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Mineral Resources Bulletin 25

GEMSTONES OF WESTERN AUSTRALIA

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

FRONTISPIECE

Euhedral black dravite tourmaline crystals from Yinnetharra. Set in a black phlogopite schist, these crystals, many doubly terminated, average 14 cm in length x 4 cm in diameter (courtesy Mark Creasy and David Vaughan)

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

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Cover photograph: Gem-quality, fancy yellow, rough, sawable diamonds (average 2 ct) from Ellendale diamond mine (courtesy Kimberley Diamond Company)

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Gemstones of Western Australia

by

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 sculptural purposes. This Bulletin systematically organizes and discusses the history and quality of virtually all known occurrences of these, together with chapters on precious metals and pearls. An extensive appendix lists precise geographical sites, where possible, for all material mentioned, and references to earlier work and discoveries are numerous.

Additional information addresses the science of gemmology, current lapidary technology, 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)*, 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, and the richly illustrated text caters not only for geologists and professional gemmologists, but also for experienced fossickers and amateur rockhounds.

KEYWORDS: Western Australia, gemstones, decorative stones, ornamental stones, mineral exploration, natural resources, history, mining legislation, chemical analysis, crystals, cabochon, lapidary, gem faceting

Chapter 1 Introduction

Object and scope

Mineral Resources Bulletin 25, Gemstones of Western Australia, is a collaborative production by the Geological Survey of Western Australia (GSWA) and the Gemmological Association of Australia (Western Australian Division). The book provides a much-expanded update of a series of booklets entitled Gemstones in Western Australia produced by GSWA between 1975 and 1994.

Minerals, rocks and organic materials, classified as gemstones or ornamental stones, constitute an arbitrary and open-ended group, and consequently the descriptions of gem minerals included in this publication have been guided largely by demand from fossickers, prospectors and mineral collectors. All of these materials have one or more interesting characteristics such as attractive colours or unusual textures. The skill of the gem or lapidary cutter is required to cut, polish and facet a gemstone, mineral or rock as specified in order to produce a polished gem or objet d'art worthy of mounting or display as an item of jewellery or 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 comprehensive.

Since the publication of the last gemstone booklet in 1994, there has been significant development in the production of diamonds in Western Australia, with the Argyle mine becoming a major world diamond source producing valuable, rare fancy pink and other coloured diamonds. Marketing through the unique annual Pink Tender has ensured Argyle's reputation as an important world gemstone producer. Also, in 2002, Ellendale, the State's second diamond mine came on stream. Ellendale specializes in the production of rare, fancy yellow diamonds that are also sold for premium prices on international diamond markets.

Throughout the 20th century, Western Australia has had a small production of pegmatite gemstones such as tourmaline, emerald, aquamarine, topaz, petalite, and phenakite (a beryllium silicate mineral), whereas other important gem minerals such as ruby, sapphire, opal, and chrysoberyl had limited or no resources available. The State also has an abundance of previously termed 'semiprecious gemstones', particularly those composed of silica in both crystalline and amorphous forms. These include amethyst, quartz crystal, common opal, petrified wood, jasper, and many others.

Western Australia has an established reputation as a producer of many varied ornamental stones (gemrocks); some of which are described in GSWA mineral resources bulletins covering dimension stone in the State (Fetherston, 2007, 2010). Dimension stones are used in the building and ornamental stone industries and may also be used as gem rocks. 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 Archean to Cenozoic. In addition, native gold and silver and other rare materials such as tektites have been included as gem materials as all find favour mounted in jewellery.

This Bulletin also includes a discussion on organic gems; a category that encompasses the production of cultured pearls (periculture). This industry followed on from the pearling and shell trade established in Broome around 1875–80. Periculture was first trialled, albeit unsuccessfully, in Roebuck Bay at Broome in the 1890s but it was not until 1956 that this important industry became commercially viable with the establishment of the Kuri Bay pearl farm off the West Kimberley coast (Brown, 2005).

Sources of information

Sources of information used in this Bulletin are from both published and unpublished information, supplemented by data gathered from limited field inspections. The Bulletin is essentially an updated and enlarged version of the booklet entitled Gemstones in Western Australia produced between 1975 and 1994 (GSWA, 1994). As such it contains almost all the relevant information from this booklet as well as additional material from many other sources listed below.

Published information is also derived from GSWA 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 is supplemented by unpublished

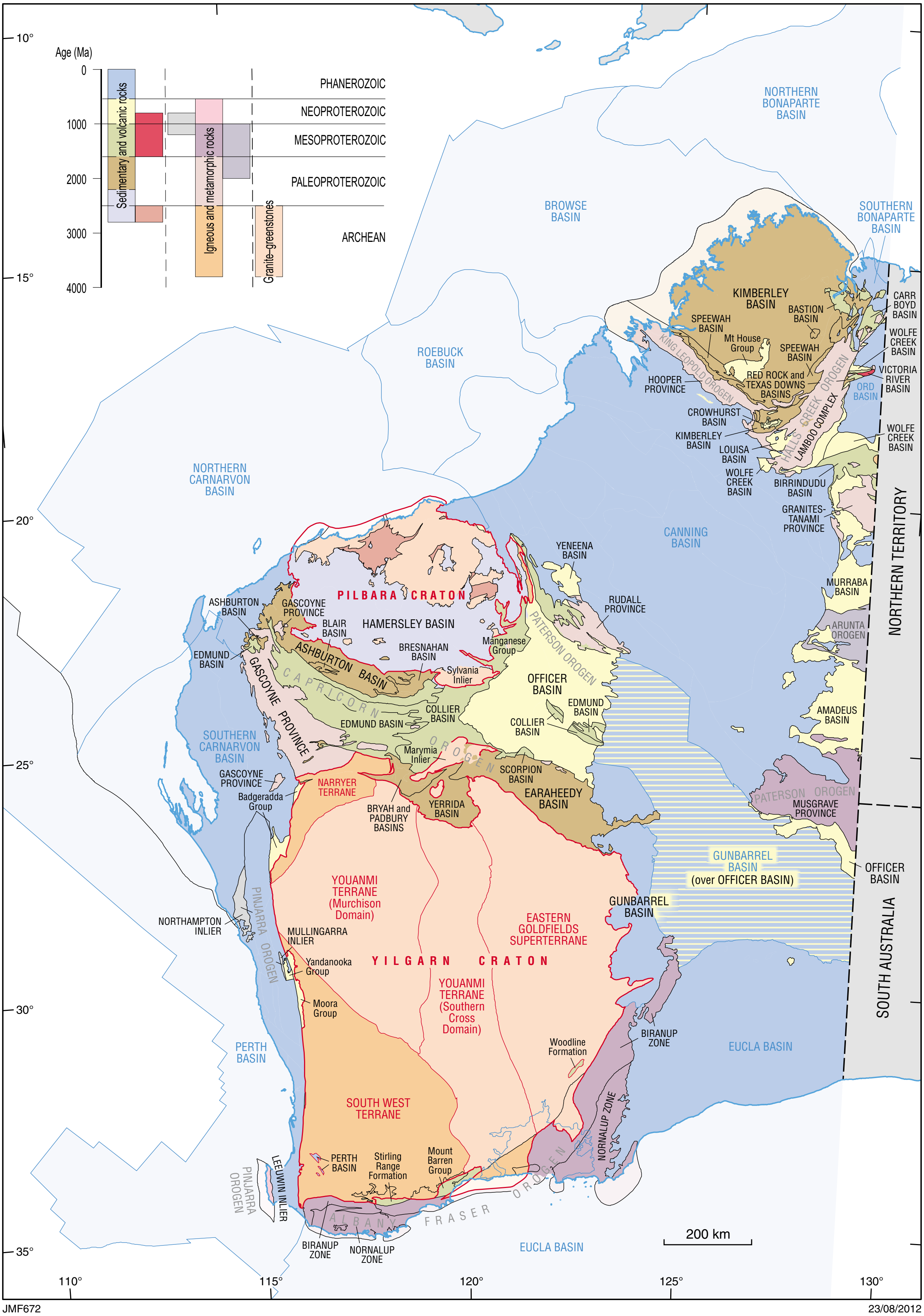

Figure 1.1 Main tectonic units of Western Australia (modified after Tyler and Hocking, 2001)

data made available by gemstone and ornamental rock producers, amateur prospectors, and fossickers.

In this publication, all 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 this would appear as (Mundiwindi, 2950), and precedes every mineral location 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.

Abbreviations

Al	aluminium
Be	beryllium
B	boron
Ca	calcium
Co	cobalt
Cr	chromium
Cs	cesium
Cu	copper
ct	carat: a unit of weight for gemstones and a measure of the purity of gold
ct/t	carats per tonne
ct/ht	carats per hundred tonnes
Fe	iron
g	gram
g/t	grams per tonne
GSWA	Geological Survey of Western Australia
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 division collection
Mg	magnesium
mm	millimetres
Mn	manganese
oz	ounces (troy weight)
Moz	million ounces (troy weight)
nm	nanometre
Mt	million tonnes
N	nitrogen
Na	sodium
Ni	nickel
ppm	parts per million
t	tonnes
S	Western Australian Museum specimen prefix
SEM	Scanning electron microscopy
UV	ultraviolet light
V	vanadium
XRD	X-ray diffraction

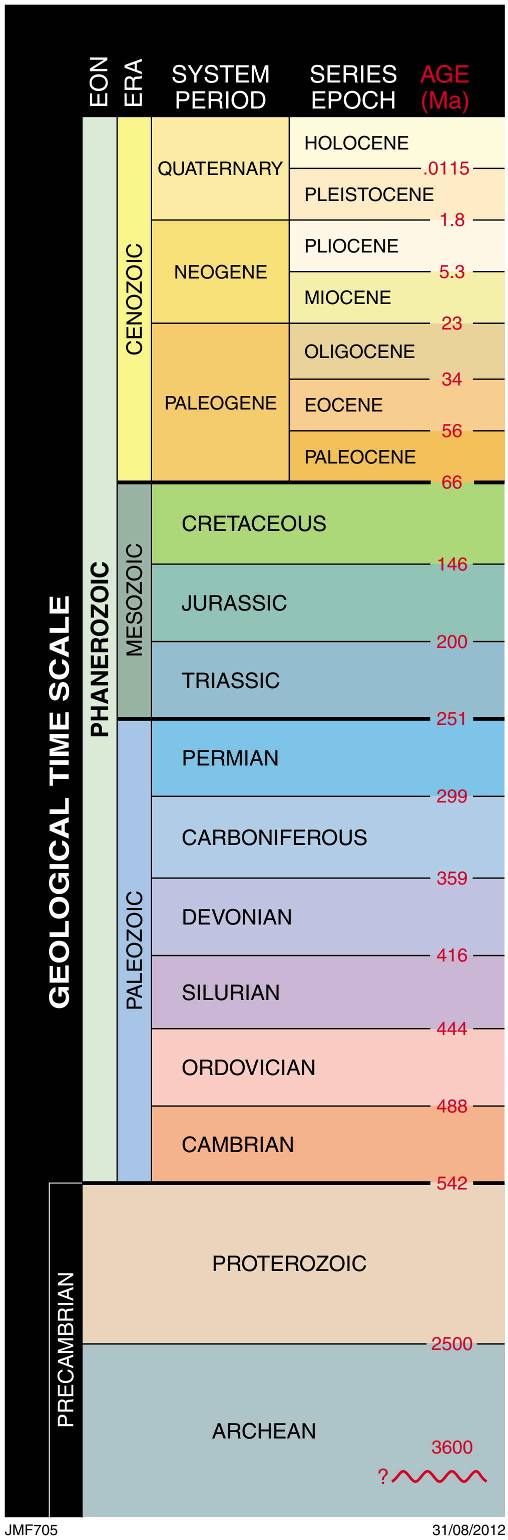

Figure 1.2 Simplified geological time scale

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Chapter 2 Aspects of the gemstone industry

Gemmology and lapidary technology

Gemmology is the science of the identification of gems and gem rocks and gemmologists are those who have undertaken a course of study to acquire the necessary skills in this science. Educational courses in gemmology are given by the Gemmological Association of Australia (GAA) (<http://www.gem.org.au>). The association has a local branch in Perth, Western Australia.

Qualified gemmologists are able to identify the majority of gem minerals by applying their knowledge and results from specialized test instruments, including portable bench top refractometers, polariscopes, dichroscopes, and spectroscopes. Gemmologists, as specialized mineralogists, also have recourse to sophisticated laboratory equipment such as energy dispersive X-ray fluorescence spectroscopy (EDXRF) and the scanning electron microscope (SEM) for the determination of rare and unusual gems and gem materials. As in all natural sciences, applied knowledge and experience with the worldwide occurrence of gems greatly assists identification work. Contemporary jewellery often features unusual gemstones and identification work for a gemmologist can be challenging, especially in the application of various treatments used to enhance the appearance of the gems.

Lapidaries and gem cutters (faceters) are skilled artisans who cut and polish gems. Lapidaries cut and polish sculptural works or produce domed-headed cabochons of standard or free-form designs. Gem cutters, working with specialized equipment and usually transparent minerals, produce a series of facets (plane faces) over the surface of a gem. Facets are usually produced to standard designs, such as circular brilliant cuts, although mixed cuts of any pattern may be applied as a matter of innovation or to improve the optical effects of the gem. Skills required for cutting and polishing may be acquired through training at lapidary clubs and faceting guilds, of which there are many in Western Australia.

Prior to the innovation of machinery to process gemstones, tumbled pebbles and crystals appear to have been used as gemstones in their natural state, but over time gemstone fashioning has progressed with the increasing sophistication of equipment used and the quality of abrasive powders. Cabochon and bead manufacture were the earliest forms of gemstone fashioning. Today, two main types of gemstone fashioning dominate the industry:

- production of gems with convex surfaces, such as cabochons and beads
- gems that are faceted, with surfaces cut by many bevels or facets.

Cabochon manufacture

Cabochons (from French caboche = head) are a rounded style of stone cutting, often circular or elliptical in outline, having a domed head (convex) and generally a flat base. There are many variations of which complex biconvex (often used to retain greater weight), concave, and convex combinations are also fashioned. Gems that are deep coloured are sometimes cut as hollow cabochons to allow more light to pass through the gem.

Cabochons may be used for any gem material but are more commonly applied to less transparent materials, opaque materials or gems with special phenomena such as play-of-colour in precious opal or chatoyancy ('cats eye' effect) in materials such as tiger eye.

Origin of the faceting technique

Although faceting is considered a more recent form of gemstone fashioning, bevels or facets are found on beads from early history, such as on the Neolithic variscite beads from Spain (4500–4000 BC).

Generally, the history of faceting is considered to date from the 14th century and it appears likely that natural crystals with their planar faces provided the inspiration. Natural crystals of diamond were mounted in jewellery prior to faceting since diamond has an unsurpassed adamantine (brilliant) lustre. Because of its supreme hardness, diamond can only be faceted and polished using diamond powder and this discovery marked an important step in the history and development of its fashioning. The diamond grinding wheel (scaife) was being used in the 14th century and for diamonds that may have been ground before this time, grindstones (made of sandstone) were used.

The point cut developed from the use of natural diamond crystals and pointed stones appeared in jewellery of the Middle Ages. These stones had the appearance of the natural octahedral form but were found to have different angles indicating they had been deliberately fashioned in this style.

The table cut was probably the first true cut for a diamond and was produced by truncating one of the corners of an octahedron to produce a square table. This style of cut is found in old Indian jewellery but is also known to have been used in Europe in the 14th century. A later innovation, the rose cut, had a circular outline with a flat base and a domed (convex) crown covered with a number of facets. Two famous diamonds from India, the Koh-i-Nur (109 ct) and the Great Mogul (280 ct) are both cut in the form of rose-cuts. It has been established that the Koh-i-Nur was cut no later than 1530.

The brilliant cut is attributed to diamond cutters working at the end of the 17th century. It is the style most suitable for the diamond as it makes the best use of the octahedral crystal form and has the potential to produce the greatest brilliance and fire (dispersion) (Bruton, 1978).

All styles of faceting, cutting and fashioning that were developed for diamonds can also be used on other gems. Lapidarists and gem faceters use and fashion all types of gems, but the cutting and polishing of diamonds is a specialized industry and the work is performed only by diamond workers.

In more recent times, it has been accepted that the actual cut selected for a gem mineral is influenced by the shape of the rough crystal, and the faceting style is often a compromise between minimizing waste, the orientation of the gem to achieve the best colour, and the achievement of greater brilliance based on knowledge of the optics of the gem. The use of new technology including laser cutting and computer-aided design has catalysed the development of new types of cuts whose complexity, optical performance and waste reduction were not previously possible.

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 of this 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 these softer materials to prolong the quality of finish.

Another consideration in the choice of a high-quality gemstone is its relative rarity. In general, value relates to rarity; hence pink diamonds as fashioned gemstones may fetch more than $1 million per carat (0.2 g). By comparison, commonly available gem rocks are generally marketed by the kilogram for a price including production costs of the finished goods in the form of beads, cut stones, tumbled goods, or hand-crafted sculptural works.

Accordingly, an informal classification has developed to divide gems into precious and semiprecious groups based largely on their relative rarity. Historically, diamond, ruby, sapphire, emerald, precious opal, and alexandrite have been considered precious gems and all others referred to as semiprecious varieties. This grouping is no longer justified as each gemstone is assessed and appreciated on its individual merits, with relative rarity determining its value. Also, a gem is sometimes more highly prized in a particular country, such as the appreciation of jade in China and neighbouring countries.

Gemmological terminology

In each of the following chapters on gemstones and other ornamental materials are highlighted boxes summarizing the gemmological properties of these materials. The boxes vary with each type of gemstone, ornamental stone, and organic substance 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 described below:

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

Birefringence, also referred to as double refraction (DR), is a measure of the difference between the lowest and highest refractive index of an optically anisotropic gem mineral (a mineral having a physical property that varies with 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 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 physical differences of the materials.

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

Mineral cleavage occurs where a mineral breaks along one or more well-defined 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 in directions 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 direction.

Colour is an important guide in the identification of gem minerals and is a specific response of the eye to visible light (380–780 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 present in beryl 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. The causes of colours in each of these minerals are varied and complex but include the effects of specific trace element chemistry and structural defects of the crystalline 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 structure of these two gem materials.

Crystal system refers to the particular 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, namely: isometric, 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 when describing columnar-shaped crystals of beryl or tourmaline.

Hardness is stated as a figure or range of figures according to the Mohs scale of hardness. The figures denote an order of hardness or resistance to scratching and have no quantitative significance. Each material in the hardness scale has been allocated a hardness figure that proves 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 ten minerals in order of their comparative hardness: from softest (1) to hardest (10):

1. talc
2. gypsum
3. calcite
4. fluorite
5. apatite
6. 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 a 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 is itself dependent on the hardness of the material. Generally, 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 as well as high RI and an adamantine lustre. This lustre type is also displayed by other gems with high RI such as zircon and demantoid garnet. Many 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 an instrument termed a dichroscope that 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 system cannot display pleochroism. Emerald and coloured tourmaline are examples of gem minerals that show strong dichroism. Andalusite is an example of a trichroic gem mineral showing three changes of colour from green, to colourless and pink. Pleochroism (both dichroism and trichroism) can be demonstrated only in coloured gems.

Refractive index (**RI**) is shown as a figure or range of figures and is the expression of the optical density or refracting power of a mineral. For the majority of minerals, refractive indices range from 1.35 to 2.42. The figure is a ratio representing the velocity of light incident to 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. Refractive index is measured using a refractometer and standard models can detect a range of Refractive index 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. Refractive index values are probably the most important information used in gem mineral identification.

Specific gravity (**SG**) is the relative density (RD) of a material being the mass (M) or weight of a substance compared with the weight of an equal volume of pure water at 4°C. Specific gravity is a ratio and is not qualified by units. It can be determined by different methods, although gemmologists usually use a specialized balance with dual pans that permit weighing of the material in air and when fully immersed in water. Calculation of specific gravity is derived using the formula:

Weight in air/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 when thin portions are viewed.

Ultraviolet light (**UV**) **and fluorescence**. Ultraviolet light responses to gemstones are uncommon but 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 usually categorized as short or long wave, based on the wavelength range produced by specific filters or mercury discharge lamps. Long wave UV has a range 315–400 nm, and short-wave UV 200–280 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 man-made gem materials such as cubic zirconia and glass (paste). Ultraviolet light will often cause surface crusts of opaline silica to fluoresce white or green and calcite will commonly fluoresce with pink. Reference tables in gemmology books provide information on UV responses and their causes.

Reference

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Chapter 3 Historical aspects of gemstones and jewellery

Early appreciation and significance

Archeological finds confirm a long association between Paleolithic man and the deliberate collecting of natural objects. There are many examples that show that some rocks, minerals, and organic materials (including shells, amber, and jet) were collected and were significant in some way to peoples of prehistory. Some of these materials have been found deliberately pierced and some rounded as beads that may have been threaded and worn decoratively. Such early finds mark the beginnings of the history of jewellery, and the recognition and appreciation of these special materials by early man is regarded as a key development in early civilization.

Collections of special materials exist from a number of geographically different locales. An early example, dating back 75 000–100 000 years ago, is from a cave site in Blombos, South Africa, where shells of a small mollusc (*Nassarius kraussianus*) were noted to have deliberate perforations and showed signs of wear where they had been originally threaded. Whilst it cannot be presumed that these were threaded and worn as jewellery, the shells were specially collected and used for some social purpose (Hirst, 2010). From a discovery at a cave site located in the French Pyrenees at Mas d'Azil, crudely fashioned necklaces and bracelets of bone, teeth, mother-of-pearl, shells and stone have been attributed to a particular culture of this region dated 17 800–6500 BC (Hirst, 2012).

Jet (lustrous, black fossil wood), amber (fossilized resins) and bone were all gem materials associated with early human cultures in the Mesolithic period (12 000–4500 BC) and many examples are displayed in museum collections in centres in Europe proximal to the original finds. In Denmark, a carved amber pendant survives from this period, as well as some small animal figural carvings dating from about 7000 BC. In Germany, the oldest finds of jet artefacts have been dated 15 000–10 000 BC.

Tomb paintings from Ancient Egypt dating back 5000 years depict craftsmen smelting ores, weighing gem materials, and fashioning gems. It is probable that the techniques of extracting and working gold and its alloys were primarily Egyptian discoveries. As well as gold, gems found in Pharaonic jewellery were commonly selected for their rich colours and included carnelian, coloured jaspers, turquoise, lapis lazuli, garnets, green feldspar (amazonite), amethyst, rock crystal, obsidian, banded chalcedonies, and calcite. Many of these gems were sourced from within Egypt and the neighbouring Sinai areas. The exception is lapis lazuli, where the closest known source is Badakhshan in Afghanistan and its use in ancient jewellery indicates the antiquity of trading routes. In China, jade carving was already established 4500 years ago.

Variscite, a green ornamental rock was selectively mined from excavations discovered in Spain that date to the Neolithic era (c. 4500–4000 BC). The mined variscite and its host rock were fashioned into beads and traded through parts of northern Europe. Also, agate was mined by the Romans near Idar–Oberstein in Germany and they developed specialized skills in their carving of this gem.

New discoveries of gems were made throughout history; diamonds were traded from India from at least the fourth century BC and since these times rubies, spinels and sapphires, sourced from gem gravels originating in India, Sri Lanka and Burma (Myanmar), were introduced into Europe.

Throughout history various cultural groups of people have created their own recognizable and specialized jewellery utilizing 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 evolved to make use of them.

Jewellery was not only created for esthetic reasons but early in history gems were attributed talismanic or amuletic powers to 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 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 gemstone industry has been largely the domain of the prospector, fossicker, and small syndicate rather than large mining companies. Major exceptions to this are in the pearling, diamond, and gold industries although the last mentioned also has a strong following of amateur and professional prospectors using metal detectors.

In general, gemstone deposits tend to be small and production somewhat limited. 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 often kept secret. The mining of ornamental rocks has tended to be on a larger scale, often utilizing large earth-moving equipment in opencut quarries, and today most of these deposits are protected by mining tenements.

Australia's pearling industry began long before European settlement of the northwest of the State. In these areas, northern Australian, coastal dwelling Aborigines harvested abundant pearl shell from shallow waters to supply their well-established trading network for pearl shell. Not long after Europeans settled in Western Australia, they were quick to see the value of the pearl fields and pearling, and in 1850 pearl shell harvesting began in earnest at Shark Bay. At this site, the basis of the Shark Bay pearling industry was the small *Pinctada albina albina* shells. These were harvested to produce small, natural pearls of about 3 mm diameter (Malone et al., 1989).

In later years, the larger shelled, silver- or gold-lipped pearl oyster, *Pinctada maxima*, also known as mother-of-pearl shell, was found farther north and the industry spread northwards along the coast to Onslow and Cossack. Around 1875–80, the industry became established in Broome and subsequently became the centre of the pearling industry. The expansion of the pearl and pearl shell industry caused a major influx of immigrants into the northwest 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. Whilst abundant gold in the form of flakes, fragments, and nuggets would have been found in the early days, very little of this would have been utilized in jewellery with the vast proportion melted down. The comparatively recent development of the metal detector has allowed the modern prospector to continue the search for surface and near-surface gold.

Most of the major pegmatite deposits in the State were discovered by the first wave of tin and gold prospectors. Many of these pegmatites were notable for the inclusion of gem minerals of the beryl group including beryl, emerald, and aquamarine. The Londonderry and Grosmont pegmatites, discovered in 1896 and 1909 respectively, are situated south of Coolgardie. Gem minerals 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. By 1915, all the major pegmatite-rich localities in the Pilbara, Coolgardie, Greenbushes, and Ravensthorpe areas had been discovered (Jacobson et al., 2007).

The first recorded discovery of diamonds in Western Australia was in 1895 at Nullagine in the Pilbara when 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 AJV 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 since 1985 and is famous for its coloured stones; yellow, brown, and the rare and extremely valuable pink diamonds.

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Chapter 4 Prospecting for gemstones

Obtaining a Miner's Right in Western Australia

The *Mining Act 1978*

The rules and regulations governing prospecting and fossicking in Western Australia are set out in the *Mining Act 1978* and subsequent amendments. This legislation is complex and can only be briefly summarized in this publication. Any person intending to carry out a serious prospecting program, including excavations or other disturbances to the environment, should consult the Mining Act and regulations and/or seek professional advice.

The Mining Act provides for a Miner's Right that can be purchased for a fee of $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 DMP website: <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 20A 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). A number of local shires such as those at Carnarvon and Norseman have set aside special fossicking areas. Information on these can be obtained from the appropriate shire office, municipal centre or tourist office.

Under the regulations prospecting is permitted on:

- Unoccupied Crown Land
- Pastoral leases, provided prior notice is given to the pastoralist
- Exploration tenements, provided written permission is obtained from the exploration licence holder and a Section 20A Permit has been obtained.

For the purposes of the Mining Act, Crown Land includes land which has not been set aside for any purpose, pastoral leases and common reserves. National Parks, nature reserves, town sites, other classified reserves, and private property are excluded.

In addition, permission must be obtained from a pastoralist or private landowner to prospect within 100 m of land that is:

- used as a yard, stockyard, garden or cultivated field
- an airstrip
- residential land where there is a house or substantial building
- within 400 m of a pastoral dam, well or bore.

Burial grounds and cemeteries are protected under the Mining Act. No prospecting is allowed within 100 m of a burial ground or cemetery.

It is important to note that before fossicking or prospecting is commenced (including the use of metal detectors), Mining Registrars should be consulted to ascertain if the area of interest is open for fossicking or prospecting.

Summaries of the Mining Act, Miner's Rights, and Section 20A Permit

Three short pamphlets are available from DMP to assist interested persons. The first of these relates to the basic provisions of the Mining Act, and the second to the issue, regulations, and application for a Miner's Right. The third pamphlet refers to the requirement to apply for a Section 20A Permit for prospecting on a granted exploration licence on Crown Land. These are available online from DMP (2011a,b,c), or from the Department's office at Mineral House in Perth.

Other legislation

Aboriginal Reserves and archeological sites are governed by other legislations. For example, damage to a site under the *Aboriginal Heritage Act 1980* carries a penalty of up to $2 000 and one year imprisonment, and under the *Heritage of Western Australia Act 1990* a fine of up to $10 000 and two years imprisonment.

Gemstone prospecting — planning and site location

In the search for gemstones, it is often best to start with localities known to have yielded gemstones of particular interest. Many of these localities are described, together with locational information and geographical coordinates, in later chapters of this book. Accuracy of these sites should normally be within tens of metres. Nevertheless, it is important to note that mainly due to limited geographical information some gemstone sites are marked ‘position approximate’ or ‘position doubtful’. Where the exact location of an occurrence is not known, then it is at least recorded as being within a particular 1:100 000 map sheet.

Also in past years, mining of gemstones was not recorded from many prospects or ground outside mining tenements. Such finds were often kept secret by the prospector and the description of these sites and their localities in this Bulletin is often incomplete.

It is important to note that the inclusion of a locality for a gem or decorative stone in this publication does not grant automatic access to the site. The prospector or fossicker must comply with the access provisions relating to prospecting and fossicking in Western Australia set out in the Mining Act and subsequent amendments, listed earlier in this chapter.

Geological maps

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 GSWA’s document download page on DMP’s website: <http://www.dmp.wa.gov.au/gswapublications>. A limited number of geological maps at other scales is also available.

Geoscience and tenement databases

There are several useful databases that can be accessed online from DMP.

Western Australian mineral exploration index (WAMEX)

Western Australian legislation requires mineral explorers to report annually on their programs. After a period of confidentiality, exploration reports and data are made publicly available, so that past exploration work is not unnecessarily repeated. These are referred to as open-file reports.

WAMEX is a searchable database of open-file reports on exploration for minerals (excluding oil and gas), and is managed by the Geological Survey Statutory Exploration Information Group (SEIG). Access to WAMEX is free of charge and digital copies of the reports are online and may be downloaded. An external disk drive containing over 60 000 open-file reports (at August 2011) is available for copying from the DMP library in Perth, and the GSWA office in Kalgoorlie. The disk drive is updated on a monthly basis. To access this copying service, prior booking with the data custodians is desirable. Reports released within the last month are available only online.

Mines and mineral deposits (MINEDEX)

MINEDEX is a comprehensive database of mines, mineral deposits, and prospects along with their operational status, location and ownership. Geological attributes include commodities, mineralization style, and resource estimates (where available). The database is updated as new information relating to sites and mineral projects becomes available.

TENGRAPH online

TENGRAPH graphically displays the position of Western Australian exploration and mining tenements, and petroleum titles in relation to other land information, and provides an easy means of determining land available for mineral exploration. It gives a current and accurate picture of the location of the tenement under mining activity in terms of exploration and mining titles, past and present owners, expiry dates etc. TENGRAPH also links with the MINEDEX database for current information on mines, mineral deposits, and prospects.

Database access

It should be noted that online access to the TENGRAPH database requires the installation of client software from CITRIX Systems Inc.

Map datum

Since 1858, in addition to latitude and longitude, series topographic and geological maps of Western Australia have been prepared from a variety of map datums using the Universal Transverse Mercator (UTM) map projection. In 1966, the Australian Geodetic Datum (AGD66) was established and was subsequently upgraded in 1984 to AGD84. This datum was in use in Western Australia until 2000 when it was replaced by the Geocentric Datum of Australia (GDA94).

Map datum AGD66 was a non-geocentric datum defined by a spheroid and a point-of-origin location. Map datum AGD84 used the same spheroid as AGD66 and a rough conversion from AGD66 to AGD84 required the addition of up to 5 m to both the easting and northing coordinates of AGD66. While the AGD provided a reference system that best fitted the shape of the Earth in the Australian region, its origin did not coincide with the centre of mass of the Earth.

Since 1994, GDA94 has replaced AGD84. GDA94 is a coordinate reference system that best fits the shape of the Earth as a whole and has an origin that coincides with the centre of mass of the Earth, hence the term 'geocentric'.

Since that time, GDA has been progressively implemented throughout Australia as the preferred map datum for all spatial information. It is currently considered to be the most effective datum as it provides:

- compatibility with satellite navigation systems, such as the Global Positioning System (GPS)
- compatibility with national mapping programs already carried out on a geocentric datum
- a single standard for the collection, storage, and dissemination of spatial information at global, national, and local levels.

The adoption of GDA94 coordinates of a point has resulted in these coordinates appearing to be located approximately 200 m to the northeast of the AGD coordinates of the same point. Exact values vary slightly from from place to place within Australia. Most published topographical and geological maps of Western Australia will record the geodetic datum used. Macros and utility programs are available to allow conversion of AGD coordinates into GDA and vice versa.

Safety and survival in the bush

Western Australia is an extremely large State with an area in excess of 2.52 million km^2, being approximately one-third of the Australian land mass. Outside of major urban centres, the State is mostly sparsely populated. Summer temperatures can be extremely high, especially in central and northern parts. In the hotter time of year, generally 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 but 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. Driving on unsealed roads requires special attention to speed, dust, water on the road, keeping to the left particularly in hilly country, animals on the road at dawn and dusk, poor track conditions, and driver fatigue.

It is essential that the fossicker is aware that travel in remoter regions of Western Australia is potentially dangerous and adequate precautions should be taken. The following points should be considered in relation to safety in the outback. It should be noted that this list is not comprehensive. 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 Royal Flying Doctor Service (2011).

Safety considerations for outback travel

Preparation for outback travel

This includes planning your route for travel, travelling at the right time of year, use of detailed maps, and using well-maintained vehicles suitable for the terrain with tools, spare parts, and communications equipment (high-frequency radios and satellite phones). Vehicles must also carry adequate fuel, water, and food. Appropriate clothing, hats and boots must be packed together with a first-aid kit (an appropriate first-aid training course should have been completed). A GPS and an Emergency Position-Indicating Radio Beacon (EPIRB) should also be included.

It must be noted that most rental vehicles, including 4WDs, are equipped with little else than a very basic tool kit and as hired are unsuitable for outback travel.

Radio communications

For close-range communication between vehicles a citizen band (CB) or high-frequency (HF) radio may be used, although for long-range radio communication an HF radio may be required (these can be hired from communications suppliers). When using HF radio in the outback it is good practice to set up a communication schedule with the Royal Flying Doctor Service (RFDS) and contact them daily advising them who you are and your current location.

Today, the use of satellite phones (satphones) is becoming increasingly common, replacing the need for an HF radio. Satphones allow the user to make a direct phone call from from remote areas via a satellite system to anywhere in Australia or overseas with no time delay.

Terrain to be covered

A study should first be conducted to establish:

- whether the area is accessible by vehicle
- nearest locations of fuel and water
- the best route and alternatives
- methods of evacuation that may be available in the area in an emergency
- location and contact details of local residents living at homesteads, Aboriginal settlements, and mining and exploration camps.

Use of maps

The Western Australian bush can be very monotonous with few landmarks and signposts on outback roads. When travelling, it is advisable to use the tracking function on your GPS unit to pinpoint your location at any given time making it possible to confirm your position to home base at least every day. Western Australia has an extensive coverage of topographical and geological maps at 1:250 000 and 1:100 000 scales. These may be purchased from Landgate at Midland (topographical maps) and DMP in East Perth (geological maps).

Also, GeoMap.WA, a geographical information systems (GIS) viewer for Windows, is available as a free download from DMP. This data package contains geological and topographical map series images as well as geological, mineral, and other useful field information that may be used interactively from field vehicles.

Weather conditions

Weather conditions must be regularly checked as road conditions vary according to local rainfall. After rain, check with police or local authorities before travelling as many outback roads may be closed.

Personal safety

Learn as much as possible about the local area to be visited. Local knowledge that may assist in your survival includes:

- Dangerous animals and reptiles
- Insects, flies, and mosquitoes
- Prickle bushes and any poisonous or irritating plants
- Edible wild foods and bush tucker (food)
- Available water supplies
- Abandoned mine sites, caves, and other dangerous sites
- Local diseases, e.g. those carried by mosquitoes.

Notification of itinerary

Before leaving on a journey through remote areas always notify a responsible adult (friends, relatives, station owners or police) with the following information:

- Departure and arrival dates, and estimated time of departure (ETD) and arrival (ETA)
- Daily call in times
- Proposed and alternative routes
- Breakdowns and other emergencies.

If your vehicle breaks down, you become lost or suffer a medical or other emergency, you should not leave your vehicle. Attempt to call for help using your HF radio or satphone. If this should prove unsuccessful or in a dire emergency, an EPIRB should be activated. The distress signal emitted from this instrument via satellite will enable local search authorities to find you in the shortest possible time. Personal emergency beacons are essential items of safety equipment that should be carried at all times in remote areas both in the vehicle and attached to a person when away from the vehicle. Two types of personal emergency beacons are available: the EPIRB and the Personal Locator Beacon (PLB). Both instruments are relatively expensive to purchase but may be hired. It should be noted that penalties apply for misuse of personal emergency beacons.

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1

Diamond

Petri dish containing rough diamonds from Argyle showing colourless, champagne, and the very rare pink diamonds (courtesy Rio Tinto Diamonds)

Chapter 5 Diamond

Diamond — gemstone properties

Diamond is composed of crystalline carbon and belongs to the isometric system. Its chemical stability and hardness relate to 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 crystals termed macles. Other crystal forms including cubic, tetrahedron, hexoctahedra, and rhombic dodecahedra are more rare. Natural surface features of crystal faces include octahedral faces characterized by equilateral triangular depressions (trigons) and the rarer, cubic faces by square, shallow depressions. Small hexagonal depressions of approximately 1 mm diameter, known as calderas, are described from the surfaces of some Argyle diamonds. These features are interpreted as trigons with truncated corners.

Diamond 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 properties including brilliance (internal and surface reflection of light related to total internal reflections from the base of the gem, and 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 can be polished to a very high finish. This 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 now be produced. Diamond facets can only be polished by diamond grits, with the random directions of the grains in the grit or polishing powder when some of the 'harder' crystal directions make contact with the 'softer' directions of the facets being polished. The perfect octahedral cleavage direction of diamond can be used on a gem-quality crystal in the initial preparation for cutting although today it is a method seldom applied.

Diamond
Crystalline carbon (C)

Physical properties of diamond

Crystal system	Isometric
Habit	Octahedral, also dodecahedral
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, black and grey, rarely blue, green, pink, red or purple
Colour cause	Trace elements: N, Al, and B; lattice structural plastic deformation; irradiation
Lustre	Adamantine
Diaphaneity	Transparent, 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 crossed polarized light
Hardness	10
Specific gravity	3.52
Fracture	Conchoidal
Cleavage	Perfect octahedral
UV fluorescence	Commonly blue or yellow. Blue fluorescence is followed by phosphorescence

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 based largely on the amount and aggregation of nitrogen within the crystal lattice. Type I diamonds, by far the most common, contain nitrogen in layers in Type Ia, whereas in Type Ib nitrogen is dispersed within the crystal lattice. The much rarer Type II diamonds (especially blue stones) are laminated and contain no nitrogen. Type IIa are not electrically conductive, whereas Type IIb will conduct electricity. It should be noted that some diamonds are an admixture of both types (Oldershaw, 2003).

The majority of cut diamonds in the trade are colourless and diamonds are generally esteemed more highly for their lack of colour. However, they occur naturally in all colours, most commonly with tints of yellow and brown, but also blue, green, pink, red, orange, purple, black, and grey. Intense colours are referred to as 'fancy' colour. Although diamond is a pure form of carbon, other trace elements in its structure are responsible for some of these colours, notably nitrogen, which causes a pale yellow, and boron, a blue. Browns and pinks are caused by a combination of plastic deformation and low nitrogen content in the crystal structure; 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 intepreting 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, enstatite–garnet (peridotitic suite) with graphite lining cleavages and fractures (Chapman et al., 1996).

