described in detail under emerald in Chapter 3 on the beryl group. Simpson (1951) records two detrital green chrysoberyl fragments weighing 25 and 19 g that were found near outcrops of emerald-bearing schist alongside a pegmatite. Both specimens showed the characteristic alexandrite colour-change effect and both contained small areas of gem-quality material.

Grundmann and Morteani (1998) later reported the presence of alexandrite aggregates associated with emerald, ruby, sapphire, and topaz that were found in dumps near the Aga Khan Deep shaft. Crystals varied 1–5 mm in diameter with crystal aggregates reaching about 10 mm. Most alexandrite crystals from this site are cloudy although a few are transparent, euhedral, poor in inclusions, and without fractures. Poona alexandrite crystals show light green, blue-green, or dark green colours in daylight, and blue, light red or violet-red in incandescent light.

Yilgarn Craton — South West Terrane

Dowerin

Dowerin pegmatite *(Dowerin, 2335)*

The Dowerin pegmatite is described in detail under chrysoberyl. Bevan and Downes (1997) carried out a detailed examination relating to the mineralogy of the site particularly relating to the alexandrite mineralization (Fig. 16.3a). They recorded that few of the deeper green chrysoberyl crystals clearly showed the characteristic colour change present in alexandrite viewed both in daylight and incandescent light. Microprobe analyses show these crystals to have detectable chromium. Only two small alexandrite crystals have been faceted with the largest weighing only 0.15 ct (Fig. 16.3b).

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Figure 16.3. Alexandrite crystals from the Dowerin prospect: a) pale green, tabular, euhedral alexandrite crystal, approximately 3 mm in length, showing many crystal faces; b) very small, broken, lemon-green faceted stone weighing only 0.15 ct (modified after Bevan and Downes, 1997)

References

Bevan, AWR and Downes, PJ 1997, Alexandrite chrysoberyl from Dowerin, Western Australia revisited: Australian Gemmologist, v. 19, no. 11, p. 460–463.

Department of Mines 1992, Annual report for 1991–92: Department of Mines, Perth, Western Australia, p. 66.

Downes, PJ and Bevan, AWR 2002, Chrysoberyl, beryl and zincan spinel mineralization in granulite-facies Archaean rocks at Dowerin, Western Australia: Mineralogical Magazine, v. 66, no. 6, p. 985–1002.

Grundmann, G and Morteani, G 1998, Alexandrite, emerald, ruby, sapphire and topaz in a biotite–phlogopite fels from Poona, Cue District, Western Australia: Australian Gemmologist, v. 20, no. 4, p. 159–167.

Jacobson, MI, Calderwood, MA and Grguric, BA 2007, Guidebook to the pegmatites of Western Australia: Hesperian Press, Perth, Western Australia, 356p.

The Natural History Museum 1993, Gemstones: The Natural History Museum, London, p. 9.

Thomas, A 2008, Gemstones—properties, identification and use: New Holland Publishers, London, 261p.

Schmetzer, K, Stocklmayer, S, Stocklmayer, V and Malsy, A 2011, Alexandrites from the Novello alexandrite–emerald deposit, Masvingo District, Zimbabwe: Australian Gemmologist, v. 24, no. 6, p. 133–147.

Simpson, ES 1932, Contributions to the mineralogy of Western Australia, series VII (chrysoberyl): Journal of the Royal Society of Western Australia, v. 18, p. 61–65.

Simpson, ES 1951, Minerals of Western Australia, volume 2: Government Printer, Perth, Western Australia, p. 13–16.

Chapter 17

Cordierite

Cordierite, a magnesium aluminium silicate of the beryl mineral group, is the magnesium-rich end member of a solid solution series with the rare, iron-rich mineral sekaninaite. It is widespread, typically resulting from regional or contact metamorphism of argillaceous rocks such as shale where it may be found in schist, gneiss, or less commonly, in hornfels. Metamorphic mineral assemblages include sillimanite–cordierite–spinel, and cordierite–spinel–plagioclase–orthopyroxene, while garnet and anthophyllite may also be present. Cordierite also occurs in norites, gabbroic magmas, and in some granites and pegmatites.

Cordierite is of limited use in industry, having previously found use in ceramic parts for catalytic converters, although in recent times this has been replaced by synthetic cordierite. Cordierite's gem form, iolite, also known as 'water sapphire', is sometimes used as an inexpensive, softer substitute for sapphire. Because of its extreme pleochroism, iolite is a challenging material to facet as it must be correctly orientated to maximize its violet or blue colour.

Cordierite properties

Cordierite mostly occurs in irregular grains and masses and less commonly as crystals. These are commonly short and prismatic in habit and are usually twinned. Single crystals and twins can appear pseudohexagonal in form. Cordierite is also known as dichroite ('two-colour rock'), a name that describes its strong pleochroism. Its colour is typically blue to bluish-violet and less commonly green, brown, yellow, and grey. Cordierite resembles quartz in appearance and its refractive indices and specific gravity are within a similar range. These two properties easily distinguish it from other similarly coloured blue minerals such as sapphire and tanzanite.

The gem form of cordierite is iolite ('violet flower'), alluding to its blue-violet colour. Iolite is strongly trichroic (pleochroism indicated by three colours: dark blue to violet, yellow or grey, and light blue) when viewed parallel to each of the three crystallographic directions. The colour change is so strong it is noticeable to the naked eye. The most desirable blue-violet colour can be seen parallel to the long axis of prismatic crystals, and gemstones are fashioned to demonstrate this colour (Geology.com, 2015). A variety of iolite displaying red iridescence under reflected light is termed 'bloodshot iolite'. The colour and optical effects are caused by orientated platelets of iron oxide inclusions within the cordierite.

Cordierite
Magnesium aluminium silicate $Mg_2Al_4Si_5O_{18}$

Physical properties of cordierite

Crystal system	Orthorhombic
Habit	Massive to granular, uncommonly as prismatic crystals
Colour range	Blue to bluish-violet, and green, brown, yellow, and grey
Colour cause	Intervalent charge transfer between Fe^{2+} and Fe^{3+} ions
Lustre	Vitreous to greasy
Diaphaneity	Transparent to translucent
Refractive index	1.527 – 1.560
Birefringence	0.01
Pleochroism	Strong
Hardness	7 – 7.5
Specific gravity	2.53 – 2.78
Cleavage	Fair to poor
Fluorescence	Inert in ultraviolet (UV) light
Absorption spectrum	Varies with direction of viewing with a series of weak absorption bands in the green and blue sections of the spectrum according to the presence of Fe^{2+} ion

Cordierite in Western Australia

To date, only one cordierite prospect has been found in Western Australia, on Springvale Station in the East Kimberley region.

East Kimberley region

Springvale cordierite prospect (McIntosh, 4462)

The Springvale cordierite prospect approximately 50 km north of Halls Creek on exploration licence E80/4753 is owned and operated by Pathfinder Exploration Pty Ltd. Access to the prospect, about 6 km west-northwest of Springvale Homestead, is by way of station tracks. Currently, visitor access to Springvale Station is restricted.

Geology

The exploration area is within the Lamboo Province, the oldest component of the Paleoproterozoic Halls Creek Orogen. The province extends for about 360 km in a north-northeasterly belt in the Halls Creek area of the east Kimberley region (Fig. 1.1, Chapter 1 on introduction to gemstones in Western Australia). It comprises a series of igneous and low- to high-grade meta-igneous and metasedimentary rocks divided into the Western, Eastern, and Central Zones.

The Western Zone is interpreted to have formed along the margin of the Kimberley Craton. The oldest rocks in the area consist of a series of metamorphosed, fine- to medium-grained turbidites of the Marboo Formation, the protoliths to which were deposited at c. 1872 Ma. The Springvale area was intruded by the layered mafic rocks of the Springvale Suite at 1864–1852 Ma. The oval-shaped intrusion, measuring 6 km wide by 13 km long, comprises two contiguous lobes (eastern and western) (Fig. 17.1). These moderately to steeply dipping lobes display prominent arcuate layering of cyclic mafic units. The Western lobe contains olivine-bearing gabbroic rocks including gabbro, gabbronorite, troctolite, and norite overlain by an arcuate, mafic succession of gabbro, anorthosite, troctolite, and gabbronorite.

Western lobe cordierite lenses

In the southern part of the Western lobe are several narrow, cordierite-rich lenses hosted by fine- to medium-grained norite and gabbronorite. These lenses were first described by Geopeko Pty Ltd in 1988 while drilling for platinum group elements in the area. Core from diamond drillhole DDH SV1 inclined to the south-southwest demonstrated the presence of cordierite–spinel lenses (interpreted as xenoliths) within the gabbronorite zone (Barrett, 1989). Detailed fieldwork by Pathfinder Exploration Pty Ltd in 2015 has shown that although disrupted by north–south dextral faulting, the cordierite-rich lenses extend at least 700 m in a slightly arcuate west-northwest trend, representing a significant cordierite resource (Fig. 17.2; Rugless, 2015).

The cordierite-rich lenses, mostly 2 m to more than 5 m in width with a moderate northerly dip, have been interpreted as metamorphosed and metasomatized rafts of aluminous metasedimentary country rock incorporated in the upper parts of the intrusion. This material may have been derived from a succession of aluminous metasediments of the Marboo Formation present on the northern side of the intrusion (Fig. 17.1; Hoatson and Blake, 2000). On the surface, lenses outcrop sporadically as boulders and surface rubble mostly along a topographic low (Fig. 17.3). Relict banding or gneissose textures preserved on dark, weathered surfaces of glassy, microcrystalline, massive cordierite-rich rocks indicate a probable sedimentary origin for the lenses.

Thin section analysis of sample no. Cordierite 1 from a massive, glassy, microcrystalline cordierite lens shows that it consists mostly of a fine-grained, granoblastic to microcrystalline cordierite mosaic matrix containing distinctive, coarse-bladed corundum crystals (≤4 mm) and fibrous clumps of sillimanite. Fine, equant, idioblastic spinel (dark green hercynite) is distributed through the matrix and locally envelops corundum. Cordierite may exhibit polysynthetic twinning in association with bladed corundum, and spinel shows serrated grain boundaries in contact with the cordierite matrix (Fig. 17.4).

Cordierite 1 is estimated to contain cordierite (85%), sillimanite (6%), spinel (hercynite; 6%), and corundum (3%). From the analysis of this sample, it is proposed that the cordierite–corundum–sillimanite assemblage is consistent with a high-temperature metamorphic and/or metasomatic origin probably from aluminous-rich, pelitic sedimentary rocks enclosed as rafts in the layered-mafic intrusion (Rugless, 2015).

Gemstone properties and testing

Cordierite rock from the Springvale prospect is very hard and may be cut into extremely thin, semitranslucent, jet-black slices that take a very high polish. When exposed to bright white light on one surface, a strong violet to purple colour is transmitted through the stone to the opposite surface. To date, polished cabochons have been fashioned to highlight this property (Fig. 17.5). This material has assumed the trade name of ‘cosmic iolite’.

Material testing continues to improve the colour transmission of the Springvale cordierite by way of thinness of cutting, the use of cordierite doublets in jewellery manufacture, and in heat treatment experiments. Larger, thin, polished cordierite plates are also under test for use as spectacular decorative tiles capable of transmitting bright violet to purple colours in public display areas.

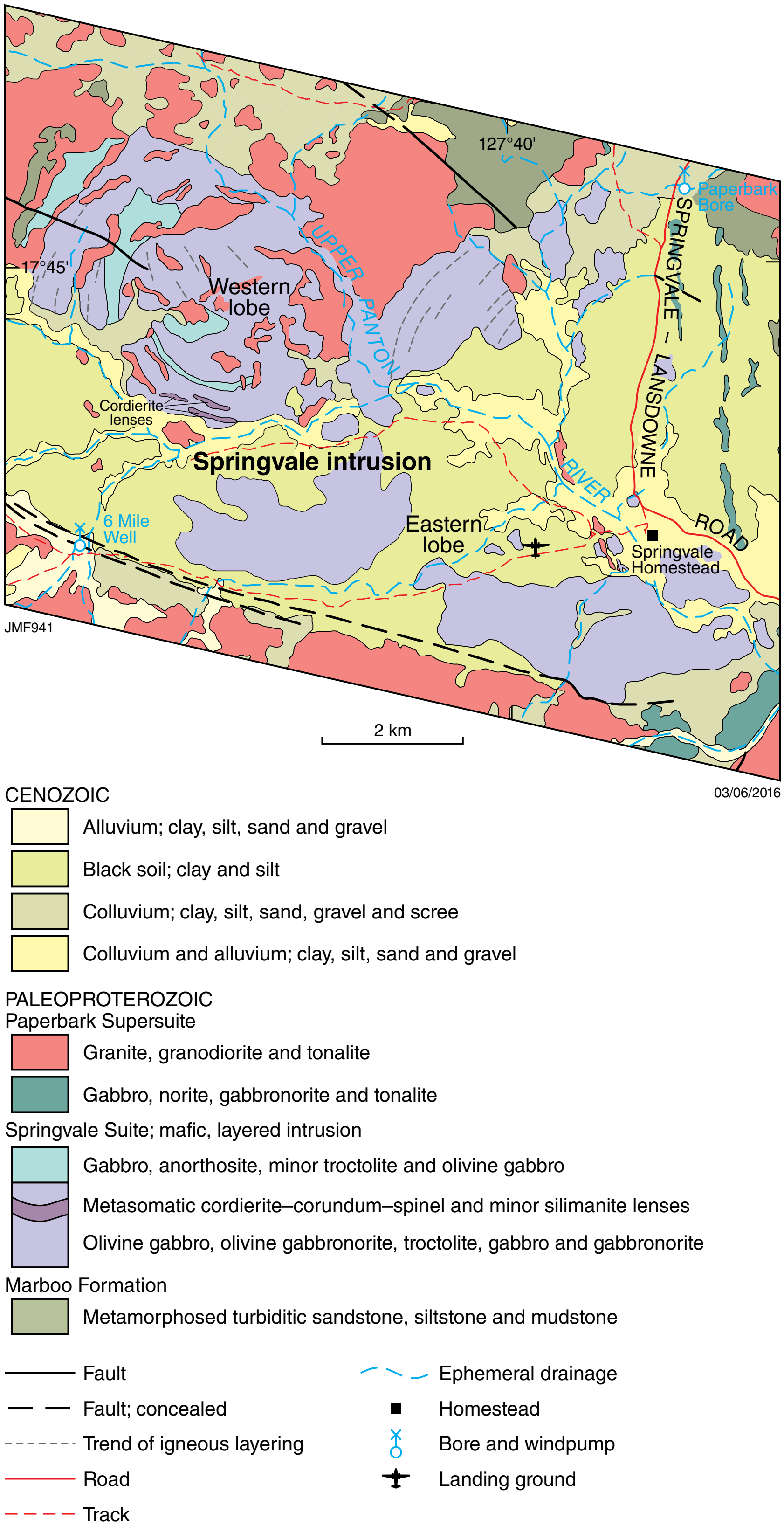

Figure 17.1. Geological map of the Springvale intrusion, East Kimberley region (modified after Tyler et al., 1997)

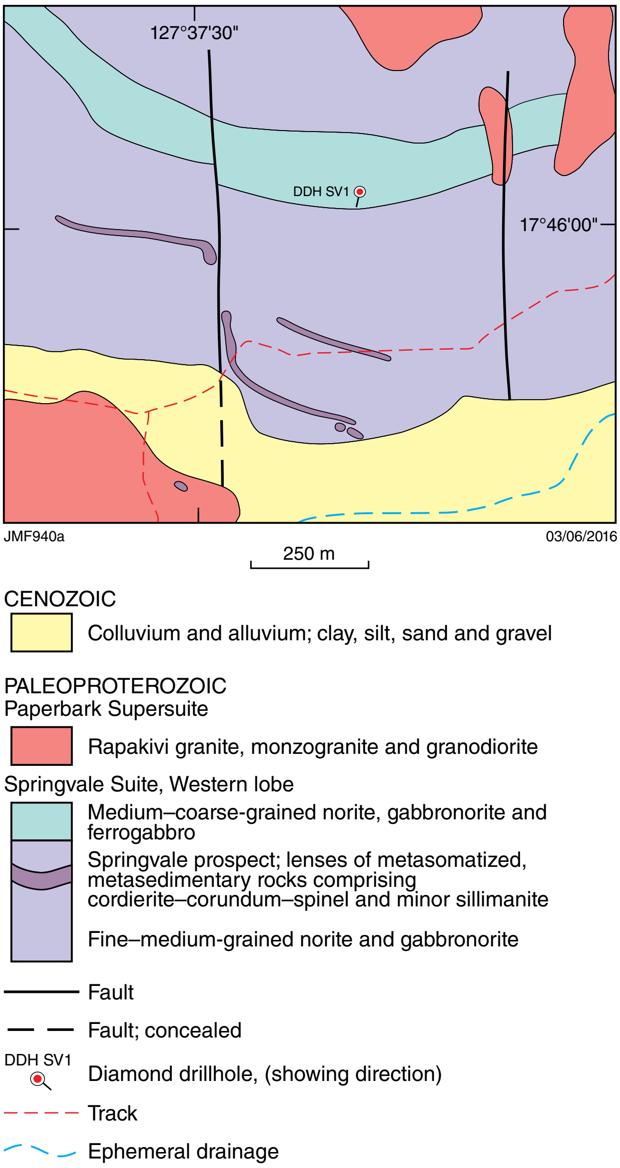

Figure 17.2. Geological sketch map showing cordierite-rich lenses in the Western lobe of the Springvale intrusion (modified after Tyler et al., 1997; Rugless, 2015)

Figure 17.3. Cordierite–corundum–spinel boulder (1 m high), an example of boulders distributed along the surface of the main cordierite lens (courtesy Craig Rugless)

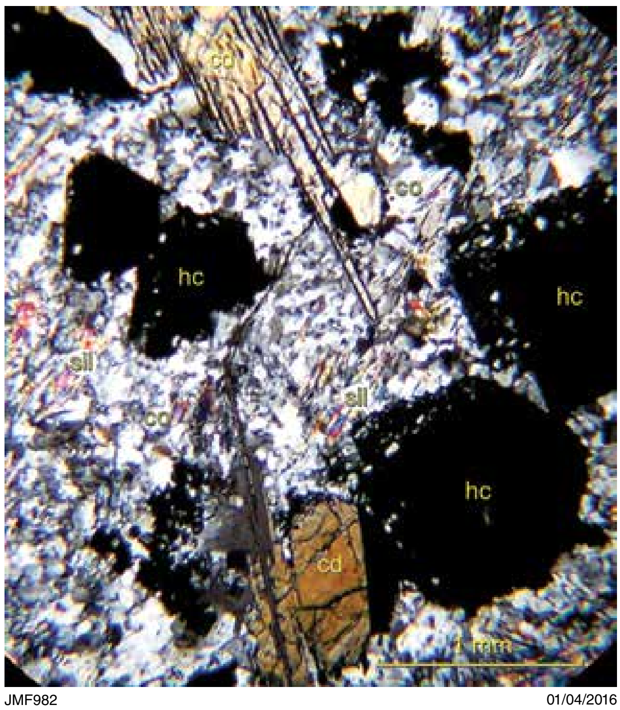

Figure 17.4. Thin section of Springvale cordierite-rich rock (sample no. Cordierite 1). Thin section shows bladed corundum (cd); equant, subidioblastic spinel (hercynite) (hc); and fibrous sillimanite (sil) in a fine-grained, granoblastic to microcrystalline cordierite mosaic matrix (co). Crossed polarization, field of view 3 mm (Rugless, 2015)

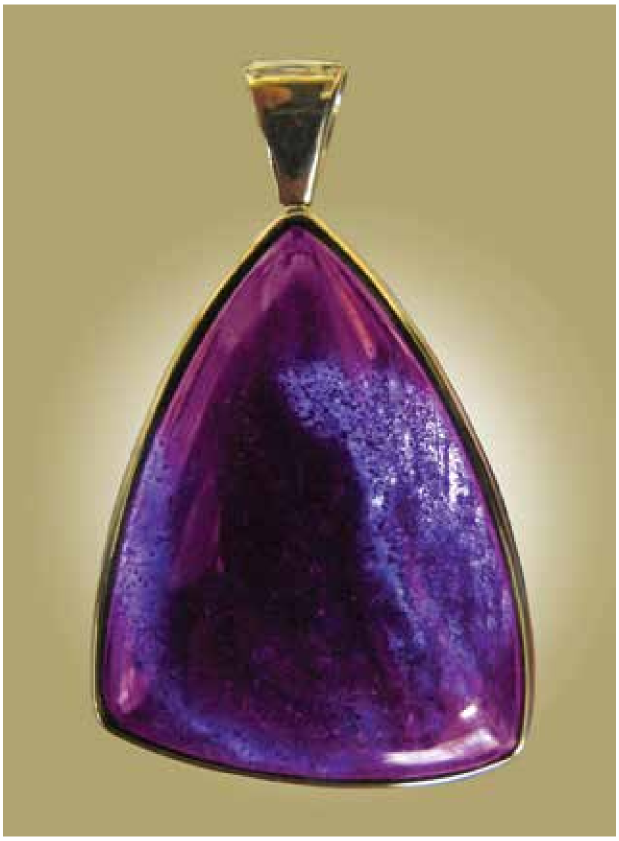

Figure 17.5. **Polished cabochon of cosmic iolite from Springvale displaying brilliant violet-purple transmitted light. Cabochon is approximately 25 mm at its widest point (courtesy Craig Rugless and Barry Kayes)**

References

Barrett, FM 1989, Annual report on exploration licence 80/746 (Springvale) for period October 6, 1988 to October 5, 1989, Geopeko Pty Ltd: Geological Survey of Western Australia, Statutory mineral exploration report, A29513 (unpublished).

Geology.com 2015, Cordierite and the gem known as 'iolite', viewed 28 August 2015, <http://geology.com/minerals/cordierite.shtml>.

Hoatson, DM and Blake, DH (editors) 2000, Geology and economic potential of the Palaeoproterozoic layered mafic–ultramafic intrusions in the East Kimberley, Western Australia: Geoscience Australia, Canberra, Bulletin 246, 469p.

Rugless, CS 2015, Springvale project, E80/4753, Western Australia. Annual Report for the period ending 15th May 2015: Pathfinder Exploration Pty Ltd, Report to Department of Mines and Petroleum, 2015, 22p (confidential).

Tyler, IM, Hoatson, DM, Griffin, TJ, Sheppard, S, Blake, DH and Warren, RG 1997, McIntosh, Western Australia, Sheet 4462, Geological Survey of Western Australia, 1:100 000 Geological Series.

Chapter 18

Corundum

Corundum gemstones

Corundum is aluminium oxide (≤99% Al_2O_3) with traces of iron (Fe^{3+} and Fe^{2+}), chromium, and titanium replacing the aluminium. Other trace elements present may include nickel, vanadium, cobalt, and gallium.

Most commonly corundum occurs as a metamorphic mineral in aluminous rocks, particularly metasedimentary rocks such as mica schists, although it also occurs in silica-poor undersaturated igneous rocks with feldspathoids and in aluminous xenoliths in igneous rocks. Corundum, as opaque and subtranslucent barrel-shaped crystals, is recorded from metasedimentary rocks, basic xenoliths, and many eluvial finds from several sites within Western Australia.

Corundum, notably as emery, is used as an industrial mineral, although it is best known in gemmology as the important gem varieties ruby and sapphire.

It is an allochromatic mineral, and would be colourless if it did not contain trace amounts of elements, particularly chromium, iron, and titanium, which impart colour. Traditionally, there are two significant gem varieties of corundum: the red variety, termed ruby, contains chromium; while the blue, green, and yellow colours of sapphire are caused by the presence of iron and titanium. Sapphire is commonly considered to be blue; other colours are described with an additional prefix, for example yellow and green sapphires. Red gem corundum is always called ruby.

Well-formed crystals of corundum, particularly sapphire, commonly form a general prismatic habit that is hexagonal in section and combined with 12 tapering faces, six above and six below. Viewed at right angles to the long dimension of crystals, hexagonal growth zoning is commonly apparent (Fig. 18.1).

Some crystals of sapphire and ruby contain geometric patterns of minute inclusions of exsolved fine acicular rutile. Gems that are fashioned in the correct orientation relative to specific crystal directions may produce chatoyancy or a six- or 12-ray star phenomenon.

Historically the most important sources for ruby have been Burma (Myanmar), Afghanistan, and Sri Lanka although ruby is now sourced from many other countries including Thailand, Madagascar, and Tanzania.

Corundum
Aluminium oxide Al_2O_3

Blue sapphire from the Kashmir region of India and from Burma are considered the most desirable and valuable. Many other countries including the US, Laos, Vietnam, Madagascar, Malawi, and Australia produce sapphire. Until recently eastern Australia was the largest producer of yellow, green, and blue sapphires, mining 75% of world supply. Current production has now decreased to about 25% of world supply (Abduriyim et al., 2012).

Various treatments have been used to improve the appearance of all colours of gem sapphires and rubies. However, as with all gems, the most valued are those that can be proven to be untreated.

All colour varieties of corundum gems have been manufactured; ruby was first manufactured in 1902 and used as small bearings in watch movements. Currently synthetic sapphire and ruby are used in applications from scratch-resistant watch glasses to lasers.

Physical properties of corundum

Crystal system	Trigonal, rhombohedral
Habit	Barrel-shaped prismatic crystals common, also tabular rhombohedral
Twinning	Common rhombohedral lamellar
Colour range	Large range of colours — grey, brown, white, colourless, blue, red, green, yellow, and orange
Lustre	Adamantine to vitreous
Diaphaneity	Transparent to translucent
Refractive index	1.75 – 1.77
Birefringence	0.016
Hardness	9 (Mohs scale standard mineral)
Specific gravity	3.95 – 4.10
Fracture	Uneven to conchoidal
Cleavage	Poor
Fluorescence	Unless quenched by iron, ruby displays strong red fluorescence in long-wave ultraviolet (UV) light

Figure 18.1. **Cabochon-cut sapphires from the Pilbara, showing hexagonal zoning. Cabochons are up to 18 mm in length (courtesy Bill Moriarty)**

Corundum gemstones in Western Australia

Although Simpson (1951) records numerous occurrences of corundum in Western Australia, several hosting well-formed crystals, there are few sites where corundum in coloured, translucent forms (such as sapphire) suitable for cabochons has been found.

Gascoyne Province

Gascoyne Junction region

Williambury Station prospect (*Lyndon, 1950*)

A decorative rock with bladed blue sapphire (Fig. 18.2) has been investigated on Williambury Station, approximately 200 km northeast of Carnarvon and 90 km north of Gascoyne Junction (Fig. 18.3). Access is via the Mount Sandiman – Williambury Road and four-wheel drive tracks.

The sapphire crystals form bladed sheaves, individual crystals, and fragments intergrown and associated with muscovite. The sapphires are opaque and vary in colour from a dark to medium blue, some with a violet hue, reminiscent of lapis lazuli. Selected sapphires were heat treated in Bangkok although no colour improvement was noted (Themelis, 2010). The rock is potentially suitable for ornamental purposes, although there are problems with polishing.

Pilbara Craton

Wodgina area

Pincunyah prospect (*Wodgina, 2655*)

Purple-grey translucent corundum crystals have been collected from an area approximately 100 km south of Port Hedland, between the Mount Newman railway line and the southern branch of the Turner River (Fig. 18.3). This unconfirmed locality is likely to be within high-grade Archean metasedimentary rocks. Figure 18.1 shows cabochons cut from this material; all have been cut to display hexagonal zoning of the crystals.

Simpson (1951) records similar corundum crystals from about 8 km north of the Abydos Station Homestead. He collected several specimens from this location; these are now housed in the Western Australian Museum collection (WAM 6030–6037). The host rock is chlorite–biotite schist.

Yilgarn Craton — Narryer Terrane

Mardagee Station area

Thoolmugga Well (*Byro, 2145*)

Several eluvial corundum occurrences were found overlying amphibolite to lower granulite facies banded gneiss, calc-silicate gneiss, and mafic granofels after layered mafic bodies (Fig. 18.3; Williams et al., 1983).

Corundum crystals up to 80 mm long have a bronze chatoyancy and are strongly zoned. The crystals are rimmed by hercynite (spinel) and many have weak magnetism attributed to inclusions of ilmenite and magnetite. The largest of several eluvial deposits is 0.5 ha in area and situated 4 km east of Thoolmugga Well north of the Byro – Milly Milly Road. There is no record of any corundum having been cut from these sites.

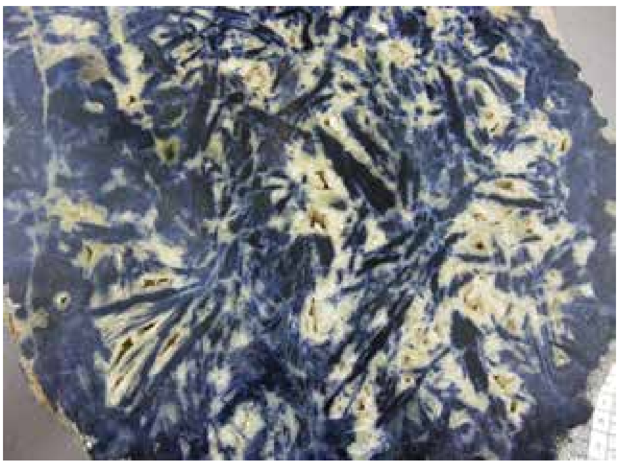

Figure 18.2. **Decorative rock with sapphire crystals in matrix, Williambury Station. Specimen is 12 cm in diameter (courtesy Barry Kayes)**

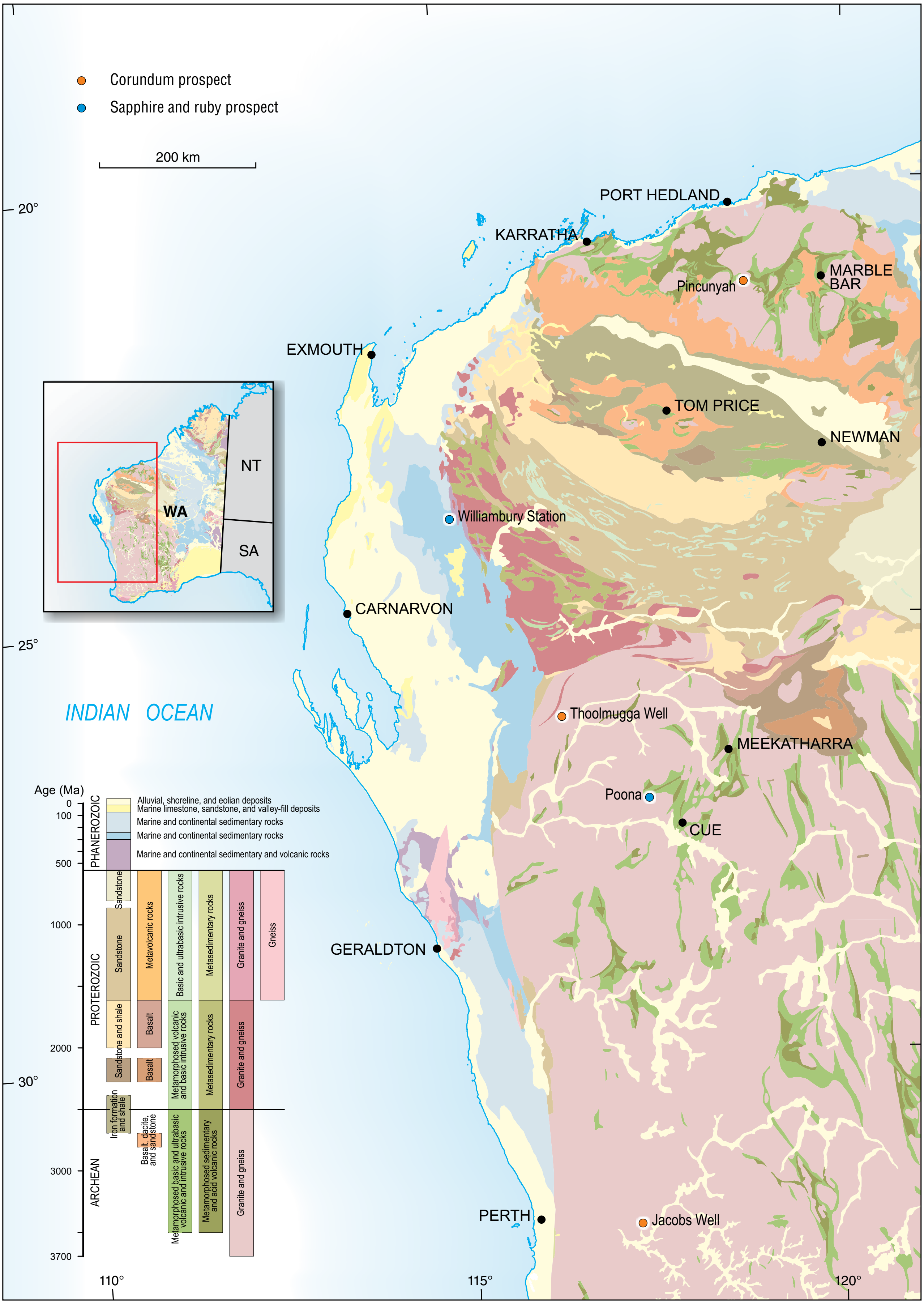

Figure 18.3. Locations of corundum mineral prospects in Western Australia

Yilgarn Craton — South West Terrane

Quairading area

Jacobs Well (*Brookton*, 2333)

Geological Survey of Western Australia (1994) records an interesting occurrence of translucent blue corundum at Jacobs Well approximately 15 km west of Quairading in the southwest of the State. No further information is given, although Simpson (1951) makes the following observations.

The Jacobs Well eluvial deposit contained rounded and subangular corundum pebbles with strong rhombohedral twinning and parting. Crystals were up to 120 mm in diameter with the largest found weighing 300 g. Most crystals were grey to greyish-lilac, and all were of low translucency and crowded with corrosion cavities.

Finer corundum fragments 1–10 mm in diameter were recovered from the underlying clay; these were described as blue with the centres almost colourless and more translucent than the blue crust.

Yilgarn Craton — Murchison Domain

Cue region

Poona (*Noondie*, 2343; *Cue*, 2443)

Some portions of the emerald-bearing phlogopite rock at Poona contain a group of minerals that were formed as part of the emerald paragenesis (Fig. 18.3). These minerals include topaz, fluorite, alexandrite, and small fragments of ruby and sapphire. The corundum (ruby and sapphire), chrysoberyl (alexandrite), and beryl (emerald) were formed at the border between greisen zones and phlogopite rock during the upper greenschist to lower amphibolite metamorphic event. The alexandrite and ruby and sapphire only exist as small crystals and are not of facetable size.

According to Grundmann and Morteani (1998) the sapphires are rarer and smaller than the rubies. Subhedral to euhedral corundum crystals commonly display tabular habit and commonly form subparallel or radial aggregates. Individual crystal sizes are 1–5 mm in length; in some instances platy crystals have a diameter of up to 10 mm. Colourless or dark blue sapphire is found in irregular patches, commonly in the centre of ruby crystals. Ruby and sapphire fragments are shown in Figure 18.4.

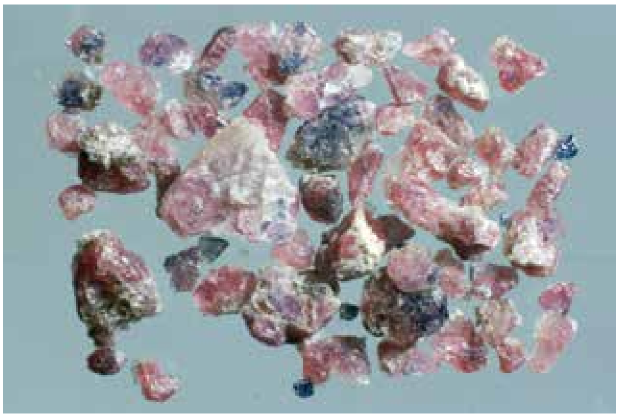

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Figure 18.4. Small fragments of ruby and sapphire from Poona. Maximum particle size is approximately 5 mm (courtesy Guilio Morteani)

References

Abduriyim, A, Sutherland, FL and Coldham, T 2012, Past, present and future of Australian gem corundum: The Australian Gemmologist, v. 24, no. 10, p. 234–242.

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, Perth, Western Australia, 52p.

Grundmann, G and Morteani, G 1998, Alexandrite, emerald, ruby, sapphire and topaz in a biotite–phlogopite fels from Poona, Cue District, Western Australia: Australian Gemmologist, v. 20, no. 4, p. 159–167.

Simpson, ES 1951, Minerals of Western Australia, volume 2: Government Printer, Perth, Western Australia, 675p.

Themelis, T 2010, The heat treatment of ruby and sapphire, 2nd edition: Private publication, p. 223–224.

Williams, IR, Walker, IM, Hocking, RM and Williams, SJ 1983, Byro, Western Australia SG50-10 1:250 000: Geological Survey of Western Australia, Geological Series Explanatory Notes, 27p.

Chapter 19

Copper gemstones

Copper gemstones comprise four secondary copper minerals: blue-green turquoise, which commonly occurs in veins in association with altered, aluminous igneous or sedimentary rocks, and green malachite, deep blue azurite, and blue chrysocolla, which typically form in oxidized zones of copper deposits.

Turquoise

Turquoise is a soft, opaque mineral that ranges in colour from blue-green to yellow-green with grey, black, or brown veining. It characteristically forms as a cryptocrystalline mineral and single crystals are extremely rare. Physical properties, including porosity, are determined by grain size with specific gravity and hardness both showing considerable ranges.

Turquoise is a secondary mineral, formed by the action of percolating acidic water on primary copper minerals during weathering. Typically it is found as vein or fracture filling and is nodular or botryoidal in form. The blue-green colour is derived from copper.

Turquoise is one of the oldest gemstones used for personal adornment. It features in many cultures since at least 3000 BCE, including the Egyptian, Persian, Aztec, and Chinese cultures.

Good-quality, fine-grained turquoise is rare and expensive. It is commonly impregnated with epoxy resins, colourless oil, or wax to stabilize and improve its colour and increase durability. Imitations of turquoise are common and much ‘turquoise’ jewellery and beads commonly offered for sale are dyed magnesite or howlite (a calcium borate). Turquoise may also be imitated using other natural minerals of similar colour, such as chrysocolla and hemimorphite (zinc silicate). Optical verification of some of these minerals can be difficult.

Copper gemstones

Turquoise — hydrous copper aluminium phosphate $CuAl_6(PO_4)_4(OH)_8.4H_2O$

Malachite — copper carbonate $Cu_2CO_3(OH)_2$

Azurite — copper carbonate $Cu_3(CO_3)_2(OH)_2$

Chrysocolla — hydrous copper silicate $(CuAl)_2Si_2O_5(OH)_4.nH_2O$

Physical properties of turquoise

Crystal system	Triclinic
Habit	Cryptocrystalline crystal aggregates, and nodular and botryoidal encrustations
Colour range	Blue-green and green
Colour cause	Copper
Lustre	Vitreous to waxy
Diaphaneity	Opaque
Refractive index	Spot test — 1.62 (mean)
Birefringence	0.040
Hardness	5–6
Specific gravity	2.6 – 2.9
Fracture	Conchoidal
Cleavage	Good
Processing and display	Commonly fashioned together with host matrix material in lapidary applications

Turquoise in Western Australia

Yilgarn Craton — Eastern Goldfields Superterrane

Kalgoorlie region

Lake Yindarlgooda copper–zinc prospect
(Kanowna, 3236)

An un-named copper–zinc prospect on the edge of Lake Yindarlgooda, about 47 km east-northeast of Kalgoorlie and about 4 km west of the Queen Lapage gold mine (Fig. 19.1), is the probable site of a minor occurrence of turquoise associated with quartz-filled joints in Archean tuffaceous rocks (Williams, 1973). The veinlets of turquoise are thin and only suitable for cutting small stones (Fig. 19.2).

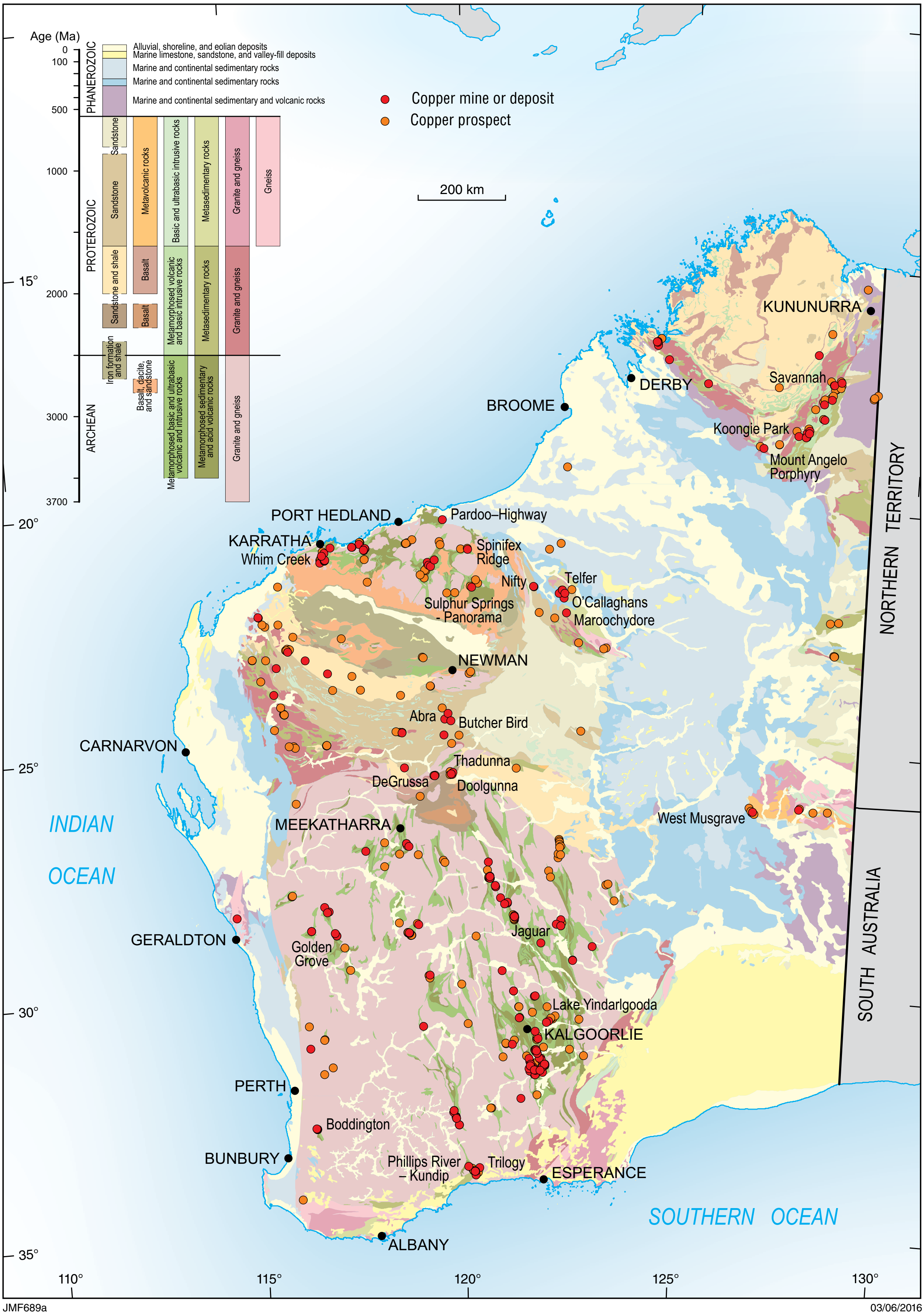

Figure 19.1. Locations of copper deposits and prospects in Western Australia (modified after Geological Survey of Western Australia, 2012)

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Figure 19.2. Collection of blue-green turquoise cabochons from the copper–zinc prospect at Lake Yindarlgooda, Kalgoorlie region. The largest cabochon is 17 mm wide (courtesy Charles East)

Malachite, chrysocolla, and azurite

Malachite and chrysocolla

Malachite and chrysocolla are secondary copper minerals formed in the oxide zone of many copper deposits in Western Australia where they are commonly associated with azurite. Malachite has a green colour of varying intensities ranging from light to dark, and produces a green streak. Chrysocolla can vary in colour from green to bluish-green and light blue, and produces a white streak.

Malachite is relatively soft although the stone is competent, with a hardness of 3.5 – 4 and typically occurs as massive to banded, botryoidal encrustations; crystals are less common. Western Australia has none of the spectacular ornamental malachite of the type found in the 19th century at Nizhne-Taglisk, in the Ural Mountains, Russia. This material is featured in its massive form as table tops and columns displayed in Russian museums. In more recent times, in central Africa, areas in the Democratic Republic of the Congo (formerly Belgian Congo), and in adjoining Zambia at the Bwana Mkubwa mine, have been major sources of massive malachite (Fig. 19.3a).

In South Australia, the Burra Burra mine at Burra is well known as a classic locality for fine-quality malachite. Copper ore was discovered at the site in 1845 and during the 30 years of its production about 700 000 tons of ore was mined. Malachite, commonly of gem quality, was the main copper ore in the upper part of the oxidized zone where it occurred in large masses and breccia fillings. It is stated that many thousands of tons of gem-quality malachite were smelted as copper ore (Grguric et al., 1994).

Green-banded malachite remains a popular ornamental gemstone with lapidaries and is used to make small, carved *objets d'art*, inlay work, and cabochon-cut items for jewellery such as cufflinks, pendants, and brooches (Fig. 19.3b).

Chrysocolla is softer than malachite, with a hardness of 2–4 and most typically forms as botryoidal encrustations or vein fillings (Fig. 19.4). It is commonly cryptocrystalline with a translucent opal- or enamel-like texture, and its colour is commonly light blue. Micro-acicular chrysocolla crystals are rare. For lapidary applications, chrysocolla is commonly used as an ornamental stone together with other copper minerals in its natural, silicified matrix (Fig. 19.5). Like turquoise, chrysocolla may be used as resin-treated material to prevent discolouration and deterioration.

Physical properties of malachite, chrysocolla, and azurite

	Malachite	Chrysocolla	Azurite
Crystal system	Monoclinic	Orthorhombic	Monoclinic
Habit	Massive, botryoidal, banded, light and dark green, also fine tufts and rosettes of acicular crystals	Compact, botryoidal, microcrystalline, rarely as acicular crystals	Fine, acicular crystal aggregates, rarely as massive crystals
Colour range	Characteristic colour is light to dark green	Bright green, bluish-green, light blue	Characteristic colour is azure blue
Streak	Green	White	Blue
Colour cause	Copper	Copper	Copper
Lustre	Vitreous to silky	Greasy, earthy to vitreous	Vitreous; also dull and earthy
Diaphaneity	Opaque to translucent	Opaque to translucent	Transparent
Refractive index	1.65 – 1.90	Spot test — 1.50 (mean)	1.73 – 1.84
Birefringence	0.025	Variable optical character	0.110
Hardness	3.5 – 4	2	3.5 – 4
Specific gravity	3.9 – 4.03	2.0 – 2.4	3.77 – 3.89
Processing and display	Carvings, cabochons, beads, and inlay work	Often used together with its matrix minerals	Carvings, cabochons, beads, and inlay work
Mineral association	Other secondary copper minerals	Other secondary copper minerals	Other secondary copper minerals

Azurite

Azurite is a characteristically azure blue mineral although it also exists in other blue colours. Azurite is an idiochromatic gemstone, so-called as its colour is determined from its essential copper composition. It is rarely found as discrete crystals as seen in the highly collectable and valuable azurite crystals once found at the Tsumeb mine in Namibia. Most commonly azurite is found as delicate, fine acicular (needle-like) crystal aggregates together with malachite within secondary, copper-oxide zones (Fig. 19.6).

Malachite, chrysocolla, and azurite in Western Australia

These secondary copper minerals are found in many Western Australian copper deposits and occurrences are too numerous to mention individually. A map showing the distribution of copper deposits and prospects in the State is shown in Figure 19.1. Some of these orebodies may have associated secondary copper minerals suitable for gemstone applications.

Secondary copper minerals are mostly found as thin surface coatings or smears on joint, fracture, or bedding surfaces and, as such, are not suitable for lapidary work. More massive secondary copper mineral specimens may also be unsuitable for lapidary work for a variety of reasons including contamination with other minerals and brittle fracture. Many of these minerals, set in their original matrix, may make attractive polished stone tiles or spectacular natural specimens and micro-mounts (mounted mineral specimens that require magnification of 10–40× for proper appreciation). Examples of more massive secondary copper minerals of this type may be seen on the small mullock heap at the old Butcher Bird mine about 80 km north of the Kumarina Roadhouse on the Great Northern Highway south of Newman (Fig. 19.7). This situation also applies to the spectacular specimens recently found at the DeGrussa project, discussed below.

Recently, a silicified form of chrysocolla from the DeGrussa mine in the Peak Hill Mining District was trialled as a polished gem material in which the visually attractive, blue, radiating chrysocolla incorporated small cavities infilled by chalcedony (Fig. 19.5).

Bryah Basin

Peak Hill region

DeGrussa copper mine (Doolgunna, 2746)

The DeGrussa copper–gold deposits are about 10 km east of the Great Northern Highway, about 140 km north-northeast of Meekatharra (Fig. 19.1). Deposits in this area are within the Bryah Basin (2014–1920 Ma), one of several Paleoproterozoic depositional basins in the central part of the Capricorn Orogen, a major tectonic unit between the Archean Pilbara and Yilgarn Cratons (Fig. 1.1 in Chapter 1 on introduction to gemstones in Western Australia).

Figure 19.3. Examples of malachite ornaments and jewellery: a) carved and polished hippopotamus ornament in green-banded malachite from Zambia; b) antique malachite and gold brooch with a central oval plaque of malachite displaying characteristic banded growth texture. Sourced from the South Australian copper mines. Attributed to Charles Edward Firnhaber from Adelaide, c. 1870. Weight 39 g, height 59 x 50 mm wide (courtesy Museum Board of South Australia, Minerals collection no. G34198; photography Diego Garcia)

Figure 19.4. Botryoidal encrustations of blue chrysocolla forming a cavity wall lining. DeGrussa copper–gold deposit, Peak Hill region (courtesy Sandfire Resources NL)

Figure 19.5. (right) Silicified form of blue chrysocolla from the DeGrussa mine, Peak Hill region. The specimen displays small cavities infilled by chalcedony within the radiating chrysocolla texture (courtesy Sandfire Resources NL)

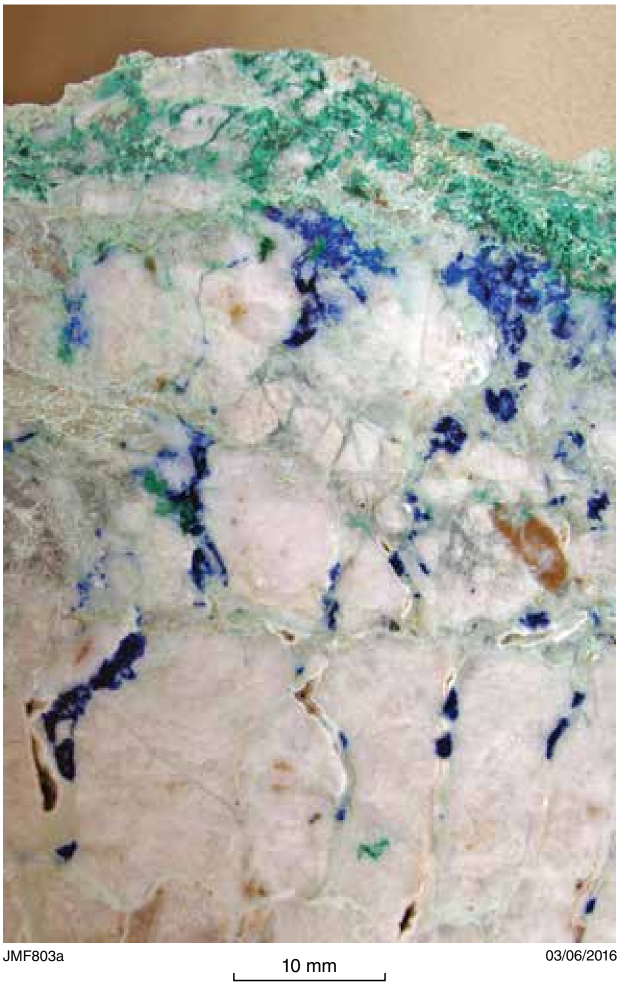


Figure 19.6. Blue azurite veins and other green copper minerals in quartz host rock from the Thadunna copper prospect, Neds Creek Station (courtesy Barry Kayes)

The DeGrussa deposits were discovered in 2009 by Sandfire Resources NL in the northeastern part of their Doolgunna mining lease M52/1046. Drilling established substantial resources of copper–gold comprising four lenses of high-grade, copper-rich, massive sulfide mineralization that are called Conductor 1, DeGrussa, and Conductors 3 and 4, and which extend for more than 6 km with the prospect of more discoveries.

At the DeGrussa mine, base metal and gold mineralization is hosted in the Karalundi Formation, a 2 km-thick succession of volcanogenic and sedimentary rocks extending over a strike length of 22 km (Hawke et al., 2015; Pirajno, 2016). This succession comprises basalts, hyaloclastites, siliciclastic sedimentary rocks, dolerite, gabbro, and minor mineralized quartz–carbonate breccias, jasper, and banded iron-formation.

At DeGrussa, volcanic-hosted massive sulfide ores are present as very large lenses of primary pyrite, chalcopyrite, and pyrrhotite with minor magnetite, sphalerite, galena, and arsenopyrite. The base of the massive sulfide is chalcopyrite-rich together with magnetite, passing upwards into iron sulfides with decreasing copper and increasing zinc contents. Gold is associated with the chalcopyrite-rich zones and occurs as electrum with a high silver content.

The oxide mineralization is vertically above Conductor 1 and DeGrussa lenses. Beneath a hardpan cap there is about 80 m of weathering over the sulfide lenses. Within the weathering profile is an upper residual, gold–oxide zone overlying an oxide–copper zone. The oxide–copper zone contains malachite, chrysocolla, native copper, minor cuprite, tenorite, and rare mcguinnessite. A secondary supergene chalcocite blanket lies beneath the oxide–copper zone and directly above fresh primary sulfides (Fig. 19.8).

This complex, multi-stage mineralogical overprinting in the oxide zone results in a huge diversity of mineral species, giving what is called a 'mineralogical rainforest'. Malachite is present as large, radiating masses of silky, acicular, crystalline clusters and other specimens display narrow zones of azurite bordering the malachite (Fig. 19.9). Carbonate alteration gives rise to aragonite crystals, some large enough to be faceted (see Chapter 28 on the carbonate group). Late-stage silicification forms turquoise-blue chrysocolla, commonly replacing the malachite, and white to colourless chalcedony and drusy quartz.

Recently, several copper-bearing matrix specimens were trialled as polished sections, cabochons, and spheres of various sizes (Figs 19.10 and 19.11). These brightly coloured items feature:

- silicified chrysocolla
- chrysocolla with malachite
- azurite and red iron oxide matrix
- copper-bearing dolomite
- silicified copper-bearing dolomite
- matrix specimens containing grains of native copper, tenorite, and cuprite.

Because of the fragile nature of specimens with microsized, mineral-filled cavities, cabochons and polished slabs are stabilized with resins prior to cutting while the mixed copper oxide, carbonate, and silicate minerals from the oxide zones pose problems for sphere cutters and polishers.

Figure 19.7. **Broken clasts of green secondary copper minerals exposed in a 3 m section of mullock heap at the old Butcher Bird mine in the Yanneri Pool area, south of Newman**

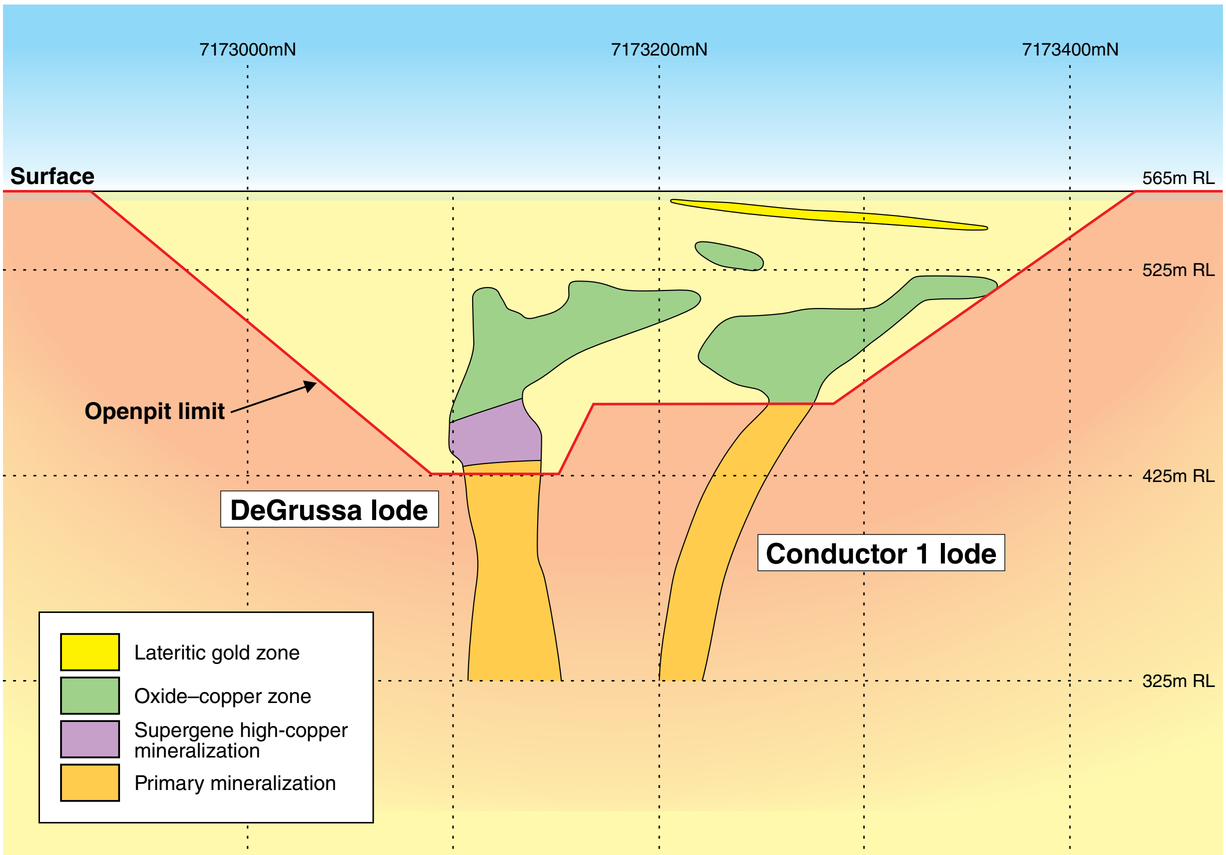
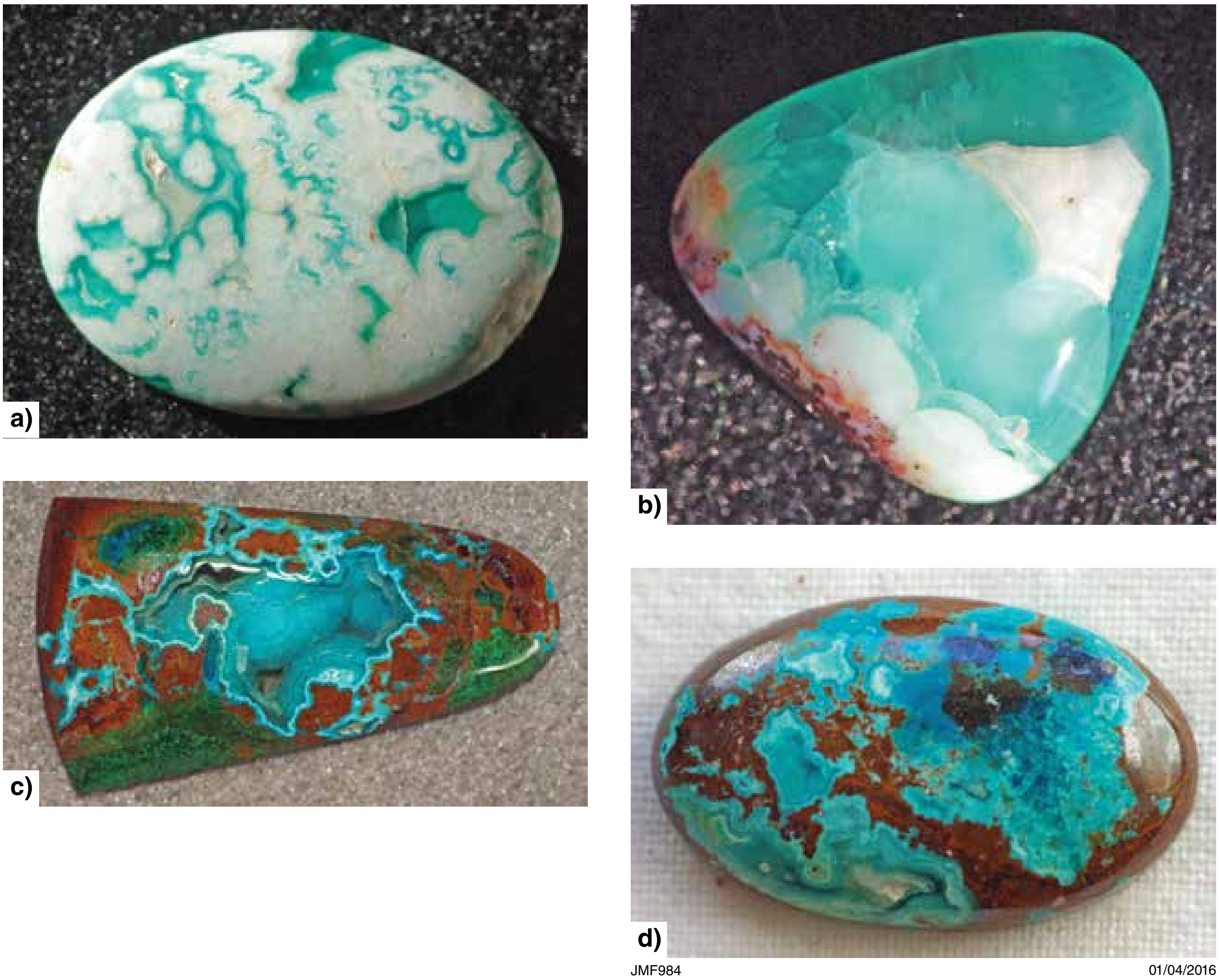


Figure 19.8. **Schematic cross-section of the DeGrussa openpit showing the lateritic gold, oxide–copper, and chalcocite zones overlying the Conductor 1 and DeGrussa sulfide lodes (modification of cross-section courtesy Sandfire Resources NL)**

Figure 19.9. **(left) Large, radiating masses of green, acicular crystalline clusters of malachite, together with white calcite, DeGrussa mine (courtesy Sandfire Resources NL)**

Figure 19.10. **(below) Selection of copper mineral cabochons and polished plaques from the DeGrussa mine: a) silicified chrysocolla cabochon 25 x 18 mm; b) white and blue-green copper-bearing dolomite; c) copper secondary minerals displaying a chrysocolla druse in a matrix of malachite and iron minerals (length 40 mm); d) copper matrix cabochon 24 x 15 mm containing chrysocolla, native copper, tenorite, and iron minerals (courtesy Sandfire Resources NL)**



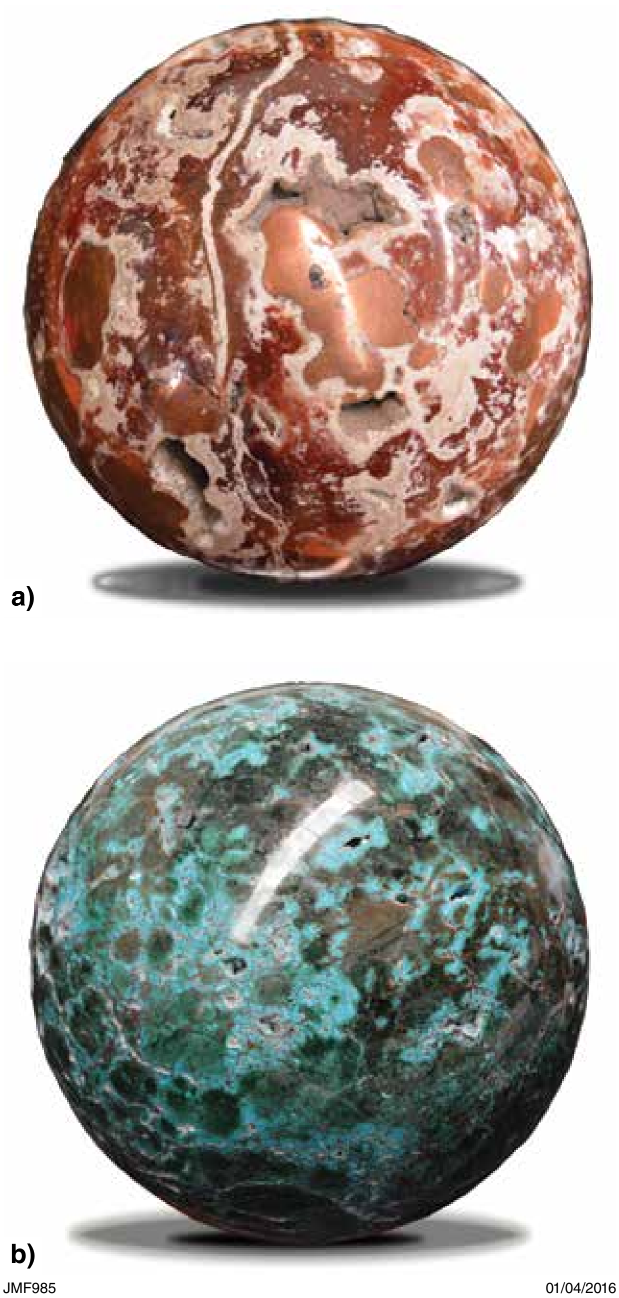


Figure 19.11. Large polished spheres of copper minerals: a) sphere displaying large, irregular masses of native copper, diameter approximately 20 cm; b) sphere displaying brightly coloured, secondary copper minerals, mainly chrysocolla and malachite, diameter approximately 30 cm (courtesy Sandfire Resources NL)

References

Geological Survey of Western Australia 2012, Investment opportunities — Copper: Geological Survey of Western Australia, Data sheet, 2p.

Grguric, B, Pring, A and Drew, G 1994, The Burra Burra Mine, Burra, South Australia: Mineralogical Record v. 25, no. 2, p. 121–129.

Hawke, M, Meffre, S, Stein, H, Hilliard, P and Large, RR 2015, Geochronology of the DeGrussa volcanic-hosted massive sulphide deposit of associated mineralisation of the Yerrida, Bryah and Padbury Basins, Western Australia: Precambrian Research, v. 267, September, p. 250–284.

Pirajno, F 2016, A classification of mineral systems, overviews of plate tectonic margins and examples of ore deposits associated with convergent margins: Gondwana Research, v. 33, p. 44–62.

Williams, IR 1973, Kurnalpi: Bureau of Mineral Resources, Explanatory Notes, 37p.

Chapter 20

Diopside

Diopside, a calcium–magnesium silicate of the pyroxene group, is of widespread occurrence as a mineral component of metamorphosed siliceous limestones, dolomites, and calc-silicates (skarns). In calc-silicate rocks diopside may be associated with other calcium minerals such as epidote, apatite, titanite, grossular garnet, and scapolite.

Diopside properties and applications

Diopside is the magnesium-bearing end member in the isomorphous diopside–hedenbergite series. Progressive substitution of magnesium by iron within the series results in more intense colours and higher values of refractive index and specific gravity. Diopside has a prismatic habit and varies in colour from colourless through various shades of light and intense green, the most attractive of which is an intense deep green that is partially caused by trace amounts of chromium.

Chromium diopside occurs in ultramafic rocks, including kimberlites, and is an indicator mineral in diamond exploration. It is also one of a large complement of micro-minerals that may be found as inclusions within diamonds.

Rocks containing large crystals of diopside and other pyroxenes (e.g. augite) may display reflection shimmer effects as they commonly contain crystallographically orientated exsolved iron minerals.

Diopside, particularly chromium diopside, is used in jewellery as a green faceted gem. Another variety of diopside is a dark green to black variety, with its dark appearance caused by inclusions of exsolved magnetite. When cabochon cut, this type may display a four-ray star phenomenon. This high-quality material originates from India and is one of the few magnetic gems, as a result of its magnetite inclusions.

Diopside
Calcium–magnesium silicate $CaMg(SiO_3)_2$

Diopside in Western Australia

Simpson (1951) described diopside as a mineral component in many different rock types throughout the State. In particular, diopside-rich rocks, with some potential as ornamental stones, were found in coarse-grained intrusive rocks similar to pegmatites, many displaying schlieren-like structures. At an unknown locality in the Wadgingarra area, northeast of Yalgoo, individual diopside crystals up to 75 mm in length were found in very coarse-grained, pegmatite-like rocks.

There is one recorded occurrence of gem-quality diopside in Western Australia, in the Yinnetharra area.

Physical properties of diopside from Yinnetharra

Crystal system	Monoclinic
Habit	Prismatic
Colour range	Colourless, to light and dark green
Colour cause	Iron
Lustre	Vitreous (glassy)
Diaphaneity	Transparent to translucent
Refractive index	1.675 – 1.704
Birefringence	0.027 – 0.028
Pleochroism	Yellow-green to olive-green, and dark green of moderate intensity
Hardness	5–6
Specific gravity	3.32
Cleavage	Well-developed prismatic
Fluorescence	Inert in ultraviolet (UV) light
Absorption spectrum	Weak absorption band at 520 nm, general absorption at both red and violet spectral ends

Gascoyne Province

Gascoyne Junction region

Vaughan prospect (Yinnetharra, 2148)

Gem-quality green diopside was discovered by prospector David Vaughan at Thirty One River, 13 km west-northwest of Morrissey Hill in the Yinnetharra area. In 1995, the prospect was investigated by Doedens (1997).

The Vaughan diopside prospect is on an isolated, low hill, west of Thirty One River (Fig. 20.1). Doedens (1997) described the deposit as a calc-silicate lens containing massive diopside probably formed during high-grade amphibolite facies metamorphism. The diopside lens is overlain by a siliceous regolith caprock (silcrete).

The siliceous caprock, developed from a highly weathered soil profile, was found to contain the highest concentration of gem-quality diopside crystals. It is likely that weathering processes concentrated the most resistant diopside crystals and these were ultimately cemented within the silcrete.

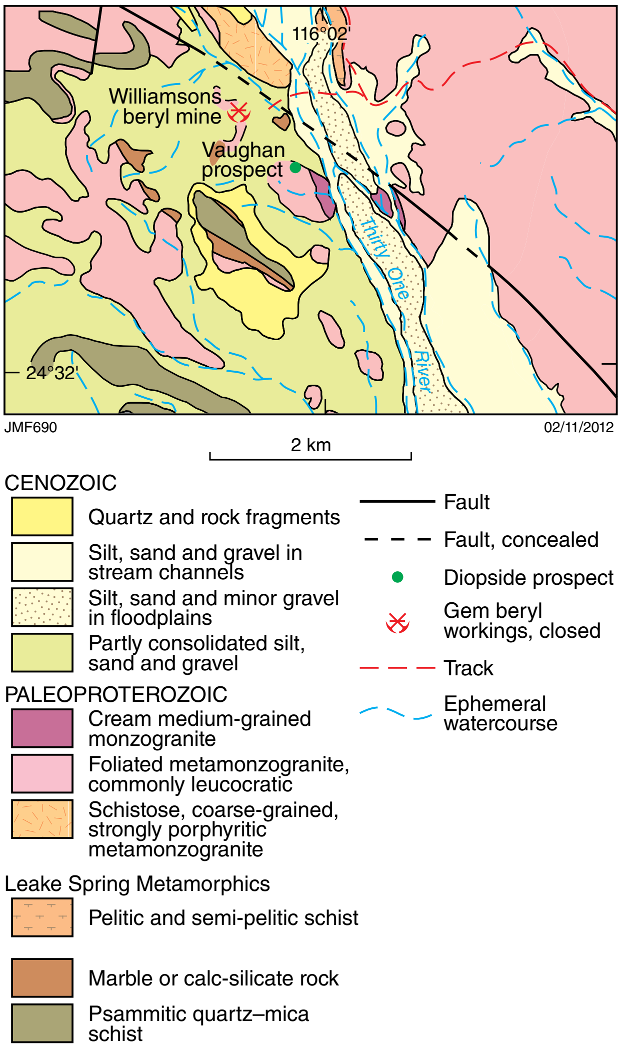


Figure 20.1. Geology of the area around the Vaughan diopside prospect, Yinnetharra area (modified after Sheppard et al., 2008)

In geologically recent times, the diopsidic lens has been partially weathered and it was found that crystals could be easily removed from the rock matrix by the use of hand tools. The largest diopside crystal found was doubly terminated although fractured, and measured 59 × 35 × 24 mm. Most crystals recovered had a length of about 20 mm. The operation yielded gem-quality rough crystals-in-matrix in excess of 100 ct and the transparent material was subsequently faceted (Fig. 20.2).

Properties of the diopside from the Vaughan prospect are recorded in the highlight box in this chapter. Note that the figures given for ranges of refractive index and specific gravity are at the higher end of established ranges and may indicate the diopside chemistry is moving towards hedenbergite (iron end member). Other observations include: most mineral inclusions and internal features are prismatic crystallites (possibly amphibole), 'healed' fractures are orientated with cleavage planes, secondary iron staining is present in cleavages, and growth tubules are evident. Also, the distinctive high birefringence of the diopside was apparent from doubling of the facet edges.

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Figure 20.2. Faceted, green diopside gemstone with several rough diopside prisms from the Vaughan prospect. The gemstone is 6.21 ct and measures 14 x 8 mm (courtesy Gemrock Enterprises)

References

Doedens, F 1997, An occurrence of gem-quality diopside, Yinnietharra Station, Western Australia: The Australian Gemmologist, v. 19, no. 9, p. 380–382.

Sheppard, S, Johnson, SP, Groenewald, PB and Farrell, TR 2008, Yinnetharra, WA, Sheet 2148: Geological Survey of Western Australia, 1:100 000 Geological Series.

Simpson, ES 1951, Minerals of Western Australia, volume 2: Government Printer, Perth, Western Australia, p. 143–151.

Chapter 21

Fluorite

Fluorite properties and applications

The mineral fluorite, also known as fluorspar, is glassy and translucent to transparent. In crystalline form, fluorite displays a wide range of colours from colourless to yellow, blue, purple, green, rose, red, purplish-black, and brown, commonly appearing as contrasting coloured bands. Fluorite may form cubes or more rarely octahedra and dodecahedra. It also occurs as massive and earthy forms, and as crusts or globular aggregates with radial fibrous texture (Fig. 21.1). Massive banded blue, violet, and purple fluorite from Derbyshire in England ('Blue John') has been fashioned as vases, vessels, and other *objets d'art* since Roman times. Natural fluorite is commonly associated with other minerals such as quartz, barite, calcite, galena, siderite, celestine, sphalerite, chalcopyrite, other sulfides, and phosphates.

Physical properties of fluorite

Crystal system	Isometric (cubic)
Habit	Cubic, octahedral, and massive
Colour range	Colourless, blue, green, pink, and violet, commonly as banded colours
Lustre	Subvitreous; less commonly dull
Diaphaneity	Transparent to translucent
Refractive index	1.43 – 1.44
Hardness	4 (Mohs scale standard mineral)
Specific gravity	3.0 – 3.2
Fracture	Irregular and conchoidal
Cleavage	Perfect octahedral in four directions, easily developed
Fluorescence	Commonly shows a blue or green response under long-wave ultra-violet (UV) light, and weaker glow under short-wave UV; some fluorite is inert

Fluorite
Calcium fluoride CaF_2

Under ultraviolet light, some fluorite displays yellow, green, blue, and violet fluorescence. Strong fluorescence may be associated with relatively high contents of rare earth elements including europium, lanthanum, cerium, and yttrium. The yellow fluorescence of brown fluorite is considered to be caused by inclusions of organic material.

Figure 21.1. Forms of fluorite: a) transparent, colourless mass of euhedral, cubic crystals up to 10 x 10 mm; b) massive form displaying contrasting purple and pale greenish bands; specimen is 5 cm wide

Fluorite cleaves readily although cleavage surfaces are rarely perfect and marked by terracing, which results in a stepped effect that makes it unsuitable for small gem cutting. Also, the hardness is far too low to resist abrasive wear encountered by jewellery items. Fluorite is manufactured into beads and cabochons, and is carved as small items (Fig. 21.2). As with calcite, fluorite is typically faceted only by collectors.

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Figure 21.2. Ornamental applications for fluorite: a) bunch of grapes carved from banded fluorite in various shades of purple and pale mauve; b) fluorite pendant mounted in silver wire (height 50 mm). The fluorite was sourced from an unknown locality west of Cue (courtesy Dorothy Netherway)

Fluorite deposition environments

Fluorite exists in a wide variety of geological environments with significant concentrations in areas of gravity lows and high heat flow. Abeysinghe and Fetherston (1997) recorded seven main modes of occurrence:

- fissure veins
- stratiform-replacement deposits
- carbonatite and alkali-rock complexes
- replacement deposits in carbonate rocks
- stockworks and fillings in shear and breccia zones
- residual concentrations from weathering of primary deposits
- recoverable gangue minerals in base metal deposits.

Fluorite in Western Australia

There are numerous occurrences of fluorite in Western Australia detailed in Abeysinghe and Fetherston (1997). Some of the more significant deposits are discussed below and their locations are shown in Figure 21.3 and given in Appendix 1.

Pilbara Craton

Split Rock area

Boddingtons mine (Split Rock, 2854)

Fluorite is present at Boddingtons mine at Split Rock about 60 km southwest of Marble Bar (Fig. 21.3). At this site, almost pure fluorite occurring as a gangue mineral has been described from a small vein of galena. The colour of the mineral varies from colourless to deep violet, the latter colour being most common.

Nullagine region

Cookes Creek (Nullagine, 2954)

The Cookes Creek fluorite prospect is about 45 km east-northeast of Nullagine (Fig. 21.3). Fluorite veins are found in mafic and granitic rocks directly east of Cookes Creek at a point approximately 3.5 km south-southeast of its confluence with the Nullagine River.

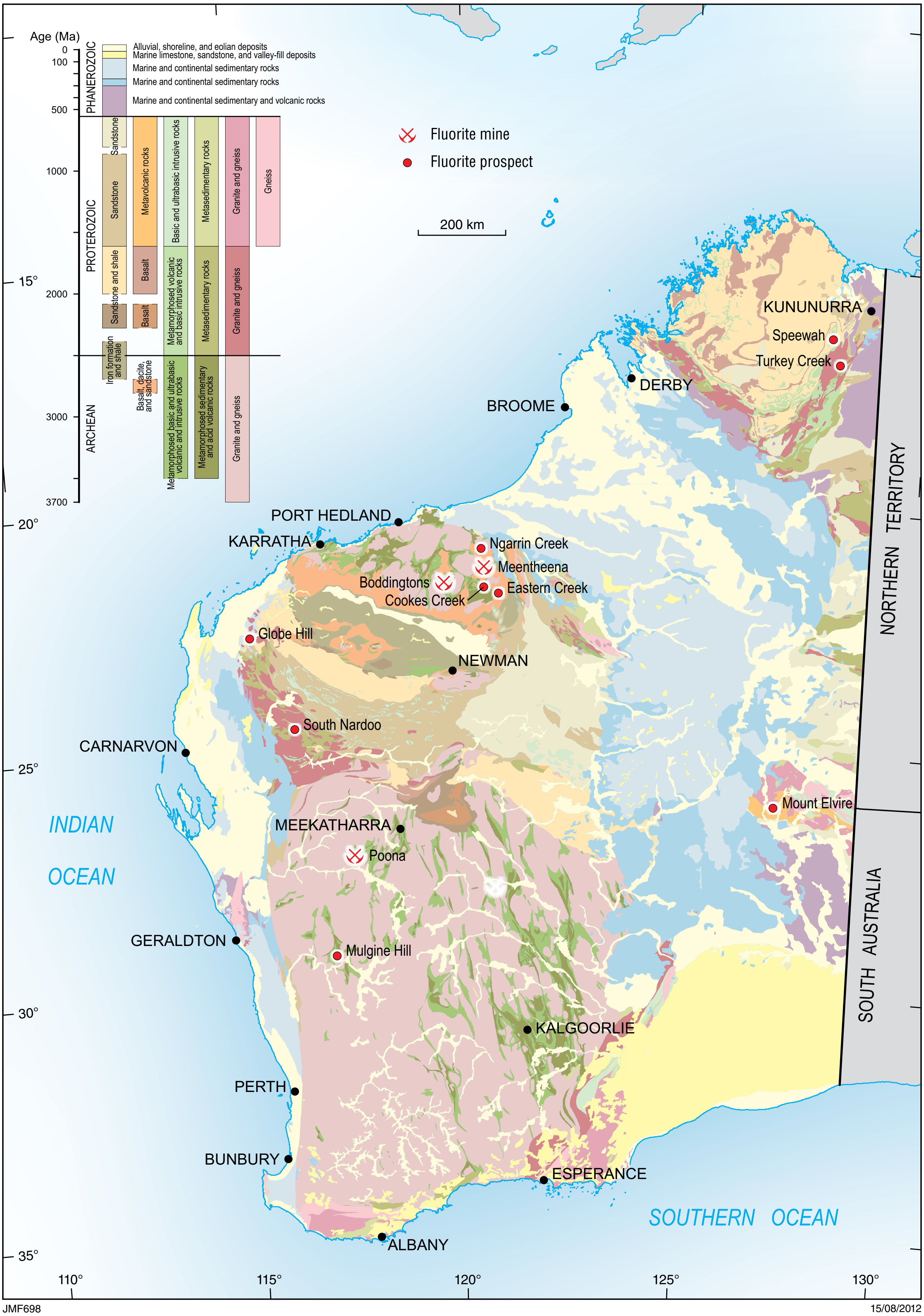

Figure 21.3. Locations of fluorite mines and prospects in Western Australia

The Nullagine 1:100 000 geological map (Bagas et al., 2004) indicates the deposit is within basalts directly south of the Cooke Creek Monzogranite. At the prospect, fluorite is associated with tungsten minerals such as scheelite and wolframite.

Meentheena (Mount Edgar, 2955)

The Meentheena fluorite deposit is on the Nullagine River, about 75 km north-northeast of Nullagine, and about 6 km north-northeast of the abandoned Meentheena Station Homestead (Fig. 21.3). Access to the site is east of Marble Bar along the Ripon Hills Road to a point about 3 km west of the Nullagine River and then south towards the old Meentheena Station Homestead.

At Meentheena, the fluorite mineralization is mostly in the form of veins and fissures developed in amygdaloidal basalt in the upper part of the Mount Roe Basalt and in the sedimentary rocks of the overlying Hardey Formation, the lowest units in the Late Archean Fortescue Group (Abeysinghe and Fetherston, 1997). Eight separate occurrences are shown on the Mount Edgar 1:100 000 geological map (Williams and Bagas, 2007a).

Fluorite veins and fracture fillings appear to be a conjugate set striking at 060° and 130°. Veins may be up to 5 m in width and up to 1.6 km in length (Fig. 21.4). A typical vein consists of an outer zone of quartz with a wide central zone of interlayered quartz and coarse-grained, massive and locally banded, anhedral, white, pale brown to purple fluorite. Fluorite zones within the veins tend to pinch and swell. Associated minerals in some localities are galena, malachite, brochantite, and atacamite. Although thick veins of calcite are present at the periphery of the mineralized area, barite was not detected (Williams and Bagas, 2007b).

Ngarrin Creek (Muccan, 2956)

A fluorite prospect is at Ngarrin Creek, approximately 27 km south-southwest of Callawa Homestead (Fig. 21.3). At this site, fluorite forms within a dacitic porphyry stock exposed as a prominent hill west of 17 Mile Bore. The stock, which consists of two distinctive rock types, is considered a Late Archean or Early Proterozoic intrusion into an Archean migmatitic quartz monzonite (Abeysinghe and Fetherston, 1997). These two types comprise:

- coarse porphyry containing large phenocrysts of quartz, feldspar, and vugs of dark blue fluorite up to 50 mm across
- fine porphyry containing phenocrysts, 3 mm in diameter, containing microcrystalline fluorite. This rock type exists within northeasterly trending dykes of the coarse porphyry at the southwestern end of the hill. In other places the intrusive relationship is obscure.

Eastern Creek (Eastern Creek, 3054)

At Eastern Creek, fluorite is present in two prospects, 8 km apart, approximately 55 km east-northeast of Nullagine (Fig. 21.3). At these sites, coarsely to rather finely granular fluorite is present with very few impurities except a small amount of galena and minor barite. There is a wide range in colour varying from colourless to almost transparent and milky white, and less-translucent, pale to deep amber-yellow, light brown, bottle-green, and lavender to dark violet varieties.

Kimberley Basin

Dunham River area

Speewah prospect (Dunham River, 4565)

The largest fluorite deposit in Western Australia is at Speewah in the Kimberley Basin approximately 45 km west-southwest of Dunham River Homestead (Fig. 21.3).

The Speewah Valley, within the Speewah Basin close to the western edge of the Halls Creek Orogen, is incised into the Hart Dolerite, which occupies the core of the Speewah Dome. This north-trending structure is 32 km long and 13 km wide. The dolerite intrudes feldspathic arenite, chloritic siltstone, and minor acid volcanic rocks of the Speewah Group.

Fourteen fluorite veins have been identified although four areas contain the most significant fluorite mineralization: Main Zone, West Zone, Northwest Zone, and Central Zone, which respectively lie to the northeast, northwest, north-northwest, and north of the abandoned Speewah Station Homestead (Fig. 21.5).

Fluorite mineralization at Speewah comprises narrow, tabular, near-vertical veins that are mostly present in variable-width shear zones locally flanked by green, chlorite-rich, lower grade material in stockworks and stringer veins. Where fresh, the fluorite is grey or white, although it weathers to pale green. Veins consist of mainly fluorite (20–80% in tabular veins), with quartz and occasional barite and silicified fragments of country rock. Chalcopyrite is commonly associated with wallrock stringer veins and stockworks, and galena is found in the West Zone.

Halls Creek Orogen

Warmun area

Turkey Creek prospect (Turkey Creek, 4563)

Fluorite is found in veins at Turkey Creek prospect, 13 km northwest of Warmun some 145 km southwest of Kununurra (Fig. 21.3). Specimens are coarsely crystalline, highly translucent, colourless, white, and with various green hues including pale emerald. It is associated with small quantities of galena and quartz.

Figure 21.4. **Veins of purple fluorite crosscutting white quartz veins at Meentheena deposit (after Abeysinghe and Fetherston, 1997)**

Ashburton Basin

Nanutarra area

Globe Hill (*Uaroo, 1952*)

Fluorite grains up to several grams in weight have been collected close to a stanniferous pegmatite near the Globe Hill Trigonometric Station about 35 km west-southwest of the Nanutarra Roadhouse (Fig. 21.3). The pegmatite contained microcline, albite, quartz, and muscovite as major minerals, and fluorite, rutile, ilmenite, cassiterite, and topaz as minor minerals. The fluorite pieces collected were coarsely crystalline and the colour varied from dark violet through light grey to light green, although most specimens ranged from indigo blue to dark violet.

Musgrave Province

Wingellina region

Mount Elvire prospect (*Mount Eveline, 4345*)

Approximately 3 km west-northwest of Mount Elvire in the Wingellina region, small lenses of purple fluorite, up to 30 m long and 2 m wide, are found in felsitized acid volcanic rocks of the Scamp Formation of the Mount Palgrave Group (Fig. 21.3).

Gascoyne Province

Yinnetharra area

South Nardoo prospect (*Yinnetharra, 2148*)

Veins of fluorite more than 1 m wide and 100 m long have been reported in the South Nardoo prospect within pelitic schists of the Paleoproterozoic Leake Spring Metamorphics, 15 km to the north of Yinnetharra Homestead (Fig. 21.3). At this locality, fluorite is associated with galena, various copper minerals, and orpiment in quartz gangue. The mineralization is thought to be associated with the pegmatite phase of the Thirty Three Supersuite.

Yilgarn Craton — Murchison Domain

Cue region

Poona (*Noondie, 2343; Cue, 2443*)

This fluorite mine is in the Poona emerald field, about 55 km northwest of Cue (Fig. 21.3). In this area, hydrothermally altered biotite schist associated with emerald-bearing pegmatites is unusually high in fluorine (4.15%). Around this site, coarsely crystalline, highly translucent fluorite, up to 3 cm in diameter, is associated with a pegmatite containing quartz, green beryl, and potassic oligoclase feldspar.

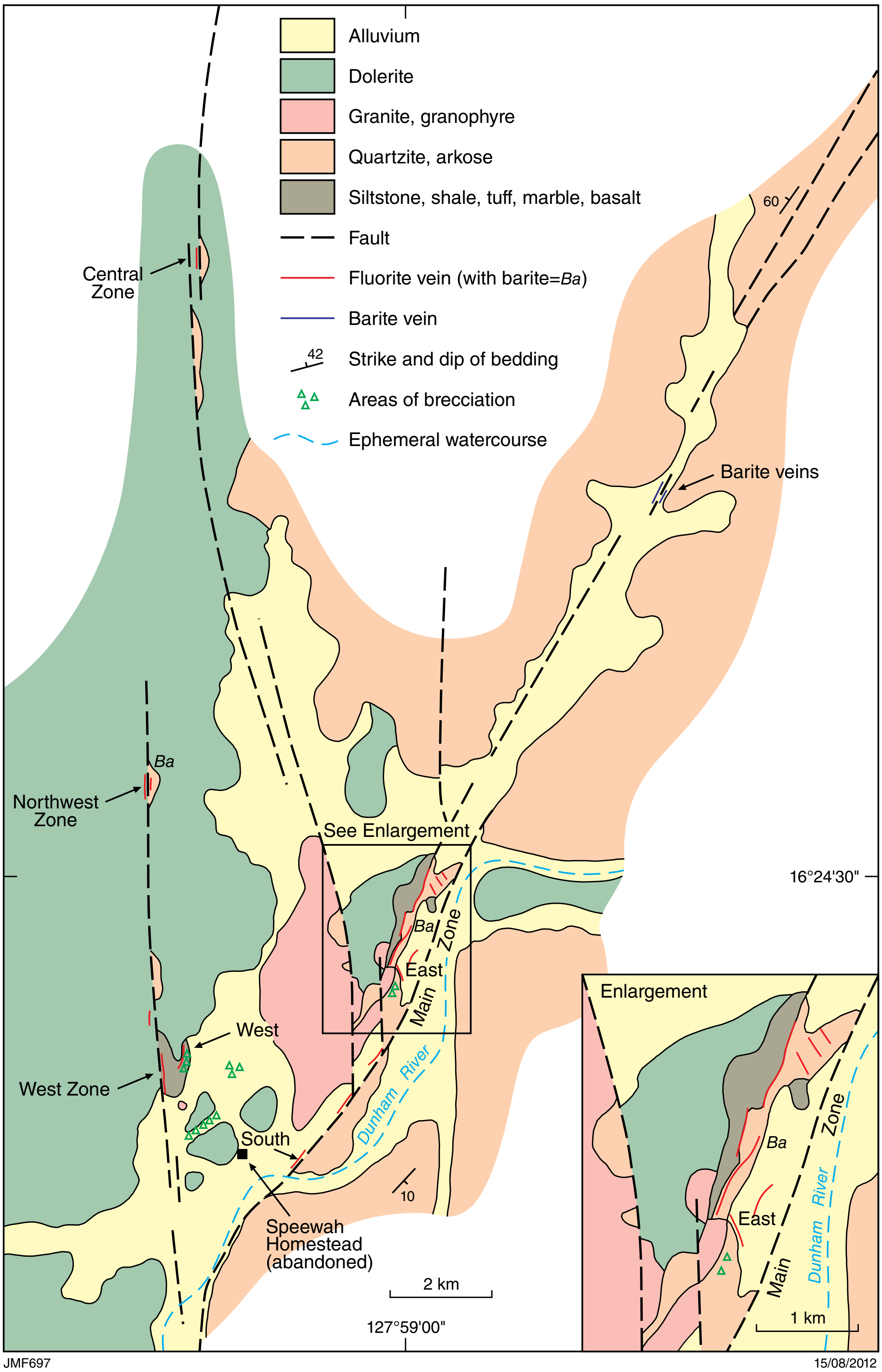

Figure 21.5. **Geological sketch map of the Speewah area showing zones of fluorite and barite mineralization (modified after Abeysinghe and Fetherston, 1997)**

Warriedar area

Mulgine Hill (Rothsay, 2239)

Minor fluorite is associated with molybdenum ore in the Proterozoic Mulgine Granite at Mulgine Hill about 70 km west-northwest of Paynes Find (Fig. 21.3). The ore is a shattered, micaceous granite impregnated with molybdenite and pyrite, locally hosting veinlets and lenses of quartz, and minor fluorite. The fluorite varies from colourless to violet black and to almost opaque. Associated minerals include muscovite, microcline, albite, quartz, molybdenite, pyrite, zircon, and titanite.

References

Abeysinghe, PB and Fetherston, JM 1997, Barite and fluorite in Western Australia: Geological Survey of Western Australia, Mineral Resource Bulletin 17, p. 71–91.

Bagas, L, Beukenhorst, O and Hos, K 2004, Nullagine, WA Sheet 2954: Geological Survey of Western Australia, 1:100 000 Geological Series.

Williams, IR and Bagas, L 2007a, Mount Edgar, WA Sheet 2955: Geological Survey of Western Australia, 1:100 000 Geological Series.

Williams, IR and Bagas, L 2007b, Geology of the Mount Edgar 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 62p.

Chapter 22

Garnet group

Garnet group minerals

Garnet is a mineral group name; its member species are defined by differences in their chemistry within the same formula, $A_3B_2(SiO_4)_3$, where Ca, Mg, Fe^{2+}, and Mn^{2+} substitute in the A cation site and Al, Fe^{3+}, Mn^{3+}, V^{3+}, and Cr^{2+} in the B site.

Most garnet group species are classified into two major isomorphous series with each defined by end members. Almandine, pyrope, and spessartine make up the end members of one ternary series and andradite, grossularite, and uvarovite are the end members of a second ternary series.

Minor chemical changes among the end members of each isomorphous series define species of intermediate composition. There is also limited miscibility between the two major series and variations exist in defining some species terms.

Other species include the less well-known hydrogrossular garnet (hydrated calcium–aluminium silicate, also termed hibschite) found in zones of metasomatized anorthosite. Hydrogrossular is used as a green or pink ornamental rock best known as 'Transvaal jade' (Cairncross and Dixon, 1995).

All garnet group minerals are isometric (cubic) in form and commonly occur as euhedral (well-formed) crystals that are typically rhombic dodecahedra (12-sided crystals with each face rhomboidal), trapezohedra (24-sided crystals with each face trapezoidal), or combinations of these two forms (Fig. 22.1).

Because of their variations in chemistry, garnets exhibit a wide range of physical properties and colours (see the summary table on garnet group characteristics and properties in this chapter). Garnets are sufficiently hard (approximately 7 on Mohs scale), they possess no cleavage, and most species are eminently suitable for use as gems in jewellery.

Garnet species of all types are of gemmological interest where found as transparent crystals. Garnet, a name that originally defined one red-coloured gem mineral in historical literature, nowadays refers to at least six well-recognized end member species and numerous intermediate species. Garnet colours include red, orange, purple, black, yellow, brown, green, blue, colourless, and colour-change varieties.

Garnet group
Almandine, common red garnet $Fe_3Al_2(SiO_4)_3$

Almandine and spessartine garnets most commonly form in gneisses, schists, and some granitic pegmatites; pyrope is restricted to ultramafic rocks; grossular garnets characteristically form in calc-silicates and skarns; and andradite garnet forms in either calc-silicates or altered serpentinite.

Uvarovite is an idiochromatic garnet species (its chemistry defines the colour) of an intense green and to date has not been found in crystals sufficiently large to facet as gems. Uvarovite may occur in serpentinite and limestone. In jewellery it is commonly mounted as small druses of tiny crystals.

Pyrope garnet, originating from the Czech Republic, is well known as the basis of a particular style of jewellery that is inset with numerous small faceted dark red garnets. This particular garnet has been termed 'Bohemian' garnet, from its historical geographic location.

Figure 22.1. **Twelve-sided, rhombic dodecahedral garnet crystal from an unknown locality in Western Australia. Crystal is 6 cm in diameter (Geological Survey of Western Australia collection)**

Garnet group characteristics and properties

Mineral	Chemistry	Refractive index	Specific gravity	Colour	Provenance
Almandine	$Fe_3Al_2 (SiO_4)_3$	1.83	4.31	Red, violet-red, and black	Igneous and metamorphic rocks (granites, schists, and gneisses)
Andradite	$Ca_3Fe_2 (SiO_4)_3$	1.88	3.85	Green, brown, yellow, and black	Metamorphosed ultramafic rocks and calc-silicates
Grossular	$Ca_3Al_2 (SiO_4)_3$	1.73	3.59	Pink, green, colourless, and yellow	Metamorphosed calc-silicates
Pyrope	$Mg_3Al_2 (SiO_4)_3$	1.71	3.58	Red and purple-red	Ultramafic rocks (peridotite and kimberlite)
Spessartine	$Mn_3Al_2 (SiO_4)_3$	1.80	4.19	Orange, orange-red, and brown	Calc-silicates, granite pegmatites
Uvarovite	$Ca_3Cr_2 (SiO_4)_3$	1.86	3.90	Bright green	Serpentinite and skarns
Hydrogrossular	$Ca_3Al_2 (SiO_3OH)_3$	1.67 – 1.73	3.13	Green, pink, and grey	Metasomatized anorthosite

The most valuable garnet is demantoid, a chromiferous bright green andradite. Demantoid was originally discovered in the Ural Mountains and the finest gems still originate from this source even though it is found in other countries including Namibia.

Gem garnets are mined in many countries from alluvial gravels while garnet sands are worked as a source of industrial garnet.

Garnet in Western Australia

In Western Australian placer deposits, almandine garnet is mined from heavy mineral sands at Port Gregory on the Hutt 1:100 000 map sheet. The source of the garnets is the Neoproterozoic Northampton Complex.

Garnets are a feature of ornamental dimension stone, including gneisses, syenites, granites, and quartz monzonites. Garnets crystallizing as bands and knots of aggregated crystals can feature as part of their rock-forming mineralogy. An example is the 'Garnet Ice' garnet–biotite gneiss in the Fraser Range east of Norseman (Fig. 22.2).

Specimens of some large garnet crystals are in the collection of the Western Australia Museum; however, there are no records of facet-grade garnet from Western Australia.

Figure 22.2. Garnet Ice, a garnet–biotite gneiss from the Fraser Range area. Numerous red garnets 2–5 mm in diameter are present in this ornamental stone, constituting up to 15% of the rock's volume (after Fetherston, 2010)

Yilgarn Craton — South West Terrane

Preston area

Glen Mervyn prospect (Bridgetown, 2130)

Large specimen-quality garnets have been collected from weathered schists at an unspecified location north of Glen Mervyn in the Preston district (Fig. 22.3; Wilde and Walker, 1982).

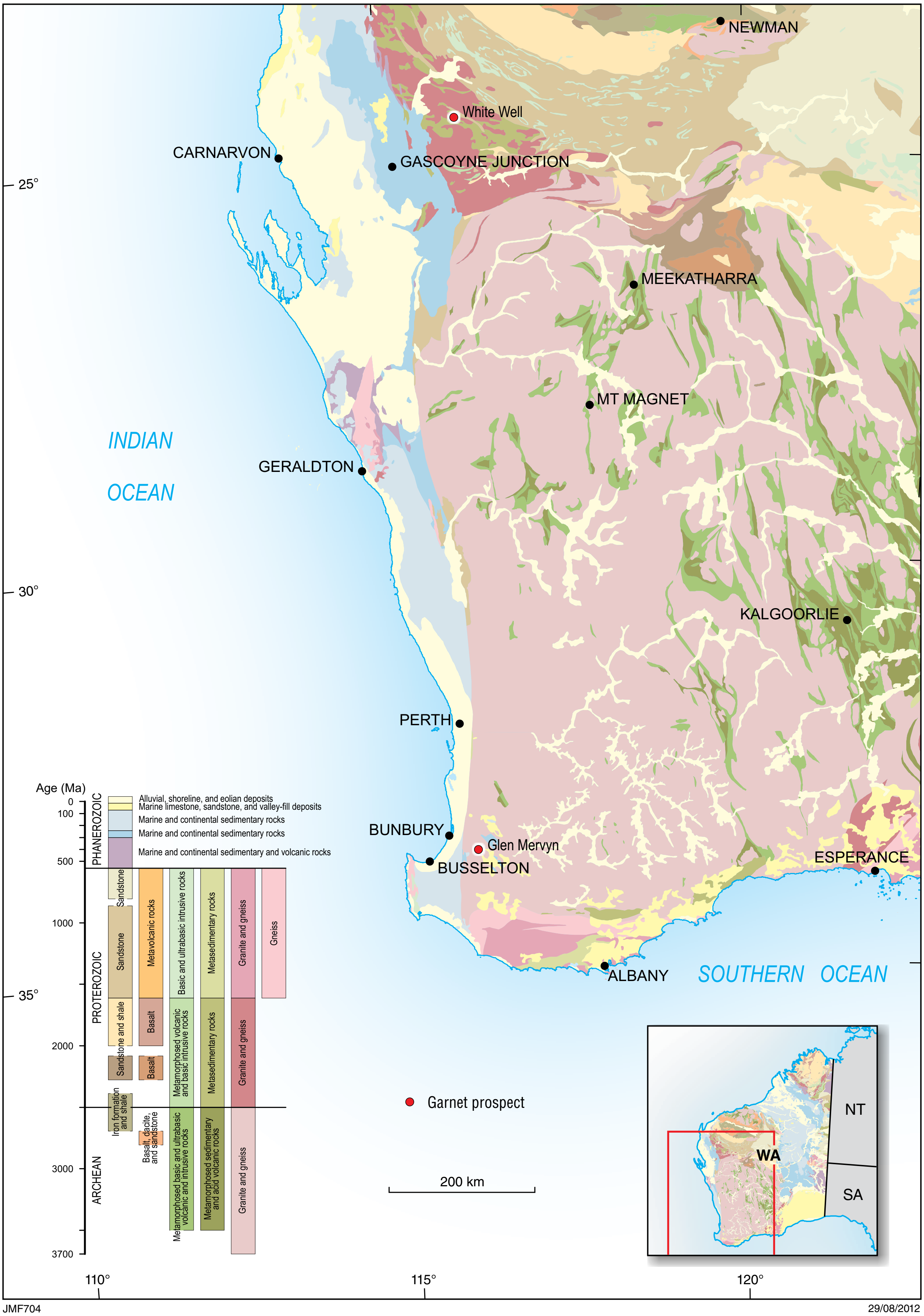

Figure 22.3. Locations of garnet prospects in Western Australia

Lake King region

Lake King (King, 2831)

Simpson (1952) recorded some fine specimens of garnet dodecahedra and trapezohedra up to 50 mm in diameter. They are reportedly dark brown and feebly translucent. Whereas the location of the garnet prospect is unknown, it may be within the gneissic terrain in the southeastern corner of the King 1:100 000 map sheet.

Gascoyne Province

Yinnetharra area

White Well prospect (Mount Phillips, 2149)

Garnet specimens have been found together with staurolite and cordierite in a unit of the Paleoproterozoic Leake Spring Metamorphics comprising staurolite–garnet–biotite–muscovite schist (Fig. 22.4). The approximate location is between White Well and Morrissey Creek on Mount Phillips Station, 30 km north-northeast of Yinnetharra (Fig. 22.3).

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Figure 22.4. Garnet dodecahedron in mica schist from Yinnetharra; 10 mm in diameter (courtesy David Vaughan)

References

Cairncross, B and Dixon, R 1995, Minerals of South Africa: Geological Society of South Africa, Johannesburg, p. 93–94.

Fetherston, JM 2010, Dimension stone in Western Australia, volume 2 — Dimension stones of the southern, central western, and northern regions: Geological Survey of Western Australia, Mineral Resources Bulletin 24, 218p.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 77–95.

Wilde, SA and Walker, IW 1982, Collie, Western Australia: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 39p.

Chapter 23

Gaspeite

Gaspeite occurrence and properties

Although gaspeite is a comparatively rare mineral, it is more familiar as a collectors' gem to Western Australian specialist collectors. In the mid-1990s, the State briefly became an important source of this gemmological material.

Gaspeite is a green nickel carbonate typically formed by surface or near-surface alteration of nickel sulfides, predominantly pentlandite, violarite, and millerite, commonly in arid or semi-arid environments. Gaspeite was named after the Gaspé Peninsula in eastern Canada and first described in 1966.

Gaspeite forms massive to reniform aggregates in fractures, as concretions in ferruginous duricrust (laterite), or as fracture infill. Rarer crystals are typically translucent. Massive gaspeite as veins up to 50 cm thick has been recorded in Western Australia (Nickel et al., 1994; Fig. 23.1). The host rock is of special interest to mineral collectors because of the association of gaspeite with other nickel minerals.

Gaspeite's bright apple-green colour and rarity make it a popular gemstone and it is most commonly cut as cabochons or slabbed and polished (Fig. 23.2). Gaspeite has also been offered commercially at mineral fairs under the trade name 'Allura' (Gems and Gemology, 1994).

In Western Australia, nickel sulfide deposits are relatively widespread in the Eastern Goldfields and the Pilbara Craton and are mainly associated with Archean rocks including volcanic peridotites, intrusive dunites, and various gabbroic rocks. Gaspeite has been recorded from several nickel mines in these areas. The best known and main source was the Mount Edwards 132N mine near Widgiemooltha in the Eastern Goldfields. Today, most of the original gaspeite sites are either depleted or covered up and much of the material that became available in the 1990s is now held by mineral traders and collectors. Gaspeite sites are shown in Figure 23.3 and additional information is given in Appendix 1.

Gaspeite
Nickel carbonate $(Ni,Fe,Mg)CO_3$

Physical properties of gaspeite

Crystal system	Trigonal
Habit	Crystal aggregates and concretions
Colour range	Pale green to apple-green
Colour cause	Nickel
Lustre	Vitreous to dull
Diaphaneity	Opaque to translucent
Refractive index	1.61 – 1.83
Birefringence	0.220
Hardness	4.5 – 5
Specific gravity	3.71
Fracture	Uneven
Cleavage	Good

Gaspeite in Western Australia

Yilgarn Craton — Eastern Goldfields Superterrane

Widgiemooltha

Mount Edwards 132N mine *(Lake Lefroy, 3235)*

Gaspeite was identified in the early 1990s at the Mount Edwards 132N nickel mine, 5 km northwest of the small town of Widgiemooltha, 80 km south of Kalgoorlie on the Coolgardie–Esperance Highway (Figs 23.3 and 23.4).

In addition to gaspeite, the Mount Edwards 132N mine is the type locality for other rare nickel minerals including widgiemoolthalite, a green to bluish-green hydrous nickel carbonate first identified in 1992, and gillardite, a bright green hydrated copper–nickel chloride named in 2007. Other rare nickel minerals from this mine are described in Nickel et al. (1994).

Figure 23.1. Massive veins of bright green gaspeite within nickeliferous ore (courtesy Glenn Archer)

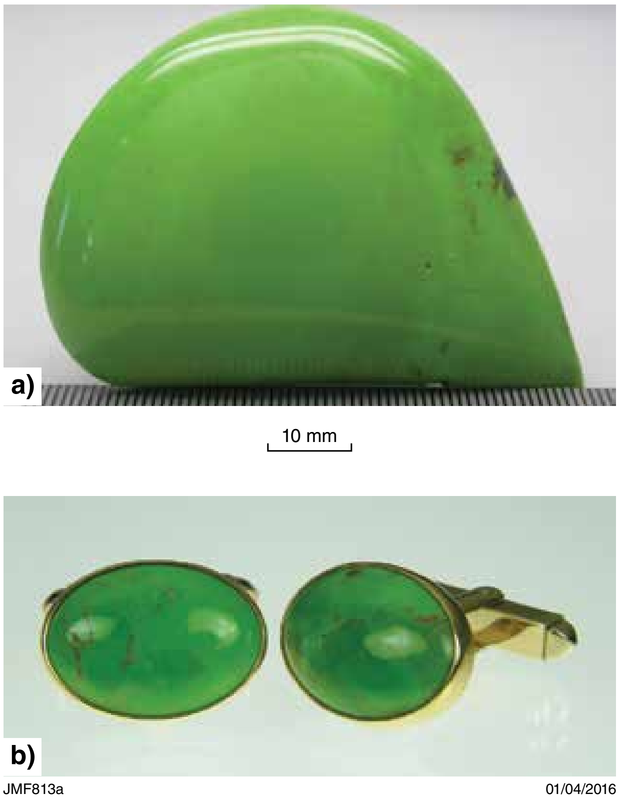

Figure 23.2. Examples of gaspeite jewellery sourced from Western Australia: a) large, highly polished cabochon of bright apple-green gaspeite (courtesy David Vaughan); b) pair of 9 ct gold cufflinks featuring gaspeite cabochons (courtesy Just Gems, Aberdeen, Scotland)

Gaspeite from Widgiemooltha is associated with talc–carbonate komatiite and nickel sulfide gossan, and was probably formed by the substitution of nickel into carbonates such as magnesite. Nickel et al. (1994) describe gaspeite at the 132N mine as 'very abundant in the carbonate zone, predominating over all the other secondary nickel minerals. Its most spectacular occurrence is in the lower part of the carbonate zone, where it was seen as massive lime-green veins up to 50 cm thick and from one to 10 metres in lateral extent'.

Gaspeite is isomorphous with magnesite and commonly occurs as thin coatings on a substrate of white magnesite. Specimens from the deposit show a complete range between the two end members, with colour changing from white magnesite to bright apple-green and dark emerald-green gaspeite. Analyses of gaspeite show nickel oxide (NiO) contents of 34.9 – 54.5% (Nickel et al., 1994).

In the late 1990s, the mine owners at that time, Western Mining Corporation, encountered a nickel ore processing problem in their on-site processing plant. As a result, much nickel ore was stockpiled and subsequently abandoned. Later, this stockpile was sold to mineral prospectors, who extracted most of the gaspeite and other minerals. Around 2007, another major nickel mining operation was started at the former mine site and waste material from the new openpit was dumped over the old stockpiles, effectively preventing access to the older material that originally contained the gaspeite.

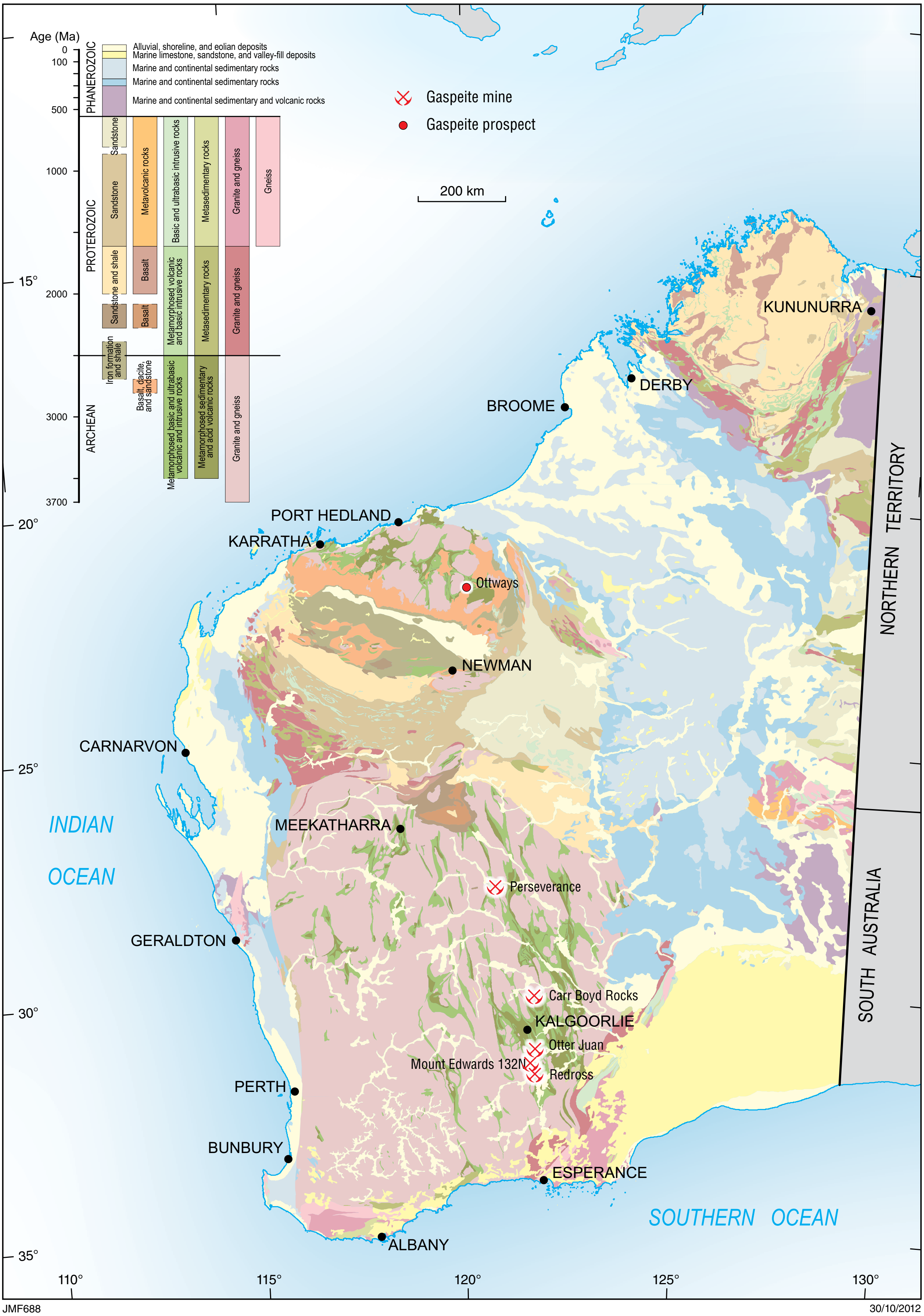

Figure 23.3. Locations of gaspeite sites in Western Australia

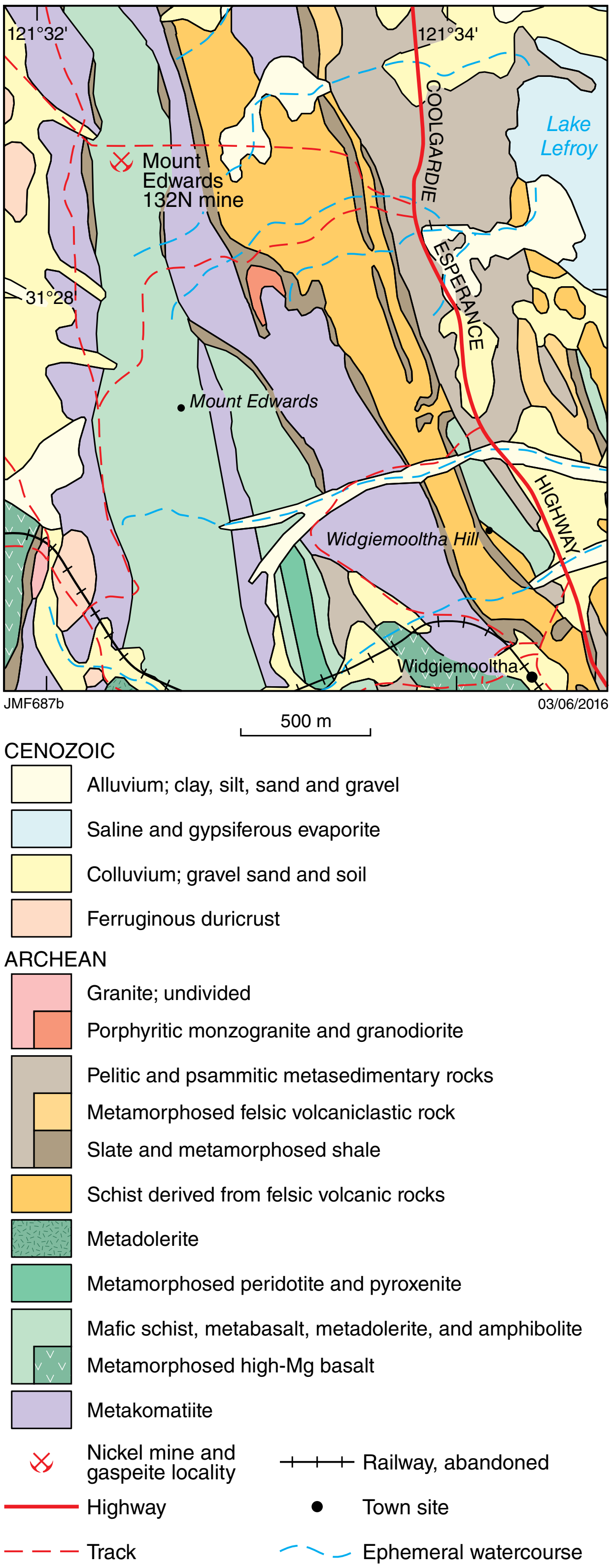

Figure 23.4. Geological map of the area around the gaspeite site at the Mount Edwards 132N nickel mine (modified after Griffin and Hickman, 1988)

Kambalda

Otter Juan nickel complex (Lake Lefroy, 3235)

In the Otter Juan nickel mine, 4 km north-northwest of Kambalda, Marston (1984) recorded the presence of gaspeite in irregular pale to apple-green veinlets up to 8 cm thick in the near-surface and gossanous portions of the Otter shoot (Fig. 23.3).

Other gaspeite sites in Western Australia

Gaspeite has also been recorded at several other nickel mines and prospects in the Eastern Goldfields Superterrane and Pilbara Terrane (Fig. 23.3).

Yilgarn Craton — Eastern Goldfields Superterrane

Gaspeite has been recorded at Redross mine, 20 km south-southeast of Widgiemooltha (Cowan, 3234); Carr Boyd Rocks mine, 51 km northeast of Broad Arrow (Gindalbie, 3237); and Perseverance mine, 11 km north of Leinster (Sir Samuel, 3042).

Pilbara Craton

Gaspeite has been recorded at Ottways prospect, 26 km north of Nullagine (Nullagine, 2954).

References

Gems and Gemology 1994, Gem news—green gems from Australia: Gems and Gemology, Summer, p. 126.

Griffin, TJ and Hickman, AH 1988, Lake Lefroy, WA: Geological Survey of Western Australia, 1:100 000 Geological Series.

Marston, RJ 1984, Nickel mineralization in Western Australia: Geological Survey of Western Australia, Mineral Resources Bulletin 14, 271p.

Nickel, EH, Clout, JFM and Gartrell, BJ 1994, Secondary nickel minerals from Widgiemooltha, Western Australia: The Mineralogical Record, v. 25, no. 4, p. 283–291, and 302.

Chapter 24

Iron-rich gemstones

Iron-rich gemstones in Western Australia

Most of the massive Western Australian hematite–goethite iron ore deposits are derived from primary magnetite, a major constituent of the banded iron-formations (BIF), and also taconite units, in the Archean–Paleoproterozoic Hamersley Basin, and to a lesser extent in the Archean Yilgarn and Pilbara Cratons. The BIF, which may attain thicknesses of tens of metres, comprise a series of rhythmically banded magnetite–silica and silicate-rich units varying in thickness from millimetres to centimetres. In turn, these iron-rich units are intercalated with similar thicknesses of tuff, shale, limestone, and volcanic rocks. The best-developed BIF units are in the Hamersley Basin where they cover an area of approximately 75 000 km^2. Smaller, linear BIFs also form part of many Archean greenstone belts within the Yilgarn and Pilbara Cratons.

In these iron ore provinces, secondary weathering processes have removed a large proportion of the silica, carbonate, and intercalated tuffaceous material and replaced them with iron minerals to form the huge hematite deposits in the Hamersley Basin, and smaller deposits in the Yilgarn and Pilbara Cratons. In the jewellery industry, hematite from these enrichment deposits is the source of gem material such as highly polished, blue-black to jet-black hematite, and may also be altered through metasomatic processes into specularite, which has been used as an attractive ornamental material.

Within BIF units, chert bands are mostly pale coloured although in some areas they may contain minute hematite inclusions that colour the stone blood red; these cherts are called jaspilite or jasper. Thin red jaspilite layers are commonly intercalated with dark grey-black, iron-rich bands forming an attractive rock that is commonly highly folded. Jaspilite units may be sufficiently thick and hard to provide excellent material for cabochons.

Iron-rich gemstones
Hematite — iron oxide Fe_2O_3
Specularite — micaceous hematite Fe_2O_3
Turgite — hydrated iron oxide $Fe_2O_3.nH_2O$
Pyrite — iron sulfide FeS_2
Marcasite — iron sulfide FeS_2
Tiger eye — silicified crocidolite $Na_2(Fe^{+2},Mg,Fe^{+3})_5Si_8O_{22}(OH)_2$
Tiger iron — banded iron-formation and tiger eye

In both the Ord Ranges in the western Pilbara Craton, and the lower units of the Hamersley Group in the Brockman area of the Hamersley Basin, silicification and oxidation of narrow seams of crocidolite (an amphibole mineral) interspersed with red bands of red jasper have formed visually attractive deposits of tiger eye and tiger iron. These have been used for jewellery, spectacular carved artwork, and polished stones.

Prospects and potential sites for iron-rich gems and ornamental stones in Western Australia are shown in Figure 24.1 and Appendix 1.

Hematite

Hard, massive, high-grade hematite may be sourced from suitable localities around the many iron ore mines, such as Mount Newman, Tom Price, Paraburdoo, and Brockman in the Hamersley Basin, and smaller deposits in the Yilgarn Craton such as Koolyanobbing and Mount Gibson (Southern Cross and Murchison Domains, respectively; Fig. 24.1).

Physical properties of hematite

Crystal system	Trigonal
Habit	Tabular, rhombohedral and massive (for gemstones), and many other habits
Colour range	Dark grey to black
Streak	Cherry red
Lustre	Metallic to earthy
Diaphaneity	Opaque
Hardness	5.5 – 6.5
Specific gravity	4.9 – 5.3
Fracture	Subconchoidal to uneven
Cleavage	None

Hematite may be cut and polished into a lustrous blue-black to jet-black gemstone, which is particularly attractive in silver settings (Fig. 24.2). Although high-grade hematite is common and relatively inexpensive, there are hematite imitations on the market. This material, known as hematine, was initially manufactured by sintering a

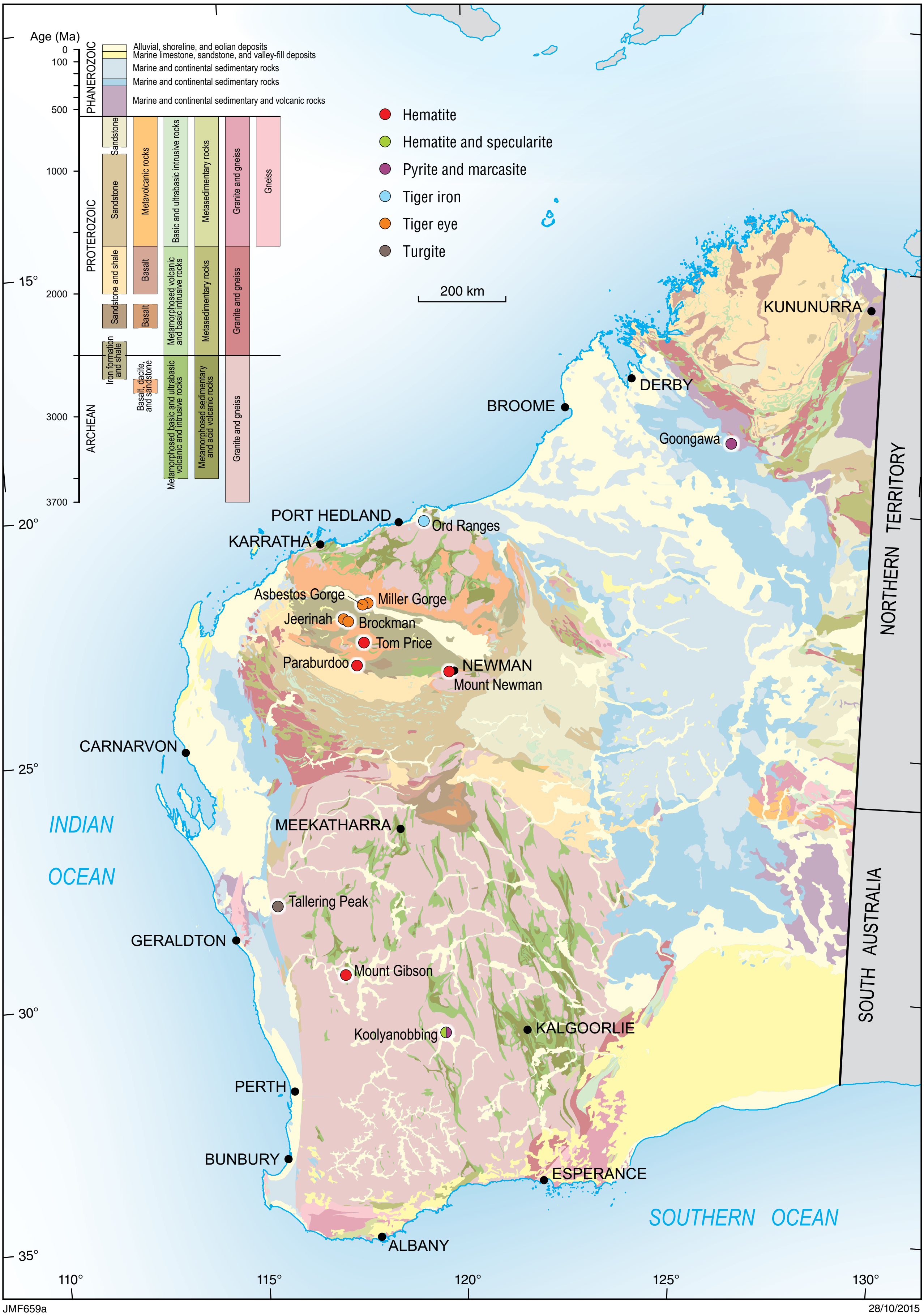

Figure 24.1. Locations of iron-rich gemstones in Western Australia

complex of iron and other oxides to yield an opaque black mass that displays a silvery metallic lustre on polished surfaces (Brown and Snow, 1988). Items of jewellery are inexpensively stamped out from this material. More recently it has been established that hematine is composed of a synthetic barium–strontium-rich ferrite compound. It is probable that all the inexpensive 'iron ore' beads and jewellery available are made of hematine.


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Figure 24.2. Polished, black hematite necklace (courtesy S Koepke)

Specularite

Specularite or specular iron (a micaceous hematite) is hydrothermally altered hematite that has crystallized into lustrous, pale grey to black, sparkling flakes that impart a bright, glistening appearance to the specimen. Although crystals are typically small and commonly occur as bands in more massive forms of hematite, they can also be relatively large, up to a maximum of 15 cm in length. Large crystals can be cut and polished to make attractive ornamental pieces such as bookends (Fig. 24.3).

Yilgarn Craton — Southern Cross Domain

Southern Cross region

Koolyanobbing *(Seabrook, 2836)*

Impressive specularite crystals can be obtained from iron ore mines around Koolyanobbing townsite, about 50 km north-northeast of Southern Cross (Fig. 24.1).

Turgite

Yilgarn Craton — Murchison Domain

Mullewa area

Tallering Peak mine *(Tallering, 2041)*

Turgite is not a recognized mineral species but is a name given to an iridescent mixture of hematite and goethite, typically found in botryoidal masses (Fig. 24.4). Originally described from the Ural Mountains in Russia, it is also found in Western Australian at the T6 Pit, part of the Tallering Peak iron ore mine, about 50 km north-northeast of Mullewa to the east of Geraldton (Fig. 24.1). Specimens of turgite show bright and varicoloured iridescence and are collected for display only, as polishing would remove the iridescent film.


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Figure 24.3. Pair of specularite bookends made from material sourced from the Koolyanobbing iron ore mine

Figure 24.4. **Turgite, an iridescent mixture of hematite and goethite from Tallering Peak iron ore mine, north of Mullewa (courtesy C Bosel)**

Pyrite and marcasite

Pyrite, or iron pyrites, is probably the most common of all metallic sulfides and can be found associated with other sulfides in quartz veins, sedimentary and metamorphic rocks, and as a replacement mineral in some fossils.

Pyrite crystallizes in the cubic system (pyritohedral class) and is commonly found as striated cubes, and as twelve-sided pyritohedra (Fig. 24.5). Pyrite is also found as massive, reniform, and nodular forms. When fresh, it is a pale yellow, brassy mineral that has a superficial resemblance to gold; hence the name 'fool's gold'. Pyrite tarnishes readily, and commonly forms cubes of goethite after pyrite known as 'devil's dice'.

Marcasite, also called white iron pyrite, is iron sulfide with an orthorhombic crystal structure that is physically and crystallographically distinct from pyrite. It is paler in colour and more brittle than pyrite. On fresh surfaces it is pale yellow to almost white, tarnishes to a yellowish or brownish colour, and has a black streak.