Although diamond is optically isotropic many specimens show anomalous birefringence, displayed as patterns of light and dark zones with first-order interference colours when viewed under crossed Nicol 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 or 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 surface, the pipe often contains considerable proportions of pyroclastic material and variable amounts of host rock material. Kimberlite and lamproite intrusions are relatively common, but 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 weathering and thus are also commonly found in secondary alluvial 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 which 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 the 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 >0.5 mm (in the longest axial direction) being referred to as 'macrodiamonds' whereas stones <0.5 mm diameter are termed 'microdiamonds.' Although microdiamonds are usually 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 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 when a few small stones were recovered from alluvial gold workings. In the early 1920s, RA Farqueson, a petrologist with GSWA sampled lamproites from the margin of the Kimberley Basin. Farqueson subsequently recognized these rocks as being of igneous 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 but 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 but the result was never repeated.

In the mid-1970s, many companies became involved in the search, the most successful of which was the Kalumburu/Ashton Joint Venture, which 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 1979 discovery of two diamonds in Smoke Creek in the east Kimberley, 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 at Bow River, downstream of the Argyle AK1 pipe, and also from around Ellendale diamond pipes 4 and 9. Many companies have explored for alluvial diamonds in buried paleochannels of the Ord, Dunham, and Keep Rivers but with limited success. Elsewhere, small occurrences of alluvial diamonds are widespread throughout the Kimberley Basin but in subeconomic quantities. Exploration for marine and littoral placer diamond deposits, similar to those mined along the coasts of Namibia and South Africa, has been undertaken along the coastline of Joseph Bonaparte Gulf but 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 occur in the immediate vicinity of some pipes. The vast majority of these kimberlitic and lamproitic bodies in Western Australia are located in, or adjacent to, the Kimberley Basin and occur within three distinct regions. These are known as the East Kimberley, North Kimberley, and West Kimberley Diamond Provinces (Fig. 5.1).

The North Kimberley 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 situated in, or near, the igneous and metamorphic rocks of the Paleoproterozoic Lamboo Complex and Hooper Province respectively. These provinces largely comprise diamond-bearing lamproite pipes, although there are 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 located in the Carnarvon Basin. Also, indicator minerals and rare diamonds have been identified from exploration in the East and West Pilbara, Nabberu–Gascoyne, and Eastern Goldfields regions. Locations of notable diamond discoveries in the State are shown in Figure 5.1 and more detailed location information on most of the State's diamond deposits and prospects is given in Appendix 1.

Halls Creek Orogen — Lamboo Complex

East Kimberley Diamond Province

Within the Halls Creek Orogen, the East Kimberley Diamond Province in the Argyle area comprises lamproites and associated alluvial diamond deposits within the igneous and metamorphic rocks of the Lamboo Complex. 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 located about 50 km southwest of Lake Argyle and 110 km south-southwest of Kununurra (Figs 5.1 and 5.2). Access is via an all-weather road from the Great Northern Highway, but access is restricted and permission to enter must be obtained. It should be noted that under the terms of the *Argyle Act 1979* 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 26 years and is famous for its coloured stones; yellow, brown, and the rare and extremely valuable pink diamonds (Fig. 5.3). Also, there are reports of the recovery of a few grey/blue/violet stones (van der Bogert et al., 2009).

During the Mesoproterozoic, the Argyle lamproite pipe intruded Paleoproterozoic to Mesoproterozoic sequences overlying crystalline basement rocks of the Lamboo Complex (1800–2200 Ma) located 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 rocks along a pre-existing fault. The diatreme is 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 northward at approximately 30º (Fig. 5.4).

Original proven 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 the remainder industrial diamonds (55%) (Jaques, 1994; Fig. 5.5).

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

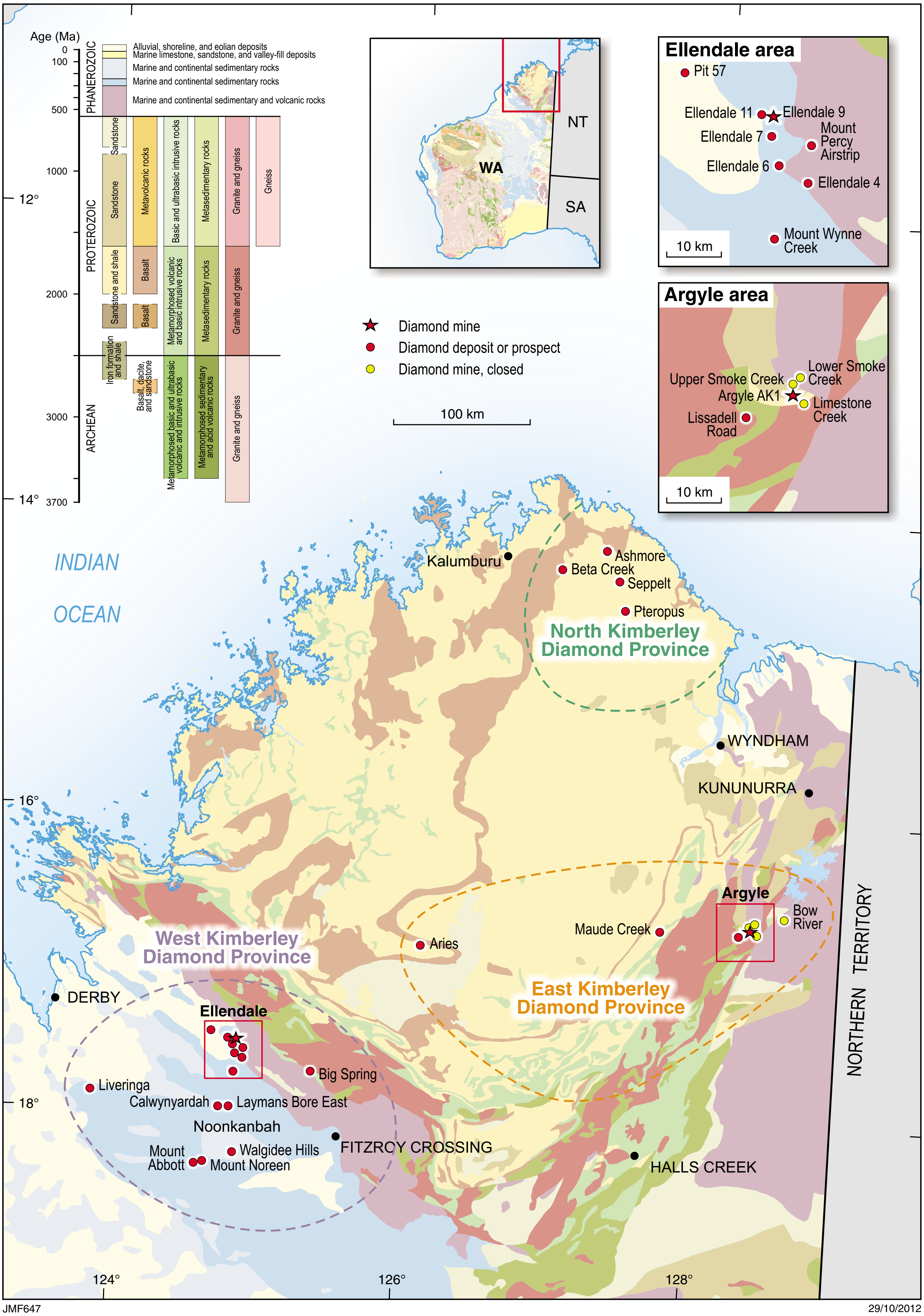

Figure 5.1 **Diamond mines and principal diamond prospects in the Kimberley region, Western Australia**

Figure 5.2 View looking north across the extensive openpit over the AK1 diamond mine in the East Kimberley region

Figure 5.3 Argyle diamond rough stones showing colourless, champagne and the very rare pink forms (courtesy Rio Tinto Diamonds)

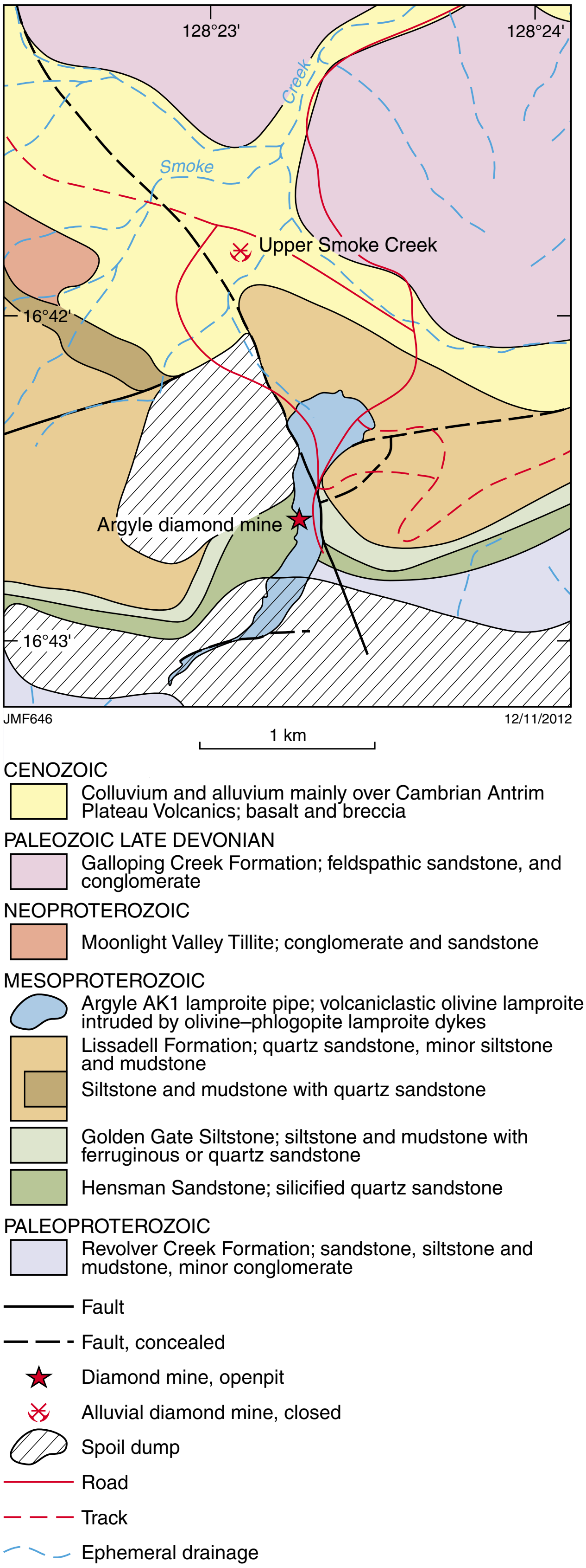

Figure 5.4 Geological sketch map of the Argyle AK1 lamproite pipe (modified after Sheppard et al., 1997; Shigley et al., 2001)

Figure 5.5 **A polished, high-quality, emerald-cut Argyle pink diamond. Specifications: weight 0.31 ct, colour 1PP (top colour), clarity VVS2 (courtesy John Mann, Inspira Diamonds)**

the openpit would return to full production in 2013 which, together with the new underground operations, would enable the life of the mine to be extended until about 2018 (Rio Tinto Ltd, 2009).

Lissadell Road (BOW, 4564)

The Lissadell Road lamproite dyke is located about 10 km west of the Argyle AK1 pipe (Fig. 5.1). The dyke comprises a discontinuous set of small stringers up to 1 m wide that intruded into the Lamboo Complex. 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)

Several formerly economic alluvial diamond deposits are located downstream of the Argyle AK1 pipe. These have all been largely mined out and are either abandoned or in care and maintenance.

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. 5.1). 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. 5.1). 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 deposits, 4 km north-northeast of the Argyle AK1 pipe, comprise several diamondiferous gravel terraces ranging in age from Miocene terraces to modern channel deposits (Fig. 5.1). Each gravel terrace has a characteristic diamond size distribution and diamond value.

Bow River (LISSADELL, 4664)

The Bow River alluvial deposit is located on the lower reaches of Limestone Creek around 35 km north-northeast of the Argyle AK1 pipe and 96 km south of Kununurra (Figs 5.1 and 5.6). 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 Bow River, diamonds were about 25% higher in quality than those from the Argyle pipe, probably because 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 (shards).

Kimberley Basin

East Kimberley Diamond Province

Within the Paleoproterozoic rocks of the Kimberley Basin, the East Kimberley Diamond Province, located to the west and southwest of the 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 m-wide kimberlite dyke intrudes the Hart Dolerite which itself is intrusive into the Speewah Group (Fig. 5.1). Small quantities of diamonds have been recovered from this occurrence including a 0.05 ct stone and several microdiamonds.

Phillips Range — Aries kimberlite (BARNETT, 4164)

The Aries kimberlite is located in the southern central Kimberley Basin about 150 km north-northeast of Fitzroy Crossing (Fig. 5.1). Covering an area of 18 ha, Aries is the largest kimberlite body discovered in Australia. This body comprises four northerly trending lobes: the boomerang-shaped South Lobe, the Central Lobe, and the North Lobe intruded into the Paleoproterozoic King Leopold Sandstone, and the North Extended Lobe intruding the Carson Volcanics. The arcuate South Lobe is made up of four smaller, diamondiferous kimberlite pipes named Helena, Athena, Persephone, and Niobe (Fig. 5.7; Ruddock, 2003).

Figure 5.6 View looking north over the Bow River alluvial diamond mine processing plant and tailings dams

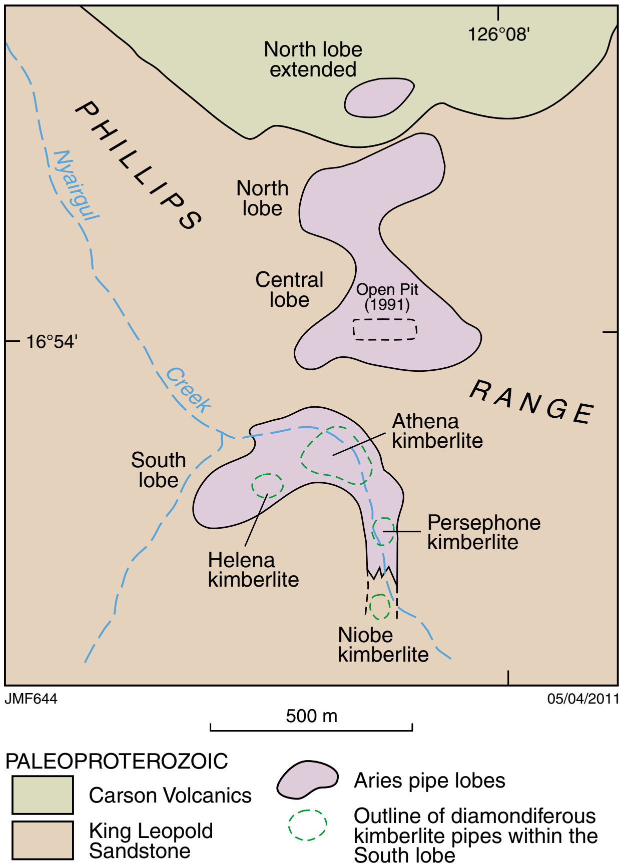

Figure 5.7 Geological map of the Aries kimberlite pipe (modified after Ruddock, 2003)

The Aries pipe is composed of a micaceous kimberlite which is 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 sub-economic 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.

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 and other rivers (Ruddock, 2003). It is possible that further diamondiferous kimberlite bodies have yet to be discovered in this region.

Access to the 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 Homestead and travelling north almost to Kalumburu about 310 km distant. Eighteen kilometres south of Kalumburu, the Carson River can be crossed and thence along poorly maintained station tracks to the King George River. In this area numerous tracks of varying standards 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 located 40–70 km east to east-southeast of Kalumburu (Fig. 5.1). 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.

Ashmore (*King George, 4369*)

The Ashmore diamond prospect comprises four separate small kimberlitic pipes (Ashmore 1–4), some 71 km east of Kalumburu (Fig. 5.1). Initial bulk sampling of the surface infill material from the upper portions of the pipes yielded an average grade of around 30 ct/ht with three stones weighing over 10 ct, although later sampling of deeper, fresher material from pipes Ashmore 2 and 4 produced lower grades of less than 10 ct/ht. The largest diamond recovered from bulk sampling at the Ashmore 2 pipe measured 9.23 ct (Fetherston and Searston, 2004).

Seppelt (*King George, 4369*)

The Seppelt kimberlite pipes are located about 80 km east-southeast of Kalumburu (Fig. 5.1). Seppelt 1 kimberlite consists of two lobes about 100 m apart with a combined area of about 0.7 ha. Grades were initially estimated to be about 40 ct/ht but 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 situated 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, white 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 and 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 being a gem-quality octahedron of 1.1 ct (Striker Resources, 2004).

Pteropus (*Collison, 4368*)

The Pteropus breccia pipe lies some 93 km east-southeast of Kalumburu (Fig. 5.1). The structure consists of a vertical pipe extending over approximately 2 ha. The pipe, of possible kimberlite origin, is filled with breccia composed mainly 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 Hooper Province through sedimentary rocks of the northern Canning Basin that extend over areas of the Lennard Shelf and Fitzroy Trough.

In 1969, the first diamonds were found in the West Kimberley province when 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 occur as pipes, plugs, sills, and rare dykes in three main fields, referred to as Ellendale, Calwynyardah, and Noonkanbah. These 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).

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

The Ellendale diamond field is located in an area approximately 140 km east-southeast of Derby (Fig. 5.1). Access is via the Gibb River Road and thence 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 lamproite intrusions in the West Kimberley Diamond Province with 50 discrete bodies intruding the Lennard Shelf, 38 of which are known to be diamondiferous. In the Ellendale area, about 60% of the diamonds recovered from lamproite intrusions are of gem quality, but overall grades tend to be low and most deposits are considered to be subeconomic.

Kimberley Diamonds commenced mining at Ellendale in 2002. In 2007, the operation was acquired by Gem Diamonds Ltd whose current operations are centred on extraction from the rich Ellendale 9 diamond pipe. In recent years, mining operations at Ellendale 4 and 7 diamond pipes have been put into care and maintenance. The Ellendale mine is well known internationally as a source of fancy yellow diamonds (Fig. 5.8). 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; Fig. 5.9).

In 2009–10, the mine produced 0.194 Mct, a significant reduction from 0.443 Mct produced in 2008–09. This reduction in output was largely attributed to the placing of Ellendale 4 in care and maintenance and also to unseasonably bad weather conditions in the second quarter of 2010. The company has a marketing agreement for the supply and sale of its yellow diamond production with Laurelton Diamonds Inc. (a subsidiary of Tiffany & Co.) until the end of the economic life of the mining operation (Abeysinghe and Flint, 2011).

Ellendale 9

In 2002, mining commenced at Ellendale 9 pipe (Fig. 5.10), which contained an estimated pre-mining resource of 31.92 Mt at 5.5 ct/ht. During the operation of the mine, individual diamonds up to 11.47 ct were recovered (Hassan, 2004b).

With a surface area of 46.9 ha, the diamondiferous, lamproite pipe comprises an oval western lobe and larger, elongated central and eastern lobes. The western lobe of the vent is made up of a thick sequence of tuffs with a central olivine lamproite core, whereas the central and eastern lobes are mainly composed of olivine lamproite with little tuffaceous material (Fig. 5.11).

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Figure 5.8 **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) among Ellendale rough stones (courtesy Kimberley Diamond Company)**

Figure 5.9 **Kimberley Diamond Company diamond sorting room (courtesy Kimberley Diamond Company)**

Ellendale 4

Discovered in 1976, the Ellendale 4 deposit is composed of a large, concealed lamproite intrusion about 76 ha in surface area, and a smaller satellite, located to the east of the main pipe, with an area of 11 ha. The intrusive structure is complex, consisting of two coalescing eruptive centres each with a core of olivine lamproite and a marginal zone of pyroclastics. The pyroclastics compose about 50% of the vent material and contain most of the diamonds. About 65% of the stones are yellow with the remainder brown, colourless, and grey. Ellendale 4 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 satellite pipe (Hassan, 2004b).

Ellendale 7

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

Ellendale 11

Ellendale 11, a proposed future mining site, is 13.1 ha in area and located 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/ht.

Ellendale 6

Ellendale 6, with a surface area of 106 ha, is the largest undeveloped lamproite intrusion in the Ellendale field. 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 a total of 0.61 ct.

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 located about 90 km west-northwest of Fitzroy Crossing (Fig. 5.1). 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 located in the Lennard Shelf about 117 km east of Derby (Fig. 5.1). 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 situated about 94 km northwest of Fitzroy Crossing (Fig. 5.1). 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. 5.1). 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 as well as numerous microdiamonds.

The Calwynyardah diamond field *(Hardman, 3861)*

The Calwynyardah diamond field covers an area of almost 50 km^2 and is traversed by the Great Northern Highway 90 km west-northwest of Fitzroy Crossing (Fig. 5.1). The field, consisting of a small group of lamproite intrusions, is mostly situated 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.

Figure 5.10 View looking northeast over the Ellendale 9 openpit, West Kimberley Diamond Province (courtesy Kimberley Diamond Company)

The 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. 5.1). Access is good with good gravel roads running south from the Great Northern Highway to 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, dumb-bell-shaped lamproite and tuff pipe containing sandstone breccia (Fig. 5.1). Extensive sampling yielded a total of five small diamonds and several microdiamonds together with indicator minerals.

Mount Noreen (Hardman, 3861)

This diamond prospect is located about 100 km west-southwest of Fitzroy Crossing (Fig. 5.1). 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 some 490 ha (Fig. 5.1). Exploration in the 1990s yielded 891 microdiamonds and 62 macrodiamonds. More recent work recovered 11 macrodiamonds; six colourless white, 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. 5.1). Bulk sampling of two of the five olivine lamproite pipes at Big Spring produced 30 microdiamonds totalling 0.37 ct together with the indicator minerals chromite, pyrope, and chrome diopside.

Liveringa (Yeeda, 3662)

The Liveringa prospect is located in the Fitzroy Trough, 72 km southeast of Derby (Fig. 5.1). During a drilling operation in 1991, a single microdiamond (0.275 x 0.275 mm) was recovered from a probable lamproite pipe.

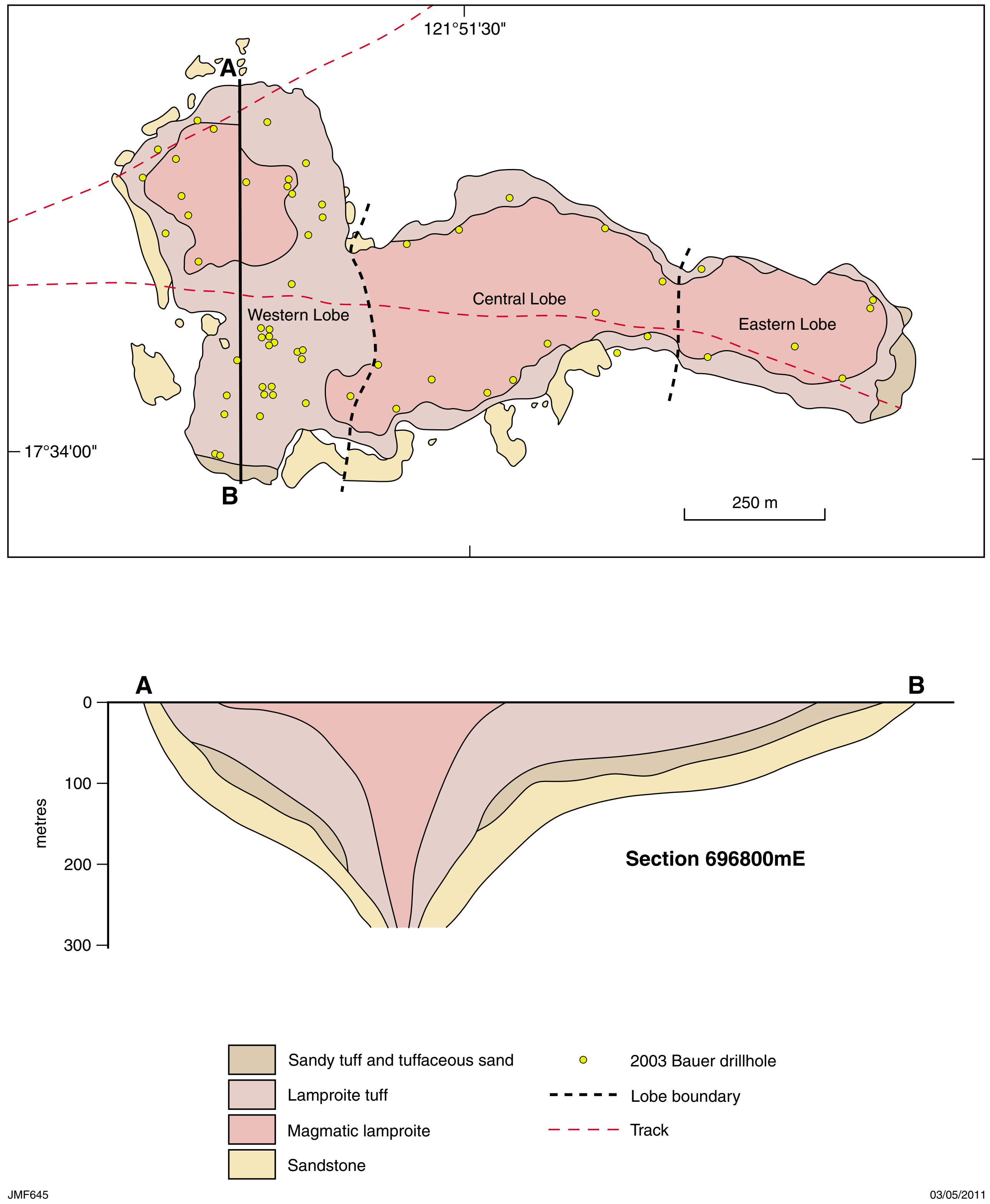

Figure 5.11 Geological map and cross section of Ellendale 9 lamproite pipe (modified after Louthean, 2003)

Southern Carnarvon Basin

Wandagee Diamond Province

The Wandagee Diamond Province is situated towards the northeastern edge of the Southern Carnarvon Basin, approximately 125 km northeast of the town of Carnarvon (Fig. 5.12). In 1975, small kimberlite-like diatremes were first discovered in the area and to date a total of 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, Mardathuna, and Wandagee pastoral leases. Access is via a good gravel road leading eastward from the Great Northern Highway to Wandagee Station and thence 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 referred to as alkali picrites. As part of the exploration program, most of the diatremes, as well as gravel samples from the Minilya River and Barabiddy 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. 5.12). Sampling from these prospects yielded only three very small diamonds.

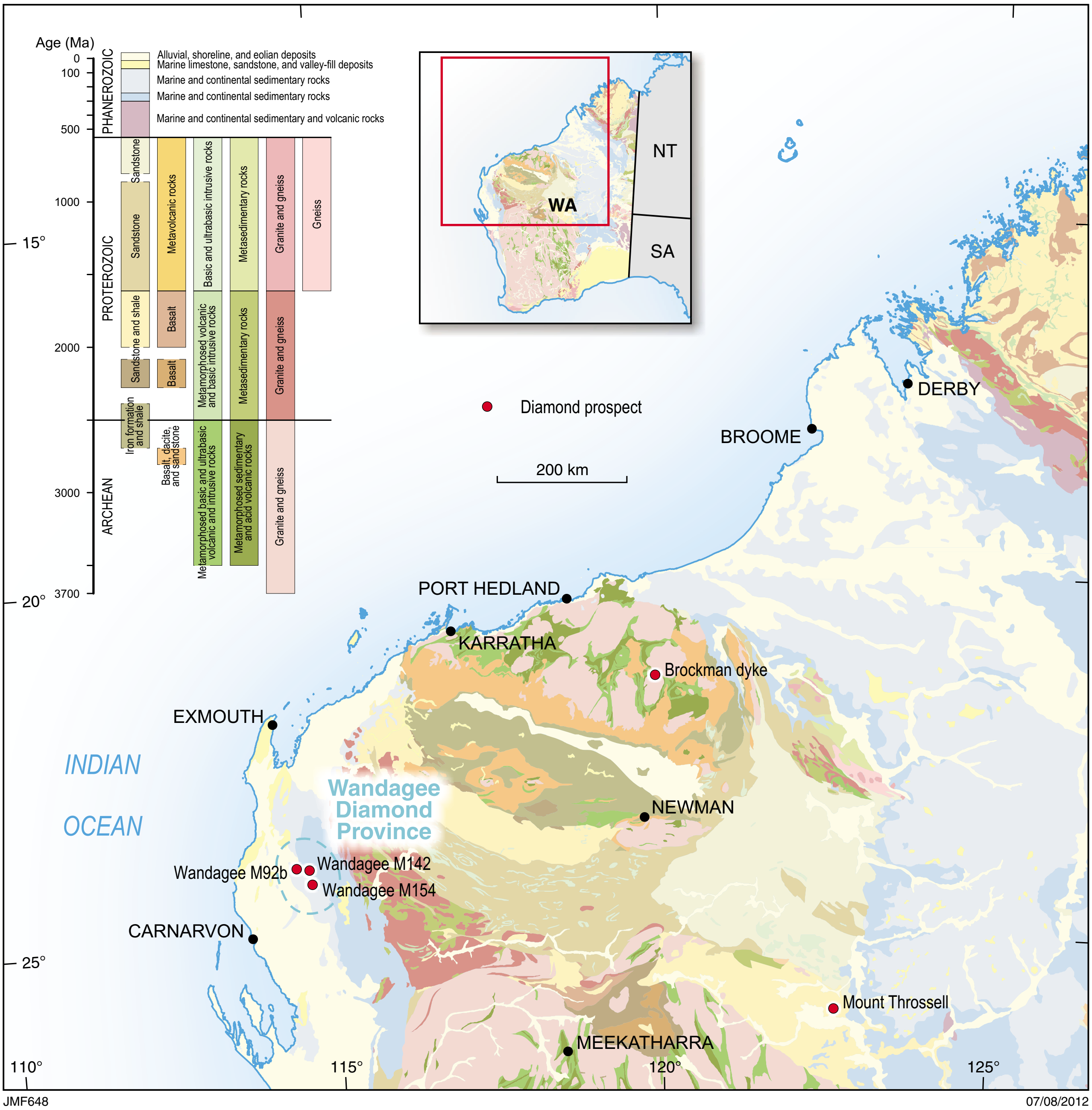

Figure 5.12 **Principal diamond prospects in the central western region of Western Australia**

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 to be 3.5 ct.

Marble Bar region

Brockman Dyke (MARBLE BAR, 2855)

The Brockman kimberlite dyke, discovered in 1998, is located about 30 km southeast of the town of Marble Bar (Fig. 5.12). 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 as well as 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.

Earaheedy Basin

Mount Throssell area

Mount Throssell (CARNEGIE, 3445)

Also known as the Bulljah Pool prospect, the Mount Throssell diamond exploration area lies about 250 km east-northeast of Wiluna, and 3 km northwest of Mount Throssell (Fig. 5.12). 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).

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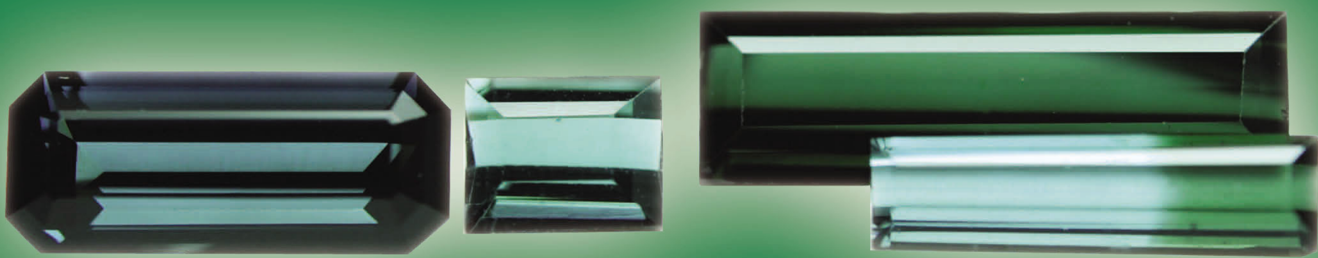
2

Gemstones associated with pegmatites



Faceted, blue-green elbaite tourmaline crystals from the Dalglish prospect near Spargoville in the Kambalda region (courtesy Francine Payette)

Chapter 6 Beryl group

Beryl

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, but twelve-sided crystals are also found. Prisms are commonly terminated by basal planes and more rarely, 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, Cs) and water. Colours and hues of beryl vary greatly due to traces of the chromophoric transition elements (colouring agents) iron, chromium, manganese, and vanadium. Blue, green, and yellow beryl varieties typically contain divalent and/or trivalent iron (Fe^{2+} and Fe^{3+} up to 1.5% FeO and 0.96% Fe_2O_3). Pink and red beryl contains manganese (Mn^{2+} and Mn^{3+} from traces to less than 0.2%). Emerald analyses commonly show the presence of chromium (0.23% Cr_2O_3 from Poona WA), minor iron and, less frequently, vanadium (0.12%), whereas cobalt, nickel, and copper are rarely reported and only in trace amounts (Sinkankas and Read, 1986).

Beryl is most commonly a granitic pegmatite mineral and occurs in rare-element lithium–cesium–tantalum-bearing pegmatites having formed at low to moderate pressures of 2.5 – 4.0 kilobars and temperatures between 500 and 650ºC within andalusite to sillimanite metamorphic facies environments.

Common 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 the metal beryllium. Colours vary through milky white, pink, yellow, blue, and green but all material is opaque (Fig. 6.1). When beryl exhibits translucence and clarity, it can generally be considered to be gem material.

Gem beryl has physical properties well suited for use as a gemstone with substantial hardness (7.5 – 8.0) and indistinct basal cleavage. Transparent beryl containing few inclusions and fractures is usually faceted, whereas lower grade material is often 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 an unnamed black beryl. To date, the rare red- and black-coloured 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 6.2 and localities of beryl group minerals in Western Australia are given in Figure 6.3. More detailed location 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 that ranges from bluish- or yellowish-green to deep green.

Physical properties of emerald

Crystal system	Hexagonal
Habit	Prismatic
Colour range	Light to dark green
Colour cause	Chromium, vanadium, iron
Lustre	Vitreous (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 6.1 **Cross section of a large, pale green beryl crystal from the Yinnetharra area**

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 6.1.

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 immediately 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 Figure 6.2a.

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. 6.3). 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 older brother of Fin. This was converted to the Reward Claim ML45, also known as the Mount Ryan lease. HP Woodward reported on the occurrence of these emeralds in 1914.

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 that mark this activity. The most significant of these

Table 6.1 Chemical analysis 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
Percentage												
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

Source: Simpson (1948)

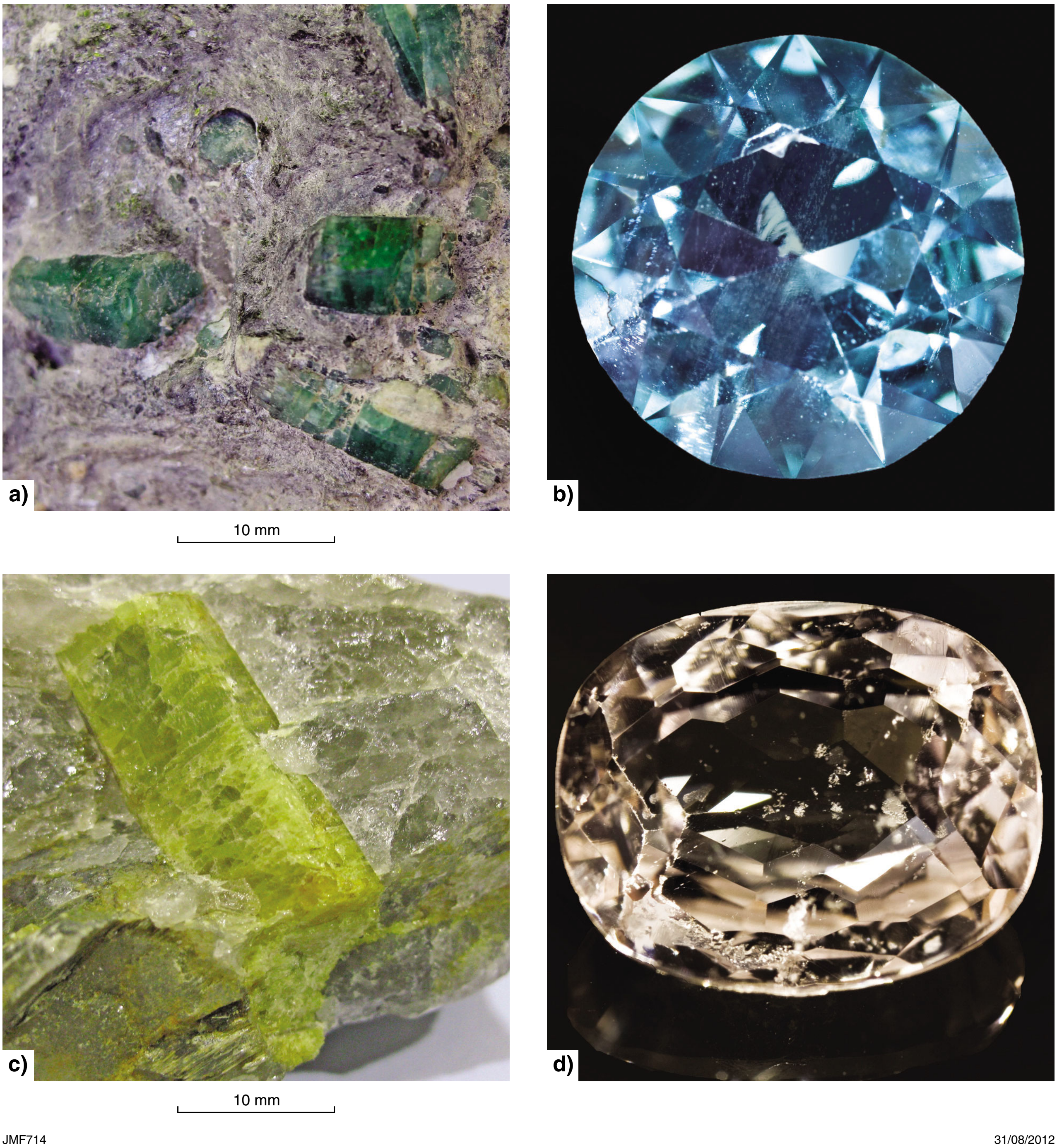


Figure 6.2 **Gem varieties of beryl from Western Australia: a) emeralds from the Curlew mine, Tambourah area, Pilbara region (courtesy Gemmological Association of Australia); b) aquamarine (1.49 ct) from Spargoville, Coolgardie region (photo Carlo Benti, courtesy Australian Museum); c) yellow beryl from Mullalyup, Donnybrook area (courtesy Western Australian Museum); d) morganite (3.59 ct) from Poona, Cue region (photo Carlo Benti, courtesy Australian Museum)**

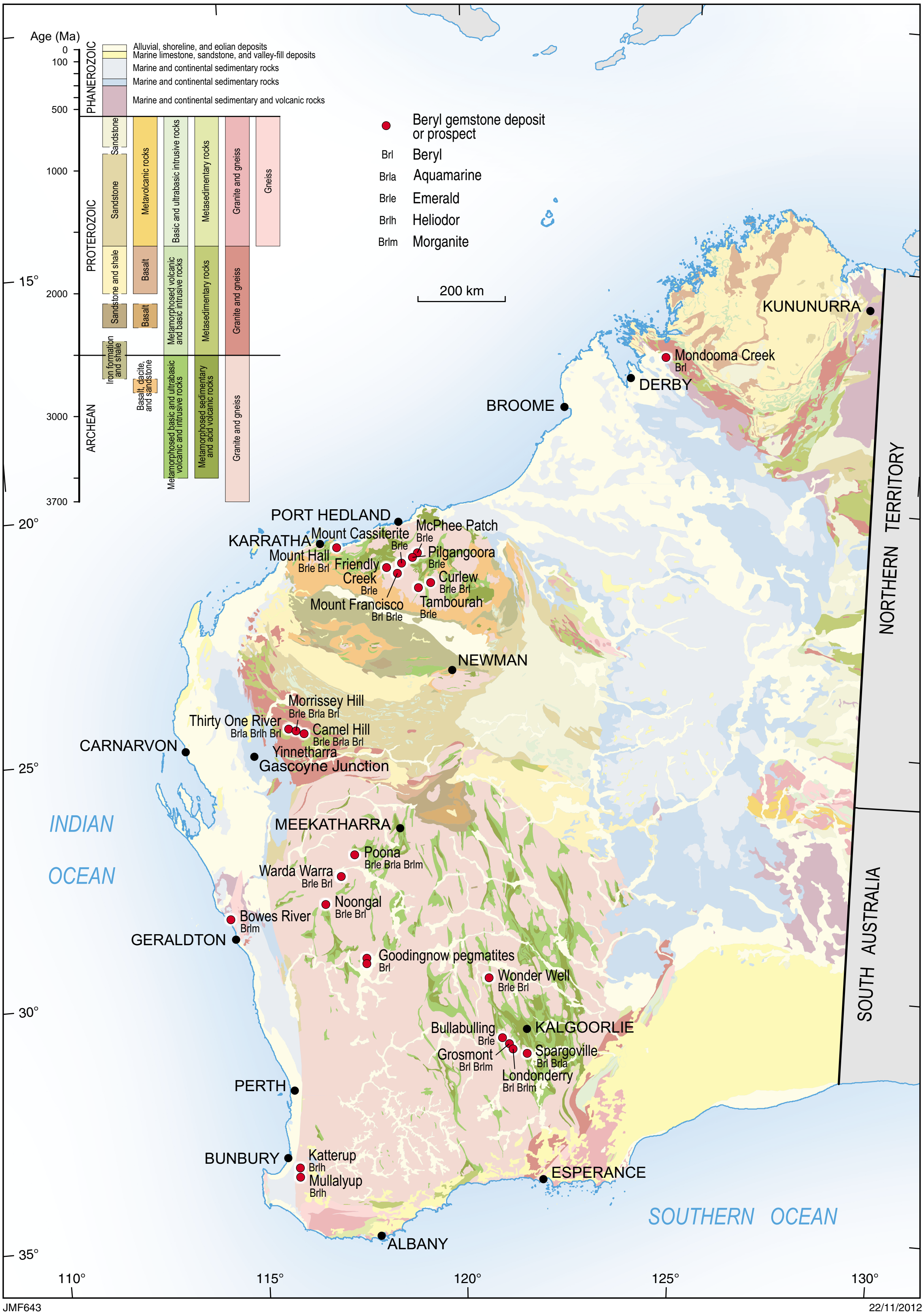


Figure 6.3 Principal beryl group mineral localities in Western Australia

are the Aga Khan, Quartz Blow, Mid-section, Solomon, Reward, and Lee's Trench (Fig.6.4).