Physical properties of pyrite

Crystal system	Isometric system, pyritohedral class
Habit	Commonly cubic with striated faces, pyritohedra with 12 pentagonal faces, and rarely as octahedra. Also massive, radiating subfibrous, reniform, globular, and stalactitic forms
Colour	Pale brassy-yellow
Streak	Greenish-black or brownish-black
Lustre	Metallic
Hardness	6 – 6.5
Specific gravity	4.95 – 5.10
Cleavage	Indistinct

Pyrite is used commercially in the production of sulfur dioxide for use in the paper industry and in the manufacture of sulfuric acid. Where exposed to air and water, pyrite decomposes into iron oxides and iron sulfate, reacting more rapidly when the pyrite exists as fine crystals or dust-sized particles. The sulfate released from decomposing pyrite combines with water, producing sulfuric acid, which may form acid groundwater.

In jewellery manufacture, pyrite is termed marcasite and so-called 'marcasite' jewellery is in reality set with cut pieces of pyrite. Pyrite has been used for ornament since prehistory; for example, pyrite beads were found from ancient Egypt. However, the widespread decorative use of pyrite in jewellery dates to Europe of the mid-18th century. Diamond jewellery was in high demand at the time and the main attraction of faceted pyrite was its use as a simulant for diamond, and pyrite-set jewellery of the period was accordingly finely crafted.

As well as marcasite jewellery, pyrite was popular in the late 18th and 19th centuries for use in items such as shoe buckles and buttons where specially shaped pieces of pyrite were attached to a silver or base metal backing. There have been several revivals of marcasite jewellery in the 20th century, particularly in the 1930s and 1950s (Barlett, 1997).

More recently, pyrite features in many types of ornament including the manufacture of beads, both shaped and as natural crystals. Jewellery, such as pendants and brooches, has been manufactured using pyrite-in-matrix (commonly quartz) as cabochons, and pyritized fossils, especially ammonites (Fig. 24.6).

Figure 24.5. **Brassy-yellow, cubic form of pyrite developed within original host rock. The pyrite clearly shows striated crystal faces. Sourced from the Dampier area (courtesy Western Australian Museum)**

Figure 24.6. **Polished disk-shaped beads, 30 mm in diameter, highlighting pyrite crystals in a quartz matrix (courtesy Kayley Usher)**

Pyrite and marcasite in Western Australia

Pyrite and marcasite are widely distributed throughout Western Australia, and Simpson (1952) devoted more than 35 pages to pyrite occurrences. Accordingly, it is beyond the scope of this publication to describe these numerous localities.

Geological environments for pyrite and marcasite

In Western Australia, the main geological environments where pyrite and marcasite are likely found may be summarized as:

- Epigenetic gold deposits in Archean granite–greenstones and Precambrian sedimentary rocks. Almost every auriferous quartz reef in the Yilgarn and Pilbara Cratons contains pyrite as crystals, masses, and disseminations.
- Volcanic-hosted, stratabound sedimentary rocks, and carbonate-hosted, base metal deposits. On the Lennard Shelf in the southern Kimberley region, pyrite is associated with copper, lead, and zinc sulfides in several large deposits. Spectacular marcasite has been obtained from large cavities in the carbonate-hosted Goongawa lead, zinc, and silver deposit (Figs 24.1 and 24.7).
- Banded iron-formations. Massive pyrite is commonly associated with iron oxides in banded iron-formations throughout the Yilgarn Craton. For example, at Koolyanobbing in the Southern Cross Domain, pyrite was evaluated as a potential source of sulfur (Fig. 24.1).
- Black, carbonaceous shales. In the Hamersley Basin, Archean–Paleoproterozoic black shales, such as those within the Mount McRae Shale in the Hamersley Group, and also in the Fortescue Group near Millstream, about 115 km south-southeast of Karratha, commonly contain nodules and crystals of pyrite (Fig. 24.8).
- Pyritic replacement of organic material including coal in a reducing environment.

Figure 24.7. **Large, tabular, pale brassy masses of marcasite with white calcite aggregates from the Goongawa lead, zinc, and silver mine, 60 km south-southeast of Fitzroy Crossing in the southern Kimberley region (courtesy Western Australian Museum)**

Figure 24.8. Pyrite sphere formed within the Mount McRae Shale, Millstream area, Hamersley Basin (© Mark Rheinberger)

Tiger eye

Tiger eye is golden-brown, chatoyant, silicified crocidolite. This material should not be confused with tiger eye opal, which is a different gemstone derived from chrysotile, and is discussed in Chapter 10 on opal. Tiger eye fibres are perfectly preserved to a compact mass with hardness of 6.5. The mineral exhibits a constantly changing pattern of reflected light because of its fibrous nature (Mayer, 1976). As a result, carefully cut cabochons exhibit silky lustre and spectacular cats eye effects. In the 19th century, Griquatown and Niekerkshoop in South Africa were the principal sources of tiger eye, which was used in the manufacture of jewellery and small decorative objects. Most of the production from local quarries was exported to Europe where it was once considered a great rarity.

Note that in the literature ‘tiger eye’ (the current, preferred spelling of the golden-brown variety) has been spelled in various ways: tiger’s eye, tiger’s-eye, tigers eye, tigereye, and tiger’s eye opal. Other tiger eye varieties have assumed the following names: hawk’s eye (blue), falcon’s eye (green), and pietersite (brecciated). Also, variegated varieties of tiger eye with mixed colours are not uncommon, and heating of golden-brown tiger eye converts contained limonite to hematite and the resultant red material is called ‘bull’s eye’.

Although there are numerous exposures of crocidolite in Western Australia, especially in the Hamersley Basin, there are relatively few recorded occurrences of tiger eye. Reports of cats eye opal (or tigereye opal) from Yarra Yarra Creek and from Lionel indicate that the material in these deposits is composed of silicified chrysotile, and accordingly are reported under the sections on cats eye and siliciophite in Chapter 10 on opal.

Originally, it was assumed that tiger eye was a pseudomorph of crocidolite formed by silica replacement of crocidolite fibres in a process similar to that of petrified wood. This replacement was thought to take place at or near ancient paleosurfaces and the process was completed together with the gradual staining of the blue crocidolite to a golden-brown by hydrous iron oxides. In this process there was evidence of blue tiger eye forming at depth, changing to a green colour at shallower intervals, and finally to golden-brown tiger eye in the near-surface environment (Fig. 24.9).

Figure 24.9. Silicification and oxidation of blue crocidolite (at top) to yellow tiger eye (beneath)

More recently, an alternative hypothesis has been advanced, suggesting that the introduction of silica was simultaneous with the formation of the crocidolite fibres by a process called 'crack-seal vein filling'. In this process, the cracking of the crocidolite host rock is followed by the deposition of columnar quartz crystals from silica-saturated fluids, and bands or trails of crocidolite microfibres are encapsulated in the quartz (Heaney and Fisher, 2003). Today, the exact mechanism of tiger eye formation remains unresolved.

In the Archean–Paleoproterozoic Hamersley Basin, crocidolite, an acicular form of the sodium–iron silicate mineral riebeckite, is common as fibrous masses within narrow seams in the Marra Mamba and Brockman Iron Formations. Each seam is 15–50 cm in width and comprises 2–20 bands of crocidolite fibres that make up between one-quarter and one-half of the thickness (Trendall and Blockley, 1970). Known tiger eye localities in the State are shown in Figure 24.1. Given that tiger eye is derived from crocidolite, it is possible that it may be found in other crocidolite-rich areas in the Hamersley Basin.

Prospectors and fossickers should note that crocidolite is an asbestiform mineral with serious personal health risks associated with breathing crocidolite microfibres commonly present in the dust. Accordingly, crocidolite outcrops, prospects, disused mines, stockpiles, and tailings dumps should be avoided. Although silicified tiger eye is not considered a health risk, it commonly forms close to the weathered surface of crocidolite veins and prospectors and fossickers should take appropriate measures to avoid any contact with the crocidolite.

Pilbara Craton — Hamersley Basin

Mount Brockman area

In the Mount Brockman area tiger eye is interspersed as blebs and bands within multiple, irregular bands of multicoloured jasper.

Brockman tiger eye jasper (JEERINAH, 2353)

The Brockman tiger eye jasper prospect is adjacent to the Caves Creek valley about 55 km northwest of Tom Price. Access is via the Mount Brockman Road west of the Tom Price Railway and then southwards along rough station tracks. The prospect is within the Archean–Paleoproterozoic Marra Mamba Formation comprising chert, BIF, and pelitic rocks (Fig. 24.10).

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-brown tiger eye. The boulder was removed by heavy machinery and transported to Perth for cutting into thick slabs approximately 3.5 m in length and 0.5 m in height, and the costean was backfilled and rehabilitated.

Polishing of this visually attractive rock revealed its truly spectacular structure of multiple bands of green, blue, red, and orange jasper interspersed with extensive bands and large, triangular-shaped blebs of golden-brown tiger eye (Fig. 24.11a). A petrological examination indicated the presence of bands or veins 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 (Fetherston, 2010).

Jeerinah tiger eye jasper (JEERINAH, 2353)

Approximately 5 km west-northwest of the Brockman tiger eye jasper prospect, and adjacent to Crossing Bore, the Jeerinah tiger eye jasper deposit is on mining lease M47/193 (Fig. 24.10). The Jeerinah deposit also occurs within the Archean Marra Mamba Formation. At this site, irregular zones of red, brown, and green jasper are interspersed with predominantly red tiger eye within banded, iron-rich, metasedimentary rock (Fig. 24.11b).

Originally, a red jasper known as 'picture jasper' was mined from this site. The prospect is currently owned and operated by Mr Barry Kayes who has manufactured polished slabs and spheres from the red tiger eye.

Mount Margaret area

Miller Gorge and Asbestos Gorge (MOUNT BILLROTH, 2454)

Kriewaldt and Ryan (1967) report poor-quality tiger eye in the Brockman Iron Formation within the PYRAMID 1:250 000 map sheet (SF 50-7). Smithies and Hickman (2004) record two occurrences of crocidolite at Miller Gorge and Asbestos Gorge, approximately 1.5 km north and 5 km west-southwest, respectively, of Mount Margaret some 80 km north of Tom Price (Fig. 24.1). It is probable that the tiger eye mentioned above is present at one or more of these localities.

Wittenoom area

Wittenoom Gorge (WITTENOOM, 2553)

There have been unsubstantiated reports of tiger eye found both as pebbles in creek beds and in mullock heaps from the old crocidolite mines in Wittenoom Gorge extending downstream to areas around the old Wittenoom townsite. In these areas prospectors and fossickers should be particularly aware of the inherent serious personal health risks associated with breathing crocidolite dust.

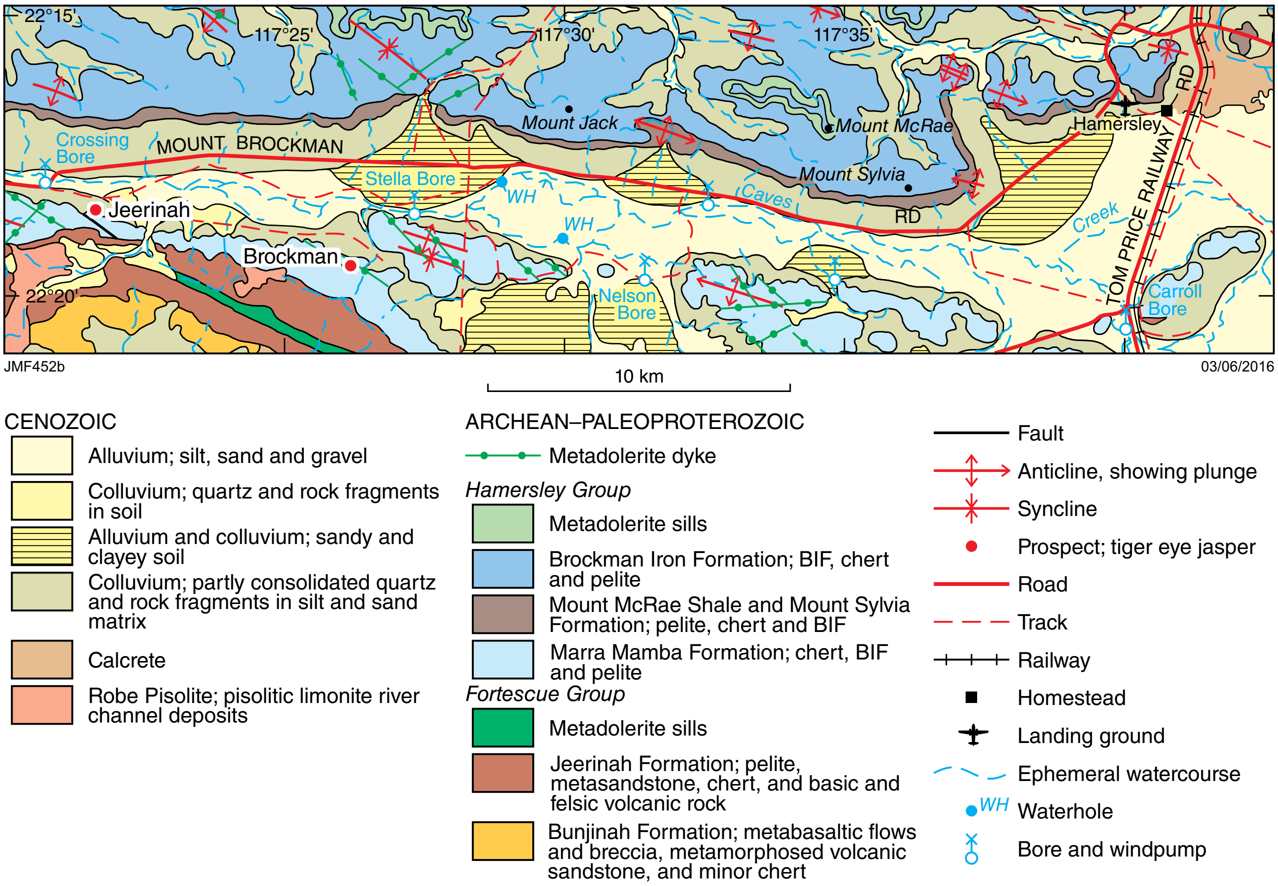

Figure 24.10. Geology of the Mount Brockman area (modified after Blight et al., 1996)

Tiger iron

Tiger iron consists mostly of alternating layers of microcrystalline red hematite and cherty quartz, with lenses and lamellae of golden-brown tiger eye. These alternating bands may vary from straight to highly contorted, tight folds. In past years, tiger iron has been slabbed and polished to emphasize the spectacular banding and tight folding.

Pilbara Craton

De Grey River region

Ord Ranges (*De Grey, 2757*)

The Ord Ranges tiger iron deposits are in the Ord Ranges about 60 km east of Port Hedland and directly west of the north-flowing De Grey River (Fig. 24.1). In this area tiger iron deposits are present within a highly folded BIF, jaspilite, chert, and shale unit within the Cleaverville Formation (Fig. 24.12).

About 1971–72, tiger iron (at that time called ‘tiger-eye opal’) was mined intermittently on former mineral claims MC 7686 (Ord Ranges 1) and about 230 m to the northeast on MC 7013 (Ord Ranges 2). A smaller, unmined site was about 700 m to the west-northwest at Ord Ranges 3. Tiger iron was extracted from a costean on Ord Ranges 1 or by surface ripping on Ord Ranges 2, which produced an unknown quantity of saleable tiger iron, possibly several hundred tonnes (Blockley, 1975). More recently, an unspecified tonnage of high-quality tiger iron was mined from the tiger iron quarry at Ord Ranges 1 (Fig. 24.12). No further details are available.

The ornamental tiger iron, shown in Figure 24.13, is composed of irregularly folded, oxidized BIF bands, on a millimetre to centimetre scale, that alternate with lenses and lamellae of tiger eye. Tiger iron has been used as decorative wall and floor tiles and table tops, and in diverse ornaments (Fetherston, 2010).

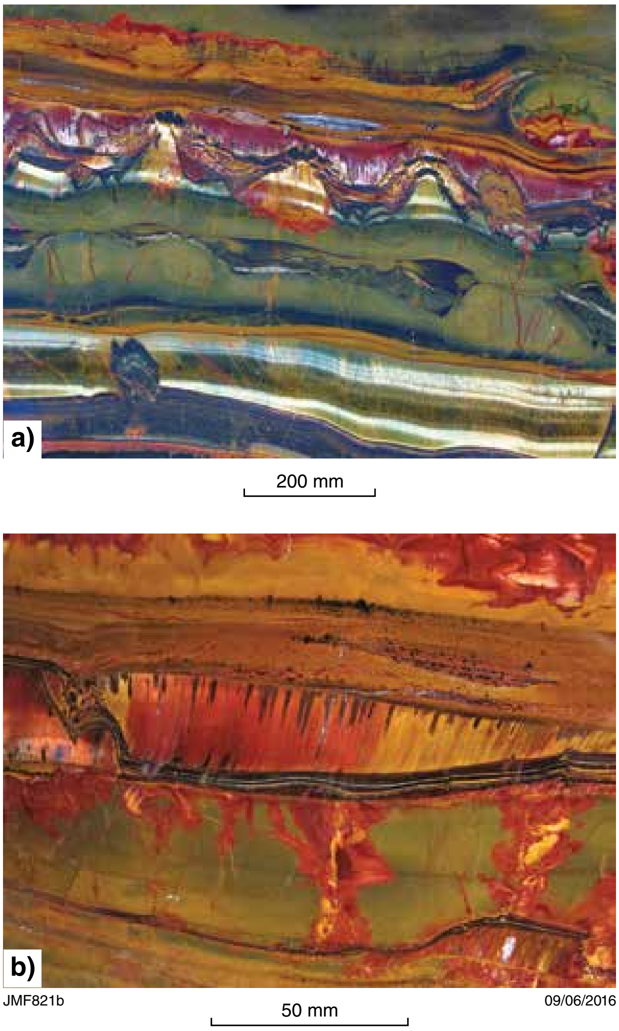

Figure 24.11. Tiger eye jasper from the Mount Brockman area, Hamersley Basin: a) polished section of a large slab of Brockman tiger eye jasper, showing bands and triangular blebs of golden-brown tiger eye interspersed with multiple bands of green, blue, red, and orange jasper (courtesy Glenn Archer); b) Jeerinah tiger eye jasper displaying predominantly red tiger eye interspersed with irregular bands of green, brown, and red jasper (courtesy Barry Kayes)

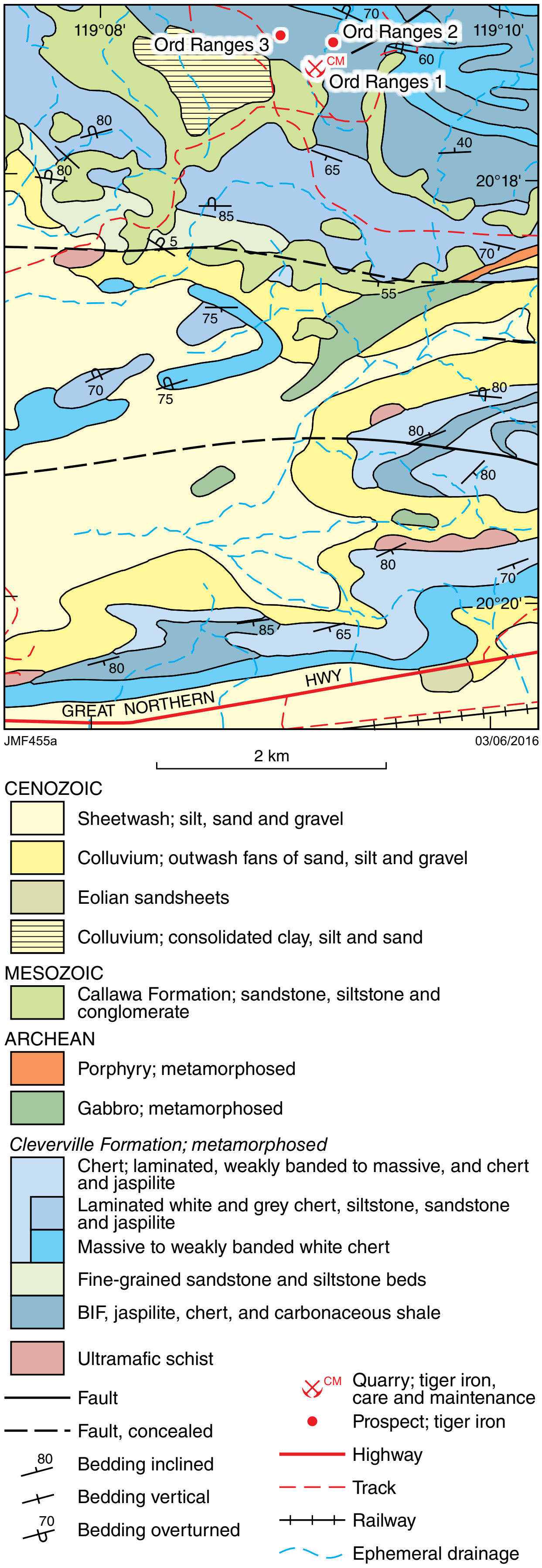

Figure 24.12. (right) Geology around the Ord Ranges tiger iron quarry and prospects (modified after Smithies, 2002)

Figure 24.13. Pair of polished tiger iron bookends showing folded bands of hematite, cherty quartz, and golden-brown tiger eye (courtesy Barry Kayes)

References

Barlett, L 1997, Fool's gold?—the use of marcasite and pyrite from ancient times: The Journal of Gemmology, v. 25, no. 8, p. 517–531.

Blight, DF, Thorne, AM, Blockley, JG and Tyler, IM 1996, Mount Bruce, WA Sheet SF 50-11, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series.

Blockley, JG 1975, The Ord Range tiger-eye deposits: Geological Survey of Western Australia, Annual Report 1975, p. 108–112.

Brown, G and Snow, J 1988, Hematite imitation: The Australian Gemmologist, v. 16, no. 10, p. 371–373.

Fetherston, JM 2010, Dimension stone in Western Australia, volume 2 — dimension stones of the southern, central western, and northern regions: Geological Survey of Western Australia, Mineral Resources Bulletin 24, p. 134–138.

Heaney, PJ and Fisher, DM 2003, New interpretation of the origin of tiger's-eye: Geology, v. 31, no. 4, p. 323–326.

Kriewaldt, M and Ryan, GR 1967, Pyramid, WA: Geological Survey of Western Australia, Explanatory Notes, 39p.

Mayer, W 1976, A field guide to Australian rocks, minerals and gemstones: Rigby Ltd, Adelaide, p. 200.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 401–436.

Smithies, RH 2002, De Grey, WA Sheet 2757: Geological Survey of Western Australia, 1:100 000 Geological Series.

Smithies, RH and Hickman, AH 2004: Pyramid, WA Sheet SF 50-7, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series.

Trendall, AF and Blockley, JG 1970, The iron formations of the Precambrian Hamersley Group Western Australia with special reference to the associated crocidolite: Geological Survey of Western Australia Bulletin 119, p. 174–254.

Chapter 25

Prehnite

Prehnite occurrence, properties, and applications

Prehnite is recorded as the first eponymous mineral. It was named in 1790, after Colonel Von Prehn, who served in the Cape of Good Hope, South Africa.

Prehnite is a common hydrothermal mineral found in cavities in igneous rocks, particularly basalts, and is commonly associated with zeolite minerals and calcite. It is also found in metamorphosed limestones and in pegmatites.

Prehnite is a calcium–aluminium phyllosilicate mineral in which limited iron can substitute for aluminium in the crystal structure. It is commonly green or yellowish-green with a waxy to vitreous lustre although it may also be colourless, white, bluish-green, yellow, brown, and rarely, orange. It is mostly translucent although rare transparent forms are found.

Because prehnite occurs naturally in a massive form, refractive index tests are commonly performed as spot readings, producing an approximate figure. Examination of specimens commonly shows a distinct fibrous, radiating texture. It is this fibrous, radiating texture that gives prehnite its moderate toughness (Fig. 25.1).

Since the early 1990s, prehnite has been supplied to international markets from sources in western Mali in West Africa, for use in the manufacture of beads and carvings, and as mineralogical specimens. Attractive specimen material may feature spherical aggregates of prehnite together with epidote, and prehnite accompanied by andradite garnet and vesuvianite sourced from zones of dolomitic marbles and calc-silicates.

Prehnite is a relatively common material available to local lapidaries. Because of its translucent to semitransparent diaphaneity, prehnite may be faceted although it is more commonly cut as cabochons or used as a bead material, and is often displayed at local gem fairs (Fig. 25.2).

Prehnite
Hydrated calcium aluminium silicate $Ca_2Al_2Si_3O_{10}(OH)_2$

Because of its pale green colour, prehnite appears similar to bowenite (a serpentine mineral) and both minerals are used to imitate jade. For example, at Wave Hill in the Northern Territory, yellow to yellow-green prehnite is mined from basalt in the Antrim Plateau Volcanics, and after carving and polishing is marketed under the registered trade mark 'SunJade' (Openallday, 2012).

Physical properties of prehnite

Crystal system	Orthorhombic (rare as individual crystals)
Habit	Nodular, commonly in groups of tabular crystals as globular, radiating rosettes
Colour range	Colourless, light green to bluish-green, grey, and brown
Lustre	Waxy, pearly, and vitreous
Diaphaneity	Translucent to semitransparent
Refractive index	1.616 – 1.649
Birefringence	0.022 – 0.033
Pleochroism	Nil
Specific gravity	2.80 – 2.95
Cleavage	Good

Figure 25.1. Detail of prehnite crystal showing its fibrous, radiating texture (courtesy Barry Kayes)

Figure 25.2. **Prehnite jewellery: a) 4 ct faceted stone exhibiting prehnite's typical milky translucency, sourced from the Kimberley region (courtesy WA Branch, Gemmological Association of Australia); b) mid-green prehnite cut and polished as decorative hearts, from the Flora Valley prehnite prospect area, east Kimberley region (courtesy Barry Kayes); c) prehnite necklace of spherical beads (diameter 15 mm) containing dark-coloured epidote inclusions (courtesy Kayley Usher)**

Prehnite in Western Australia

Most prehnite marketed in Western Australia comes from the Antrim Plateau Volcanics, which cover large areas that extend over 400 km along the State border in the east Kimberley region. Prehnite is also recorded in pegmatites, accompanying copper minerals, and is associated with calcite and gypsum in some gold veins (Simpson, 1952). The School of Mines Museum in Kalgoorlie features a specimen of quartz and prehnite from the Londonderry pegmatite south of Coolgardie.

The late Cambrian Antrim Plateau Volcanics form Australia's largest Phanerozoic flood-basalt province. The unit outcrops extensively in the east Kimberley region of Western Australia and the Victoria and Daly River Basin areas of the Northern Territory. The present area of exposure covers about 35 000 km^2 although there is evidence that the field extends as far east as the Northern Territory – Queensland border. Outliers of these volcanic rocks are also found west of Halls Creek, which suggests that the Antrim Plateau volcanic field covered an original area of up to 400 000 km^2 (Pirajno, 2000).

The Antrim Plateau Volcanics are predominantly tholeiitic basalts that show a remarkably uniform chemistry. They have a maximum thickness of more than 1000 m in the west and typically exhibit very gentle dips and appear to have had little tectonic disturbance. Individual lava flows are typically 20–60 m thick with a maximum thickness of 200 m. The flows are mostly aphanitic, massive basalt with vesicular or brecciated flow tops intercalated with sedimentary rocks including sandstone, conglomerate, siltstone, and chert. Some chert deposits may be derived from hot spring precipitates.

In the Antrim Plateau Volcanics, prehnite readily weathers out from the decomposed basalt to form rounded nodules that can be found on the surface or concentrated in stream channels. Prehnite may be found almost anywhere in the Antrim Plateau Volcanics, although the best known occurrence is at Wave Hill in the Northern Territory (Bracewell, 1989). In creek beds between Halls Creek and Kununurra, waterworn prehnite pebbles up to 30 mm in length are relatively common. These are translucent and may vary from almost colourless to pale green and some specimens show the mineral's radiating texture.

Ord Basin

Flora Valley area prospects *(Antrim, 4561)*

Between Halls Creek and the State border, the Antrim Plateau Volcanics, which comprise the lowermost unit of the early Paleozoic Ord Basin, form extensive outcrops of basalt (Mory and Beere, 1998). In this area, many sites containing prehnite have been found within the basaltic flows.

About 80 km and 50 km east-northeast of Halls Creek and Flora Valley Homestead, several prehnite sites have been evaluated intermittently over the last 20 years. At these sites, known as the Mound and Flora Valley prospects, respectively, prehnite forms in either amygdales or veins, and is also commonly found scattered as nodules on the surface (Fig. 25.3). In a few places there are concentrations of residual material containing prehnite (Mullumby, 1996). More recently, a third prospect, known as the New Prospect, has been located about 2 km southwest of the Mound prospect (Fig. 25.4). No further information relating to these prospects is available.

Figure 25.3. (left) Prehnite crystals, showing rosette structure, attached to a portion of an inside wall of an amygdale formed in basaltic lava at Flora Valley, east Kimberley (courtesy Barry Kayes)

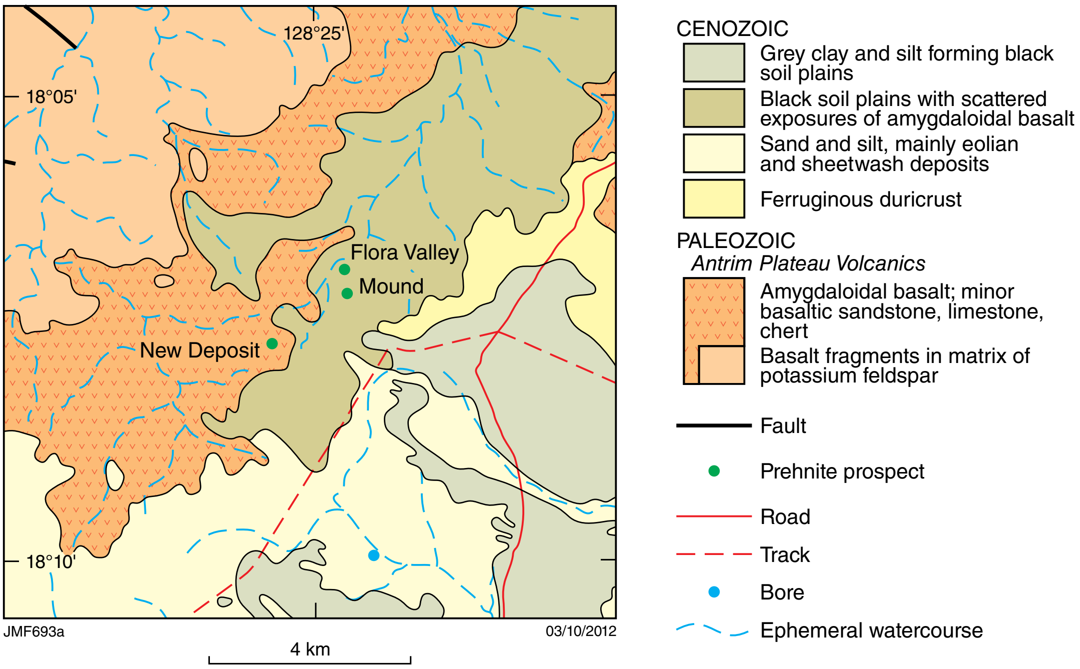

Figure 25.4. Geological map of the area surrounding the Flora Valley prehnite prospects (modified after Blake et al., 2000)

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry feldspar pegmatite (Yilmia, 3135)

The Londonderry feldspar pegmatite is about 20 km south-southwest of Coolgardie via the Nepean Road (Fig. 8.5, Chapter 8 on minor pegmatite gemstones).

In the Londonderry feldspar pegmatite quarry, prehnite forms light green prehnite–quartz pseudomorphs after petalite displayed as fine- to coarse-grained masses with a faint relict basal (001) cleavage. The prehnite may account for up to 80% of these pseudomorphs and have mutually interfering sheaves or fan-shaped crystals up to 3 × 2 mm. Masses of light green prehnite crystals up to 3–4 cm are common in mullock heaps and debris within the southwestern pegmatite pit. Occasional vugs up to 0.5 cm in diameter are present in masses containing radiating euhedral green prehnite crystals (Jacobson et al., 2007).

Edmund Basin

Mount Vernon area

Mount Vernon (Mount Vernon, 2549)

In the Mount Vernon area, about 110 km south-southeast of Paraburdoo, there are unconfirmed reports of prehnite north of Mount Vernon. No information is available on the exact location or size of this deposit, although a large cut and polished specimen of prehnite purporting to be from this locality has been reported by Cyril Richter (Fig. 25.5).

Figure 25.5. Pale blue prehnite from an unknown locality north of Mount Vernon (courtesy Cyril Richter)

References

Blake, DH, Warren, RG, Griffin, TJ, Tyler, IM and Thorne, AM 2000, Gordon Downs, WA Sheet SE 52-10, 2nd edition: Geoscience Australia, Canberra, 1:250 000 Geological Series.

Bracewell, H 1989, Wave Hill prehnite: The Australian Gemmologist, v. 17, no. 4, p. 127–128.

Jacobson, MI, Calderwood, MA and Grguric, BA 2007, Guidebook to the pegmatites of Western Australia: Hesperian Press, Perth, Western Australia, p. 275.

Mory, AJ and Beere, GM 1988, Geology of the onshore Bonaparte and Ord Basins in Western Australia: Geological Survey of Western Australia, Bulletin 134, p. 9–15.

Mullumby, BG 1996, Annual report. Exploration Licence E80/1479, Flora Valley Area, Kimberley Mineral Field: Geological Survey of Western Australia, Statutory mineral exploration report, A47529 (unpublished).

Openallday 2012, Prehnite (grape stone) SunJade, viewed 18 June 2012, <http://www.openallday.com.au/SunJade.html>.

Pirajno, F 2000, Ore deposits and mantle plumes: Kluwer Academic Publishers, Dordrecht, p. 166–167.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 362–364.

Chapter 26

Rhodonite

Rhodonite properties

Rhodonite is never pure manganese silicate ($MnSiO_3$), as it always contains some calcium, with the calcium-rich variety known as bustamite. Also, it may contain a little ferric iron, and ferrous iron up to 14.5% FeO.

Rhodonite is normally pale pink to red, although yellow and grey varieties have been reported. It is commonly attractively patterned with black bands, veinlets, and dendrites of secondary manganese and is best known as an ornamental mineral in its massive form, with well-formed crystals being rare (Fig. 26.1). Spectacular rhodonite crystals have been found at the Broken Hill mine in New South Wales.

Physical properties of rhodonite

Crystal system	Triclinic
Habit	Prismatic, or massive
Colour range	Black, brown, pink, and red
Lustre	Vitreous to dull
Diaphaneity	Subtransparent to opaque
Refractive index	1.711 – 1.751
Birefringence	0.014
Pleochoism	Weak
Hardness	5.5 – 6.5
Specific gravity	3.57 – 3.76
Cleavage	Perfect

Rhodonite may occur as a primary manganese mineral and is commonly associated with tephroite (Mn_2SiO_4) and hausmannite (Mn_3O_4) among others. Hausmannite is especially common in New South Wales where most manganese exists as metamorphosed stratiform deposits of manganese silicates that probably formed on ancient sea floors. Rhodonite may be found in pegmatites as the result of assimilation of manganese-rich country rock, and it also forms from the contact metamorphism of rhodochrosite ($MnCO_3$) or calc-silicate rocks. It has been found that rhodonite from contact-metamorphosed environments is of higher quality and brighter colour than material from regionally metamorphosed deposits. The most significant rhodonite occurrences in Australia are in New South Wales, particularly in the New England region.

JMF827 06/09/2012

Figure 26.1. Pink rhodonite patterned with black veinlets and dendrites of secondary manganese from Tamworth, New South Wales (courtesy Barry Kayes)

Rhodonite in Western Australia

Even though there are numerous deposits of manganese in Western Australia, most are oxide type and rhodonite is rare. Geological Survey of Western Australia (1994) reported only one occurrence in the Pilbara region.

Rhodonite
Manganese silicate $(Mn,Fe,Ca)SiO_3$

Pilbara Craton

Roebourne area

Five Mile Well (Roebourne, 2356)

Rhodonite has been reported from Five Mile Well, approximately 7 km northeast of Roebourne (Fig. 26.2a). No further information is available.

Albany–Fraser Orogen

Hopetoun area

Hamersley Gorge (Cocanarup, 2830)

Simpson (1952) reported small patches of flesh-pink rhodonite associated with psilomelane (a manganese oxide mineral) in the Hamersley River area close to the south coast. This river rises a few kilometres north of the South Coast Highway between Jerramungup and Ravensthorpe and flows through the Fitzgerald River National Park into the ocean directly to the west of Edwards Point. De la Hunty (1963) reported on syngenetic manganese from the Hamersley Gorge about 18 km west-northwest of Hopetoun (Fig. 26.2b). This prospect may be the location of the rhodonite samples.

References

De la Hunty, LE 1963, The Geology of the Manganese Deposits of Western Australia: Geological Survey of Western Australia, Bulletin 116, p. 111.

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, 52p.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 487.

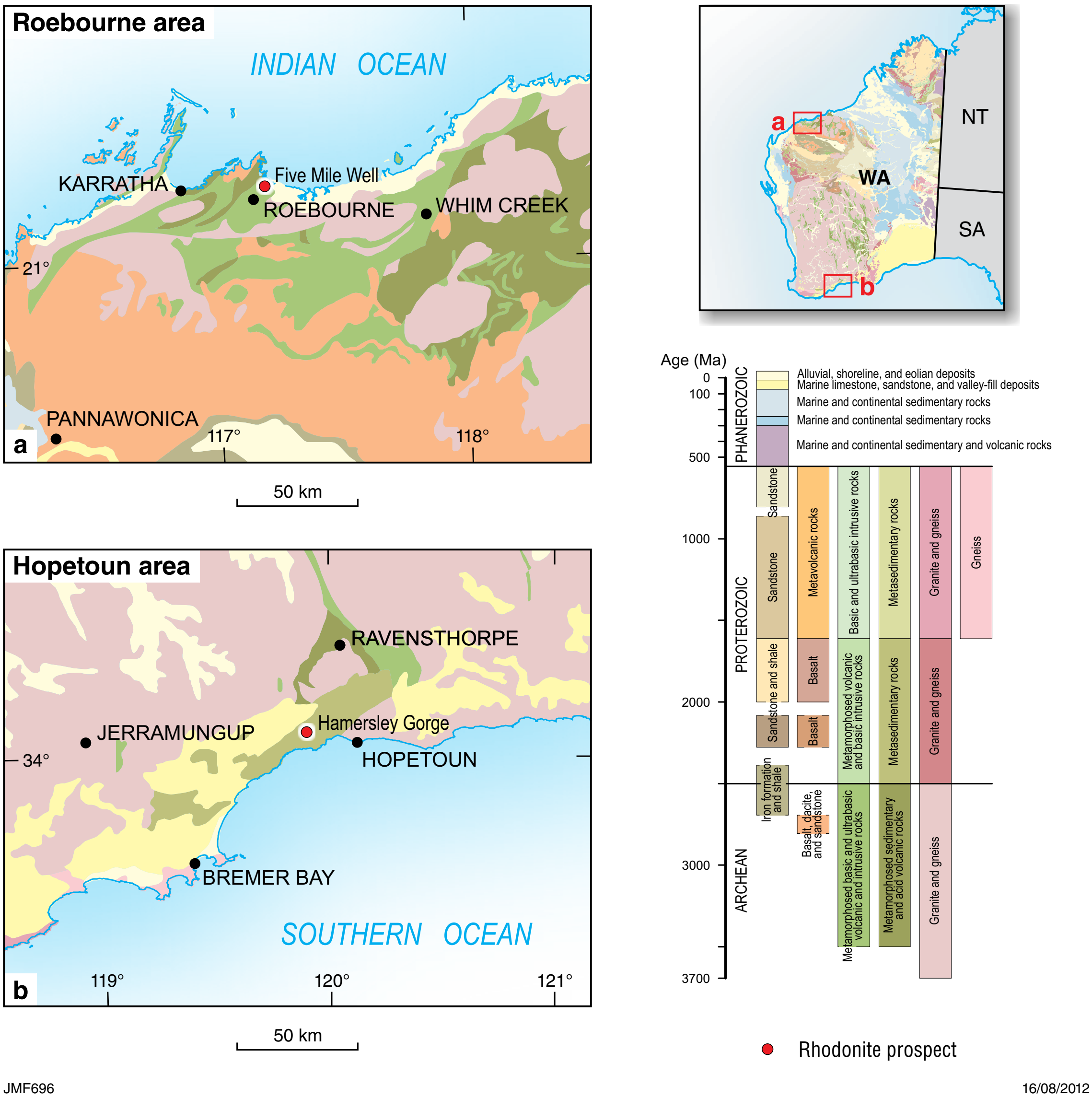

Figure 26.2. Locations of rhodonite prospects in Western Australia: a) Roebourne area; b) Hopetoun area

Chapter 27

Variscite

Variscite properties

Ornamental variscite, a hydrated aluminium phosphate, is a visually attractive, fine-grained, massive mineral typically yellow-green to blue-green, although may also be white to light brown. Variscite is commonly closely associated with turquoise, the best-known ornamental phosphate gem material, which is commonly bright blue and comprises hydrated copper–aluminium phosphate. These two minerals have several physical characteristics and applications in common. For example, as a gemstone, variscite is commonly used together with its matrix minerals and relict host rock with the resulting reticulated patterns reminiscent of variations in colour and textures commonly seen in turquoise-in-matrix.

Variscite is an orthorhombic, secondary mineral that forms at low temperatures and is commonly associated with other hydrated minerals, particularly as its monoclinic dimorph metavariscite. Variscite commonly forms as veins and nodular encrustations both within and over a variety of rock types. Variscite may also form as a replacement mineral in situ from phosphate-bearing fluids reacting with fine-grained, clay-bearing aluminous rocks. It is also reported forming at ambient temperatures with other phosphate minerals within soils, and by chemical action from bird guano on various substrates including serpentinite.

Variscite can be cut, carved, and polished. However, because of its moderate hardness and the porous nature of its associated matrix materials it is commonly impregnated with synthetic resins to minimize damage and staining (Fig. 27.1).

Variscite in Western Australia

Variscite deposits and prospects in Western Australia are comparatively few in number and are mostly in the central western part of State in the Paleoproterozoic–Mesoproterozoic Bryah and Edmund Basins (at two and four sites, respectively). Another two locations are recorded further south in the northern Murchison Domain, part of the Archean Yilgarn Craton. Also, small variscite occurrences, mostly from unknown sites, have been recorded together with other phosphate minerals associated with bird guano deposits.

Intermittent variscite mining is recorded from only two sites at Mount Deverell in the Edmund Basin from the early 1970s to the mid-2000s. Department of Mines and Petroleum statistical returns indicate the total production of variscite was about 850 t over 14 years from 1992 to 2005. More recent exploration in the Edmund Basin has located a new, high-quality variscite deposit in the Waldburg Range on Woodlands Station.

Locations of variscite mines and prospects in the State are shown in Figure 27.2 and more detailed locational information on these sites is given in Appendix 1.

Variscite
Hydrated aluminium phosphate $Al\ PO_4.2H_20$

Physical properties of the Waldburg variscite

Crystal system	Orthorhombic
Habit	Microcrystalline, commonly fibrous, forming in seams and as encrustations in colloform or botryoidal aggregations
Colour range	Yellow-green to blue-green, and white to light brown
Colour cause	Chromium and vanadium chromophores
Lustre	Subvitreous to waxy
Diaphaneity	Opaque to semitranslucent
Refractive index	1.570 – 1.582
Birefringence	Small
Pleochroism	Not detectable
Hardness	4–5
Specific gravity	2.49 – 2.55
Fracture	Splintery (massive forms), uneven (glassy forms)
Processing and display	Some samples are impregnated with synthetic resins to stabilize colour and matrix material. Cut, polished, and carved, and commonly used together with host rock matrix
Associated minerals	Metavariscite, crandallite, wardite, and other hydrated phosphate and iron-bearing minerals

Source: Willing et al. (2008)

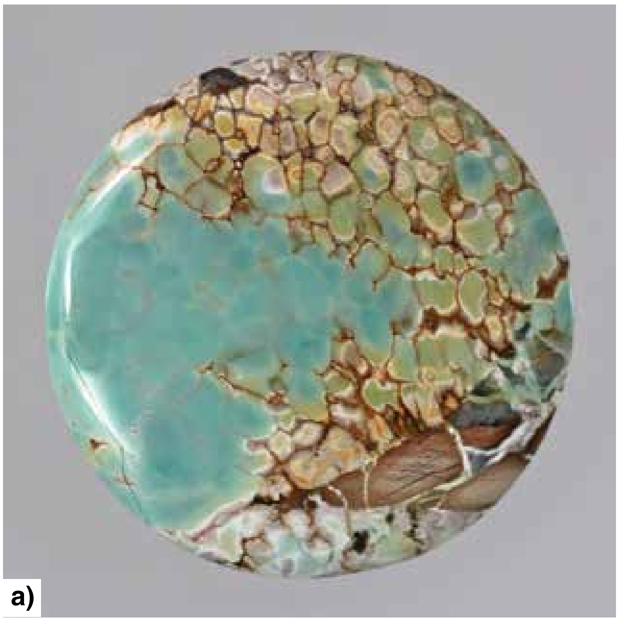

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Figure 27.1. **Examples of variscite jewellery from Mount Deverell, Gascoyne River region: a) circular, blue-green variscite cabochon 36 mm in diameter (courtesy Murray Thompson); b) pendant, 35 mm in diameter, consisting of bluish-green variscite veins interspersed with fine-grained, siliceous mudstone (courtesy Barry Kayes)**

Bryah Basin

Robinson Ranges

Dimble Creek 1 and 2 (Padbury, 2546)

Dimble Creek 1 and 2 variscite prospects are directly north of the Robinson Ranges, approximately 110 km north-northwest of Meekatharra, and 8 km northwest (Dimble Creek 1) and 11 km north-northwest (Dimble Creek 2) of Mount Padbury (Fig. 27.2).

At these sites, the variscite consists of green encrustations over deeply weathered, high-magnesium metabasalt, and ultramafic to mafic schists of the Narracoota Formation, part of the Paleoproterozoic Bryah Group. In the case of the Dimble Creek 1 prospect, Elias and Williams (1980) suggested that because the variscite is only at the summit of a prominent hill, it may have been formed by the reaction of bird guano with the underlying basaltic rocks.

Edmund Basin

Sawback Range

Sawback Range prospect (Marquis, 2447)

The Sawback Range variscite prospect is directly south of the Gascoyne River on Milgun Station, about 175 km north-northwest of Meekatharra (Fig. 27.2).

In this area, variscite is found in the Paleoproterozoic–Mesoproterozoic Jillawarra Formation, which comprises siltstone and shale with minor chert. At the main site, variscite forms irregular patches in brecciated chert. Nearby, another minor variscite occurrence is present in thin, crosscutting veins, up to 10 mm thick, in a dark grey mudstone overlying a dolerite sill (Elias and Williams, 1980).

Milgun Station

Mount Deverell and Mount Deverell East (Mulgul, 2548)

In the Gascoyne River region, 180 km north-northwest of Meekatharra and approximately 15 km north-northwest of Milgun Station, the Mount Deverell (prospecting licence P52/1324) and Mount Deverell East (mining lease M52/1044) deposits were, until now, the main production sites for variscite in Western Australia (Fig. 27.2). As previously mentioned, between 1992 and 2005 these opencut mines produced about 850 t of variscite. Campaign mining continues according to demand.

The Mount Deverell deposits are within the Mesoproterozoic shale and mudstone of the Kiangi Creek Formation near the adjoining dolomite of the Irregully Formation (Fig. 27.3). The variscite is found in narrow,

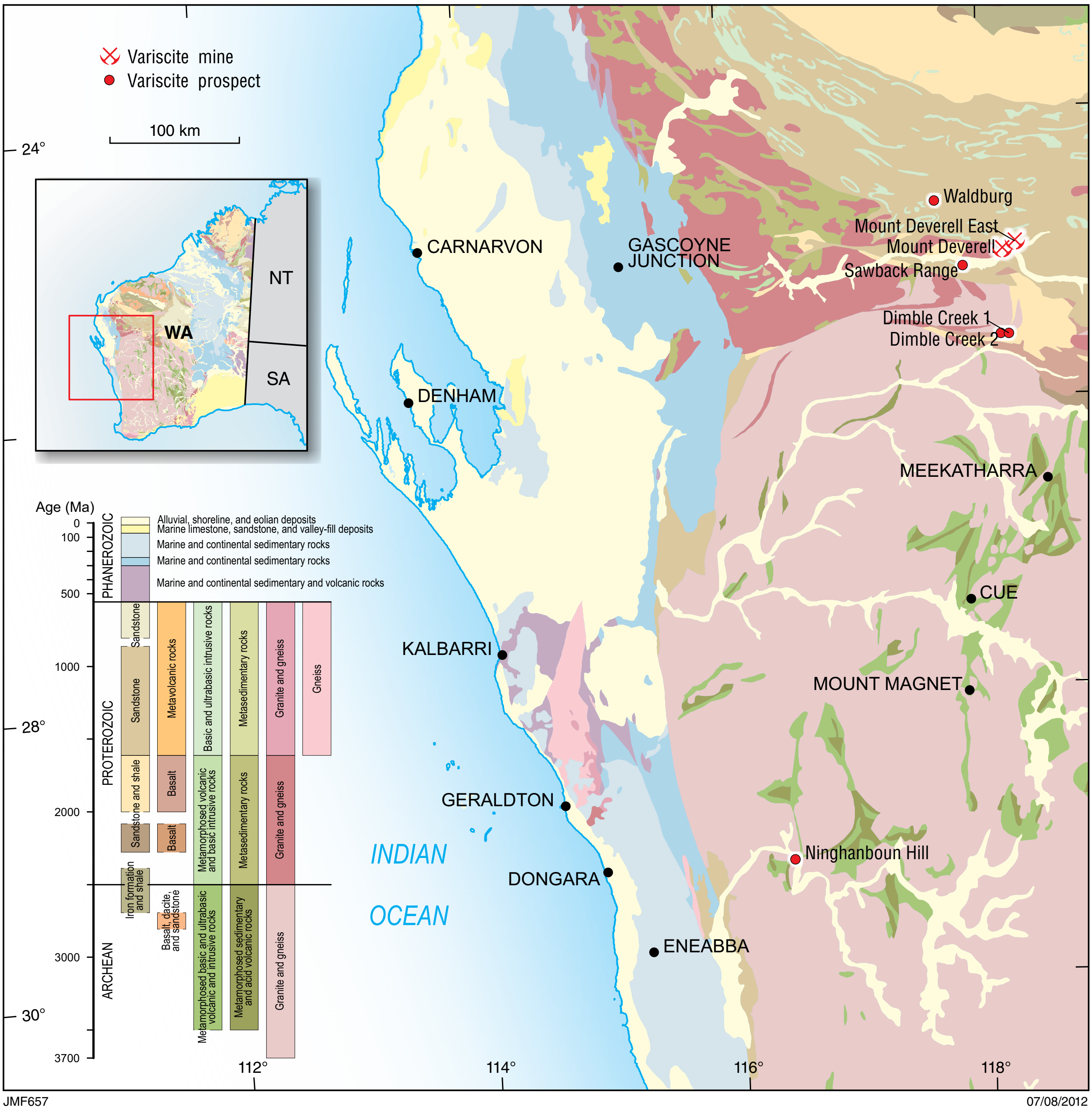

Figure 27.2. Locations of variscite mines and prospects in Western Australia

near-surface, fault-controlled veins less than 100 mm wide, cutting irregularly silicified shale and mudstone. Associated minerals include wardite (Na–Al phosphate mineral), crandallite, turquoise, alunite, gypsum, and rare magnesian collinsite (Bridge and Pryce, 1974).

In recent years, most varicite production has come from the Mount Deverell opencut. At this site variscite mineralization extends in north–south trending veins over 2–3 km. Owned and operated by Mr Barry Kayes, variscite recovered from this operation has produced spectacular cabochons and pendants (Fig. 27.1).

Woodlands Station

Waldburg deposit *(Mount Egerton, 2448)*

The Waldburg variscite deposit (also known as Woodlands variscite) was discovered in 2005 by prospectors in the Waldburg Range approximately 230 km north-northwest of Meekatharra, and 47 km west-northwest of Woodlands Station (Fig. 27.2).

This newly explored deposit outcrops sporadically for at least 1 km along strike and trial mining has been carried out at one small opencut. At this site variscite mineralization

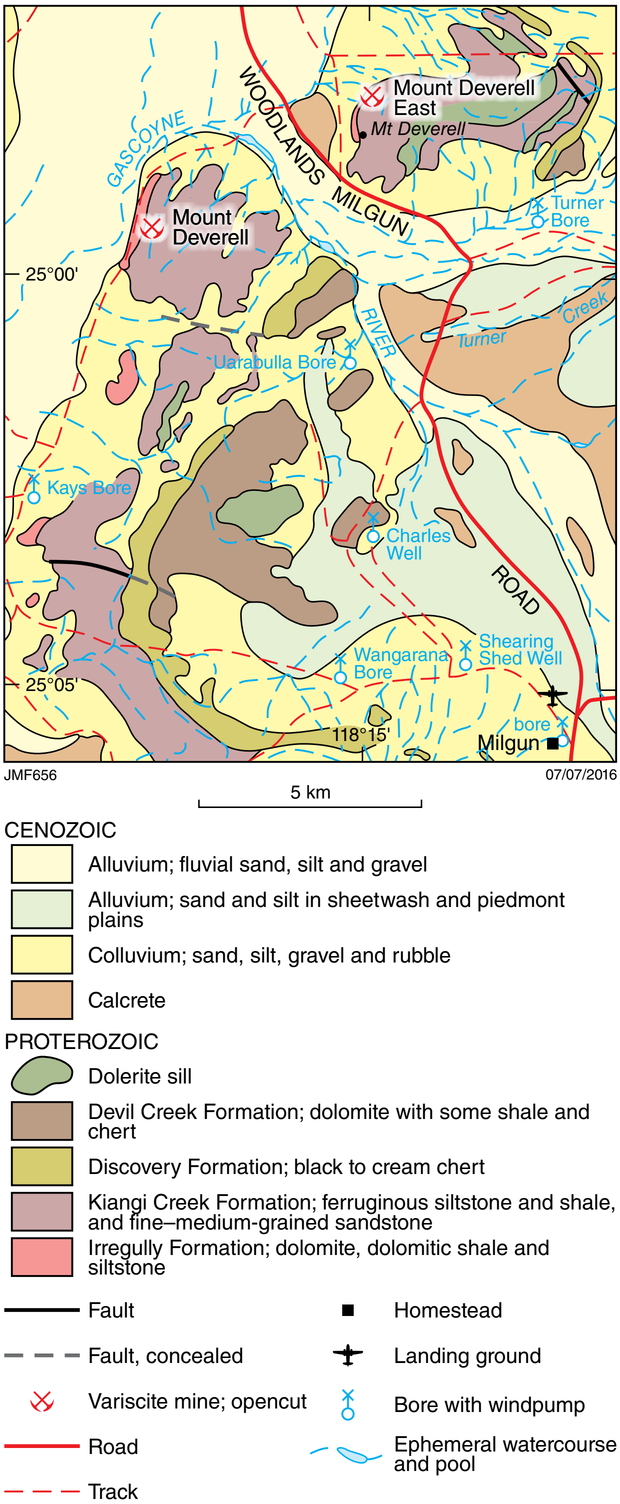

Figure 27.3. **Geological map of the area around the Mount Deverell variscite mines (modified after Muhling et al., 1977 and Occhipinti et al., 2002)**

occurs in a zone 0.5 m wide as several veins or sheets within folded, brecciated shale, siltstone, and fine-grained sandstone of the Mesoproterozoic Kiangi Creek Formation, locally intruded by Mesoproterozoic dolerite sills (Fig. 27.4). Veins contain both massive and spindle-shaped aggregations of variscite together with other phosphate minerals: metavariscite, turquoise, crandallite, apatite, wardite, and small amounts of montgomeryite, millisite, and strengite. Non-phosphatic minerals include gold, quartz, kaolinite, alunite, and jarosite.

Within the mineralized zone, conformable, stratabound variscite veins are comparatively thin, ranging from 10 to 50 mm thick. Also the ‘main vein’, a discordant, late-stage vein 30–50 mm thick, cuts across the sedimentary rocks at a low angle. The conformable, early-stage veins consist in places of pale green variscite, with spherules of wardite along vein margins. However, at other sites conformable seams contain mostly porous, bluish turquoise, and small inclusions of apatite, along with larger, nodular, intergrown masses of variscite, quartz, and apatite. By contrast, the thicker, discordant main vein differs markedly from the thinner conformable veins because it contains a heterogeneous intergrowth of variscite and crandallite in a variety of textures and colours ranging from pale lime-green to mid-green (similar to high-quality, green chrysoprase), and to translucent emerald-green (Figs 27.5 and 27.6).

The discordant main vein is of principal gemmological interest because it contains gem-quality, translucent variscite that is commonly dark emerald-green. Nickel et al. (2008) demonstrated that the chromophore element chromium (up to 0.2% Cr by weight) is responsible for the colour zonation present in the variscite, which ranges from light to dark emerald-green.

Diverse textures present in the main vein variscite include:

- relatively massive blocks of colour-zoned, green variscite (Fig. 27.7)
- finely fractured, spindle-shaped masses up to 1–2 cm in diameter of colour-zoned variscite displaying a spiderweb fracture pattern infilled with pale brown crandallite commonly intermixed with yellow alunite–jarosite and kaolinite (Fig. 27.8a,b)
- balloon-shaped masses of colour-zoned, green variscite
- nodular variscite aggregates in a brown siltstone matrix
- brecciated material comprising fragments of dark green variscite, quartz, and siltstone.

Also, variscite in the main vein has been shown to have an association with irregularly dispersed gold particles, which vary from visible, spongy grains, some with dendritic growths, present on boundaries and fractures in the variscite, and micrometre-sized particles with a delicate, lace-like texture (Fig. 27.8c; Nickel et al., 2008). Waldburg variscite has been cut and polished as spectacular slabs, cabochons, and carvings (Fig. 27.9).

The Waldburg (Woodlands) variscite deposit is discussed in some detail in a paper by Willing et al. (2008).

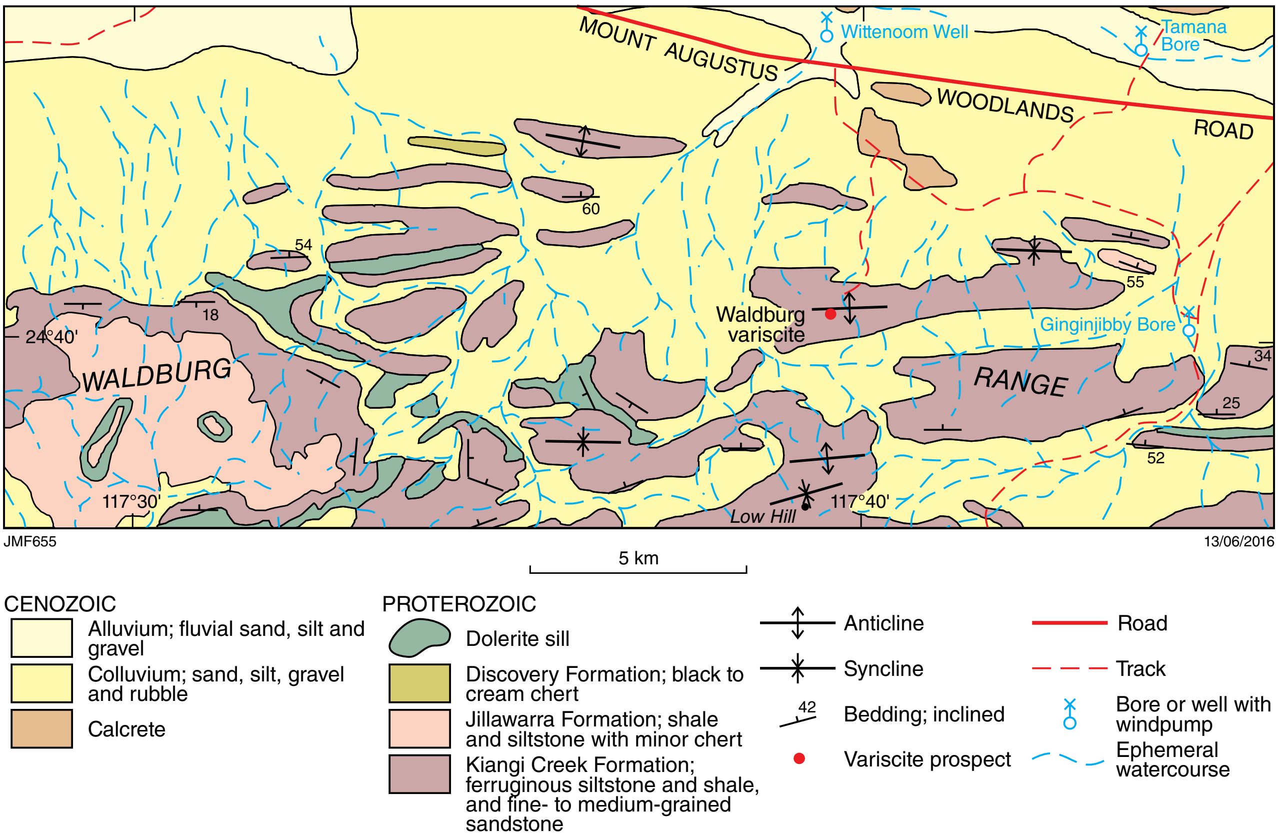

Figure 27.4. Geological map of the area around the Waldburg variscite deposit (modified after Muhling et al., 1977)

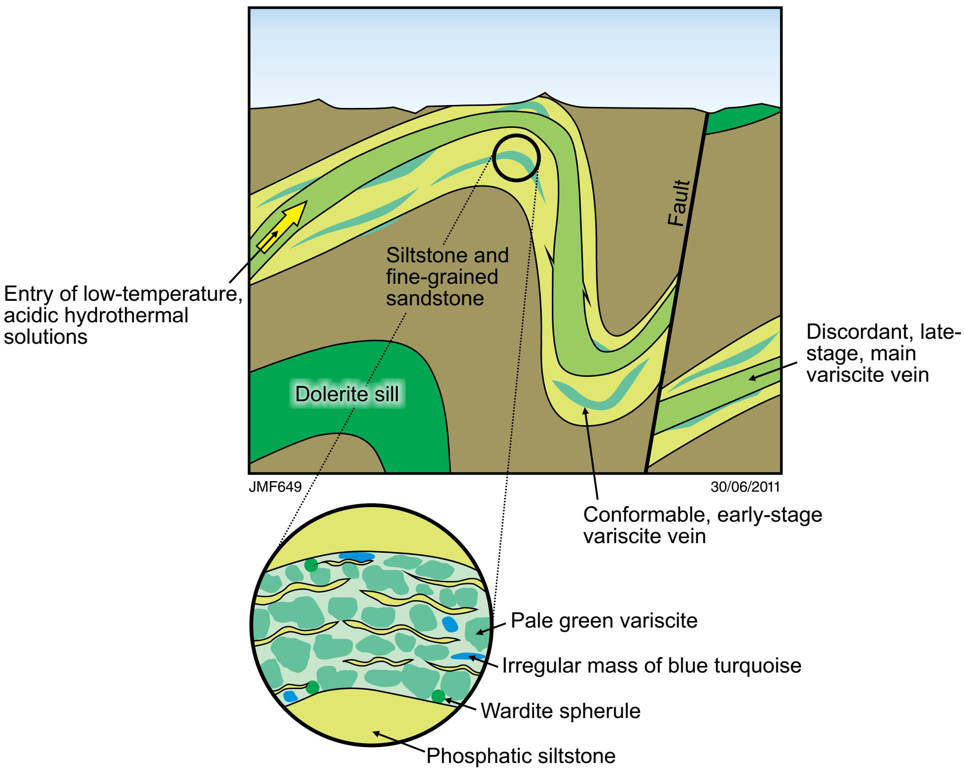

Figure 27.5. Schematic cross-section of the Waldburg variscite deposit (modified after Nickel et al., 2008)

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~ 250 mm

Figure 27.6. Mineralized variscite zone exposed in the Waldburg opencut (courtesy Glenn Archer, Australian Outback Mining)

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Figure 27.7. Superb carving in massive Waldburg variscite. Created by German master craftsmen, the fish is approximately 25 cm in length. The polished red eye is hessonite, a variety of grossular garnet (courtesy David Vaughan)

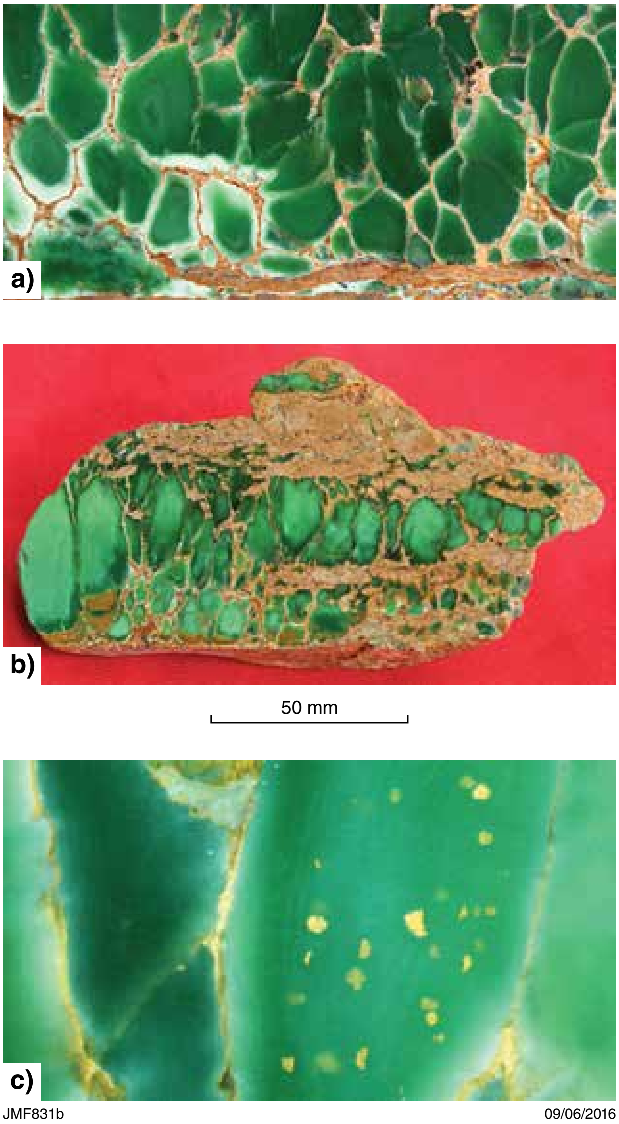

Figure 27.8. **Spindle-shaped masses of main vein, deep green, colour-zoned variscite: a) distinctive spiderweb fracture pattern surrounding variscite spindles 1–2 cm in diameter with fractures filled with pale brown crandallite; sectioned parallel to main vein upper surface; b) cross-section of variscite spindles in a crandallite matrix, normal to the surface of the main vein; c) variscite spindle containing approximately 1 mm-diameter, irregularly dispersed gold particles (courtesy David Vaughan and Lena Hancock)**

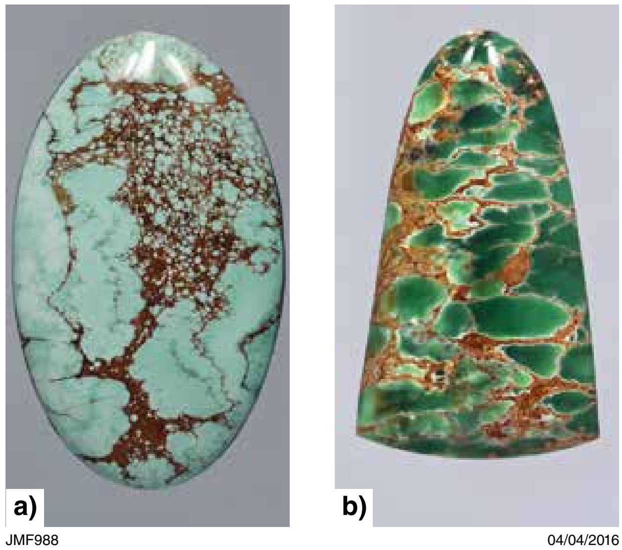

Figure 27.9. **Artistically cut and polished variscite cabochons from the Waldburg deposit: a) oval blue-green cabochon measuring 62 x 31 mm; b) thimble-shaped cabochon displaying the distinctive emerald-green variscite in matrix spiderweb fracture pattern, height 48 x 27 mm basal width (images courtesy Murray Thompson)**

Yilgarn Craton — Murchison Domain

Weelhamby Lake

Ninghanboun Hill (*Perenjori, 2139*)

Variscite is found in two, narrow, east–west-trending Archean serpentinite veins on a hillock adjacent to Ninghanboun Hill, 30 km north-northeast of the town of Perenjori and approximately 1 km west of Weelhamby Lake (Fig. 27.2).

At Ninghanboun Hill, the variscite is multicoloured, ranging from pure white to various shades of green, pink, and light brown. It is intimately mixed with granular chalcedony and opal. Simpson (1952) reported that most of this material is redonite, an aluminium–iron phosphate variety of variscite, with the green colour caused by the presence of chromium. Simpson (1952) also stated that the redonite occurrence on the serpentine hillock close to the lake edge may have been formed by the reaction of bird guano with the underlying serpentine-rich rocks as replacement vein and fissure fillings.

Meekatharra area

Belele Station (Tieraco, 2545)

Brown and green variscite has been reported from an unknown locality on Belele Station near Meekatharra. Simpson (1952) reported that this material was redonite, a ferriferous variety of variscite with the green caused by the presence of chromium.

References

Bridge, PJ and Pryce, MW 1974, Magnesian collinsite from Milgun Station, Western Australia: Mineral Magazine, v. 39, p. 577–579.

Elias, M and Williams, SJ 1980, Robinson Range Western Australia Sheet SG 50-7: Geological Survey of Western Australia 1:250 000 Geological Series, Explanatory Notes, p. 28.

Muhling, PC, Brakel, AT and Davidson, WA 1977, Mt Egerton, WA Sheet SG 50-3: Geological Survey of Western Australia, 1:250 000 Geological Series.

Occhipinti, SA, Sheppard, S, Swager, CP, Myers, JS and Tyler, IM 2002, Robinson Range, WA Sheet SG 50-7, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series.

Nickel, EH, Hough, RM, Verrall, MR, Hancock, E, Thorne, AM and Vaughan, D 2008, The Woodlands variscite–gold occurrence in the north Gascoyne region of Western Australia: Australian Journal of Mineralogy, v. 14, no. 1, June, p. 27–36.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 690–695.

Willing, M, Stocklmayer, S and Wells, M 2008, Ornamental variscite: a new gemstone resource from Western Australia: The Journal of Gemmology, v. 31, no. 3–4, p. 111–124.

7

Decorative stones

Angular fragments of brecciated pink opal, cemented by iron and silica, from the near-surface zone (courtesy Glenn Archer)

Chapter 28

Carbonate group

Carbonate minerals

The minerals listed in this chapter are the most common in the anhydrous carbonate group. While most crystallize in the trigonal (rhombohedral) system, aragonite ($CaCO_3$) crystallizes in the orthorhombic system. Ferruginous magnesite, $FeMg(CO_3)_2$, is known as breunnerite and is commonly associated with magnesite. Crystal specimens of calcite, siderite, and ankerite are all featured as display specimens in both the Kalgoorlie School of Mines Museum, and the Western Australian Museum in Perth.

Carbonate minerals are not commonly encountered in jewellery although transparent calcite (also known as 'Iceland spar') and magnesite are occasionally faceted to demonstrate their high birefringence (Fig. 28.1). Carbonate rocks (limestone, marble, dolomite, and magnesite) are all used as carving and bead materials and are cut and polished to make small decorative items. Limestone and dolomite are quarried on a large scale and used as dimension stone, and stromatolitic limestone is favoured for ornamental works. All of these carbonate rocks are degraded by acidic solution action, which affects their durability. As they are also porous, they are commonly dyed for jewellery use.

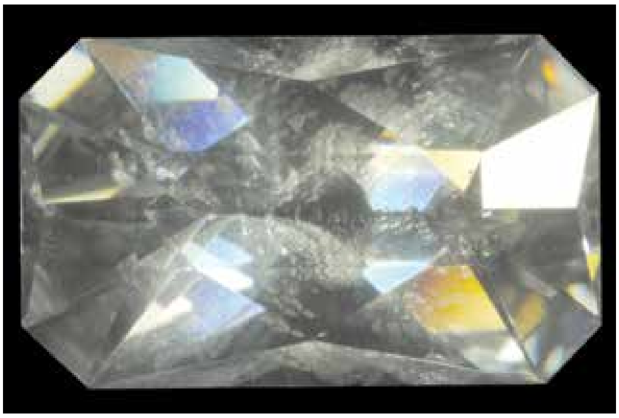

Figure 28.1 Faceted, colourless magnesite crystal, 12.25 x 7.77 mm, showing a doubling effect of facets and inclusions (Courtesy Brian Jackson, image by Bill Crighton)

Carbonate group	
Calcite $CaCO_3$	Ankerite $CaCO_3.(MgFe)\ CO_3$
Aragonite $CaCO_3$	Magnesite $MgCO_3$
Dolomite $CaCO_3.MgCO_3$	Siderite $FeCO_3$

By contrast, rare carbonate minerals including gaspeite (a green nickel carbonate; see Chapter 23 on gaspeite) and stichtite (a purple-coloured magnesium–chromium carbonate) are collectors' items. Some specimens featuring azurite and malachite (secondary copper carbonate minerals; see Chapter 19 on copper gemstones) are set into jewellery as crystal aggregations, used as display items, and collected for micromount examination.

Calcite

Although calcite ($CaCO_3$) may form spectacular crystals in vein fillings and cavities, it is relatively soft (3 on Mohs hardness scale) and has three perfect directions of rhombohedral cleavage, which severely limit its use as a gem mineral. However, because of its extreme transparency and large double refraction, calcite is occasionally faceted to demonstrate these optical characteristics, which are especially dramatic using twinned crystals (Fig. 28.2).

Physical properties of calcite

Crystal system	Trigonal, rhombohedral
Habit	Commonly forms rhombohedral crystals. Crystals exhibit a greater variety of forms and habits than many other minerals; also fibrous, lamellar, granular, nodular, compact, and earthy
Colour range	Colourless, and in many colours including grey, red, green, blue, violet, yellow, some banded
Lustre	Vitreous, subvitreous, some earthy
Diaphaneity	Transparent to translucent
Refractive index	1.48 – 1.66
Hardness	3 (standard on Mohs scale)
Specific gravity	2.71
Fracture	Conchoidal
Cleavage	Highly perfect in three rhombohedral directions, easily developed and producing 'cleaved rhomb crystals'
Fluorescence	Commonly shows a variable and patchy pink or white response under ultraviolet (UV) light

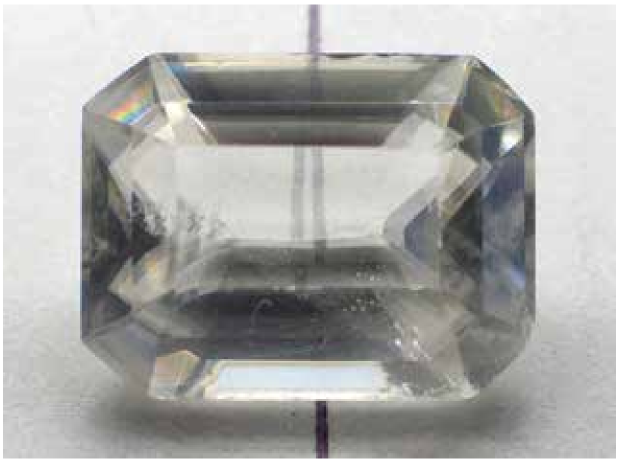

Figure 28.2. Faceted, 5.19 ct, colourless calcite crystal demonstrating the doubling effect of a line (courtesy Peter Groenenboom)

Transparent and untwinned-quality calcite is termed 'Iceland spar', which until the mid-20th century was used in optical instruments such as polarizing microscopes and dichroscopes. More recently, Iceland spar has been replaced by synthetic plastic polarizers.

Simpson (1948) recorded numerous occurrences of calcite crystals in vein and amygdale fillings throughout Western Australia.

Aragonite

Aragonite was first named in 1797 for the type locality of Molina de Aragón in Spain. It is a dimorphous form of calcite, crystallizing in the orthorhombic system. Aragonite is best known in gemmology as the biogenic carbonate of coral, nacreous pearls, and mother-of-pearl shells. Both calcite and aragonite may form in different layers of shell material. Aragonite forms under a narrower range of physiochemical conditions than does calcite and is a metastable mineral, altering to calcite in time and where heated above 400°C. It is also commonly precipitated from solutions rich in magnesium and other salts and can be found as nodules on the edges of salt lakes, and in mud-like deposits in brackish lakes (Simpson, 1948). Abundant small boulders of aragonite are plentiful on the surface of Lake Barlee while marls making up the beds of Lake Clifton and Lake Walyungup are aragonite-rich.

Aragonite crystals are commonly long prismatic or tabular in habit and show steep pyramidal terminations, while some are flattened or bladed. They are also grouped as stellate aggregations, and as acicular or fibrous crystals found as crusts within cavities. Twinned crystal groups comprising single crystals twinned cyclically commonly produce the appearance of a six-sided prismatic form with a pseudohexagonal section. Spectacular radiating masses of flattened, prismatic aragonite crystals have been exposed in the near-surface supergene enrichment zone of the DeGrussa copper mine in the Peak Hill region (Fig. 28.3; see also Chapter 19 on copper gemstones).

Aragonite crystals are appreciated as display specimens that may be faceted as collectors' gems. A faceted example from the DeGrussa copper mine is shown in Figure 28.4. As faceted specimens, aragonite gems are characterized by their optical characteristics and the strong double refraction (the appearance of prominent doubled facet edges), fine striations internally due to the repeated twinning, and their higher specific gravity than calcite.

Aragonite may also be incorporated in layered travertine, commercially termed 'Mexican onyx', composed largely of calcite together with aragonite. This material is used for carving decorative *objets d'art* and may be sourced from many countries.

Physical properties of aragonite

Crystal system	Orthorhombic
Habit	Acicular, and bladed stellate
Colour range	Colourless and in many colours including brown, grey, white, and yellow
Lustre	Vitreous
Diaphaneity	Transparent to translucent
Refractive index	1.53 – 1.69 (DeGrussa aragonite 1.530 – 1.686)
Hardness	3.5 – 4
Specific gravity	2.93 – 2.95 (DeGrussa aragonite 2.987)
Fracture	Subconchoidal
Cleavage	Distinct (010)
Fluorescence	White weak response under ultraviolet (UV) light

Carbonate rocks in Western Australia

Magnesite

Magnesite occurrences in Western Australia can be broadly grouped into two categories based on their geological associations (Abeysinghe, 1996):

- secondary magnesite in Paleogene sedimentary rocks, which are only known from deposits at Bandalup near Ravensthorpe
- residual magnesite in Archean altered, serpentine-rich, ultramafic rocks, which are widespread throughout the State. Good examples are at Bulong, Coolgardie, and Ravensthorpe.

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Figure 28.3. Stellate aggregates of bladed aragonite crystals from the supergene enrichment zone of the DeGrussa mine; longest crystal is about 80 mm in length

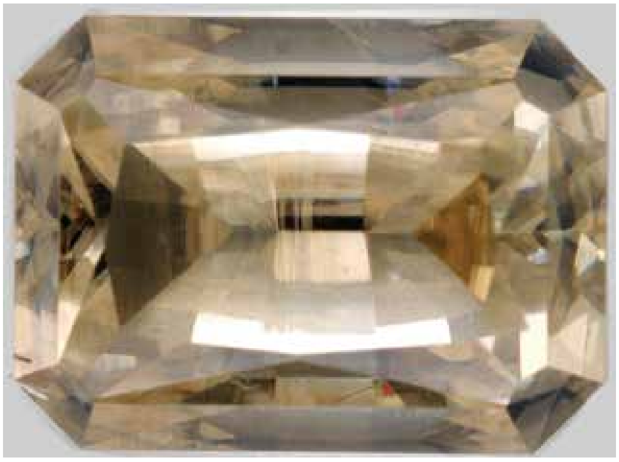

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Figure 28.4. Faceted aragonite, 7.7 x 10.5 mm, from the DeGrussa mine (faceting by Murray Thompson, photography by Geoff Deacon, Western Australian Museum)

Residual magnesite deposits are developed over Archean serpentinite, amphibolite, quartzite, and schist. Faulkner (1962) defined two discrete varieties as a lean superficial type, and a dense accumulate type:

- The lean superficial type is commonly 1.0 – 2.5 m thick and overlain by a soil horizon typically 0.5 – 1.0 m thick.
- The dense type forms as lensoid, lumpy bodies with well-defined margins, found in low-lying to intermediate physiographic levels, and adjacent to creeks. Thickness varies between 0.5 and 10.0 m, and the lump magnesite varies from hard, flinty (locally dolomitic) material to soft, porous, and chalky material. At times it lies directly on siliceous metasedimentary rocks. Basement rocks are commonly present as either isolated boulders or as thin remnants.

Most magnesite deposits are white or cream in colour and of relatively little interest to the fossicker. Significant magnesite deposits, some of which have been mined, include Bandalup, Coolgardie, Bulong, Northam, Westonia, Mount Hunt, Munglinup, Mount Burges, Lawlers, Eulaminna, Siberia (Waverley), and Comet Vale. Locations of many of these magnesite deposits are given in Abeysinghe (1996), and Simpson (1952) recorded numerous other occurrences.

Magnesite applications

One of the main gemmological uses for white magnesite is for making dyed blue beads and inexpensive jewellery marketed as ‘turquenite’, imitating turquoise. A more attractive form of this mineral is nickeliferous magnesite, which is commonly light green and often called ‘citron’ or ‘lemon’ magnesite. This form is commonly associated with apple-green chrysoprase, and in this association may be incorrectly called citron or lemon chrysoprase. It is commonly found as surface cappings on weathered nickel-rich ultramafic rocks where the magnesite typically occurs as rounded structures or loose boulders (Fig. 28.5).

Figure 28.5. **Rough boulders of citron magnesite (nickeliferous magnesite) sourced from Marshall Pool mine (courtesy Barry Kayes)**

This attractive rock is commonly found in the Eastern Goldfields area of Western Australia in a belt of nickel-rich ultramafic rocks that extend from Norseman in the south to near Wiluna in the north. It is also possible that light green nickeliferous magnesite may be found overlying nickeliferous ultramafic rocks in other areas of the Yilgarn Craton. Chemical assays of a yellowish-green magnesite from Western Australia give values up to 3.6% NiO (Brown and Bracewell, 1987).

Nickeliferous magnesite takes a good polish and, where veined with brown limonite, it makes attractive tumbling and cabochon material and may also be carved into attractive *objets d'art* (Fig. 28.6). Some of the better known localities are recorded below.

Figure 28.6. **Carved and polished bowl, about 25 cm in diameter, in citron magnesite from Marshall Pool (courtesy Glenn Archer)**

Yilgarn Craton — Eastern Goldfields Superterrane

Lake Rebecca area

Duck Hill and Jump Up Dam prospects (Edjudina, 3338)

Geological Survey of Western Australia (1994) reported nickeliferous magnesite at Lake Rebecca, approximately 120 km northeast of Kalgoorlie. The exact location is difficult to ascertain although Chen (1999) reported that chrysoprase has been mined from several small openpits west of Jump Up Dam and at Duck Hill (Fig. 28.7). Accepting the close association of citron magnesite with chrysoprase, it is probable that one or both of these locations could be the reported occurrence.

Yerilla area

Yerilla chrysoprase mine (Yerilla, 3239)

The Yerilla chrysoprase mine, situated on mining leases M31/104 and M31/112, is approximately 145 km north-northeast of Kalgoorlie and 13 km south of the Yerilla Homestead (Fig. 28.7). The mine area may be accessed by the well-maintained Kookynie–Yarrie gravel road and is directly north of the Cranky Jack Road intersection.

Apart from chrysoprase, the deposit is stated to have a significant potential for the recovery of highly siliceous magnesite of varying colours. The Yerilla tenements have had a long history of citron, lemon prase, or lime prase magnesite mining for the carving and ornamental stone markets (Bellmount Holdings Pty Ltd, 2007).

Bulong–Mulgabbie region

Bulong complex (Kanowna, 3236; Mulgabbie, 3337)

The Bulong complex is a large, discordant, layered intrusive body ranging in composition from peridotite to gabbro situated in the Bulong – Lake Yindarlgooda area. It forms a broad, almost north–south striking zone of mafic and ultramafic units with a total strike length of over 70 km (Ahmat, 1995). The centre of the complex lies approximately 35 km east of Kalgoorlie in an area containing numerous gold and nickel mines (Fig. 28.7).

In this area, magnesite is found as a surface or near-surface weathering product over most ultramafic rocks shown on the Kanowna 1:100 000 geological map with the best deposits in the Bulong complex. The Kanowna map also shows numerous unspecified gemstone localities in the northern half of the Bulong complex to the northeast and east of the Kalgoorlie–Bulong–Curtin Road. Also, Williams (1970) reported that nickeliferous magnesite has been found within the Bulong complex and on the shores of Lake Rebecca.

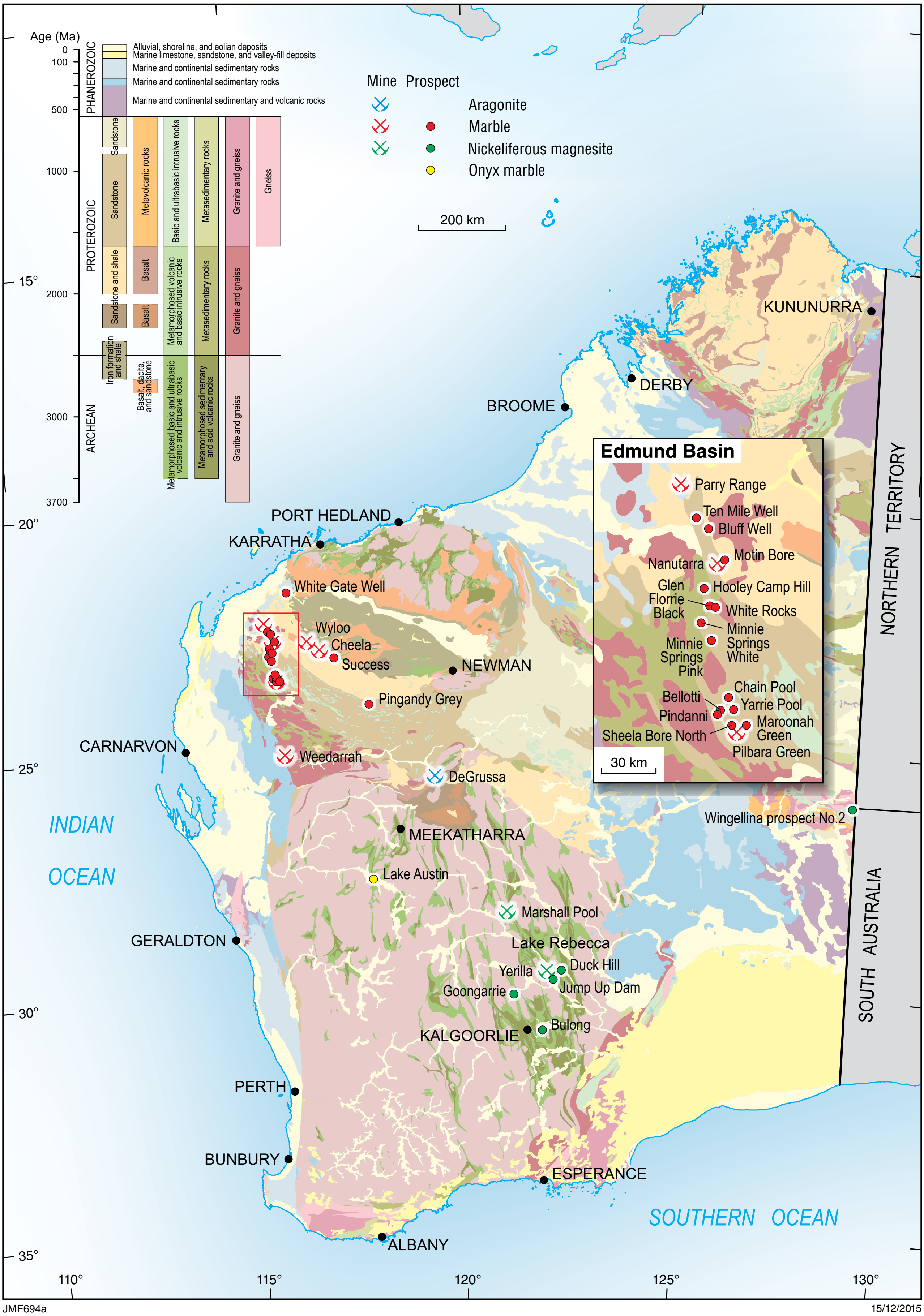

Figure 28.7. **Locations of carbonate group decorative stones in Western Australia**

Goongarrie Hill area

Goongarrie *(Bardoc, 3137)*

Citron magnesite is reported at Goongarrie approximately 100 km to the north of Kalgoorlie (Fig. 28.7). The 1:100 000 geological map (Witt and Swager, 1989) shows a north-striking belt of ultramafic rocks between Goongarrie Hill and the main Kalgoorlie–Leonora Road. It is assumed that the occurrence is in this area.

Leonora area

Marshall Pool deposit *(Wildara, 3041)*

Gemstone prospectors Australian Outback Mining report nickeliferous magnesite in the belt of serpentine–talc and talc–chlorite schists lying approximately 70 km north-northwest of Leonora and 5.5 km to the east of Marshall Pool (Fig. 28.7). Access from Leonora is along the graded Leonora to Agnew road and then northwards along station and mining roads. In recent years, small quantities of large, roughly rounded boulders of citron magnesite up to 1 t were mined from this deposit (Fig. 28.7).

Musgrave Province

Wingellina area

Wingellina prospect *(Bell Rock, 4645)*

Geological Survey of Western Australia (1994) reported that in 1972, Wingellina Nickel Australia Ltd mined 5.073 t of magnesite (probably nickeliferous) from the Wingellina area adjacent to the State border with South Australia (Fig. 28.7). Much of this area is underlain by the extensive mafic–ultramafic Giles Suite. Weathering is deep in places and nickel laterites are locally well developed. Abundant surface magnesite has been recorded. Chrysoprase has also been mined in this area. It is highly likely that nickeliferous magnesite would be found in this area.

Apart from the remoteness of the area, fossickers should note that these sites are on Aboriginal lands and permission to enter and fossick must first be obtained from the Ngaanyatjarra Council in Alice Springs.

Onyx marble

'Onyx marble' is a term that is applied to a translucent, banded variety of marble with an attractive colour. It is commonly incorrectly called 'onyx' (a type of banded chalcedony) or alabaster (a massive variety of gypsum).

Onyx marbles are formed by the precipitation of calcite or aragonite from carbonate-rich waters that produce travertine in hot springs and form stalactites and stalagmites in caves. Normally the background colour of onyx marbles is white, although they are commonly veined by coloured fractures or by areas containing metallic oxides. This precipitation gives rise to a delicate banding of amber, orange, and green which, together with their translucence, makes them extremely popular as a sculpting medium.

Yilgarn Craton — Murchison Domain

Lake Austin *(Wynyangoo, 2542)*

Geological Survey of Western Australia (1994) reported the occurrence of deep cream through amber to dull brown fragments of onyx marble on and around Lake Austin about 15 km south of Cue (Fig. 28.7). This material takes a good polish and has a fibrous structure with concentric banding. Nothing further is known about this locality.

Marble

Marble is derived from metamorphosed limestone, dolomite, and serpentine rocks. During the metamorphic process the carbonate minerals, principally calcite and/or dolomite, are recrystallized to a greater or lesser degree, forming an interlocking crystal structure. It is this recrystallization process that enables marble to take a high polish for decorative or ornamental purposes (Fetherston, 2007).

There are numerous previously mined marble deposits and prospects distributed over a wide area in the central western region of Western Australia. Most are within the western end of the Paleoproterozoic Ashburton Basin and the western part of the overlying Paleoproterozoic–Mesoproterozoic Edmund Basin. Outside of these basins the only other high-quality marble deposit is within the Paleoproterozoic Gascoyne Province.

Apart from the Cheela Marble in the Ashburton Basin, almost all other marble in the region are designated as dolomitic marble with chemical contents in the range 24–41% CaO and 11–22% MgO. The marble displays a wide range of textures varying from fine to coarsely crystalline, to banded, veined, stylolitic, stromatolitic, and brecciated. There is also considerable variation in marble colours ranging from pure white, through cream, yellow, orange, pink to deep red and brown, and green, mauve, grey, and black. It appears that trace element contents bear little relationship to the colour of the marble.

Thin sections revealed the presence of green serpentine minerals in much of the marble, and iron-rich minerals such as hematite and limonite. Also, it is possible that the dark colour of some marble may be attributable to disseminated, cryptocrystalline carbonaceous material (Fetherston, 2010).

The Western Australian marble quarries are described in considerable detail by Fetherston (2010) and interested persons should consult this work for further information. Note that these quarries are not the only sources of marble and specimens could be obtained from almost anywhere in suitable lithological units within the Ashburton and Edmund Basins.

Ashburton Basin

There are 11 named marble deposits in the Ashburton Basin, four with precise locations and seven others whose precise locations are unknown (Figs 28.7 and 28.8). All are hosted within the 2008–1799 Ma Duck Creek Dolomite of the Wyloo Group. Locations are shown in Appendix 1 and details are summarized in Table 28.1.

Edmund Basin

Of the 20 dolomitic marble deposits in the western end of the Edmund Basin almost all are located in three discrete areas: on western Glen Florrie, Maroonah, and Nanutarra Stations. A fourth area contains one deposit, south of Paraburdoo (Figs 28.7 and 28.9). All Edmund Basin marble deposits are hosted by the Irregully Formation. Locations are shown in Appendix 1 and details are summarized in Table 28.2.

Gascoyne Province

Weedarrah marble (Daurie Creek, 2047)

The Weedarrah Marble quarry is 60 km east of the town of Gascoyne Junction and about 6 km south-southeast of Weedarrah Homestead (Fig. 28.7). The Paleoproterozoic, coarsely crystalline, white marble lens is enclosed by dark green, weathered mica schist, amphibolite, and minor quartzite (Fig. 28.10). The marble is penetrated in places by steeply dipping, anastomosing veins of pale green, schistose serpentine.

Table 28.1. Summary of marble quarries and prospects in the Ashburton Basin

1:100 000 map sheet	*Quarry or prospect*	*Location*	*Colour*
Pannawonica 2154	White Gate Well prospect	25 km WSW of Pannawonica	Red, cream
Hardey 2252	Cheela marble quarry	60 km ESE of Wyloo Homestead	Grey
Wyloo 2152	Wyloo quarry	17 km SE of Wyloo Homestead	Dark grey-green
Ashburton 2351	Success prospect	60 km WNW of Paraburdoo	Multicoloured
Hardey 2252	Swan Black prospect	Cheela area[(a)]	Black
Hardey 2252	Gala Mauve prospect	Cheela area[(a)]	Pinkish-grey
Hardey 2252	Cheela Grey prospect	Cheela area[(a)]	Dark grey
Hardey 2252	Beasley Pearl prospect	Cheela area[(a)]	Dark grey
Hardey 2252	Wonangara Rose prospect	Cheela area[(a)]	Rose-pink
Wyloo 2152	Wyloo Smoky Pink prospect	Wyloo area[(a)]	Pink, white
Wyloo 2152	Kooline Opal prospect	Wyloo area[(a)]	Green-grey

NOTE: (a) Position doubtful

Table 28.2. Summary of marble quarries and prospects in the Edmund Basin

1:100 000 map sheet	*Quarry pr prospect*	*Location*	*Colour*
Cane River 2053	Ten Mile Well prospect	14 km ENE of Nanutarra	Yellow, pink
Cane River 2053	Parry Range quarry	25 km NNW of Nanutarra	White to cream
Boolaloo 2052	Bluff Well prospect	20 km E of Nanutarra	Off-white to buff
Boolaloo 2052	Nanutarra quarries (3)	30 km SE of Nanutarra	Red, white
Boolaloo 2052	Motin Bore prospect	35 km SE of Nanutarra	Red, cream
Boolaloo 2052	Hooley Camp Hill prospect	35 km SSE of Nanutarra	White
Boolaloo 2052	Glen Florrie Black prospect	45 km SSE of Nanutarra	Dark grey to black
Boolaloo 2052	Minnie Springs White prospect	55 km SE of Nanutarra	White
Boolaloo 2052	White Rocks prospect	50 km SSE of Nanutarra	Creamy white
Maroonah 2051	Minnie Springs Pink prospect	65 km SE of Nanutarra	Pink
Maroonah 2051	Bellotti prospect	17 km ENE of Maroonah Homestead	Green
Maroonah 2051	Pindanni prospect	17 km ENE of Maroonah Homestead	Green
Maroonah 2051	Sheela Bore North prospect	24 km ENE of Maroonah Homestead	Dark green
Maroonah 2051	Yarrie Pool prospect	25km ENE of Maroonah Homestead	Green-grey
Mangaroon 2050	Pilbara Green quarry	25 km SE of Maroonah Homestead	Green
Maroonah 2051	Chain Pool prospect	26 km ENE of Maroonah Homestead	Mid-grey
Mangaroon 2050	Maroonah Green prospect	30 km ESE of Maroonah Homestead	Green
Boggola 2450	Pingandy Grey prospect	90 km S of Paraburdoo	Grey

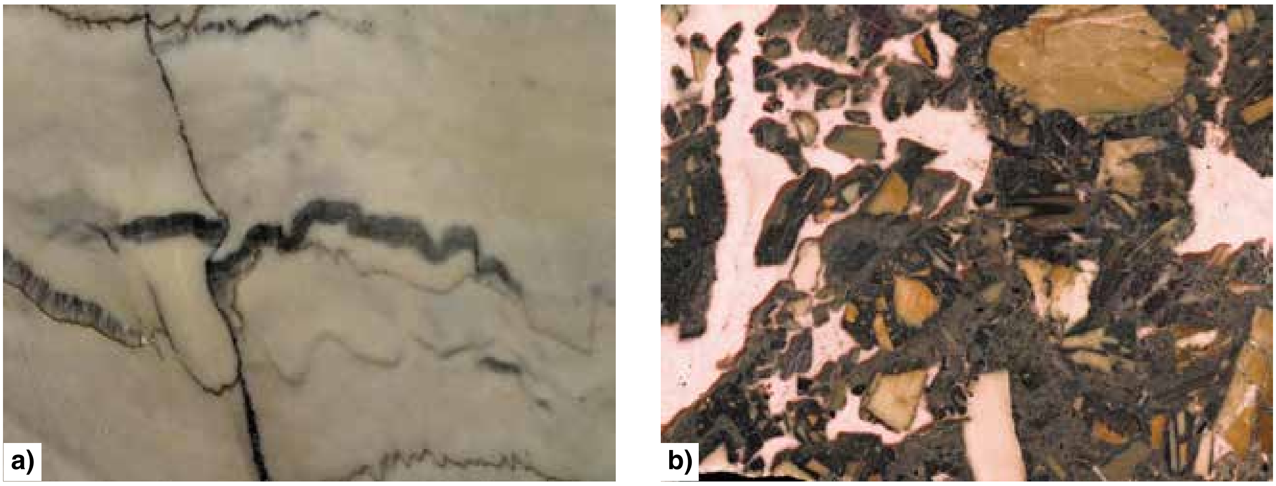

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Figure 28.8. **Marble from the Ashburton Basin: a) pale grey Cheela marble with dark green veins and stylolites; b) brecciated, grey-green Wyloo marble with pink veins of coarse-grained sparry carbonate. Polished slabs average 90 mm in width**

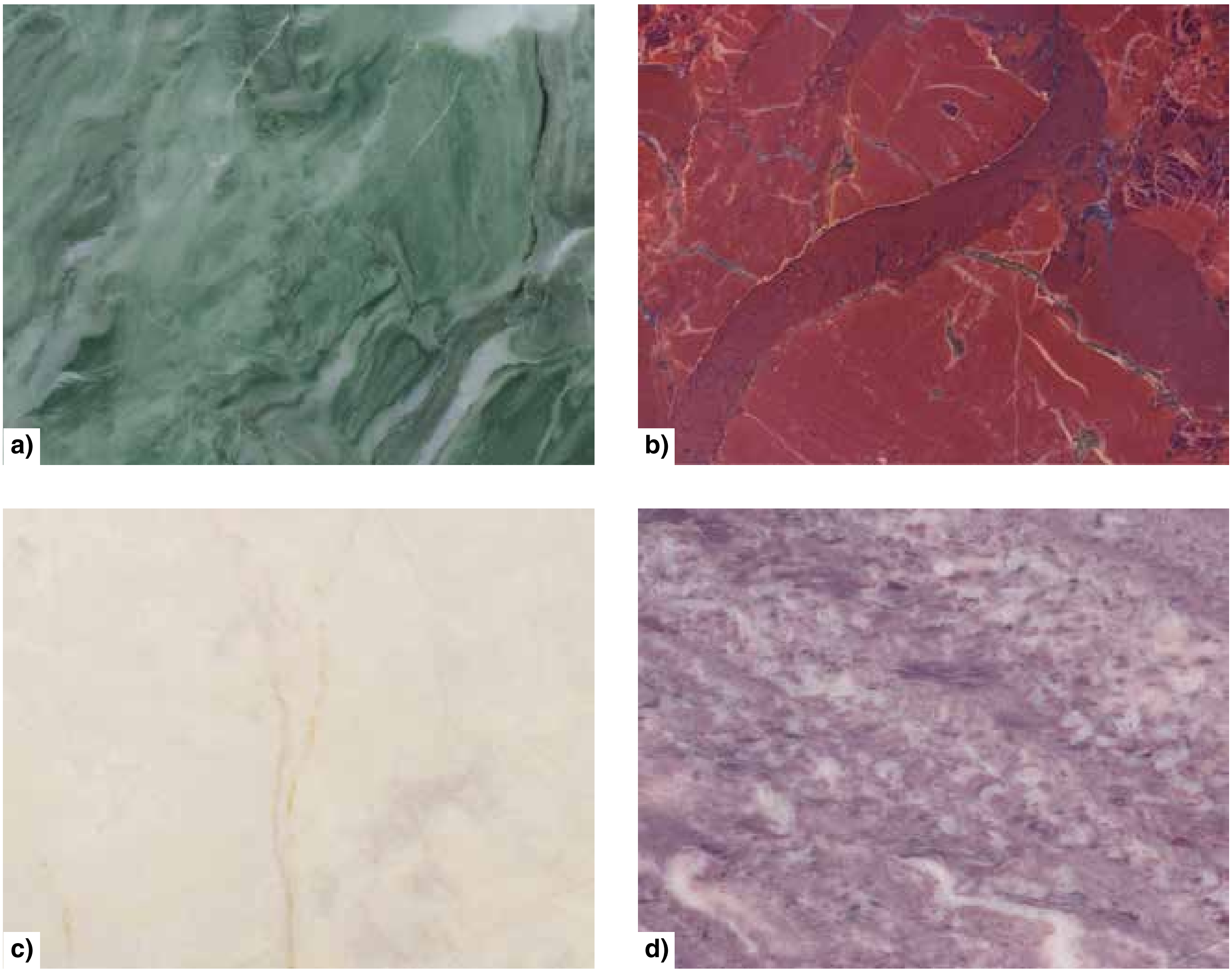

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Figure 28.9. **Marble from the Edmund Basin: a) Pilbara Green marble from Maroonah; b) Rosso Venezia red marble from Nanutarra; c) Austral Pearl cream marble from Nanutarra; d) mauve-coloured marble from Hooley Camp Hill. Polished slabs average 90 mm in width**

Figure 28.10. Coarsely crystalline white marble from Weedarrah

Limestone and dolomite

True limestone is a sedimentary rock composed primarily of calcium carbonate with less than 5% magnesium carbonate. As the magnesium carbonate content increases to 5–40%, the rock becomes a dolomitic limestone, and at more than 40% the material becomes dolomite. In many instances, limestone and dolomite grade into each other. Limestone containing a high proportion of quartz grains is known as calcarenite. Calcitic rocks precipitated around hot and cold calcareous springs are termed calcareous tufa and travertine while oolitic limestone may be formed in shallow-water environments or by inorganic precipitation (Fetherston, 2010).

In Western Australia, limestone and dolomite are both common and widely distributed, being present in a variety of rock sequences ranging in age from Proterozoic to Quaternary. Many of the younger limestone deposits, such as the Tamala Limestone, which fringes the southwestern coastline, are soft and porous. They contain abundant quartz grains and shell fragments, which are commonly derived from calcareous beach and dunal deposits.

Finer grained, more competent limestone and dolomite horizons are found in many of the large sedimentary basins throughout the State including the Canning, Carnarvon, and Eucla Basins. As cut stone, many limestones and dolomites take a good polish and are suitable for lapidary work. Details of these units are given in the relevant Geological Survey of Western Australia 1:250 000 and 1:100 000 maps, reports, and bulletins and these should be consulted for further information. Lapidary enthusiasts and fossickers should be consulted for specific locations of suitable specimens.

Stromatolites

Stromatolites and thrombolites are layered structures formed in shallow water by the trapping, binding, and cementing of fine sedimentary material by thin films containing communities of micro-organisms or microbials. These sticky films are formed as a protection from ultraviolet radiation. Calcium carbonate, either precipitated from the seawater or from the microbial skeletal framework, cements the grains of sediment to form the laminated structures that are stacked one on top of the other (Fig. 28.11). The microbials are both photosynthetic and able to move towards the light, keeping pace with the accumulating sediment and remaining on the outer surfaces of the stromatolite.

Stromatolites, which commonly have a colloform shape similar to that of a cauliflower, grow extremely slowly with growth rates estimated to be as little as 0.4 mm per year (McNamara, 1992). There are numerous forms differing in internal structure, depending on their location in relation to the shore and the species involved in their formation. In the intertidal zone, they are of a pustular mat type, in which the internal structure is poorly defined with no layering. In the zone between the intertidal zone and the subtidal zone, there are ‘smooth mat’ stromatolites. Their internal structure is well defined and the outer surface is smooth. Stromatolites growing at depths greater than about 3.5 m have a coarse structure that is poorly laminated and grow to about 1 m in height (Monroe, 2011).

Stromatolites are common as fossils and have been found in rocks formed 3.45 Ga, making them some of the oldest organisms known. In Western Australia stromatolites are abundant in sedimentary rocks older than 500 Ma. Although stromatolites still living today are comparatively rare, they may be found in several localities in the State. The most

Figure 28.11. Columnar stromatolites (*Gymnosolen* sp.) of possible Mesoproterozoic age from the Three Springs area. Image is about 425 mm wide (courtesy Glenn Archer)

significant of these is at Hamelin Pool in the Shark Bay World Heritage Area. Other areas are in saline, brackish, and freshwater lakes along the southwestern coastline including Lake Clifton, Lake Walyungup, Lake Thetis, and Lake Richmond, as well as Government House Lake on Rottnest Island and Pink Lake at Esperance. There is also a colony of living stromatolites in a freshwater spring in the northern Great Sandy Desert (Crowe et al., 1978). Western Australia has one of the most continuous and best-studied records of fossil stromatolites that have been recorded from at least 75 of the 163 1:250 000 onshore geological map sheets (K Grey, 2016, written comm., 13 June; Figs 28.12 and 28.13).

Fossickers and collectors should note that although stromatolites may be found as fossils throughout most of the older carbonate-rich formations in Western Australia, they are of important scientific value and should be treated as such. There is legislation in relation to the export of fossils and it is recommended that fossickers consult with Department of Mines and Petroleum staff prior to any fossil-collecting trip.

Lapidary applications

Stromatolites are commonly slabbed and made into small objects such as bookends, cutting boards, and table tops. In the Moora area, the stromatolitic carbonate horizon of the Noondine Chert has been silicified into a tough chert (Abeysinghe, 2003). Material from this unit, which contains fragmented stromatolites, has been used for making cabochons (Fig. 28.14).

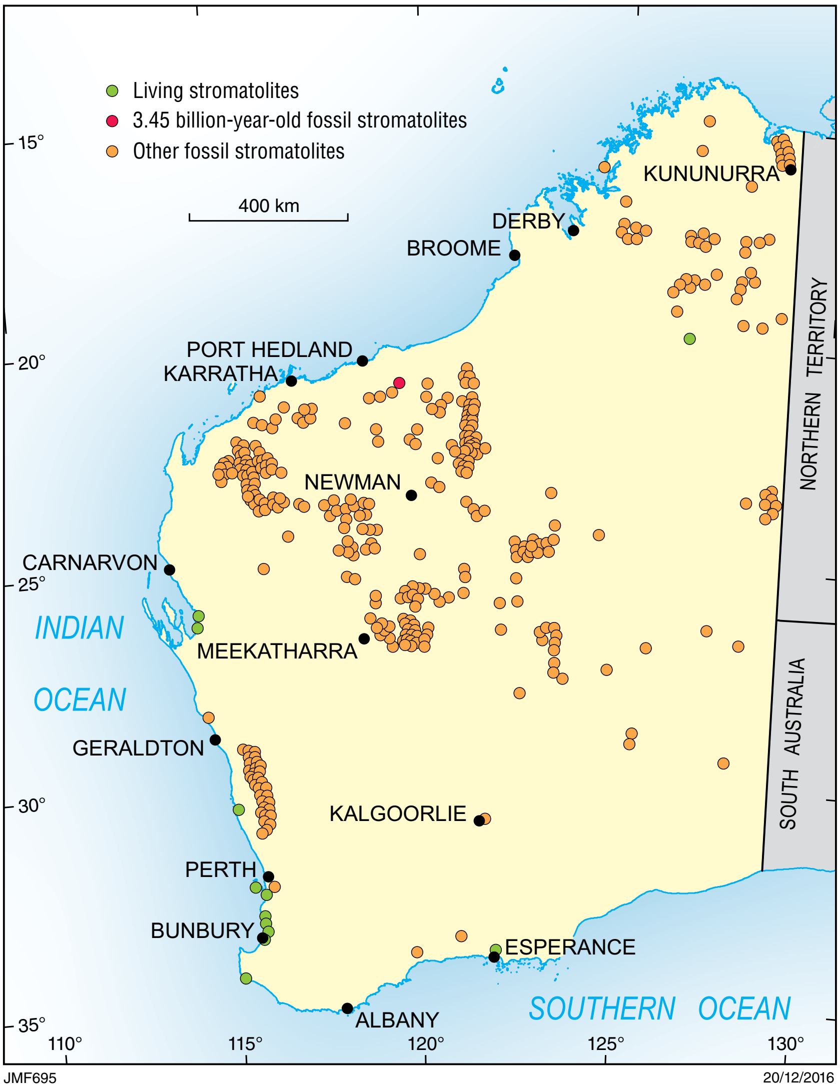

Figure 28.12. Distribution of stromatolite locations in Western Australia (courtesy Kath Grey)

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Figure 28.13. Selection of polished, Paleoproterozoic stromatolitic carbonate rocks (1.83 – 1.6 Ga) from Western Australia. Stromatolite specimens range from 10 to 18 cm in width (images courtesy Glenn Archer): a) *Asperia ashburtonia* from the Duck Creek Dolomite, Wyloo Group; b) *Pilbaria perplexa* from the Duck Creek Dolomite, Wyloo Group in the Paraburdoo area; c) *Earaheedia kuleliensis* from Kulele Limestone, Nabberu Basin; d) *Pseudogymnosolen* (form indeterminate) from an un-named dolomite near the top of the Wyloo Group, Kunderong Ranges, Turee Creek area; e) *Asperia digitata* from the Sweetwaters Well Member, Yelma Formation, Tooloo Group, near Wiluna; f) domical stromatolite, possibly *Paniscollenia* (form indeterminate), from the Irregully Formation at Irregully Gorge

Figure 28.14. Cabochon of Noondine Chert, a silicified, fragmented stromatolitic limestone, 5 cm in diameter

References

Abeysinghe, PB 1996, Talc, pyrophyllite and magnesite in Western Australia: Geological Survey of Western Australia, Mineral Resources Bulletin 16, p. 81–109.

Abeysinghe, PB 2003, Silica resources of Western Australia: Geological Survey of Western Australia, Mineral Resources Bulletin 21, p. 139–155.

Ahmat, AL, 1995 Geology of the Kanowna 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 28p.

Bellmount Holdings Pty Ltd 2007, Information memorandum for the Sale of the Yerilla Chrysoprase Mine.

Brown, G and Bracewell, H 1987, Citron chrysoprase: The Australian Gemmologist, v. 16, no. 6, p. 231–233.

Chen, SF 1999, Edjudina, WA, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 32p.

Crowe, RWA, Yeates, AN and Grey, K 1978, Living stromatolites in the northern Great Sandy Desert, Western Australia: a modern analogue for probable Tertiary deposits in the area: Geological Survey of Western Australia, Annual Report, 1977, p. 73–75.

Fetherston, JM 2007, Dimension stone in Western Australia, volume 1 — Industry review and dimension stones of the southwest region: Geological Survey of Western Australia, Mineral Resources Bulletin 23, p. 5–14.

Fetherston, JM 2010, Dimension stone in Western Australia, volume 2 — Dimension stones of the southern, central western, and northern regions: Geological Survey of Western Australia, Mineral Resources Bulletin 24, p. 95–115.

Faulkner, JW 1962, Prospecting and testing of the magnesite deposits at Ravensthorpe, Western Australia: Broken Hill Pty Co Ltd, and Pickands Mather & Co International, Geological Survey of Western Australia, Non-statutory mineral exploration report, A1932, (unpublished).

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, 52p.

McNamara, K 1992, Stromatolites: Western Australian Museum, Perth, Western Australia, 27p.

Monroe, MH 2011, Stromatolites in Australia: the land where time began, viewed 9 August 2012, <http://austhrutime.com/stromatolites.htm>.

Simpson, ES 1948, Minerals of Western Australia, volume 1: Government Printer, Perth, Western Australia, p. 336–354.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 77–95.

Williams, IR 1970, Kurnalpi, Western Australia: Bureau of Mineral Resources 1:250 000 Geological Series Explanatory Notes, 37p.

Witt, WK and Swager, CP 1989, Bardoc, 3137, 1:100 000 geological map series, Geological Survey of Western Australia.

Chapter 29

Chinese writing stone

Chinese writing stone description

Chinese writing stone is a trade name used to describe decorative rocks that have a porphyritic texture created when white or light-coloured crystals (phenocrysts) form contrasting patterns scattered throughout a fine-grained, dark groundmass. In Western Australia, the term is applied to phenocrysts in porphyritic basalts, although this property has been used in describing similar textures in other igneous rocks sourced worldwide where they are referred to by a variety of names such as 'chrysanthemum stone' in Japan. The crystals in Western Australian chinese writing stone are white feldspar phenocrysts and the dark groundmass is a fine-grained intergrowth of pyroxenes and feldspars. The rock is also known by a typically Australian name, 'chook's foot rock'.

Chinese writing stone is composed of a fine-grained greenish-grey matrix in which irregular groups (up to 20 mm diameter) of lath-shaped, light-coloured feldspar crystals, <10 mm in length, form a distinctive texture. In some groups the crystals diverge to form rosette patterns (Fig. 29.1). The green colour of both the groundmass and coarser crystals is the result of metamorphism and weathering where the original plagioclase feldspars have been replaced by albite and fine-grained zoisite, clinozoisite, or epidote and the groundmass minerals have been altered to chlorite, calcite, and iron oxides. Other minerals may include vestigial pyroxene, olivine, magnetite in a chevron arrangement, and irregular grains of pyrite. Variations in colour are a function of the degree of alteration.

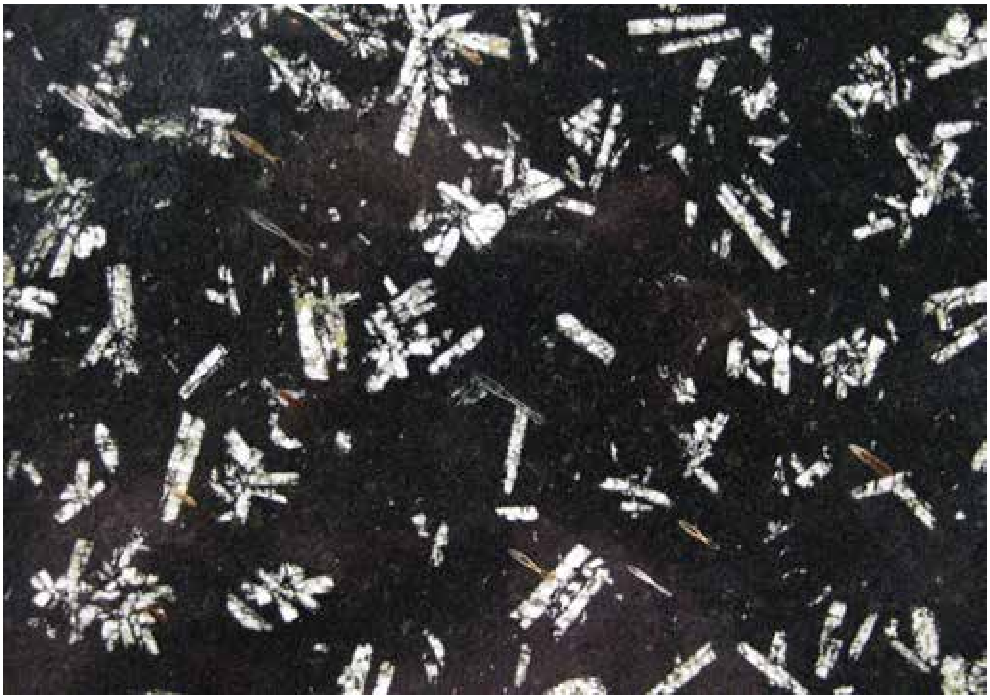

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Figure 29.1. Chinese writing stone showing clusters and rosettes of lath-shaped, light-coloured feldspar crystals up to 10 mm in length

Chinese writing stone
Porphyritic basalt

Decorative stone properties

Chinese writing stone is a tough material with variable hardness according to alteration and mineralogy. Unaltered material is hard and takes a high polish, whereas altered rock is typically softer, may be easily scratched and does not take a high polish. In some instances, surface pitting on polished stones may be caused by changes in differential hardness between mineral types within the rockmass.

Chinese writing stone in Western Australia

Pilbara Craton

Whim Creek region

Western Australian examples of porphyritic basalts containing chinese writing stone occur in the Whim Creek region of the Pilbara Craton within the Mount Roe Basalt, the lower part of the Archean Fortescue Group. The Mount Roe Basalt comprises lava flows of basaltic and andesitic composition interspersed with local sedimentary rocks and agglomerates. Textures and grain sizes may vary within these flows, which are commonly vesicular at the top, fine grained on the flow margins, and coarser grained in the centre. Only a few flows are porphyritic with clusters and rosettes of coarse-grained plagioclase feldspar laths present within the fine-grained groundmass.

The basaltic source rocks containing chinese writing stone are found in several areas around Whim Creek. Chinese writing stone has been collected from sites 5 km east and 15 km north of Whim Creek, and near Langwell Gorge about 40 km south-southwest of Whim Creek. It is also present in several porphyritic basalts in the Illingotherra Hills and between Whim Creek and Warambie Station, 45 km to the west (Bevan et al., 1999).

In the past, chinese writing stone was collected by local prospectors and fashioned and marketed through a number of outlets, the nearest in Port Hedland.

Langwell Gorge prospect (Mount Wohler, 2455)

The Langwell Gorge chinese writing stone prospect is in an isolated area of the Archean Mount Roe Basalt on Mallina Station approximately 40 km south-southwest of Whim Creek and about 7 km north of Langwell Gorge (Fig. 29.2). The exact location is uncertain (see Appendix 1). Access is by roads leading from the North West Coastal Highway to Croydon Homestead and thereafter by bush tracks. No further information is available for this site.

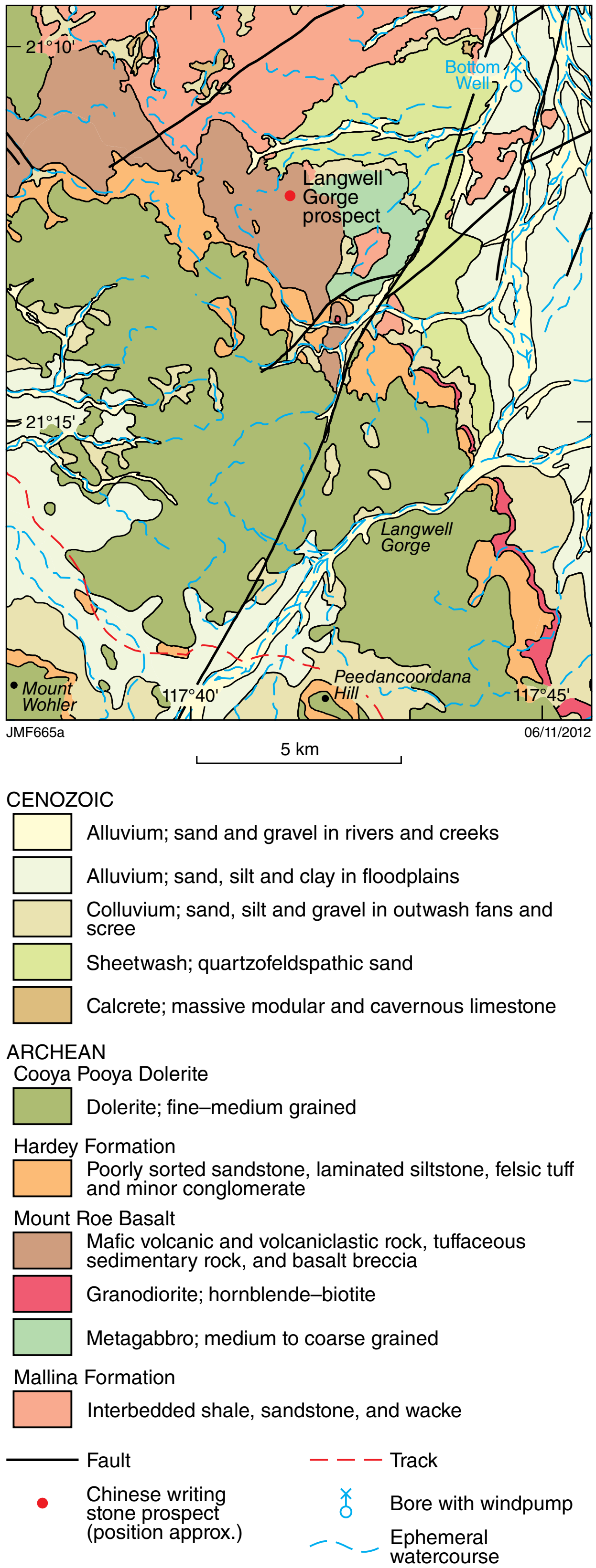

Figure 29.2. Geological map of the area around the Langwell Gorge chinese writing stone prospect (modified after Smithies, 1998)

References

Bevan, A, Downes, P and Bevan, J 1999, Australian chinese writing stone, an appraisal of a decorative porphyritic basaltic rock from Western Australia: The Australian Gemmologist v. 20, no. 5, p. 178–181.

Smithies, RH 1998, Mount Wohler, WA Sheet 2455: Geological Survey of Western Australia, 1:100 000 Geological Series.

Chapter 30

Epidote group

Epidote minerals

Epidote is a group name for a variety of related hydrous calcium–aluminium silicate minerals. The International Mineralogical Association recently assigned new species nomenclature to the epidote mineral group and now accords this group name to refer to only the monoclinic crystal system members — epidote and clinozoisite. However, because all the former members of the group are commonly associated, and others are dimorphs of one another (e.g. clinozoisite and zoisite), they are still described together.

Only a few coloured epidote varieties are classified as gems or form visually attractive ornamental stones; these are described in this publication. Coloured, transparent stones are rare and to date, none from Western Australia have been processed as gemstones for marketing. Nevertheless, a variety of ornamental rocks containing epidote group minerals from the State have been used as lapidary-grade material.

Minerals used as gemstones include clinozoisite and epidote (both monoclinic and isomorphous with iron substituting for aluminium), and zoisite (orthorhombic). Both clinozoisite and zoisite can contain trace amounts of manganese (<1%), which results in pink colouration. Both minerals may be constituents in pink ornamental rocks known as clinothulite and thulite, respectively.

Epidote group minerals are of metamorphic origin and all originate under similar conditions as secondary minerals, commonly occurring in calc-silicates, contact metamorphic rocks, especially at granite–greenstone contacts, and as a result of saussuritization and epidotization of calcic feldspars in mafic rocks. Epidote is also found as a filling in the vesicles of basalt.

Epidote group

Epidote — hydrous calcium–aluminium–iron silicate $Ca_2(Al,Fe)_3(SiO_4)_3(OH)$

Zoisite — hydrous calcium–aluminium silicate $Ca_2Al_3(SiO_4)_3(OH)$

Thulite — Manganoan zoisite; hydrous manganese–calcium aluminium silicate $(CaMn)_2Al_3(SiO_4)_3(OH)$

Unakite — epidote-rich hydrothermally altered granite

Marshmallow rock — porphyritic dolerite containing pink clinozoisite (clinothulite)

Epidote–quartz–axinite rock — axinite, a complex borosilicate

Epidote

The mineral epidote may occur as a green rock-forming mineral or as single crystals that are commonly of prismatic habit and intense green (pistachio green) or brown in colour. Transparent and light-coloured epidote crystals may be faceted as gems (Fig. 30.1). Epidote may vary in colour if chemical substitution with chromium, manganese, or vanadium has taken place. A rare chromium epidote variety is bright green. This variety has a Cr_2O_3 content of 6.79% and is found in Finland and Burma as a granular constituent of an ornamental rock known as tawmawite.

Epidote is only known in Western Australia as a green rock-forming mineral. Simpson (1951) recorded many occurrences of epidote and epidotized mafic rocks in the State although none are recorded as the source of lapidary material. Epidote also contributes the bright green zones and pods to the ornamental rock termed unakite.

Physical properties of epidote

Crystal system	Monoclinic and orthorhombic varieties
Habit	Prismatic or granular
Colour range	Grey, colourless, yellow, green, and pink
Colour cause	Iron, chromium, manganese, and vanadium
Lustre	Vitreous
Diaphaneity	Transparent to translucent
Refractive index	1.69 – 1.78
Birefringence	0.010 – 0.035
Pleochroism	Strong in coloured varieties
Hardness	6.5
Specific gravity	3.35 – 3.4
Cleavage	Perfect prismatic, and imperfect

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Figure 30.1. Typical pistachio green epidote rock

Zoisite (tanzanite)

Zoisite is best known for the rare, blue-violet, and strongly pleochroic gem variety termed 'tanzanite'. First discovered in 1967 in the Merelani Hills, in the Lelatema district of northwestern Tanzania, the gem is only sourced from several deposits in this region. Tanzanite crystals are found in various colours: blue, green, yellow, pink, brown, and khaki. All these colours may be altered to blue by heat treatment, a process routinely used. Yellow and green zoisite crystals from Tanzania are also collectors' items and a source of gemstones.

Clinozoisite

Clinozoisite, a monoclinic dimorph of zoisite, is commonly a grey or colourless mineral of the epidote group although it may also show a strong pink colour if it contains trace amounts of manganese. Pink clinozoisite is termed 'clinothulite'. This pink clinothulite forms phenocrysts in the decorative Western Australian porphyritic dolerite marketed as 'marshmallow rock' (described below under Mindoolah porphyritic dolerite). The pink crystals within the dolerite result from metamorphic alteration of the primary feldspars, a process termed 'saussuritization'.

Thulite

The term 'thulite' refers to both a manganoan zoisite and to a rock composed predominantly of this mineral. First discovered in Norway in 1820, thulite takes the name from the mythical island of Thule, with legends indicating different islands in the North Atlantic Ocean although modern interpretations identify it as Norway. Thulite is a tough, attractive pink and rose-coloured mineral, commonly variegated with white zones. It is proven as excellent for carving and polishing. It is recorded from Greenland and several sites in the US.

Thulite rock is essentially composed of zoisite although clinozoisite is not uncommon as a constituent. Thulite has a hardness of around 6 on the Mohs scale and the Norwegian material has a refractive index of 1.70 and specific gravity of 3.10.

Unakite

Unakite was first discovered in the Unakas Mountains of North Carolina in the US. It is essentially an altered granite composed of pink orthoclase feldspar, green epidote, and typically, colourless quartz.

Unakite is a relatively low-temperature, hydrothermally altered granite in which the orthoclase feldspar has developed a pinkish colour from the presence of minute hematite inclusions, and the original plagioclase feldspar has been partially converted to green epidote. The colourless quartz remains unaffected. The result is an attractive mottled pink and green rock that can be cut into cabochons or made into beads and other decorative items (Fig. 30.2).