In general, the emeralds at Poona were of low quality and of 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 granitoid intrusions, which 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; Van Kranendonk et al., 2012).

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 occurring as crystals up to 40 mm long can be found in both the margarite–quartz–topaz veins and immediately adjacent phlogopite schists. Some of these are of gem quality. These commonly are found at the Poona East emerald mine.
- Emeralds associated with ruby, sapphire, topaz, and alexandrite tend to be light green with crystal sizes 1–10 mm. Specimens of these were collected from the dumps of a small exploration shaft near the Aga Khan Deep mine.
- Emeralds associated with quartz, feldspar, garnet, and muscovite comprise mostly colourless beryl but can be light green and zoned and are always cloudy due to 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 inclusions, both two- and three-phase types.

Poona emerald deposits

In 1914, a syndicate mined an area close to the current Aga Khan workings. They extracted many thousands of carats of poor-quality emeralds as well as two fine stones. The project was abandoned and the lease surrendered in 1916. All the Poona leases were forfeited by the end of the First World War. 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 but nothing of significance (Palmer, 1990; Jacobson et al., 2007).

The first underground emerald mine, the Aga Khan Deep mine, was not established until 1975 but mining ended in 1977. The mine was re-opened in 1980 but closed in 1982 owing to 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 was established in 1963 and a few stones of reasonable quality were obtained as well as poorer quality emeralds. 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 ceased.

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 was mined in 1982 but returns proved inadequate for operating at a profit.

Other emerald mines in the Poona area

The Emerald Pool mine (formerly the Emerald Gem mine) is located about 6.5 km northeast of the 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 their contract to buy emeralds from the Emerald Pool mine and were renamed Biron Corporation Ltd. The company marketed the manufactured stones as Biron emeralds until May 2001, when its emerald production business was sold to Russian competitors.

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

Yalgoo region

Noongal *(YALGOO, 2241)*

Beryl and poor-quality emerald were discovered at Noongal (also referred to as Melville), located about 20 km north of Yalgoo and 4 km north of the old Melville Townsite (Fig. 6.3). In this area, beryl-bearing pegmatites are located 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 to be randomly scattered among the pegmatites, emerald is recorded only 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, but 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 but it is almost certainly located on the YALGOO 1:100 000 map sheet (2241). No production figures are available for emeralds from Noongal but the amount is assumed to have been small.

Warda Warra (DALGARANGA, 2342)

The Warda Warra emerald occurrence is located immediately north of Warda Warra Hill about 95 km northeast of Yalgoo (Fig. 6.3). 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 comprise phlogopite–biotite, actinolite–tremolite, chlorite, and talc. However, deposits are variable and the outer zones are often 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 both within 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 as being a beautiful green in colour but 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 located astride the Riverina – Snake Hill Road immediately north of the Riverina Station Homestead about 60 km west of Menzies (Fig. 6.3).

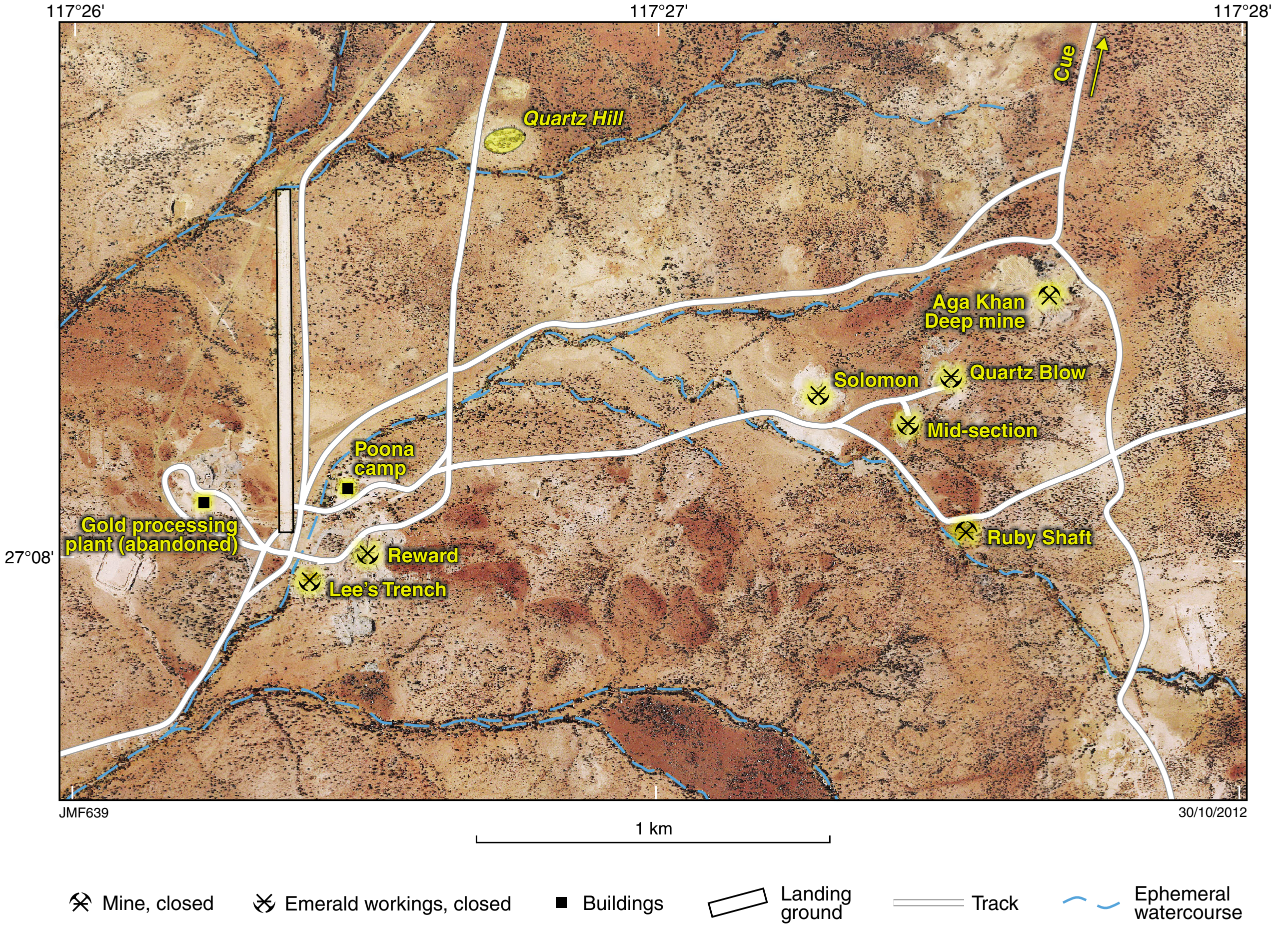


Figure 6.4 Location of emerald mining operations at Poona, Cue region (after Grundman and Morteani, 1998)

Emeralds were discovered circa 1974 and mining commenced in that year. Mining continued intermittently until 2003, producing both specimen- and facet-grade material. The largest working comprised an opencut 38 m in length and depth to 7 m (Garstone, 1981). During this period, North Kalgurli Mines Ltd conducted a complete geological evaluation of the emerald deposits including drilling and mapping. Metallurgical testwork was inconclusive and the project did not advance (Mumme, 1982).

At Wonder Well, emerald-bearing pegmatites occur within a northerly trending greenstone belt composed predominantly of mafic lavas and sedimentary rocks with intercalated ultramafic bodies (Fig. 6.5). The mafic lavas have been metamorphosed to chlorite–amphibole–plagioclase schist, whereas the ultramafic bodies show a more varied mineralogy, changing from chlorite schist and talc schist (close to the surface) to tremolite/actinolite–phlogopite/biotite schist (at depth).

At this site, the beryl-bearing pegmatites comprise braided networks of plagioclase–quartz veins which are concordant with the foliation of the enclosing phlogopite and biotite schists and amphibolites. Metamorphism and metasomatism associated with the pegmatite emplacement have resulted in selvedges comprising predominantly 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 immediately adjacent to the pegmatites and crystals up to two centimetres long have been found (Fig. 6.6). Associated minerals are biotite, plagioclase, quartz, and topaz (Garstone, 1981).

Coolgardie region

Bullabulling *(Dunsville, 3036)*

The Bullabulling emerald deposit is located immediately north of the main Perth to Kalgoorlie highway, approximately 22 km west of Coolgardie (Fig. 6.3).

According to Sullivan (2000), beryl was discovered in 1987 within an area of biotite schists situated at the extreme western end of the Archean Norseman–Wiluna Greenstone Belt composed of metamorphosed mafic and ultramafic sequences overlain by felsic lithologies. Extensive Archean granite bodies surround the volcanic sequences and smaller intrusives with associated pegmatites occur within them. The beryl mineralization at Bullabulling occupies 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 sent to South Africa for gemmological examination. The emeralds were found to have well-developed crystal symmetry and be 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.

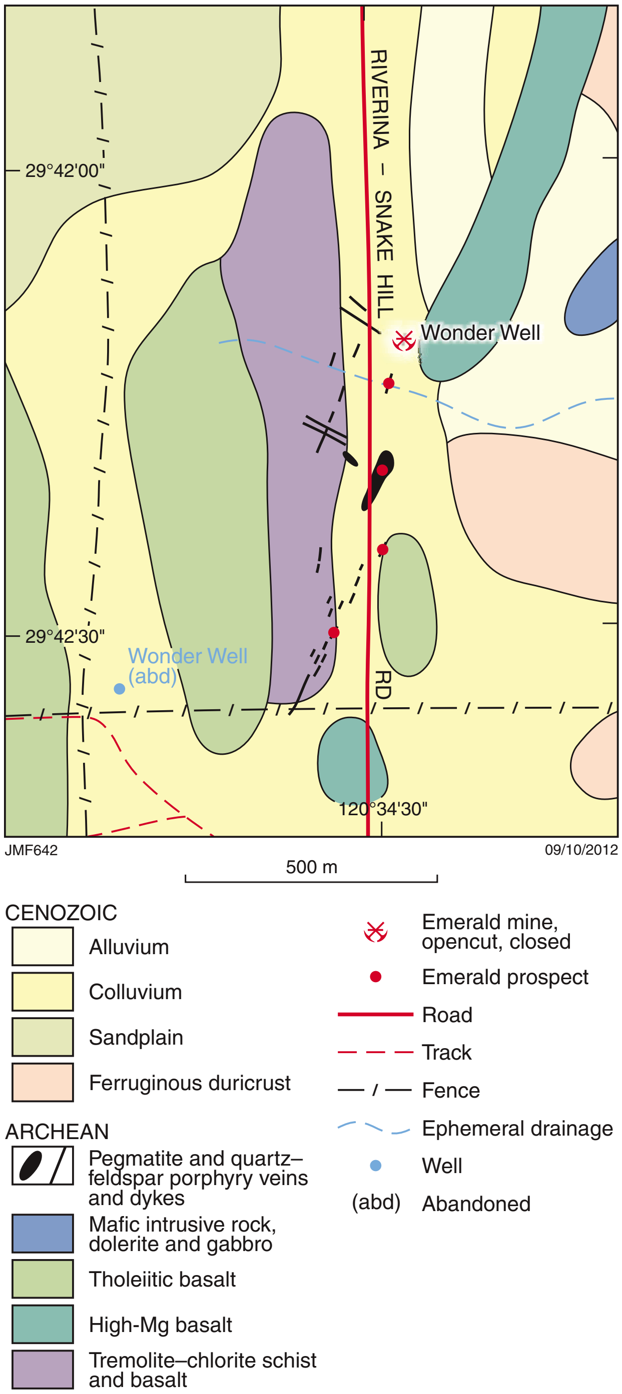


Figure 6.5 Geology of the Wonder Well emerald-bearing pegmatites at Riverina, Menzies region (modified after Wyche and Swager, 1996; Garstone, 1981)

Coolgardie area (*Coolgardie, 3136*)

There are unconfirmed reports of a small occurrence of emerald at an unknown location a few kilometres northeast of Coolgardie, to the north of the Great Eastern Highway between Coolgardie and Kalgoorlie. A sample of material from the deposit comprises biotite–phlogopite schist crowded with numerous emerald crystals up to 25 mm in length. Most emeralds are fragmented, flawed, and contain inclusions, but some do contain clear areas that may be suitable for faceting. There are reports of some faceted stones from this deposit although no further information is available.

Pilbara Craton

The names, locations and general descriptions of the various emerald occurrences in the Pilbara Craton given by various authors tend to be somewhat 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.

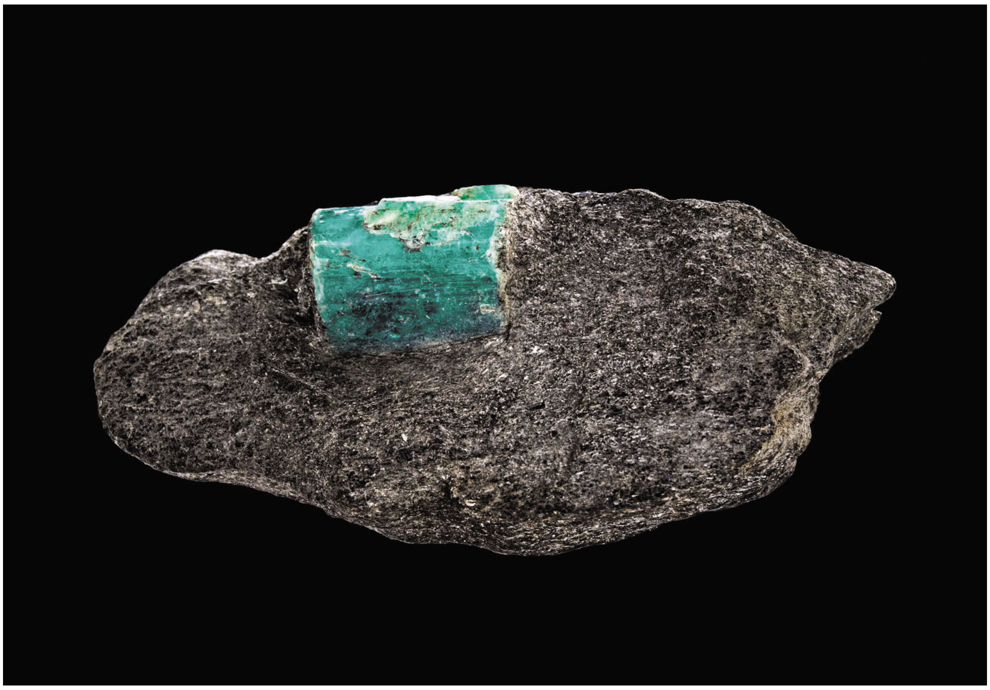
Jacobson et al. (2007) reported emerald discoveries from at least seven localities: McPhees Hill, an unknown locality north of the main tantalite dyke at Wodgina, Friendly Creek, Tambourah, a site southeast of Roebourne, the Curlew deposit at Tambourah, and at Desert Rose near the Shaw River. While some 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 6.3.

Tambourah region

Curlew emerald mine (*Tambourah, 2754*)

The Curlew emerald mine (also known as White Quartz Hill or Calverts) is situated on the western side of the Shaw River on Hillside Station, approximately 65 km southwest of Marble Bar (Fig. 6.3). 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 but there is no recorded mining activity until 1976; the first leases were pegged around 1967 (Laurie, 1982). At that time, a preliminary assessment of the site revealed the deposit contained about 2500 t of emerald-bearing material (Jacobson et al., 2007). Mining commenced in 1977 by the small syndicate 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 contained a 600 ct emerald which was later shown to be too flawed to be facetable. Mining operations comprised at least two shafts, one large opencut, and numerous pits and costeans. The main shaft was sunk to a depth of 14 m; the opencut was originally an area of underground mining where stoping took place from 14 m depth to the surface.



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20 mm

Figure 6.6 Emerald crystal in schist, Wonder Well deposit at Riverina in the Menzies region (courtesy Australian Museum)

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 to be 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:

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

It was 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.

Geology of the Curlew mine area

Archean metavolcanics 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. 6.7).

The fault zone trends northerly and dips steeply to the west. 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 constitute a narrow zone, not exceeding 1.5 m wide and 250 m in length, of biotite or phlogopite schists containing boudins of quartz and pegmatite. These mica schists contain gem-quality emerald and green beryl occurring as medium- to coarse-grained crystals, which range from less than 1 mm to larger crystals up to several centimetres in diameter (Fig. 6.2).

Emeralds of good colour are also found within the quartz veins but are crowded with inclusions, whereas 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 occurring 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 located about 90 km southwest of Marble Bar on the old road from Woodstock Station to Hillside Station (Fig. 6.3).

Wodgina region

Mount Cassiterite pegmatite field *(Wodgina, 2655)*

The Mount Cassiterite pegmatite field at Wodgina is situated 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. 6.3).

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, reaching up to 10 mm in length and 5 mm in width, occurred as prisms embedded in feldspar. 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-southwest of Port Hedland within the Yandeyarra Aboriginal land (Fig. 6.3). Permission of the Aboriginal Council is required for access.

Mount Francisco and the surrounding area are composed of ultramafic rocks with lesser amounts of amphibolite schist, metabasalt, and metasedimentary rocks. This structure 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 also contained the reported emeralds. No further information is available.

Pilgangoora *(Wodgina, 2655)*

The Pilgangoora pegmatites are located about 85 km south-southeast of Port Hedland. Access is via the Great Northern Highway, the Port Hedland railway access road, the Port Hedland to Wittenoom road, and station tracks (Fig. 6.3). Emeralds of variable quality have been found in pegmatites intruding ultramafic schists 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 referred to as McPhee Hill) emerald occurrence is uncertain but appears to be located approximately 85 km south-southeast of Port Hedland and about 6–7 km north of Lynas Find (Fig. 6.3). 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 were 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 being sourced from Friendly Creek, approximately 110 km south-southwest of Port Hedland and 1 km from Bamboo Creek on Sherlock Station although the exact location is uncertain.

Roebourne region

Mount Hall pegmatites *(Roebourne, 2356)*

Emeralds have been reported previously from a locality 9.6 km southeast of Roebourne near Mount Hall (Fig. 6.3). At this site, narrow prisms of flawed green beryl have been 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

Upper Gascoyne 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. 6.3). These pegmatites were mined on a small scale for beryl and columbite and were also favoured as a source of gemstones such as amethyst and dravite. The pegmatites are of the beryl–columbite class and most occur within muscovite schists and migmatites of the Morrissey Metamorphics. Emeralds have been recovered from stream sediments at Morrissey Hill, 12 km north of Yinnetharra Homestead, and from an opencut at Camel Hill. More detailed location data relating to these deposits is given under Yinnetharra aquamarine.

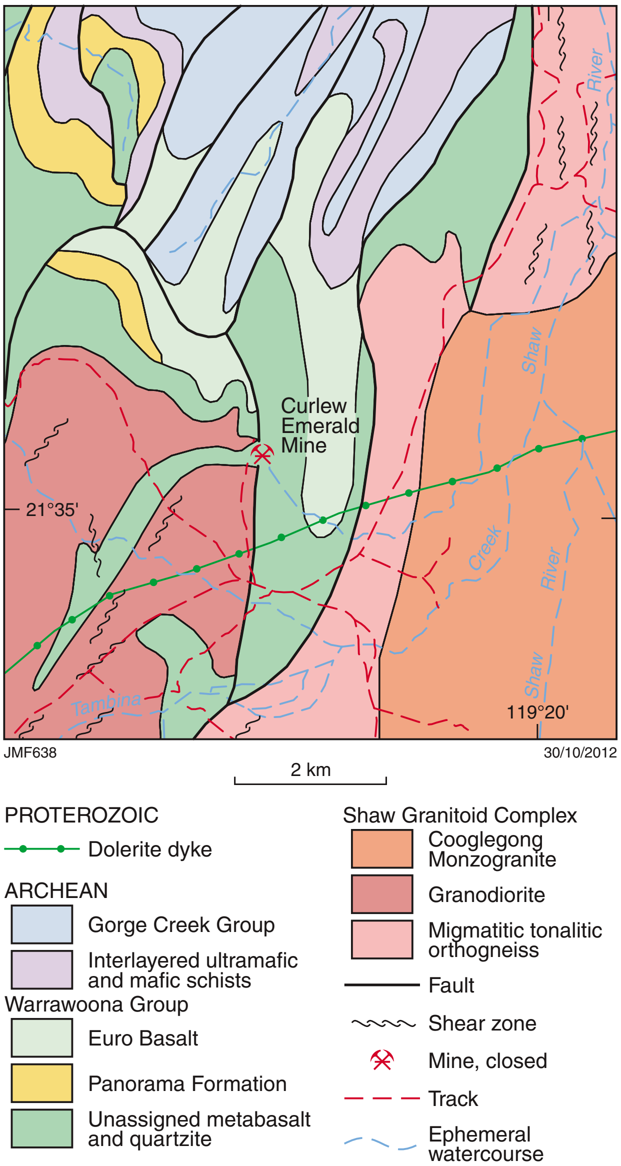

Figure 6.7 **Geology of the area surrounding the Curlew emerald mine, Tambourah region (modified after Van Kranendonk, 2003)**

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. 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 in either transparent or semi-transparent form. Aquamarine, as a varietal name, was so named after the similarity of its colour to that of the sea.

The colour of aquamarine is attributed to divalent and/or trivalent iron (Fe^{2+} and Fe^{3+}; maximum 1.5% FeO and 0.96% Fe_2O_3). Iron in the two valency states occurs in 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 is not in the correct crystallographic site, no colour results.

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

Although facet-grade material can be cut in any style, aquamarine is commonly faceted as ‘emerald cut’ that 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 (as well as other high-quality pink, colourless, and yellow varieties of beryl) has been found, but it appears production sites for these stones were never recorded. Occurrences of aquamarine have been reported from a number of pegmatites in Western Australia.

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 (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

Gascoyne Province

Upper Gascoyne region

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

Extensive beryl-rich pegmatite fields are present on Yinnetharra Station about 175 km to the east-northeast of Gascoyne Junction (Fig. 6.3). Gem beryl occurrences including aquamarine, emerald, and heliodor have 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 6.8 and 6.9a–c).

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 occur 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) recorded several specific pegmatites containing aquamarine, though not necessarily of facetable size or clarity:

- In the Thirty One River pegmatite field, Williamsons beryl mine (possibly the same as the Lake Moore mine) forms a conspicuous conical hill on the west bank of the Thirty One River (Fig. 6.9a) Among the reported minerals recovered that include manganocolumbite, uranpyrochlore, uranmicrolite, and chrysoberyl were aquamarine and heliodor. A 10.2 ct light-coloured aquamarine is reportedly from Williamsons beryl mine (Fig. 6.10).
- In the Morrissey Hill pegmatite field, the Roe and Hassell pegmatite workings are located on the east bank of Morrissey Creek, approximately 2 km southeast of Mica Well (Fig. 6.9b). 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, located about 9 km north of Morrissey Hill (see under Tourmaline, page 59).
- Kenyon (1993) records the common occurrence of blue-green aquamarine in the Camel Hill pegmatite field approximately 1.5 km southwest of Camel Hill (Fig. 6.9c). He commented that the distribution of aquamarine in the pegmatites was erratic but that 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 as that mentioned in Gemstones in Western Australia (Geological Survey of Western Australia, 1994) which recorded 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.

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Giles pegmatites at Spargoville (*Yilmia, 3135*)

The Giles columbite–beryl pegmatites are located about 3 km southeast of Spargoville and 45 km southeast of Coolgardie. They are situated about 600 m west of the Norseman–Coolgardie road and are accessed by dirt roads (Fig. 6.3).

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 four tonnes of columbite were 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 finest 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 in length 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 occurs as 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. Glassy, green zones are present within the interiors of some of these crystals that may be facetable. It has been reported that facetable blue to blue-

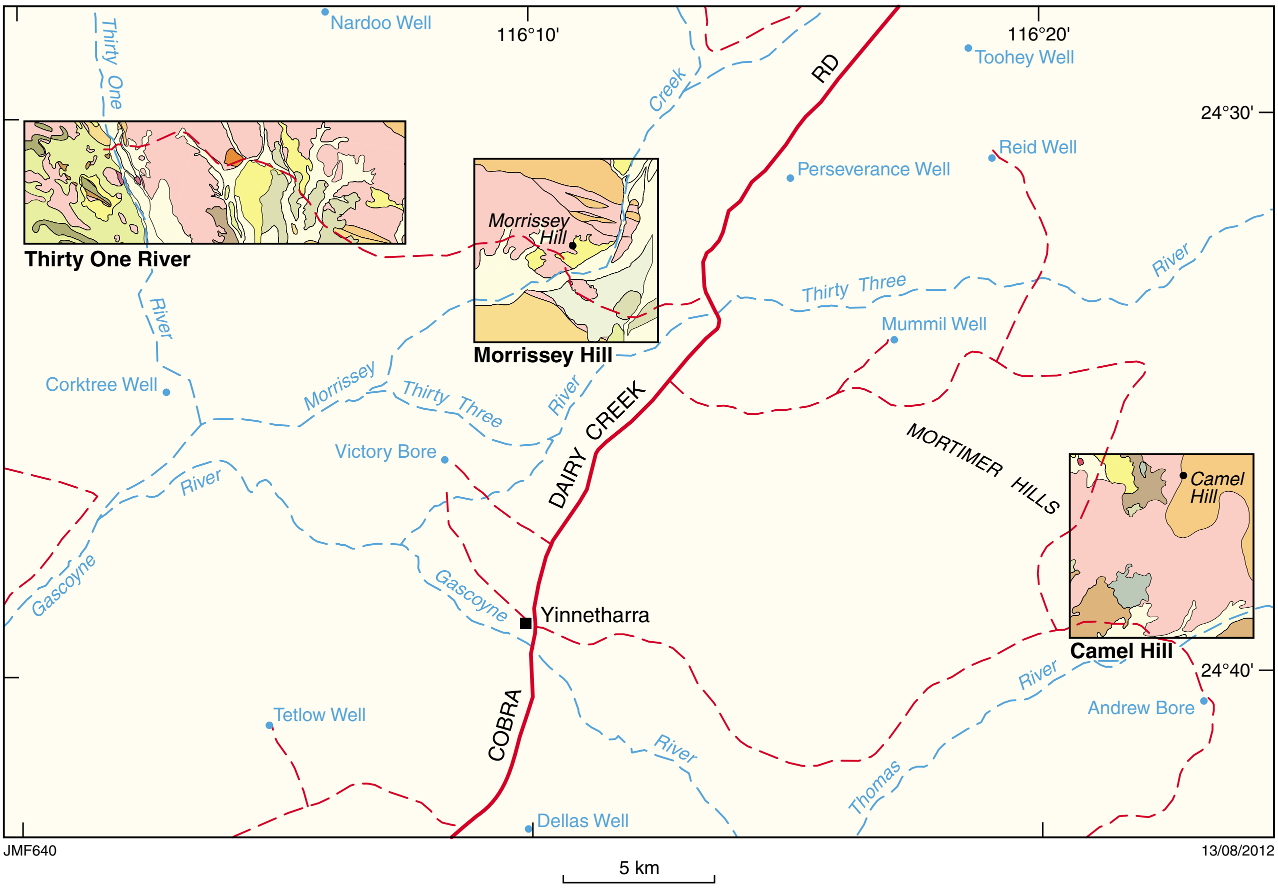

Figure 6.8 **Location of gem beryl mining areas at Yinnetharra, Upper Gascoyne region**

green beryl was found on the mine dumps (Reeve, 1973). The Australian Museum in Sydney has a 1.49 ct round brilliant-cut aquamarine from Spargoville (Fig. 6.2b).

Yilgarn Craton — Murchison Domain

Cue region

Poona *(Noondie, 2343)*

There are reports of small aquamarine crystals being found in the old dumps at Poona about 55 km northwest of Cue (Fig. 6.4) 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 usually 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 — Murchison Domain

Paynes Find area

Goodingnow pegmatites *(Maranalgo, 2439)*

The Goodingnow pegmatite prospects are situated in the Mount Edon pegmatite field in the Paynes Find area. Spaced about 400 m apart, the two pegmatite pits (northern and southern) are located about 400 m northeast of Mount Edon on former prospecting licence P59/7104 (Fig. 6.3).

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,

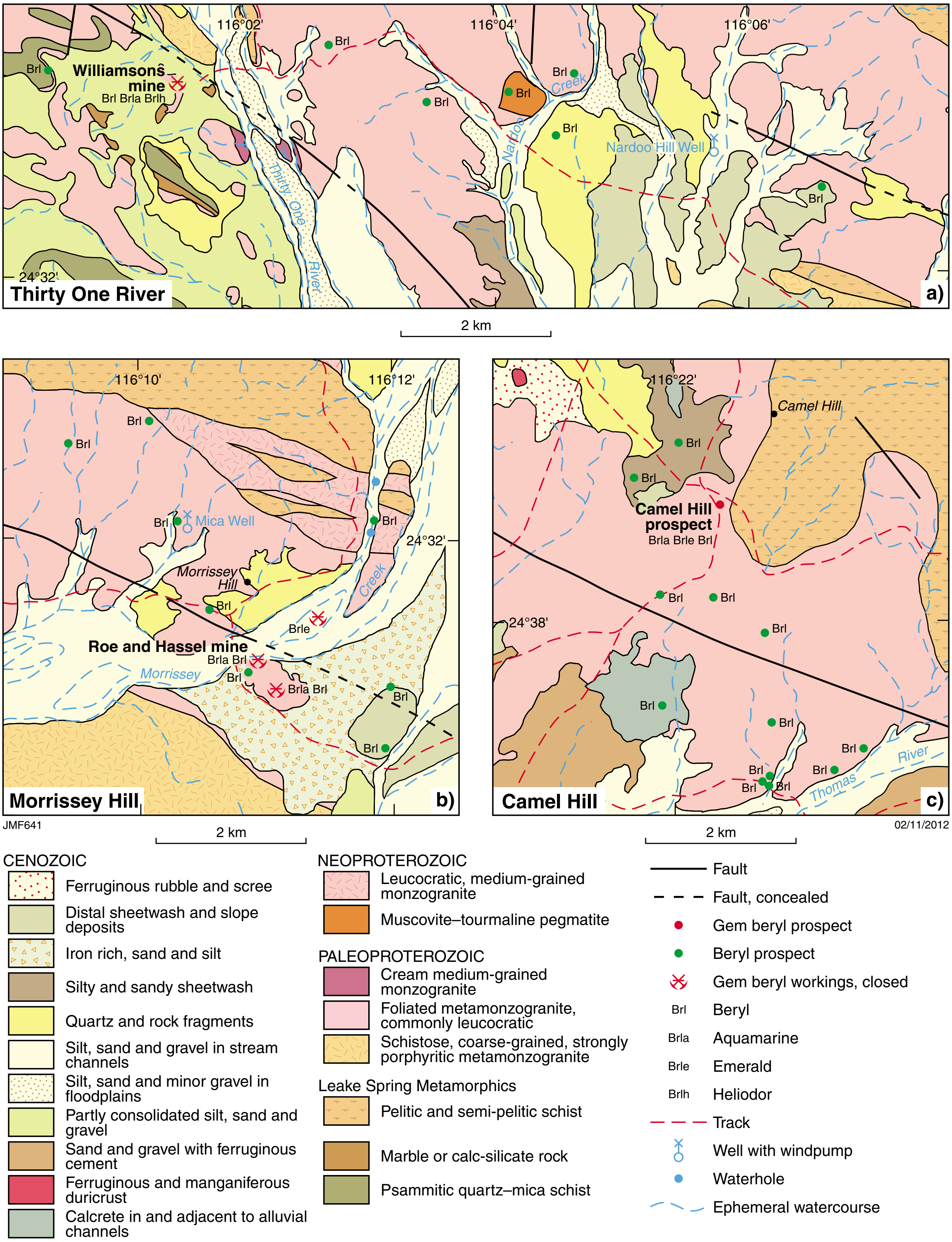

Figure 6.9 Geology of gem beryl mining areas at Yinnetharra (modified after Sheppard et al., 2008)

the Goodingnow pegmatites produced 5.85 t of beryl, mostly from the northern pit, including 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).

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 6.4 but there are no details of exact locations. The Australian Museum has a 3.5 ct cushion-cut morganite from Poona (Fig. 6.2d).

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry (Yilmia, 3135)

The Londonderry pegmatite is located 19 km south-southwest of Coolgardie. Access from Coolgardie is via the Nepean Road and thence west along a prominent dirt road (Fig. 6.3).

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 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 situated 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 thence north along a dirt road (Fig. 6.3).

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-northeasterly, 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 occurring with topaz.

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. 6.3).

Heliodor and goschenite

Heliodor is a variety first named in 1910 for the golden-yellow beryl found in granitic pegmatites near Klein Spitzkoppjie in Namibia. Heliodor from the original finds were stated to be weakly radioactive and yellow beryls elsewhere 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 that often contain small amounts of radioactive elements can induce a yellow colour by ionizing the iron in beryl and changing divalent iron into trivalent iron. This causes a colour change from blue to green to yellow.

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

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

Gascoyne Province

Upper Gascoyne region

Yinnetharra area (Yinnetharra, 2148)

In addition to the aquamarine produced at Williamsons beryl mine in the Thirty One River pegmatite field, the mine was also reported to contain the golden-yellow beryl heliodor (Fig. 6.10).

Yilgarn Craton — South West Terrane

Donnybrook region

Katterup area (Donnybrook, 2030)

The Katterup pegmatite is located approximately 10 km east-northeast of Donnybrook. 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. 6.3). The location is on freehold land and will require 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*)

Olivers pegmatite, one of the Mullalyup group of pegmatites, is located approximately 22 km south-southeast of Donnybrook and 800 m west of the former Mullalyup railway station (Fig. 6.3). In this vicinity a narrow pegmatite, 1.3 m in width, is intruded into quartz–feldspar–biotite gneiss. One visually attractive, terminated yellow beryl (heliodor) 2.5 cm in length and 1 cm in diameter is reported from this location (Fig. 6.2c).

Other beryl occurrences

King Leopold Orogen

Derby region

Mondooma Creek (*Tarraji, 3764*)

The Mondooma Creek mica–beryl pegmatite at Stewarts East prospect is located immediately west of the Kimberley Downs to Mondooma road, approximately 6.5 km south of Mondooma and 95 km northeast of Derby (Fig. 6.3). 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 Marboo Formation in the Paleoproterozoic Hooper Province. 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 (Jacobson et al., 2007).

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry (*Yilmia, 3135*)

The Londonderry pegmatite, located 19 km south-southwest of Coolgardie, already discussed under morganite, is also reported to contain dark green, yellow, and colourless beryls. These beryls are often 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. 6.3).

Grosmont (*Yilmia, 3135*)

The Grosmont pegmatite (Fig. 6.3) described above is also reported to carry colourless beryl together with pink morganite.

Figure 6.10 Gem beryl stones from Williamsons beryl mine in the Yinnetharra area. The figure shows a large, uncut, pale green aquamarine (left); a smaller, uncut, yellow heliodor (right); and a 10.2 ct emerald-cut aquamarine (below) (courtesy Gemrock Enterprises)

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Chapter 7 Tourmaline group

The tourmaline group

The tourmaline group of minerals comprises complex aluminium borosilicates with a chemical composition constant in their general structure although variable in regard to replacements by substitutional elements. Accordingly, the general aluminium borosilicate composition may be substituted by Mg, Fe, and alkali metals (Ca, Na, K, and Li). Several isomorphous series exist within the group, and minor transitional elements such as Cu, Mn, Cr, V, and Fe are responsible for a number of colour variations. As a result 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 be determined only from chemical analyses since tourmalines of similar colour from different sources may belong to different groups.

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

- **Elbaite**, Na (Al, Li)$_3$ Al$_6$ (BO$_3$)$_3$ Si$_6$O$_{18}$ (OH)$_4$, is the most common variety of transparent gem tourmaline and is associated with granitic pegmatites. Alkali-rich elbaite tourmalines usually 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), Na Fe$_3$Al$_6$ (BO$_3$)$_3$ Si$_6$O$_{18}$ (OH)$_4$, is a ferrous iron-rich tourmaline, commonly black, dark blue, or bluish-green. Schorl occurs 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**, Na Mg$_3$ Al$_6$ (BO$_3$)$_3$ Si$_6$O$_{18}$ (OH)$_4$, tourmalines are magnesium rich and are commonly isomorphous with schorl when ferrous iron (Fe^{2+}) substitutes for magnesium. 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 triangular in section and terminated by a combination of pyramidal or basal pinacoid faces. 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/or pressure that induce electrical charges in crystals. Electrical polarity is likely to be 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 from Spargoville in the Kambalda region display this duality of colours (Fig. 7.1).