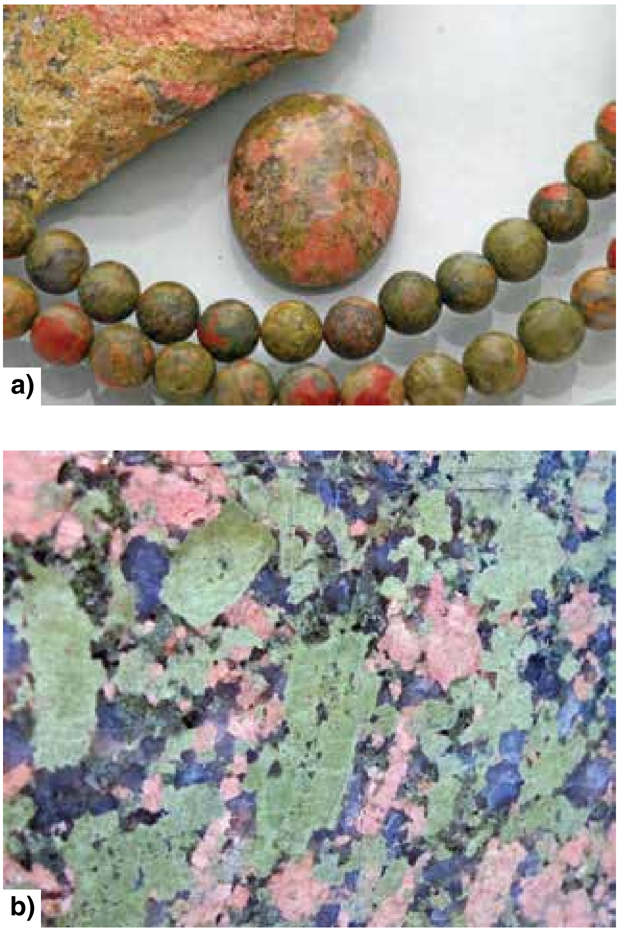

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Figure 30.2. Examples of unakite in natural and polished forms: a) unakite as natural rock with polished beads and cabochon; b) polished unakite slab displaying pink orthoclase, green plagioclase, and grey quartz. Samples from the Corunna Downs prospect in the Marble Bar region, width approximately 10 cm (courtesy Glenn Archer)

Epidote minerals in Western Australia

Unakite

In Western Australia, unakite occurrences are not common, with the best localities within granitic zones of the Albany–Fraser Orogen along the south coast.

Albany–Fraser Orogen

Denmark area

Lowlands Beach *(Albany, 2427)*

Narrow veinlets of unakite were noted by the authors in granitic outcrops bounding Lowlands Beach 17 km southeast of Denmark (Fig. 30.3). At this site, a unakite vein has cut the local coarse-grained, porphyritic, microcline-bearing quartz monzonite.

Cheyne Bay area

Cape Riche *(Cheyne, 2628)*

Geological Survey of Western Australia (1994) mentions an occurrence of unakite in a large shear zone on the coastline west of Cape Riche about 95 km east-northeast of Albany (Fig. 30.3). Nothing further is known about this occurrence.

Pilbara Craton

Marble Bar region

Corunna Downs *(Split Rock, 2854)*

Recently, unakite has been found on expired mining lease M45/936, formerly owned by Messrs G Jenkins, T Kapitany, and J Pas. The tenement is on Corunna Downs Station about 48 km south-southeast of Marble Bar (Fig. 30.3). A polished slab of unakite from this prospect is shown in Figure 30.2b.

Thulite

Pilbara Craton

Roebourne area *(Roebourne, 2356)*

Taylor (1967) reported on thulite from an unknown locality near the town of Roebourne (Fig. 30.3). The thulite occurrence is described as widely scattered, small lenses about 2 m in width enclosed in serpentine. The lenses are found in a few places in an albite-rich rock that can be traced for several kilometres.

Both pink zoisite and clinozoisite are present in this thulite. The zoisite is lighter pink and forms grains sized from very fine (10–15 µm) to relatively coarse euhedra (0.2 – 0.4 mm). By contrast, the clinozoisite grades into a deeper rose colour that may have a mauve tinge. The pink and rose clinozoisites are recorded as having a ferric iron content of 0.48 – 0.59% Fe_2O_3 and a manganese content of 0.09 – 0.30% MnO_2. Honey-coloured and grey grossular garnets are commonly present as veins, and are finely dispersed throughout the zoisite and clinozoisite. The cryptocrystalline rock is tough and finished samples take a fine polish.

Yilgarn Craton — Murchison Domain

Mindoolah area

Mindoolah porphyritic dolerite *(Kalli, 2344)*

The Mindoolah porphyritic dolerite is in prospecting licence P20/2122 about 75 km northwest of Cue and about 1.5 km east of Mardoonganna Hill (Fig. 30.3). At this site, the steeply dipping, east-northeasterly trending Mindoolah porphyritic dolerite dyke has intruded Archean basalt (Fig. 30.4).

This stone, termed ‘marshmallow rock’ by prospectors, contains hard, pink clinozoisite megacrysts 20–40 mm in diameter, set in a metamorphosed doleritic matrix. The clinozoisite megacrysts, which approach clinothulite in chemical composition, together with minor quartz were formed by replacement of former phenocrysts of plagioclase (Fig. 30.5a). The altered phenocrysts also contain lenses and veins of iron-rich epidote. Aggregates of actinolite–albite–clinozoisite–sericite–chlorite–titanite and quartz have replaced pyroxene, plagioclase, and opaque oxide in the original matrix (Fetherston, 2010).

In recent years marshmallow rock has been slabbed and manufactured into items such as decorative table tops, polished spheres, and sculptured *objets d’art* (Fig. 30.5b).

Lake Weelhamby area

Ninghanboun Hill *(Perenjori, 2139)*

Simpson (1951) records the presence of thulite at Ninghanboun Hill 30 km north-northeast of Perenjori (Fig. 30.3). At this site, a relatively large pale pink to grey inclusion of a few metres in length is enclosed within an outcrop of hornblende rock. The pale pink material, consisting of almost pure zoisite, grades imperceptibly into the greyer parts consisting of a dark amphibole intergrown with zoisite. The zoisite rock portions show specific gravity values of 3.28 – 3.32, and contain minor minerals including feldspar, amphibole, titanite, and zircon.

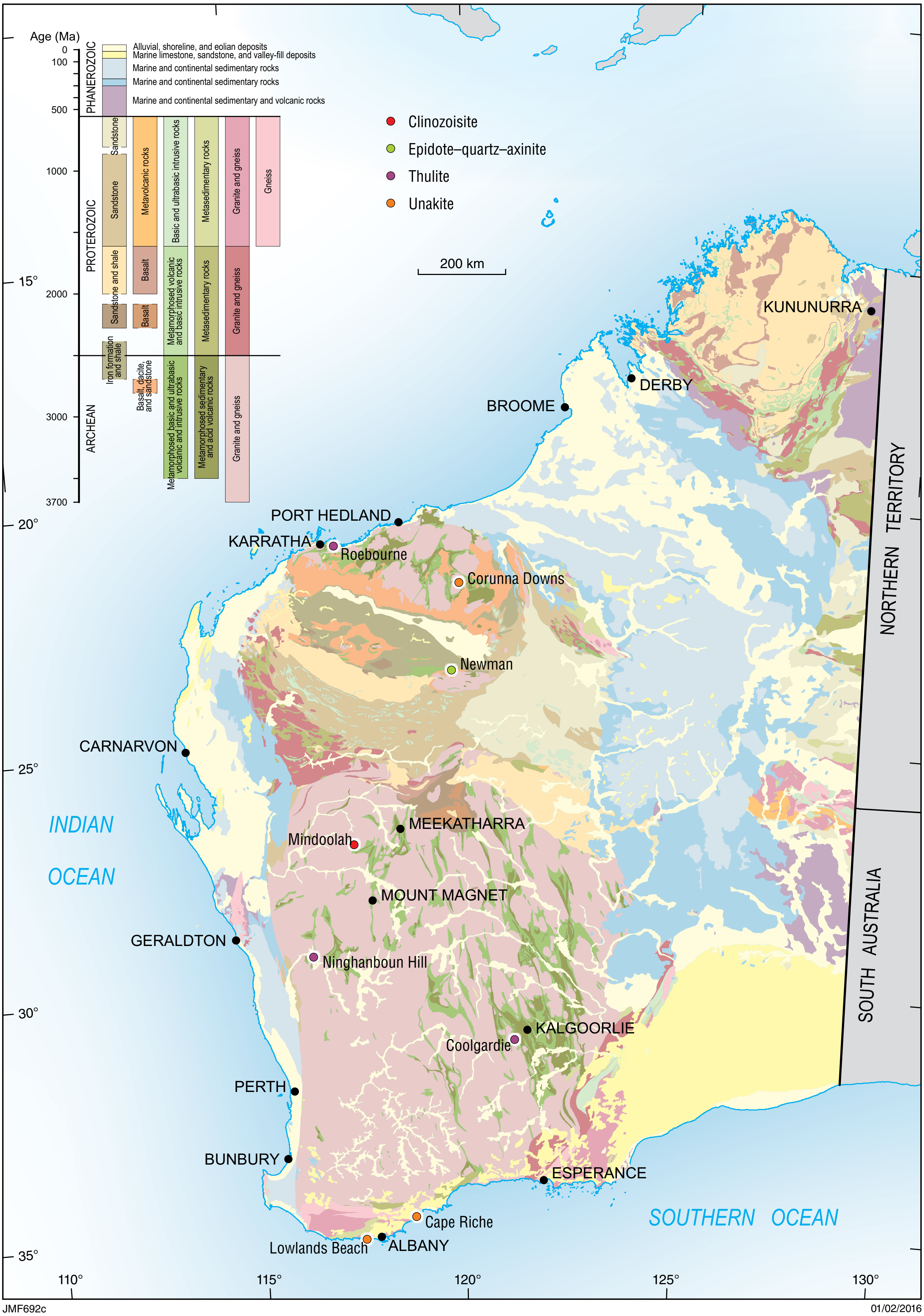

Figure 30.3. Locations of epidote group minerals in Western Australia

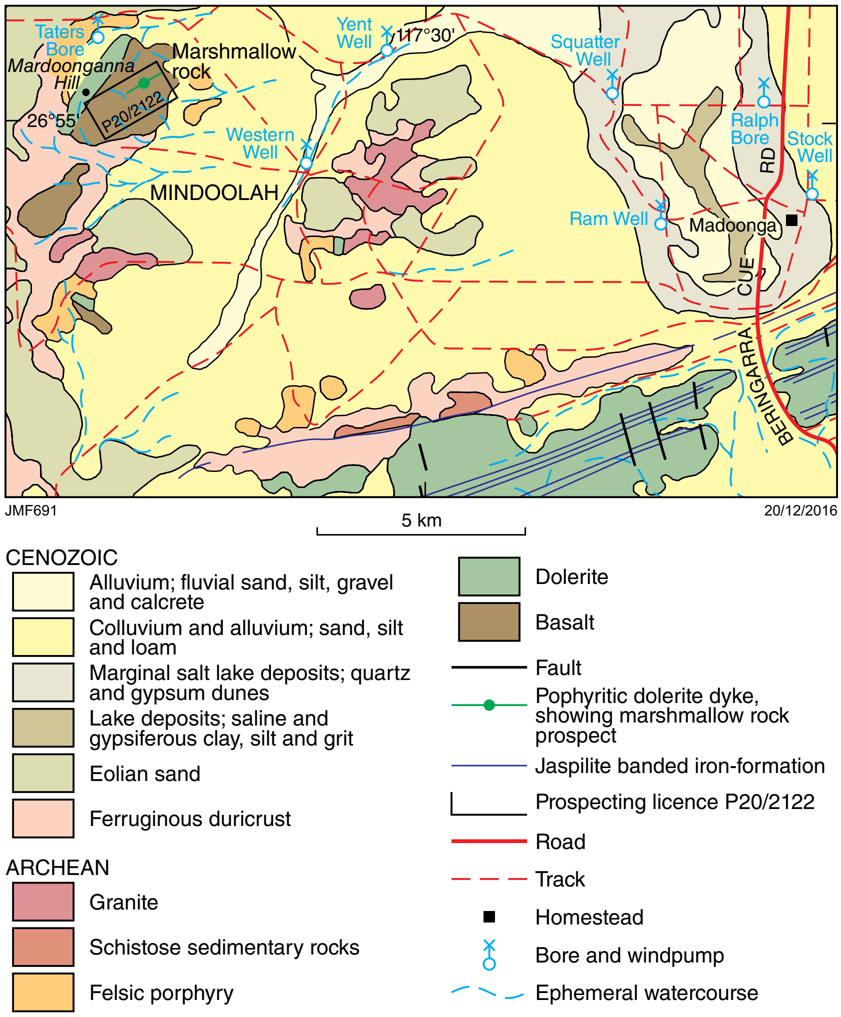

Figure 30.4. Geology of the Mindoolah area, northwest of Cue (modified after Elias et al., 1983)

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie area (*Kalgoorlie, 3136*)

The Western Australian Branch of the Gemmological Society of Australia holds a sample of thulite reportedly originating from an unknown locality near Coolgardie (Fig. 30.3). Nothing further is known about the origins of this sample, shown in Figure 30.6.

Epidote–quartz–axinite rock

Pilbara Craton — Hamersley Basin

Newman region (*Newman, 2851*)

In Western Australia, epidote has also been found forming part of a complex mineral assemblage of an epidote–quartz–axinite rock present as a vein of well-developed green, white, and brown crystals. Axinite is a complex, hydrous, borosilicate mineral, $Ca_2(Fe,Mn)Al_2BSi_4O_{15}(OH)$, containing iron and manganese, and may also contain appreciable sodium. Colour varies from brown to violet, blue, green, and grey. Also known as ‘glass schorl’, this triclinic mineral commonly forms glassy, wedge-shaped crystals.

Gem prospecting company Australian Outback Mining reported the discovery of a single occurrence of epidote–quartz–axinite rock at an unknown site on Turee Creek Station, about 110 km west-southwest of Newman in the Archean–Paleoproterozoic Hamersley Basin. The occurrence comprises a vein of epidote–quartz–axinite, typically no thicker than 25 cm, which intersects the Weeli Wolli Formation (Fig. 30.7). The Weeli Wolli Formation is composed of banded iron-formation intruded by numerous concordant dolerite sills. It is proposed that the epidote–quartz–axinite mineralization was formed as a product of hydrothermal alteration (Australian Outback Mining, 2012).

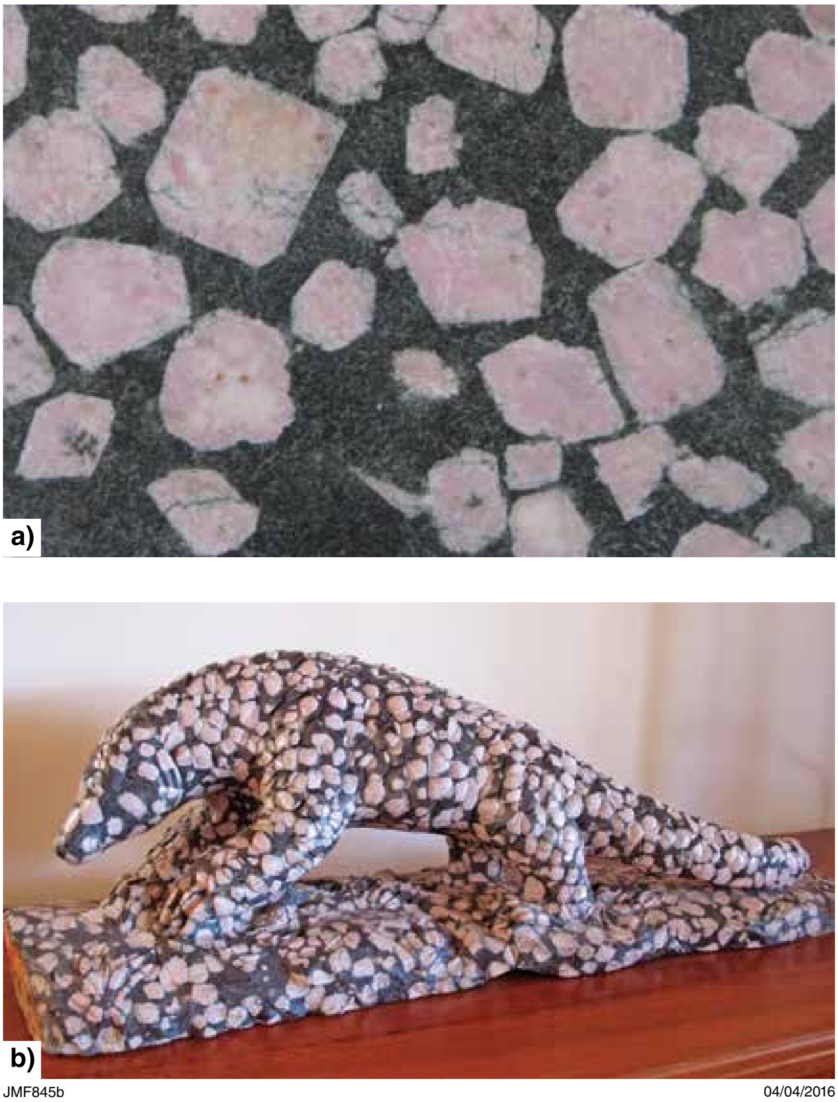

Figure 30.5. Mindoolah marshmallow rock: a) polished slab of a metamorphosed porphyritic dolerite containing hard, pink clinozoisite (thulite) megacrysts, 20–40 mm in diameter; b) sculptured work of a pangolin carved from marshmallow rock, total length 90 cm (courtesy Glenn Archer)

Figure 30.6. Polished specimen of pink thulite reportedly from the Coolgardie area. Collection of the Western Australian Branch of the Gemmological Society of Australia

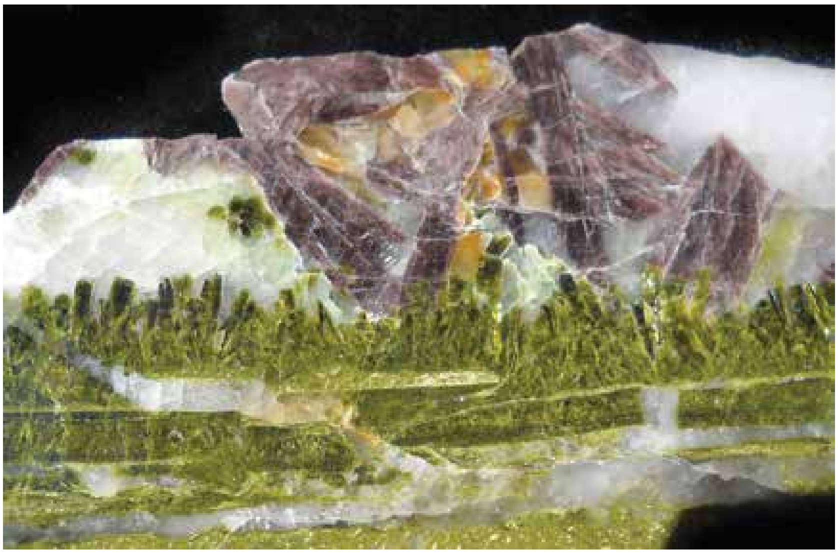

Figure 30.7. Polished epidote–quartz–axinite rock showing green epidote crystals, milky quartz, and brown axinite crystals from Turee Creek Station, west-southwest of Newman. Slab is approximately 15 cm wide (courtesy Glenn Archer)

References

Australian Outback Mining 2012, Epidote, quartz & axinite, viewed 6 August 2012, <http://outbackmining.com/>.

Elias, M, Wharton, PH, Walker, IW and Williams, SJ 1983, Belele, WA Sheet SG 50-11: Geological Survey of Western Australia, 1:250 000 Geological Series.

Fetherston, JM 2010, Dimension stone in Western Australia, volume 2 — Dimension stones of the southern, central western and northern regions: Geological Survey of Western Australia, Mineral Resources Bulletin 24, p. 64–65.

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, 52p.

Simpson, ES 1951, Minerals of Western Australia, volume 2: Government Printer, Perth, Western Australia, p. 35–61.

Taylor, AM 1967, Massive thulite from Roebourne, WA: The Australian Gemmologist, v. 9, no. 20, p. 5–6.

Grunerite — desert gold

Desert gold in Western Australia

Desert gold is found in one locality in Western Australia.

Pilbara Craton

Wallareenya area

Desert Gold prospect *(Wodgina, 2655)*

'Desert gold' is the local prospectors' name applied to the golden-brown grunerite–quartz rock, mainly composed of grunerite, an iron-rich amphibole. Grunerite is the iron-rich end member of the cummingtonite–grunerite mineral series. Also known as 'gold flake', this visually attractive stone is found on Wallareenya Station on mining lease M45/1134, owned by Mr B Kayes, about 33 km southeast of the Wodgina mining centre (Fig. 31.1).

The prospect is on a low hill, possibly as an amphibolite lens within an area of metamorphosed, Archean banded iron-formation, pelite, and quartzite. X-ray diffraction analysis of the desert gold rock shows it is composed mainly of grunerite and quartz with minor amounts of riebeckite-rich arfvedsonite, a greenish-black mineral of the amphibole group. Although some specimens display mineral lineation, many others do not.

Visually, desert gold has a coarse-grained, felted texture comprising large, golden-brown prismatic laths of grunerite up to a maximum length of 15 mm set within masses of reddish-brown iron-rich minerals including riebeckite. Viewed in reflected light, the grunerite plates display a silky lustre with a pronounced glitter effect (Fig. 31.2). The stone also contains quartz and is sufficiently hard (6.5 on Mohs scale), for it to be suitable for cutting and polishing as a decorative stone (Fig. 31.3).

Grunerite — desert gold
Iron-rich amphibole $Fe^{2+}_2(Fe^{2+},Mg)_5Si_8O_{22}(OH)_2$

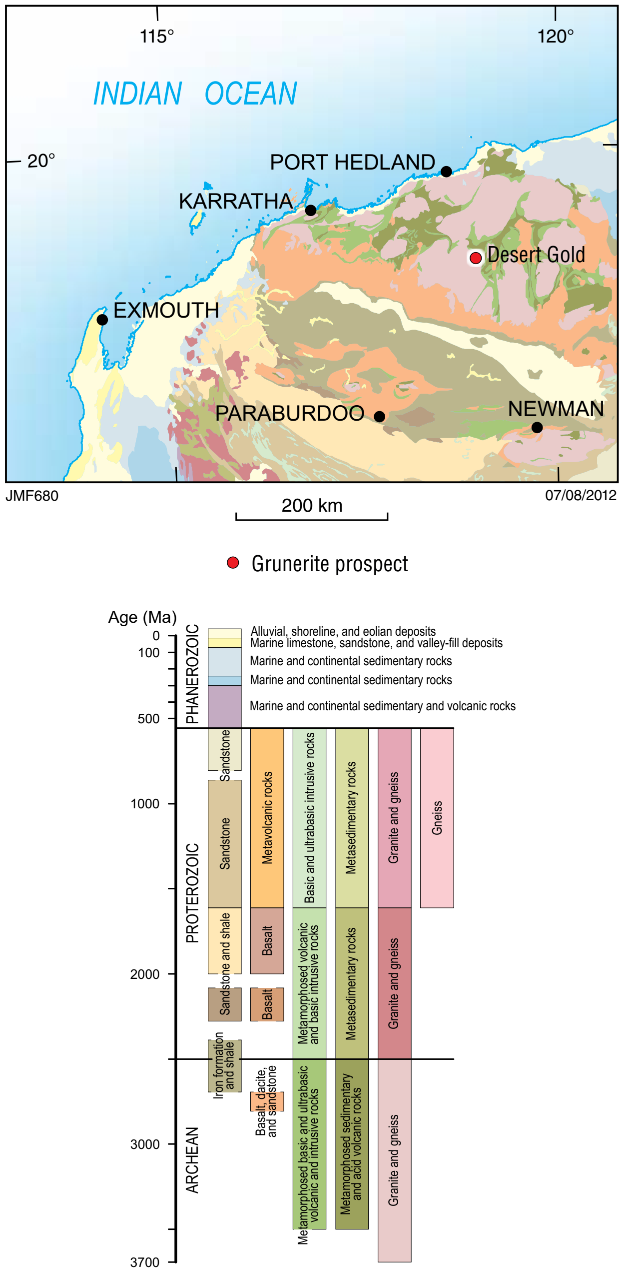

Figure 31.1. Location of the Desert Gold grunerite prospect

Figure 31.2. Polished specimen of desert gold displaying masses of golden-bronze grunerite with individual crystal laths up to 15 mm in length

Figure 31.3. Polished desert gold cabochon, 20 mm in diameter, with coarse laths of golden-brown grunerite clearly visible (courtesy Murray Thompson)

Chapter 32

Jade

Jade properties

Jade is a non-specific term used for a few different fine-grained, hard rocks, commonly of green or white colour, which are used for jewellery and ornamental purposes. Jadeitite and nephrite are the only two rocks considered true jades and each has specific mineralogical compositions and textural properties.

Jadeitite, or jadeitic jade, is a high-grade metamorphic rock composed almost entirely of the clinopyroxene mineral, jadeite, with small amounts of feldspar or feldspathoids. It is the rarest and most valuable form of jade, found mainly in Burma, Guatemala, and Japan (Fig. 32.1).

Nephrite or nephritic jade contains greenish or bluish amphiboles, tremolite, or actinolite as major constituents and is commonly formed by metasomatism (chemical replacement) of igneous or sedimentary rocks. Nephrite is found in many locations worldwide including China, The Russian Federation, British Columbia in Canada, Alaska in the US, New Zealand, and Cowell in South Australia (Fig. 32.2a). In New Zealand, nephrite is known as 'pounamu' by the Maori people who source and carve it into prized artworks. Found in the Hokitika district on the west coast of New Zealand's South Island, the nephrite is translucent, bright to dark green, with black spots and other inclusions (Fig. 32.2b).

Both jadeitic jade and nephrite have random, finely felted or granular textures, which results in extreme toughness. Nephrite jade typically has a finer texture and therefore greater toughness, whereas jadeitic jade may also have a fine texture although its prismatic pyroxenes may be slightly more coarsely grained.

Physical properties of Jade

	Jadeite	*Nephrite*
Refractive index	1.666 – 1.68	1.606 – 1.632
Specific gravity	3.34	2.95

Jade
Extremely tough, compact metamorphic rocks
Jadeite $Na(Al,Fe^{3+})Si_2O_6$
Nephrite $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$

Although both jades may appear visually similar they can be distinguished by differences in refractive index and specific gravity.

Both varieties of jade have been used and revered in many ancient cultures from Paleolithic times (>4500 years BCE) to the present day and are especially well represented in sculptural works and artefacts from ancient Chinese dynasties.

JMF850 10/09/2012

Figure 32.1. Pale green jadeite carved pendant from Burma, height 30 mm

a)

b)

JMF851 10/09/2012

Figure 32.2. Two forms of nephrite jade: a) olive-green nephrite from the Cowell deposit in South Australia carved as a vintage Rolls Royce car by sculptor David Noble (courtesy J Olliver, Destiny Stone Australia); b) mid-green, translucent pendant of pounamu stone, height 70 mm, from the Hokitika district in New Zealand's South Island (courtesy Te Koha Gallery, Franz Josef, New Zealand)

Jade in Western Australia

No true jades have been recorded as being mined from Western Australia although there are unconfirmed reports of nephrite jade sampled from unknown locations in the Pilbara, Eastern Goldfields, and Ashburton regions (see below).

There are also various different ornamental stones that have been mined and marketed under the term 'jade'.

Ornamental stone terminology

Common or trade name	*Mineral or rock type*
Ninghan black jade	Mafic intrusive rocks including magnesium-rich metabasalt and amphibolite
Pilbara jade or Marble Bar jade	Serpentine and chlorite
Indian jade	Aventurine
Karratha jade or Mount Regal jade	Microcrystalline quartz or chert with green fuchsite mica[(a)]
Pear Creek jade	Cryptocrystalline silica (chert) possibly with green fuchsite mica[(a)]
Australian jade (or Queensland jade)	Chrysoprase (apple-green variety of chalcedony)[(b)]

NOTES: (a) See Chapter 35 on siliceous decorative stones
(b) See Chapter 11 on the chalcedony group

Stones from this table marketed as Indian (aventurine), Karratha, and Pear Creek jades are discussed in Chapter 35 on siliceous decorative stones, and Australian jade (chrysoprase) is discussed in Chapter 11 on the chalcedony group. The locations of Ninghan black jade and Pilbara jade are shown in Figure 32.3 and more accurate locations are given in Appendix 1.

Ninghan black jade

Yilgarn Craton — Murchison Domain

Yeoh Hills (*Ninghan*, 2339)

Black jade is the trade name given to a hard, dark, greenish-black, massive to foliated rock that is very finely crystalline and able to take an excellent polish. At Yeoh Hills, deposits are present in areas of Archean, mafic intrusive rocks including magnesian-rich metabasalt and amphibolite (Fig. 32.4).

Access to the Yeoh Hills black jade deposits, about 40 km west of Paynes Find, is via the gravel Yalgoo–Ninghan Road, which intersects the Great Northern Highway adjacent to the Ninghan Station turnoff. The Yeoh Hills lie to the east of the gravel road about 14 km from the highway turnoff and can be reached by rough, narrow miner's tracks. In this area there are two black jade mining operations and a black jade prospect (Fig. 32.5).

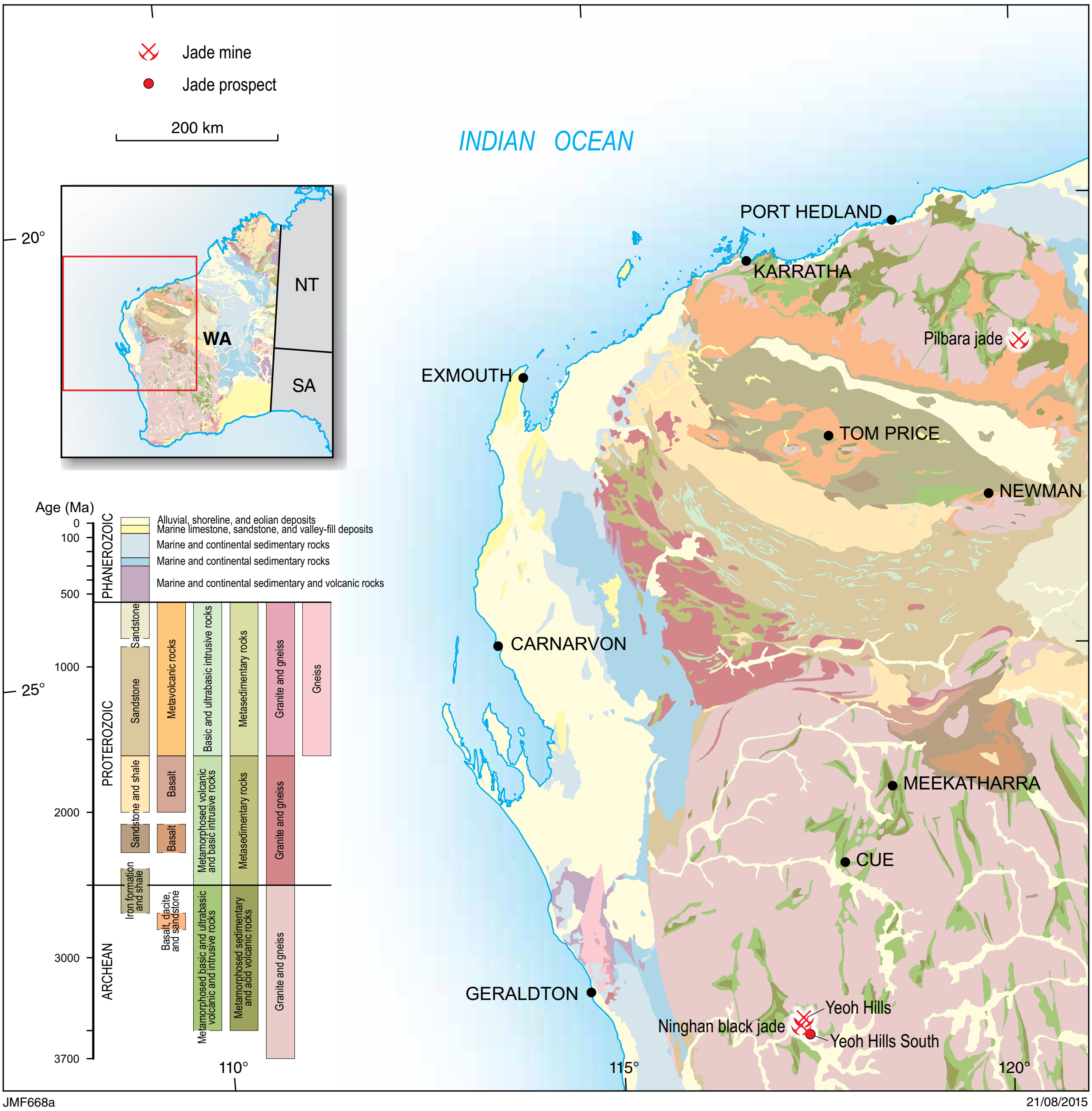

Figure 32.3. Locations of jade deposits in Western Australia

Figure 32.4. Finely crystalline Ninghan black jade from the Yeoh Hills deposit. The rock consists almost entirely of fibrous prisms of magnesian hornblende (courtesy Australian Outback Mining)

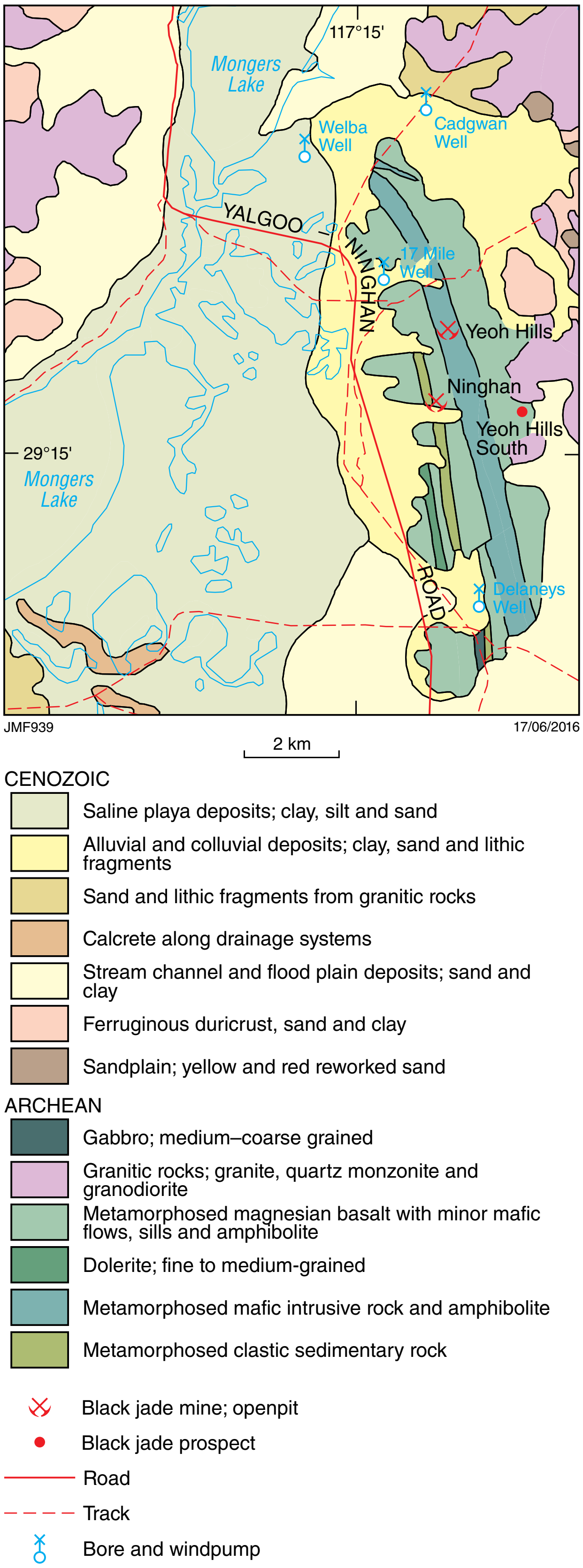

Figure 32.5. Geological map of the Yeoh Hills area showing the locations of black jade deposits (modified after Lipple et al., 1982)

The Ninghan black jade mine, owned by Soklich Holdings Pty Ltd, is sited on mining lease M59/557. Openpit mining commenced in 2010 and by the end of 2013 had produced a combined total of 22 t of ore and waste rock. The Yeoh Hills openpit mine is 2 km north-northeast of the Ninghan black jade mine on mining lease M59/753. This operation, owned by Australian Outback Mining Pty Ltd, is currently producing black jade for the manufacture of high-quality polished ornaments. At Yeoh Hills South prospect, 2 km east of the Ninghan black jade mine on mining lease M59/752, two north-trending ridges of amphibolite-rich black jade have been identified. Prospect owners headed by Mr R Thackwell have carried out surface mapping and bulk sampling on the tenement. Samples were subsequently sent to prospective overseas end users, who carved and polished rough samples to produce highly polished ornamental statues.

Yeoh Hills and the adjacent Nyounda Hill form part of the Ninghan Fold belt and consist of a series of Archean, north-northwesterly trending, metamorphosed, mafic greenstones composed of mainly tholeiitic basalt with intercalations of differentiated mafic flows, sills, and amphibolite. The area has been extensively explored for gold, with numerous pits, trenches, and small shafts in evidence (Lipple et al., 1983).

In this area, black jade is present as relatively narrow, well-defined bands intercalated within the mafic volcanic succession and can be easily identified by its distinct outcrop pattern. In outcrop the more massive material comprises large, sharply angular blocks with a distinctive conchoidal fracture and is coated with a thin red-brown iron oxide weathering rind (Fig. 32.6). In more deformed areas, the black jade becomes foliated or fractured and may be less suitable for commercial use.

Microscopically, black jade consists almost entirely of fine, commonly felted amphibole. Fibrous prisms of amphibole, probably magnesian hornblende, are typically 0.25 mm in length although can reach up to 0.5 mm in coarser zones. Interstitial areas throughout the amphibole mass comprise intergrown cryptocrystalline to microcrystalline albite with or without quartz. Fine grains of ilmenite make up about 5% of the rock. Assays have shown the jade to contain 157 ppm nickel, 998 ppm chromium, 51 ppm cobalt, 37 ppm copper, 286 ppm vanadium, and 7.32% iron, which is consistent with a magnesian-rich, tholeiitic metabasalt.

The Ninghan black jade with its uniform, dark colour and fine-grained texture is extremely tough and able to take an excellent polish in the manufacture of finely carved ornaments, which have included large animals, fish, and Buddha figures. An example of a black jade ornament from the Yeoh Hills mine is shown in Figure 32.7.

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10 cm

Figure 32.6. **Angular blocks of massive Ninghan black jade showing its characteristic thin, red-brown iron oxide weathering rind (courtesy Australian Outback Mining)**

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Figure 32.7. **Finely detailed carving of a bear, approximately 12 cm in height, in Ninghan black jade from Yeoh Hills in the Paynes Find area (courtesy Australian Outback Mining)**

Pilbara jade (Marble Bar jade)

Pilbara Craton

Marble Bar area

Pilbara jade deposit *(Nullagine, 2954)*

Pilbara jade was first discovered in the Marble Bar area in the early 1970s and was initially described and marketed as ‘jade’. A detailed examination of a slab of the material in 1974 confirmed that the material was a chloritic serpentinite that may contain irregular patches of fibrous serpentine (Hudson, 1974; Segnit, 1987).

The original discovery of the Pilbara jade was reported to be in the Hales Grave Well area, near the old Lionel asbestos mining area, about 25 km north of Nullagine township. The probable location is approximately 4.5 km northeast of the old Hales Grave Well where mining leases M46/63 and M46/44 are located. Access is northwards along the Nullagine – Marble Bar Road and then along a track that leads northeast from the abandoned Hales Grave Well.

The Pilbara jade deposit is within a group of Archean metamorphosed mafic and ultramafic rocks of the Dalton Suite, which is part of the Pilbara Supergroup (Williams and Hickman, 2007). Hudson (1974) described the Pilbara jade as a predominantly fine-grained, massive green to grey-green rock composed almost entirely of chlorite.

Physical properties of Pilbara jade

Mineralogy	Dominantly massive chlorite		
	Chlorite	*Al-serpentine*	*Chrysotile serpentine*
Colour range	Green to grey-green	White	Pale yellow-green
Habit	Massive to microbanded	Fibrous	Asbestiform
Lustre	Waxy	–	–
Diaphaneity	Turbid to smoky translucence	–	Translucent
Refractive index	1.570 – 1.572	1.553 – 1.555	1.530 – 1.536
Birefringence	Low	–	–
Hardness	–	2.5 – 3	–
Specific gravity	2.58 – 2.71	–	–
Fracture	Subconchoidal	–	–
Weathering	Weathers to a brown to brownish-red, subvitreous, irregular surface	–	–

NOTE: – not available

Source: Hudson (1974)

The rock weathers to produce a brown to brownish-red irregular surface although freshly broken surfaces have a waxy lustre with subconchoidal fractures. Microscopic banding can be seen on some polished faces although the purest specimens are typically massive, displaying a slightly turbid to smoky translucence if held against the light.

Hudson (1974) also states that a characteristic feature of the Pilbara jade is the occurrence of irregular white patches that may form veins in the massive green chlorite. These patches are composed of a fibrous white matrix of Al-serpentine cut by pale yellow-green, subparallel fibres of chrysotile serpentine (Fig. 32.8).

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Figure 32.8. Sample of Pilbara jade, approximately 30 cm wide, showing green chlorite surrounding white Al-serpentine cut by narrow fibres of asbestiform serpentine (courtesy Cyril Richter)

Pilbara jade forms as lenses within serpentinite and it appears that both formed during the hydrothermal alteration of olivine and pyroxene present in ultramafic rocks. Also, the formation of chlorite requires aluminium, which was probably introduced along channelways during the alteration process.

Mineable Pilbara jade is found in kidney-shaped bodies (commonly fractured in the near-surface environment) and are contained in what appears to be narrow dykes of 'jade' in serpentine. The kidney bodies are mined by undercutting them, lifting them with a bulldozer and then extracting them from the site with a front end loader to avoid undue fracturing (Hudson, 1974).

An example of Pilbara jade used in jewellery is shown in Figure 32.9.

Nephrite jade

Although no localities are recorded at which true nephrite jade has been mined, there are unconfirmed reports of possible nephrite specimens sampled from several unknown sites in the State.

Pilbara region

Hudson (1974) recorded that he was shown two specimens possibly originating from an unknown location in the Pilbara region. Both specimens were hard and dark green with specific gravity values of 2.95 and 3.02, and refractive index values of 1.612 – 1.618 and 1.620 – 1.624, respectively. X-ray diffraction examination confirmed that they were amphibole-related minerals and hence could be termed 'nephrite'.

Grey to grey-green, very dense and tough material was sourced from Nunyerry Station area, approximately 115 km south-southeast of Roebourne. This material

Figure 32.9. Handcrafted pendant of Pilbara jade inset with an 18 mm-diameter Broome mabe pearl (courtesy Marion Egger)

was very difficult to diamond saw, and the colour was unsuitable for gems. However, the stone may prove ideal for base work in box making and overlay work (CM Moriarty, 2011, written comm., March).

Yilgarn Craton — Eastern Goldfields Superterrane

Grey-green to yellow-green, opaque and fibrous material was found in an area known as Lindin, in the Eastern Goldfields (CM Moriarty, 2011, written comm., March).

Ashburton region

Pale grey-green to pale green, flaky, and milky translucent material was sourced from an unknown locality somewhere in the Ashburton region (CM Moriarty, 2011, written comm., March).

References

Hudson, DR 1974, Pilbara jade: The Australian Gemmologist, v. 12, no. 4, p. 127–133.

Lipple, SL, Baxter, JL and Marston, RJ 1982, Ninghan, Western Australia: Sheet SH 50-7: Geological Survey of Western Australia, 1:250 000 Geological Series.

Lipple, SL, Baxter, JL and Marston, RJ 1983, Ninghan, Western Australia: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 23p.

Segnit, ER 1987, Decorative serpentinite from the Marble Bar area: The Australian Gemmologist, v. 16, no. 5, p. 182–183, and 198.

Williams, IR and Hickman, AH 2007, Nullagine, Western Australia Sheet SF 51-5, 3rd edition: Geological Survey of Western Australia, 1:250 000 Geological Series.

Chapter 33

Mookaite and other decorative porcellanites

Porcellanite rock description

Porcellanites are a group of compact dense siliceous rocks that are widespread within the Carnarvon Basin. Several decorative, coloured varieties have been commercially exploited as gem materials. The best-known porcellanitic rock is mookaite, although other commercial varieties include pink opal and breccia.

The Early Cretaceous Windalia Radiolarite, part of the Winning Group of the Southern Carnarvon Basin, comprises a series of sedimentary lithologies formed under marine shelf conditions during times of high sea levels when siliceous microfauna (zooplankton) were abundant. The resultant rocks are fine grained, dominantly siliceous and comprise radiolarian siltstones, sandy radiolarite, siltstone, and chert. Casts of ammonites, belemnites, and bivalves are also locally present (Hocking et al., 1985, 1987).

The Windalia Radiolarite is a uniform white-weathering rock with poor blocky bedding, which rarely displays bedding structures. Fresh exposures are described as medium to dark grey ranging to grey-brown where carbonaceous, and green-grey or olive-black where glauconitic. Although the Windalia Radiolarite is regionally widespread, it appears that colourful porcellanites only form in specific zones where the effects of surface and near-surface secondary silicification have resulted in the localized development of cherts or porcellanites. Localized colour mottling and varicolouration of these cherts are the result of blotchy iron staining by later meteoric water activity.

It appears that these porcellanites occur wherever these conditions are satisfied and there are unconfirmed reports of numerous minor discoveries over a wide area to the north and northwest of Gascoyne Junction.

Mookaite properties and applications

Mookaite is a commercial name for the varicoloured, ornamental porcellanitic rock taking its name from the former Mooka Station, where it has been quarried since the mid-1960s. It is a popular lapidary material with desirable qualities as an ornamental stone including a wide range of colours displaying attractive, mottled patterns, a general lack of directional weakness, a very fine-grained nature, and adequate hardness. These properties make it very suitable for cutting and polishing.

Mookaite is found within the Early Cretaceous Windalia Radiolarite, part of the Winning Group of the Southern Carnarvon Basin.

Examination of thin sections shows mookaite is dominantly composed of cryptocrystalline silica with a finely banded texture and coloured by hematite and/or goethite granules in varying concentrations. Throughout the groundmass are scattered spheroidal and ellipsoidal structures (0.05 – 0.2 mm in diameter) that are poorly preserved microfaunal structures, dominantly radiolaria (Stocklmayer and Stocklmayer, 2010).

Mookaite

Silicified, iron-stained radiolarite

Physical properties of mookaite

Crystal structure	Amorphous
Habit and mineralogy	Dominantly massive ultrafine silica
Colour range	Varicoloured — white, cream, light brown, grey, orange-red, purple-red, yellow, and mauve
Colour cause	Iron oxide and/or iron hydroxide granules
Lustre	Vitreous with some patches of matte appearance
Diaphaneity	Translucent to opaque
Refractive index	1.536 – 1.538
Hardness	6–7
Specific gravity (hydrostatic method)	2.537 – 2.568 — variability is caused by compositional changes and variable porosity
Fracture	Markedly conchoidal
Patterns	Variable; mostly rounded forms of mottles and blebs. Colour is commonly variable along microfissures and fractures; liesegang banding patterns are common

Coloured mookaite shows a wide variation in hues and shades including yellow, red, brown, purple, and light mauve, with each hue varying in intensity, tone, and shade (Fig. 33.1). The colours result from iron oxide-rich groundwater that has penetrated along conduits of fractures and microfissures and deposited iron oxide granules (hematite and goethite up to 0.1 mm in diameter) throughout the host rock. It is these iron-rich granules that appear to be the cause of colour variations and intensity in mookaite. Accordingly, colourless zones indicate low concentrations of iron-rich granules, and by contrast, intensely coloured zones have a high concentration of the granules. At the same time, hue changes are reflected in different states of iron oxidation present in different zones throughout the rock.

Figure 33.1. Selection of tumbled, polished mookaite stones showing a wide range of colours and patterns

In reflected light, sections of red and yellow mookaite show dense concentrations of hematite and goethite granules, respectively. Some of these coloured zones exhibit fine liesegang banding comprising lighter and darker shades of one colour (Fig. 33.2).

Figure 33.2. Fine liesegang red–pink banding in mookaite reflecting lighter and darker iron oxide zones

Surface lustres of natural unpolished mookaite vary. Freshly broken surfaces have a matte or earthy appearance with low reflection whereas mookaite exposed at the surface may commonly show bright reflections resulting from a natural patina or desert varnish. Polished mookaite artworks and ornaments typically display a high vitreous lustre, although some unpolished patches of matte appearance may remain.

Mookaite and other decorative porcellanites in Western Australia

Southern Carnarvon Basin

Gascoyne Junction region

Mookaite at Mooka Creek (Binthalya, 1848)

Mookaite is mined on the former Mooka Station from several closely spaced sites on Mooka Creek adjacent to the Mardathuna Road, about 32 km northwest of Gascoyne Junction, and 13 km north of the Gascoyne River (Fig. 33.3). In this area, surface mining of mookaite slabs is carried out on a campaign basis from three contiguous mining leases: M09/86 (owned by Mr G Archer), M09/18 (Mr A Butler), and M09/109 (Messrs T Kapitany and J Pas).

The mookaite mining area is located over a comparatively small outcrop of Early Cretaceous Windalia Radiolarite partially exposed by erosion of Cenozoic, unconsolidated, alluvial sediments on Mooka Creek and by ferruginous and siliceous duricrust at a higher elevation. Not all of the Windalia Radiolarite in the area has been silicified and ferruginized and it appears the best mookaite is present in the area in and around Mooka Creek directly south of the ruined homestead.

Brecciated porcellanite mines (Binthalya, 1848)

Brecciated porcellanite including mookaite is present at various sites in the Kennedy Range area within the Southern Carnarvon Basin. It is typically found in narrow, laterally intermittent fault zones and comprises angular blocks of varicoloured porcellanite in a matrix consisting of small shards and rock-flour of porcellanitic material. The specimen in Figure 33.4, displaying the full range of fragment sizes, was sourced from the Mooka Creek area on mining lease M09/109 owned by Messrs T Kapitany and J Pas (Fig. 33.3).

Other varieties, marketed as 'brecciated mookaite', comprise multicoloured, small to large angular fragments and smaller, well-rounded pebbles cemented by an iron-rich matrix. This brecciated porcellanite was probably formed within a near-surface regolith horizon (Fig. 33.5).

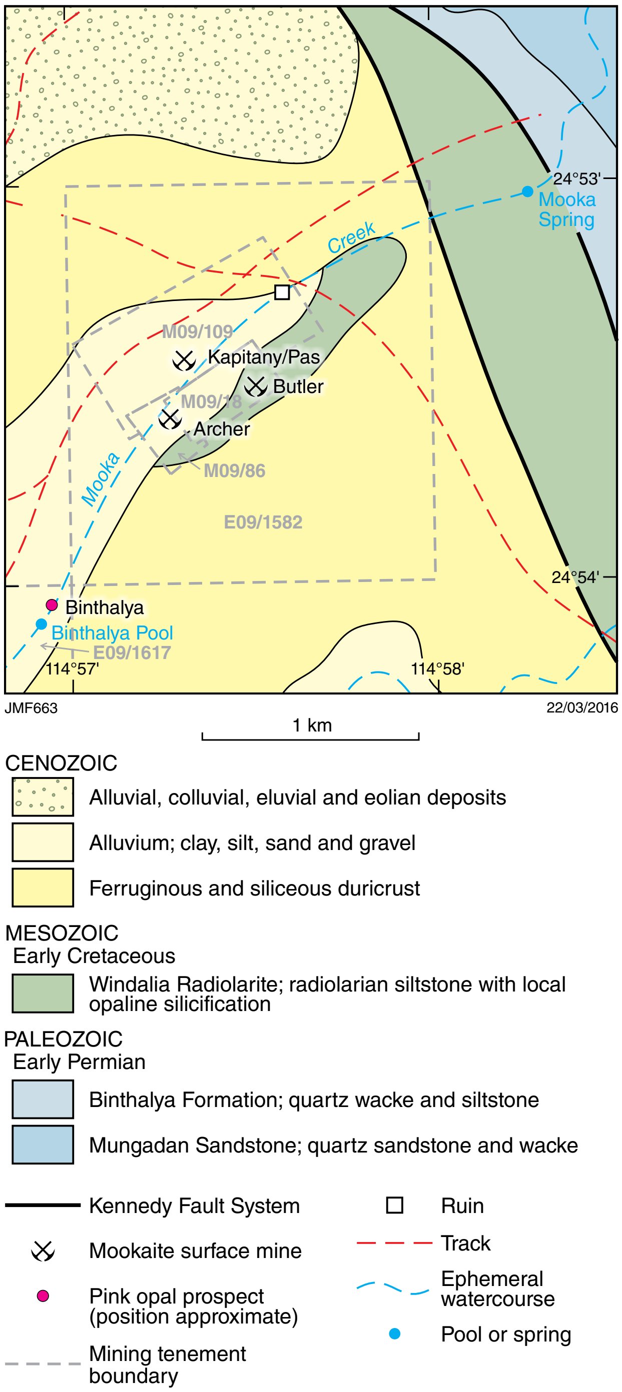

Figure 33.3. Sketch map of mookaite mining operations and pink opal prospect at Mooka Creek (modified after Denman et al., 1985)

Fossickers should note that the best mookaite localities are within the area of the three mining leases mentioned above and permission for fossicking must be sought from individual tenement owners.

Binthalya pink opal prospect *(Binthalya, 1848)*

'Pink opal' is a prospector's name applied to a different variety of porcellanite that outcrops as a persistent bed of extremely bright pink, opalized radiolarite near Binthalya Pool, approximately 1 km downstream from the Archer mookaite mine on Mooka Creek (Fig. 33.3). Pink opal is somewhat different from the opal gemstones described in Chapter 10 on opal. This site, known as the Binthalya prospect, is contained within exploration licence E09/1617 held by Mr Glenn Archer.

At this site, pink opal is present as a dominant, horizontal bed within zones of coloured porcellanites beneath a surface-brecciated zone in which angular fragments of pink porcellanite have been cemented by iron and silica solutions producing an attractive pink breccia. The pink zone beneath has already been tested by trial mining to ascertain the extent and consistency of the pink, opalized material (Fig. 33.6).

Examination of pink opal thin sections has confirmed the rock is radiolarite with a dominantly isotropic, fine-grained mineral composition. Although not verified by X-ray diffraction analysis, the pink opal's physical and visible optical properties suggest it is dominantly opaline silica, and has a lower bulk density than the locally porcellanized mookaite material. Pink opal commonly shows liesegang banding and contains small vugs and fine fractures infilled with microcrystalline quartz. Microscopic, lustrous grains within the rock result from reflections of granular quartz that has infilled pores and replaced radiolarian structures.

The microphotograph shown in Figure 33.7 shows two types of radiolarians. The conical form is assigned to the nasselarian group, and the circular object in the right-hand corner, with one protruding spine is identified as part of the spumellarian group (D Haig, 2012, written comm., November).

In a similar manner to the origin of mookaite, the re-silicification of the Windalia Radiolarite to form the pink opal porcellanite has resulted in a visually attractive, bright pink material displaying a high vitreous lustre. Pink opal is extremely hard and brittle with a conchoidal fracture visible in Figure 33.6b. These properties allow pink opal to take a high polish, making it suitable for the production of colourful, polished tumbled stones, cabochons, and other artworks (Fig. 33.8).

The locations of mookaite mines and a pink opal prospect are shown in Figure 33.3 and more accurate positions are given in Appendix 1.

Figure 33.4. **Brecciated porcellanite sourced from the Mooka mining area. This large, polished slab displays the angular nature and variable sizes of the multicoloured shard-like fragments, maximum slab width 34 cm (courtesy Mr T Kapitany)**

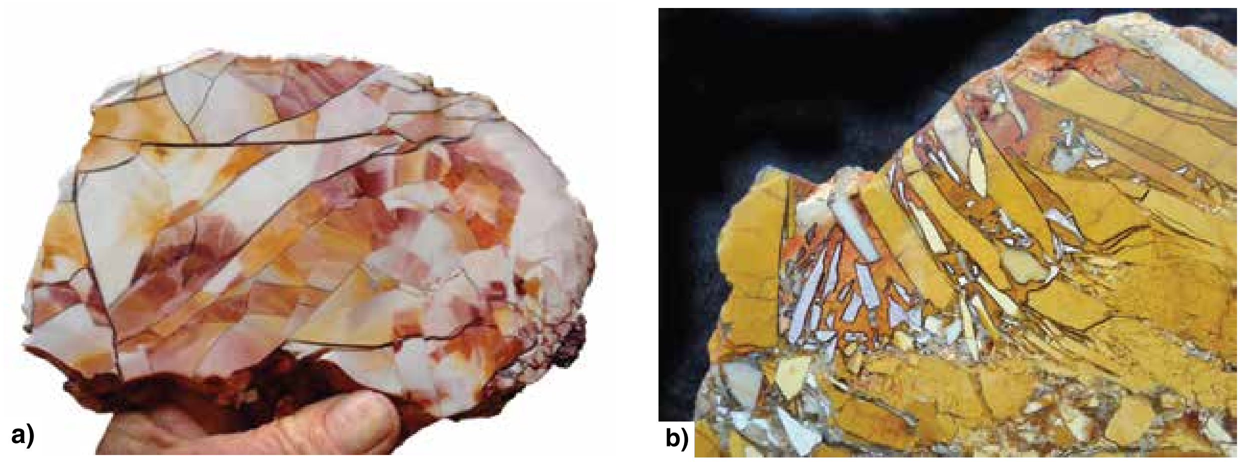

Figure 33.5. **Samples of brecciated mookaite in enlarged view (images courtesy Glenn Archer): a) predominantly brown, interlocking, straight-walled fragments tightly cemented by black iron oxide particles; b) yellow and white, highly angular porcellanite shards cemented by black iron oxide particles**

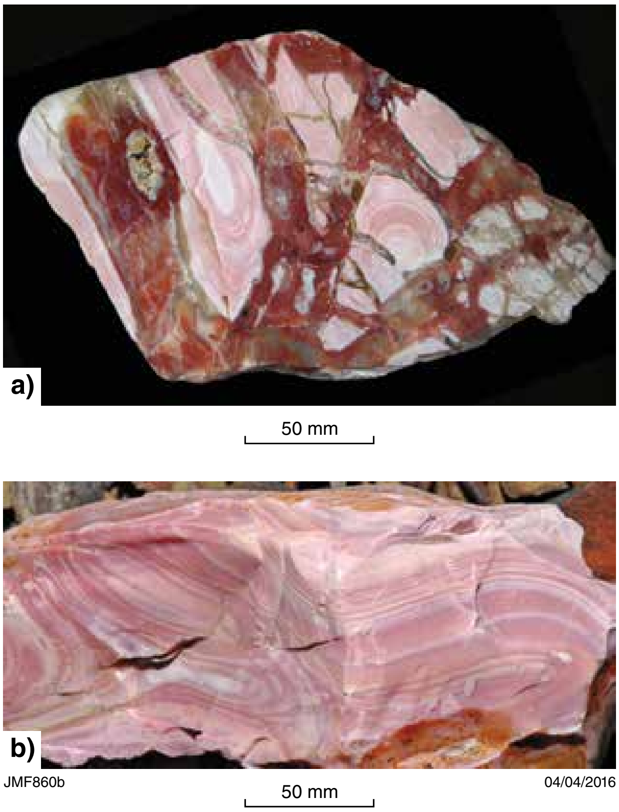

Figure 33.6. **Pink opal specimens from the Binthalya prospect at Mooka Creek: a) angular fragments of brecciated pink opal, cemented by iron and silica, from the near-surface zone; b) visually attractive, banded pink opal from the lower pink zone, showing its distinctive conchoidal fracture pattern (courtesy Glenn Archer)**

Figure 33.8. **Colourful polished cabochons of pink opal (upper left) and mookaite (lower right) (courtesy Judy Brewster)**

Figure 33.7. **Micrograph of a section of pink opal showing two varieties of radiolarian. The conical form is assigned to the nasselarian group, and the circular object with one protruding spine, in the upper right-hand corner, is from the spumellarian group**

References

Denman, PD, Hocking, RM, Lavaring, IH, Moore, PS, Van de Graaff, WJE and Williams, SJ 1985, Kennedy Range, WA Sheet SG 50-1: Geological Survey of Western Australia, 1:250 000 Geological Series.

Hocking, RM, Williams, SJ, Moore, PS, Denman, PD, Lavaring, IH and Van de Graaff, WJE 1985, Kennedy Range Sheet SG 50-1: Geological Survey of Western Australia 1:250 000 Geological Series Explanatory Notes, p. 26.

Hocking, RM, Moors, HT and Van De Graaff, WJE 1987, Geology of the Carnarvon Basin: Geological Survey of Western Australia, Bulletin 133, 289p.

Stocklmayer, S and Stocklmayer, V 2010, Mookaite — a Western Australian ornamental rock: The Australian Gemmologist, v. 24, no. 3, p. 56–60.

Orbicular granite

Orbicular granite description

Orbicular granite, also known as orbicular granodiorite, is a relatively rare orbicular form of granitic rock known only from a few sites around the world including Western Australia, Chile, Scandinavia, Antarctica, South Africa, Zimbabwe, New Zealand, and the island of Corsica in the Mediterranean where it is known as 'corsite,' an orbicular form of diorite.

Orbicular granite has a very distinctive appearance, being crowded with concentrically formed orbicules composed largely of hornblende and plagioclase feldspar, within a lighter coloured matrix of granitic composition. Individual orbicules average 140 mm in diameter, and up to 12 distinct shells have been observed in many of these structures. There is considerable variation in both size and internal structure of orbicules, which may range from relatively small types containing fewer shells with less-defined outlines to larger, multilayered varieties with mafic outer shells (Fig. 34.1).

A generalized succession from the centre of an orbicule consists of a coarsely radiating mix of hornblende and plagioclase and the different shells are commonly fairly sharply defined by crystal aggregation, crystal shape, and differing granularity. The outer radiating shells commonly have a coarser texture and greater proportion of ferromagnesian minerals including opaques and titanite. Green biotite is commonly a dominant mineral in the orbicule outer shells, where it appears as a replacement mineral caused by later changes in magma chemistry. Pockets and veins of complex sulfide intergrowths may also be associated with larger orbicules. The groundmass between orbicules is leucocratic (light coloured) with a variable composition of quartz–plagioclase–biotite with small amounts of K-feldspar. Large euhedral crystals of titanite with lengths of up to about 20 mm are also present in the groundmass.

Orbicular granite is an unusual and attractive igneous rock mainly used as a dimension stone. It is also a spectacular lapidary material and artistically carved smaller objects such as bookends, coasters, and slabbed, polished tiles have been made from the rock.

Orbicular granite
Granodiorite

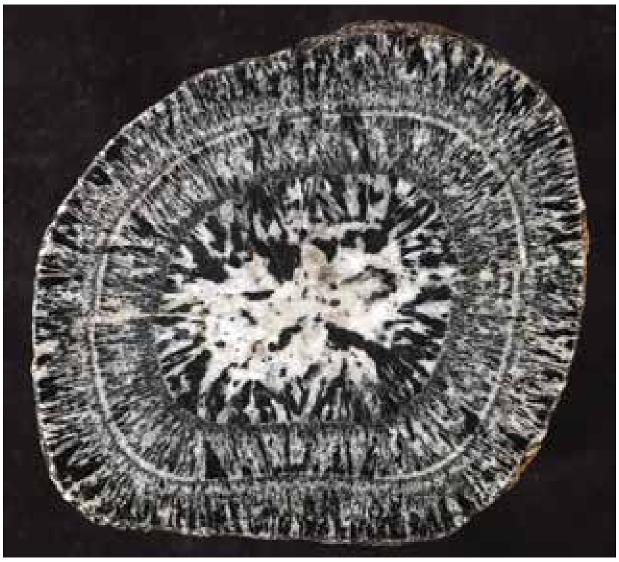

Figure 34.1. Spectacular hornblende diorite orbicule of Boogardie orbicular granite. The orbicule is composed largely of white plagioclase feldspar, and large, black, radially aligned hornblende crystals. Diameter of longest axis is about 150 mm (Fetherston, 2010)

Orbicular granite in Western Australia

Yilgarn Craton — Murchison Domain

Mount Magnet area

Boogardie *(Mount Magnet, 2441)*

The Boogardie orbicular granite deposit is on Boogardie Station, 35 km west of Mount Magnet. At the Boogardie minesite, the central tenement mining lease M59/28, owned by Mr K Seivewright, encloses the Boogardie quarry, which is currently in care and maintenance. Although the quarry is not currently in production, there is abundant stockpiled material (Fig. 34.2). A more accurate location is given in Appendix 1.

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). 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. 34.2).

The orbicular granite is hosted by a pink, medium-grained, northeasterly trending, late Archean granitic rock, comprising biotite granodiorite that becomes tonalitic in places. Previous diamond drilling programs have provided information to suggest that the orbicular granite bodies may have formed as saucer-shaped, sill-like structures within the host rock. Six drillholes completed over the area of the main Boogardie quarry delineated an oval-shaped body about 40 m wide (east–west) and at least 55 m long (north–south) with a maximum thickness of 11.4 m in the centre, tapering off in all directions. Another three drillholes drilled in the North prospect produced similar results (Fig. 34.2; Fetherston, 2010).