Although the principal hosts of all tourmaline gemstones are pegmatite and quartz veins directly or indirectly related to granitic intrusions, tourmaline also occurs 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 as a result of boron metasomatism, an example of

Physical properties of tourmaline

Crystal system	Trigonal
Habit	Prismatic
Surface features	Crystal faces often exhibit etch pits. Prism faces may be vertically striated and may appear rounded to barrel-shaped
Lustre	Vitreous
Hardness	7.0 – 7.5
Fracture	Subconchoidal
UV fluorescence	Inert

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)

which is given in the following chapter on tourmalite and warrierite, a massive variety of tourmaline from Warriedar Station in the Lake Mongers region.

Transparent forms of gemstone-quality tourmaline crystals are usually cut and faceted in elongated rectangular step-cuts that maximize the weight recovered from prismatic crystals. Colour-zoned varieties are often 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.

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; one at Spargoville in the Coolgardie region where blue-green elbaite occurs, and a deposit of pink to intense red rubellite tourmaline south of Southern Cross. Locations for the main tourmaline group mineral deposits in Western Australia are given in Figure 7.2 and more accurate locations are given in Appendix 1.

Tourmaline in Western Australia

Yilgarn Craton — Eastern Goldfields Superterrane

Spargoville, Kambalda region

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. 7.2). 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 in length and 10 mm diameter. From this initial find, other specimen crystals around 30–40 mm in length were found, and from these, 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 in length and 12 mm in 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 that they may have originated from clay-filled vugs or pockets.

In the 1960s, the location of the Giles elbaite pegmatite was re-established and pegged. It was worked to about 1966 with pink, green, blue, and watermelon-coloured elbaite taken from an area known as the western pit. The steeply dipping pegmatite trends in an easterly direction over a length of at least 200 m with a 1–2 m thickness 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 on the other. The central core contains cleavelandite, quartz, elbaite, fine-grained lepidolite, and minor beryl and schorl.

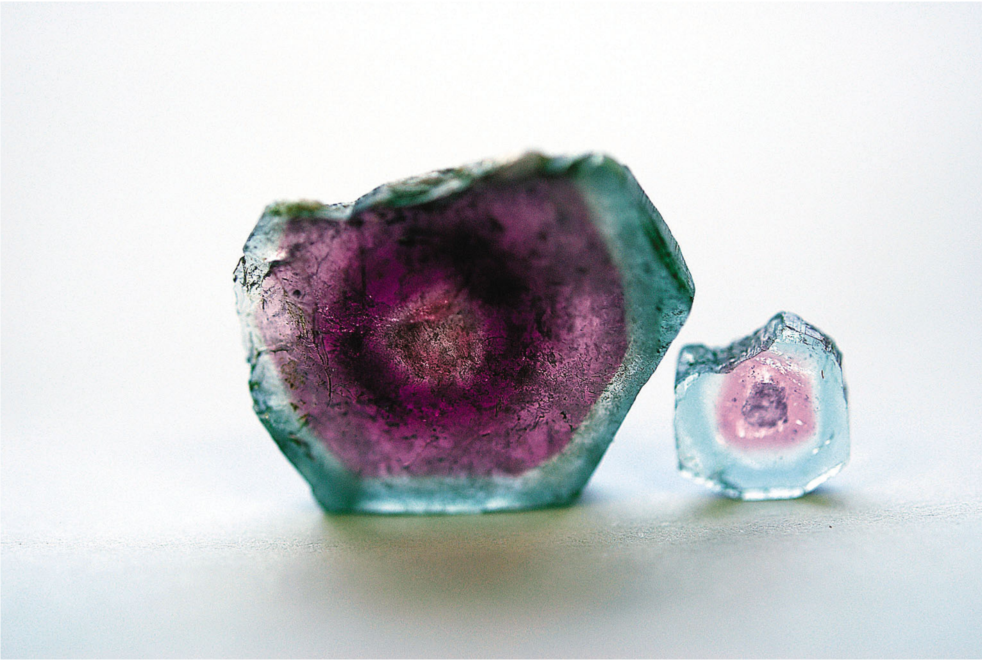

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Figure 7.1 **Green, blue, and pink watermelon tourmaline from Spargoville in the Kambalda region. The smaller crystal measures 6 mm in diameter (courtesy Vernan Potter)**

After 1966, a number of 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. 7.2). 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 1m 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 which has produced green and blue gem-quality elbaite is the Dalglish prospect located about 6 km south-southwest of Spargoville on prospecting licence P15/4783 (Fig. 7.2).

The prospect consists of a shallow pit about 1.6 m deep and up to 12 m in diameter (Fig. 7.3). 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 bicoloured green and blue when viewed perpendicular to the principal axis, and concentrically zoned in shades of blue. Colours in the bicoloured 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.

Evaluation of chemical analysis of five specimens indicated 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 to 55 mm, with the largest weighing 3120 ct (Fig. 7.4; Payette and Klemm, 2011).

Yilgarn Craton — Southern Cross Domain

Mount Holland area

Forrestiana rubellite pegmatite (Holland, 2833)

The Forrestania rubellite pegmatite deposit (also known as the Southern Cross rubellite deposit) is located 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. 7.2).

The discovery of tourmaline on the periphery of a narrow belt of northerly-trending Archean greenstones was made by Kim Robinson and Associates in the 1970s during an

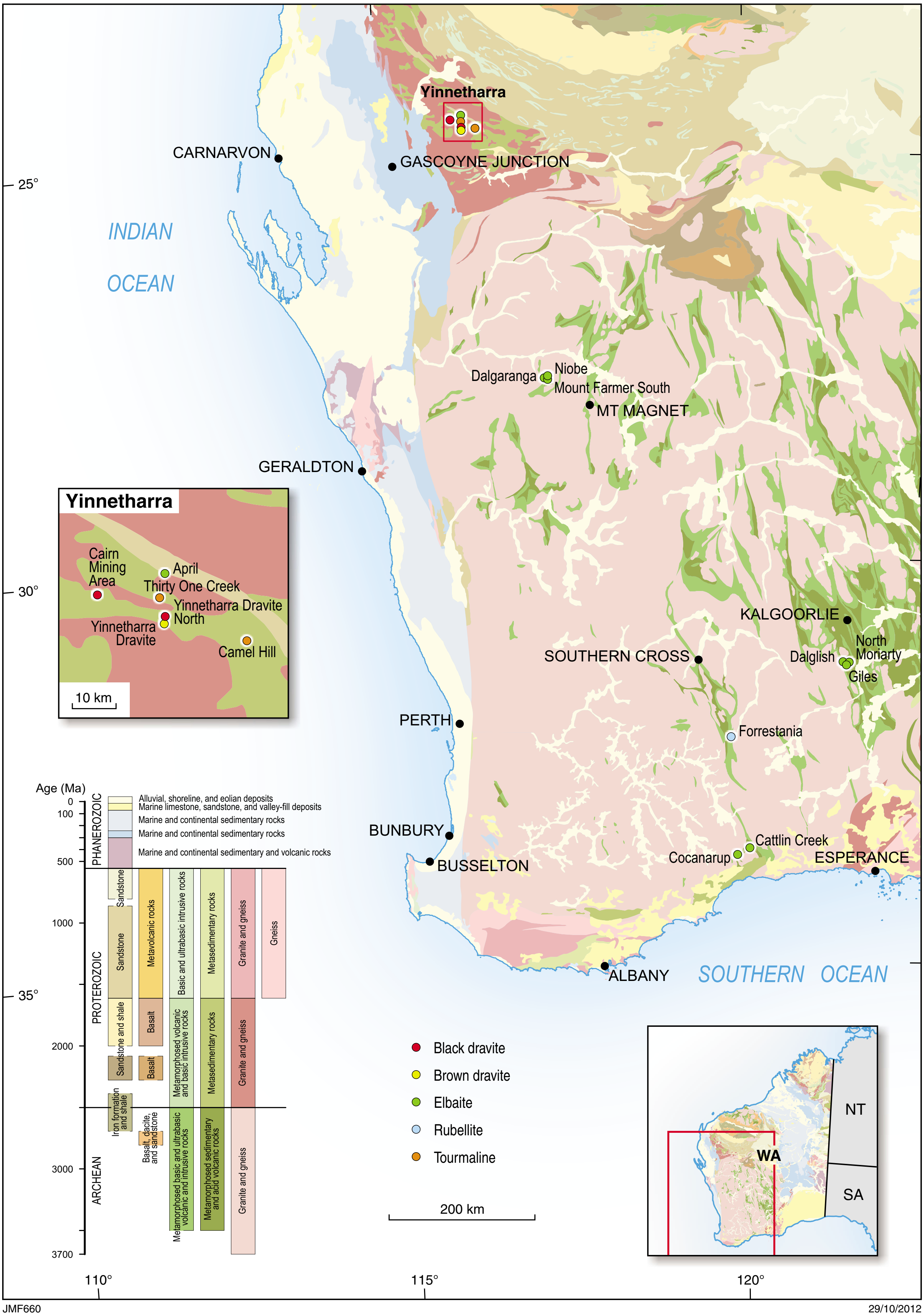

Figure 7.2 Location of tourmaline group minerals in Western Australia

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Figure 7.3 **The Dalglish prospect in the Spargoville area has produced green and blue gem-quality elbaite tourmaline. The exploration pit is approximately 12 m in diameter x 1.6 m deep (courtesy Francine Payette)**

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Figure 7.4 **Faceted blue-green elbaite gemstone (2.39 ct) from the Dalglish prospect near Spargoville in the Kambalda region (courtesy Australian Museum; photographer Stuart Humphreys)**

exploratory 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 later 1990s, pegmatite mining ceased and apart from visits by fossickers 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 via a gem shaft located on the northwest side of the east–west openpit.

The Forrestania pegmatite has been intensely weathered to a clay-like material. It appears likely that the rubellite tourmaline occurred within gem pockets located in a central pegmatite zone because 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 multi-coloured tourmaline stones, although there is no record relating to their quality.

Ravensthorpe area

Cattlin Creek pegmatites *(Ravensthorpe, 2930)*

The Cattlin Creek pegmatites are situated about 2 km north of the town of Ravensthorpe in the far south of the State (Fig. 7.2). 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, as well as a number of granitic bodies ranging from quartz diorite to tonalite. The Cattlin Creek pegmatites comprise several large, flat-lying tabular sheets up to 800 m in length 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 a number of feasibility studies for tantalum and lithium were carried out on this pegmatite-rich area but 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 tonnes per annum 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 but the general change in colours within crystals from core to margin follows a pink–darker pink–colourless–light green–dark green pattern. 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 located in hilly country about 16 km west-southwest of Ravensthorpe (Fig. 7.2). 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 plus a number of smaller sheets. These pegmatites have intruded Archean rocks comprising amphibolite gneiss of the Annabelle Volcanics, plus 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, and 0.75 t columbite–tantalite with lithium minerals amblygonite, lithiophilite, and lepidolite.

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

Yilgarn Craton — Murchison Domain

Dalgaranga area

Dalgaranga pegmatites (DALGARANGA, 2342)

The closed Dalgaranga pegmatite opencut is located about 80 km northwest of Mount Magnet (Fig. 7.2). The mine, on mining lease M59/106, was operated as a tantalum mine by Tantalum Australia NL until 2002 when it was closed owing 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) and the Mount Farmer South pit, 5 km east-northeast and east-southeast respectively. 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 east-northeast of Gascoyne Junction (Fig. 7.2). Tourmaline is found mainly 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 located about 2 km west-southwest of Camel Hill but no information about this site is available. Green elbaite has also been recorded from the April pegmatite, 9 km north of Morrissey Hill (Fig. 7.5a–c).

In past years, the Yinnetharra area was notable for the occurrence of rare tantalum–niobium minerals as well as potential gem minerals such as beryl, emerald and aquamarine (see Beryl Group, Chapter 6), chrysoberyl, corundum, variscite, amethyst, rose quartz, garnet, and diopside. Simpson (1951) stated that brown dravite tourmaline crystals were first collected near Morrissey Hill in 1918, and numerous, small to large, prismatic crystals of black shorl (now demonstrated to be black dravite) were found in pegmatite veins on Morrissey Hill. The area was a small, intermittent producer of muscovite mica, 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. 7.5a). Between January 1969 and January 1971, the Soklich Trading Company mined the tourmaline from the Yinnetharra dravite openpit located 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 some 75% were high-quality, euhedral, doubly terminated crystals. These crystals were sold mostly 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. Maximum recorded weight of a single crystal was around 11.5 kg (Bridge et al., 1977).

At the Yinnetharra dravite openpit, mining was carried out using front-end loaders following limited blasting to loosen the mica to ease crystal extraction. Dravite crystals were found sporadically within pockets and production was unpredictable. Also, near-surface crystals were found to be of generally poor quality because of fracturing and the main excavation zones were located 3–6 m below surface. Crystals are brown with most appearing opaque although translucent in thin section; they have vitreous lustre with surfaces commonly indented by small booklets of mica. They occur as 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 often pockmarked by phlogopite and plagioclase, and in the upper levels of deposits are commonly encrusted by secondary opal and carbonates formed as a result of weathering. At the Yinnetharra openpit, crystal habits of dravite are varied but many are almost equidimensional or equant with short prismatic zones terminated by rhombohedra, superficially resembling the dodecahedral morphology of garnets, which initially caused confusion among collectors. Crystal forms present include the hexagonal prism, trigonal prism, and rhombohedral terminations.

At the Yinnetharra North deposit, 1.5 km 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,

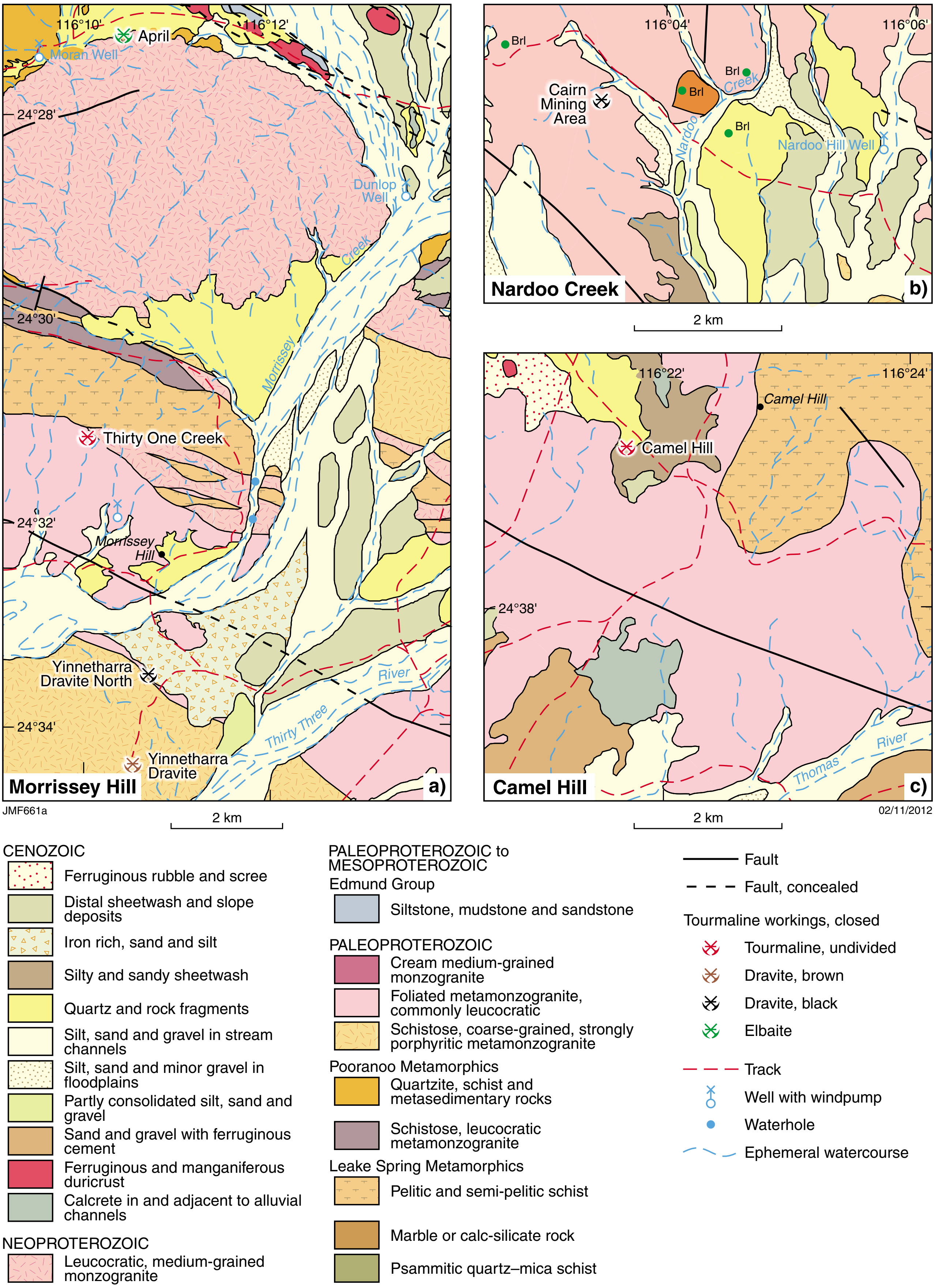

Figure 7.5 **Geology of the gem tourmaline mining areas at Yinnetharra (modified after Sheppard et al., 2008)**

with an MgO content of 9.85%. The Yinnetharra North deposit, located on former mineral claim MC09/215, is situated 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. 7.6). 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, located 2.5 km north-northwest of Morrissey Hill, is an old shallow pit known as Thirty One Creek (Fig. 7.5a). 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 located about 13 km west-northwest of Morrissey Hill (Fig. 7.5b). 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 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 located 9 km north of Morrissey Hill (Fig. 7.5a). 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, but these were too fractured to be classed as gem quality.

A set of specimens held by the Western Australian Museum shows the opaque green elbaite crystals, up to 30 mm long and 10 mm in diameter, enclosed in albite and associated with milky quartz and fine-grained lepidolite (sample number: MDC 4968).

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Figure 7.6 Black dravite crystals from Yinnetharra. These large, euhedral, terminated crystals, set in a black phlogopite schist, are approximately 15 cm in length x 5 cm in diameter (courtesy Mark Creasy and David Vaughan)

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Chapter 8 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 located 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. 8.1). 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 that 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, and high-quality polished cabochons were cut and animals carved and polished. 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. 8.1). 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).

Tourmalite and warrierite

Mg–Fe-rich tourmalite (dravite–schorl series)
$[Na(Mg,Fe)_3Al_6(BO_3)_3Si_6O_{18}(OH)_4]$

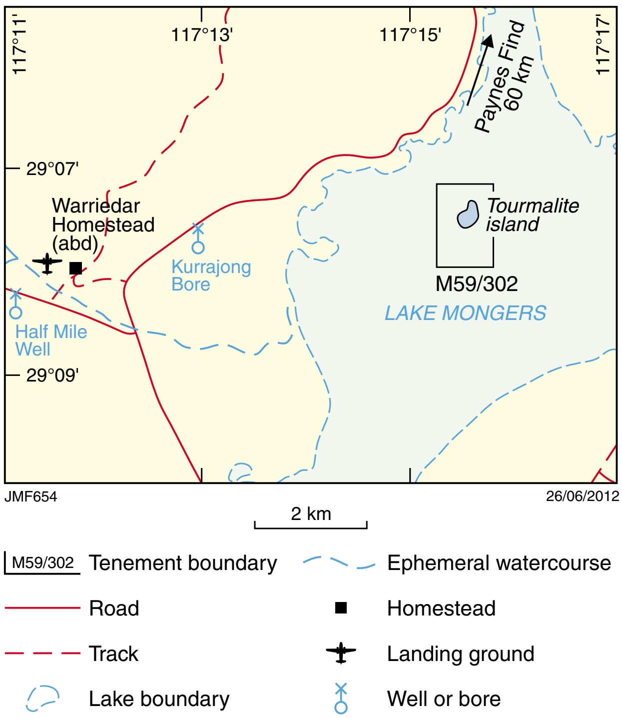

Figure 8.1 Location of the tourmalite island and mining lease M59/302 in Lake Mongers

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, ultra-fine-grained texture, uniform black colour, and ability to be polished to a high lustre. This led to the name 'Warrierite' being devised for marketing purposes. Today, mining lease M59/302 is owned by Aradon Pty Ltd.

More detailed locational information on the Warriedar tourmalite deposit is given in Appendix 1.

Regional geology

A suite of folded, Archean greenstone rocks of the Warriedar Fold Belt lies in the area immediately north of Warriedar Homestead, and west of Lake Mongers (Fig. 8.2). 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 located 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 sequence 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.

Geology of the tourmalite island

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 northeasterly trend (Fig. 8.2). 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, as well as other finer grained colluvial material.

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

1. Warrierite, a hard (7.0 – 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 ultra-fine 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 those resulting from columnar jointing. High-quality material of this type was classified as A-grade black (Olliver and Thompson, 1995; Fig. 8.3a).

2. The dominant rock type is tourmalite, a hard, mid- to dark grey, mottled quartz–tourmaline rock with varying proportions of each mineral, which

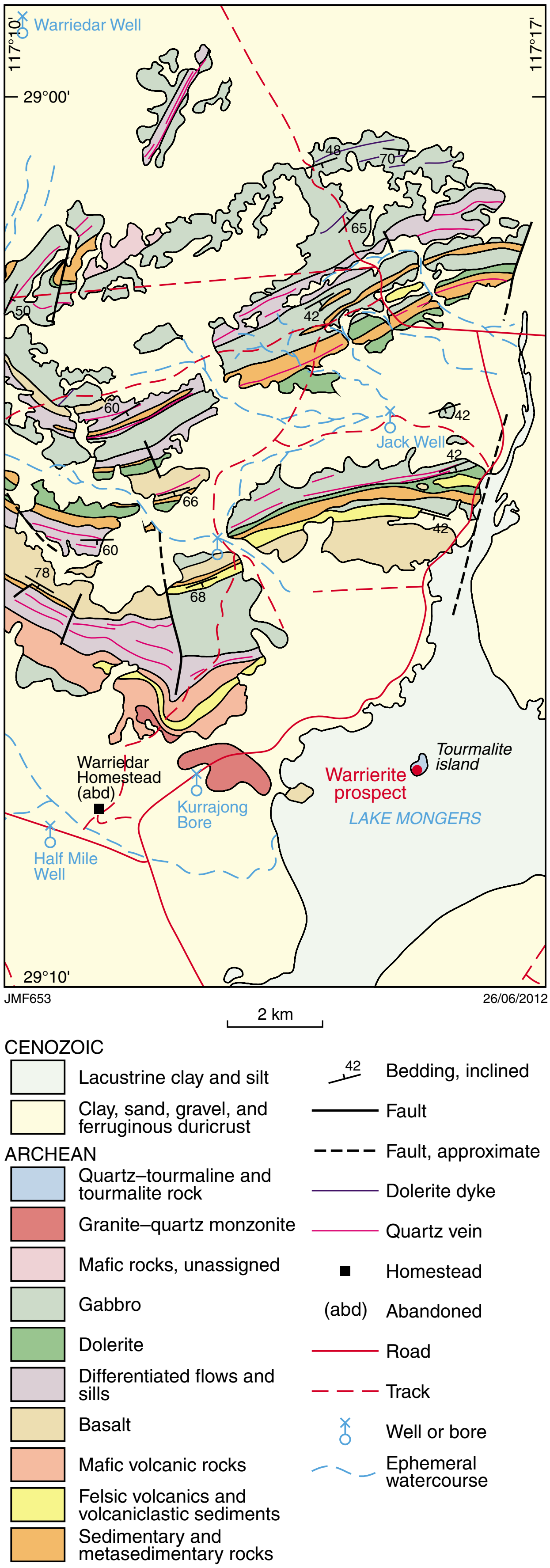

Figure 8.2 Geology of the Warriedar area (modified after Lipple et al., 1982; Baxter, 1991)

determine the rock's colour. The rock is notable for its distinctive ragged blebs, veins, and boxworks of black tourmaline, many of which are distinctly elongate and almost linear. The remainder have an ovoid or subrounded appearance. This material was classified as M-grade mottled (Olliver and Thompson, 1995; Fig. 8.3b).

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 one metre in thickness (Fig. 8.3c).

It is suggested that the warrierite mineralization may have formed by boron-metasomatic replacement of pre-existing 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.

Dravite–schorl series: physical properties

Since 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 for the reader.

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	7.0 – 7.5
Tenacity	Brittle
Specific gravity	3.08 – 3.25
Fracture	Uneven to conchoidal
Processing display (warrierite)	Cabochon cut and highly polished, carved artwork

Warrierite

In hand specimen, warrierite (the massive microcrystalline tourmaline) appears black and homogeneous, it is extremely compact with no visible evidence of crystallinity and breaks with a subconchoidal fracture. Microscopically, it is composed of acicular and fibrous tourmaline generally less than 100 μm in length, loosely packed in subradiating crystal groups as rounded to ovoid spherulites typically

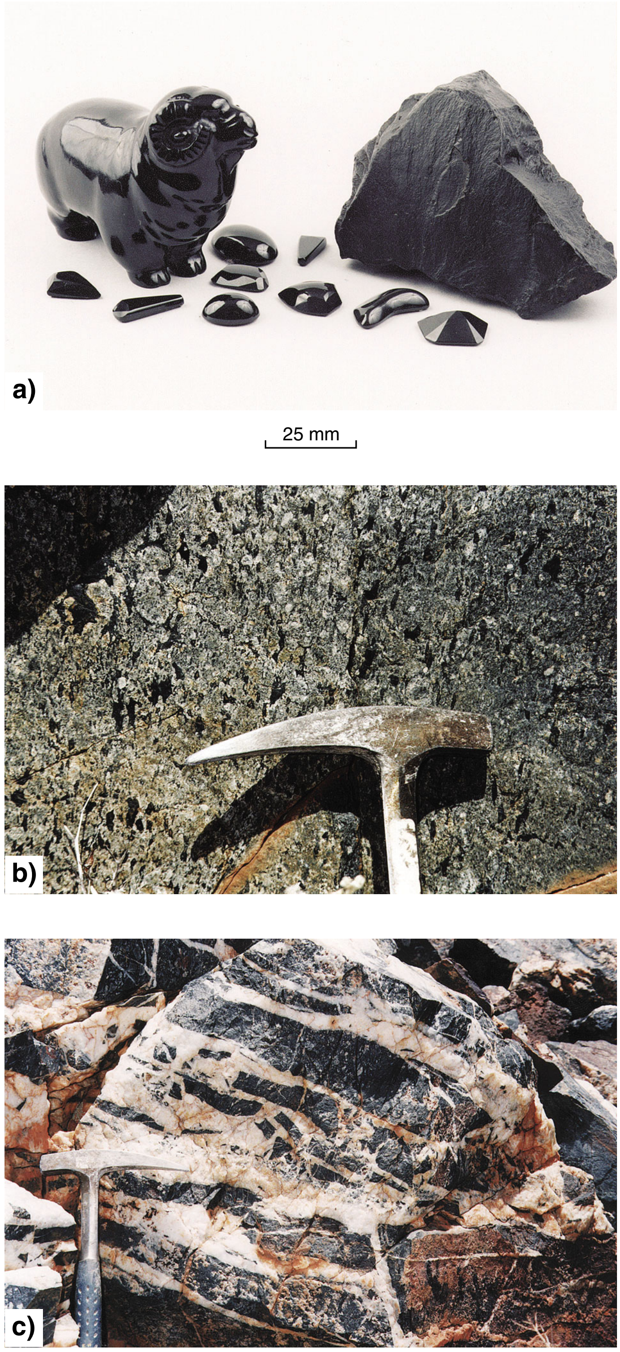

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Figure 8.3 Tourmalite island rock types: a) warrierite, a massive, microcrystalline tourmaline rock (at right) showing its distinctive, conchoidal fracture, with the cabochons and carved merino ram showing the surperb polish that may be achieved; b) 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)

0.1 – 0.2 mm in diameter. Colour within these more regular-size spherulites ranges from almost colourless to pale greenish-blue.

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 homogeneous 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 SEM photomicrographs from Olliver and Thompson (1995). These show randomly oriented and interlocking tourmaline rosettes 50–200 µm in diameter, each displaying a broad fabric of bunches of subradiating crystals, commonly less than 100 µm long (Fig. 8.4a). Individual subradiating prismatic to columnar crystals, showing prominent terminations, can be seen at higher magnification (Fig. 8.4b).

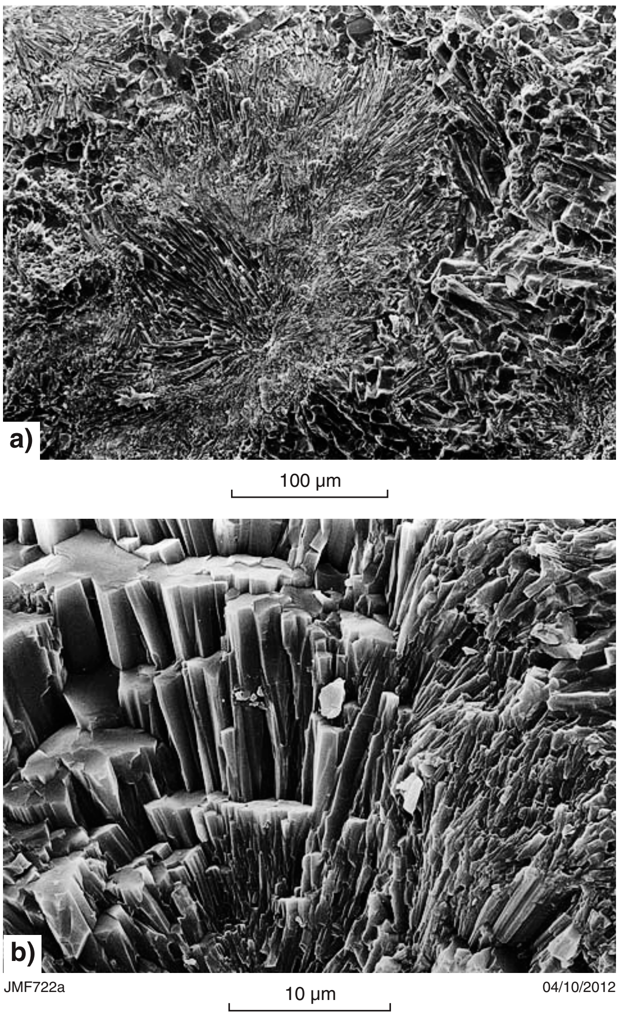

Figure 8.4 **Scanning electron photomicrograph images of warrierite spherulites: a) tourmaline rosettes displaying subradiating crystals commonly less than 100 µm in length; b) higher magnification of individual prismatic to columnar tourmaline crystals showing prominent terminations (after Olliver and 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. 8.5a).

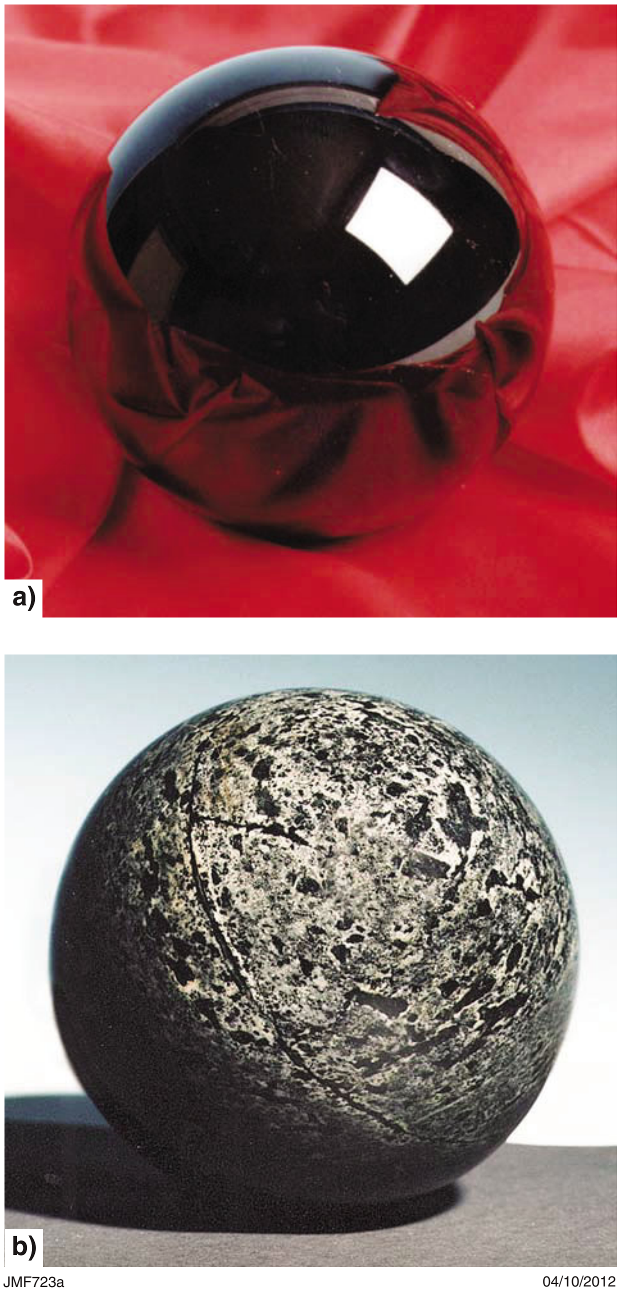

Figure 8.5 **Two polished spheres of lapidary-grade warrierite and tourmalite each approximately 13 cm in diameter: a) highly polished sphere of A-grade black warrierite; b) polished sphere of M-grade mottled quartz–tourmaline rock (tourmalite) (after Olliver and Thompson, 1995)**

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 8.5b.

Further reading

The Warriedar tourmalite deposit is discussed in greater detail in Olliver and Thompson (1995) and Fetherston et al. (1999).

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Chapter 9 Feldspar group

The feldspar group

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

Feldspars occur in rock types that were formed under different physical conditions (high and low temperatures) but form a closely allied group in form and habit. Like quartz, feldspars can be found in large crystals, especially from granitic pegmatite sources. One crystal of feldspar in a quarry north of Kristiansand, Norway, was reported as about 9 x 4 x 2 m in size. Feldpars consititute an important mineral in many ornamental rocks used as dimension stone. Large crystals of feldspar with broad tabular crystal faces and well-developed cleavage provide surfaces for light reflection (Fig. 9.1).

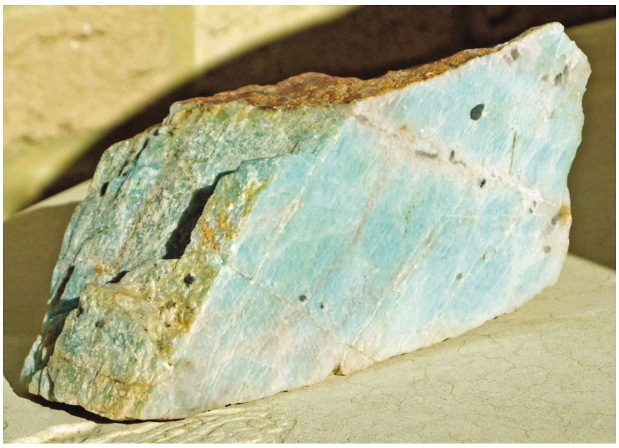

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Figure 9.1 Rough crystal fragment of amazonite feldspar from Paynes Find (courtesy Maria Isaacs)

Feldspar group

Alkali feldspars: orthoclase (monoclinic) and microcline (triclinic) (K, Na) $[Al\ Si_3\ O_8]$
Plagioclase feldspars: : albite – anorthite series (triclinic) Na $[Al\ Si_3\ O_8]$ to Ca $[Al_2\ Si_2\ O_8]$

All feldspar group members crystallize in the monoclinic or triclinic systems and have closely related physical and optical properties. In appearance, they are light-coloured with tabular habit. Most feldspars have complex twinning, sometimes observable in hand specimen. Feldspars' blocky habit, combination of twinning patterns, well-developed cleavages, and pearly lustre assist in distinguishing feldspar from quartz, as 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 and plagioclase.

Physical properties of feldpars

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

NB: barium feldspars are not included

Optical effects

Some of the optical effects seen in feldspar include:

- Schiller is a silver sheen effect caused by reflections from cleavage planes, commonly seen in blue-green amazonite

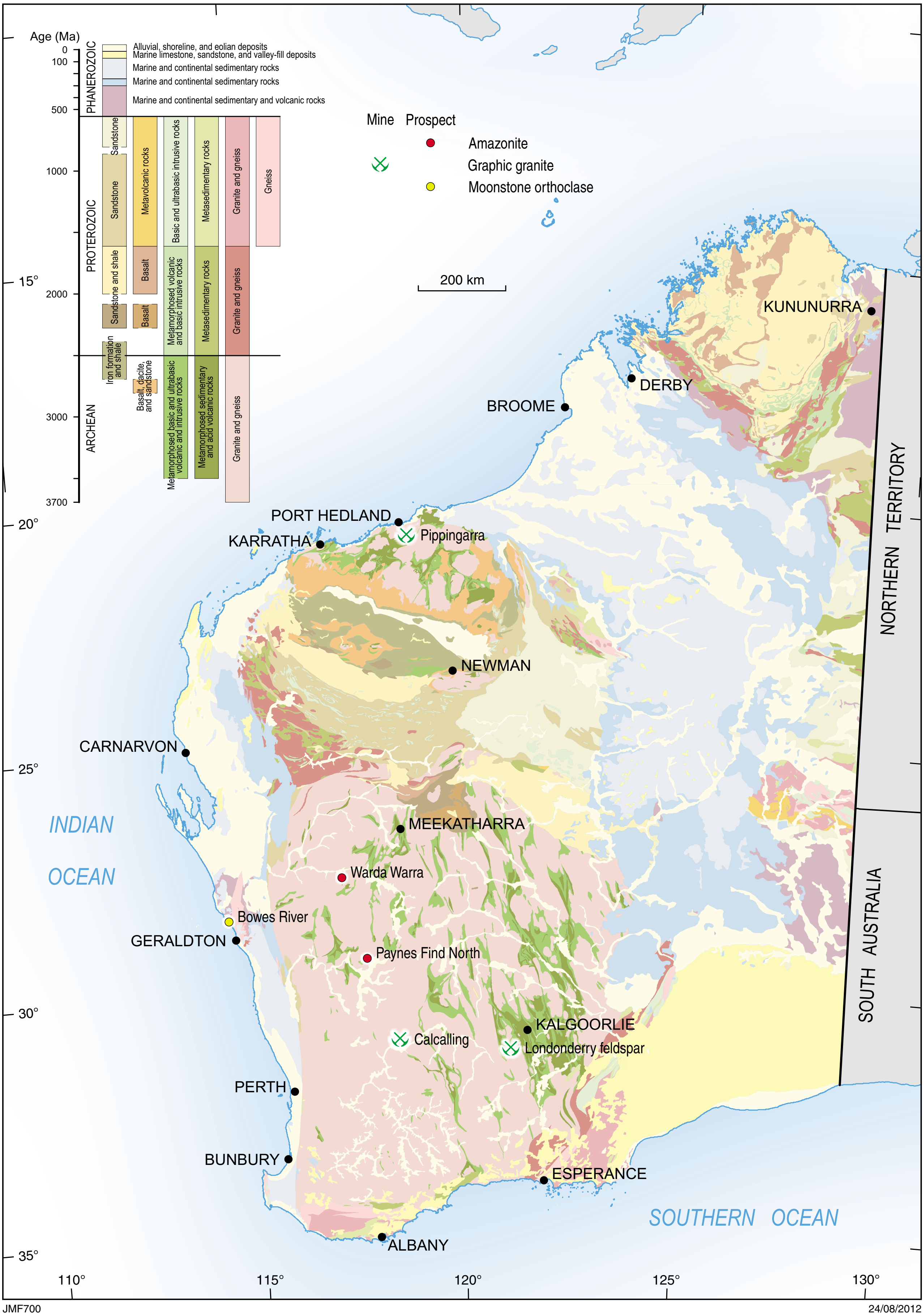

Figure 9.2 **Location of lapidary-grade feldspar minerals in Western Australia**

- Aventurescence is a bright or strongly coloured effect caused by light reflection from a regular pattern of inclusions
- Adularescence (also termed opalescence) is a silvery effect caused by light scattering from exsolved compositional layering
- Labradorescence and similar interference phenomena result in an iridescent play-of-colour from the lamellar compositional structure of feldspar.