Within the sill-like structures, abundant granitic orbicules are contained in a leucocratic body of granodioritic–tonalitic composition. The black and white, concentrically banded orbicules are mostly ellipsoidal and contain lesser numbers of near-spherical, irregular, and broken shapes. Orbicules have an average diameter in the longest axis of around 140 mm, although the diameter may extend up to 200 mm. Individual orbicules are typically separated from the enclosing granodiorite–tonalite matrix by an outer shell of up to 10 mm in thickness comprising hornblende, biotite, and plagioclase with minor opaque oxide and titanite. Within this shell, orbicules commonly contain five to seven or more well-defined zones of variable width, structural complexity, and mineralogy.

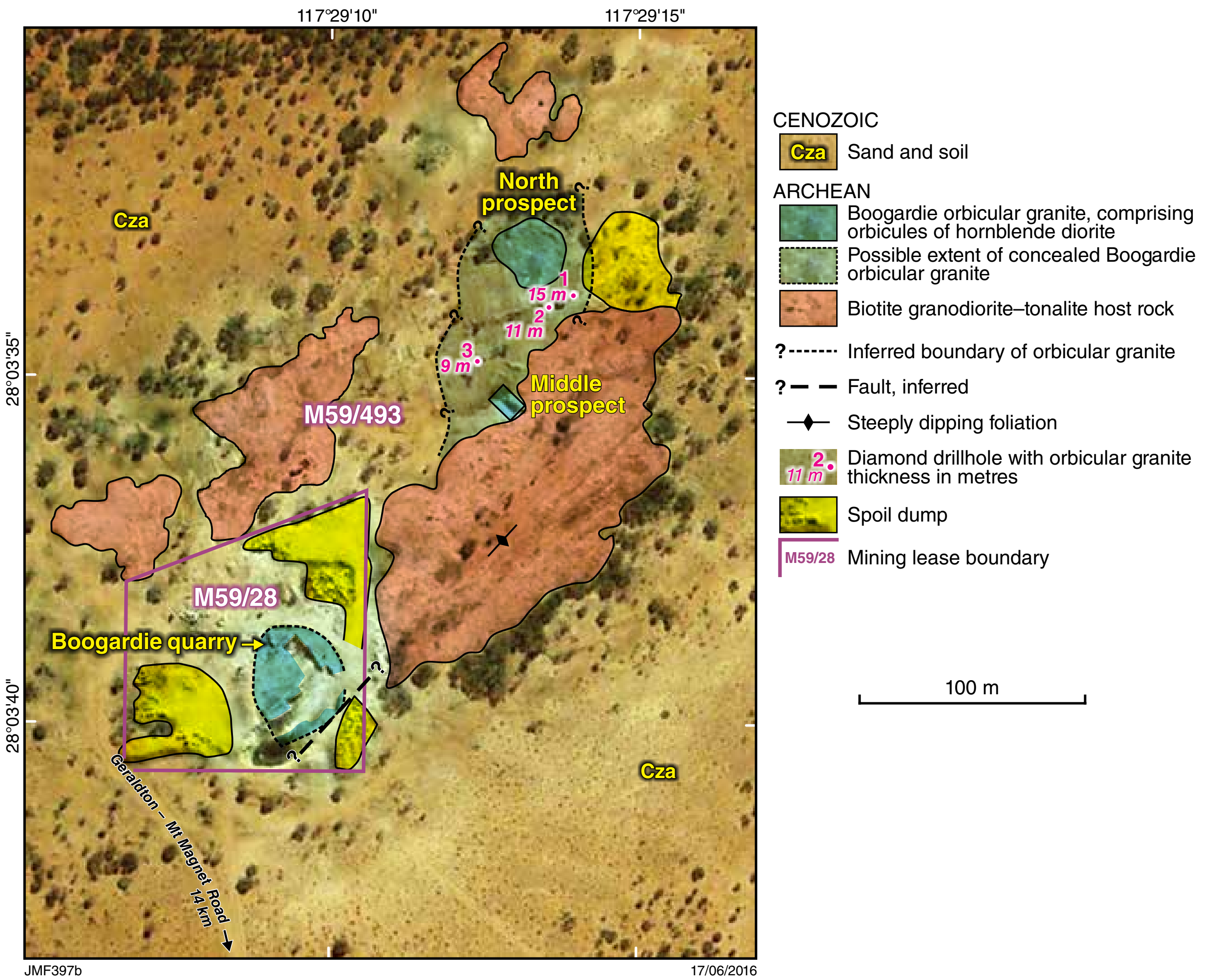

Figure 34.2. **Geological sketch map of the Boogardie orbicular quarry and exploration areas (modified after Fetherston, 2010)**

The distribution and morphology of the orbicules suggest a multi-stage history of nucleation and development. It appears that orbicules developed during early crystallization. Each major orbicule may have formed on a central core of a seed crystal, most commonly coarse-grained plagioclase, although cores may also be mafic xenoliths or fragments of previously formed orbicules (Fig. 34.3; Bevan, 2007). These orbicules seem to have settled under gravity into discrete deposits where evidence shows some to have been deformed or moulded one against another. The development of biotite cutting primary crystals and both titanite and calcite showing replacement textures indicate later chemical changes (Bevan and Bevan, 2009).

References

Bevan, JC and Bevan, AWR 2009, Nature and origin of the orbicular granodiorite from Boogardie Station, Western Australia: an ornamental stone of monumental proportions: The Australian Gemmologist, v. 23, no. 9, p. 373–432.

Bevan, JC 2007, Orbicular granitoids from W.A.: Newsletter to the Friends of the E de Clarke Earth Science Museum, September, 12p.

Fetherston, JM 2010, Dimension stone in Western Australia, volume 2 — Dimension stones of the southern, central western, and northern regions: Geological Survey of Western Australia, Mineral Resources Bulletin 24, p. 35–43.

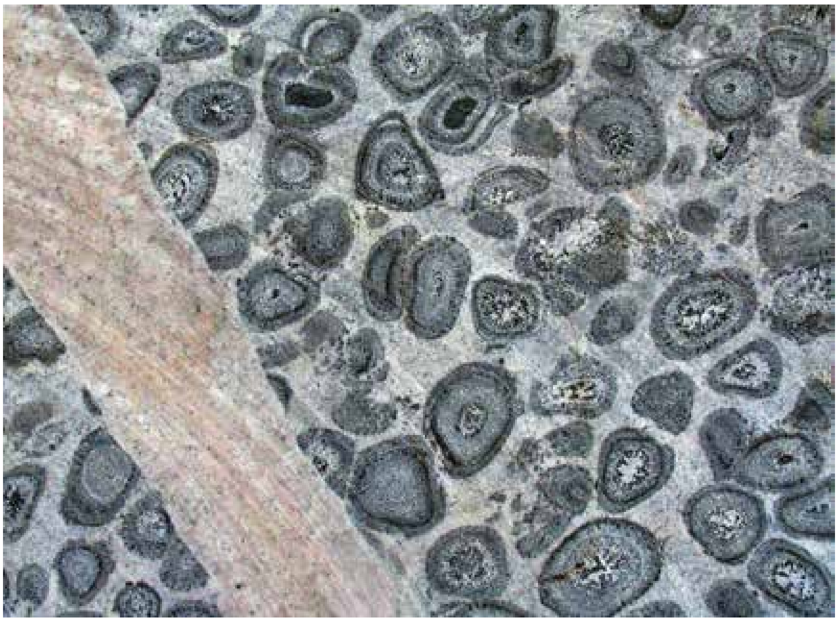

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Figure 34.3. Boogardie orbicules enclosed in a granodiorite–tonalite matrix. The rockmass, including orbicules, has been cut by a late-phase, pink pegmatite vein approximately 120 mm thick (Fetherston, 2010)

Chapter 35

Siliceous decorative stones

Siliceous decorative stones

Western Australia is endowed with a large number of siliceous decorative stones although only a small number of representative rock types are discussed in this publication (as shown on Fig. 35.1). First, the various forms of quartz present in this material should be considered. This classification applies not only to decorative stones, but also to the siliceous gemstones already discussed in earlier chapters, especially gem quartz (Chapter 9), opal (Chapter 10), and chalcedony (Chapter 11).

The quartz classification is represented by three groups: macrocrystalline quartz, microcrystalline quartz, and amorphous silica materials. Note that many siliceous gem and decorative stones are commonly found as mixtures of more than one form of silica, such as a mix of chalcedony and opal. Impure silica may contain iron oxide, calcium carbonate, clay, sand, and other inclusions. The following subdivisions include all the known varieties mentioned as gemstones in Western Australia (Simpson, 1952a).

Macrocrystalline quartz

This group includes colourless, coarse-grained quartz (rock crystal), amethyst, citrine, rose, smoky, milky, and prasiolite (green) quartz varieties that contain other mineral inclusions as in sagenitic quartz (containing acicular minerals especially rutile), cats eye quartz, and aventurine quartz. These minerals form either as primary minerals in veins, reefs, and quartzose pegmatite, or as secondary vein and cavity infillings including amygdales, and siliceous replacements of other minerals. Silica is commonly mixed with opal, and impure silica may contain iron oxide, calcium carbonate, clay, sand, and other inclusions. Quartz group gemstones are described in detail in Chapter 9 on the quartz group.

Microcrystalline quartz

Microcrystalline quartz requires a microscope to view individual crystal grains. The group includes chalcedony, chert, carnelian, chrysoprase, chrome chalcedony, prase, agate, moss agate, onyx, flint, jasper, siliciophite, silicified wood, and other siliceous pseudomorphs.

Under examination by petrological microscope, quartz is visible as a very fine-grained granular mosaic or in a fibrous form that may be in layers, bands, or patches, or radiating or spherulitic groups. The fibrous variety is called chalcedony, a quartz variant with optical and physical properties differing slightly from quartz, such as lower refractive index. These fine-grained quartz varieties commonly contain a mix of silica polymorphs (other forms of SiO_2) including microquartz, chalcedony, opal, and moganite. Chalcedony and its colour variants are the most common materials of this group.

Chert is a term applied to fine-grained quartz that is less transparent than chalcedony because of other mineral impurities. Chert commonly forms extensive horizons in sedimentary rock formations, commonly in the form of jaspers associated with Archean banded iron-formations in Western Australia.

Other fine-grained quartz varieties may be formed as nodules and bizarre shapes within sedimentary horizons by chemical segregation, such as flint nodules in chalk. Chalcedony commonly forms as a secondary material within the surface horizons of many different rock types as vein, fracture, and cavity infillings in the form of agate and carnelian. Other chalcedonies show evidence of their origin by replacement of existing mineralogy such as chrome chalcedony after silicification of serpentinite. Microcrystalline quartz gemstones are described in detail in this chapter and in Chapter 10 on opal and Chapter 11 on the chalcedony group.

Amorphous and cryptocrystalline quartz

Opaline silica is an amorphous or poorly crystalline form of silica. Gem varieties include precious and common opal. Some gem varieties are formed by replacement and include opalized fossil wood and cats eye opal. Opaline silica is a secondary material of widespread occurrence found on and within many different rock types, especially as near-surface encrustations.

Siliceous decorative stones
Silica and hydrated silica SiO_2 and $SiO_2.nH_2O$

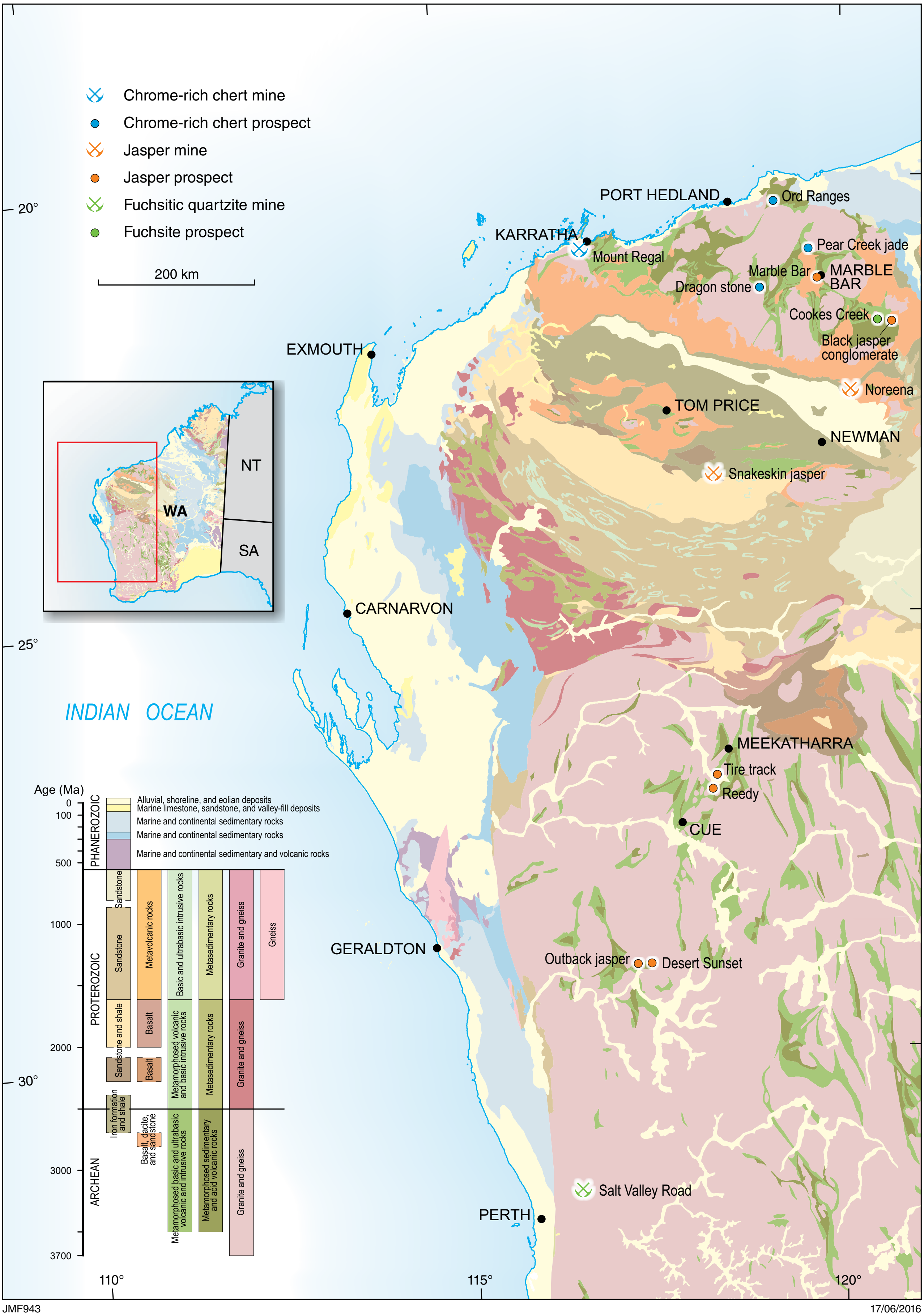


Figure 35.1. Locations of siliceous decorative stones in Western Australia

Opaline silica may only be characterized by X-ray diffraction and is commonly found associated with coarser silica polymorphs such as chalcedony and microquartz, and the quartz polymorphs cristobalite, tridymite, and moganite. Opal gemstones are described in detail in Chapter 10.

Green siliceous decorative stones in Western Australia

There are many occurrences of green ornamental stones throughout the State. Several are quarried for dimension stone (dressed building stone), such as Toodyay quartzite and Karratha 'jade'. Karratha jade is unrelated to jadeite and nephrite, which are discussed in Chapter 32 on jade. Other green ornamental stones are exploited from numerous occurrences and are used to make small decorative items such as bookends, coasters, table tops, carvings, sculptural works, cabochons, and beads.

Quartz is the dominant rock component of most of these green ornamental rocks although its fine-grained varieties chalcedony and chert (impure cryptocrystalline types) may also be present. The green colour in these ornamentals derives from minor rock mineralogy with fuchsite, a green mica, the most common and important.

Fuchsite

Fuchsite is a green chromiferous muscovite mica with the chemical formula $K(Al,Cr)_2AlSi_3O_{10}(OH)_2$ in which chromium substitutes for aluminium; one analysis reported 4.81% Cr_2O_3 in a fuchsite rock although it may be as much as to 6% (Deer et al., 1962). Although the source of chromium is not typically recorded in most fuchsite-bearing rocks, residual chromite grains are recorded in the petrology of the Pear Creek occurrence described below. In some whole-rock analyses, Simpson (1952b) recorded various percentages for the chromium content: from 1.10% Cr_2O_3 for a fuchsite schist at Nullagine to 2.20% Cr_2O_3 for a rock with andalusite and corundum from Burbanks.

Also known as 'chrome mica', fuchsite is a comparatively soft mineral (hardness 2 – 2.5) that may crystallize as tabular laminae aggregates or small flakes. Its colour ranges from pale to bright green depending on the degree of chromium substitution. Small crystals may impart a glistening appearance to the surface of the stone.

Simpson (1952b) described many occurrences of fuchsite in various types of rocks including a common association in the Meekatharra and Kanowna gold-bearing areas with gold and sulfide mineralization, and in altered greenstones and within higher grade metamorphic rocks where it is associated with corundum and kyanite. Simpson (1952b) also noted that fuchsite is 'a marked feature of the metamorphosed sediments (quartzites) of the early Precambrian succession'.

Colour is the most important feature of these rocks and includes many hues and intensities of greenness (some are described as 'malachite' green). Some rocks additionally show variation of colours caused by banding, schistosity, and veining.

Aventurine

Some green quartzites show a glistening sheen effect caused by light reflection off platelets of green fuchsite mica inclusions. This effect is greater where the mica inclusions occur in planes, which is common in schists. These glistening, speckled, and metallic effects are termed 'aventurescence' and a quartzite showing this effect is 'aventurine quartzite'. Aventurine quartzite is a rock, although some minerals, for example feldspars and cordierite, and some special synthetic glasses (manufactured specially for this quality), also can demonstrate this reflection effect from their inclusions. Aventurescent materials are not only green, and are found in many colours including blue, brown, white, and yellow. The colour depends on the mineral inclusions (such as iron oxides, copper, fuchsite mica, and chlorite) within the rock or mineral. The best aventurine effects are seen where the host rock or mineral is colourless and transparent, and the inclusions are discrete and in planes.

The physical properties of aventurine quartzite are variable because it is a rock: refractive index readings are approximately 1.55, specific gravity is 2.64 – 2.69, and hardness is lower than quartz (7) at about 6.5. Fuchsite quartzite gives a positive Chelsea filter (a green filter that only transmits green and red) response; showing red indicates its chromium content.

Chrome-rich fuchsite and chert in Western Australia

Yilgarn Craton — South West Terrane

Toodyay area

Salt Valley Road fuchsitic quartzite (Wooroloo, 2134)

A notable example of fuchsitic quartzite is found in an extensive Archean quartzite unit known as Toodyay stone. The site is at the Salt Valley Road quarry in the Darling Range about 65 km northeast of Perth and 9 km south-southwest of Toodyay (Figs 35.1 and 35.2). Interpreted as medium–coarse-grained orthoquartzite (the metamorphosed equivalent of a sedimentary quartz sandstone), the stone forms as massive to flaggy bands consisting of interlocking quartz grains, with minor muscovite, fuchsite, feldspar, and accessory minerals.

Fuchsite crystals with a characteristic sparkle are distributed throughout the unit and are most visible in silver-grey, flaggy quartzite bands where they form thin, pale emerald-green bands up to 3 mm thick and coatings along cleavage planes (Wilde and Low, 1978; Fig. 35.3).

In past years, Toodyay stone, with its visually attractive, green overtones, has been used as a green, decorative stone in monument and feature walls in the Perth region (Fetherston, 2007).

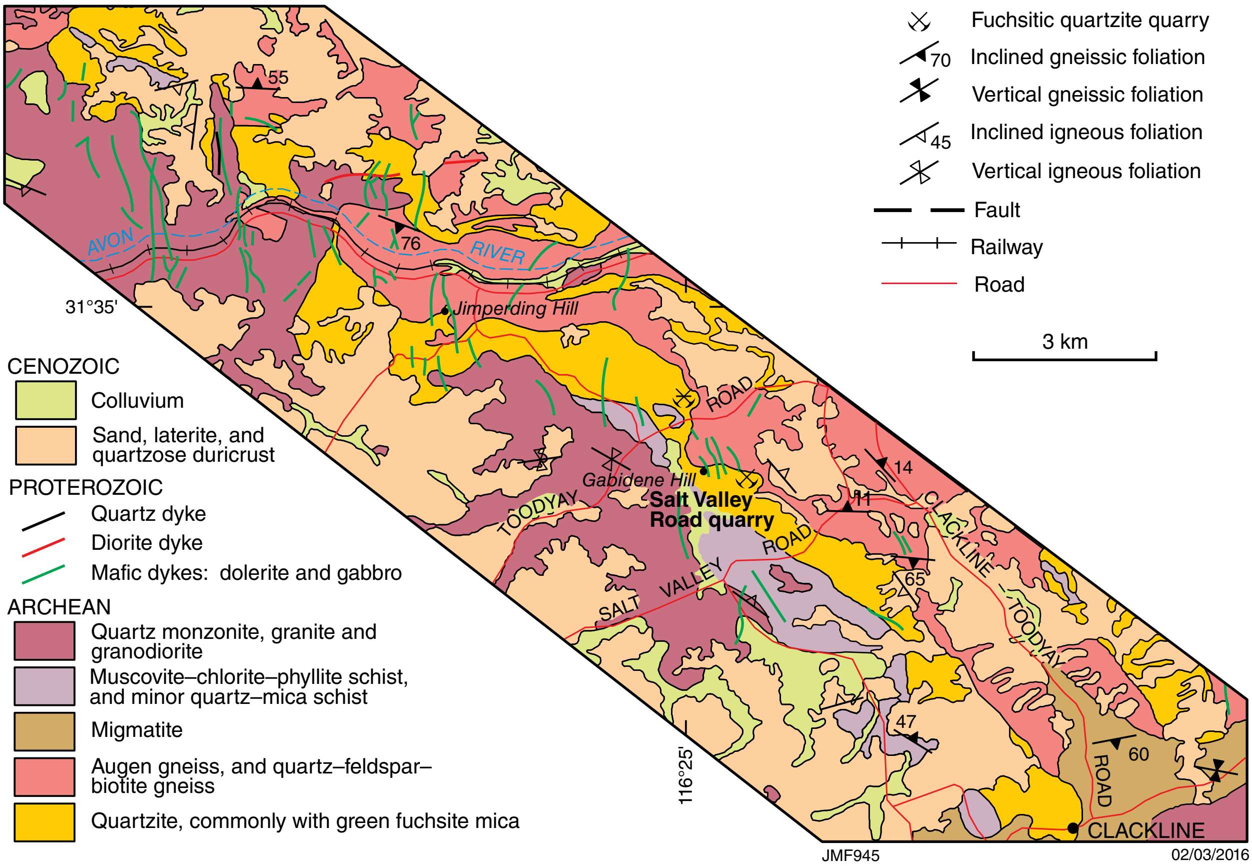


Figure 35.2. **Geology of the area south of Toodyay showing location of Salt Valley Road fuchsitic quartzite quarry (modified after Fetherston, 2007)**

Figure 35.3. **Example of Toodyay stone containing coarse-grained quartzite and displaying pale green fuchsite on parting planes. Salt Valley Road quarry, Toodyay area**

Pilbara Craton

Cookes Creek area

Cookes Creek fuchsite prospect (Nullagine, 2954)

The Cookes Creek fuchsite prospect is 42 km east-northeast of the town of Nullagine in the east Pilbara region within prospecting licence P46/1618 owned and operated by Mr Barry Kayes (Fig. 35.1). The prospect is sited on an east–west trending ridge of metamorphosed, layered chert incorporated within Archean, ultramafic, and talc-rich serpentinite from the Pilbara Supergroup (Fig. 35.4). The Cookes Creek deposit comprises massive blocks of hard, medium to dark green fuchsite and vertically dipping banded chert (Fig. 35.5). Applications for this material have included polished slabs, decorative table tops, and small items of jewellery such as pendants (Fig. 35.6).

Karratha area

Mount Regal mine (Dampier, 2256)

The Mount Regal chrome-rich chert mine is on mining lease M47/363 12 km southwest of Karratha on the Pilbara coast (Fig. 35.1). The mine is sited on a ridge of folded, moderately dipping beds of green, Archean, chrome-rich chert near ultramafic rocks, possibly the source of the green chromium colouration in these beds (Hickman, 1997).

At the quarry site, the green chert beds are very brittle and the operators take care with stone removal through the exclusive use of large excavators. This process results in the production of moderately large, tabular boulders together with an assortment of smaller, broken material that is stockpiled separately for use as a very hard, visually attractive, mid-green decorative stone marketed under the local name of 'Karratha jade' (also known as Mount Regal jade; Fig. 35.7).

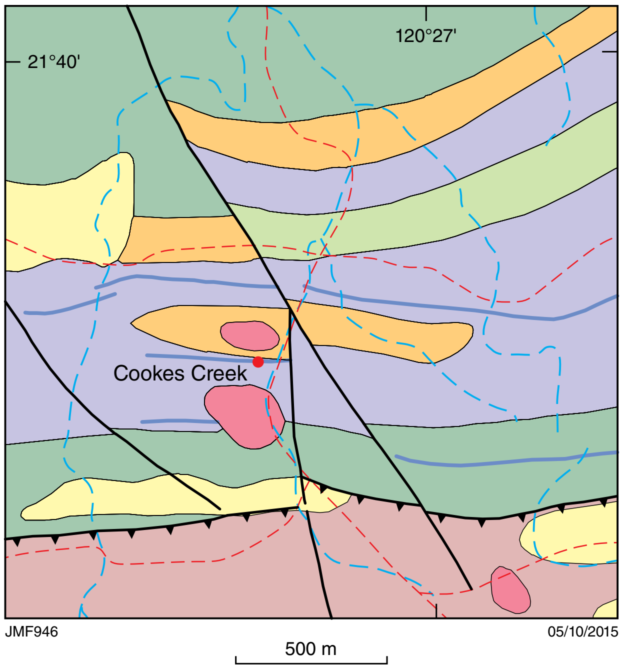
Laboratory testing has shown this rock may have an altered ultramafic lithology. It consists mainly of massive, extremely fine-grained quartz–sericite–kaolinite, together with fuchsite mica, which provides the rock's green colour, vein quartz, and quartz–chalcedony stringers (Purvis, 2005).

In past years, Karratha jade has been locally marketed as an attractive decorative stone in the form of polished slabs for use in items such as clock faces and for trial carving and sculpting of artworks.

De Grey River region

Ord Ranges green chert prospect (De Grey, 2757)

The Ord Ranges green chert prospect is approximately 60 km east of Port Hedland and 2 km southeast of the Ord Ranges tiger iron quarry (Figs 35.1 and 35.8). The location of a green chert outcrop in this area is only approximate. In this area of the Ord Ranges, the chrome-rich chert is incorporated within an extensive unit of laminated white to grey chert, siltstone, sandstone, and jaspilite that forms part of the highly folded, metamorphosed succession of Archean banded iron-formation, jaspilite, chert, and shale of the Cleaverville Formation (Fig. 35.8). The mid-green chert is very hard and has proved excellent as tumble-polished stones suitable for some items of jewellery (Fig. 35.9).



CENOZOIC

Colluvium; sand, silt and gravel

PALEOPROTEROZOIC

Quartz syenite to quartz monzodiorite

ARCHEAN

Pilbara Supergroup

Serpentinite; ultramafic and talc-rich schist

Wacke, siltstone and shale

Basalt; metamorphosed

Komatiitic basalt and minor basalt

Layered chert; metamorphosed

Felsic tuff; metamorphosed

Fault

Thrust or reverse fault

Fuchsite prospect

Track

Ephemeral drainage

Figure 35.4. Geology of the area around the Cookes Creek fuchsite prospect (modified after Bagas et al., 2004)

JMF998 5 cm 17/06/2016

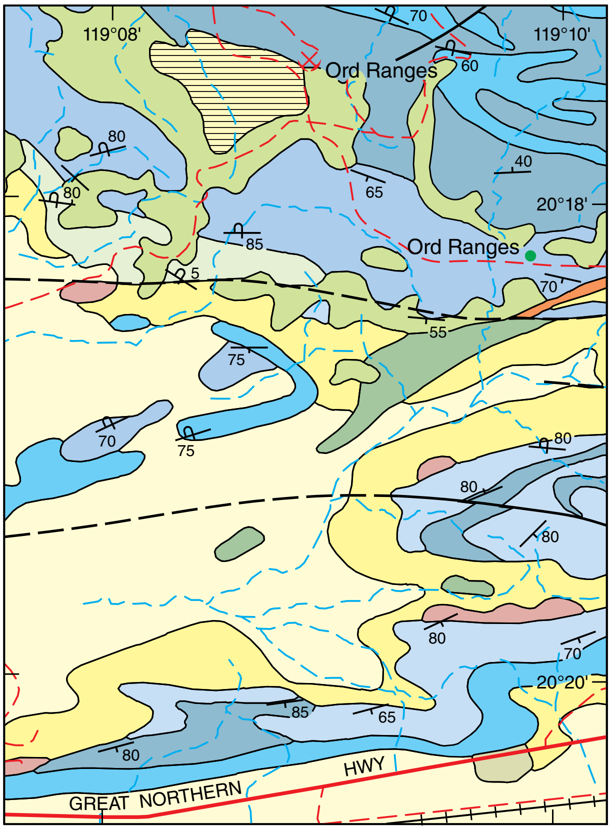
Figure 35.5. **Block of hard, mid-green fuchsite and banded chert from the Cookes Creek prospect (courtesy Barry Kayes)**

JMF999 20 cm 17/06/2016

Figure 35.6. **Table top made of polished slabs of green fuchsite from Cookes Creek inlaid with orange-brown tiger eye jasper from the Mount Brockman area (courtesy Barry Kayes)**

JMF865a 20 mm 04/04/2016

Figure 35.7. **Polished slab of mid-green Karratha jade**



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

Cleaverville Formation; metamorphosed

Chert; laminated, weakly banded to massive, and ferruginous 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

Quarry; tiger iron

Prospect; green chert, position approximate

Highway

Track

Railway

Ephemeral drainage

Figure 35.8. Geology of the area around the Ord Ranges green chert prospect (modified after Smithies, 2002)

Figure 35.9. Polished, tumbled stones from the Ord Ranges green chert prospect

Marble Bar region

Pear Creek jade prospect (COONGAN, 2856)

The Pear Creek jade deposit is in a small quarry on the side of a small hill in mining lease M45/838 about 1 km west of Pear Creek and 39 km north-northwest of Marble Bar (Fig. 35.1).

Trial mining has yielded small to medium-sized boulders of a massive dark green siliceous rock. This green rock is extremely hard with a subconchoidal fracture and appears to take a very high polish (Fig. 35.10). The rock is found in an area where Archean mafic and ultramafic schists are known.

Figure 35.10. Siliceous, dark green Pear Creek jade

Petrographic examination showed that the rock is dominated by cryptocrystalline silica, partially composed of chert, together with small amounts of muscovite mica. Also present are small masses and veinlets of quartz, small lenses of sericite, minor limonite and leucoxene, and sparse black opaque, possibly chromite, grains. These minerals suggest the Pear Creek jade is possibly an altered, silicified ultramafic rock with residual chromium producing the green colour (Purvis, 2005).

Abydos area

Dragon stone prospect (WODGINA, 2655)

The dragon stone prospect is on Kavir Downs Station within mining lease M45/1004, about 35 km east-southeast of the Wodgina mining centre (Fig. 35.1).

Small-scale mining in past years has produced very large boulders of massive, mid-green, chrome-rich, fuchsitic chert. The rock, known as 'dragon stone' or 'dragon's blood stone', is in an area of Archean schist and quartzite adjacent to an intrusion of metamorphosed ultramafic rock, the likely source of the chromium anomaly.

X-ray diffraction analysis of this rock has shown that it is largely composed of microcrystalline quartz in the form of chert together with small amounts of muscovite of which fuchsite, the bright green, chrome-rich variety, is probably responsible for the stone's green colour.

Visually, dragon stone has a mid-green cherty matrix, commonly interspersed with fine red, probably ferruginous-rich bands and red blebs; hence the name 'dragon's blood stone' (Fig. 35.11). This attractive stone is very hard, making it possible to achieve a high polish for use as a high-quality ornamental stone, especially for carving (Fig. 35.12).

JMF1001 ~ 25 cm 17/06/2016

Figure 35.11. Mid-green dragon stone displaying fine red bands and blebs of ferruginous-rich material (courtesy Glenn Archer)

JMF868b 25 mm 23/06/2016

Figure 35.12. Carving of a fabulous beast in dragon stone

Jasper in Western Australia

Jasper, a variety of chert, is widespread in Western Australia, commonly in areas associated with iron ore, especially the Archean Pilbara and Yilgarn Cratons. The stone is characteristically red because of inclusions of hematite, although colours may include brown and yellow (goethite), greyish-blue (pyrite and carbonaceous material), and dark grey, dark brown, and black (manganese), and green jasper. Green jasper of a uniform colour is sometimes called 'prase', and lighter green is called 'plasma' (Webster, 1975). Note the term prase is nowadays also used in describing other green-coloured rocks, especially fuchsitic quartzites.

With a decrease in the amount of impurities, the rock assumes lighter colours and grades into the typical pale chert. The boundary is arbitrary with some defining only the red variety as jasper with the other colours being called green, brown, or black chert. Typically, it appears that the well-coloured material is called jasper with only the very pale colours called chert (Mayer, 1987).

It is widely agreed that most of the sediment that forms banded iron-formations was deposited as a chemical precipitate and that the precipitation probably involved the formation of gels and other colloids (McConchie, 1987). Hematite particles of less than 10 nm impart the red colour to the red jaspers. Cherts may also form by the silicification of fine-grained calcareous rocks, siltstones, and shales that are predominantly pale coloured, although more intensely coloured jaspers may occur.

Jasper is opaque and has a dull lustre; these are the two most significant features that distinguish it from chalcedony. The microstructure of both is similar although jaspers comprise a heterogeneous mass of fibrous chalcedonic silica, commonly forming spherulitic aggregates, and interspersed with fine-grained quartz crystals. Metamorphosed jaspers may consist almost totally of granular quartz.

Physical properties of jasper show a wide range because of variable mineral impurities. Refractive indices measure approximately 1.54 (as spot readings) and specific gravity is commonly 2.58 – 2.91. Hardness is just below that of quartz (7 on Mohs scale) although jasper is a tougher material.

Jaspilite, a banded variety of red jasper present in banded iron-formations, comprises thin, oxidized bands of black iron oxides alternately bedded with red jasper. These bands may be irregularly folded with waved patterns, making an attractive polished stone. An excellent example of jaspilite in the form of tiger iron from the Ord Ranges in the Port Hedland region features in the frontispiece of this book.

Jasper and jaspilite can usually be worked to take a high polish and both are used as lapidary materials for a wide variety of decorative objects including carvings, beads, cabochons, inlay work, coasters, bookends, and polished slabs. Polished slabs of brightly coloured banded jaspilite will commonly reveal the fineness of the original sedimentary bedding as waved and contorted layering with microfolding and other small-scale structural features such as fracturing, brecciation, and secondary cementation.

Jasper and jaspilite are common throughout the Yilgarn and Pilbara Cratons and can be found in many of the banded iron-formation units. They are also composed of hard and tough material resistant to weathering and pebbles and cobbles may be found in most creeks draining these units. Jasper localities in Western Australia are too numerous to describe in this publication although numerous sites are listed in Simpson (1952c). Likewise, a large selection of jaspilite localities in the State was described in Simpson (1951), and Geological Survey of Western Australia (1994) listed some eight locations in which jaspers can be found. A selection of Western Australian jaspers is described below.

Pilbara Craton

Marble Bar area

Marble Bar chert (Marble Bar, 2855)

The Marble Bar chert, 3.5 km west-southwest of the town of Marble Bar (Fig. 35.1), is a visually attractive red and white chert (a jasper), which outcrops in the Coongan River at the Marble Bar Pool.

Although this particular outcrop is protected by a reserve, the Marble Bar Chert Member, part of the Archean Warrawoona Group, extends for considerable distances north and south of the pool. Waterworn chert and jasper pebbles can be found in most creeks in the area (Fig. 35.13a). Recent work has suggested that the Marble Bar chert was, in part, formed by the silicification of a slightly iron-rich carbonate rock (Van Kranendonk and Johnston, 2009).

Pilbara Craton — Hamersley Basin

Paraburdoo region

Snakeskin prospect (Snowy Mount, 2551)

The Snakeskin jasper mine is on mining lease M52/32 about 80 km east-southeast of Paraburdoo in the Archean–Paleoproterozoic Hamersley Basin (Fig. 35.1). The jasper is within banded iron-formation jaspilites of the Weeli Wolli Formation. At this site, these metasedimentary rocks are folded and intruded by crosscutting quartz veins. The Snakeskin jasper is orange to red in colour and has a variety of textures including the folded, siliceous 'snakeskin' pattern (Fig. 35.13b). The jasper is mined on an intermittent basis and processed for ornamental applications.

Yilgarn Craton — Murchison Domain

Cue region

Reedy area (Reedy, 2543)

Red-banded jasper is recorded from an unspecified gold mining pit approximately 60 km northeast of Cue (Fig. 35.1). At this site, a finely banded and folded, dark-red jasper (chert) is intersected by a network of white quartz veins (Fig. 35.13c). Small lenses of iron pyrite also exist in this jasper. No other information is available.

Fields Find area

Desert Sunset (Ninghan, 2339)

The Desert Sunset banded jasper is on pending mining lease M59/723 in the Fields Find area, about 50 km northwest of Paynes Find (Fig. 35.1).

At this site, the mining lease application covers interlayered, Archean mafic, felsic, and metasedimentary rocks containing steeply dipping banded iron-formations. These outcrop discontinuously in a southwesterly direction over about 2 km and range from a few metres to tens of metres in thickness. The banded iron-formations in this area are rich in zones of banded jasper containing relatively minor amounts of iron. Examination of the rocks has shown they are composed of banded limonite–hematite–quartz jasper in broad, visually attractive red and yellow bands (Fig. 35.13d; Fetherston, 2010).

In 2008, polished specimens of Desert Sunset were exhibited at the Marmomacc international trade fair and received some strong interest.

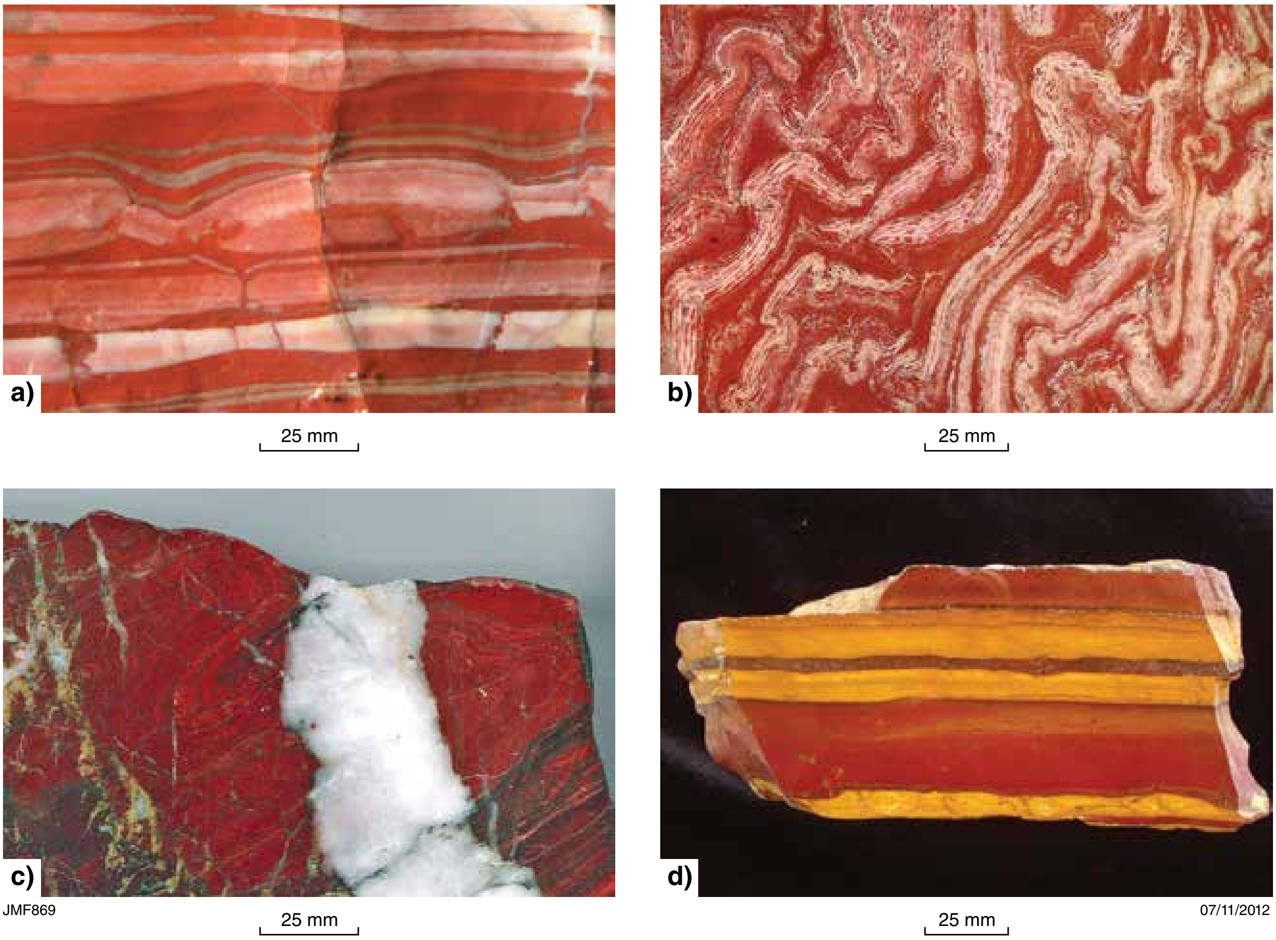


Figure 35.13. Selection of Western Australian jaspers: a) Marble Bar chert (banded red and white jasper; after Van Kranendonk and Johnston, 2009); b) orange-red Snakeskin jasper from the Hamersley Basin, showing its 'snakeskin' texture; c) red-banded jasper intersected by a white quartz vein from the Reedy mining area, northeast of Cue; d) Desert Sunset, a visually striking yellow and red-banded jasper from Fields Find (photos b) and d) courtesy Glenn Archer)

Jasper misnomers

For commercial reasons, the term 'jasper' is commonly used as a suffix in describing many ornamental rocks of unspecified type that are not true jasper or jaspilite. For example, some 'jaspers' are named for the place of origin, and others for a particular texture. These rocks are derived from many different rock types and all have distinguishing features. Some have attractive colour patterns caused by percolation of groundwater, resulting in secondary iron oxide and hydroxide staining as the dominant source of imprinted colour. Irregular fracture fillings, blebs, bands with fretted patterns, and concentric, varicoloured liesegang banding may all feature in these 'jaspers'.

Jasper misnomers specific to Western Australia include Outback jasper, Noreena jasper, Turee Creek jasper, Convoluted jasper, Honey bee jasper, Duck Creek jasper, Black jasper conglomerate, and Tire track jasper. A small selection of these jaspers is described below.

Yilgarn Craton — Murchison Domain

Fields Find area

Outback jasper (Ninghan, 2339)

Pink, white, grey, and black Outback jasper, previously called Fields Find picture jasper, is found on mining lease M59/723 in the Bullajungadeah Hills at Fields Find (Fig. 35.1). It is also present at an unknown locality in the Gnows Nest Range approximately 65 km to the north-northwest.

The best material is present within well-defined, almost vertical, seams typically no wider than about 15 cm within repetitive banded iron-formation bands. Outback jasper comprises pale pink, mauve, and grey contorted and fractured banded chert bands with textures varying from lobate to embayed boudins, surrounded by a very dark brown, iron-rich matrix, forming visually attractive intricate patterns (Fig. 35.14a).

Mining of Outback jasper has proved difficult and expensive and this occurrence has only produced a limited amount of quality material used to make jewellery items such as pendants (Fig. 35.15a).

Nannine townsite area

Tire track jasper (MEEKATHARRA, 2544)

Tire track jasper was collected by a prospector from a site described as 'from the main pit in the old Nannine townsite' (M Soklich, 2016, written comm., March). Nannine is a historic gold mining town, now almost deserted and situated on the Great Northern Highway, 36 km south-southwest of Meekatharra. The probable pit referred to is known as 'Nannine alluvials', although this remains uncertain (Fig. 35.1).

Tire track jasper is probably a brecciated jaspilite comprising broken bands of orange-red and black jaspilite shards mostly rectangular in outline (Fig. 35.14b). This material is reportedly relatively scarce from within the openpit in which it was found. In 2014, it was displayed at the Tucson Gem and Mineral Show in Arizona, US, where it acquired its name.

Pilbara Craton — Hamersley Basin

Noreena Downs area

Noreena jasper (NOREENA DOWNS, 2953)

Noreena jasper is mined from a site approximately 65 km south of Nullagine on mining lease M46/249 owned by Mr Glenn Archer (Fig. 35.1). The mine operates within the Jeerinah Formation, part of the Archean Fortescue Group. Noreena jasper is composed of a fine-grained silicified pelite, similar in appearance to Munjina stone

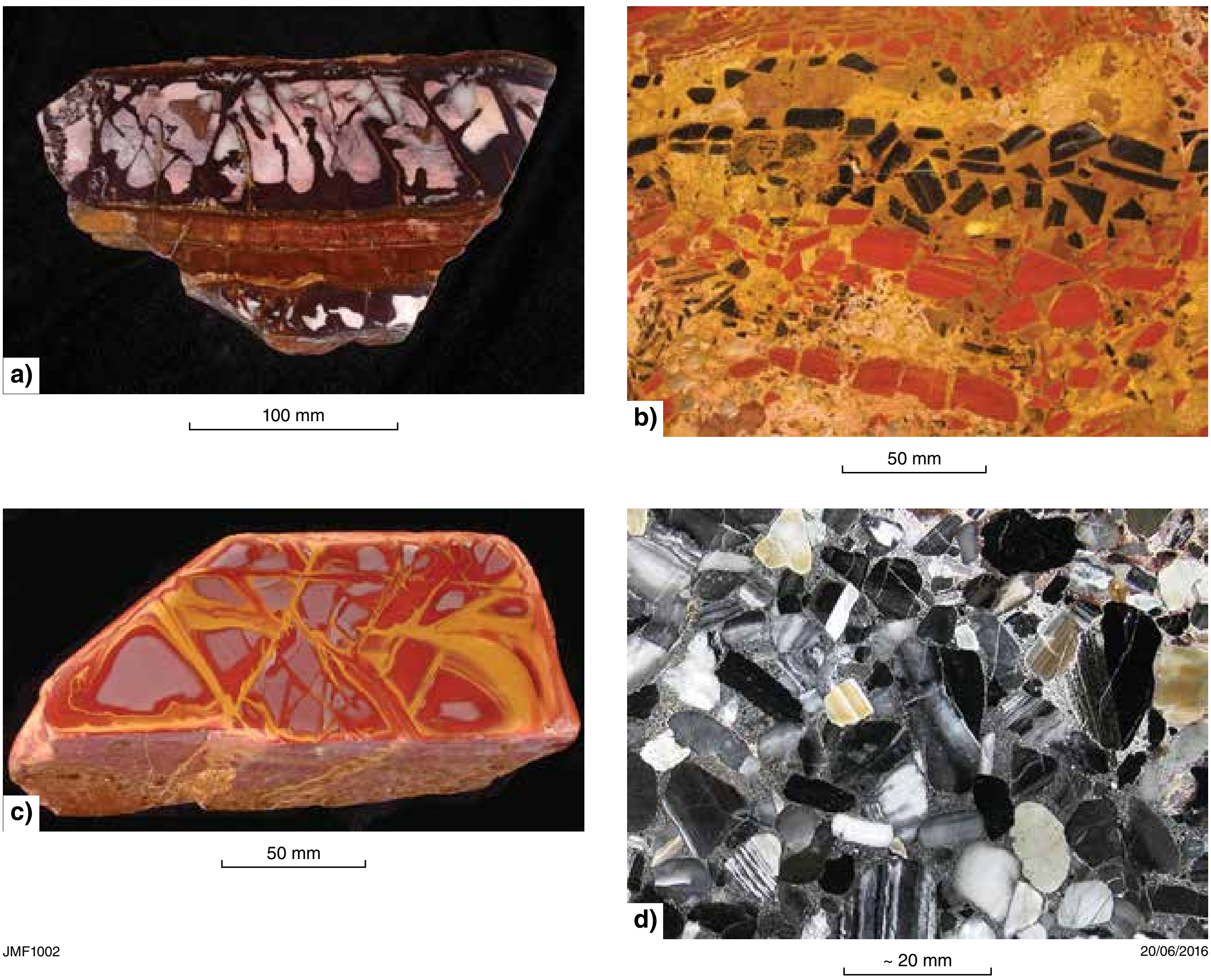


Figure 35.14. Selection of decorative ornamental stones commercially named 'jasper': a) pink and mauve Outback jasper from Fields Find; b) Tire track jasper, probably a brecciated jaspilite from Nannine; c) Noreena jasper, a multicoloured pelite from Noreena Downs area; d) Black jasper conglomerate, a dark grey to black, polymictic conglomerate from Eastern Creek (photos a), c), and d) courtesy Glenn Archer; photo b) courtesy Martin Soklich)

also formed in the Jeerinah Formation, approximately 130 km to the west, and described in detail in Chapter 38 on other decorative stones from Kununurra and the Pilbara. Noreena jasper also possesses an internal cellular structure composed of grey pelite surrounded by linear fractures infilled with yellow, red, and red-brown iron oxides (Fig. 35.14c).

The rock tends to break into angular pieces that display attractive geometric and abstract patterns. It has been manufactured into a variety of ornaments and jewellery such as beads and cabochons (Fig. 35.15b).

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Figure 35.15. Decorative examples of 'jasper' jewellery: a) large, 60 mm-diameter pendant crafted in Outback jasper (courtesy Kayley Usher); b) selection of cabochons cut and polished from Noreena jasper (courtesy Murray Thompson)

Eastern Creek area

Black jasper conglomerate (Eastern Creek, 3054)

This conglomerate was sourced from the former prospecting licence P46/1396 in the Eastern Creek area about 60 km northeast of Nullagine (Fig. 35.1).

The Black jasper conglomerate, within the Archean Fortescue Group, comprises a coarse, dark grey to black, polymictic, clast-supported conglomerate (Fig. 35.14d). The clasts, varying from less than 1 cm to several centimetres in length, are made up of two distinct types: the larger tabular clasts are probably composed of well-banded chert fragments showing minimal rounding, and the smaller clasts are subrounded to round. The relatively coarse-grained matrix contains pyrite. Similar conglomerates from elsewhere in the State are recorded in Fetherston (2010).

References

Bagas, L, Beukenhorst, O and Hos, K 2004, Nullagine, Western Australia, Sheet 2954: Geological Survey of Western Australia, 1:100 000 Geological Series.

Deer, WA, Howie, RA and Zussman, J 1962, Rock forming minerals, volume 3 — Sheet silicates: Longman, London, 270p.

Fetherston, JM 2007, Dimension stone in Western Australia, volume 1 — Industry review and dimension stones of the southwest region: Geological Survey of Western Australia, Mineral Resources Bulletin 23, p. 124–127.

Fetherston, JM 2010, Dimension stone in Western Australia, volume 2 — Dimension stones of the southern, central western, and northern regions: Geological Survey of Western Australia, Mineral Resources Bulletin 24, p. 129–133, and 207–208.

Hickman, AH 1997, Dampier, WA Sheet 2256: Geological Survey of Western Australia, 1:100 000 Geological Series.

Mayer, W 1987, Jasper, *in* How and where to find gemstones in Australia and New Zealand *edited by* B Myatt: Landsdowne Press, Sydney, New South Wales, p. 186–189.

McConchie, D 1987, The geology and geochemistry of the Joffre and Whaleback Shale Members of the Brockman Iron Formation, Western Australia, *in* Precambrian iron formations *edited by* PW Uitterdijk and GL La Berge: Theophrastus Publications, Athens, p. 541–597.

Purvis, AC 2005, Mineralogical report no. 8666: Pontifex & Associates, report (unpublished).

Simpson, ES 1951, Minerals of Western Australia, volume 2: Government Printer, Perth, Western Australia, p. 514–543.

Simpson, ES 1952a, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 487.

Simpson, ES 1952b, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 277–285.

Simpson, ES 1952c, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 476–477.

Smithies, RH 2002, De Grey, WA Sheet 2757: Geological Survey of Western Australia, 1:100 000 Geological Series.

Van Kranendonk, MJ and Johnston, JF 2009, Discovery trails to early Earth — a traveller's guide to the east Pilbara of Western Australia: Geological Survey of Western Australia, Perth, Western Australia, 168p.

Webster, R 1975, Gems — their sources, descriptions and identification: Butterworths, London, 988p.

Wilde, SA and Low, GH 1978, Perth: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 36p.

Serpentine and talc

Serpentine and talc

Serpentine and talc are related mineral groups of hydrous magnesium silicates. They are secondary metamorphic minerals commonly derived from the alteration of ultramafic rocks containing olivine, pyroxene, and amphibole minerals. They are relatively soft, commonly greenish minerals with a greasy feel, and suitable varieties are used for ornamental carving of high-quality sculptures and other visually attractive pieces of ornamental stone such as clock faces and coasters.

Serpentine group minerals

The serpentine group of minerals comprises several polymorphic forms with the general formula $Mg_3Si_2O_5(OH)_4$, the most important being chrysotile, lizardite, and antigorite. Differences among them are minor and they are almost indistinguishable in hand specimen although chrysotile is more likely to have an asbestiform habit, and antigorite and lizardite are commonly found as cryptocrystalline masses. Lizardite is volumetrically the most common serpentine variety. There is relatively little chemical substitution in these minerals by other elements, except by nickel and aluminium.

Secondary metamorphic minerals of the serpentine group are derived mainly from ultramafic rocks such as dunites, pyroxenites, and peridotites by hydrothermal alteration at relatively low temperatures during metamorphism. Accessory chlorite, talc, and magnetite may also be present. Serpentine minerals are also found in metamorphic rocks and in metamorphosed limestones and dolomites especially where in contact with dolerite intrusions. In these cases, siliceous dolomite is altered to forsterite and subsequently serpentinized (Deer et al., 1962).

Rock composed predominantly of serpentine group minerals is known as serpentinite. In areas where it is present together with dolomite, magnesite, or calcite, serpentinite commonly appears as a clouded green or veined rock. Remnant crystal pseudomorphs, especially after olivine, are commonly conspicuous, and black, opaque grains of relict chromite or magnetite are commonly preserved.

Physical properties of serpentine minerals

	Chrysotile	*Lizardite*	*Antigorite*
Crystal system	Monoclinic	Monoclinic	Monoclinic
Habit	Fibrous	Lamellar	Fibrous
Colour range	Yellow, white, and grey-green	Green or white	Green, green-blue, and white
Lustre	Silky	Waxy	Waxy
Diaphaneity	Translucent to opaque	Translucent	Translucent
Refractive index	1.532 – 1.556	1.538 – 1.560	1.558 – 1.574
Hardness	2.5	2.5	3.5 – 4
Specific gravity	2.22	2.55	2.60
Cleavage	Prismatic	Perfect basal	Perfect basal

Serpentine and talc
Hydrous magnesium silicates

Gemmological materials

Serpentine minerals and serpentinite rocks show a wide variety of colours and are commonly grouped into two categories as gemmological materials.

Precious or noble serpentine

This material is light to dark green and translucent, even in thick pieces. The most distinctive and important variety is bowenite, a massive, fine-grained variety of antigorite that is also translucent, light yellowish-green with a waxy lustre commonly containing white cloudy patches. Bowenite resembles nephrite jade and is commonly used and marketed as a substitute for jade under commercial names such as New jade and Styrian jade.

Common serpentine

Common serpentine is a more intense green serpentine variety with varying shades of brown, black, and red. It is subtranslucent to opaque and may include other rock types containing mixtures of other minerals such as chlorite, talc, and magnesite. It is also commonly veined with chrysotile. Serpentinites are commonly speckled with black opaque minerals such as magnetite and chromite. A commercial term used to describe some common varieties is ‘retinalite’ which is a massive, honey-yellow to light green, waxy variety of chrysotile. Also, ‘verde antique’ is a dark green, massive serpentine with veins and/or fracture fillings of calcite, dolomite, and/or magnesite. Verde antique is capable of taking a polish. The overall hardness of serpentine minerals varies from about 2 to 5 on Mohs hardness scale according to mineral composition.

Applications

Because serpentine minerals are relatively soft, and are found in an extensive range of attractively patterned colours, they are popular mediums for sculpting, carving into small artefacts and trinkets, or for the manufacture of pendants, beads, and other items of jewellery (Fig. 36.1). Serpentine can be easily distinguished from nephrite jade by its lower hardness and refractive indices.

Serpentine minerals in Western Australia

Serpentine minerals are common in the Archean rocks of Western Australia and it would appear that almost all outcropping ultramafic lithologies exhibit some degree of serpentinization. Simpson (1948) recorded more than 60 different occurrences of serpentinite within the State and since that time detailed field mapping has identified many more occurrences. It seems that most serpentinite sites have not been investigated for their ornamental stone attributes. Accordingly, only the more significant and better documented serpentine occurrences are discussed below; they are shown in Figure 36.2.

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Figure 36.1. Cabochon (38 mm diameter) displaying relict cumulate texture in which green serpentine minerals have replaced the original olivine crystals. Location unknown (courtesy Dorothy Netherway)

Pilbara Craton

Marble Bar area

Pilbara jade deposit (Nullagine, 2954)

Serpentine minerals are present throughout the Pilbara jade deposit near the old Lionel asbestos mining area, about 25 km north of Nullagine township (Fig. 36.2). The probable location is approximately 4.5 km northeast of the old Hales Grave Well where two mining leases, M46/63 and M46/44, are located. Access is northwards along the Nullagine to Marble Bar Road and then along a track that leads northeast from the abandoned Hales Grave Well.

Hudson (1974) stated that a characteristic feature of the Pilbara jade is the appearance of irregular white patches that irregularly form veins in the massive green chlorite. These patches are composed of a fibrous white matrix of Al-serpentine cut by pale yellow-green, subparallel fibres of chrysotile serpentine (Fig. 32.8, Chapter 32 on jade).

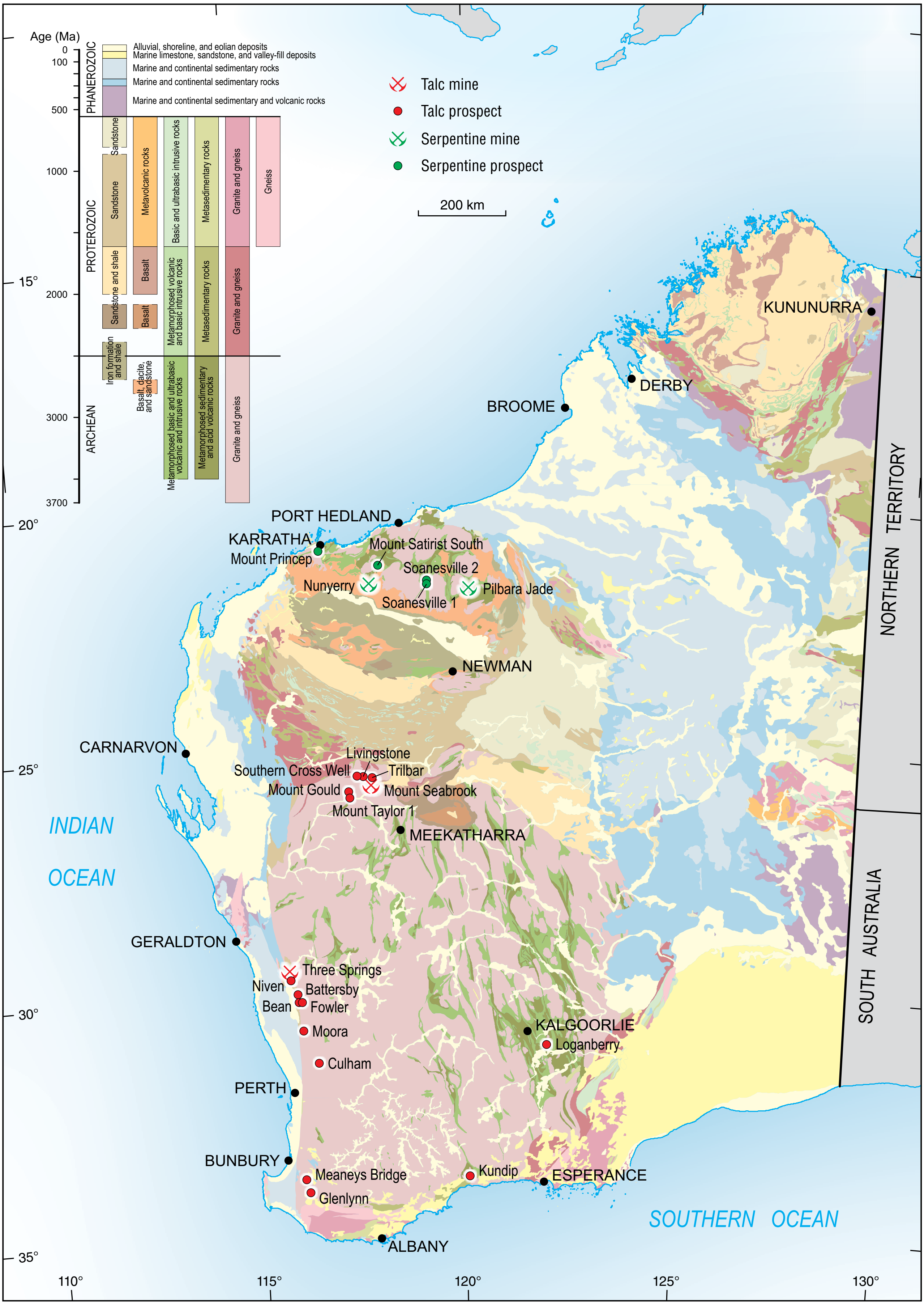

Figure 36.2. Locations of ornamental-grade serpentine and talc deposits in Western Australia

Tambourah region

Soanesville Mining Centre (Tambourah, 2754)

The Soanesville Mining Centre is about 70 km southwest of Marble Bar (Fig. 36.2). The area is somewhat inaccessible and may be reached by 4WD vehicles from the BHP Iron Ore Railway Road from the west, or the Woodstock–Hillside – Marble Bar Road from the south and east.

The Soanesville mining area comprises a series of four, small workings near the northern edge of the Tambourah 1:100 000 map sheet and trending north–south for some 7 km (Van Kranendonk and Pawley, 2002). Directly west of the Soanesville Mining Centre are peridotites and ultramafic schists that are probably the source of serpentinite rock in the vicinity. Reports state that chrysotile was mined from Soanesville up to the end of 1977 (Van Kranendonk, 2003).

Geological Survey of Western Australia (1994) described serpentinite traversed by innumerable small veins of chrysotile from the Soanesville area. The most striking pieces are those from slightly weathered material, which is harder and commonly tinted by ferric oxide. Such specimens, which show all tints from bronze through golden-yellow to various greens, exhibit chatoyancy caused by the fibrous structure of the asbestos veinlets. This material has been carved into visually attractive trinkets.

Whim Creek region

Mount Satirist South (Satirist, 2555)

The Mount Satirist South serpentine locality is probably in an isolated area approximately 45 km south-southeast of Whim Creek and about 10 km south-southwest of Mount Satirist (Fig. 36.2).

In this area, a series of relatively narrow, north-trending, linear ultramafic outcrops are present (Smithies and Farrell, 2000). These rocks comprise chlorite–actinolite–serpentine–epidote schist altered after a succession of high-Mg basalt, and komatiite. Geological Survey of Western Australia (1994) also recorded masses of scaly, greenish-black chlorite obtained from the hills in this general area. It is recorded that material recovered from this rock was sufficiently dense and tough to be sawn and polished for the manufacture of pendants and other trinkets.

At another unknown locality in the area, Simpson (1948) recorded the presence of columnar, pale green serpentinite with massive and recrystallized magnetite from Harris Well on Mount Satirist Station.

Nunyerry (Mount Billroth, 2454)

The historic chrysotile mine at Nunyerry is about 80 km south of Whim Creek (Fig. 36.2). The Nunyerry mine workings are close to Nunyerry Spring and may be accessed by a track that leads northwards from the Roebourne–Wittenoom Road from a point a few kilometres north of Mount Florence Station Homestead.

The old chrysotile mine is in a narrow, northeast-trending lens of altered komatiite ultramafic rock comprising serpentine–talc–tremolite (Smithies and Hickman, 2004). It is reported that more than 6000 t of chrysotile was obtained from serpentinite and it is suggested that this area could potentially supply material for use as a semiprecious stone (Kriewaldt and Ryan, 1967). The area surrounding the Nunyerry minesite is currently held under mineral exploration licence E47/651 by Archean Gems. The company has recently produced a variety of high-quality carved ornaments as test samples from various ultramafic rock types present at this site (Fig. 36.3).