Alkali feldspars

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

- Moonstone, a 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 rock comprising an intergrowth of microcline and quartz.

Plagioclase feldspars

This group forms an isomorphous series ranging from sodic albite to calcic anorthite. Within this group there are several varieties of potential gem interest, including:

- Sunstone, which exhibits a spangled sheen (aventurescence) caused by mineral inclusions of hematite, goethite, and rarely copper
- Labradorite can display iridescent bright colour flashes, especially blue, caused by light interference. Madagascar currently supplies much of the labradorite available for sale in Australian outlets
- Other plagioclase group members, all of which have been found as 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.

Graphic granite

Also known as runic granite, graphic granite is an intergrowth of feldspar and quartz. The feldspar component is typically 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 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, and although a number of these (such as the Londonderry pegmatite) are commercially important, gem material is virtually 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 the occurrence of 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, Gemstones of Western Australia (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 two kilometres 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 a total of 0.7 km from the highway, the dumps and a shallow shaft can be seen on the right (Fig. 9.2). Simpson (1952) mentions pegmatite dykes 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 exist. Specimens of amazonite in the collection of the Western Australian Museum include S 1685A and S 4286 from the Daphne gold mine and S 1685C from the Carnation gold mine, both in the general area (Fig. 9.3).

Warda Warra area *(Dalgaranga, 2342)*

A specimen of amazonite from the collection of the Western Australian Museum (4278) is reported to be from 1.8 km northeast of Warda Warra (Fig. 9.2). No further details are on record.

Orthoclase feldspar

Northampton Inlier

Bowes River area *(Northampton, 1841; Butt, 1741)*

A silver-grey specimen of moonstone orthoclase in the collection of the Western Australian Museum (S 4331), shown in Figure 9.4, is recorded as originating from the 'mouth of the Bowes River'(Fig. 9.2). Other specimens of

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Figure 9.3 **Cabochons of amazonite from Melville in the Yalgoo district. Free-form amazonite measures 38 x 42 mm and oval stone 26 x 36 mm (cut and polished by Maria Isaacs)**

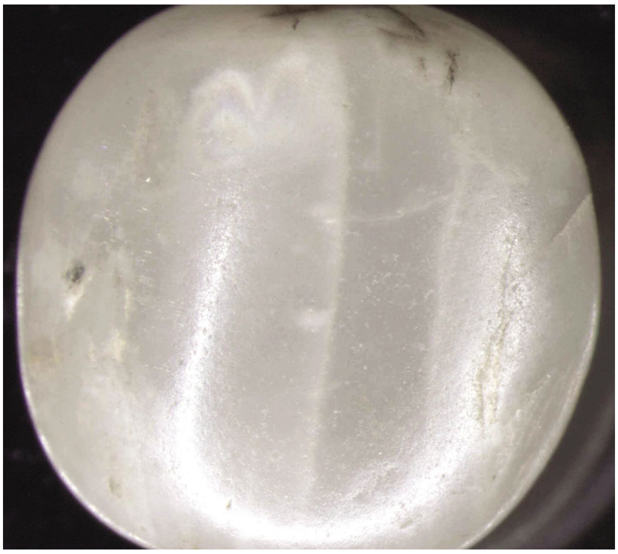

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Figure 9.4 **Naturally tumbled specimen of moonstone approximately 10 mm in diameter from the WA Museum Collection**

orthoclase moonstone may be coloured light green or light brown. The specimens illustrated in Figure 9.5 are uncut, tabular cleavage fragments, which show the requisite silvery schiller effects of moonstone. The precise source of all these specimens is unknown.

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 adamellite that is part of the Carlindi Batholith (Fig. 9.2). The contact between the pegmatite and the biotite adamellite is gradational, progressing from the biotite adamellite to a graphic granite pegmatite with a biotite-enriched band in direct contact with the adamellite (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. 9.2). 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.9.2). Graphic granite is seen in sections of the pegmatite quarry.

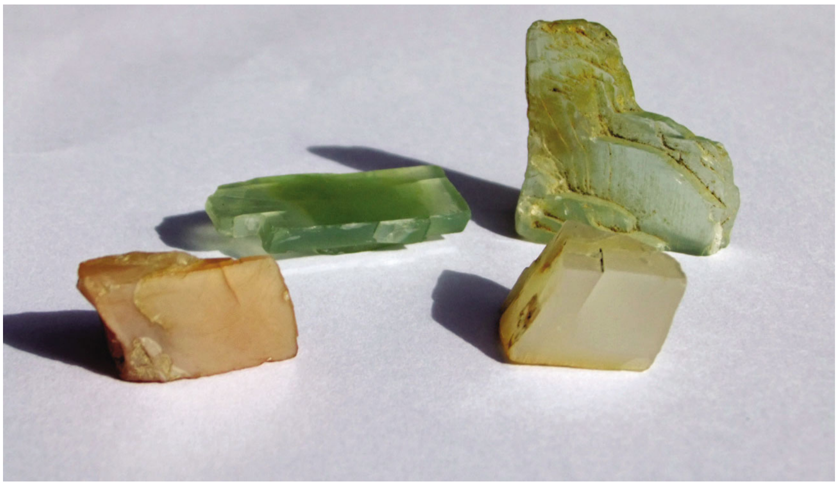

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Figure 9.5 **Four pieces of uncut, green, white and peach-coloured moonstone (courtesy Maria Isaacs and the Lapidary Club of Geraldton)**

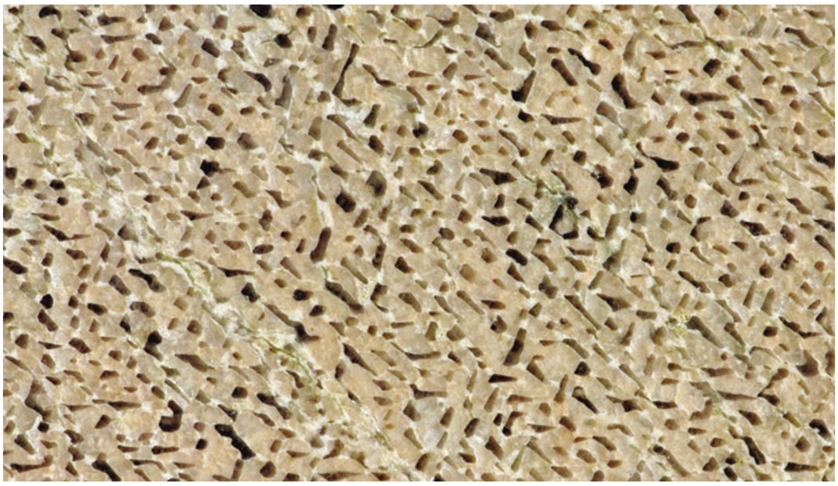

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Figure 9.6 Polished specimen of graphic granite from Northampton (courtesy Ken Bussola)

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Figure 9.7 A cabochon of graphic granite (75 x 57 mm) from Northampton (cut and polished by Maria Isaacs)

Northampton Inlier

East Bowes area *(Northampton, 1841)*

Specimens of graphic granite are from an undisclosed site, reportedly from the East Bowes area. A large polished specimen of graphic granite is displayed in the Geological Museum at The University of Western Australia (Figs 9.6 and 9.7), purporting to be from Moonyoonooka area in the Geraldton region. No further details are available.

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Chapter 10 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 usually the table facet of a cut gem is positioned at a small angle to this direction in order to assist polishing and avoid accidental breakage. Iridescence in the form of planar, rainbow-like inclusions in cut topaz gems may be an indication of incipient cleavage. Topaz takes a high polish and has a brighter vitreous lustre compared with quartz gems of similar colours. Yellow quartz (citrine) is at times incorrectly described as topaz in the jewellery trade.

Although topaz occurs naturally in a wide variety of colours it most commonly appears as blue or colourless varieties. Most valuable colours are pink, red, and purple hues with yellow, orange, and brown stones generally more common; natural green topaz is rare (Fig. 10.1a). Cut colourless topaz is commonly marketed as 'silver topaz'. The diaphaneity of topaz can range from transparent to translucent. In the jewellery industry, transparent gem material is faceted and lower grades 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, fluorine (F) and hydroxyl (OH) ions are interchangeable and form an isomorphous series with variations occurring in all colours. 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 effects. 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 that involve a vacancy or defect in the atomic structure that absorbs light. Colour centres may be natural or can be induced with treatment involving irradiation (Fig. 10.1b). 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 in a few days after being mined (Nassau, 1980). Colourless, light yellow, and blue topaz from mining operations are often colour-enhanced for use in jewellery using irradiation treatment often followed by an annealing process involving heating the stones to 200–300°C. This treatment results in a 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 chromium (Cr^{3+}), and blue, yellow, reddish-brown, and orange colours 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)
UV fluorescence	Varied response, mostly inert, although some topaz shows yellow and green fluorescence in long and short wave UV. Topaz with high hydroxyl (OH) ion content may show strong orange in long wave, and white in short wave UV
Absorption spectrum	A weak doublet at 682 nm in Cr^{3+}-bearing topaz

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 shades of colour.

Brazil and Pakistan are sources of natural pink topaz. Chromium is the cause of 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 occurs as an accessory mineral in some granite and associated hydrothermally altered rocks, as well as pegmatites and associated miarolitic cavities and greisens, rhyolites and other aluminous rocks. At Torrington in New South Wales, numerous intrusions of silexite, a quartz–topaz rock containing 15–20% topaz, occur near margins of granitic bodies and have been assessed as a potential source of industrial topaz. Because of its hardness, topaz commonly occurs 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. There are numerous other topaz localities around the world including significant sites in USA, Mexico, Sri Lanka, Nigeria, Madagascar, Pakistan, and Russia.

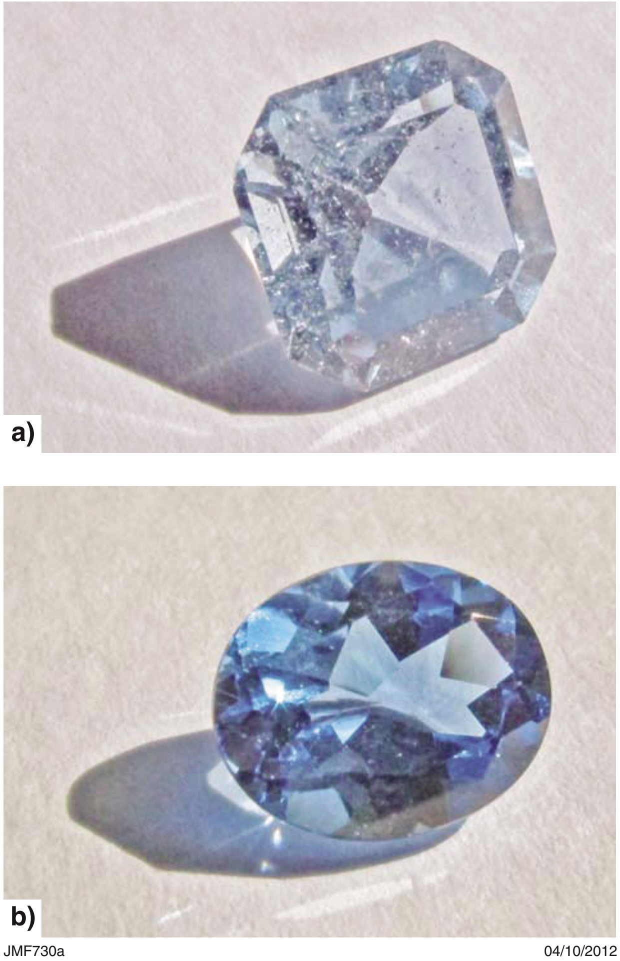

Figure 10.1 **Faceted, blue topaz gemstones: a) natural blue topaz from Saint Ann's mine, Zimbabwe, dimensions are 10 mm square, weight approximately 5 ct; b) artificially irradiated, colour-enhanced, blue topaz, dimensions are 7 x 5 mm (courtesy Gemrock Enterprises)**

Topaz in Western Australia

In Western Australia, topaz occurs 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 10.2 and more detailed locational information on these sites, together with Western Australian Museum specimen numbers, is given in Appendix 1.

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Grosmont *(Yilmia, 3135)*

The Grosmont pegmatite is situated about 15 km southwest of Coolgardie and 7 km north-northwest of Londonderry (Fig. 10.2). Access from Coolgardie is southwestward along the Victoria Rocks Road for nearly 15 km and thence north along a dirt road. In recent years, the Grosmont opencut has been a popular collecting site for opaque blue topaz masses as well as large plates of lepidolite mica.

Prospectors discovered this 3–4 m-thick pegmatite in 1896 and after a succession of developments over the years the prospect 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. The pegmatite was visible only 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 (Jacobson et al., 2007).

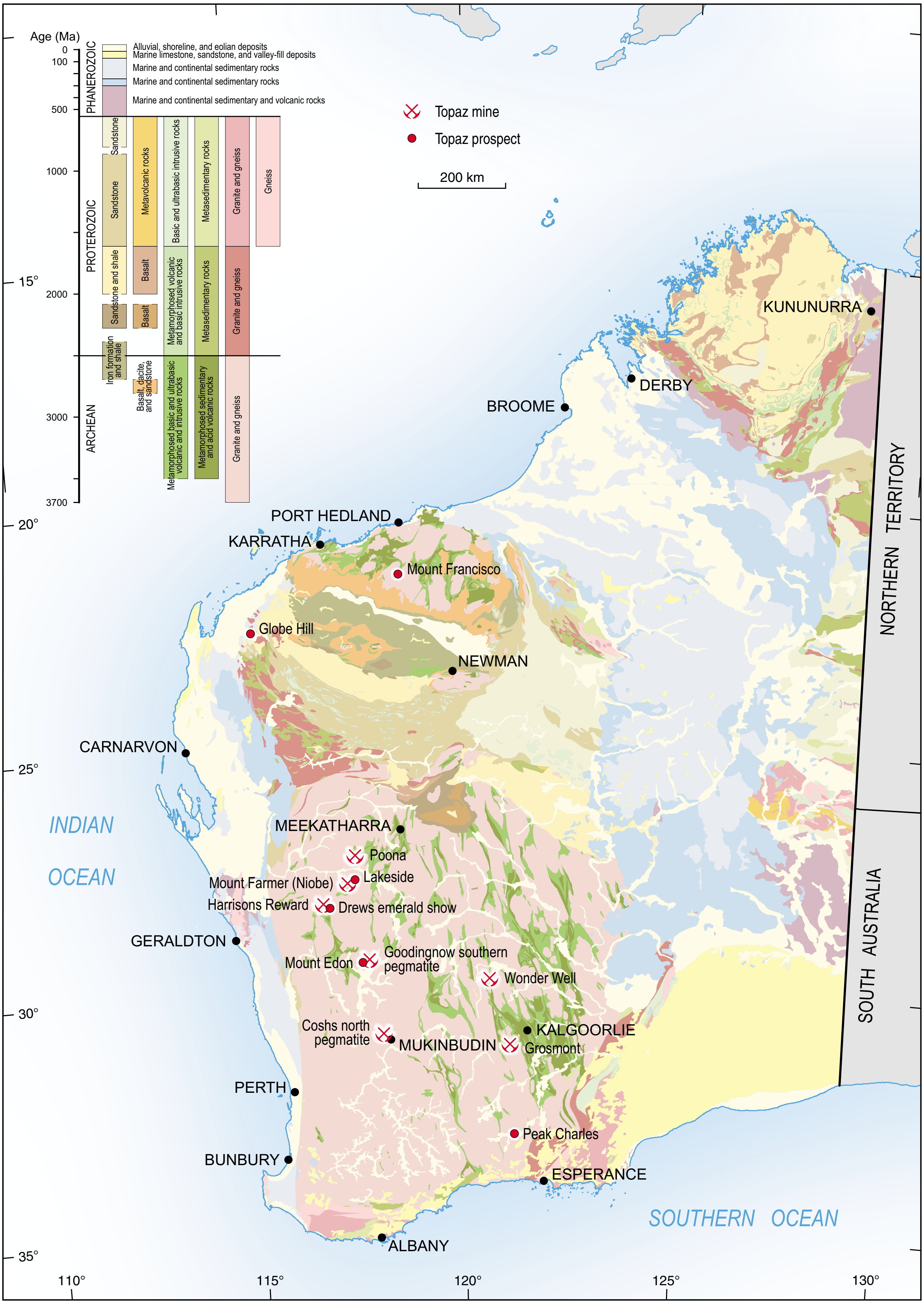

Figure 10.2 Principal topaz localities in Western Australia

The Grosmont pegmatite was concordantly intruded into Archean, fine- to medium-grained amphibolites striking north-northeasterly and dipping 80–85º to the west. Poor exposure of the structure has for the most part precluded attempts to describe pegmatite zoning or mineral associations, although it was reported by Reeve (1973) that the topaz was found as massive pieces of a visually attractive blue stone almost invariably 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 (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 ranges in colour 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 waterless, high-F topaz containing 17.86% fluorine.

Menzies region

Wonder Well (Riverina, 3038)

The Wonder Well pegmatites are located astride the Riverina – Snake Hill Road immediately north of Riverina Homestead, about 60 km west of Menzies (Fig. 10.2).

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 but with frosted faces, euhedral, and terminated in biotite schist was recovered from the emerald deposit. The terminated crystal was 8 cm in length and 5 cm wide.

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. 10.2). These specimens (WAM M 11 and M 594) are part of the collection of the Western Australian Museum. Both crystals are semitransparent (almost clear), show good prismatic crystal form, and one crystal has a completed termination (Fig. 10.3).

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, there is an abundance of quartz-cored pegmatites that have intruded post-tectonic, Archean, quartz monzonite bodies surrounding local greenstone belts (Fig. 10.2). The pegmatites belong to the allanite–monazite NYF rare-element class. Topaz is recorded from a number of these pegmatites, commonly as white, non-gemstone varieties.

Cue region

Lakeside pegmatite (Dalgaranga, 2342)

The Lakeside pegmatite is located about 50 km west-southwest of Cue, and 5 km west-northwest of Lakeside Homestead (Fig. 10.2). At this location the pegmatite has intruded a north-northeasterly 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, which includes 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) lies 70 km northwest of Mount Magnet and 24 km northeast of Dalgaranga Homestead (Fig. 10.2).

The zoned pegmatite has a surface width of approximately 50 m, dips 30–40º 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 35 cm in length. Most crystals had a sharp contact with 1–2 cm-thick white hydromica alteration coatings.

Poona (Noondie, 2343)

The Poona mineral field is some 55 km northwest of Cue (Fig. 10.2). In this area, a pegmatite sited on the Reward Claim (ML45) contains a number of imperfect topaz crystals. They are described as being up to 25 mm in length, colourless to very light blue, transparent and having a basal parting (Simpson, 1952). The topaz is

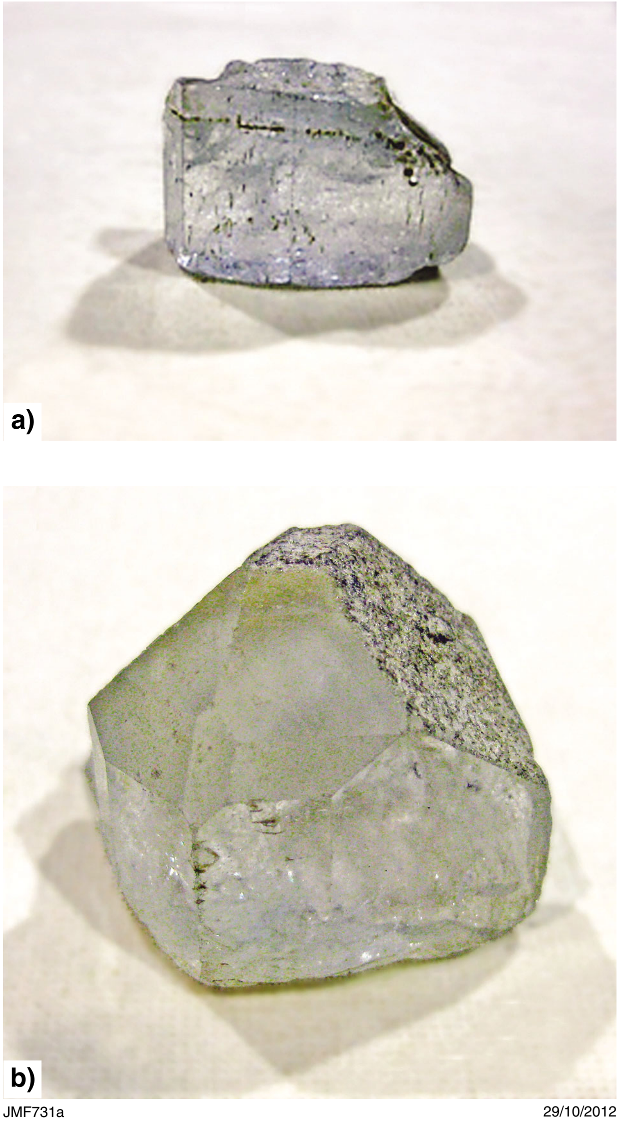

Figure 10.3 Examples of gem-quality topaz from the Peak Charles area, Norseman region: a) semitransparent topaz about 30 mm wide (Western Australian Museum specimen WAM M594); b) terminated, euhedral, colourless topaz 27 mm in height(Western Australian Museum specimen WAM M11)

associated with muscovite, quartz, and beryl. Also, detrital pebbles of topaz up to 5 cm in diameter and containing a number of parallel, colourless and iron-stained crystals were found at the western end of the field (Fig. 6.4, Beryl Group, Chapter 6).

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 is that the topaz is a pale red due to many tabular inclusions of ruby (Grundmann and Morteani, 1998).

Paynes Find area

Mount Edon pegmatite field (Maranalgo, 2439)

The Mount Edon pegmatite field covers an area between 5 and 9 km south of Paynes Find and consists of numerous, irregularly shaped pegmatites that for the most part concordantly intrude a northeasterly trending sequence of Archean greenstones comprising mafic, ultramafic, and metasedimentary rocks (Fig.10.2). The Mount Edon pegmatite field is described in detail in Jacobsen et al. (2007).

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

Goodingnow southern pegmatite (Maranalgo, 2439)

The Goodingnow feldspar pegmatites are located within the Mount Edon pegmatite field about 5 km south of Paynes Find (Fig. 10.2). 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, the Goodingnow southern pegmatite was mined by Universal Milling, with 2416 t of high-grade K-feldspar having been recovered (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 has a non-gem-grade topaz specimen from this site (MDC 1087).

Yalgoo region

Noongal

Harrisons Reward (Yalgoo, 2241)

The Noongal pegmatite field (also referred to as Melville) is situated on Carlaminda and Noongal Stations about 20 km north of Yalgoo and 5 km north-northwest of the old Melville Townsite (Fig. 10.2). The field contains numerous pegmatites including Harrisons Reward pegmatite on former mining lease ML26, located about 3 km northeast of Bottom Well. Harrisons Reward, a highly siliceous pegmatite composed mostly of quartz and biotite, trends southeast, parallel to the foliation of its host metapyroxenite.

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 located 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) describes the topaz as colourless, or milk-white, and in masses up to 'several pounds in weight' (possibly to 1.5 kg). Each mass represented a single crystal with parts being 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 to be high F-type containing fluorine (18.55%).

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. 10.2).

Mukinbudin area

Coshs north pegmatite *(Barbalin, 2536)*

Coshs north pegmatite (also known as Whytes south) is located approximately 20 km northwest of the town of Mukinbudin (Fig. 10.2). Access from Mukinbudin is westward along the Koorda–Bullfinch Road for about 18 km and thence northward for about 5 km. The pegmatite is situated 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 edges 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 weighing over 40 kg. Crystal faces are found on most fragments recovered from several sites on both 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 located on the south side of the Ashburton River, approximately 27 km west of Nanutarra Homestead and 11 km north-northeast of Globe Hill (Fig. 10.2). This site is located in an area of amphibolitic and quartzofeldspathic gneisses forming part of the Paleoproterozoic Gascoyne Province. The exact location of the pegmatite is uncertain, but according to Simpson (1952), alluvial topaz, associated with tin, exists 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) recorded white translucent topaz in a pegmatite at Mount Francisco about 120 km south-southwest of Port Hedland (Fig. 10.2). No further information is available for this deposit, although Simpson (1952) recorded one or two specimens of topaz without site location from the Wodgina district. It should be noted that the Mount Francisco pegmatite field lies within the Yandeyarra Aboriginal land and permission of the relevant Aboriginal Council is required for access.

Roebourne area *(Roebourne, 2356)*

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

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Chapter 11 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 and is associated with petalite, amblygonite, and spodumene. Lepidolite is most commonly violet, bluish-violet or pink. Material from Western Australia is found in many shades of purple, and blue from the Carlaminda Blue quarry north of Yalgoo (Fig. 11.1).

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Figure 11.1 **Blue lepidolite mica interspersed with white albite feldspar and grey quartz, Carlaminda Blue quarry, Yalgoo area**

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)

Lepidolite may form as large tabular crystals but is more commonly found in aggregates, sometimes as botryoidal, scaly flakes. It is the fine-grained, massive variety that is most sought after by lapidaries for carving into objets d'art (Fig. 11. 2).

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	1.53 – 1.556
Birefringence	0.026
Hardness	2.5 – 4
Specific gravity	2.8 – 3.3
Fracture	Irregular, uneven
Cleavage	Perfect (001)

Lepidolite in Western Australia

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry pegmatite field *(Yilmia, 3135)*

The Londonderry pegmatite field is located about 20 km south-southwest of Coolgardie via the Nepean road (Fig. 11.3). 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. Quarrying for microcline feldspar was the economic focus at Londonderry from 1929 to 1983.

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, 200–280 m wide, and is asymmetrically zoned. Eight zones have been recognized, each defined by specific mineral assemblages. For example, purple lepidolite mica occurs in the quartz–albite–microcline–lithium mica zone, where it is found in association with lithium muscovite and zinnwaldite (Fig. 11.4). The purple mica is found in several different forms including light purple balls up to 6 cm in diameter, and most commonly as fine-grained, randomly orientated flakes (Jacobson et al., 2007). A geological map of the area surrounding the Londonderry pegmatite field is shown in Figure 11.5.

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Figure 11.2 An 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 (courtesy Bill Moriarty)

Lepidolite Hill pegmatite

The Lepidolite Hill pegmatite is situated 1.6 km north of the Londonderry feldspar quarry and 400 m southeast of the Tantalite Hill pegmatite. The site may be accessed via a track about 1.5 km in length from the Nepean–Coolgardie road (Fig. 11.5).

The pegmatite at Lepidolite Hill is present as two bodies within Archean greenstones of the Yilgarn Craton with the larger, northeastern pegmatite having a length of slightly over 200 m and a width 24–90 m. 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 in length 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 or Dollar Well) within the Melville pegmatite field has developed into a blue lepidolite-bearing pegmatite some 20 km north of the town of Yalgoo (Fig. 11.3).

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, but 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).

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. 11.1).

Rough and slabbed blue lepidolite is sold by rock and lapidary shops and is often utilized for objects d'art (Fig. 11.6).

Pilbara Craton

Wodgina area

Wodgina greenstone belt (*Wodgina, 2655*)

Wodgina Main Lode

The Wodgina Main Lode (or Tantalite Lode) is located in the Wodgina tantalum mining area about 100 km south of Port Hedland (Fig. 11.3).

The Wodgina Main Lode is a northerly striking pegmatite vein 3–10 m wide that dips 40° east over a length of 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 but is concentrated primarily in the feldspathic portions (Ferguson and Ruddock, 2001).

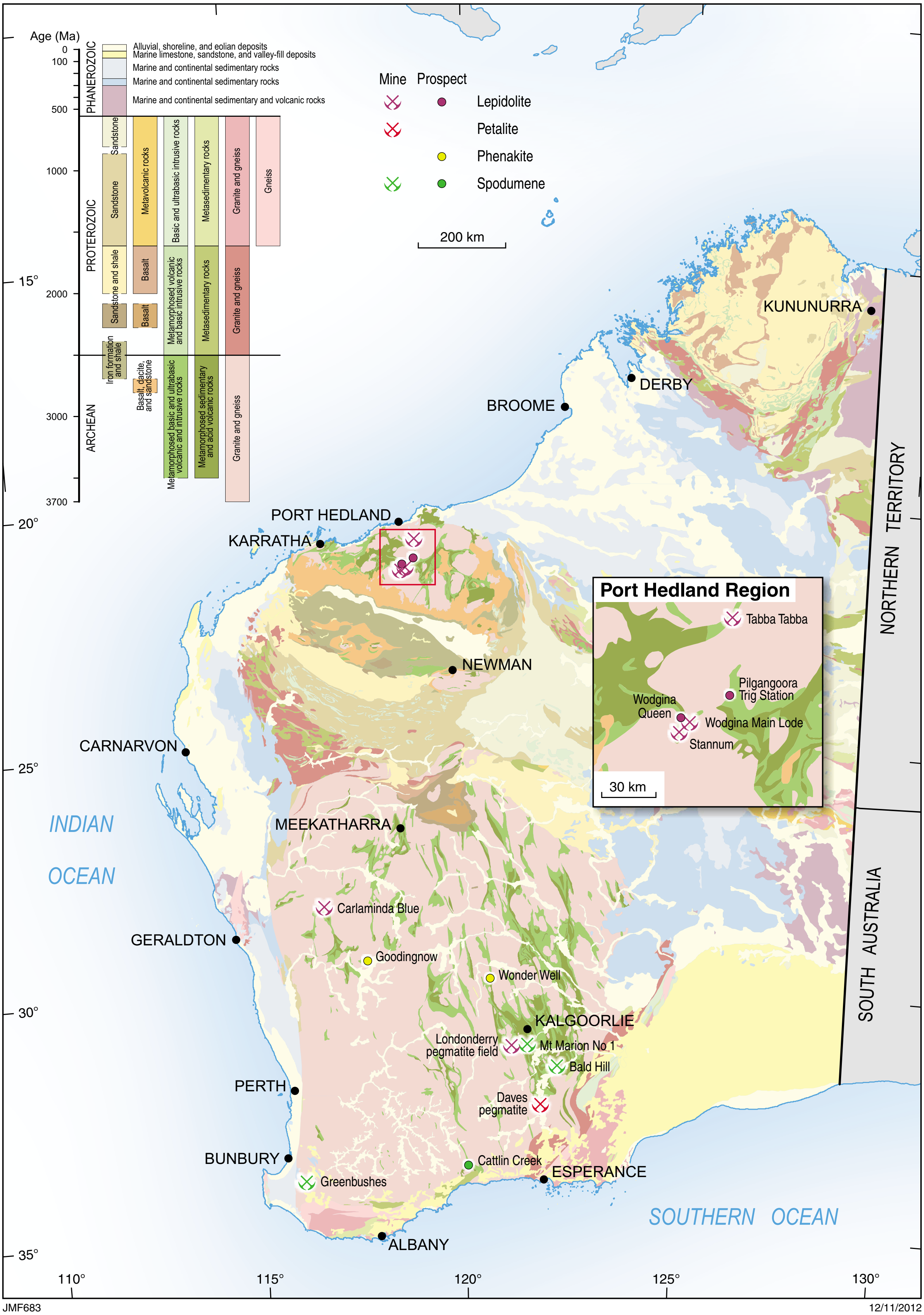

Figure 11.3 Location of minor pegmatite gemstones in Western Australia

Wodgina Queen

The Wodgina Queen prospect is located about 2.6 km west-northwest of the Wodgina Main Lode (Fig. 11.3). This prospect forms part of the West Wodgina pegmatite group and contains simple and zoned pegmatites comprising 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 located in an old tin mining area about 8 km south-southwest of the Wodgina Main Lode (Fig. 11.3). 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.

Pilgangoora area

Pilgangoora pegmatite field (WODGINA, 2655)

The Pilgangoora pegmatite field on Wallareenya Station is located about 90 km south-southeast of Port Hedland and contains swarms of lepidolite–spodumene-bearing pegmatites (Fig. 11.3). 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 located 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. 11.3).

Also at Tabba Tabba, the occurrence of crystals, plates, and mammilated masses of lepidolite is recorded in Geological Survey of Western Australia (1994), and Jacobson et al. (2007) shows the location of a discrete lepidolite zone

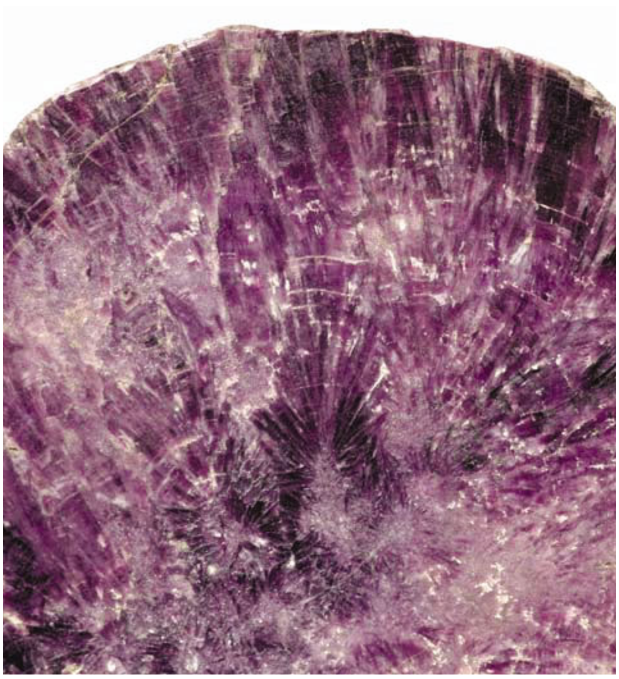

Figure 11.4 Botryoidal lepidolite, cut and polished section 16 cm diameter, from the Londonderry feldspar pegmatite (courtesy Peter Bridge)

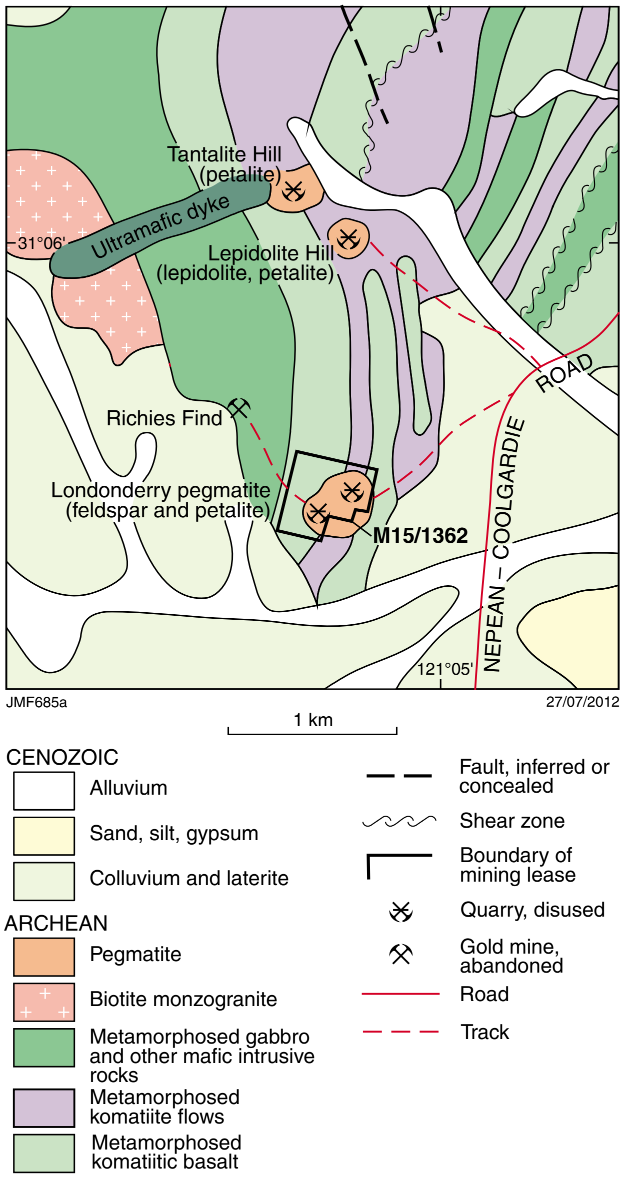

Figure 11.5 The geology of the area surrounding the pegmatites at Londonderry (modified after Fetherston et al., 1999)

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Figure 11.6 Lepidolite from the Carlaminda Blue deposit carved as a pod of dolphins. The carving is 30 cm high x 25 cm wide (courtesy Glenn Archer)

located within the Tabba Tabba main tantalite pegmatite workings on mining lease M45/376.

Petalite

Petalite is a granitic pegmatite mineral often found associated with other lithium minerals such as spodumene, amblygonite, eucryptite, and lepidolite as well as other 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. Petalite may be faceted when found as transparent, quality material (Fig. 11.7).

The host pegmatite group for petalite is the lithium–cesium–tantalum-bearing pegmatites (LCT–type) that form at low to moderate pressures (2.5 – 4 kilobars) and temperatures of 500–650ºC (Jacobson et al., 2007). Several mineral assemblages occur as pseudomorphs after petalite. These include spodumene and 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 over 40 ct are not unusual. 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, incipient cleavages may be present. Internal features of gems show distinct doubling as the birefringence of petalite is high

Figure 11.7 **Faceted petalite gemstones from Londonderry: left, 5.91 ct; right, 6.07 ct (courtesy Bill Moriarty)**

relative to that of 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	2.39 – 2.422
Cleavage	Perfect basal (001) and good (021) faces

Petalite in Western Australia

Petalite has been recorded from several Western Australian pegmatites but 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 (Jacobson et al., 2007).

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry pegmatite field

Londonderry feldspar pegmatite (Yilmia, 3135)

The Londonderry feldspar pegmatite is located about 20 km south-southwest of Coolgardie via the Nepean road (Figs 11.3 and 11.5). The pegmatite was first discovered in 1909 and 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 an ovoid body about 1000 m long, 200–280 m wide, and tapers 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 mineral assemblages (Fig. 11.8).

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 located about 2 km west-northwest of the Londonderry feldspar pegmatite quarries (Fig. 11.5). 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 numerous mullock heaps. Small masses of grey to white petalite are

Figure 11.8 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 no. 9536)

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.

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. 11.5). These pegmatites are distinctly zoned and the petalite–quartz–microcline zone is up to 14 m thick in the northeast pegmatite. Petalite occurs as grey to pearly white masses with single crystal fragments averaging 20 x 8 cm in size. 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 situated in the Mount Deans pegmatite field and is located about 13 km south of Norseman and 3 km east of the Coolgardie–Esperance Highway (Figs 11.3 and 11.9). 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 observed (Jacobson et al., 2007).

Spodumene

Spodumene is a pyroxene group mineral and one of a few gems that compositionally contains lithium. It is best known from its coloured gem varieties: kunzite (pink and violet),

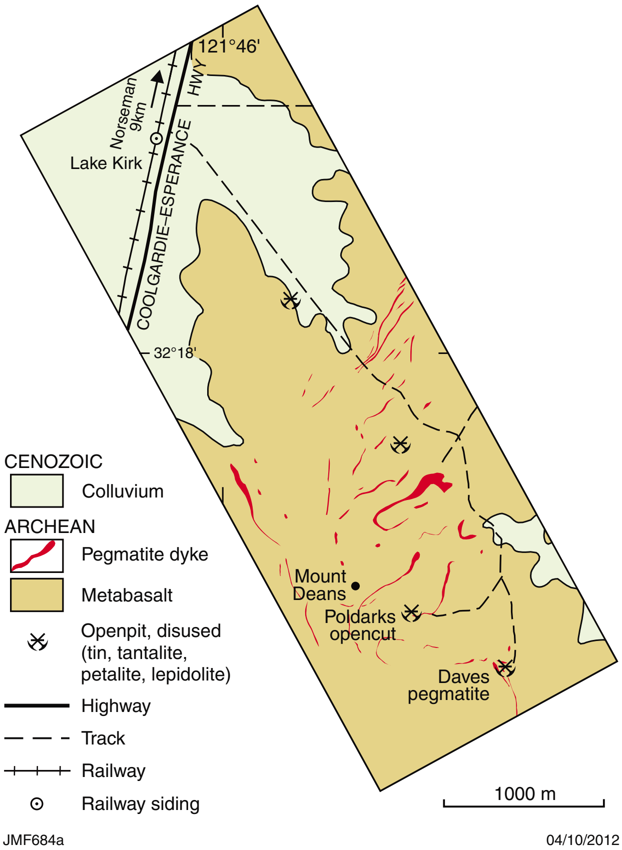

Figure 11.9 Geology of the Mount Deans area showing the location of Daves pegmatite opencut (modified after Fetherston, 2004)

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 Mn, Fe or Cr
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 hue

hiddenite (green), and a yellow variety. Both kunzite and hiddenite are eponymous varieties first recognized in the USA in the late 19th century. Originally, the term hiddenite was used specifically for the bright green, chromium-bearing spodumene from the USA. Today, it is customary to market green spodumene as hiddenite irrespective of the cause of colouration. Although gem spodumene is still sourced from the USA, other important world sources now are Afghanistan, Pakistan, Brazil, Madagascar, and Burma.

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

The chemical composition of spodumene shows only minor element 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 after the original prisms of the host spodumene. Spodumene also often contains microinclusions 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 but rarely as facetable-quality crystals. When transparent quality gem spodumene is faceted, it requires particular skill in cutting owing to its 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 book ends. 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. 11.3). These pegmatites are of an unzoned quartz–spodumene type intruding Archean greenstones of the Eastern Goldfields Superterrane. The pegmatites contain substantial spodumene resources but there is no record of gem-quality material present. One pegmatite contains pale green to white spodumene crystals reaching 30 cm in length 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, is located in and around the Bald Hill tantalite mine on Binneringie Station about 60 km southeast of Kambalda (Fig. 11.3). The Bald Hill pegmatites, which exist as gently dipping sheets, contain steeply dipping veins that are aligned in a northerly direction, parallel to regional foliation. These pegmatites range in thickness from a few metres to around 30 m, and in some instances occur as 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 operations 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 in length. Vugs reaching 2 cm in diameter are locally found in the albitic zones of the spodumene-bearing unit, and these mostly contain albite and micro-quartz 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 is the first recorded occurrence of spodumene in Western Australia. The pegmatite is located 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. 11.3).

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 but since mining operations 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 by 400 m wide and approximately 25 m in thickness.

Spodumene crystals from this site ranging up to 0.7 x 0.15 x 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 gem-quality spodumene from this pegmatite.

Also, detailed studies of the so-called ‘rotten’ spodumene from Ravensthorpe showed that it consists of muscovite with 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 located 80 km southeast of Bunbury and just south of the small town of Greenbushes on the Southwestern Highway (Fig. 11.3).

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 from 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 spodumene openpit.

The 2.5 billion-year-old Greenbushes pegmatite was intruded into the Donnybrook–Bridgetown shear zone during a period of metamorphic shearing. 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 lithium–cesium–tantalum type containing mineralogical and compositional zones including a spodumene–quartz zone, a microcline–quartz zone, an albite–quartz zone, and a border zone (Fig. 11.10). Other lithium minerals recorded at Greenbushes include lithiophilite and amblygonite (lithium phosphates), lepidolite (lithium mica), and the lithium amphibole, holmquistite (Freeman and Donaldson, 2004).

The spodumene–quartz zone is composed of 60–80% sucrose to coarse-grained spodumene in which anhedral spodumene crystals have been found reaching 70 mm in length. 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 gem-quality spodumene from the Greenbushes deposit although a spodumene–quartz rock makes an attractive variegated pink and grey ornamental stone (Fig. 11.11). In hand specimen, the rock consists of anhedral, prismatic, pink 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; fluorescence was not detected (Brown and Bracewell, 1989).

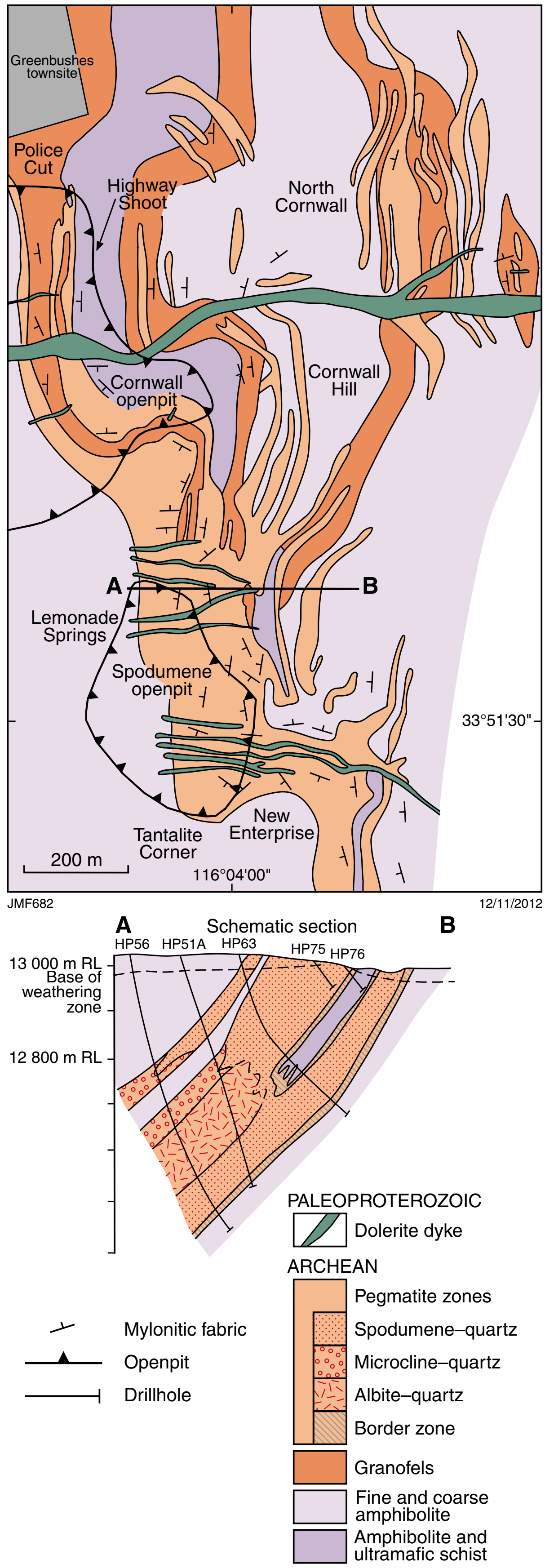

Figure 11.10 Geological map of the Greenbushes pegmatite, with schematic cross section showing the pegmatite zonation pattern (modified after Partington et al., 1995)

Figure 11.11 Polished tile of decorative pink spodumene–quartz rock from Greenbushes. Tile is 40 mm wide

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 on prearranged visits.

Pilbara Craton

Pilgangoora area

Pilgangoora pegmatite field *(Wodgina, 2655)*

The Pilgangoora pegmatite field on Wallareenya Station lies 90 km south-southeast of Port Hedland and contains a large lepidolite–spodumene resource (Fig. 11.3).

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 Lepidolite in Western Australia.

Phenakite

Phenakite is a beryllium silicate mineral first identified in 1833 by the Finnish mineralogist Nils von Nordenskiöld from samples originating 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 is a collector's gem. It is commonly colourless, but may be found in yellow, brown, and pink varieties. 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 sizeable crystals, particularly from Brazil, from which large faceted gems of around one hundred carats have been fashioned.

Phenakite occurs in granitic and miarolitic pegmatites and also in greisens and hydrothermal veins. It is found in the emerald–chrysoberyl–phenakite mineralogical association in black schist-type emerald deposits. In this environment, phenakite exists 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 in the Ural Mountains deposits of northern Russia (Schmetzer, 2010).

Beryl is the most common beryllium mineral, more rare are euclase, chrysoberyl, and phenakite. Both euclase (a beryllium aluminium silicate) and phenakite (a beryllium silicate) occur as alteration and replacement products of beryl. Phenakite forms in a wider range of deposits than euclase but appears to be restricted to environments with medium to low aluminium availability. It can be a precursor to emerald and may be replaced if aluminium and alkalis become available. Intergrowths of chrysoberyl (alexandrite), emerald and, locally, phenakite may be 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 (Cassedanne, 1985; Chaves et al., 1998).

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, 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

Because of rarity and identification difficulties, neither phenakite nor euclase are target minerals of prospectors. Production and availability of both minerals is strictly as a byproduct of exploration and mining of other gems such as aquamarine, emerald, and topaz.

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 a 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 colourless gemstone, phenakite is faceted to display its moderate light dispersion. Some faceted gems, each of several carats, have been produced from Western Australian specimens.

Yilgarn Craton — Murchison Domain

Paynes Find area

Goodingnow pegmatites (Maranalgo, 2439)

The Goodingnow pegmatites are contained within the Mount Edon pegmatite field in the Paynes Find area. Spaced about 400 m apart, the two pegmatites (northern and southern) are located 400 m northeast of Mount Edon on former prospecting licence P59/7104 (Fig. 11.3). The Goodingnow pegmatites are 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 of microcline–quartz–muscovite, albite and several quartz segments. At its eastern end is a 15 x 4 x 1.5 m pit 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 is the first recorded identification of phenakite in the State. The Western Australian Museum possesses a specimen consisting of 2–4 cm-long, greyish-white masses provisionally identified as phenakite (specimen number MDC 3648).

Yilgarn Craton — Eastern Goldfields Superterrane

Menzies region

Wonder Well (Riverina, 3038)

Wonder Well emerald pegmatites situated on Riverina Station have been described in detail earlier (The Beryl Group, Chapter 6). At Wonder Well, emerald-bearing pegmatites are located astride the Riverina – Snake Hill road immediately north of the Riverina Homestead some 60 km west of Menzies (Fig. 6.3).

In the late 1970s, a large crystal of white-grey, twinned phenakite was discovered by prospector David Vaughan. The crystal was found within the black/brown biotite or phlogopite micaeous lens zones. Mica is attached both to the crystal and also between the two components forming the twin. The crystal measures 75 x 56 mm and is well formed with slightly worn faces displaying a waxy appearance. It is also partly transparent but has a number of fine fractures (D Vaughan, 2010, written comm.; Fig. 11.12).

Additional crystals have been collected by the current owner of mining lease M30/8 and it is known that gems have been faceted from this material. No further details are available.

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Figure 11.12 White-grey twinned phenakite crystal from Wonder Well emerald mine on Riverina Station. The speciman measures 75 mm x 65 mm (courtesy David Vaughan)

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3

Siliceous gemstones

Faceted amethyst gemstones from Wyloo (courtesy Bill Moriarty)

Chapter 12 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; as a low-temperature form termed common or alpha-quartz (α-quartz), and the high-temperature form, beta-quartz (β-quartz). Common α-quartz forms as trigonal crystals at temperatures below 573ºC and occurs within rocks in vugs and pockets. At temperatures 573–870ºC, β-quartz forms, with a symmetry change to 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 also an important source of gem-quality quartz crystals especially where miarolitic cavities or clay-filled pockets provided space and a suitable soft matrix in which euhedral (near perfectly formed) crystals developed unimpeded. Quartz crystals that develop within vugs and geodes are commonly colourless, transparent, and euhedral with lustrous crystal faces (Fig. 12.1). 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 constitutes a major component of granitic pegmatites and vein quartz. Milky quartz is generally translucent to opaque white due to evenly distributed gas and/or fluid inclusions.

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

Quartz crystals may attain gigantic size, for example one such aggregate measuring 4.4 x 2.4 x 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 attractive 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 usually cut and polished as faceted gems. Translucent quartz is usually cut as cabochons, made into beads or carved and fashioned as sculptural objects. 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)

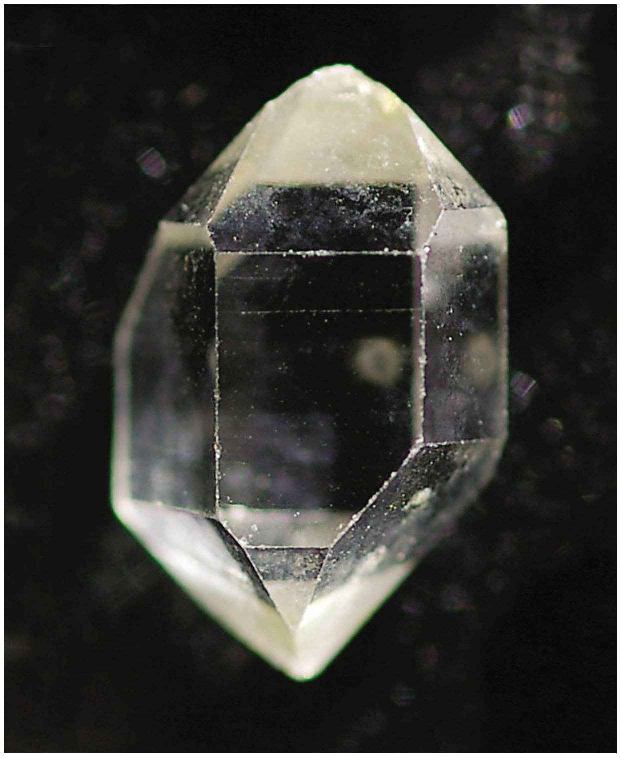

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Figure 12.1 Photo showing the prismatic habit of an 8 mm, doubly terminated, colourless quartz crystal from Yinnetharra in the Gascoyne region

Physical properties of quartz

Crystal system	Trigonal (trapezohedral)
Habit	Prismatic with mostly short hexagonal prisms (often 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 Plus other colours from mineral inclusions
Colour cause	Colour variants may result from several causes: • traces of iron (green quartz also with inclusions) • colour centres and inclusions (rose quartz: pink inclusions, white quartz: liquid inclusions and light scattering,) • the ionic state of iron (amethyst: Fe^{4+}, citrine: Fe^{3+}) • irradiation of quartz containing traces of Al (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
UV fluorescence	Inert
Absorption spectrum	Weak iron absorption bands

ε and ω: extreme values for uniaxial minerals

In Western Australia, quartz deposits are widespread and numerous records of their occurrence are detailed in Simpson (1952) and Jacobson et al. (2007). Quartz gems found in the State have been sourced from a number of geological environments. A selection of these 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. 12.2).

Forms exhibited by quartz crystals and the nature of their atomic structure have a number of exceptional characteristics not found in other gem materials. Quartz crystallizes in the trigonal trapezohedral class of the rhombohedral subsystem of the trigonal system. Its most common habit is as short, six-sided hexagonal prisms. Each prism termination comprises six rhombohedra (known as + and – rhombohedra), generally of different sizes. Unequal development of crystal faces results from differential speed of growth of particular faces forming crystals that often appear misshapen. Hexagonal prism faces are commonly striated across the prism faces in a direction parallel to the plane of the horizontal axes. These striations are formed by oscillatory development of prism and rhombohedra faces. Quartz that has equal development of the rhombohedra may develop as bipyramidal 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 but 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, consisting of two quartz crystals, is in contact with the crystals' c-axes inclined at

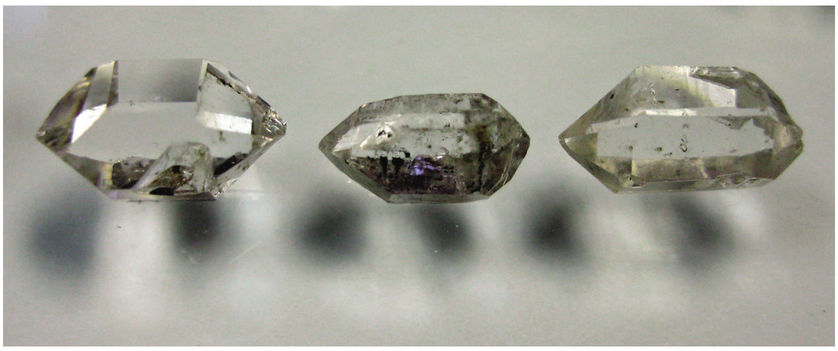

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Figure 12.2 Euhedral, transparent quartz crystals, each approximately 10 mm in length, recovered from surface deposits at Yinnetharra (courtesy Gemrock Enterprises)

84° 33′. Examples of this form of twinning for amethyst and citrine crystals are described in (O'Donoghue, 1987). Twinning may be readily observed by microscopic examination under crossed polarized light where various complex patterns of extinction can be viewed (Fig. 12.3).

Also under the microscope, quartz is seen to be unique in having a spiral crystal structure that causes circular polarization, rather than plane polarization of light. Single crystals of quartz often display a distinctive optical interference figure, sometimes referred to as a bull's eye figure, and a gemmologist noting this optic figure can confirm the identity of the gem under test as quartz (Fig. 12.4).

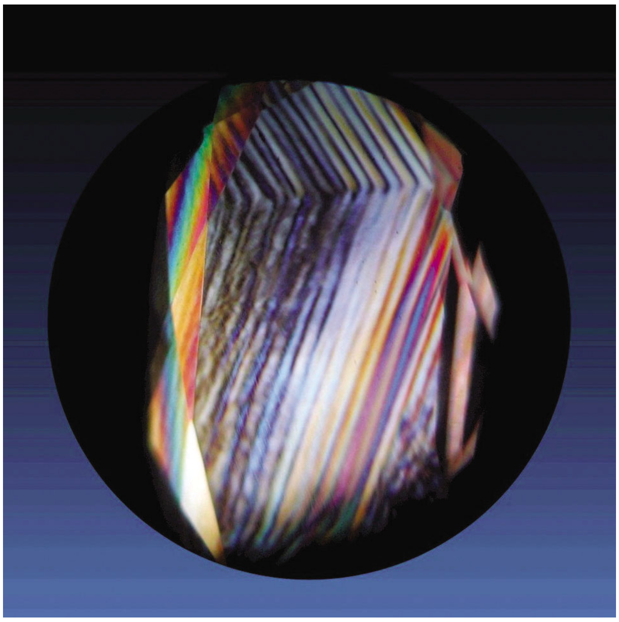
Quartz mineral varieties

Colourless quartz is known as 'rock crystal', and objets d'art and gems fashioned from colourless quartz are commonly referred to as 'crystal'. It should be noted that the term crystal is also used to describe objects made from manufactured lead-glass. Simpson (1952) made reference to clear quartz as 'water-clear'. Quartz also occurs naturally in many coloured varieties listed below:

- Amethyst (purple)
- Smoky and cairngorm (brown to brownish-grey)
- Morion (black)
- Citrine (yellow)
- Prasiolite (green)
- Rose (pink)
- Ametrine (displays distinct colour zones of purple and yellow in a single crystal).

Colour banding is common especially in amethyst and citrine quartz and can be observed as chevron-style banding commonly parallel to directions of the rhombohedra faces. Quartz crystals commonly contain other minerals as inclusions and these can impart colour variations and optical phenomena to the host crystal such as asteriated and chatoyant varieties.

'Phantom quartz' is a term given to a common growth feature of crystals that show 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. 12.5). 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 is common in amethyst and citrine quartz.



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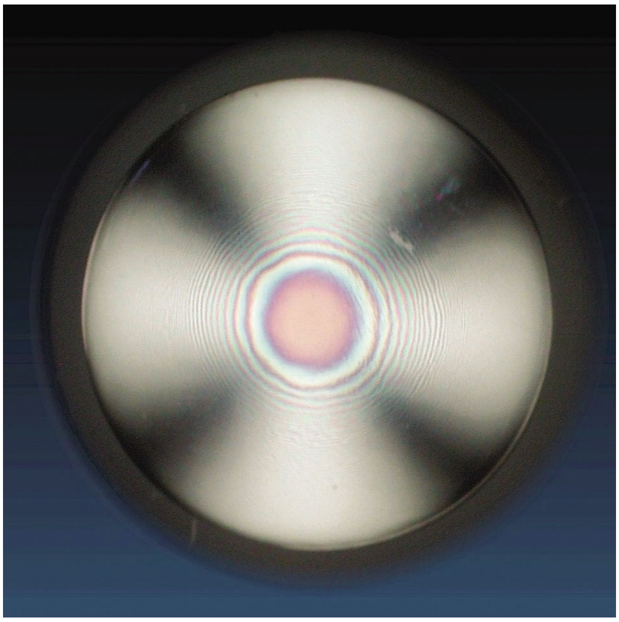
3 mm

Figure 12.3 Micrograph of an amethyst gem showing multiple twin planes viewed in crossed polarized light (courtesy John Harris)



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10 mm

Figure 12.4 Micrograph of the unique bull's eye uniaxial quartz figure (courtesy John Harris)

Figure 12.5 Zoned growth of an amethyst quartz crystal displaying a sharply delineated colourless border with contact planes marked by mineral inclusions. Wyloo area, Ashburton region (Western Australian Museum, specimen number 888)

Artificial treatments

Although quartz in all its colour variants occurs naturally, quartz gems are routinely treated to improve or change colour. The long-used heat treatment and mineral irradiation are two methods. For example, an amethyst heated to 250ºC may cause the mineral to 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 valency state from Fe^{4+} to Fe^{3+} of iron within the quartz. Heat-induced colour change starting with amethyst can also produce green quartz (prasiolite) as a substitute for the rare, naturally occurring variety.

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

Geological occurrence

Of most interest to collectors are locations where quality crystals can be readily found. These 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 pockets and '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 development of 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 a number of 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 crystal pockets, also known as blows, are well known as a potential source of euhedral crystals, especially when clay filled (Fig. 12.6).

Recorded examples of gem crystals that include quartz sourced from cavities in pegmatites 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 Forrestiana rubellite pegmatite. Quartz crystal vugs within quartz cores are found in some deposits such as those 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). Occurrences of 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.

Quartz in amygdales

Amygdales or gas cavities that develop within igneous rocks, especially basalts, are a common source of quartz crystals, habitually occurring with chalcedony. Quartz crystals are reportedly widespread from amygdales of the Archean Maddina Formation (Thorne and Tyler, 1997; Fig. 12.7) and from basalts in the Cambrian Antrim Plateau Volcanics (Gemuts and Smith, 1968).

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Figure 12.6 Amethyst quartz crystals lining the cavity of a slightly flattened vug (Western Australian Museum, specimen number 5076)

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Figure 12.7 A 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 development. The largest crystal measures 4 cm across (courtesy Glenn Archer)

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. Simpson (1952) notes that when blows occur within quartz veins they are generally barren of gold. Vein quartz is a common gangue mineral of metalliferous veins and is usually white, translucent, and massive (amorphous). When 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. 12.8).

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Figure 12.8 A spectacular quartz crystal cluster or 'quartz blow' from the Pilbara region on display at the Western Australian Museum

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 located 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 the Mount Belches tantalum prospect (Fig. 12.9).

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 occur 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 occur as multiple, parallel dykes separated by a few metres of metasedimentary rock. Binneringie pegmatite mineralogy is similar to pegmatites located immediately east at Bald Hill where the mineralogy comprises 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 Binningerie pegmatites also contain beryl and black tourmaline.

Saint John pegmatites

The Saint John pegmatites, part of the Binneringie pegmatite field, are poorly exposed, tantalum-bearing pegmatites located on adjoining mining leases M15/1305 and1308, about 10 km northeast of Binneringie Homestead (Fig. 12.9).

Prior to 2002, the area was worked for weathered pegmatite material situated 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 in length and weighing 5 kg, as well as several 2–3 kg masses of water-rounded citrine quartz. 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. 12.10). 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)*

Located about 6 km south of Spargoville in the Kambalda region, the Giles and South Spargoville pegmatites are only 400 m apart (Fig. 12.9). 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 located about 180 km north-northeast of Kalgoorlie and about 1.5 km south of the old Linden townsite (Fig. 12.9). It is recorded that about 40 kg of clear, doubly terminated, single quartz crystals up to 140 mm in length were collected from a clay-filled vug at the top of a quartz blow on the northeast 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 located 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. 12.9).

This pegmatite has already been described in the tourmaline chapter. It is situated within the north-trending greenstone belt of the Southern Cross Domain. Opencut mining in the early1980s resulted in a pit 10–18 m deep, 30–50 m wide, and 75–150 m in length. The pegmatite was worked for tantalite (manganotantalite and microlite) as well as for gem pink tourmaline (rubellite). During the mining period, two rare tantalum minerals, stibiotantalite and kimrobinsonite were found associated with the quartz–cleavelandite–lepidolite pegmatite.

Tantalite mining ceased by the late 1980s but 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. The pegmatite is currently worked and the owners have continued to mine pink tourmaline in a tunnel extending northeast from the small gem shaft located 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

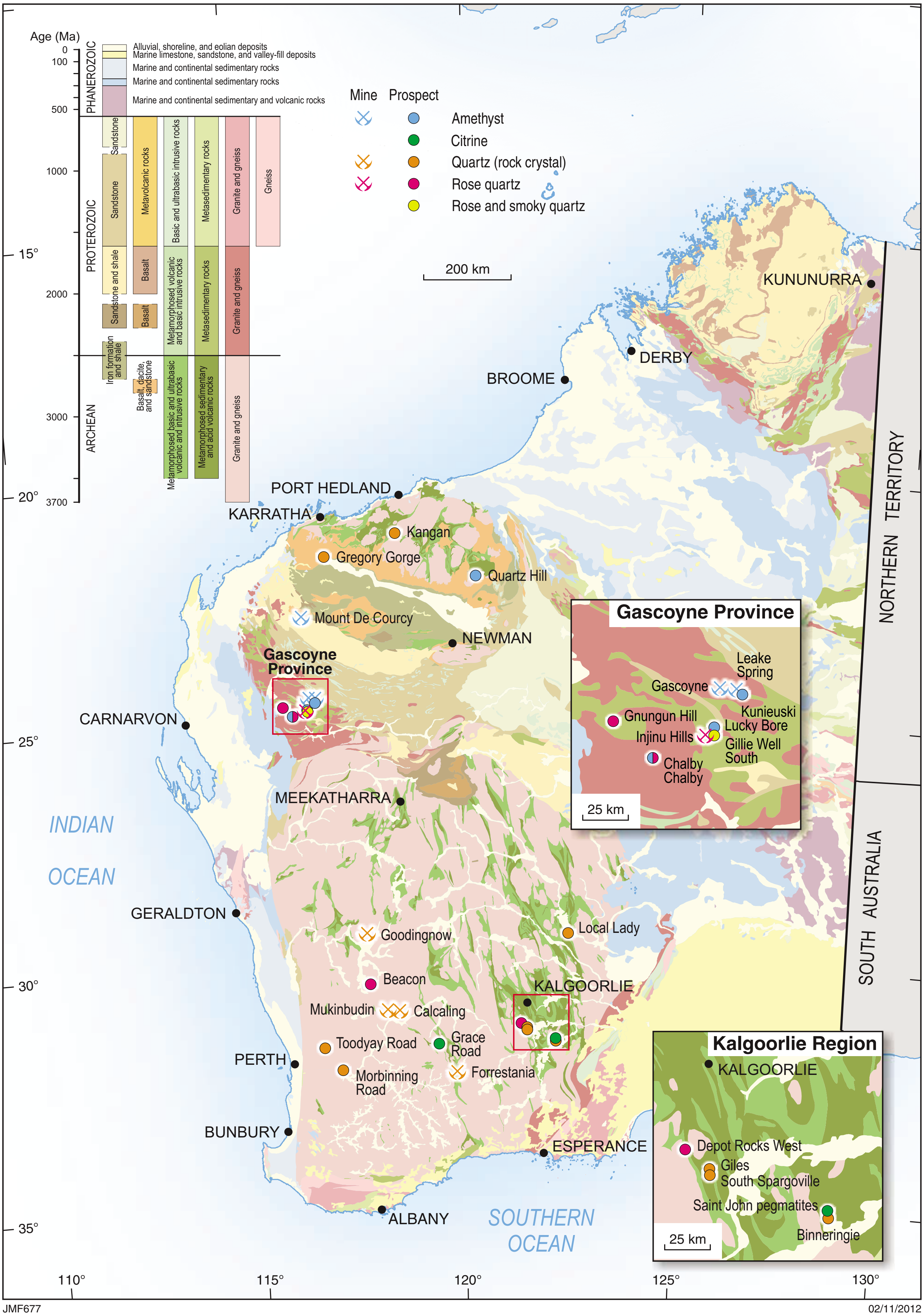

Figure 12.9 Location of gem-quality quartz minerals in Western Australia

Figure 12.10 Cut and polished citrine quartz gemstone, 35 mm in diameter, from the Saint John pegmatites (courtesy Bill Moriarty)

to clay. The remaining residual minerals are mostly fractured and brecciated, and quartz masses do not exceed 15 cm 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 2 cm in length (Jacobson et al., 2007) .

Yilgarn Craton — Murchison Domain

Mukinbudin area

Mukinbudin feldspar mine (Barbalin, 2536)

The Mukinbudin feldspar mine (also referred to as the Snowstone quarry) is located adjacent to the Koorda–Bullfinch Road, about 7 km west-northwest of the town of Mukinbudin in the central wheatbelt region (Fig. 12.9).

The deposit is located 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 are currently in care and maintenance and contained within mining lease M70/118 owned by Sibelco Australia Ltd.

Initial exploration indicated that the pegmatite mass contained a large quartz core, estimated to be 750 m long by 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 are 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, being about 50 m wide by 75 m long by 7 m deep. At this site, it is possible to observe the zonation of the pegmatite from the massive white quartz core to the adjacent zone of pure microcline and zone of intergrown quartz–microcline–plagioclase with scattered metre-sized biotite crystals near the contact with the granitic wall rock. 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, and until recently, well-crystallized albite and microcline feldspars were still found in these cavities.

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 x 15 cm, and that groups of parallel growth crystals lining fractures may exceed 30 cm and 10 kg in weight. Crystals vary from white, clear, and clear with hematite inclusions to dark, smoky quartz crystals. The smoky quartz crystals are highly lustrous and sometimes display overgrowth phantoms. All the quartz crystal vugs and fragments are described as being noticeably darker and clearer compared with opaque white quartz of the core (Jacobson et al., 2007).

Calcaling pegmatite

The Calcaling pegmatite is located on farmland about 21 km east from Mukinbudin (Fig.12.9). The pegmatite, outlined by a low quartz hill, was first investigated about 1994. Mining operations followed initial exploration and an oval-shaped quarry was developed from which feldspar was exported between 1995 and 1997. 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 that 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 from its formation being 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 albitic feldspar occupies the western part of the quarry floor and contains a few smoky quartz masses. One miarolitic cavity was found containing euhedral microcline, albite, and smoky quartz crystals.

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 heaps.

During mining operations 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 by 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 by 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 by 2–8 cm in diameter (Fig. 12.11). Additional crystals have since been removed from this pocket.

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 located 7 km south-southwest of Paynes Find (Fig. 12.9).

Figure 12.11 Smoky quartz crystal cluster from the Calcaling pegmatite, Mukinbudin area (courtesy Stewart Cole)

The Paynes Find greenstone belt comprises a northeast-trending sequence of ultramafic and mafic greenstones and metasedimentary rocks intruded by largely concordant but irregularly shaped bodies of felsic pegmatite and aplite. Pegmatites in the area are simple quartz–microcline–muscovite pegmatites but several of them 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 between 1965 and 1990. 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 located about 5 km to the south-southwest of the Goodingnow quarries. At this site, on former mineral claim MC59/5799, a group of three pegmatites have yielded small, glassy, clear quartz crystals as well as fragments of tantalite found in local debris piles.

Simpson (1952) records 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) describes 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 quartz crystals were reported by Blight et al. (1984) from the property of Mr F Ayres, about 17 km northwest of Beacon township (Fig. 12.9). The crystals were found in soil covering quartz-infilled easterly trending fractures parallel to dolerite dykes intruding local granitic rocks.

Southern Cross region

Grace Road prospect (Holleton, 2734)

An occurrence of citrine is reported at the Grace Road prospect approximately 38 km south of Southern Cross (Fig. 12.9). The crystals formed as a quartz blow (not in a vein or a pegmatite) and were exposed over a distance of 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 reaching 4.5 x 2.2 cm in topsoil on the Northam–Toodyay

Road in the former Oakfield Estate about 5.6 km from Northam (Fig. 12.9).

Some of the crystals are described as perfectly clear and colourless, some containing phantom structures, and some with alternate prism faces corroded. Although the quartz crystals may originate from a pegmatite possibly located 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), records an occurrence of clear, colourless to pale, smoky-brown quartz at the Morbinning Road prospect some 10 km east of Beverley (Fig. 12.9). The quartz prisms and pyramids are generally 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 but it is noted that only a few were of the minimum size (approximately 12 mm) that would 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 (specimen number 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 located approximately 20 km west-northwest of the Wodgina tantalite mine and 1.6 km west-northwest of Kangan Homestead (Fig. 12.9).

In 1944, quartz was investigated from pegmatites in an area of Archean greenstone rocks within the Wodgina pegmatite field. At the Kangan quartz prospect, situated in former 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 on 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 were described as being up to 30 mm in length, terminated at one end, whereas others consisted of flattened forms of hexagonal, prismatic crystals with one or both ends terminated by pyramids. Crystal sizes varied from about 6 mm wide and 25 mm in length to 100 x 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 in a wide range of crystalline development and varying sizes up to lengths of around 28 cm. Many crystals showed obvious pyramidal development at both ends and all crystals showed extensive twinning, intergrowth and cloudy inclusions, although some of the 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 number 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. 12.7). This site is at an unknown location in the Gregory Gorge area on the Fortescue River, approximately 18 km west-northwest of Millstream (Fig. 12.9). No further information is available.

Amethyst in Western Australia

Amethyst is the purple form of quartz, although the colour is often unevenly distributed and commonly banded. The colour of amethyst is caused by iron colour centres, as well as iron inclusions in crystals, particularly goethite [FeO(OH)] or hematite (Fe_2O_3).

When 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 shades of red, grey, and in some instances of smoky appearance. Amethyst shows a weak dichroism, displaying a colour change from grey-violet to purple. Colour may fade with exposure to sunlight and it is well known to prospectors that the purple colour may improve and intensify with depth in an excavation.

Amethyst-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. 12.12).

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Figure 12.12 Amethyst-quartz vein with central replacement vein (4 cm wide) of quartz and chalcedony after bladed calcite crystals from the Mount Phillips area. The outer zones of mixed purple and colourless amethyst-quartz display serrated borders marked by pyramidal crystal terminations (E de C Clarke Museum, University of Western Australia)

Gascoyne Province

Mount Phillips area

Gascoyne amethyst field (Mount Phillips, 2149)

Amethyst was mined intermittently between 1970 and 1990 from the Gascoyne Amethyst Field located in the Mount Phillips area, about 42 km west-southwest of Mount Augustus (Fig. 12.9). The amethyst mining operation is located on mining lease M09/28 currently owned by Mr B Kayes. The operation was formerly known as the Mount Phillip amethyst mine, the Soklich amethyst mine, and also the Gascoyne amethyst deposit. In this area, amethyst was mined from sites referred to as 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 occurs in quartz segregations near calc-silicate and marble metamorphosed host rocks (Fig. 12.13). In zones of mineralization exposed in the Main and No. 2 pits are breccia pipes several metres wide that contain a complex open-space filling assemblage of minerals including gem-quality amethyst. 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 to be 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 suggests an epithermal origin for these pipes (Johnson, 1995).

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 to the 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 is consistent with the brecciated nature of the pipes. Although sulfides are generally 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 but 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 two or three metres around the main structures. Main alteration types are argillization and silicification. Argillic alteration comprises green clays with lesser 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 vicinity of Mount Phillips, and one beneath Breccia Hill. Samples from the top 16 m of the hole at Breccia Hill revealed a continuation of quartz breccia, including a clay-rich band extending 9–6 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 when 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 located 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. 12.9). A total of 4163 kg of amethyst was produced from this openpit in the period 1971–72 (Connolly, 1980).

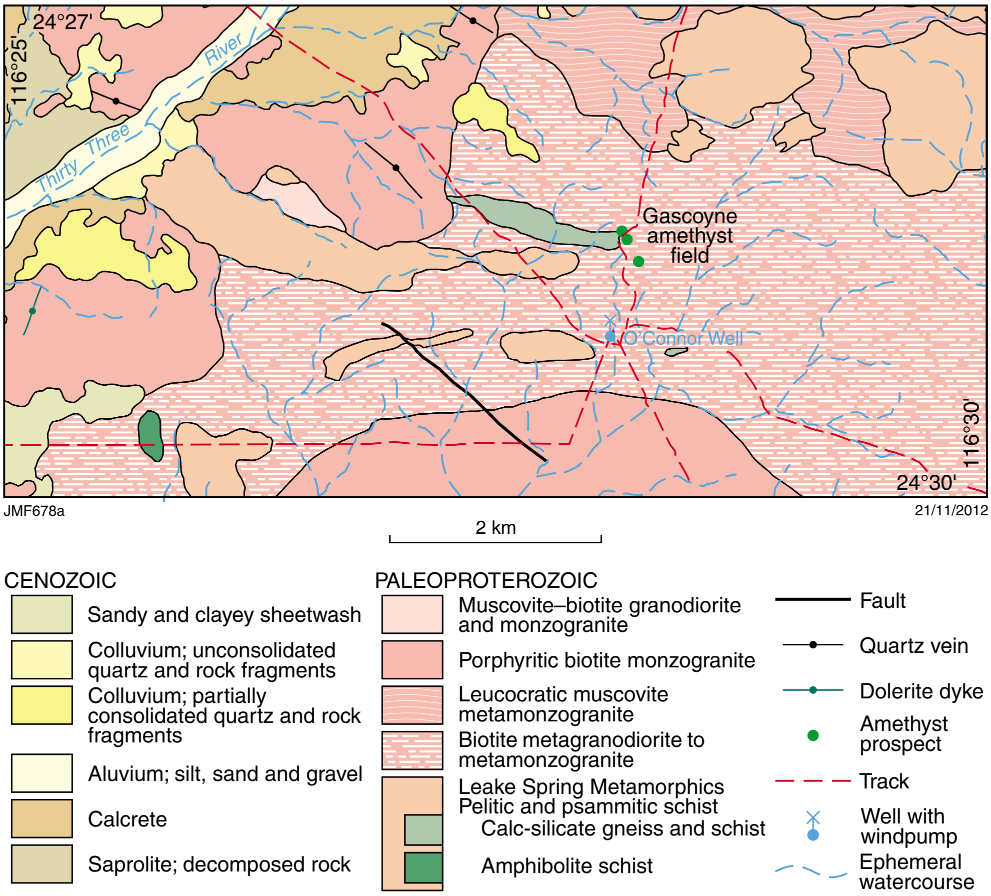

Figure 12.13 Geological map of the area surrounding the Gascoyne amethyst field (modified after Sheppard et al., 2008)

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 located on mining lease M09/72 (Fig. 12.9). 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 but 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, 4 km south-southwest of Gillie Well in the Camel Hill area (Williams et al., 1983) (Fig. 12.9).

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. 12.9).

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 about18 km southeast of Wyloo Homestead and adjacent to the Wyloo marble mine, has been an important mining area for the production of amethyst (Fig. 12.9).