Figure 36.3. Exquisitely carved fish from the Nunyerry chrysotile deposit (courtesy Archean Gems)

Dampier region (Dampier, 2256)

The Dampier 1:100 000 geological map (Hickman, 2001) shows a relatively wide belt of serpentinite rock trending east–west and centred on Mount Princep adjacent to the Tom Price Railway Road about 14 km south-southwest of Karratha (Fig. 36.2).

Almost all the ultramafic rocks in this zone, other than those within layered mafic–ultramafic intrusions, are confined to the area north of the Sholl Shear Zone and concentrated in the lower part of the Archean Roebourne greenstones (Hickman, 2001). Serpentinite, replacing metamorphosed peridotite, is the most common ultramafic rock together with talc–chlorite schist probably formed from sheared metamorphosed ultramafic lava.

This area may have some potential as a source for ornamental serpentinite stone; however, this is yet to be demonstrated.

Talc properties

Talc is a hydrated magnesium silicate with the formula $Mg_3Si_4O_{10}(OH)_2$ that typically shows little variation in composition. However, some talc contains small amounts of aluminium and titanium that may substitute for silicon, and small amounts of iron, manganese, and aluminium that may substitute for magnesium. It is an extremely soft, sectile mineral with a hardness of 1 on Mohs scale. It has a characteristic soapy or greasy feel and a pearly lustre, and is commonly found as scaly, foliated, or massive aggregates, with the scaly aggregates comprising laminae that are commonly flexible although not elastic. The colour of talc varies from white through greenish-white to grey or pale brown.

Steatite and soapstone are massive forms of talc. Steatite is commonly found as a very pure form of white to grey-green talc with a waxy appearance and can be sawn or machined into precise shapes for industrial applications. Soapstone is soft with an unctuous feel and is commonly grey to bluish in colour. It is used as a raw material by the sculpture and carving industry.

Talc results from two main processes: the hydrothermal alteration of ultramafic rocks, typically called ‘steatitization’, and the metamorphism of siliceous dolomites. Talc may also be derived by the hydrothermal alteration of mafic lithologies, a considerably rarer process.

Steatitization is commonly, although not everywhere, associated with the serpentinization process. However, some talc schists may form directly from unserpentinized ultramafic rocks. In other environments it has been shown that the steatitization took place subsequent to the serpentinization process during a period of greenschist facies metamorphism (Deer et al., 1962).

Magnesium-rich sedimentary rocks, particularly dolomite, that have been altered by regional or contact metamorphism can cause large and high-grade talc deposits. In Western Australia, the Three Springs and Mount Seabrook talc deposits were derived from Proterozoic sedimentary rocks containing considerable thicknesses of dolomite. At Three Springs, the talc appears to have been formed from the alteration of dolomite by hydrothermal fluids from dolerite dykes intruded into the carbonates. At Mount Seabrook, talc is present as steeply dipping lenses within dolomite, and was probably formed by low-temperature hydrothermal alteration of dolomite by fluids derived from a nearby granitic body (Fetherston et al., 1999).

Physical properties of talc

Crystal system	Monoclinic or orthorhombic
Habit	Massive, foliated or fibrous, with rare crystals
Colour range	Apple-green to silvery-white, greenish-grey, and brown
Lustre	Pearly
Diaphaneity	Subtransparent to translucent
Refractive index	1.539 – 1.589
Birefringence	0.05
Pleochroism	Rare
Hardness	1 – 1.5
Specific gravity	2.7 – 2.8
Cleavage	Perfect basal

Talc is a popular medium in the sculpting and carving industry where soft and reasonably competent forms such as steatite and soapstone are mostly preferred. Also, material displaying attractive patterns and colour variations are sought after. A set of carved talc vases in different colours from the Three Springs talc mine is shown in Figure 36.4.

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Figure 36.4. Set of carved talc vases in different colours from the Three Springs talc mine (courtesy Imerys Talc Australia)

Talc in Western Australia

Talc is widely distributed in Western Australia, mainly in the Archean Pilbara and Yilgarn Cratons, and the Neoproterozoic Pinjarra Orogen (Fig. 36.2). Deposits are mainly present in altered ultramafic bodies within greenstone belts, and to a lesser extent, within sedimentary rock successions containing dolomite. Simpson (1952) recorded numerous talc localities and Abeysinghe (1996) described the larger deposits in some detail and listed many of the smaller ones. Abeysinghe (1996) is referred to in many of the following descriptions of the larger and more significant occurrences.

Deposits derived from dolomite

Pinjarra Orogen

In the Pinjarra Orogen, talc mineralization is present in the Three Springs – Marchagee belt within the Coomberdale Subgroup of the Proterozoic Moora Group where the subgroup is intruded by northerly trending dolerite dykes.

The Moora Group is exposed adjacent to the western margin of the Yilgarn Craton, and is truncated along its western boundary by the Darling Fault.

Talc mineralization is predominantly developed within the Noondine Chert, a member of the Coomberdale Subgroup. The Noondine Chert is a silicified carbonate containing a considerable thickness of dolomite. The most favourable sites for talc mineralization are in areas where dolomite alteration has been affected by hydrothermal fluids injected from dolerite dykes intruded into the carbonates. The Coomberdale Subgroup has not undergone significant deformation and metamorphism, except for contact metamorphism adjacent to the dolerite dykes (Fetherston et al., 1999).

The area of talc mineralization is contained within the Three Springs – Marchagee belt, which extends for about 70 km south from the Three Springs talc mine to the area around Marchagee and contains several significant deposits (Fig. 36.5).

Three Springs area

Three Springs talc mine (Carnamah, 2038)

The Three Springs talc mine is 12 km northeast of Three Springs townsite and about 330 km north-northeast of Perth (Fig. 36.5). Talc was first discovered at this site in the 1940s by a local farmer and underground mining commenced in 1948. In 1959, Western Mining Corporation Ltd acquired a 50% share of the project and openpit operations and extensive exploration drilling ultimately proved the site's potential as a major talc mine. By 1987, Western Mining controlled 100% of the operation and in September 2001 the mine was sold to Luzenac Australia. In August 2011 the mine was sold to Imerys Talc, currently the world's largest talc producer.

At Three Springs, the talc occurs as a subhorizontal orebody, trending north–south with a maximum width of 200 m and a thickness varying from a few metres to more than 30 m. The talc varies in colour from white to dark green with the degree of colouration dependent on the amount of chlorite present in the ore. The talc is not fibrous and contains no asbestiform minerals. The talc appears to have been formed from the alteration of dolomite by hydrothermal fluids from dolerite dykes intruded into the carbonates.

The mine is currently in operation and access to the minesite is only with permission from the mine operators, Imerys Talc Australia, which can be contacted at the mine office at Three Springs.

Niven deposit (Carnamah, 2038)

The Niven deposit is approximately 8 km north-northwest of Carnamah (Fig. 36.5). Exploratory drilling by various companies between the 1970s and 1991 identified a zone of talc mineralization 30 m wide, 200 m long, and 1–10 m thick in altered dolomitic sedimentary rocks close to mafic dykes. Drill samples from five drillholes confirmed the presence of high-quality, pure talc.

Marchagee area

Battersby deposit (Caron, 2138)

The Battersby Farm (or Coorow) deposit is approximately 6 km south-southwest of the small town of Coorow and approximately 50 km south-southeast of Three Springs (Fig. 36.5). Initial interest in the area resulted from the reported presence of talc in a borehole. In the 1970s, Western Mining Corporation Ltd drilled 49 vertical diamond drillholes to depths of 40–50 m although it did not locate talc of commercial grade.

Fowler and Bean deposits (Watheroo, 2137)

The Fowler and Bean deposits are on properties directly south of the town of Marchagee where the original exploration by Western Mining Corporation delineated talc mineralization (Fig. 36.5). Follow-up drilling by various companies concentrated on the Fowler deposit and a northerly trending talc body more than 500 m long with a maximum width of about 180 m was delineated. A cross-section of the Fowler talc deposit is shown in Figure 36.6.

The talc in the Fowler prospect is commonly off-white with tinges of pale grey to pale green. It has undergone deep weathering, causing a lack of pearly lustre (Fig. 36.7). Weathering has also resulted in iron oxide staining, mainly along fractures and joints.

By contrast to the Three Springs deposit where talc mineralization is found adjacent to dolerite dykes, a younger granite is considered the heat source for the development of talc from the dolomite (Fetherston et al., 1999).

Capricorn Orogen — Padbury Basin

Mount Seabrook area

In the Mount Seabrook area, about 175 km northwest of Meekatharra, there are numerous talc deposits in an area known as the Mount Seabrook – Livingstone belt within the Padbury Group of the Paleoproterozoic Padbury basin. In this area, talc has been formed by the metamorphism of dolomite forming part of a schist–dolomite–chert–quartzite–talc succession that was intruded by granite of the 1820–1775 Ma Moorarie Supersuite.

Mount Seabrook talc mine (Moorarie, 2446)

The Mount Seabrook talc mine, operated by Imi Fabi (Australia) Pty Ltd on a campaign basis, is on mining lease M52/58 about 1.5 km north-northeast of Mount Seabrook (Fig. 36.2). Mount Seabrook is the second-largest operating talc mine in Western Australia. The deposit was discovered in 1965 and extensively drilled by various companies until an exploratory pit was opened during 1969–72.

Rock types within the mine and adjoining area consist of metamorphosed sandstone, dolomite, quartzite, pebble conglomerate, and quartz–muscovite schist together

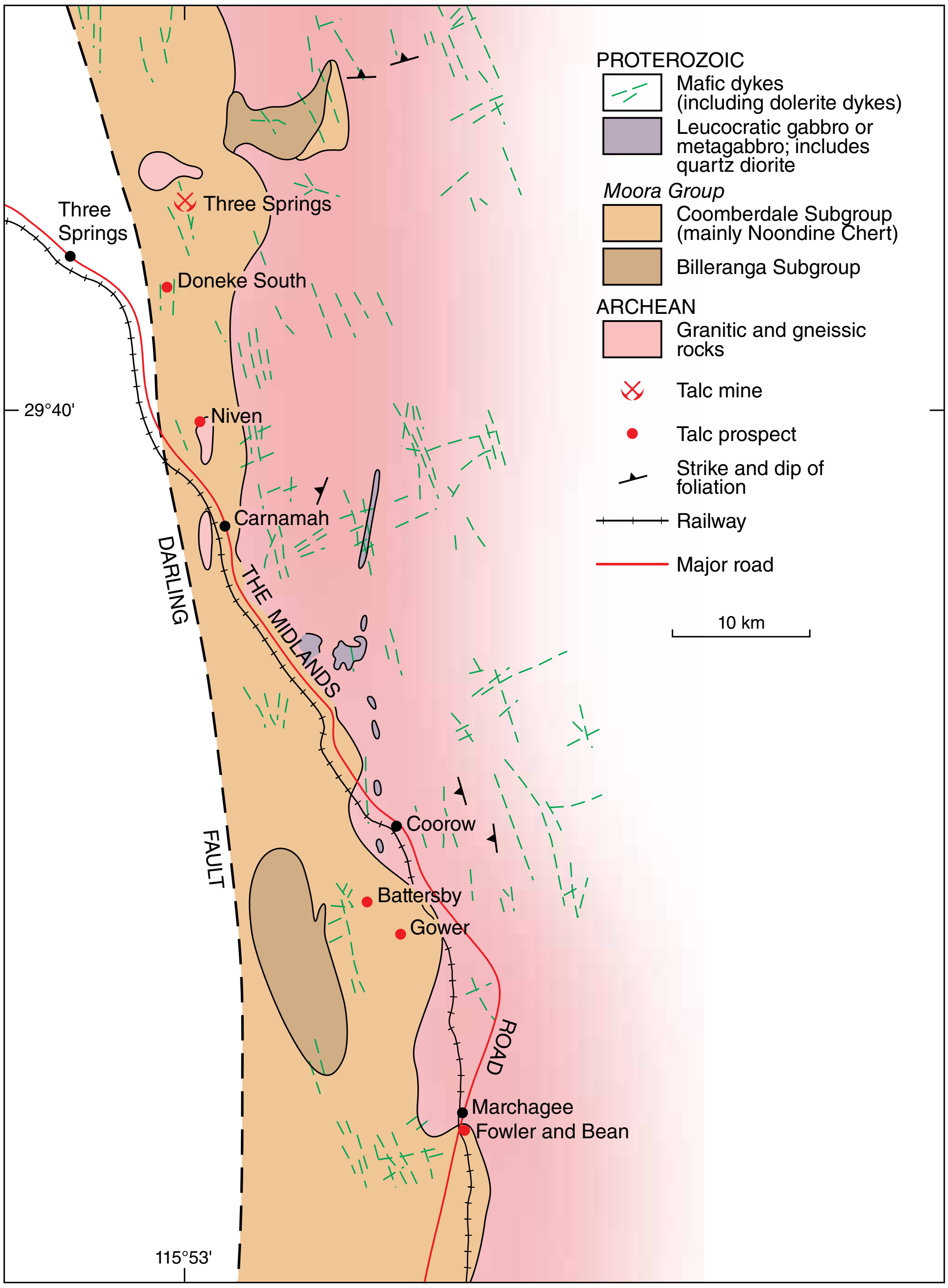

Figure 36.5. **Map showing the locations of the Three Springs talc mine and associated talc prospects in the Three Springs – Marchagee belt (modified after Fetherston et al., 1999)**

with biotite- and chlorite-bearing lenses of white to light green, contorted talc schist. The talc is described as fine grained, massive to weakly foliated, with minor rounded and anhedral quartz, and veinlets of fine opal with talc developed as steeply dipping lenses within dolomite. The dolomite–quartzite–talc unit and schist are intruded by granite at the eastern side of the mine area.

The talc was probably formed by the alteration of sandy, dolomitic rocks by hydrous metamorphism between 200 and 250°C. In general, the talc from Mount Seabrook is massive, white to pale green, fine grained, and opaque to locally translucent, and contains quartz inclusions (Fig. 36.8). After initial processing, about 40% of production was of cosmetic-grade talc and a substantial proportion of the remainder was intended for high-grade industrial talc applications. This material was mostly exported through the Port of Geraldton to customers mainly in Europe (Fetherston, 2008). Access to the minesite is only with permission of the owners of the mining lease.

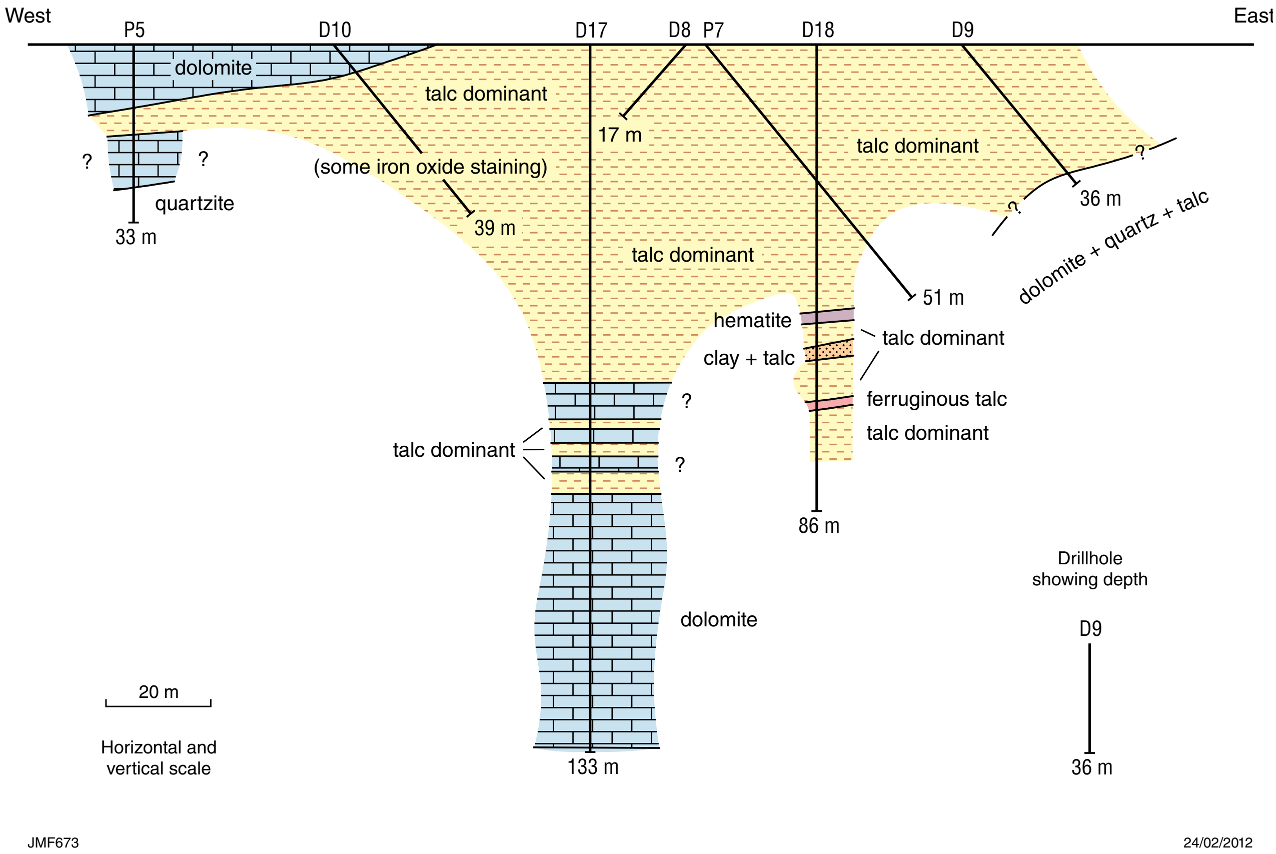

Figure 36.6. Cross-section through the Fowler talc deposit at Watheroo (modified after Fetherston et al., 1999)

Livingstone talc prospect *(Moorarie, 2446)*

Discovered in 1983, the main Livingstone talc prospect is 7 km west-northwest of Mount Seabrook (Fig. 36.2). By 1986, a second high-grade deposit and 12 other talc sites had been discovered in the Livingstone area. These prospects comprise successions of metasedimentary rocks intruded by granitic rocks and have been classified into three categories based on their associated host rocks:

- massive, high-grade talc and high-grade, disseminated talc in dolomitic rock at the contact zones of altered quartzite
- talc schist in quartzite
- talc schist in altered quartzite in contact with dolomite.

The high-grade Livingstone talc varies from light to dark green in colour and a large number of samples contained significant amounts of kaolin.

Trilbar prospect *(Moorarie, 2446)*

The Trilbar prospect is about 2 km north-northeast of Mount Seabrook (Fig. 36.2). At this site the talc occurs in subvertical lenses up to 8 m in true thickness (average 2–5 m) within a Paleoproterozoic metasedimentary rock succession. Drilling intersected high-quality talc in several exploratory drillholes.

Southern Cross Well prospect *(Moorarie, 2446)*

The Southern Cross Well prospect is about 11 km west-northwest of Mount Seabrook (Fig. 36.2). The prospect was evaluated by drilling between 1987 and 1990. Most drillholes intersected only minor talc zones within marble and chert units, although significant talc intersections, with thicknesses of 8–16 m, were obtained in three holes.

Albany–Fraser Orogen

Kundip area

Kundip prospect *(Ravensthorpe, 2930)*

The Kundip talc prospect is about 12 km southwest of Kundip township (Fig. 36.2). The prospect, first noted by Simpson (1952), occurs in a metamorphosed dolomitic unit forming part of the Kybulup Schist, a formation within the Proterozoic Mount Barren Group. The Mount Barren Group forms a narrow, northeast-trending belt along the northern margin of the Albany–Fraser Orogen between the towns of Ravensthorpe and Hopetoun adjacent to the central south coast.

At the Kundip site, a significant deposit of high-grade, coarsely crystalline talc is present. The talc is a pale

Figure 36.7. White massive talc excavated from a costean at the Fowler deposit

sea-green colour and strongly foliated. More recent exploration identified several areas of talc mineralization within dolomitic sedimentary rocks extending from the surface to approximately 45 m in depth.

Deposits derived from ultramafic rocks

Yilgarn Craton — Narryer Terrane

Mount Gould area

Mount Taylor 1 prospect (Gould, 2346)

The Mount Taylor 1 talc prospect is in the Jack Hills, about 135 km west-northwest of Meekatharra, and 0.5 km north of Mount Taylor (Fig. 36.2). The Jack Hills consist of a north-northeasterly trending belt of an Archean ultramafic and mafic succession of metamorphosed, jaspilitic banded iron-formation, chert, and chloritic schist. In this area, large pods of pure talc are developed in chloritic schist at the northern end of the range.

Trial mining took place at this deposit around 1910 when a parcel of talc was dug out and sent to Perth for testing. Simpson (1952) described the talc from Mount Taylor as light greenish-grey, micaceous, schistose, and strongly foliated. Later descriptions state that talc samples were heavily stained with limonite and to a lesser extent with manganese oxides. Small amounts of fine quartz, opal, and traces of chlorite and apatite were also present.

Mount Gould prospect (Gould, 2346)

The Mount Gould talc deposit is within mining lease M52/236 on the slopes of Mount Gould, approximately 14 km north-northwest of Mount Taylor (Fig. 36.2). Massive talc of very high quality occurs in a north-northeasterly trending ultramafic and mafic Archean succession intruded by Archean biotite monzogranite. Talc schists, striking east-northeast, outcrop at the foot of the northern slopes of Mount Gould (Ellis, 1963).

Yilgarn Craton — Eastern Goldfields Superterrane

In Archean greenstones of the Eastern Goldfields Superterrane, talc is an extremely common product of hydrothermal alteration of ultramafic rocks, especially serpentinite. Numerous small occurrences are known although large deposits are rare.

Mount Monger area

Loganberry prospect (Lake Lefroy, 3235)

The Loganberry deposit is approximately 1.5 km north-northwest of Mount Monger and 60 km southeast of Kalgoorlie (Fig. 36.2). At this site, foliated talc lenses within serpentinites are present in mafic and ultramafic rocks forming part of a north-northwest-trending Archean succession.

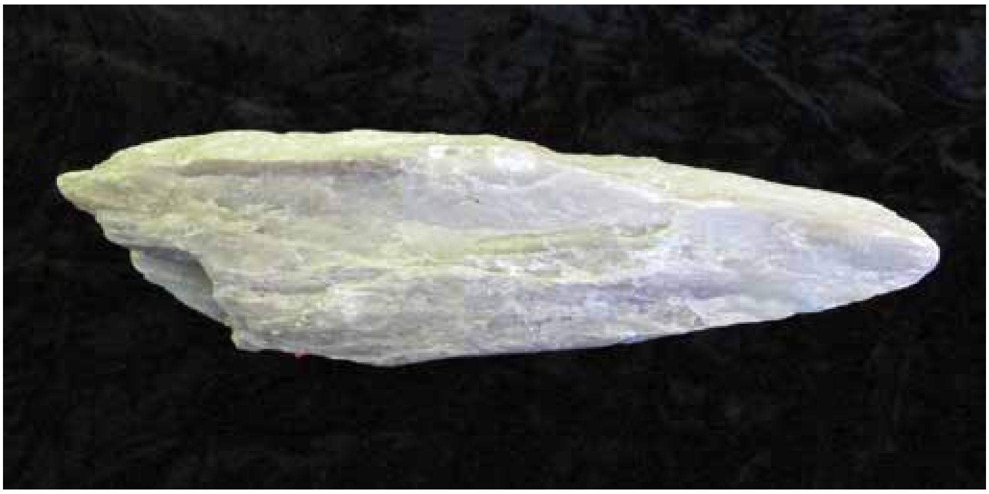

Figure 36.8. Export-grade, fine-grained, white to pale green cosmetic-grade talc from Mount Seabrook

The best quality talc in the area southwest of the Loganberry site is pale apple-green with a small proportion of relict minerals including rutile, chlorite, and iron ore. In 1942, mining commenced at Loganberry and talc and soapstone were mined from the hangingwall and footwall, and from matrix material contained in gold-bearing shears.

Yilgarn Craton — South West Terrane

Bridgetown Area

Glenlynn prospect *(Manjimup, 2129)*

The Glenlynn talc prospect is approximately 8 km south-southeast of Bridgetown (Fig. 36.2). The deposit was first mined in 1942 and currently comprises a series of shallow costeans that have been excavated at different times.

The talc is a massive, greenish-grey soapstone containing chlorite, rutile, and actinolite with some limonite staining. The host rock is not exposed, and appears to comprise weathered Archean biotite schist, gneiss, and coarse-grained greenstone lenses intruded by pegmatite and quartz veins. The talc appears to have been formed by local alteration of ultramafic rock lenses within the metamorphic complex.

Balingup area

Meaneys Bridge prospect *(Bridgetown, 2130)*

A soapstone deposit, comprising 17 discontinuous lenses, is in a complex of quartz–mica gneiss, quartz veins, and quartz and dolerite dykes at Meaneys Bridge, about 9 km east-northeast of Balingup (Fig. 36.2).

Records are incomplete, although it is recorded that 10 t of soapstone was mined from the deposit in 1942. Simpson (1952) also reported massive talc at a location approximately 8 km east of Balingup, which is possibly the same location as the Meaneys Bridge deposit. This report states that the talc is pale greenish-grey and scaly with no prominent foliation.

Bolgart area

Culham prospect *(Chittering, 2135)*

The Culham talc prospect is about 8 km south-southwest of Bolgart township (Fig. 36.2). The deposit was mined in 1952 from several shallow pits and costeans 1–3 m deep. Some of the talc was massive, fine grained, and pale green in colour although other samples were darker green and coarser grained. There are no rock outcrops in the area, although altered ultramafic rocks in the general region contain talc and asbestiform minerals.

Deposits derived from mafic rocks

Yilgarn Craton — South West Terrane

Moora area

Moora prospect *(Moora, 2136)*

In the Moora area, soapstone is exposed in an old quarry on the western side of a low hill approximately 11 km east-southeast of the town of Moora (Matheson, 1945;

Fig. 36.2). The deposit is lenticular, with a length of 76 m and a maximum width of 8 m, and is sheared and veined with quartz. Host rocks are mainly granitic and hornblende gneisses intruded by quartz, pegmatite, and dolerite.

The unweathered soapstone is a fine-grained, light green, foliated rock composed predominantly of talc with a little finely disseminated magnetite associated with thin seams of anthophyllite and chlorite and small irregular masses of sericite, chlorite, and quartz. The presence of magnetite and thin seams of anthophyllite and chlorite in the fresh soapstone suggest the derivation of talc from localized hydrothermal alteration of lenses of mafic rock rich in ferromagnesian minerals.

Minor talc deposits

There are numerous minor talc deposits in Western Australia, particularly within the Eastern Goldfields Superterrane and the South West Terrane of the Yilgarn Craton. Most of these are described, together with locations, in tables contained in Abeysinghe (1996).

References

Abeysinghe, PB 1996, Talc, pyrophyllite and magnesite in Western Australia: Geological Survey, of Western Australia, Mineral Resources Bulletin 16, 118p.

Deer, WA, Howie, RA and Zussman, J 1962, Rock forming minerals, volume 3 — Sheet silicates: Longman, London, 270p.

Ellis, HA 1963, Notes on the occurrence of magnesite, vermiculite, talc in Western Australia (taken from field notes by the former Government Mineralogist): Geological Survey of Western Australia report (unpublished).

Fetherston, JM 2008, Industrial minerals in Western Australia: the situation in 2008: Geological Survey of Western Australia, Record 2008/16, p. 24–25.

Fetherston, JM, Abeysinghe, PB, Jiang, S-Q and Wang, G-W 1999, Six industrial mineral deposits of significance in Western Australia: bentonite, feldspar, kaolin, micaceous iron oxide, talc, and tourmaline: Geological Survey of Western Australia, Report 67, p. 53–67.

Geological Survey of Western Australia 1994, Gemstones in Western Australia, 4th edition: Geological Survey of Western Australia, 52p.

Hickman, AH 2001, Geology of the Dampier 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 39p.

Hudson, DR 1974, Pilbara jade: The Australian Gemmologist, v. 12, no 4, p. 127–133.

Kriewaldt, M and Ryan, GR 1967, Pyramid, WA: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes.

Matheson, RS 1945, Report on soapstone deposit, approximately 7 miles east-southeast of Moora: Geological Survey of Western Australia, Annual Report for 1944, p. 43.

Smithies, RH and Farrell, TR 2000, Satirist, WA Sheet 2555: Geological Survey of Western Australia, 1:100 000 Geological Series.

Smithies, RH and Hickman, AH 2004, Pyramid, WA Sheet SF 50-7: Geological Survey of Western Australia, 1:250 000 Geological Series.

Simpson, ES 1948, Minerals of Western Australia, volume 1: Government Printer, Perth, Western Australia, 466p.

Simpson, ES 1952, Minerals of Western Australia, volume 3: Government Printer, Perth, Western Australia, p. 614–624.

Van Kranendonk, MJ 2003, Geology of the Tambourah 1:100 000 sheet: Geological Survey of Western Australia 1:100 000 Geological Series Explanatory Notes, 57p.

Van Kranendonk, MJ and Pawley, M 2002, Tambourah, WA Sheet 2754: Geological Survey of Western Australia, 1:100 000 Geological Series.

Tektites

Tektite nomenclature and strewn fields

Tektites are relatively small, pebble-sized, natural glass objects varying in colour between pale green and black. Their name comes from the Greek word 'tektos', meaning molten.

Around the world, tektites are only found in specific areas known as strewn fields. Tektite strewn fields, which take their names from the geographical regions in which they are found, include Central European (Czech Republic, Austria, and Germany), North American (southeastern US and the Caribbean), Ivory Coast (west Africa), and Australasian (Australia, China, South-East Asia, and Indian Ocean). To date, tektite-rich areas in South-East Asia and Australia have been the most productive whereas only a few specimens have been obtained from the Ivory Coast field.

Tektites are named geographically according to their strewn fields:

- australites (Australia)
- bediasites (Texas, US)
- billitonites (Billiton Island, Indonesia)
- georgiaites (Georgia, US)
- indochinites (Thailand and Cambodia)
- irgizites (Irgiz, Kazakhstan)
- javaites (Java, Indonesia)
- moldavites (Czech Republic and Slovakia)
- philippinites and rizalites (Philippines)
- thailandites (Thailand).

Tektites
Silica glass 65–82% SiO_2

Origin

Numerous theories have been advanced on the formation of tektites although it is now accepted that these natural glass objects were produced by the melting and ejection of crustal material during the impact of large meteorites striking the Earth's surface. The energy produced by these impacts would have been sufficient to vaporize or melt material in the impact zone, and propel it for large distances through the atmosphere before it fell to Earth.

In Europe, tektites found in Miocene sedimentary rocks (15 Ma) have been linked to the Nördlinger Ries crater in western Bavaria, which has been identified as the impact site. The crater rim had an estimated diameter of 24 km and the present floor of the depression is approximately 100–150 m below the eroded remains of the rim.

The source crater for the Australasian tektite strewn field has not yet been identified although a crater lake in Cambodia has been targeted as a possible source. It is now considered that about 800 000 years ago an asteroid or comet of about 3 km diameter impacted, probably in Indochina, with the resultant tektite and microtektite (<1 mm in diameter) strewn field extending for thousands of kilometres from southern China to the Southern Ocean and from the western Pacific to the southwestern Indian Ocean. Microtektites have also recently been reported from Antarctica (McNamara and Bevan, 2001).

Dating of tektites

The oldest tektites are those from the North American field, which have been dated at 35–34 Ma (McNamara and Bevan, 2001). In Australia, australites are considerably younger with a date of around 800 ka (ka = thousand years). Age determination work has been carried out on some australites collected in 2009 from a salt lake 140 km southeast of Kalgoorlie using the ^{40}Ar–^{39}Ar step-heating method. This technique was carried out at the Western Australian Argon Isotope Facility in the John de Laeter Centre of Isotope Research at Curtin University, Perth, Western Australia. Results of this research produced a mean date for two fractions of 796 ± 10 ka, which agrees well with the estimated date of impact of 793 ka (GSWA, 2012).

Composition

Chemically, tektites are similar to silica-rich igneous rocks and some sedimentary rocks, especially lithic wacke (impure sandstones) with a high silica content of 68–82%, alumina 10–14%, together with lesser amounts of iron, magnesium, calcium, potassium, and titanium. One major difference is the almost total lack of water in tektite glass.

Shapes

Tektites are found in many shapes and nearly 30 different forms have been described. Australites are by far the most variably shaped tektites and show the most complete record of shape development. The most familiar australite form is the 'button' popularly known as 'blackfellows' buttons', an allusion to their distinct button-like form (Webster, 1975). Other forms include asymmetric dumbbells, boats, canoes, lenses, ovals, and teardrops.


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Figure 37.1. Faceted moldavite gemstone, 7 x 5 mm, displaying gas bubbles and swirled interior

European tektites (moldavites)

Moldavites from the Czech Republic, which are green or greyish-green tektites, were the first tektites studied in a scientific manner by gemmologists. When first discovered in the late 18th century, moldavite was considered glassy remains from an early glassworks plant, a theory maintained until similar pieces were found in other parts of the world.

Moldavites have been used in jewellery commonly in their natural form, preserving both shapes and characteristic surface textures. Moldavites occur as irregular fragments ranging 10–50 mm in size and are drop-like, discoidal, or rod-like in form. Moldavites are also processed into cut stones and have been marketed under names such as 'bottle stone', obsidian and 'bouteillen-stein' (Konta and Saul, 1976; Fig. 37.1).

Physical properties of moldavites include a hardness of 5.5, specific gravity of 2.34 – 2.39, and refractive index of 1.488 – 1.503. Internal examination of moldavite glass commonly shows a swirled texture (schlieren), spiral patterns of non-homogenized glass (lechatelierite), and gas bubbles that are commonly oval or spherical. Unlike natural volcanic glass (such as obsidian) tektites contain no crystallites (De Goutiere, 1995).

Australian tektites (australites)

Australites tend to concentrate in an east–west belt across the south of the continent, mainly south of 25° latitude, covering most of South Australia, Victoria, New South Wales, and Tasmania, and parts of Western Australia, Northern Territory, and Queensland.

Originally, the distribution of australites would have been totally random but subsequent weathering and erosion in some areas has transported australites and concentrated them in shallow lakes, depressions, playas, and watercourses. Although most australites found in southern Australia are considered to be from their original sites, tektites found in parts of Western Australia, especially in the north, are thought to have been more strongly affected by landscape erosion (McNamara and Bevan, 2001).

Also, some redistribution of australites was carried out by Aboriginal people, who collected and used them for tools and weapons. Percussion flaking of tektites produces very sharp-pointed fragments and flakes, which have been used as scrapers, knives, points, and ceremonial knives. Currently, tektites found on the Nullarbor Plain are typically quite small and flakes are plentiful, which indicates that larger tektites from the region may have been used for tool and weapon making.

Australites tend to show a much wider range of shapes than tektites from other geographical regions. Of the almost 30 different forms identified to date, notable shapes include spheres, spheroids, ellipsoids, dumbbells, bowls, plates, buttons, boats, lenses, ovals, and teardrops. Australite shapes are attributed to three basic processes:

- primary solidification in flight through the atmosphere where the shape of the molten blob is affected by whether the blob was rotating or not, and the speed of rotation
- secondary modification in flight (ablation) caused by frictional heating at hypersonic speeds, resulting in the loss of frontal material of blobs travelling in steadily orientated flight

- continuing ablation as velocity decreases, resulting in remelting of the anterior surfaces to produce the most common disk-like shapes, such as bowl and plate australites.

On the Earth's surface, australites are subject to modification by physical and chemical weathering and transport processes. Examples of variations in australite shapes are shown in Figure 37.2.

Tektites in Western Australia

In Western Australia, it is reported that tens of thousands of tektites have been collected mainly in the Eastern Goldfields, the Wheatbelt, and the Nullarbor Plain. Certain areas appear to contain australites from a particular size range. For example, 32 australites heavier than 100 g were collected from a relatively small area in the southwest bounded by Corrigin in the north, Cuballing in the west, Newdegate in the east, and Chillilup in the south.

From one site at Lake Yindarlgooda, east of Kalgoorlie, more than 22 000 weathered australites have been found. Most are deeply etched, having been eroded and washed into the lake from ephemeral drainage channels. Also, nearly 7000 australites were recovered from a lake near Israelite Bay on the south coast (McNamara and Bevan, 2001). A map of the distribution of australite sites in Western Australia is shown in Figure 37.3.

Australites do not have the translucent green colour of the European moldavite. Instead, they are commonly black and opaque with a similar hardness to moldavite and a slightly higher range of refractive index (1.49 – 1.53) and specific gravity (2.36 – 2.52). The specific gravity largely depends on mineral composition, although the presence of gas bubbles tends to reduce the values mentioned above.

Australites are unique materials with an interesting origin that are collected and appreciated by fossickers, and are typically preserved in their natural state. A sample of Western Australian australites is shown in Figure 37.4.

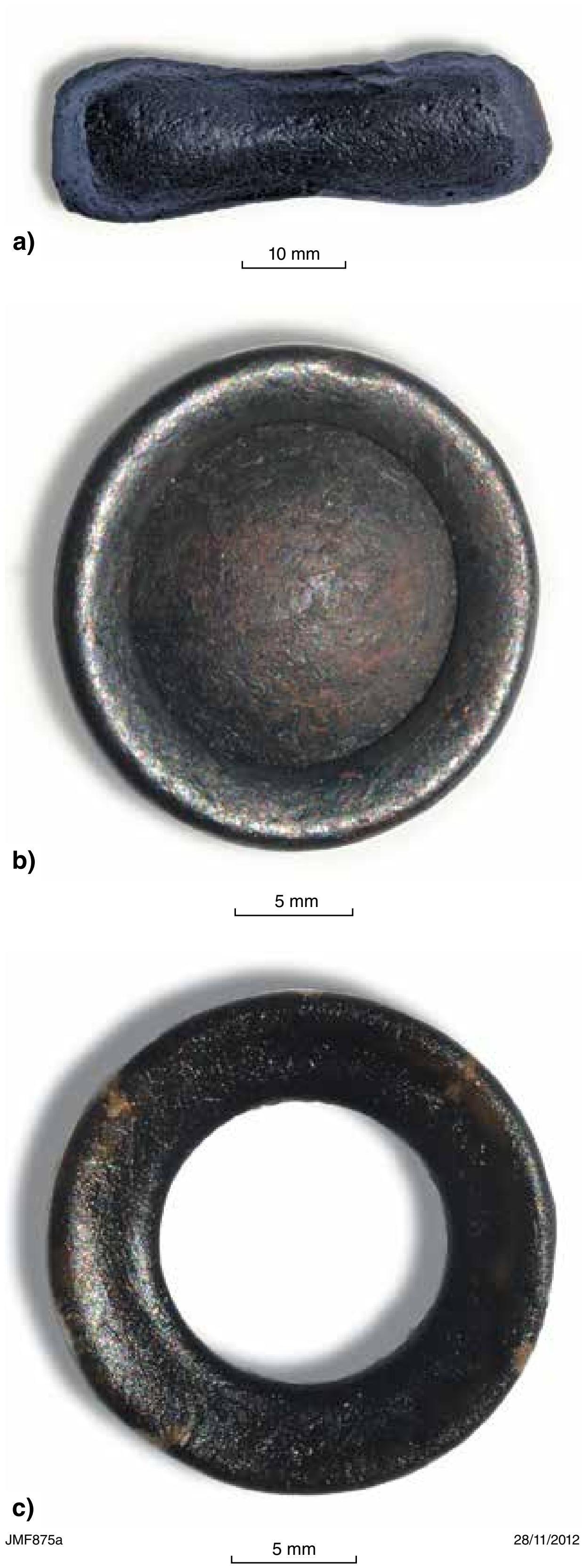

Figure 37.2. Examples of Western Australian australite shapes: a) dumbbell; b) flanged button; c) detached flange

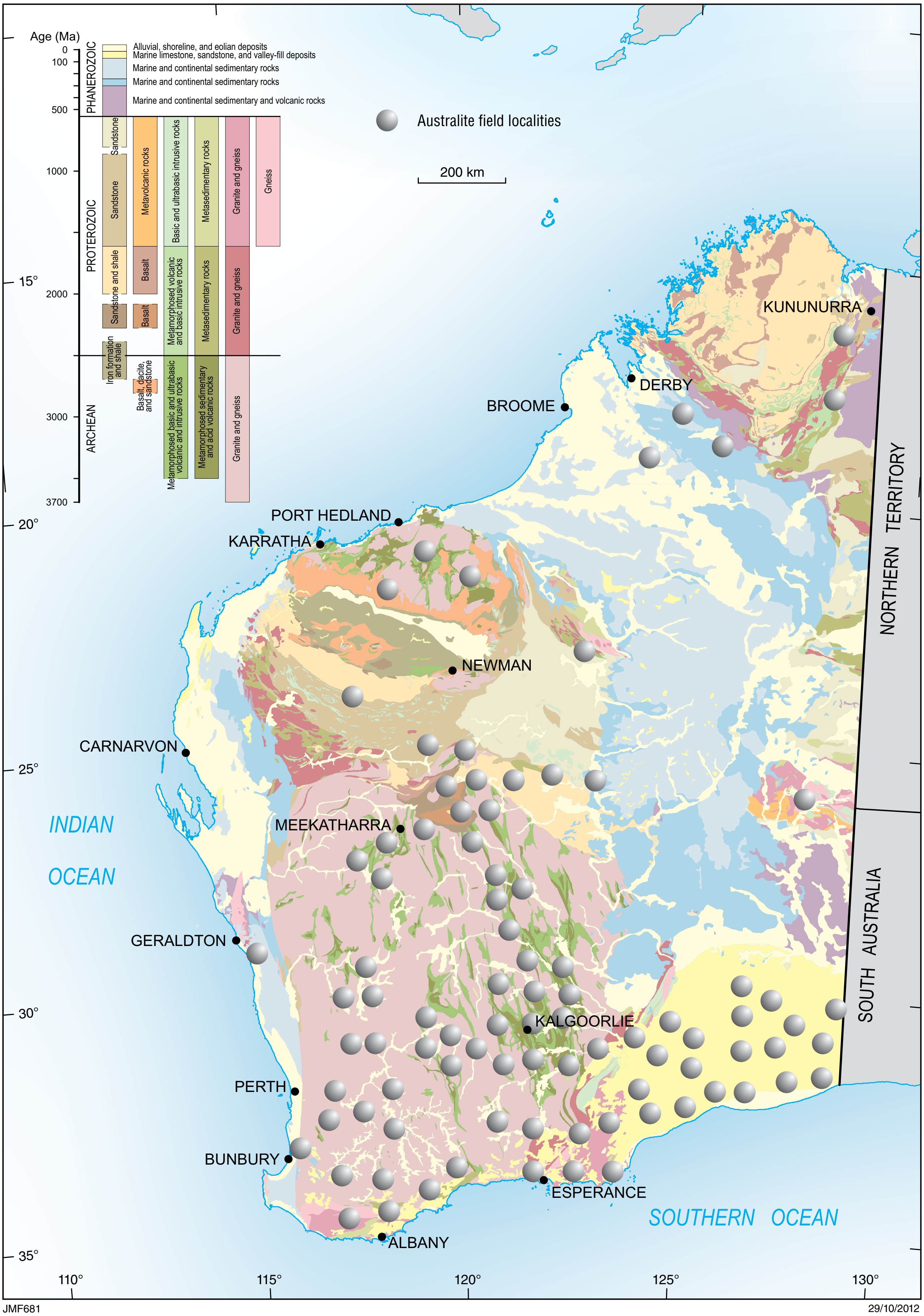

Figure 37.3. Distribution of australite sites in Western Australia (modified after McNamara and Bevan, 2001)

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Figure 37.4. Sample of Western Australian australites from southeast of Kalgoorlie (after Geological Survey of Western Australia, 2012)

References

De Goutiere, A 1995, Photogenic inclusions in moldavite: The Journal of Gemmology, v. 24, no. 6, p. 415–419.

Geological Survey of Western Australia 2012, Tektite dating: Geological Survey of Western Australia, Field Notes, January, p. 9.

Konta, J and Saul, JM 1976, Moldavites and a survey of other naturally occurring glasses: The Journal of Gemmology, v. 15, no. 4, p. 179–204.

McNamara, K and Bevan, A 2001, Tektites, 3rd edition: Western Australian Museum, Perth, Western Australia, 38p.

Webster, R 1975, Gems—their sources, descriptions and identification: Butterworths, London, 938p.

Chapter 38

Other decorative stones from the Kununurra and Pilbara regions

Kununurra region

Zebra rock and other ornamental stones from the Ranford Formation

Geological setting

The Ranford Formation, located to the south and southeast of Kununurra in the extreme northeast of the State, forms the upper part of the late Neoproterozoic to early Cambrian Duerdin Group (Thorne et al., 1999). The upper part of the Ranford Formation is composed largely of fine-grained, thin-bedded, micaceous, iron-rich siltstone. It is this siltstone unit that contains discrete sites for local, decorative stones such as the well-recognized zebra rock and other patterned stones including ribbon stone, okapi stone, primordial stone, and astronomite (Fig. 38.1).

Decorative stones

Zebra rock (*Argyle Downs, 4665*)

Zebra rock was first discovered by T Blachford in 1924 at a site not far from the old Argyle Downs Homestead, now submerged beneath the northern edge of Lake Argyle. Later exploration revealed that the stone could be found in lens-like structures within in the upper part of the Ranford Formation trending in a north-northeasterly direction from the Snappy Gum Ridge deposit in the south more than 50 km towards the Northern Territory border. Today, several known deposits are submerged below Lake Argyle.

Currently there are three openpit zebra rock operations: two in the south in the Lake Argyle area at Snappy Gum Ridge and Remote Island, at Zebra rock 1 and 2 pits, respectively, and one in the north of the area at the Kununurra zebra rock pit. These operations are worked on a campaign basis during the dry season according to demand for raw material. Hancock (1969) identified two other zebra rock prospects: one on the northern end of Hagan Island in Lake Argyle, and the other close to the lake shore on Spider Point, approximately 7 km to the northeast. These prospects may also be subject to seasonal inundation. Zebra rock sites are shown on Figure 38.2 and more detailed locational information is given in Appendix 1.

Other decorative stones from Kununurra and Pilbara regions
Siltstone, shale, and metamudstone

Zebra rock at Lake Argyle

Located approximately 65 km south-southwest of Kununurra, operations at Snappy Gum Ridge and Remote Island are controlled by the rise and fall of Lake Argyle during the wet and dry seasons. At these sites, the Zebra rock 2 deposit on Remote Island becomes submerged below the surface of the lake during the wet season, and Snappy Gum Ridge may become an island with possible inundation of the Zebra rock 1 openpit. Even during the dry season, access for the openpit operators, together with the removal of quality zebra rock, is only by boat.

At the Lake Argyle sites, zebra rock is present only in a single zone of relatively thin beds of hard, blocky siltstone that vary in width from 25 to 400 mm. Average bed thickness is about 150 mm and maximum block size is around 0.75 m length by 20 cm width. Despite the thin bedding, the zebra rock beds have been shown to be of remarkably consistent quality for up to 8 km along strike. In addition, the stone has been extensively folded and faulted with the bedding being consistently near vertical and horizontal fault displacements up to 1 m.

Zebra rock exists in a variety of forms, the most common of which are the regularly spaced, ferruginous, brown bands on a white to pale brown clay-rich matrix. These bands are commonly arcuate and appear to vary in thickness according to the width of individual beds. For example, narrow beds up to 40 mm thick may contain parallel bands only 1–2 mm wide whereas thicker beds may contain bands up to a maximum width of around 25 mm with an average band with of approximately 5–10 mm. These arcuate bands extend across the bed from top to bottom at a high angle to the bedding plane (Fig. 38.3).

Other zebra rock forms include rods and irregular blebs that extend through the rock in parallel rows similar to the near-vertical alignment of bands. In section, rods commonly appear as an ovoid shape that may be 8 mm wide by 17 mm on the longest axis (Fig. 38.4).

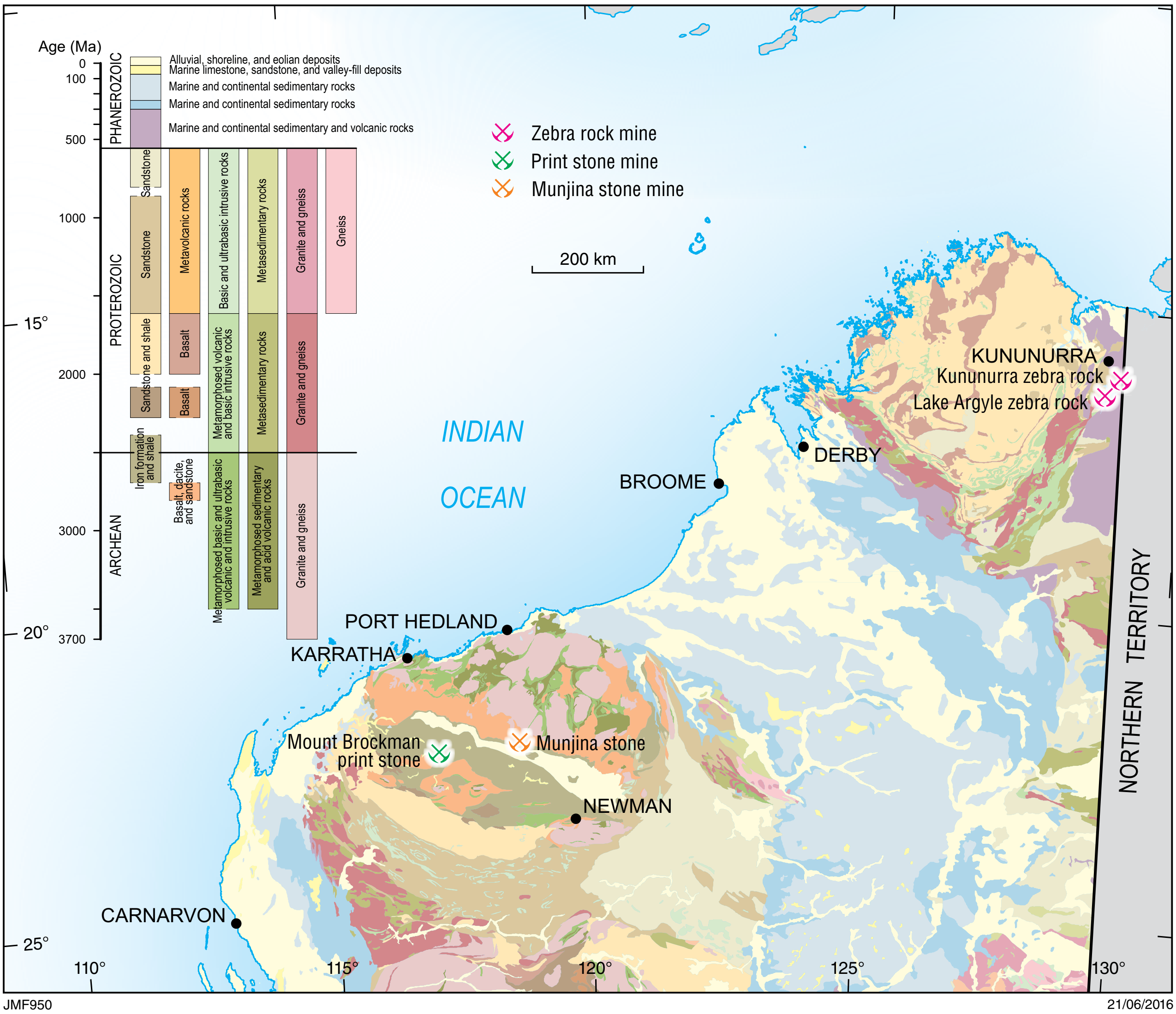

Figure 38.1. **Locations of zebra rock in the east Kimberley region, and Munjina stone and Mount Brockman print stone in the Pilbara region**

Petrographic studies by Loughnan and Roberts (1990) showed that zebra rock is largely composed of ultrafine-grained quartz, and sericite (white mica). Other minerals present included kaolinite and its polymorph, dickite, alunite, and traces of feldspar. Bevan (2001) proposed that the colour banding seen in the zebra rock probably resulted from the rhythmic precipitation of well-defined, hematite-rich liesegang bands in selected parts of the siltstone caused by the percolation of warm hydrothermal fluids or other chemical activity during a period of alteration of the rock.

Zebra rock 1 openpit

The zebra rock operation at Snappy Gum Ridge has been worked for at least 25 years, largely by the Read family, and to date has been the largest producer of this material (Fig. 38.2). Situated within mining lease M80/185, this openpit has produced the traditional white and brown-banded material for which the stone is renowned (Fig. 38.5).

Depending on demand for the stone, up to eight miners have worked the openpit at times during the dry season. Until recently, zebra rock extraction was entirely a hand-mining operation to remove quality stone without damage from the narrow beds in which it is contained. More recently, a backhoe has been used to expose the seams before hand removal. Despite the reduction in stone removal time, it is still a labour-intensive process as exposed beds tend to be covered with a thin coating of brown clay-rich material that requires wiping down to expose the zebra rock layers. Approximately 1 t of high-quality zebra rock is removed by boat after each mining campaign.

Zebra rock 2 openpit

Situated on tiny Remote Island, about 8 km to the northeast, Zebra rock 2 openpit is within mining lease M80/442 (Fig. 38.2). Mainly operated by the Read family using the same extraction techniques as for Zebra rock 1, the operation on Remote Island is one of the main sources of high-quality, rod-shaped material. At this location, zebra rock is found in relatively narrow, near-vertical beds within the openpit (Fig. 38.6).

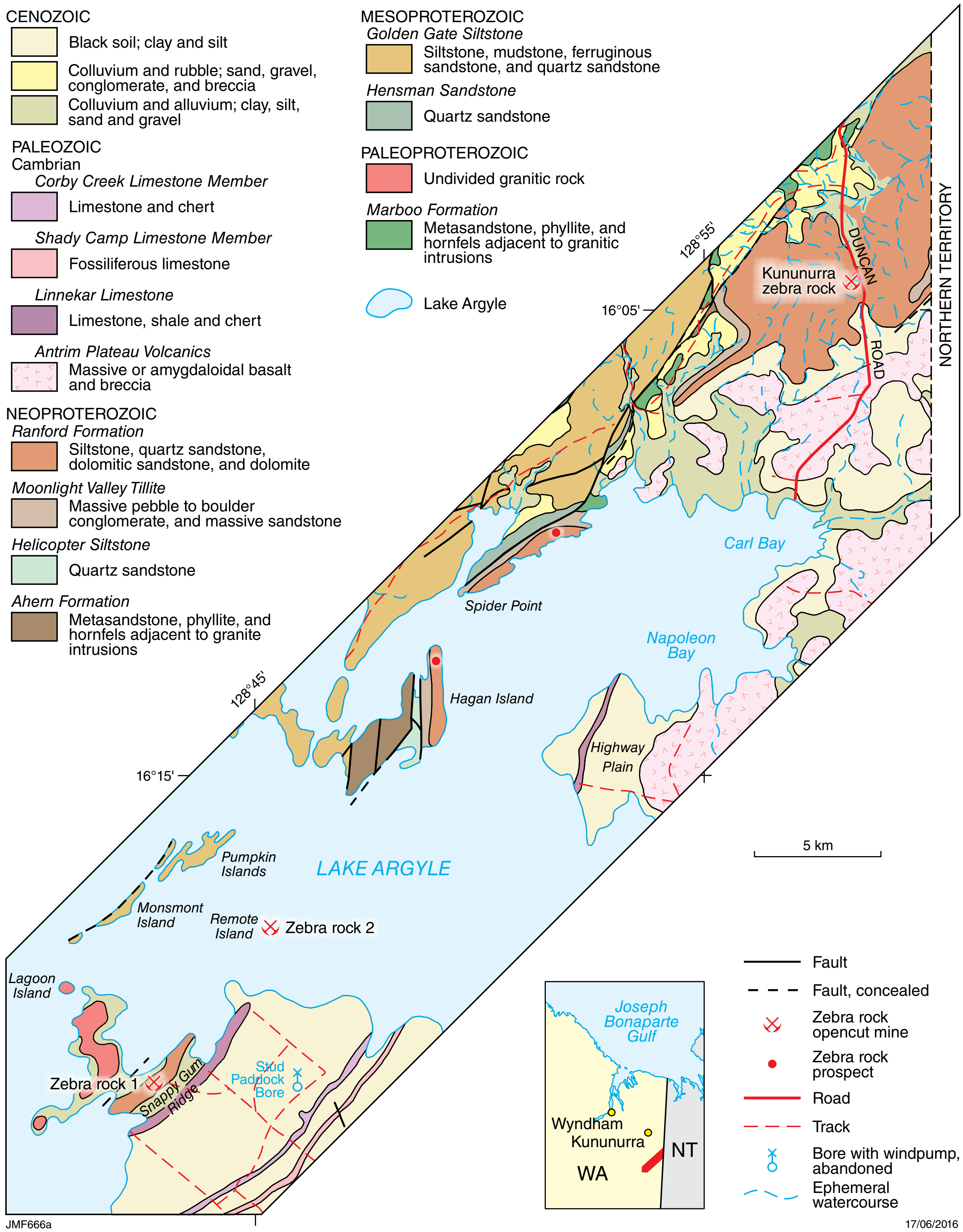

Figure 38.2. **Locations of zebra rock deposits within the Ranford Formation, Lake Argyle area (modified after Thorne et al., 1998)**

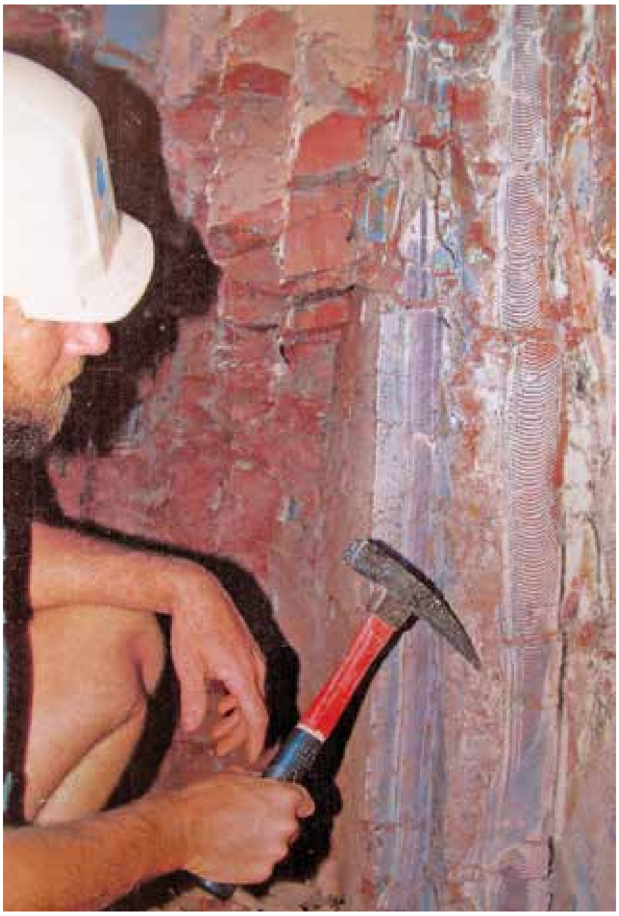

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Figure 38.3. **Vertical zebra rock bed, estimated at 60 mm width, in the Zebra rock 1 openpit at Snappy Gum Ridge, Lake Argyle. Note the comparatively thin, arcuate, brown bands 38 mm wide by 17 mm along the longest axis**

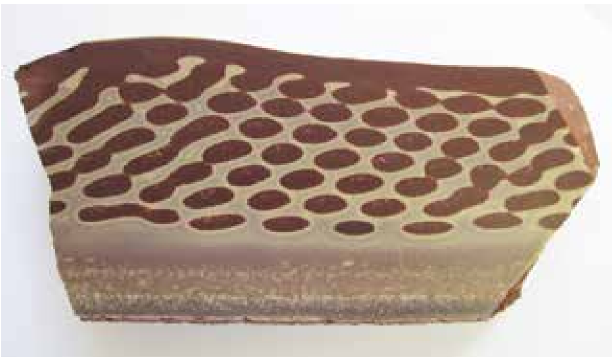

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Figure 38.4. **Zebra rock rods from Remote Island in Lake Argyle. Sectional view shows ovoid-shaped rods approximately 8 mm wide by 17 mm along the longest axis**

Kununurra zebra rock area

The Kununurra zebra rock area is in the northern area of the Ranford Formation, which extends from the northern end of Lake Argyle northeast to the Northern Territory border (Fig. 38.2). This area contains the Kununurra zebra rock openpit, about 40 km southeast of Kununurra on mining lease M80/576 operated by Messrs T Kapitany and J Pas. Little is known about the structure and mining of zebra rock at this site although the material appears similar to that at Lake Argyle. In 2011, a proposal was made to remove up to 200 t of rock to extract zebra rock as the target mineral.

Previously, it has been observed that zebra rock block size within the Ranford Formation from sites closer to the Northern Territory border were larger than material from the Lake Argyle area in the south. Blocks up to 1 m^3 have been reported from this northern area although the zebra rock quality tended to be of a poorer grade in some samples.

Properties and applications

Zebra rock is essentially a compact, argillaceous (clay-rich), fine-grained siltstone and is sufficiently soft to precisely cut and carve using hand tools. The stone has a smooth, silky texture that enables it to be finished using ultrafine wet and dry emery paper, resulting in an extremely smooth, semigloss finish. Sealing the stone is carried out using talcum powder or warm clear Vaseline. Final colour is enhanced by the application of up to several coats of polyurethane solvent to obtain either satin or gloss finishes as required. Zebra rock products include jewellery, bowls, jugs, and many other attractive items (Fig. 38.7).

Other ornamental stones from the Ranford Formation

Ranford Formation (*Argyle Downs, 4665*)

In the northern area of the Ranford Formation, extending from the northern end of Lake Argyle northeast to the Northern Territory border, several unidentified, closely spaced sites contain other visually attractive ornamental stones. These stones may also be in the upper part of the Ranford Formation roughly at the same stratigraphic horizon as for zebra rock and several of these stones are clearly similar to zebra rock. According to prospector Mr Johan Pas, 'astronomite' typically exists in the uppermost layers of the Ranford Formation, overlying the zebra rock horizon and underlying 'primordial stone' present in some places. At another site, close to the Northern Territory border, 'okapi stone' overlies the zebra rock whereas astronomite and primordial stone are absent from this location (J Pas, 2011, written comm., 17 August).

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Figure 38.5. High-quality zebra rock from Snappy Gum Ridge, Lake Argyle. Bands and rods are approximately 5–6 mm wide

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Figure 38.6. Zebra rock rods enclosed in a vertical bed in Zebra rock 2 openpit on Remote Island, Lake Argyle (courtesy John Read)

Ribbon stone

Ribbon stone is considerably harder than zebra rock and consequently harder to work. Colours are highly variable and include white, cream, orange, pink, burgundy red, beige, light to dark grey, and black. There is also a wide range of textures present including stripes, spots, and streaks, and combinations of all three. Welded and displaced fractures are a common highlight of this stone and crystal imprints are present in places. The combination of random colour patches and textures may commonly create the illusion of landscape pictures in the stone.

Okapi stone

In terms of composition, okapi stone is quite similar to zebra rock as it is a fine-grained, thin-bedded, iron-rich siltstone. By contrast, okapi stone lacks zebra rock's extremely regular reddish-brown banding on a white clayey matrix (Fig. 38.8). Instead, the banding present in okapi stone is not regular, but varies in thickness with irregular spacing, and colours vary from a rich, dark to mid-brown to soft pink bands on a cream to white clay-rich matrix.

Primordial stone

This stone appears to be a hard, banded, fine-grained siltstone consisting of small, red-brown lensoid structures that may be set in a pale blue-grey to dark grey matrix. Welded, displaced fractures are a common highlight of this stone. Primordial stone is similar to okapi stone although is physically stronger.

Astronomite

Of all the decorative stones found in the Kununurra region, astronomite is unique. Astronomite was discovered in 2002 by local prospector Johan Pas. This stone is an indurated, very fine-grained, dark chocolate-brown siltstone. Within this dark brown matrix are numerous irregularly spaced orbicules ranging from 1 to 10 mm in diameter. In section, the orbicules have a slightly flattened, ovoid appearance probably resulting from tectonic pressures applied during lithification of the stone. The orbicules are composed of concentric, ferruginous siltstone rings with most containing an indistinct, pale yellowish-cream-coloured centre. The rings progress outwards through a broad, lightly banded, pink or orange zone before reaching a thin although very distinct, cream-coloured ring. The outer rings in shades of brown have a halo-like appearance against the dark brown matrix. Other, less-common orbicules are composed mainly of two or three thicker ferruginous rings (Fig. 38.9). The overall effect of these circular structures set in a dark brown matrix is to create a visually attractive decorative stone.

Applications for stones from the Ranford Formation

In addition to zebra rock, most of the ornamental stones mentioned above are processed and carved in the Kununurra area for sale out of Kununurra or distribution to other rock shops around the State and further afield. Most applications appear to relate to jewellery, especially in attractive pendants and earrings. The stones may also be transformed into polished shapes such as pyramids and carved ornaments, decorative items highlighting orbicules, and impressionistic landscape pictures in stone (Fig. 38.10).