In this area, amethyst is found in late-stage quartz-cavity infillings in faulted, slope-facies breccia in the Paleoproterozoic Duck Creek Dolomite. The dolomite here is a thin to thickly bedded unit, locally stromatolitic with minor chert and mudstone horizons (Fig. 12.14). Amethyst found in the area has been described as mainly inferior in colour although some good-quality material is reported to have been found (Thorne and Seymour, 1991). Despite various reports, some large crystal display specimens have been sourced from the claims (Figs 12.15 and 12.16).

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. 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 the current mining area on Wyloo Station. A test sample of amethyst crystals from the Wyloo claims was taken to Onslow by camel. From

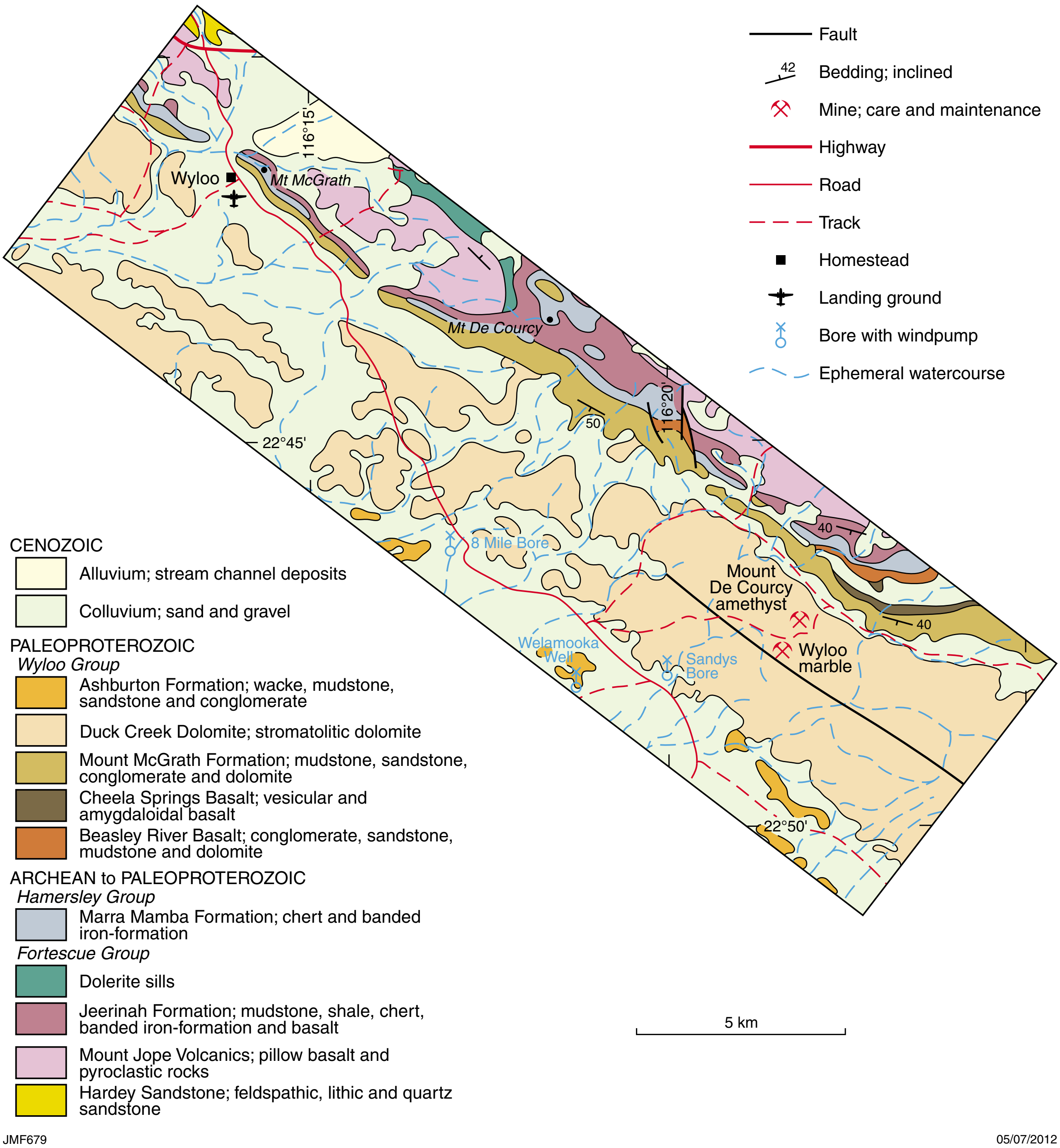

Figure 12.14 Geological map of the area surrounding the Mount De Courcy amethyst mine (modified after Blight et al., 1986)

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 that, ‘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 but 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 as ‘sun bleached’, although it is known that 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, a number of 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 as well as doubly terminated crystals, stating that these forms were ‘not scarce’.

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Figure 12.15 Amethyst quartz crystal terminations from the Mount De Courcy mine at Wyloo (courtesy Murray Thompson)

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Figure 12.16 Rectangular, step-cut, 1.71 ct amethyst from Wyloo (courtesy Australian Museum, Sydney)

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. 12.9). These openpits, 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. There are several mechanisms involving mineral inclusions that may result in the pink colour in quartz. One important mechanism is the presence of nanofibrous mineral inclusions. Rose quartz deposits in Western Australia have been reported rarely 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 *(Yilmia, 3135)*

Specimens of rose quartz have been collected from pegmatites located at unrecorded sites in the Spargoville area, although photographic images still exist showing faceted rose quartz gemstones from this area (Fig. 12.17).

Kambalda region

Depot Rocks West prospect (Yilmia, 3135)

A prospector has reported the occurrence of pegmatite prospect at Depot Rocks West containing rose quartz, mica, and feldspar in its outer rim (Fig. 12.18). The pegmatite is hosted by andalusite-rich metamorphosed rocks. This prospect is located on former prospecting licence P15/5337, about 17 km southwest of Mount Marion in the Kambalda region (Fig. 12.9). No other information is available on this site.

Figure 12.17 Faceted, light pink, translucent rose quartz gemstones from the Spargoville area (courtesy Bill Moriarty)

Gascoyne Province

Yinnetharra region

Bracewell (1996), reported a deposit comprising masses of ‘coconut ice’ coloured rose quartz at an unspecified locality on Yinnetharra Station, although no faceting quality material was found. Kenyon (1993) reported that numerous pegmatites in the area contained 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 a number of sites in the area had been severely damaged by blasting.

Injinu Hills mine (Yinnetharra, 2148)

The Injinu Hills rose quartz mine is located on mining lease M09/58 about 8 km southwest of Gillie Well in the Camel Hill area (Fig. 12.9). 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.

Gillie Well South prospect (Yinnetharra, 2148)

The Gillie Well South prospect is located approximately 5 km south-southwest of Gillie Well in the Camel Hill area (Fig. 12.9). Rose and smoky quartz have been sourced from quartz segregations in a zoned pegmatite at this site.

Gnungun Hill (Lockier, 2048)

Simpson (1926) recorded an occurrence of highly translucent, pale rose-pink quartz found in masses weighing several kilograms from an unknown site in the Gnungun Hill area, located between the Lockier Range and Pyramid Hill on Bidgemia Station, some 30 km west-northwest of Yinnetharra Homestead (Fig. 12.9). 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

That there are numerous other sites for gem-quality quartz in Western Australia is indicated by the many attractive stones forming 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 below:

Mineral	*Locality (approximate)*	*WA Museum specimen number*
Quartz (perfect doubly termi-nated 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’ level	S 3859
Rose quartz	Cairn Mining Centre, Yinnetharra area	688
Smoky quartz (cluster)	Baddera lead mine, Northampton	S 3448

Figure 12.18 Rose quartz site at Depot Rocks West prospect in the Kambalda region. The exposure is about 4 m in diameter (courtesy Francine Payette)

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Chapter 13 Opal

Opal — gemstone 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 spectral colours against the background of light to dark body colour tones. Precious opal can be translucent or opaque in diaphaneity. Common opal occurs in a range of body colours and can also be opaque or translucent but shows no play-of-colour.

The distinction between precious and common opal results from differences in their paracrystalline structures and mineralogy. All opal is composed of silica, of micron-sized particles, chemically combined with water and is expressed as a formula ($SiO_2.nH_2O$) but its full characterization can only be established by XRD techniques.

The submicroscopic structure of precious opal is demonstrable only from electron microscopy studies. These investigations show the constituent silica particles are in the form of microspheres, known as lepispheres, of regular dimensions and which may be aggregated in domains of orderly three-dimensional arrays. When these spheroids have diameters 150–300 nm and are aggregated in blocks, they can act as diffraction gratings. This may result in the creation of an array of iridescent spectral colours (play-of-colour), resulting from diffraction and interference of impinging light passing through void spaces. 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 either red, green or blue primary colours. These spectral colours are dependent on the diameters of the lepispheres, the precision of their stacking arrangements, and the size of the gaps or voids between spheroids.

Opal
Hydrated silicon dioxide ($SiO_2.nH_2O$)

Potch opal is a form of common opal that does not show play-of-colour but commonly occurs 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 opal gel from which it precipitated. Although potch opal shows a structure of silica spheres they are irregular in size and randomly aggregated and as a result no play-of-colour is present.

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 chromophores: Cr, Ni, Cu, Fe as discrete mineral inclusions 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 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	Opals are usually freeform or cabochon cut, translucent and transparent opals may be faceted. Some opals are cut and displayed with host rock matrix attached

With no play-of-colour, constituent silica particles in common opal may crystallize as ultra-fine fibrous masses. Scanning electron microscopy has identified the silica polymorphs cristobalite and tridymite and this type of opal is termed 'Opal-CT'. Mineralogy of common opal by petrological microscope demonstrates that the fibres are anisotropic and have low birefringence. Precious opal is optically isotropic and is termed 'Opal-AG' (amorphous gel opal; Frazier and Frazier, 2007).

The water content of opals, expressed as a percentage by weight, can vary from 1 to 21%. Chemical analyses 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% (Simpson, 1952).

Opal terminology

Opals have an uncommon set of terms used for their description. Most of these are reproduced in the following glossary.

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	A term used for finished gemstones that are manufactured from more than one piece of material, often consisting of 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	A synonym for opal, or a generic term for opal lacking play-of-colour
Fire (flame) opal	A translucent or transparent red-brown common opal variety
Honey opal	Translucent red or orange-yellow common opal
Hyalite	A colourless, transparent variety of opal
Moss (dendritic) opal	Common opal with dendritic or arborescent inclusions, usually green silicate minerals
Nobby opal	A nodule of opal
Opal	A 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 XRD to comprise the silica polymorphs cristobalite and tridymite, microscopically fibrous and birefringent

Glossary (continued)

Opaline silica	A field term describing surface silica of unknown character
Opalite	A 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; an optical effect
Potch	A term originating in Australia describing common opal found together with precious opal. It does not display play-of-colour
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
Prase opal (or prasopal)	Nickel-bearing green common opal
Siliciophite	A mixture of chrysotile and opal, or serpentine and opal
Siliciophitic	A 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

Precious opal in Western Australia

Precious opal is rare and is the most valuable type of opal. In Western Australia, two deposits, Three Mile Hill and Cowarna, have been mined by opencut methods, both in the Kalgoorlie Mining District (Fig. 13.1). 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 Western Australian sites differ from the usual geological environments present at the major sources of precious opal in other Australian states. In those 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 demonstrated structural similarities to opals occurring in mainly Cretaceous sedimentary rocks in New South Wales, South Australia, and Queensland. Opal formation in these rocks is considered to have occurred during periods of deep weathering in the mid-Cenozoic era.

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

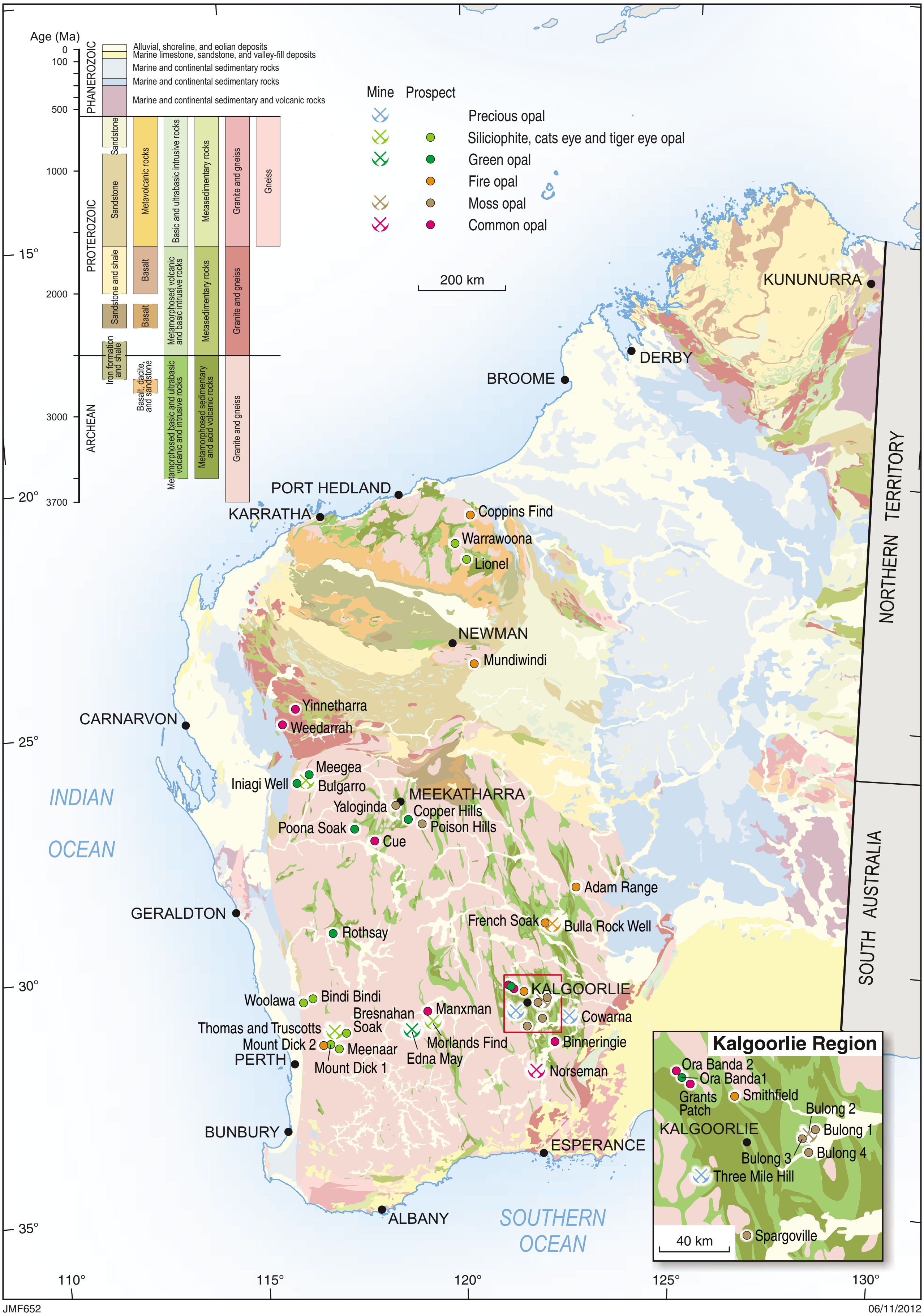

Figure 13.1 Opal mines and prospects in Western Australia

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. The opal mining site is located within an area of gold mines known as the Three Mile group, situated about 5 km north-northeast of Coolgardie railway station, close to the Coolgardie–Kalgoorlie railway and main road (Fig. 13.2).

The Three Mile Hill opal mine lies within mining lease M15/1456, which covers an area of 4.9 ha. The mining lease is within an area of Archean metamorphosed interbedded basic lavas, ultramafic, and metasedimentary rocks. The occurrence of opal is confined to a shear zone, about 9 m wide, within graphitic slate bands that grade across strike in places into thin sandy feldspathic bands with a steep southerly dip. These bands are situated at or near the boundary with adjoining greenstone rocks, where they outcrop as thin, discontinuous and probably highly folded, laminated bands of sedimentary rock. In this situation, the bands have been silicified and in one locality thin seams of precious opal have developed along cleavage and joint planes (Fig. 13.2).

The siliceous matrix is a relatively hard, black or dark grey, fine-grained rock and 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 with the remainder being of no commercial value. The largest veins were about 2.5 mm thick but thicker veins were reported by miners and occasionally good specimens exhibiting a brilliant display of colours were found (Fig. 13.3).

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 to be depleted and was later described as being '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 short period. Currently, the Three Mile Hill opal deposit is located on mining lease M15/1456 owned by Mr J Houldsworth.

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. One black opal weighing 16.5 kg and another of 2.5 kg were reported. The surrounding potch veins were generally found to be much wider than the precious opal and were glassy and bluish in colour.

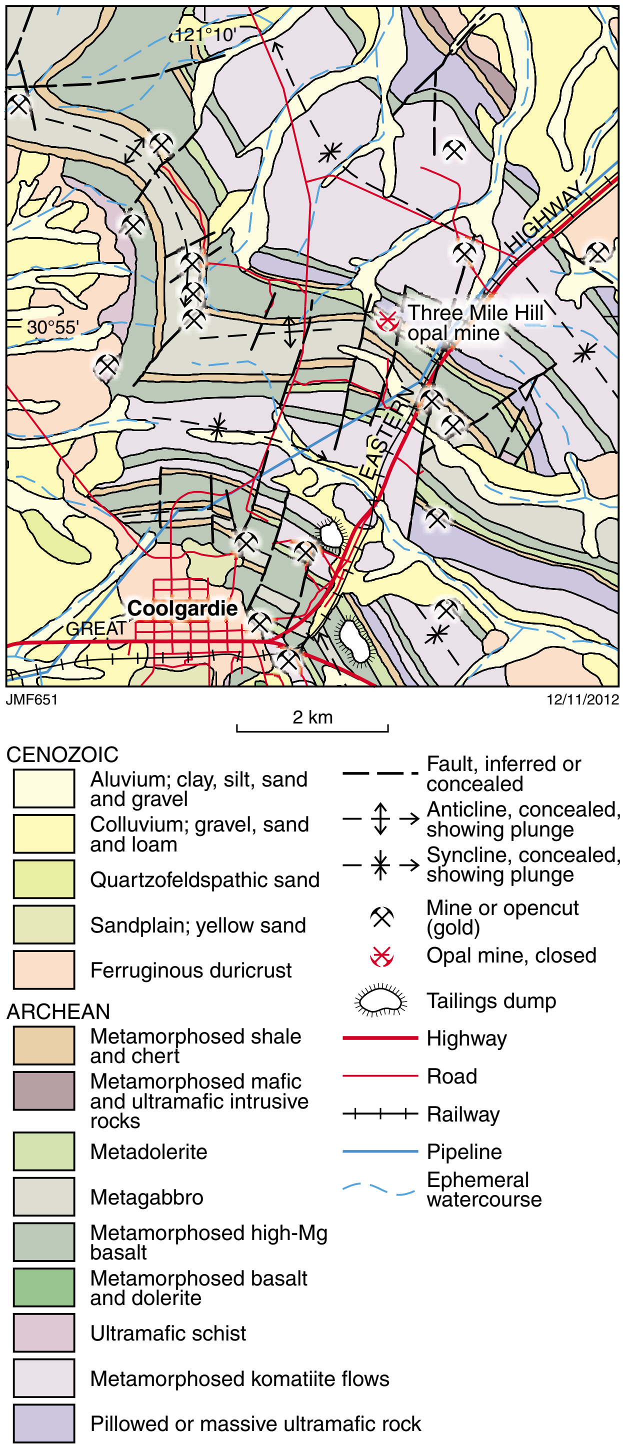

Figure 13.2 Geological map of the Coolgardie area showing the location of the Three Mile Hill opal mine (modified after Hunter, 1985)

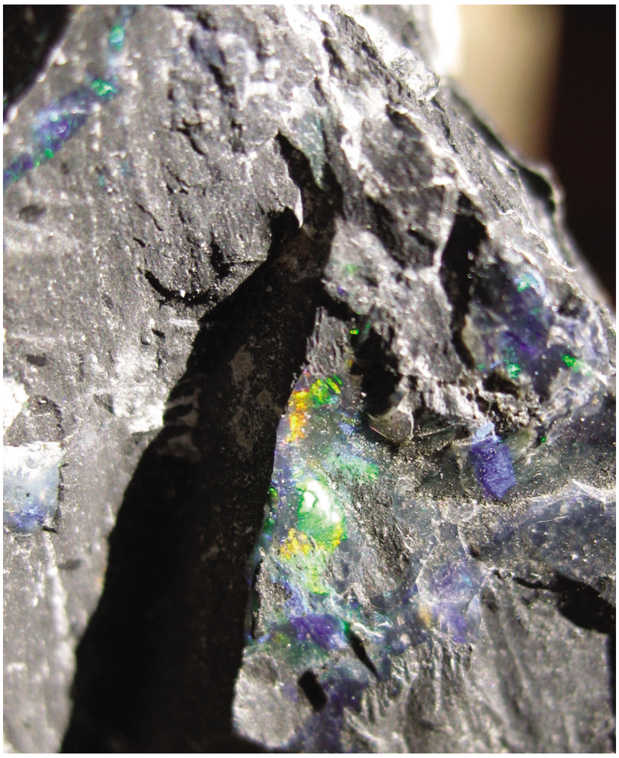

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Figure 13.3 Precious opal with play-of-colour on graphitic schist from Three Mile Hill opal mine, Coolgardie

Currently, the Cowarna deposit is held under prospecting licence P28/1007 and pending mining lease M28/372 by Bullabulling Pty Ltd.

Geology of the deposit

The Cowarna opal deposit is located within a north-trending zone of thinly bedded, Archean graphitic quartz schist and tuff beds within an amphibolitic sequence that appears to extend north and possibly south of the exploration area for several kilometres in relatively poor outcrop (Fig. 13.5).

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Figure 13.4 A polished specimen of Cowarna opal (16 mm wide) showing play-of-colour (courtesy Bill Moriarty)

Cowarna Downs Homestead area

Cowarna opal mine (Mount Belches, 3335)

The Cowarna opal mine is located about 100 km east-southeast of Kalgoorlie, and 11 km east-southeast of Cowarna Downs Homestead (Fig. 13.1). 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 proceeded on-site followed by the construction of three shafts to a maximum depth of 11.6 m. This 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 immediately to the north and south. During investigations of the shafts, Caldwell holes and drives, many traces, veinlets and pockets of precious and common opal were found, although none was assessed to be 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 to be host rock, yielded some 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. 13.4; Connolly, 1976).

In the exploration area (mineral claim K392), a mineralized strike length of 220 m has been demonstrated. The host rocks strike at 348° and the prevailing dip is 70º, or steeper, west. 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 concordantly intruded by quartz porphyry. At a later stage, the porphyry appears to 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 in thickness, whereas potch veins range up to 7.5 cm thickness. 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).

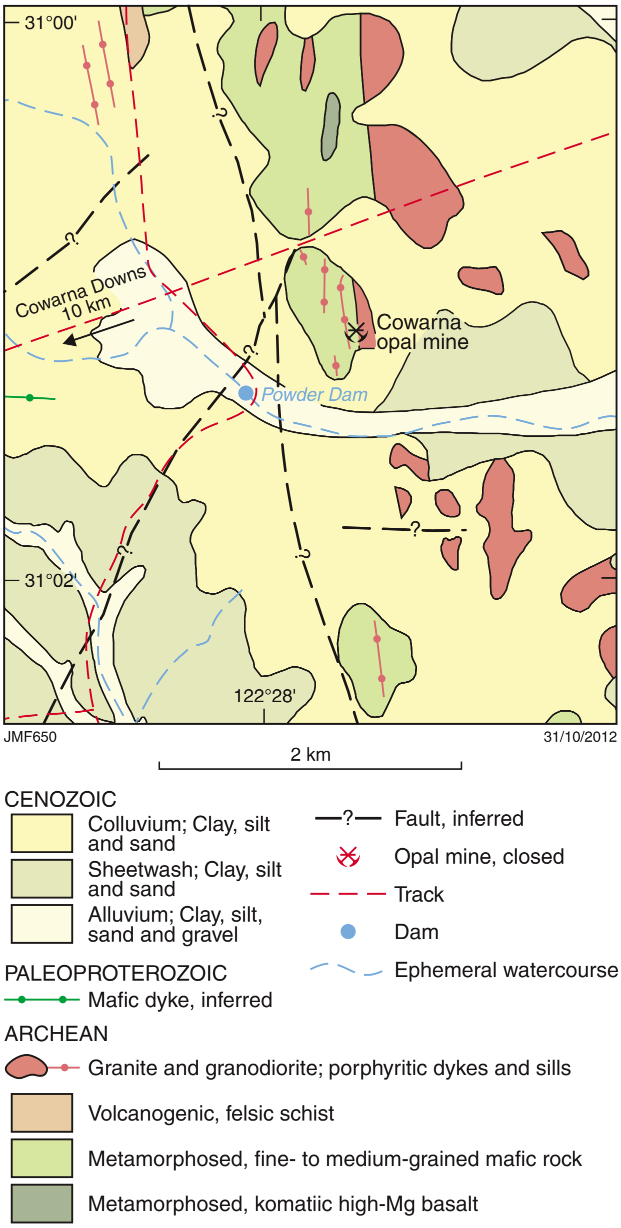

Figure 13.5 **Geological map of the area surrounding the Cowarna opal mine (modified after Painter and Groenewald, 2000)**

Common opal

Common opal may occur as colourless masses or in a variety of colours including green, white, cream, red, brown or black. Some common opals, notably green varieties, are coloured by the presence of nickel, chromium, and copper. Although chemical analyses may show the presence of chromophores their actual nature is rarely reported or confirmed. Other causes of colour within common opal include different mineral inclusions, such as clays, phyllosilicates, and hydrated iron minerals. White opal results from light scattering due to microfissuring within the opal.

Other forms of common opal include cats eye and siliciophite opals that display chatoyancy (cats eye effect) from fibrous inclusions within the opal, fire (or flame) opal that occurs as coloured nodules ranging from red to orange and yellow, and moss (or dendritic) opal containing visually attractive dendritic inclusions.

Common opal in Western Australia

Common opal is widespread in Western Australia and is commonly found associated with magnesite and/or other forms of silica, especially chalcedony. There are numerous locations where attractive material is present (Fig. 13.1). Common opal from these sites may be coloured, patterned or translucent or may display attractive inclusions and many of these are collected for cutting and polishing. More detailed locational information on most of the 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 occurrences of common opal are in the form of narrow veins, thin coatings and nodular aggregations on rocks at or near the current land surface. In this environment, opal is often 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 normally 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, there are many sites in the State where 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 opal occurrences are not of 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 below. 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 and siliciophite

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 formed mainly 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 tiger eye, crocidolite, anthophyllite, and tremolite. Cabochon-cut gems orientated with the fibre inclusions parallel to the base of the stone can produce a cats eye effect in the form of 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 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, but little work was done. This deposit is probably the same as the opal mine located 20 km east-southeast of Byro Homestead (Fig. 13.1). In 1960, it is recorded that the mine produced 54.4 kg of tiger eye opal (Williams et al., 1983).

The tiger eye opal is a replacement of massive, fibrous serpentine present in both wide and narrow veins throughout the rock prior to silicification. The 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.

The tiger eye displays an 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 a number of recorded sites containing siliciophite opal.

Physical properties of siliciophite

Colour range	Yellowish-green, yellowish-brown, brown
Lustre	Resinous, silky appearance of fibres
Refractive index	1.455
Hardness	6
Specific gravity	2.13
Fluorescence	Inert in UV light
Inclusions	Chrysotile fibre inclusions, healed fissures, black octahedra (possibly chromite), brown platy inclusions (possibly chlorite)

Source: Brown (1989)

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. 13.1). 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. 13.6; 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 Salgash Road (Fig. 13.1).

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 (Simpson, 1952).

Yilgarn Craton — South West Terrane

Goomalling

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. 13.1). Some of the opal was siliciophite, whereas other forms of common opal were white, brown and black and mottled specimens showed bright green, violet, and grey colours (Simpson, 1952).

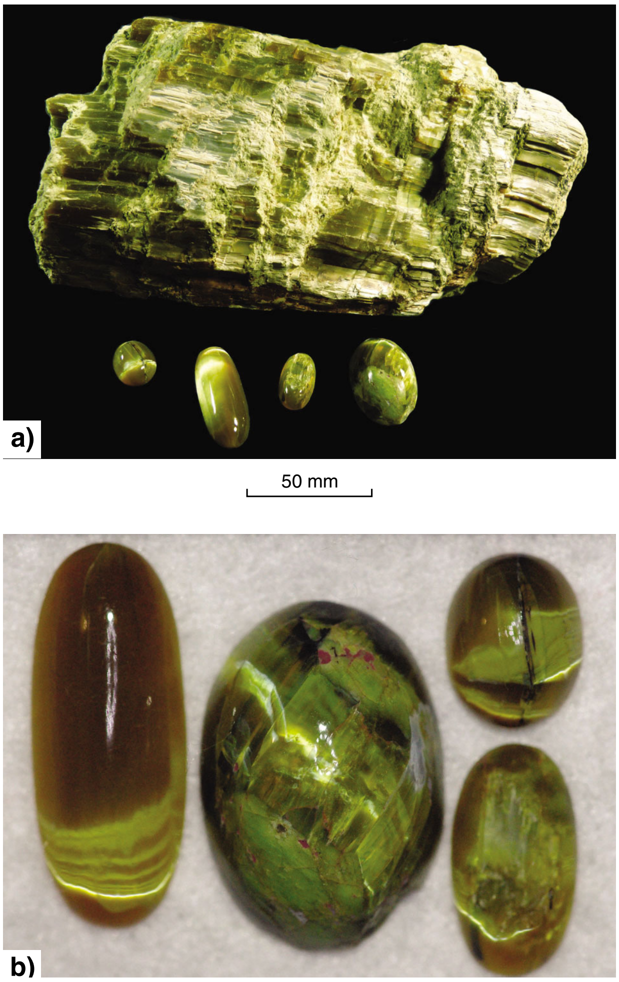

Figure 13.6 **Two photographs of cats eye siliciophite from Lionel in the Nullagine area. These specimens have been described as chatoyant opal pseudomorphs after chrysotile: a) a fibrous, greenish-yellow form with cats eye cabochons; b) detail of golden-yellow to greenish-yellow, polished cats eye cabochons. The centre cabochon is 14 mm wide (courtesy Western Australian Museum)**

Goomalling area

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. 13.1; Simpson, 1952).

Moora area

Woolawa (Moora, 2136)

Occurrences of abundant, green and brown siliciophite were recorded in an area of Archean migmatite rocks on Woolawa (formerly Wandera) Station, about 14 km east-southeast of Moora (Fig. 13.1; 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 anthopyllite (Fig. 13.1). This material contains semitransparent, light to dark olive-green siliciophite pseudomorphs after serpentine and anthopyllite and also commonly contains perfectly preserved fibre inclusions (Simpson, 1952).

Northam area

Mount Dick 1 (Northam, 2234)

Mount Dick is located about 7 km north-northeast of Northam (Fig. 13.1). 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 with 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 is abundant in the Meenaar area, 20 km east of Northam, and about 2.5 km south-southwest of Meenaar (Fig. 13.1; Simpson, 1952).

Fire or flame opal

Fire or flame opal is one of the more unusual forms of common opal. It is a translucent variety occurring as nodules, often together with chalcedony, and is red, orange-red, orange or yellow.

Collier Basin

Mundiwindi area

Mundiwindi (Mundiwindi, 2950)

Red-brown translucent fire opal is found in nodules at an unknown locality in the vicinity of Mundiwindi Aboriginal Community about 70 km southeast of Newman (Fig. 13.1). The opal nodules are reported to be up to 20 mm or more in diameter.

Pilbara Craton

Yarrie Station area

Coppins Find (Muccan, 2956)

Intense yellow opaque nodular-form opal is recorded from an unknown locality in the vicinity of Coppins Find about 65 km northeast of Marble Bar (Fig. 13.1).

Physical properties of fire opal	
Colour range	Yellow to orange, red, and red-brown
Lustre	Resinous
Refractive index	1.42
Hardness	5 – 5.5
Fracture	Conchoidal
Specific gravity	1.98 – 2.0
Fluorescence	Inert in UV light
Inclusions	Flow structures, dark dendritic inclusions, and internal veins

Source: Brown and Bracewell (1989)

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. 13.1).

Yundamindera 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. 13.1). Opals are embedded in the weathered host rock or in a chalcedonic matrix and are often 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 fire opal is recorded approximately 4 km northeast of Bulla Rock Well in deeply weathered granite breakaways (Fig. 13.1). 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, often 2.5 cm or more in diameter, are frequently 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, 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 (Mc Millan, 3441)

Red-brown, translucent fire opal was found in an area associated with monzogranite in the Adam Range area adjacent to Deeba Rockhole, approximately 34 km northeast of Laverton (Fig. 13.1). A flawless 4 ct red fire opal was cut from this material (Fig. 13.7; Simpson, 1952). Currently, the Adam Range area is being prospected for fire opal by Holdfast Exploration Pty Ltd.

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. 13.1). Apparently this material included dark green and brown opal, and hyalite common opal (Simpson, 1952).

Green opal

Green common opals can be coloured by the presence of nickel, chromium or copper. Prase opal and prasopal are informal terms used to describe green opal coloured by nickel-bearing inclusions, and chromopal coloured by chromium-bearing inclusions.

Yilgarn Craton — Eastern Goldfields Superterrane

Laverton area *(Laverton, 3340)*

A white and light-green chromiferous banded opal was collected from an unknown locality east of Laverton (Fig. 13.8; S 3799).

Ora Banda area

Ora Banda 1 (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. 13.1). This green opal contained 1.2% Cr_2O_3 (Simpson, 1952).

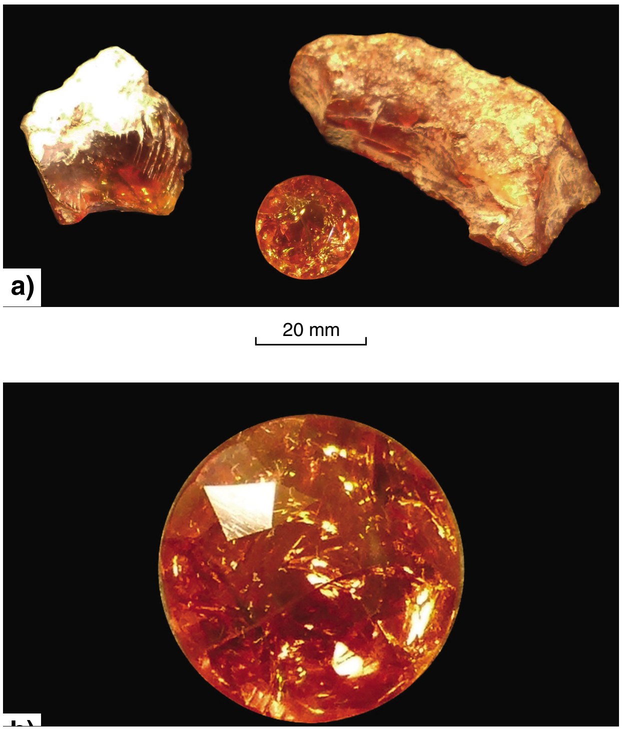

Figure 13.7 Red-brown, translucent fire opal from the Adam Range area, Laverton region: a) rough pieces of fire opal together with a 4 ct red-brown gem; b) detail of the 4 ct red-brown gem (courtesy Western Australian Museum)

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. 13.1). The colour is attributed to the presence of copper silicate (Simpson, 1952).

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 ML 94 at Poona Soak about 53 km northwest of Cue (Fig. 13.1). At this locality, opaline masses reach 2–3 cm in length, 1 cm in thickness, and are distinctly platy in structure. The surfaces of the plates and parallel partings are slightly undulating. The opal is translucent in chips of 0.5 mm thickness and contains possible chromium-rich fuchsite and other minerals. A chemical analysis revealed a Cr_2O_3 content of 6.41%.

Other specimens from this area are white, green, and brown and are replacements after serpentinite (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. 13.1). The opal, located 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) recorded 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 goldmine at Westonia (Fig. 13.1). 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 (WESTONIA, 2635)

Chromiferous green opal is reported from an unknown locality north of the Trans-Australian Railway between Merredin and Southern Cross, a distance in excess of 100 km.

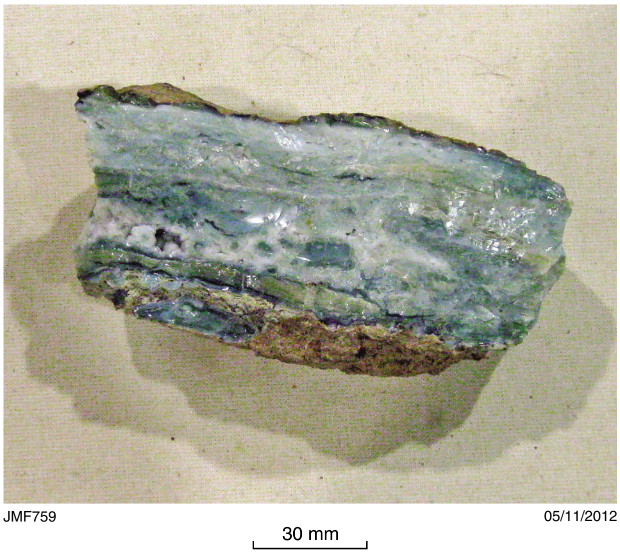

Figure 13.8 Green chrome opal collected east of Laverton (courtesy Western Australian Museum)

Yilgarn Craton — Narryer Terrane

Byro area

Bulgarro opal mine (Byro, 2145)

Green opal is recorded at the Bulgarro (or Bulgaroo) opal mine. This is possibly the same deposit as the opal mine located 20 km east-southeast of Byro Homestead. The deposit also contains brown and white opalized serpentine or scenic opal (Fig. 13.1; Simpson, 1952; Williams et al., 1983).

Iniagi Well (Byro, 2145)

At Iniagi Well, 13 km south-southeast of Byro 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. 13.1; Williams et al., 1983).

Meegea (Byro, 2145)

Approximately 11 km north-northwest of Meegea Hill and 24 km east-northeast of Byro Homestead, green opaline silica and jasperoidal chalcedony are contained within silica-rich caprock overlying nickeliferous schist (Fig. 13.1). According to Williams et al. (1983), the caprock contains small amounts of potentially gem-quality opaline silica.

Moss and dendritic opal

Moss opal, or dendritic opal, are terms used to describe varieties of common opal characterized by inclusions forming arborescent (dendritic) patterns of a very natural appearance within the opal. The inclusions are commonly dark green, brown or black, whereas the matrix opal may be either opaque or translucent. The secondary minerals forming the dendritic patterns include chlorite, iron oxide, and clay inclusions (Fig. 13.9a).

Another form of moss opal is 'golden lace opal', an informal, local name for the opal from the Norseman area, characteristically yellow-brown with black dendritic patterns (Fig. 13.9b).

Yilgarn Craton — Eastern Goldfields Superterrane

Bulong area

Bulong 1–4 (Kanowna, 3236)

Moss opal, and common yellow-brown opal are recorded at a number of localities (Bulong 1–4 and others) between Bulong and Lake Yindarlgooda, approximately 40 km east of Kalgoorlie (Fig. 13.1). 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 opal material from the Bulong area was slabbed, faceted or tumbled for marketing as moss and 'lace' opal in the Goldfields area (Williams, 1973). At one site, approximately 6 km northeast of Bulong (Bulong 2 opal mine), 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. 13.1). Various colours of moss opal, including opaque, yellow gold lace, translucent green (including chromiferous opal), brown, and white opal are all found in the local area. Since 1967, 0.15 t of moss opal and chalcedony have been mined in this area.