Pilbara region

Hamersley Basin

Munjina stone (Mount George, 2653)

The Munjina stone quarry is on a ridge top in former prospecting licence P45/2377 about 0.7 km west of the Great Northern Highway in the Chichester Range, 200 km south of Port Hedland, and 25 km north-northeast of Munjina Roadhouse (Fig. 38.1).

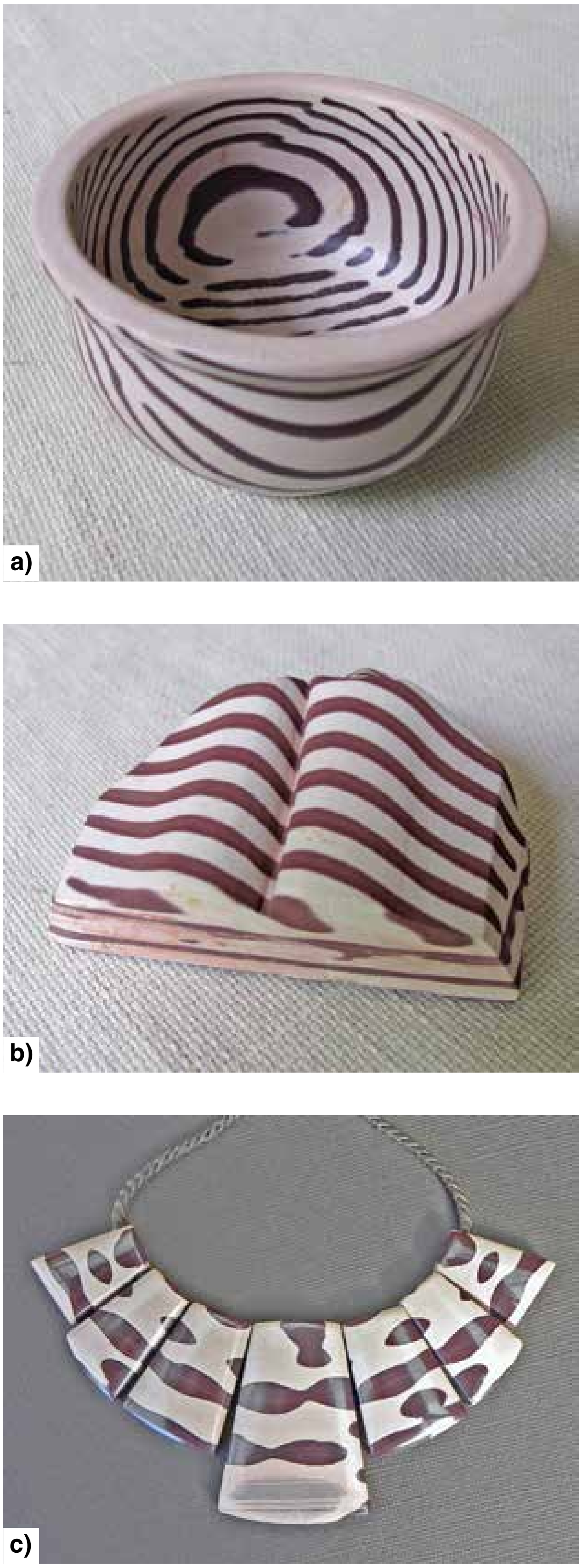

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Figure 38.7. **Examples of high-quality products from Lake Argyle zebra rock: a) semigloss bowl featuring dark brown banding, diameter 10 cm; b) carved open book in the well-known white and mid-brown colours, width 10 cm (courtesy John Read); c) necklace with a gloss finish, width 15 cm**

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10 cm

Figure 38.8. **Okapi stone is similar to zebra rock although it lacks the extremely regular reddish-brown banding on a white clayey matrix (courtesy Arcgems)**

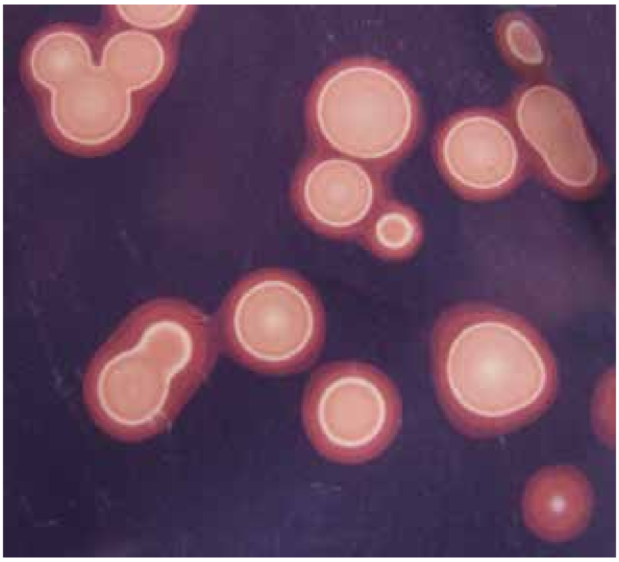


Figure 38.9. Concentric astronomite orbicules set in a dark brown siltstone matrix. Maximum orbicule diameter is 10 mm

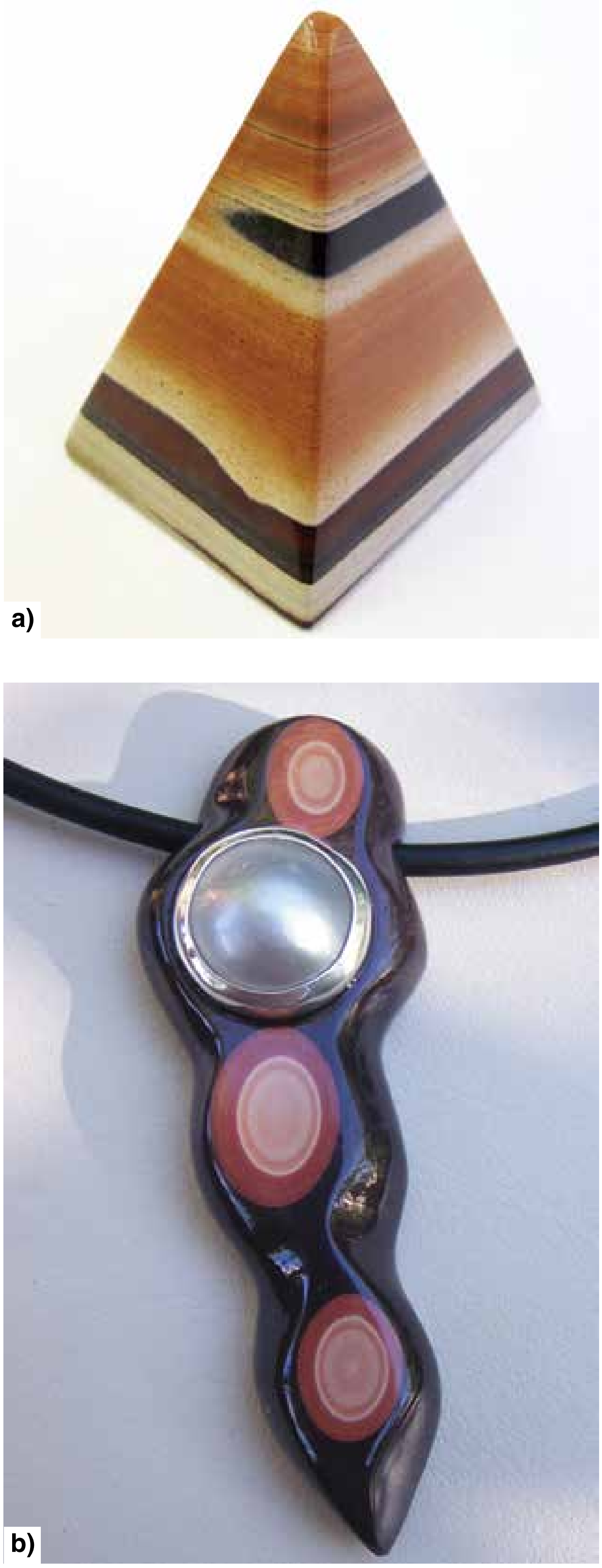


Figure 38.10. Applications for other decorative stones from the Ranford Formation: a) carved and lacquered pyramid of Okapi stone, height 70 mm; b) carved piece of astronomite designed to highlight the oval-shaped orbicules and incorporating an 18 mm-diameter Broome pearl (courtesy artisan Marion Egger)

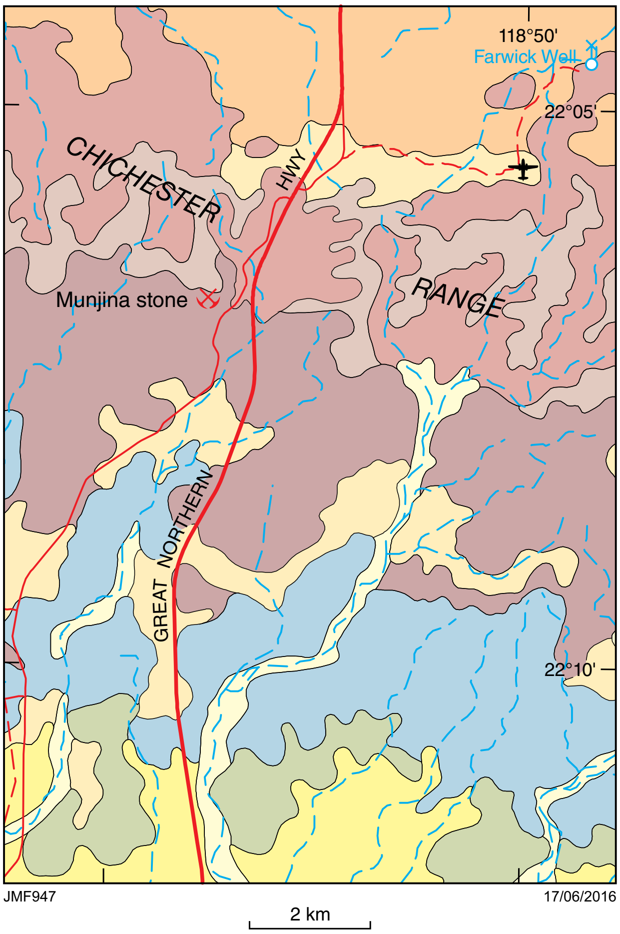
Munjina stone is an extremely fine-grained, silicified pelite (metamudstone) from the Jeerinah Formation, part of the Archean Fortescue Group of the Hamersley Basin (Figs 1.1 and 38.11). The stone has an internal cellular appearance with irregular, white to reddish-brown cells commonly arranged in parallel rows surrounded by a red and/or yellow matrix that can be filled with fine, concentric liesegang bands (Fig. 38.12a). A magnified image of Munjina stone displaying this finely detailed banding is shown in Figure 38.12b.

Munjina stone was mined at this site during the late 1990s and an estimated 20 t of high-grade material was removed for cutting and polishing into decorative slabs. The polished stone was subsequently onsold for the manufacture of jewellery items such as cabochons, beads, and other decorative ornaments.

Mount Brockman print stone (JEERINAH, 2353)

Print stone is a massive, indurated, very fine-grained, red-brown shale that has a semiconchoidal fracture. Print stone’s visually attractive feature is its unusual liesegang band patterns that are displayed over the stone’s red-brown to orange background colour. On these surfaces, dark brown, hematite-rich liesegang bands commonly form large, non-continuous, concentric bands commonly interspersed with bands of greyish-white material. Bands may also develop as complex semiconcentric to irregular or even ‘chicken wire’ patterns. A concentric band pattern may be up to 0.5 m in length (Fig. 38.13).

Because of the indurated, very fine-grained nature of this uniform material, print stone may be easily cut into decorative slabs and given a high polish. Moreover, it can be intricately carved and polished into complex shapes



CENOZOIC

- Alluvium; sand, silt and gravel
- Colluvium; unconsolidated quartz and rock fragments in soil
- Alluvium and colluvium; red-brown sandy and clayey soil
- Colluvium; partly consolidated soil and rock fragments in silt and sand matrix
- Hematite–goethite deposits on BIF and scree

ARCHEAN

Hamersley Group

- Marra Mamba Iron Formation; chert, BIF and pelite

Fortescue Group

- Jeerinah Formation; pelite, chert and metasandstone
- Woodiana Member; metamorphosed quartzitic sandstone, pelite and chert
- Maddina Basalt; metabasaltic flows and breccia

- Munjina stone quarry; not worked
- Highway
- Road
- Track
- Landing ground
- Bore with windpump
- Ephemeral drainage

Figure 38.11. Geology of the area surrounding the Munjina stone quarry (modified after Thorne and Tyler, 1996)

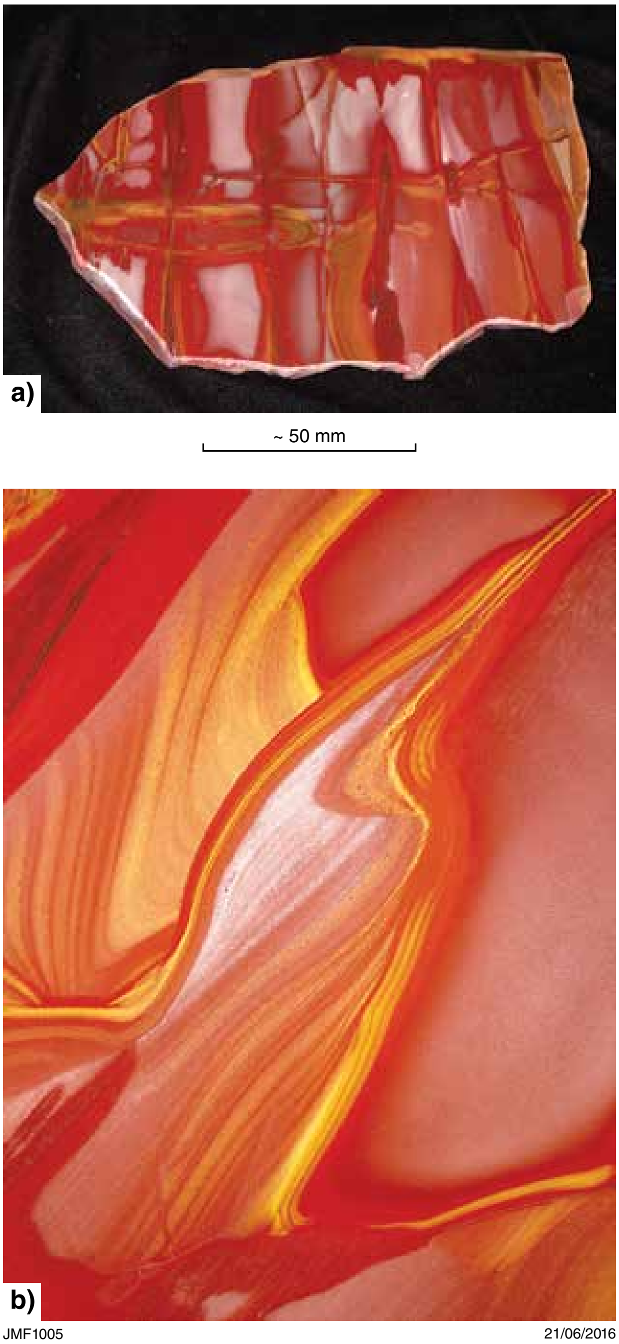


Figure 38.12. Examples of Munjina stone: a) irregularly shaped, white to pink cores surrounded by a red to orange matrix; b) magnified image showing the finely detailed liesegang banding (courtesy a) Glenn Archer; b) Bill Atkinson and Glenn Archer © Bill Atkinson Photography)

Figure 38.13. Distinctive concentric banding in a print stone block, approximately 0.5 m long

displaying distinctive colour banding in artwork forms such as spheres, statuettes, pendants, and other decorative items (Fig. 38.14).

The Mount Brockman print stone quarry is directly below cliffs of the Hamersley Range escarpment on the northern side of Caves Creek valley about 65 km northwest of Tom Price. Access is via the Mount Brockman Road west of the Tom Price Railway Road for about 35 km west of Hamersley Homestead and then northward along the mine track (Figs 38.1 and 38.15). The mine is within mining lease M47/194 owned by Aradon Pty Ltd and operated by Mr Barry Kayes. The opencut quarry consists of a bench cut into the steep slope above the valley floor with the inner wall accessible for the extraction of print stone.

Geological setting

The print stone deposit is in the Archean Mount McRae Shale, a unit of the Hamersley Group, in the central part of the Hamersley Basin (Fig. 1.1 in Chapter 1 on introduction to gemstones in Western Australia, and Fig. 38.15). Print stone is found in the lower shale member of the Mount McRae Shale, which comprises shale, dolomitic shale, and chert overlain by a thick bed of massive blue chert, with total thickness ranging from about 35 to 70 m (Trendall and Blockley, 1970). The print stone quarry is sited in a bed of hematitic shale approximately 10 m thick. Print stone is extracted by hydraulic excavator as large prismatic blocks up to 0.6 m in length by 0.3 m in square section (Fig. 38.16). The quarry has been in intermittent operation since the 1980s and it is estimated several hundred tonnes of decorative stone have been excavated up to 2015.

Liesegang banding

A study on the magnetic remanence directions of hematitic pigments contained in the original stone and in the liesegang banding has revealed distinct differences between the materials in terms of age of pigment development (Abrajevitch et al., 2014). By correlating the magnetic remanence direction of the hematite pigments with the Australian apparent polar wander path, the magnetic remanence of the pigment contained in the original shale has been dated between c. 25 and 15 Ma. Conversely, the magnetic remanence of the hematitic pigment in the dark brown liesegang bands indicates a much older date of either middle Carboniferous (c. 320–310 Ma) or Mesoproterozoic (c. 1.5 Ga) as predicted by the Australian polar wander path.

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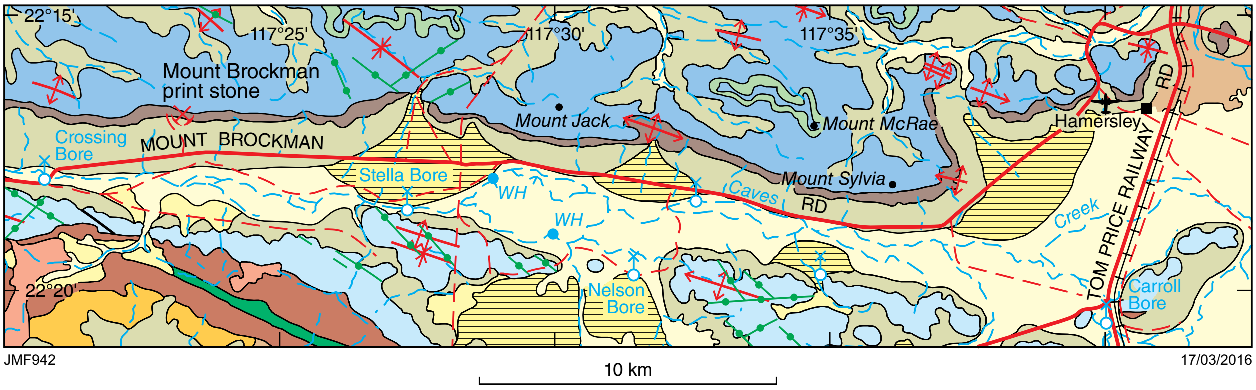
Figure 38.14. Examples of print stone cutting and polishing: a) intricately carved Buddha statuette approximately 10 cm wide; b) attractive print stone cabochon set as a pendant, 3 cm wide (courtesy Barry Kayes)



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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
- Mine, print stone
- Road
- Track
- Railway
- Homestead
- Landing ground
- Ephemeral watercourse
- *WH* Waterhole
- Bore and windpump

Figure 38.15. Geology of the Mount Brockman area, showing the location of the Mount Brockman print stone mine (modified after Blight et al., 1996)

Figure 38.16. Blocks of massive, indurated, very fine-grained print stone up to 0.6 m in length, Mount Brockman print stone mine

References

Abrajevitch, A, Pillans, BJ and Roberts, AP 2014, Haematite pigmentation events and paleomagnetic recording: implications from the Pilbara print stone, Western Australia: Geophysical Journal International, November, v. 199, no. 2, p. 658–672.

Bevan, AWR 2001, Zebra rock, an ornamental stone from the East Kimberley, Western Australia: Australian Gemmologist, v. 21, p. 165–168.

Blight, DF, Thorne, AM, Blockley, JG and Tyler, IM 1996, Mount Bruce, WA Sheet SF 50-11, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series.

Hancock, PM 1969, Location and investigation of zebra rock occurrences, East Kimberley region: Geological Survey of Western Australia, Annual Report for the Year 1968, *in* Extract from the Report of the Department of Mines, 1969, p. 67–68.

Loughnan, FC and Roberts, FI 1990, Composition and origin of the 'zebra rock' from the East Kimberley region of Western Australia: Australian Journal of Earth Sciences, v. 37, p. 201–205.

Thorne, AM, Sheppard, S and Tyler, IM 1998, Lissadell, Western Australia: Sheet SE 52-2, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series.

Thorne, AM, Sheppard, S and Tyler, IM 1999, Lissadell, Western Australia: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 2nd edition, p. 50–51.

Thorne, AM and Tyler, IM 1996, Roy Hill, Western Australia, Sheet SF 50-12, 2nd edition: Geological Survey of Western Australia, 1:250 000 Geological Series.

Trendall, AF and Blockley, JG 1970, The iron formations of the Precambrian Hamersley Group Western Australia: Geological Survey of Western Australia, Bulletin 119, p. 86–89.

Appendix 1

Gemstone localities in Western Australia

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
Chapter 2 – Diamond									
	Halls Creek Orogen — Lamboo Complex	East Kimberley diamond province	n/a	Diamond – colourless, yellow, brown, pink, and red	Argyle AK1 mine	434519	8152209	52	
			n/a	Diamond	Lissadell Road prospect	426233	8147795	52	
			n/a	Diamond	Limestone Creek mine	436648	8150870	52	
			n/a	Diamond	Upper Smoke Creek mine	434429	8154380	52	
			n/a	Diamond	Lower Smoke Creek prospect	451462	8173898	52	
			n/a	Diamond	Bow River mine	458822	8161643	52	
	Kimberley Basin	East Kimberley diamond province	n/a	Diamond	Maude Creek prospect	368432	8148169	52	
			n/a	Diamond	Aries prospect	194298	8129601	52	
		North Kimberley diamond province	n/a	Diamond	Beta Creek prospect	284190	8410709	52	
			n/a	Diamond	Lower Bulgurri prospect	317438	8427782	52	
			n/a	Diamond	Ashmore prospect	315770	8425673	52	
			n/a	Diamond	Seppelt prospect	325918	8403599	52	
			n/a	Diamond	Pteropus prospect	331035	8382263	52	
	Canning Basin — Lennard Shelf and Fitzroy Trough	West Kimberley diamond province	Ellendale field	Diamond – including fancy yellow, colourless	Ellendale 9 mine	697466	8057122	51	
				Diamond — including fancy yellow, colourless	Ellendale 9 North Alluvials, Western Channel mine	696752	8057971	51	
				Diamond — including fancy yellow, colourless	Ellendale 9 North Alluvials, Eastern Channel mine	697993	8057645	51	
				Diamond — including fancy yellow, colourless	Terrace 5 Alluvials Pit 1 prospect	689755	8058119	51	
				Diamond — including fancy yellow, colourless	Terrace 5 Alluvials Pit 2 prospect	686558	8059217	51	
				Diamond – including fancy yellow, colourless	Ellendale 4 mine	704095	8045029	51	
				Diamond – including fancy yellow, colourless	Ellendale 7 mine	697221	8053499	51	
				Diamond	Ellendale 11 prospect	695400	8057420	51	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*[†]
				Diamond	Ellendale 6 prospect	698708	8048167	51	
				Diamond	Mount Wynne Creek prospect	698025	8034720	51	
				Diamond	Pit 57 prospect	681140	8064860	51	
				Diamond	Mount Percy Airstrip prospect	704568	8051871	51	
				Diamond	Laymans Bore East prospect	694535	8009256	51	
			Calwynyardah field	Diamond	Calwynyardah	687004	8008996	51	
			Noonkanbah field	Diamond	Mount Abbott prospect	669735	7967656	51	
				Diamond	Mount Noreen prospect	675735	7968856	51	
				Diamond	Walgidee Hills prospect	697730	7975775	51	
				Diamond	Big Spring prospect	754354	8035707	51	
				Diamond	Liveringa prospect	593257	8020845	51	
	Southern Carnarvon Basin	Wandagee province	n/a	Diamond	Wandagee M92b prospect	235250	7349129	50	
			n/a	Diamond	Wandagee M154 prospect	258599	7324469	50	
			n/a	Diamond	Wandagee M142 prospect	254900	7345980	50	
	Pilbara Craton	Marble Bar	n/a	Diamond	Brockman Dyke prospect	802236	7632536	50	
		Pannawonica	n/a	Diamond	Blacktop Kimberlite 1 prospect	459653	7623194	50	
	Earaheedy Basin	Mount Throssell	n/a	Diamond	Mount Throssell prospect	464963	7123032	51	
Chapter 3 – Beryl group									
Emerald	Yilgarn Craton — Murchison Domain	Poona	Poona	Emerald, aquamarine, morganite	Aga Khan Deep mine	545707	6999444	50	
				Emerald	Reward mine	543795	6998730	50	
				Emerald	Quartz Blow mine	545400	6999240	50	
		Yalgoo	Noongal (Melville)	Emerald, beryl	Emerald Show prospect	475530*	6888075*	50	
		Warda Warra	n/a	Emerald, beryl	Prospect	513458	6950022	50	
	Yilgarn Craton — Eastern Goldfields Superterrane	Riverina	Wonder Well	Emerald, beryl	Wonder Well mine	265464	6712302	51	
		Bullabulling	n/a	Emerald	Bullabulling prospect	302319	6569999	51	
		Coolgardie	n/a	Emerald	Mungari prospect	330651*	6583285*	51	
	Pilbara Craton	Tambourah	n/a	Emerald, beryl	Curlew mine	737822	7612573	50	
			Tambourah pegmatite field	Emerald	Prospect	709300^	7602500^	50	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number[†]
		Wodgina	Mount Cassiterite pegmatite field	Emerald	Prospect	671700*	7658700*	50	
			Mount Francisco pegmatite field	Beryl, emerald	Prospect	661400*	7636300*	50	
			Pilgangoora pegmatites	Emerald	Prospect	698058*	7671625*	50	
			McPhee Patch	Emerald	Prospect	700200*	7676000*	50	
		Friendly Creek	n/a	Emerald	Prospect	637800^	7650100^	50	
		Mount Hall	Mount Hall pegmatites	Emerald, beryl	Prospect	523200	7699000	50	
	Gascoyne Province	Yinnetharra	Camel Hill	Emerald, aquamarine, beryl	Camel Hill prospect	436504	7277069	50	
Aquamarine			Thirty One River	Aquamarine, heliodor, beryl	Williamsons mine	401322	7288920	50	
			Morrissey Hill	Emerald, aquamarine, beryl	Roe and Hassel mine	417200*	7284850*	50	
	Yilgarn Craton — Eastern Goldfields Superterrane	Spargoville	n/a	Beryl, aquamarine	Giles pegmatites mine	354900*	6541500*	51	
Morganite		Londonderry	n/a	Beryl, morganite	Londonderry mine	316603	6556303	51	
		Grosmont	n/a	Beryl, morganite	Grosmont prospect	314526	6562654	51	
	Northampton Inlier	Northampton	n/a	Morganite	Bowes River prospect	256640^	6858850^	50	
Heliodor	Yilgarn Craton — South West Terrane	Katterup	n/a	Heliodor	Katterup prospect	400950*	6286600*	50	
		Mullalyup	n/a	Heliodor	Oliver's pegmatite prospect	401560*	6265640*	50	
Beryl	King Leopold Orogen	Mondooma Creek	n/a	Beryl	Stewarts East prospect	651514	8130892	51	
	Yilgarn Craton — Murchison Domain	Paynes Find	Mount Edon pegmatite field	Beryl	Goodingnow northern pegmatite prospect	566507	6757653	50	
			Mount Edon pegmatite field	Beryl	Goodingnow southern pegmatite prospect	566497	6757143	50	
Chapter 4 – Tourmaline group									
	Yilgarn Craton — Eastern Goldfields Superterrane	Spargoville	n/a	Elbaite	Giles prospect	354603	6537587	51	
			n/a	Elbaite	North Moriarty prospect	354600*	6537740*	51	
			n/a	Elbaite	Dalglish prospect	350582	6538547	51	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*[†]
	Yilgarn Craton — Southern Cross Domain	Mount Holland	Mount Holland pegmatite field	Rubellite	Forrestania mine	763410	6435304	50	
		Ravensthorpe	n/a	Elbaite	Cattlin Creek mine	226042	6281794	51	
			n/a	Elbaite	Cocanarup mine	766773*	6272868*	50	
	Yilgarn Craton — Murchison Domain	Dalgaranga	n/a	Elbaite	Dalgaranga mine	521389	6934790	50	
			n/a	Elbaite	Niobe mine	526335	6935167	50	
			n/a	Elbaite	Mount Farmer South prospect	525904	6933872	50	
	Gascoyne Province	Yinnetharra	Morrissey Hill	Brown dravite	Yinnetharra dravite mine	416519	7282064	50	
			Morrissey Hill	Black dravite	Yinnetharra dravite north mine	416798	7283707	50	
			Morrissey Hill	Tourmaline	Thirty One Creek prospect	415700*	7288000*	50	
			Morrissey Hill	Elbaite	April prospect	416354	7295275	50	
			Nardoo Creek	Black dravite	Cairn mining area mine	404117	7289006	50	
			Camel Hill	Tourmaline	Camel Hill prospect	435420*	7277680*	50	
Chapter 5 – Tourmalite and warrierite									
	Yilgarn Craton — Murchison Domain	Lake Mongers tourmalite island	n/a	Tourmalite (warrierite)	Tourmalite mine	524875	6778075	50	
Chapter 6 – Feldspar group									
	Yilgarn Craton — Murchison Domain	Paynes Find	n/a	Amazonite	Paynes Find north prospect	566925	6764984	50	
		Warda Warra	n/a	Amazonite	Warda Warra prospect	513457	6950019	50	
		Mukinbudin area	n/a	Graphic granite	Calcaling mine	636704	6578725	50	
	Yilgarn Craton — Eastern Goldfields Superterrane	Coolgardie region	Londonderry pegmatite field	Graphic granite	Londonderry feldspar mine	316605	6556300	51	
	Northampton Inlier	Northampton area	n/a	Moonstone orthoclase	Bowes River prospect	250480*	6854780*	50	
	Pilbara Craton	Port Hedland area	n/a	Graphic granite	Pippingarra	684400	7724000	50	
Chapter 7 – Topaz									
	Pilbara Craton	Wodgina	Mount Francisco pegmatite field	Topaz	Mount Francisco prospect	661400*	7636300*	50	
	Gascoyne Province	Nanutarra	n/a	Topaz	Globe Hill prospect	318920*	7509540*	50	MDC 1376, 4861
	Yilgarn Craton — Murchison Domain	Poona	Poona	Topaz	Reward and Aga Khan mines	545707	6999444	50	S 1678A, B

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
		Dalgaranga	n/a	Topaz	Mount Farmer (Niobe) mine	526335	6935167	50	S 110, 1968, MDC 219, 294, 1371, 5865
		Cue	n/a	Topaz, beryl	Lakeside prospect	543637	6945868	50	MDC 3093, 3171A, 3281, 3795, 4413
		Yalgoo	Noongal	Topaz	Harrisons Reward mine	472753	6887359	50	MDC 4180
			Noongal	Topaz	Drews emerald show prospect	474319	6885277	50	S1959, 1960V, 1960X, 2180, 2181, MDC 61, 600, 1358, 2311, 4798
		Paynes Find	Mount Edon pegmatite field	Topaz	Mount Edon prospect	564431	6756458	50	
			Mount Edon pegmatite field	Topaz	Goodingnow southern pegmatite mine	566664	6757373	50	MDC 3787 (SW of Paynes Find), MDC 5918 (Paynes Find)
		Mukinbudin	n/a	Topaz	Coshs north pegmatite prospect	599700	6591526	50	MDC 1087
	Yilgarn Craton — Southern Cross Domain	Norseman	n/a	Topaz	Peak Charles prospect	328195^	6360285^	51	WAM M56
	Yilgarn Craton — Eastern Goldfields Superterrane	Grosmont	n/a	Topaz	Grosmont mine	314526	6562654	51	WAM M11, M594
		Riverina	Wonder Well	Topaz	Wonder Well mine	265464	6712302	51	S 111, 176B, 4452, MDC 419, 1544, 1781
Chapter 8 – Minor pegmatite gemstones									
	Yilgarn Craton — Murchison Domain	Yalgoo	Melville pegmatite field	Lepidolite	Carlaminda Blue mine	470146	6880590	50	
		Paynes Find	Mount Edon pegmatite field	Phenakite	Goodingnow northern pegmatite	566507	6757653	50	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*[†]
	Yilgarn Craton — Eastern Goldfields Superterrane	Coolgardie region	Londonderry pegmatite field	Lepidolite, petalite	Lepidolite Hill mine	316752	6557636	51	
				Petalite	Tantalite Hill mine	316276	6557905	51	
				Petalite	Londonderry feldspar mine	316605	6556300	51	
		Kambalda region	Mount Marion pegmatites	Spodumene	Mount Marion No. 1 pegmatite prospect	353330	6560933	51	
		Binneringie area	Binneringie pegmatites	Spodumene	Bald Hill mine, south pit	422039	6512529	51	
		Mount Deans	Mount Deans pegmatite field	Petalite	Daves pegmatite mine	385570	6423500	51	
		Riverina	Wonder Well	Phenakite	Wonder Well	265464	6712302	51	
	Yilgarn Craton — Southern Cross Domain	Ravensthorpe area	Cattlin Creek pegmatites	Spodumene	Cattlin Creek pegmatite prospect	224900	6282149	51	
	Yilgarn Craton — South West Terrane	Greenbushes	Greenbushes pegmatite field	Spodumene	Greenbushes spodumene mine	413550	6253135	50	
	Pilbara Craton	Wodgina	Wodgina greenstone belt	Lepidolite	Wodgina Main Lode mine	673737	7656644	50	
				Lepidolite	Wodgina Queen prospect	670907	7658006	50	
				Lepidolite	Stannum mine	669490	7649750	50	
		Pilgangoora	Pilgangoora	Lepidolite, spodumene	Pilgangoora trig station prospects	697142	7670859	50	
		Tabba Tabba	Tabba Tabba pegmatite field	Lepidolite, simpsonite	Tabba Tabba main tantalite mine	700082	7713472	50	
Chapter 9 – Quartz group									
	Yilgarn Craton — Eastern Goldfields Superterrane	Spargoville	n/a	Quartz	Giles prospect	354603	6537587	51	
			n/a	Quartz	South Spargoville prospect	354848	6537307	51	
		Kambalda region	n/a	Rose quartz	Depot Rocks West prospect	341188*	6549965*	51	
		Binneringie	n/a	Quartz	Binneringie prospect	420104	6513397	51	
			n/a	Citrine	Saint John pegmatites prospect	419814*	6516821*	51	
		Edjudina	n/a	Quartz	Local Lady gold mine	444632	6756844	51	
	Yilgarn Craton — Southern Cross Domain	Mount Holland	Mount Holland pegmatite field	Quartz	Forrestania mine	763410	6435304	50	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number[†]
	Yilgarn Craton — Murchison Domain	Mukinbudin	n/a	Quartz, K-feldspar	Mukinbudin mine	609432	6581594	50	
			n/a	Quartz, K-feldspar	Calcaling mine	636704	6578725	50	
		Paynes Find	Mount Edon pegmatite field	Quartz, beryl, feldspar	Goodingnow mine	566665	6757369	50	
		Bencubbin region	n/a	Smoky quartz	Beacon prospect	571345*	6642194*	50	
		Southern Cross region	n/a	Citrine	Grace Road prospect	724043*	6501422*	50	
	Yilgarn Craton — South West Terrane	Northam area	n/a	Quartz	Toodyay Road prospect	463030^	6498750^	50	
		Beverley area	n/a	Quartz	Morbinning Road prospect	503131*	6447273*	50	S 3849
	Pilbara Craton	Wodgina area	n/a	Quartz	Kangan quartz prospect	656091*	7666779*	50	211
		Nullagine area	n/a	Amethyst	Quartz Hill amethyst prospect	219657	7566551	51	
	Pilbara Craton — Hamersley Basin	Millstream area	n/a	Quartz	Gregory Gorge prospect	490720^	7616780^	50	
	Gascoyne Province	Mount Phillips area	Gascoyne amethyst field	Amethyst	Gascoyne amethyst mines	445918	7292800	50	
			n/a	Amethyst	Leake Spring mine	454983*	7291697*	50	
			n/a	Amethyst	Kunieuski prospect	458181	7289205	50	
		Yinnetharra region	n/a	Amethyst	Lucky Bore prospect	441904	7268723	50	
			n/a	Rose quartz	Injinu Hills mine	437682	7267253	50	
			n/a	Rose and smoky quartz	Gillie Well South prospect	441950*	7267175*	50	
			n/a	Amethyst, rose quartz	Chalby Chalby prospect	407551	7256110	50	
			n/a	Rose quartz	Gnungun Hill	386300^	7276500^	50	S 3739
	Ashburton Basin	Wyloo area	n/a	Amethyst	Mount De Courcy mine	434739	7479515	50	888
Chapter 10 – Opal									
	Collier Basin	Mundiwindi area	n/a	Fire opal	Mundiwindi prospect	218958*	7365776*	51	S 3831
	Gascoyne Province	Weedarrah area	n/a	Common opal	Weedarrah prospect	385280^	7238880^	50	MDC 5884
		Yinnetharra area	n/a	Common opal	Yinnetharra prospect	415800^	7273250^	50	MDC 4090
	Pilbara Craton	Nullagine	n/a	Cats eye, siliciophite	Lionel prospect	198246	7602187	51	S 1601, MDC 6154, 6155
		Yarrie Station	n/a	Fire opal	Coppins Find prospect	206280^	7704020^	51	MDC 3666
		Marble Bar	n/a	Siliciophite	Warrawoona prospect	794322*	7639771*	50	S 3826
	Southern Carnarvon Basin	Upper Gascoyne region	n/a	Moss opal	Wonong Creek prospect	291530*	7243540*	50	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
	Yilgarn Craton — Eastern Goldfields Superterrane	Ora Banda area	n/a	Common opal	Grants Patch prospect	320113*	6629868*	51	
		Ora Banda area	n/a	Green opal	Ora Banda 1a prospect	315412	6633349	51	MDC 3911
		Ora Banda area	n/a	Common opal	Ora Banda 2 prospect	311998	6637126	51	S 3891
		Binneringie area	n/a	Common opal	Binneringie prospect	408912	6504460	51	MDC 3376
		Norseman area	n/a	Common opal, moss opal	Norseman opal mine	377313*	6444207*	51	MDC 3322, 4832
		Laverton region	n/a	Fire opal	Bailey Range prospect	497079*	6855474*	51	S 1602a,b
		Laverton region	n/a	Fire opal	Adam Range prospect	460200*	6861740*	51	
		Yundamindera area	n/a	Fire opal	Bulla Rock Well opal mine	396944*	6778888*	51	
		Yundamindera area	n/a	Fire opal	French Soak prospect	394239*	6779696*	51	
		Kalgoorlie region	n/a	Fire opal	Smithfield prospect	345780^	6623220^	51	
		Ora Banda area	n/a	Moss opal	Ora Banda 1b prospect	316300*	6632900*	51	MDC 3911
		Bulong area	n/a	Moss opal	Bulong 1 prospect	391460	6604050	51	
		Bulong area	n/a	Moss opal	Bulong 2 opal mine	388480	6602060	51	MDC 1643, GSWA 10225
		Bulong area	n/a	Moss opal	Bulong 3 prospect	387230	6600220	51	
		Bulong area	n/a	Moss opal	Bulong 4 prospect	388550	6592700	51	
		Spargoville area	n/a	Moss opal	Spargoville prospect	354060^	6543840^	51	S 3884, MDC 4374
		Cowarna Downs Homestead area	n/a	Precious opal	Cowarna opal mine	449794	6568225	51	
		Coolgardie area	n/a	Precious opal	Three Mile Hill opal mine	327284	6578070	51	5660, 5660a, 5661, 5661a, 5662
	Yilgarn Craton — Murchison Domain	Cue area	n/a	Common opal	Cue prospect	588807	6969461	50	S 3810, MDC 5041
		Gabanintha area	n/a	Green opal	Copper Hills prospect	668276	7015390	50	MDC 3323
		Poona area	n/a	Green opal	Poona Soak prospect	544087	6996944	50	S 1239, 1603, 3911
		Perenjori region	n/a	Green opal	Rothsay prospect	487985	6761247	50	MDC 426

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
		Westonia	n/a	Green opal, common opal	Edna May mine	661783	6536875	50	S 1613H, 1613X, 3762 (yellow common opal)
		Yaloginda–Chunderloo area	n/a	Moss opal, common opal	Yaloginda prospect	640240*	7049340*	50	MDC 4929
	Yilgarn Craton — Narryer Terrane	Byro area	n/a	Green opal	Iniagi Well prospect	419404	7102807	50	
		Byro area	n/a	Green opal	Meegea prospect	438396*	7119026*	50	
		Byro area	n/a	Green opal, tiger eye	Bulgarro opal mine	435000	7110489	50	S 3804, MDC 2045, 2372, 2418, 6997 (green), SWA 10237
	Yilgarn Craton — Southern Cross Domain	Bullfinch area	n/a	Common opal	Manxman prospect	699154*	6577991*	50	S 1606
		Poison Hills area	n/a	Moss opal, common opal	Poison Hills prospect	700000^	7004600^	50	MDC 3323
		Bullfinch area	n/a	Siliciophite	Morlands Find mine	710112*	6554528*	50	
	Yilgarn Craton — South West Terrane	Northam	n/a	Fire opal, common opal	Mount Dick 2 prospect	468964*	6506007*	50	S 1604, 1610, 3797, 3830
		Moora area	n/a	Siliciophite	Bindi Bindi prospect	437299*	6611183*	50	
		Ucarty	n/a	Siliciophite	Bresnahan Soak prospect	508360*	6532930*	50	S 3822
		Northam	n/a	Siliciophite	Mount Dick 1 prospect	471415	6505261	50	S 1610,3885, MDC 415, 2643, 3673
		Moora area	n/a	Siliciophite	Woolawa prospect	418561*	6605088*	50	S 3808
		Northam	n/a	Siliciophite, common opal	Meenaar prospect	488856*	6497619*	50	
		Goomalling	n/a	Siliciophite, common opal	Thomas and Truscotts mine	484405	6537010	50	S 3761a,b
Chapter 11 – Chalcedony Group									
	Pilbara Craton	Balfour Downs region	n/a	Agate	Noreena Downs Station prospects	209204*	7532219*	51	
		Roy Hill region	n/a	Agate	Marillana Station — Archer mine	763204	7488744	50	
			n/a	Agate	Marillana Station — Kayes mine	769619	7481499	50	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*†
	Perth Basin	Bunbury area	n/a	Agate	Gelorup quarry (mine)	374607	6303899	50	
	Sylvania Inlier	Newman region	n/a	Chrome chalcedony	Warrawanda prospect	781301*	7373640*	50	
			n/a	Chrysoprase	Warrawanda Creek prospect	793885	7404678	50	
	Yilgarn Craton — Eastern Goldfields Superterrane	Lake Rebecca	n/a	Chrysoprase	Duck Hill mine	429800	6734700	51	
			n/a	Chrysoprase	Jump Up Dam mine	410900	6712600	51	
		Boyce Creek area	n/a	Chrysoprase	Yerilla (Boyce Creek East) mine	395874	6731995	51	
			n/a	Chrysoprase	Boyce Creek mine	394766	6735989	51	
		Yundamindra Station area	n/a	Chrysoprase	Eucalyptus mine	421765	6766936	51	
		Gindalbie area	n/a	Chrysoprase	Binti Binti mine	394274	6666874	51	
		Bulong area	n/a	Chrysoprase	Taurus prospect	388720*	6602036*	51	
		Goongarrie Hill area	n/a	Chrysoprase	Goongarrie Hill prospect	321925	6679065	51	
		Menzies area	n/a	Chrysoprase	Comet Vale mine	320720	6682880	51	
		Leonora area	n/a	Chrysoprase	Marshall Pool mine	302563	6865927	51	
		Wingellina area	n/a	Chrysoprase	Wingellina prospect No. 2	494702	7120461	52	
Chapter 12 – Fossil wood									
	Southern Carnarvon Basin	Mooka Creek	n/a	Peanut wood	Mooka Creek prospecting area	293833*	7245322*	50	4953
		Giralia Range	n/a	Fossil wood	Giralia Range prospecting area	206400*	7440700*	50	
		Merlinleigh Station area	n/a	Fossil wood	Merlinleigh Station prospecting area	316250*	7309600*	50	4390, P 97.2–7, P 97.33
		Carbla Station area	n/a	Fossil wood	Carbla Point prospect	222150*	7092060*	50	
Chapter 15 – Andalusite and chiastolite									
	Yilgarn Craton — Eastern Goldfields Superterrane	Kambalda region	n/a	Chiastolite	Spargoville prospect	357533	6545286	51	
		Ora Banda area	n/a	Andalusite, chiastolite	Credo Station prospect	283698	6624480	51	
	South West Terrane	Toodyay area	n/a	Andalusite, chiastolite	Lovers Lane prospect	439900	6503700	50	
Chapter 16 – Chrysoberyl and alexandrite									
	Gascoyne Province	Yinnetharra	Thirty One River	Chrysoberyl	Williamsons mine	401322	7288920	50	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number[†]
	Yilgarn Craton — South West Terrane	Manjimup	Smithfield	Chrysoberyl	Donovans Find mine	408288	6231457	50	
		Dowerin	n/a	Chrysoberyl, alexandrite	Dowerin chrysoberyl prospect	504313	6547815	50	
	Yilgarn Craton — Murchison Domain	Poona	Poona emerald field	Alexandrite	Aga Khan mine	545707	6999444	50	
Chapter 17 – Cordierite									
	Halls Creek Orogen – Lamboo Province	Halls Creek region	n/a	Cordierite	Springvale prospect	354312*	8034821*	52	
Chapter 18 – Corundum									
	Gascoyne Province	Gascoyne Junction region	n/a	Sapphire	Williambury Station prospect	297710*	7359854*	50	
	Pilbara Craton	Wodgina area	n/a	Corundum	Pincunyah prospect	685115^	7652830^	50	
	Yilgarn Craton — Narryer Terrane	Mardagee Station area	n/a	Corundum	Thoolmugga Well prospect	436068	7105632	50	
	Yilgarn Craton — South West Terrane	Quairading area	n/a	Corundum	Jacobs Well prospect	520571*	6457084*	50	
	Yilgarn Craton — Murchison Domain	Cue region	Poona emerald field	Sapphire, ruby	Aga Khan mine	545707	6999444	50	
Chapter 19 – Copper gemstones									
	Yilgarn Craton — Eastern Goldfields Superterrane	Lake Yindarlgooda	n/a	Turquoise	Copper–zinc prospect	398050*	6612300*	51	
	Bryah Basin	Peak Hill region	n/a	Chrysocolla, malachite	Degrussa copper–gold mine	733933	7173137	50	
	Collier Basin	Yanneri Pool area	n/a	Secondary copper minerals	Butcher Bird copper mine	775719	7297250	50	
	Yerrida Basin	Neds Creek Homestead area	n/a	Azurite, secondary copper minerals	Thadunna copper prospect	772417	7176640	50	
Chapter 20 – Diopside									
	Gascoyne Province	Yinnetharra	Thirty One River	Diopside	Vaughan prospect	401797	7288427	50	
Chapter 21 – Fluorite									
	Pilbara Craton	Split Rock area	n/a	Fluorite	Boddingtons mine	769115	7615480	50	
		Nullagine region	n/a	Fluorite	Cookes Creek prospect	237935	7602781	51	
			n/a	Fluorite	Meentheena mine	237844	7649256	51	
			n/a	Fluorite	Ngarrin Creek prospect	231400	7690600	51	
			n/a	Fluorite	Eastern Creek prospect	272550*	7589230*	51	
	Kimberley Basin	Dunham River area	n/a	Fluorite	Speewah prospect	391041	8186396	52	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
	Halls Creek Orogen	Warmun area	n/a	Fluorite	Turkey Creek prospect	409680*	8127760*	52	
	Ashburton Basin	Nanutarra area	n/a	Fluorite	Globe Hill prospect	316700*	7497800*	50	
	Musgrave Province	Wingellina region	n/a	Fluorite	Mount Elvire prospect	311640*	7114220*	52	
	Gascoyne Province	Yinnetharra area	n/a	Fluorite	South Nardoo prospect	414700*	7289030*	50	
	Yilgarn Craton — Murchison Terrane	Cue region	Poona emerald field	Fluorite	Poona mine	545707	6999444	50	
		Warriedar area	n/a	Fluorite	Mulgine Hill prospect	497751	6772000	50	
Chapter 22 – Garnet group									
	Yilgarn Craton — South West Terrane	Preston area	n/a	Garnet	Glen Mervyn prospect	413800^	6290500	50	
	Gascoyne Province	Yinnetharra area	n/a	Garnet	White Well prospect	406500*	7293000*	50	
Chapter 23 – Gaspeite									
	Yilgarn Craton — Eastern Goldfields Superterrane	Widgiemooltha	n/a	Gaspeite	Mount Edwards 132N mine	361217	6518735	51	
		Kambalda	n/a	Gaspeite	Otter Juan mine	371512	6551152	51	
		Widgiemooltha area	n/a	Gaspeite	Redross mine	371940	6493881	51	
		Broad Arrow region	n/a	Gaspeite	Carr Boyd Rocks mine	367572	6673117	51	
		Leinster	n/a	Gaspeite	Perseverance mine	273997	6920833	51	
	Pilbara Craton	Nullagine area	n/a	Gaspeite	Ottways prospect	197850	7602100	51	
Chapter 24 – Iron-rich gemstones									
	Pilbara Craton	Ord Ranges	n/a	Tiger iron	Ord Ranges mine	724651	7754851	50	
	Hamersley Basin	Mount Newman	n/a	Hematite	Mount Newman mine	773500*	7413489*	50	
		Tom Price	n/a	Hematite	Tom Price mine	579188*	7482158*	50	
		Paraburdoo	n/a	Hematite	Paraburdoo mine	561526*	7430326*	50	
		Mount Brockman	n/a	Tiger eye jasper	Brockman prospect	544356	7531082	50	
		Mount Margaret	n/a	Tiger eye	Miller Gorge prospect	586531*	7571472*	50	
		Mount Margaret	n/a	Tiger eye	Asbestos Gorge prospect	582043*	7568064*	50	
	Yilgarn Craton — Southern Cross Terrane	Koolyanobbing	n/a	Hematite, specularite, pyrite	Koolyanobbing mine	740985*	6590177*	50	
	Yilgarn Craton — Murchison Terrane	Mount Gibson	n/a	Hematite	Mount Gibson mine	515603*	6728200*	50	
		Mullewa area	n/a	Turgite	Tallering Peak mine	364500	6889299	50	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*†
	Canning Basin	Lennard Shelf	n/a	Marcasite	Goongawa mine	801564	7937802	51	
Chapter 25 – Prehnite									
	Ord Basin	Flora Valley Station	n/a	Prehnite	Flora Valley prospect	438888	7997041	52	
			n/a	Prehnite	Mound prospect	438940	7996567	52	
			n/a	Prehnite	New Deposit prospect	437482	7995567	52	
	Yilgarn Craton — Eastern Goldfields Superterrane	Coolgardie region	Londonderry pegmatite field	Prehnite	Londonderry feldspar mine	316605	6556300	51	
	Edmund Basin	Paraburdoo region	n/a	Prehnite	Mount Vernon prospect	604967^	7329237^	50	
Chapter 26 – Rhodonite									
	Pilbara Craton	Roebourne area	n/a	Rhodonite	Five Mile Well prospect	520000^	7708500^	50	
	Albany–Fraser Orogen	Hopetoun area	n/a	Rhodonite	Hamersley Gorge prospect	768089*	6244191*	50	
Chapter 27 – Variscite									
	Bryah Basin	Robinson Ranges	n/a	Variscite	Dimble Creek 1 prospect	621280	7169140	50	
			n/a	Variscite	Dimble Creek 2 prospect	617500	7169400	50	
	Edmund Basin	Milgun Station	n/a	Variscite	Mount Deverell mine	621435	7235468	50	
			n/a	Variscite	Mount Deverell East mine	626333	7238199	50	
		Sawback Range	n/a	Variscite	Sawback Range prospect	587420	7222600	50	
		Woodlands Station	n/a	Variscite	Waldburg prospect	566746	7272404	50	
	Yilgarn Craton — Murchison Domain	Weelhamby Lake	n/a	Variscite	Ninghanboun Hill prospect	444469	6768983	50	
Chapter 28 – Carbonate group									
	Yilgarn Craton — Eastern Goldfields Superterrane	Lake Rebecca	n/a	Nickeliferous magnesite	Duck Hill prospect	429800	6734700	51	
			n/a	Nickeliferous magnesite	Jump Up Dam prospect	410900	6712600	51	
		Yerilla area	n/a	Nickeliferous magnesite	Yerilla mine	395874	6731995	51	
		Bulong–Mulgabbie region	n/a	Nickeliferous magnesite	Bulong prospecting area	388459*	6597669*	51	
		Goongarrie Hill area	n/a	Nickeliferous magnesite	Goongarrie prospecting area	321500*	6677700*	51	
		Leonora area	n/a	Nickeliferous magnesite	Marshall Pool mine	302563	6865927	51	
	Paterson Orogen — Musgrave Province	Wingellina area	n/a	Nickeliferous magnesite	Wingellina prospect No.2	494702	7120461	52	
	Yilgarn Craton — Murchison Domain	Lake Austin	n/a	Onyx marble	Lake Austin prospecting area	586515*	6944132*	50	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*[†]
	Bryah Basin	Peak Hill region	n/a	Aragonite	DeGrussa copper–gold mine	733933	7173137	50	
	Ashburton Basin	Pannawonica area	n/a	Marble	White Gate Well prospect	403600*	7599500*	50	
		Cheela	n/a	Marble	Cheela mine	476089	7467180	50	
		Wyloo	n/a	Marble	Wyloo mine	434293	7479022	50	
		Paraburdoo region	n/a	Marble	Success prospect	509000*	7449900*	50	
	Edmund Basin	Nanutarra area	n/a	Marble	Ten Mile Well prospect	358083	7512670	50	
			n/a	Marble	Parry Range quarry	350335	7531397	50	
			n/a	Marble	Bluff Well prospect	365000*	7506700*	50	
			n/a	Marble	Nanutarra quarries	369303	7488285	50	
			n/a	Marble	Motin bore prospect	373481	7489291	50	
			n/a	Marble	Hooley Camp Hill prospect	362000*	7474000*	50	
			n/a	Marble	Glen Florrie black prospect	364400*	7464600*	50	
			n/a	Marble	Minnie Springs White prospect	359500*	7455500*	50	
			n/a	Marble	White Rocks prospect	367538	7463612	50	
			n/a	Marble	Minnie Springs Pink prospect	365200*	7445600*	50	
		Maroonah area	n/a	Marble	Bellotti prospect	368742	7406894	50	
			n/a	Marble	Pindanni prospect	367605	7405846	50	
			n/a	Marble	Sheela Bore North prospect	375309	7399168	50	
			n/a	Marble	Yarrie Pool prospect	375900*	7407700*	50	
			n/a	Marble	Pilbara Green quarry	377262	7397522	50	
			n/a	Marble	Chain Pool Prospect	373517	7414373	50	
			n/a	Marble	Maroonah Green prospect	383466	7398826	50	
		Paraburdoo region	n/a	Marble	Pingandy Grey prospect	587300*	7342200*	50	
	Gascoyne Province	Gascoyne Junction region	n/a	Marble	Weedarrah marble quarry	390376	7229440	50	
Chapter 29 – Chinese writing stone									
	Pilbara Craton	Whim Creek	n/a	Chinese writing stone	Langwell Gorge prospect	571600*	7655600*	50	
Chapter 30 – Epidote group									
	Albany–Fraser Orogen	Denmark area	n/a	Unakite	Lowlands Beach prospect	545743	6119894	50	
		Cheyne Bay	n/a	Unakite	Cape Riche prospect	663167*	6168879*	50	
	Pilbara Craton	Marble Bar region	n/a	Unakite	Corunna Downs	801700*	7612450*	50	
		Roebourne	n/a	Thulite	Roebourne prospect	515090^	7703095^	50	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
	Yilgarn Craton — Murchison Domain	Mindoolah area	n/a	Clinozoisite (thulite)	Marshmallow rock prospect	543334	7023786	50	
		Lake Weelhamby	n/a	Thulite	Ninghanboun Hill prospect	443289*	6770454*	50	
Chapter 31 – Grunerite — desert gold									
	Pilbara Craton	Abydos area	n/a	Grunerite	Desert Gold prospect	703464	7638587	50	
Chapter 32 – Jade									
	Yilgarn Craton — Murchison Domain	Yeoh Hills	n/a	Black jade	Ninghan black jade mine	526462	6765027	50	
			n/a	Black jade	Yeoh Hills mine	526227	6766897	50	
			n/a	Black jade	Yeoh Hills South prospect	527795	6765163	50	
	Pilbara Craton	Marble Bar area	n/a	Pilbara jade	Pilbara jade prospect	201202*	7601570*	51	
Chapter 33 – Mookaite and other decorative porcellanites									
	Southern Carnarvon Basin	Mooka Creek	n/a	Mookaite, brecciated mookaite	Archer M09/86 mine	293405	7245342	50	
			n/a	Mookaite	Butler M09/18 mine	293795	7245491	50	
			n/a	Mookaite, brecciated porcellanite	Kapitany/Pas M09/109 mine	293463	7245603	50	
			n/a	Pink opal	Binthalya prospect	292720*	7244450*	50	
Chapter 34 – Orbicular granite									
	Yilgarn Craton — Murchison Domain	Mount Magnet area	n/a	Orbicular granite	Boogardie mine and prospect	547729	6895980	50	
Chapter 35 – Siliceous decorative stones									
	Yilgarn Craton — South West Terrane	Toodyay area	n/a	Fuchsite	Salt Valley Road quarry	446542	6500089	50	
	Pilbara Craton	Karratha area	n/a	Chrome-rich chert	Mount Regal mine	475386	7698008	50	
		Cookes Creek area	n/a	Fuchsite	Cookes Creek prospect	235563	7600881	51	
		De Grey River region	n/a	Chrome-rich chert	Ord Ranges prospect	726021*	7753419*	50	
		Pear Creek area	n/a	Chrome-rich chert	Pear Creek jade prospect	769308	7691957	50	
		Abydos area	n/a	Chrome-rich chert	Dragon stone prospect	705478	7643724	50	
		Marble Bar area	n/a	Jasper	Marble Bar prospect	781566	7654956	50	
		Paraburdoo region	n/a	Jasper	Snakeskin jasper mine	639845	7408014	50	
	Hamersley Basin	Noreena Downs area	n/a	'Jasper'††	Noreena jasper mine	202029	7511431	51	
		Eastern Creek area	n/a	'Jasper'††	Black jasper conglomerate prospect	253929	7599501	51	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
	Yilgarn Craton — Murchison Domain	Cue region	n/a	Jasper	Reedy area mine	627800^	7007400^	50	
		Fields Find area	n/a	Jasper	Desert Sunset prospect	524857	6787660	50	
			n/a	'Jasper'††	Outback jasper prospect	524575	6787527	50	
		Nannine townsite area	n/a	'Jasper'††	Tire track jasper prospect	633864*	7025489*	50	
Chapter 36 – Serpentine and talc									
	Pilbara Craton	Marble Bar area	n/a	Serpentine	Pilbara jade mine	201202*	7601570*	51	
		Tambourah region	n/a	Serpentine	Soanesville 1 prospect	727039*	7617606*	50	
			n/a	Serpentine	Soanesville 2 prospect	726989*	7618456*	50	
		Whim Creek region	n/a	Serpentine	Mount Satirist South prospect	614900*	7657900*	50	
			n/a	Serpentine	Nunyerry mine	593824	7616185	50	
		Dampier region	n/a	Serpentine	Mount Princep prospect	478977	7693879	50	
	Yilgarn Craton — Narryer Terrane	Mount Gould area	n/a	Talc	Mount Taylor 1 prospect	536960	7132610	50	
			n/a	Talc	Mount Gould prospect	534559	7147025	50	
	Yilgarn Craton — Eastern Goldfields Superterrane	Mount Monger area	n/a	Talc	Loganberry prospect	397134*	6567432*	51	
	Yilgarn Craton — South West Terrane	Bridgetown area	n/a	Talc	Glenlynn prospect	422376*	6234778*	50	
		Balingup area	n/a	Talc	Meaneys Bridge prospect	414234	6264920	50	
		Bolgart area	n/a	Talc	Culham prospect	449372	6531537	50	
		Moora area	n/a	Talc	Moora prospect	416574*	6606059*	50	
	Capricorn Orogen — Padbury Basin	Mount Seabrook area	n/a	Talc	Mount Seabrook mine	572750	7168249	50	
			n/a	Talc	Livingstone prospect	566145	7170770	50	
			n/a	Talc	Trilbar prospect	573697	7169696	50	
			n/a	Talc	Southern Cross Well prospect	562524	7171665	50	
	Pinjarra Orogen	Three Springs area	n/a	Talc	Three Springs talc mine	389593	6735557	50	
		Carnamah area	n/a	Talc	Niven prospect	389802	6721037	50	
		Coorow area	n/a	Talc	Battersby prospect	405296	6689187	50	
		Watheroo area	n/a	Talc	Fowler prospect	412450*	6670720*	50	
			n/a	Talc	Bean prospect	410981*	6670760*	50	
	Albany–Fraser Orogen	Kundip area	n/a	Talc	Kundip prospect	229010	6262717	51	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
Chapter 38 – Other decorative stones from the Kununurra and Pilbara regions									
	Duerdin Group	Snappy Gum Ridge	n/a	Zebra rock	Zebra rock 1 mine	469339	8191161	52	
		Remote Island	n/a	Zebra rock	Zebra rock 2 mine	474038	8197463	52	
		Kununurra area	n/a	Zebra rock	Kununurra Zebra rock mine	496487	8223319	52	
		Hagan Island	n/a	Zebra rock	Prospect	480660*	8207930*	52	
		Spider Point	n/a	Zebra rock	Prospect	485250*	8213170*	52	
	Pilbara Craton — Hamersley Basin	Pilbara region	n/a	Munjina Stone	Mine	683901	7553924	50	
			n/a	Print Stone	Mine	537539	7535823	50	

* position approximate
^ position doubtful
† Western Australian Museum number
n/a not applicable
†† 'Jasper' is a misnomer for stones that are not true jasper or jaspilite, and is a term specific to Western Australia.

Index 1

Gems, decorative stones, and important minerals

Page numbers in bold represent maps.

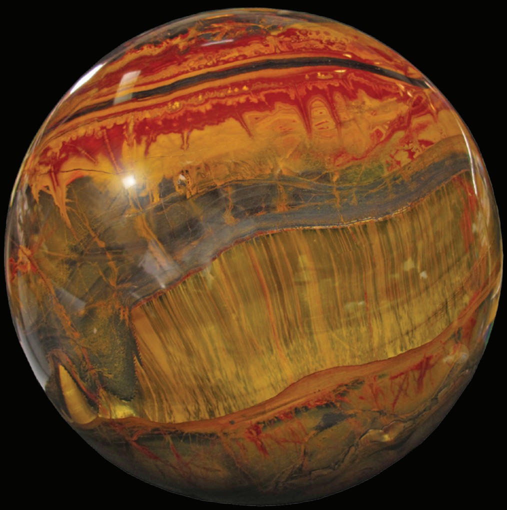
Index 2

Mines, mineral deposits, and prospects

Page numbers in bold represent maps.

The second edition of Gemstones of Western Australia is an updated version published in response to public demand following depletion of copies of the 2013 edition. These editions form the first systematic works on the subject of gemstones found in the State since the formal inception of the Geological Survey of Western Australia (GSWA) in 1896. In this second joint publication by GSWA and the Gemmological Association of Australia (GAA), the authors have once again assembled a comprehensive resource on almost all gemstones and decorative stones used in jewellery and ornamental sculpture known in the State. The second edition has been updated and expanded to include additional occurrences of emerald, opal, agate, chalcedony, organic gems, tiger eye jasper, aragonite, cordierite, black jade, mookaite, fuchsite, jasper, and Munjina and Print stones, together with numerous, new gemstone images. Geographical locations are indicated where possible, and abundant references to earlier work given.

While systematically sound and scientifically authoritative, the second edition of Gemstones of Western Australia is written not only for the professional geologist and gemmologist, but also with the experienced fossicker and amateur rockhound in mind.



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