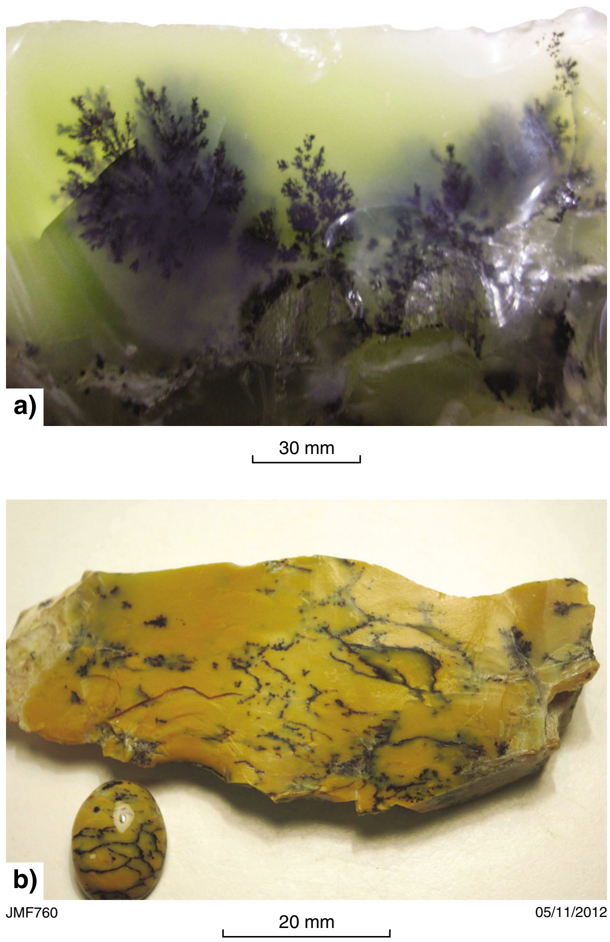

Figure 13.9 Two forms of moss opal: a) moss opal displaying dark dendritic inclusions within a translucent opal matrix; b) black, dendritic-patterned golden lace opal with yellow-brown opaque matrix

Spargoville area

Spargoville *(Yilmia, 3135)*

Golden and yellow moss opal occurs at an unknown locality in the Spargoville area (Fig. 13.1).

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 also moss opal has been found at an unknown site in an area of north-northeasterly trending schistose ultramafic rocks (Fig. 13.1)

Yilgarn Craton — Southern Cross Domain

Poison Hills area

Poison Hills *(Youno Downs, 2743)*

White opal with black dendrites and also moss opal has been found at an unknown locality in the Poison Hills area approximately 70 km southeast of Meekatharra (Fig. 13.1).

Other common opal

Gascoyne Province

Weedarrah and Yinnetharra areas
(Yinnethara, 2148)

In the southern area of the Gascoyne Province, brown-coloured common opal is found at an unknown locality on Weedarrah Station (Fig. 13.1). Farther north, a green and honey-coloured common opal is present at an unknown site on Yinnetharra Station (Fig. 13.1).

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, located close to the edge of Lake Cowan and about 4 km east of Binneringie Homestead (Fig. 13.1).

Ora Banda area

Grants Patch *(Bardoc, 3137)*

Variably coloured common opal is found at Grants Patch 10 km southeast of Ora Banda (Fig. 13.1). Opal colours vary considerably and include white, red and brown, yellow and green (Fig. 13.10).

Ora Banda 2 *(Bardoc, 3137)*

Small angular pieces of common opal of colours similar 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. 13.1; Simpson,1952).

Widgiemooltha area

Widgiemooltha *(Lake Lefroy, 3235)*

Bright red to black, streaky common opal and moss opal has been collected from an unknown location east of Widgiemooltha (Simpson,1952; red opal: S 3706, S 3814; 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. 13.1).

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. 13.1; Simpson, 1952).

Yilgarn Craton — South West Terrane

Northam area

Mount Dick 2 *(Northam, 2234)*

Dark green and brown common opal, and hyalite are recorded 8 km north of Northam (Fig. 13.1; Simpson, 1952).

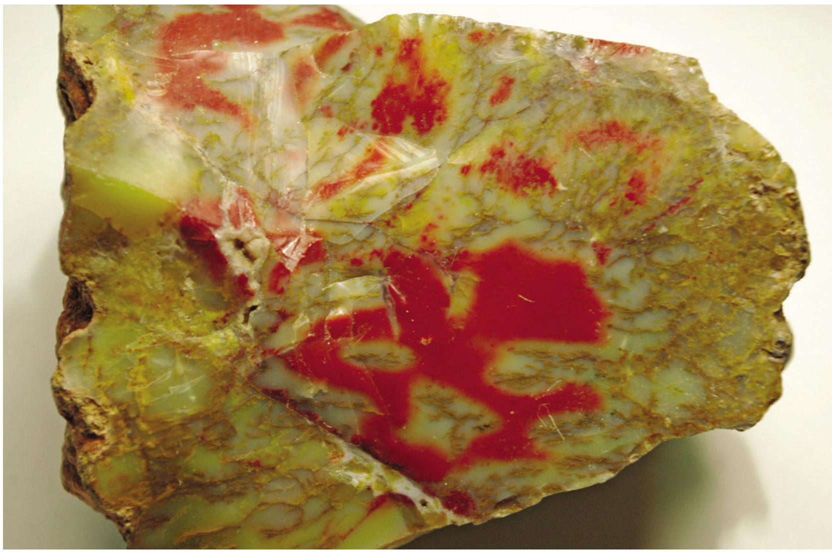

Figure 13.10 Variably coloured common opal from Grants Patch

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 4WD track) situated 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 (Hocking, R, 2012, written comm.).

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Chapter 14 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 commonly coloured by iron (pink, red, orange-red) and are 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 occur as veins and fracture fillings within weathered ultramafic rocks, particularly serpentinites, and were formed as part of siliceous caprock. Some occurrences represent zones of replacement of the host rock. Both are coloured green caused by nickel or chrome.

Chalcedony

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 length, from only a few micrometres in diameter and up to several hundred micrometres in length. Crystallites can also reach sizes visible under a hand lens, or even to the unaided eye (Frondel, 1962). Individual fibres are not physically separable and coarser fibres can be viewed under high magnification by light microscope (microcrystalline). Chalcedony has a conchoidal fracture, in places with a splintery appearance and waxy or subvitreous lustre.

Chalcedony is translucent or semitransparent as thin pieces. It may be opaque, particularly when intergrown with other minerals. Opaque chalcedonic silica is termed chert and/or jasper, and some gem varieties (jasper and jaspilite) are described in other chapters.

Natural colours of chalcedony are many but mainly grey, light blue, white or colourless, with some variations of these shades of colour being due to light scattering (Tyndall and Rayleigh effects). Other colour varieties of chalcedony are generated by different mineral inclusions, iron being most common, and are described by a wide variety of terms.

Chalcedony has physical properties that differ from quartz, with notably lower refractive indices and specific gravity. Specific gravity covers a small range of values, due mainly to differences in texture, compositional homogeneity, and porosity.

Microscope examination under polarized light will demonstrate that chalcedony is optically anisotropic; textures commonly produce spherulitic and/or wavy extinction patterns when viewed in thin sections under crossed Nicol prisms. These extinction patterns denote a high degree of alignment and orderliness of the microscopic quartz crystallites.

Chalcedony occurs mainly as nodules with domed and spherulitic shapes and is commonly growth banded as can be seen in agate and onyx. However, chalcedony

Chalcedony group

Microcrystalline quartz (SiO_2) — chalcedony; agate, carnelian, and onyx; chrome chalcedony; chrysoprase

Physical properties of chalcedony

Chemistry	SiO_2 (90–99%) with water and impurities including iron and aluminium
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, also affected by mineral inclusions, 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 UV due to uranyl oxide $(UO_2)^{2+}$ in low ppm

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.

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 (40–60°C) temperature. Research suggests that the formation temperature is generally less than 100°C (Moxon, 2009). Chalcedony forms as a secondary material and is commonly found as linings or infillings to cavities in many kinds of rocks and may have a direct relationship with the rock type in which it occurs.

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 minerals may be responsible for other 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.

Green chalcedony, a group that exhibits a range of green colours, is described under the terms chrysoprase and chrome chalcedony. Chrysoprase is a translucent bluish-green chalcedony and it has been demonstrated that nickel minerals are the cause of the green colour. Chrome chalcedony is translucent chalcedony of a dark green colour caused by the presence of chromium.

The colours of chalcedony cover a range similar to those of common opal and these two forms of silica typically occur together. A variety of names are given to chalcedony, based on colour and patterning. Additional information relating to the chalcedony group minerals is available on The Quartz Page (2012).

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 is horizontally banded agate, and carnelian is an orange-red form of chalcedony which may display growth banding.

Principal types of agate recognized are wall-banded and vein-banded agate that infill vesicles, cavities, and veins and develop growth rings following the approximate outline of the cavity, and level agate (termed onyx) where bands form gravity-controlled horizontal parallel layers (Pabian et al., 2006). Wall agate typically develops within cavities such as vesicles and is commonly sourced from amygdales originally formed in various lavas. Most Western Australian agate is found as the wall type. Vein agate develops as a vein, or breccia infilling material within a particular contact horizon. One principal type 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) but is distinguished by its higher density and higher RI.

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 typically follows a similar pattern of development and mineralogy.

The first-formed layers of agate 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

Glossary of rock-cavity terms

Vesicles — are cavities in igneous rocks formed 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 but 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 generally larger in basaltic lava than in 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 a range in size 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 most are nearly spherical, tubular or irregularly shaped geodes are also known. 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 are doubly terminated.

Druse — is a crust of crystals that develops along the walls of a cavity or mineral vein. The crystals are euhedral and mostly 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 may be lined with minerals. Vugs are the source of many gem materials such as 'crazy lace' agate, and the amethyst form of quartz.

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 centre 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 to be of an age similar to, or within a few million years of, the time of formation of the host rock in which they occur.

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, möganite, an increase in the crystallinity of quartz, and an increase in specific gravity in geologically older agates (Moxon, 2009).

In Western Australia, agates are derived from lavas from Archean to Early Cretaceous host rocks and include possibly some that are the oldest in the world (Moxon, 2009).

Agate in Western Australia

Agate has been collected from many locations within the State and sourced from a range of geological situations.

Agate, onyx, and carnelian amygdales weathered from their host rock are collected as loose entities. These are rounded, irregular forms, commonly with geometrically shaped imprints of mineral casts over the outer surface deriving from the period when the agate was enclosed within the host rock. Kriewaldt and Ryan (1967) described agate from the Mount Roe Basalt, for example, as plentiful and eroded out to form 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 also be found in association with caprock material, formed as a silicification feature in recent geological time (Cenozoic). Crazy lace vein agate at Marillana Station is an example of this type (Fig. 14.1).

Agate is a porous material and 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 and are accented by dye treatment. Brighter brownish or yellowish agates can be heat treated, converting hydrous iron oxides into simple oxides that are red, and producing a colour that is regarded as more popular.

Agate occurrences are widespread in the State. A few sites are described but many additional sites are known to prospectors, fossickers, and lapidary club members.

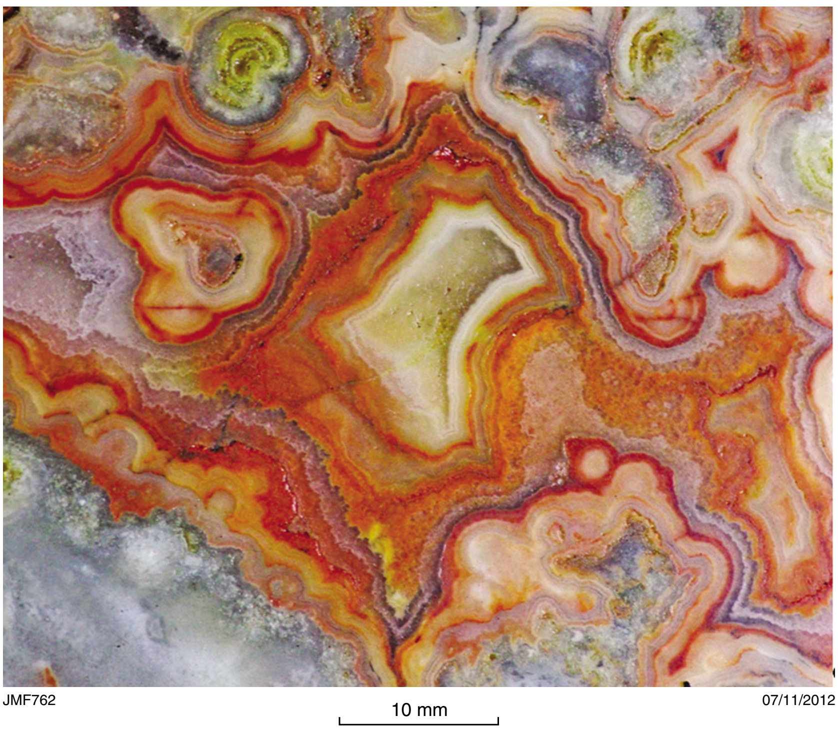

Figure 14.1 A polished section of multi-coloured 'crazy lace' vein agate from Marillana Station, Pilbara region

Pilbara Craton

Occurrences of agate are widespread and cover extensive areas within the Pilbara Craton; in particular, areas where basalts and other lavas outcrop. Lavas featured as a source of agate include Maddina (Fig. 14.2), Kylena, Mount Roe, and the Bamboo Creek dacitic lavas. Other sources include conglomerates of the Coondoon and Lilian Formations.

Balfour Downs region

Noreena Downs Station (Balfour Downs, 3052)

Noreena Downs Station is located about 125 km north-northeast of Newman. Various agate–carnelian (Fig. 14.3) fossicking sites are known by lapidary club members on this station.

Agate and carnelian are reportedly abundant in the upper parts of the Maddina and Kylena Formations throughout Balfour Downs although specific sites are not stated (Fig. 14.4).

Both the Maddina and Kylena Formations are part of the Fortescue Group of the Archean–Paleoproterozoic Hamersley 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 to 50 cm across, mainly infilled with pink to red carnelian-bearing agate. Amygdales also contain chlorite, carbonates, quartz, and stilpnomelane.

Agate also occurs in the Coondoon Formation, a poorly sorted boulder conglomerate containing clasts of chalcedonic silica and agate (Williams, 1989). In the Davis River area, brown, and white agate is abundant in gravels of the Davis–Oakover–De Grey River system (Geological Survey of Western Australia, 1994).

Northern Pilbara region

Yarrie 1:250 000 sheet area

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. The Bamboo Creek Member consisting of porphyritic, amygdaloidal, massive fine-grained and flow-banded rhyolites, rhyodacites, and dacitic flows is 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 the Mount Edgar area. From within the Wyman Formation of the McPhee Greenstone Belt, black hydrothermal chert veins, many carrying open vugs lined with banded chalcedony (agate), intrude the entire felsic volcanic succession. Individual flows of the Mount Roe Basalt are amygdale-rich containing calcite, chalcedony (some banded agate), and chlorite. From the Bamboo Creek Member, vesicular rhyodacite and dacitic lavas contain amygdales with carbonate, quartz, and banded chalcedony (agate). In the upper successions of the Kylena Formation, amygdales are reported to contain quartz, carbonate, and banded chalcedony. The Maddina Formation contains amygdales up to 30 mm diameter that incorporate red-brown to red carnelian-bearing agate.

Pilbara Craton — Hamersley Basin

Chichester Range (Mount Bilroth, 2454; Mount Marsh, 2753)

The Maddina Formation of the Archean Mount Bruce Supergroup, 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, but specific localities are not recorded (Kriewaldt and Ryan, 1967).

Marillana Station mine (Weeli Wolli, 2752)

The only recorded agate production from this area is from the Marillana Station mine on mining lease M47/514, where 68 t of ore was processed prior to 1992 (Thorne and Tyler, 1997). At this site, agate material, marketed as ‘crazy lace’ agate occurs in association with siliceous caprock and calcrete overlying part of the Wittenoom Formation in the Fortescue Valley (Figs 14.4 and 14.4).

The agate is mined from surface outcrop exposed in the Fortescue Valley floodplain. The deposit covers about 0.4 ha although only small areas yield agates of good colour with attractive banding. 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 shows 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 and yellow (Figs 14.1 and 14.5).

Large amygdales and cavities up to 30 mm across are reported in basalts of the Maddina Formation, and many contain quartz together with carbonate and chlorite although there is no mention of the quartz type. Gemstones in Western Australia (Geological Survey of Western Australia, 1994) described some other occurrences of agate from this general area. Quartzite and basalt rocks near Bamboo Springs contain veins of chalcedony and opaline silica.

Bulloo Downs Station (Ilgarari, 2849)

Onyx and carnelian are found on Ilgarari outstation on Bulloo Downs Station (Geological Survey of Western Australia, 1994). A specimen from the collection of the Western Australian Museum (S 3713) is of straight-banded onyx.

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Figure 14.2 A cut specimen of agate derived from the Maddina Formation. Specimen is 70 mm from top to bottom (courtesy Glenn Archer)

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Figure 14.3 Carnelian-coloured (orange-red) agates from Noreena Downs Station in the east Pilbara region. Centre agate is 40 mm in width (courtesy Ken Bussola)

Musgrave Province

Warburton area

Ainslie Hill *(Warburton Range, 4245)*

Poor-quality brown and white agate up to 45 cm in diameter is common in conglomerates of the Mesoproterozoic Lilian Formation, 5–10 km northwest of Ainslie Hill in the Warburton Range. The quality of the agate is described as being heavily fractured. 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)*

Northeast of Halls Creek, amethyst, quartz, and chalcedony are contained in amygdales and geodes of the Cambrian Antrim Plateau Volcanics.

Perth Basin

Gelorup quarry *(Bunbury, 2031)*

The Lower 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. The basalts are locally vesicular and outcrop can be seen along the foreshore at Bunbury and is also exposed as dramatic columnar or pillar-like cliffs of about 7 m at Gelorup Quarry, 8 km south of Bunbury (Fig. 14.4). Agates have

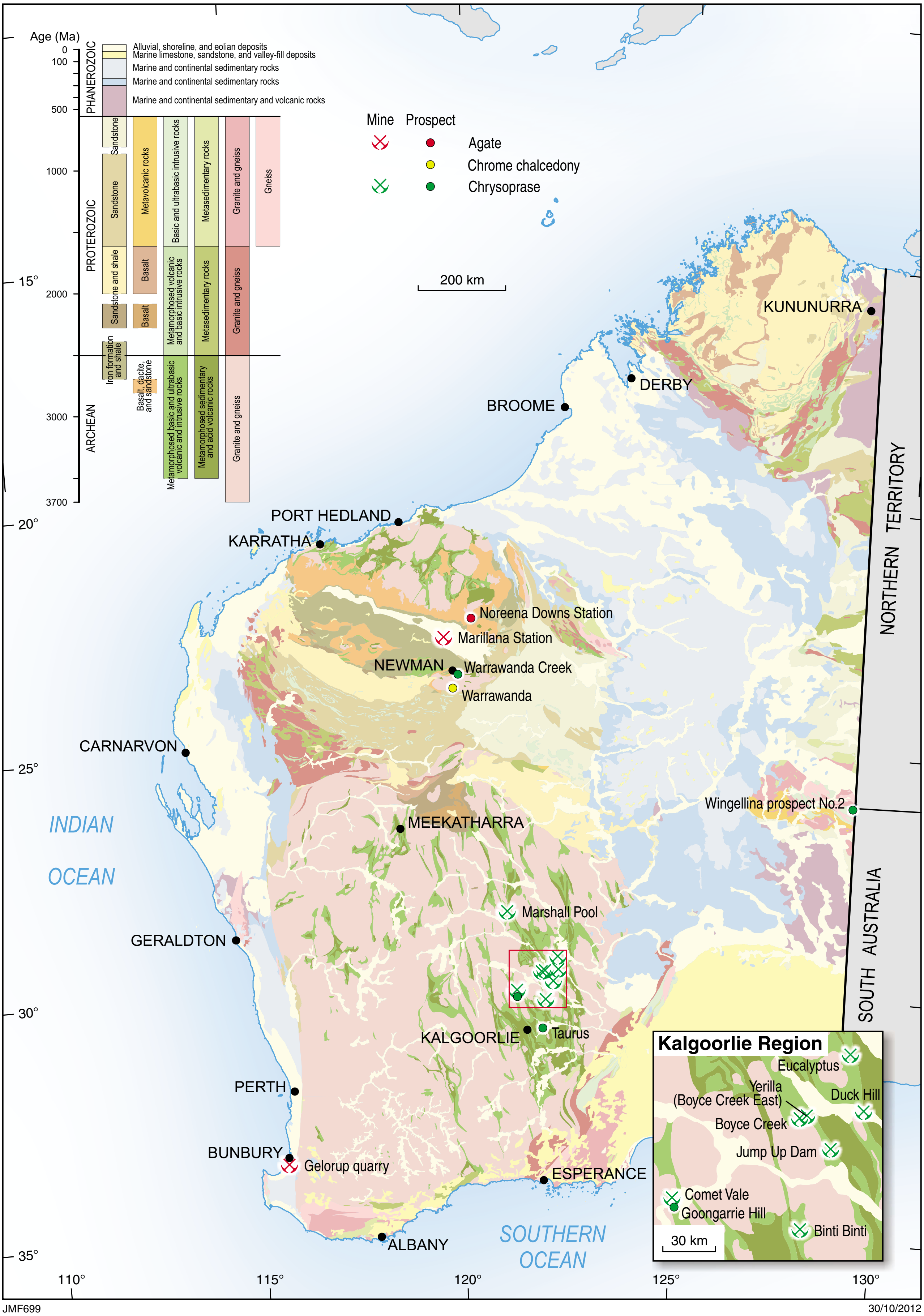

Figure 14.4 Location of chalcedony group gems and decorative stones in Western Australia

been collected from this basalt, some dredged during operations on the harbour development. Commonly they are grey and nodular in form with sections of moss-type agate, and others are green jasper-like nodules (Fig. 14.6).

Chrome chalcedony

In the 3rd century AD, 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 to the green mineral prase, which is coloured by associated (or included) green minerals. In recent times, chrome chalcedony has been sourced from Zimbabwe, where it is known commercially as mtorolite. In Zimbabwe, the chrome chalcedoney occurs as narrow veins within ultramafic horizons of the Great Dyke. Chrome chalcedony is also recorded from Boliva, where it is commercially termed chiquitanite.

Green, chrome chalcedony was first discovered about 30 years ago in the Sylvania Inlier in the Newman region of Western Australia.

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Figure 14.5 (left) 'Crazy lace' vein agate cabochon cut and polished from Marillana Station mine. Pendant measures 75 x 45 mm (courtesy Kayley Usher)

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Figure 14.6 Grey, nodular chalcedony and moss agate geode from the Bunbury Basalt. Interior of 120 mm-wide geode displays mammillary growth of chalcedony (courtesy Ken Bussola)

Chrome chalcedony in Western Australia

Sylvania Inlier

Newman region

Warrawanda chrome chalcedony prospect
(Warrawanda, 2850)

The Warrawanda chrome chalcedony prospect is located on Sylvania Station, some 40 km south of Newman and approximately 3 km east of the Great Northern Highway (Fig. 14.4).

The prospect is located in the Sylvania Inlier, an Archean granite–greenstone body adjacent to the southeastern boundary of the Hamersley Basin. The actual site is within a relatively narrow, intrusive serpentinite body known as the 'Southern Ultramafic Intrusion' that trends east for about 30 km.

The quarry site is on a small hill of massive silica capping developed over weathered ultramafic serpentinite rock. The chrome chalcedony occurs mostly as irregular masses of dark green material within subordinate areas of light green, relict host serpentine (Fig. 14.7). It is thought to have formed by pervasive silicification of the serpentinite at or near the watertable during the Early Cenozoic. The green colour of the stone is due to the presence of chromium (0.24% Cr_2O_3) derived from chromite grains contained in the ultramafic body.

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Figure 14.7 Highly siliceous, deep green Warrawanda chrome chalcedony from the Newman region (courtesy Australian Outback Mining)

Mineralogically, the massive chrome chalcedony includes 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 exist within the groundmass and there are numerous opaque mineral grains of hematite, magnetite, and chromite. The XRD pattern shows quartz as the major mineral component with traces of talc and möganite, a monoclinic polymorph of microcrystalline silica (Willing and Stocklmayer, 2003).

Chrome chalcedony is a robust material, which breaks with a conchoidal fracture exposing fresh surfaces with a waxy appearance. Transmitted light shows the deep green colour to exhibit considerable variation, commonly with a speckled appearance due to 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.

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).

It has also been sourced from India, Brazil, the Urals of Russia (from nickel ochre at Revdinsk), and the USA, especially the nickel mine on Nickel Mount in Oregon. Australia has been a important source of chrysoprase since the 1960s, particularly Queensland and Western Australia.

Chrysoprase develops in weathered nickeliferous mafic and ultramafic rocks, where it is often associated with serpentinites. There are few reports detailing the identification of the nickel minerals within chrysoprase, although recent work on specimens from the Newman area has identified the presence of kerolite, a talc-like nickeliferous mineral (Nagase et al., 1997).

Specimens of chrysoprase generally show a non-homogeneous texture with a dominant groundmass of cryptocrystalline granular or fibrous quartz, often with zones and patches of embedded idiomorphic quartz microcrystals (lining minute cavities), common opal and amphibole, chlorite, and clay minerals originating 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 different localities.

Translucent chrysoprase is a durable gem material and is usually fashioned as cabochons and beads; high-grade material is also set into finely crafted jewellery. It is a popular carving material and is often artistically carved together with adherent matrix material, thereby providing both colour and textural contrast in the finished sculptural works.

A high proportion of the chrysoprase mined in Western Australia is marketed in Hong Kong, Taiwan, China, and Thailand and is also traded at international gem and mineral fairs.

Chrysoprase in Western Australia

Gemmological testing of chrysoprase

In Western Australia chrysoprase from Yerilla has the following gemmological properties: a 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.

Polished sections of chrysoprase will often produce two shadow edges on a refractometer. This is due to quartz fibres embedded in opaline silica and the refractive indices of the two materials being slightly different.

The colour of chrysoprase fades when subjected to heating, possibly the result of dehydration; in jewellery, a chrysoprase intaglio seal is recorded to have lost its colour after use (Bauer, 1904). Similar decolouration has been observed when chrysoprase is exposed to sunlight. The occurrence of chrysoprase, prase, various coloured chalcedonies, and common opal is 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 total production of 122 202 kg (Connolly, 1976). These are the Wingellina centre, and the Taurus group in the Bulong district. At these localities, secondary magnesitic concretionary cappings are encountered within which chrysoprase is found 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. At Wingellina, the chrysoprase occurs in a nickeliferous laterite. Chalcedonic material also present is likely to be impure and diaphaneity may vary from opaque to semitranslucent.

There are many occurrences of green chalcedony within the State; many have been referred to as chrysoprase, some as chrome chalcedony, but few have been investigated for detailed mineralogical study and analysis.

Sylvania Inlier

Warrawanda Creek (*Newman, 2851*)

Warrawanda Creek is located 44 km south-southeast of Mount Whaleback and 18 km east-southeast of Newman (Fig. 14.4). Chrysoprase from this occurrence is marketed as Murramunda chrysoprase.

In this area, chrysoprase is located within and near the contact of serpentinites of the Sylvania Inlier and granite; 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 and is up to a few tens of metres in thickness and about 160 m in length. Chrysoprase occurs as a vein network in granite or as an irregular lens-like shaped nodule in the serpentinite. High-quality chrysoprase shows a homogeneous and 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. This exists within small cavities in the chrysoprase infilled with a clay-like mineral. Kerolite also occurs as 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 silcification of the surrounding serpentinite. It is inferred that the nickel-bearing kerolite was derived from the silicified serpentine and is the likely cause of the green colour of the chrysoprase (Nagase et al., 1997).

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). Although chrysoprase is mined from several openpits at Boyce Creek, west of Jump Up Dam, Duck Hill, and 1 km southeast of Eucalyptus Bore, there is no recorded production (Fig. 14.4).

Simpson (1952) recorded the occurrence of variably coloured chalcedony from just east of Comet Vale township as nodules and veins in the laterite overlying serpentine. The colours vary from colourless through grey, milky white, yellow, and bright green. The green chalcedony is present as veins 15–22 mm wide. Analysis of a portion of this green chalcedony recorded 1.43% nickel (NiO) and no chromium; specific gravity was 2.60. Microscopic examination showed that it is a mixture of granular quartz, fibrous chalcedony, and opal.

There are also a number of sites where chrysoprase has been worked by openpit mining on Yerilla and Yundamindra Stations in areas covered by the following 1:100 000 sheets: Yerilla (3239), Lake Carey (3339), Edjudina (3338), Boyce (3238), and Gindalbie (3237).

Yerilla (Boyce Creek East) (*Yerilla, 3239*)

The Yerilla chrysoprase mine extends over two mining leases M31/104 and M31/112 and is located approximately 160 km north of Kalgoorlie and 13 km south of Yerilla

Homestead (Fig. 14.4). The mine area can be best accessed by the well-maintained Kookynie–Yarrie gravel road and is immediately north of the Cranky Jack Road intersection.

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 (Fig. 14.8).

Chrysoprase has also been investigated in an opencut operation at a prospect 5 km east-southeast of Mount Catherine on Yerilla Station. The prospect was worked in a small way prior to 1992 but since then has been operated by Gembank Group.

Chrysoprase is collected within the weathered profile by bulldozer where it occurs as swarms of green veins throughout an ironstone caprock overlying a hill of ultramafic rock. Fragmental chunks of less than 25 mm to 100 mm in thickness consist of veins of white to grey chalcedony, nodules of white magnesite, and bright green veins of chrysoprase. They occur as elliptical pods of a few centimetres, long stringers of a metre or more, 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.

Gemmological investigations of this chrysoprase within ironstone revealed quartz (and 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).

Boyce Creek *(Boyce, 3238)*

Chrysoprase has been worked together with magnesite from openpits at Boyce Creek, some 50 km northwest of Edjudina (Fig. 14.4).

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Figure 14.8 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)

Eucalyptus mine *(Lake Carey, 3339)*

Eucalyptus mine is situated on Yundamindra Station about 95 km east-southeast of Leonora (Fig. 14.4). At this site, chrysoprase and magnesite are mined from mining lease M39/289 operated by Glenn Archer.

The chrysoprase from these occurrences is referred to as eucalyptus, named after an early gold mining location. It forms in nodules of all sizes and shapes, with one specimen reportedly weighing 35 kg (Fig. 14.9). 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.

Other sites are recorded from Western Australian Museum specimens at an opencut prospect 5 km south-southeast of Eucalyptus on Yundamindra Station and at Pyke Hill 9.6 km east-northeast of Yundamindra Homestead.

Binti Binti *(Gindalbie, 3237)*

The Binti Binti chrysoprase project, 56 km southwest of Edjudina (Fig. 14.4), is recorded as currently active from shallow workings.

Taurus chrysoprase *(Kanowna, 3236; Mulgabbie, 3337)*

The site of the Taurus chrysoprase deposit lies some 35.6 km east of Kalgoorlie and is currently reported as inactive. The chrysoprase occurs within the Bulong Complex (described in Chapter 13) as part of the siliceous caprock and can be found together with magnesite, various colours of chalcedony, and common opal (Williams, 1970; Ahmat, 1995).

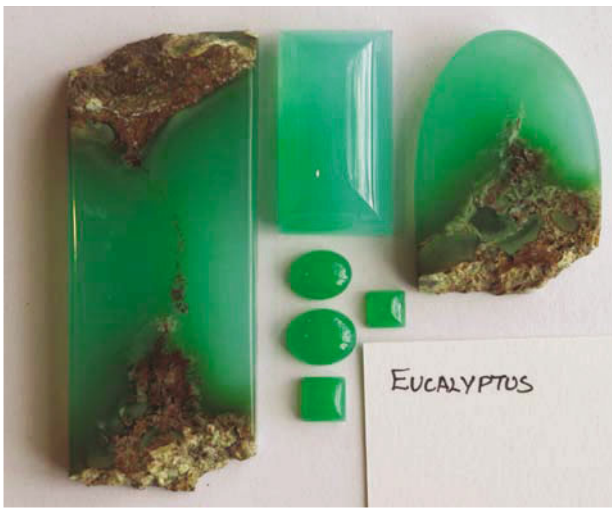

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Figure 14.9 Chrysoprase from the Eucalyptus mine, Leonora region. Oblong cabochon measures 50 x 30 mm (cut and polished by Murray Thompson)

Goongarrie Hill chrysoprase (BARDOC, 3137)

Citron magnesite is reported at Goongarrie Hill approximately 100 km to the north of Kalgoorlie (Fig. 14.4). 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 to Leonora road. Chrysoprase is reported about 40 and 41 km north-northeast of Ora Banda. Records show the Goongarrie Hill chrysoprase site to be inactive.

Comet Vale mine (Menzies, 3138)

Chrysoprase is described from the Comet Vale gold mining centre, a group of workings, later known as Lake View, near the western edge of Lake Goongarrie, some 70 km north of Kalgoorlie on the main Goldfields Highway (Fig. 14.4). The Happy Jack mine, a part of this group, was a most significant source of fine crocoite specimens 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 Happy Jack mine. Veins of chrysoprase from the Blue Speck Creek area (1.5 km south east of 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 cap rock (Fig. 14.10). The chrysoprase lies some 70 km north-northwest of Leonora and 5.5 km to the east of Marshall Pool (Fig. 14.4).

Reference to the occurrence of chrysoprase at this site is made in Chapter 30, where nickeliferous magnesite in the belt of serpentine–talc and talc–chlorite schists is described.

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Figure 14.10 Chrysoprase specimen from Marshall Pool deposit, Leonora area. Speciman is 140 mm in height (courtesy Glenn Archer)

Musgrave Province

Wingellina area

Wingellina prospect (BELL ROCK, 4645)

The Wingellina chrysoprase prospect is located in the Wingellina area, approximately 240 km east of Warburton (Fig. 14.4) In this area, deep weathering of folded interbanded mafic and ultramafic rocks of the Giles Complex has produced a nickeliferous ochre (see Chapter 30) in an area near Wingellina. Associated with the deposit is chromite, chrysoprase, moss agate, and nickeliferous magnesite. It has been reported that the chrysoprase included dark apple green material and that some specimens had faded when exposed to light and become 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. The prospect is currently situated within Aboriginal lands and permits are required for entry and fossicking (Parker, 1995).

Table 14.1 A selection of chrysoprase specimens in the collection of the Western Australian Museum

1:100 000 Sheet no.	*Specimen no.*	*Location*
2136	S 3724	Koojan
2136	6280	Cairn Hill, 8 km N of Moora
2850	5716	MC717, 44 km SSE of Mount Whaleback
2950	6068	Sylvania Station
2741	6281	5 km S of Sandstone
3137	3910	Goongarrie
3138	S 3796	Comet Vale
3338	4035	Lake Rebecca
3235	4163	Mount Monger
3339	4162	Just N of Mount Florence
3339	4349	Eucalyptus
3339	4620	Pyke Hill, corner MC8, 9,10,11FB
3339	4927	Yundamindera, 3.5 km SE of Eucalyptus
3340	3958	16 km SE of Mount Margaret Mission
3340	4682	24 km S of Mount Margaret Mission
4245	4655	Warburton Range
4645	4709	Wingellina Lease 501P
3239	7654	Yerilla
3239	7655	Yundamindera
3239	7662	Yerilla
3239	3843	Kookynie
3239	S 3725	Mount Catherine,Yerilla

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Chapter 15 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, Southern Carnarvon, Perth, and Eucla, as well as 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 there are various angiosperms (flowering and seed producing species) found within younger woods from the Cenozoic era (Fig. 15.1).

Western Australia's oldest petrified logs are of early Permian age. These 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 (from 200 to 66 million years ago) show structural anatomies characteristic of evergreen, podocarpacean and araucarian conifers, corroborated by studies of foliage preserved within terrestrial strata. There are a number of sites in the Southern Carnarvon Basin for lapidary-grade fossil wood specimens from mid-Cretaceous rocks.

Fossil woods from the Cenozoic era (from 66 million years ago to the present time) include both conifers and angiosperms but 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; angiosperm woods have also 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-age woods and specimens of opalized peat are suitable as lapidary-grade specimens and can be cut and polished. Specimens exhibiting fossil leaf impressions make visually attractive display materials.

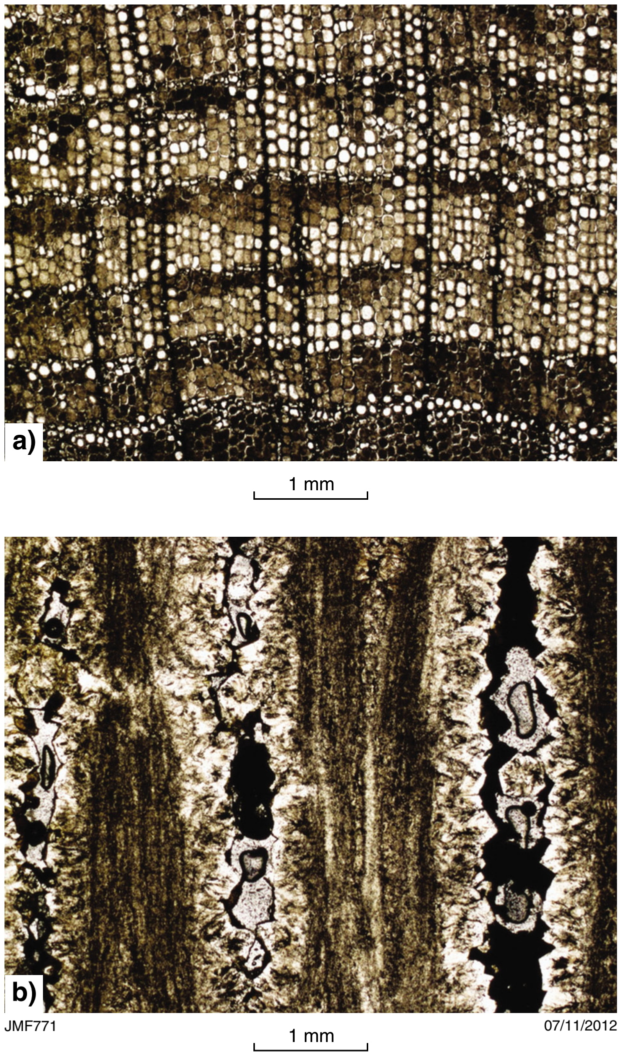

Figure 15.1 Photomicrographs of Paleogene age fossil woods from the North Stirling Ranges: a) permineralized conifer wood showing cellular structure with growth rings; b) permineralized angiosperm wood showing open cavities infilled with microcrystalline quartz displaying good crystal form (courtesy Stephen McLoughlin)

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 a selective process 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 but is commonly lost by alteration and weathering. Preserving processes may be improved by ample porosity of the enclosing sediments that allow 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 occur together 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 generally the most suited and robust for cutting and polishing. Fossil wood is also found preserved by other minerals including calcite, aragonite, apatite, clays, and the iron minerals goethite, hematite, and siderite.

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Figure 15.2 Lattice pattern coating of drusy quartz on fossil sheoak from southwest Western Australia. This type of silicified wood is unsuitable for cutting and polishing (courtesy Western Australian Museum)

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. 15.2). Fine-grained silica in the form of chalcedony or opal can usually 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.

Lapidary-grade fossil wood sites

Southern Carnarvon Basin

The Cretaceous Winning Group in the Southern Carnarvon Basin contains detrital petrified wood. This material is abundant in areas west of the Kennedy Ranges including Mount Sandiman and Minnie Creek Stations, Mooka Creek, and in the Giralia Range, east of Coral Bay (Fig. 15.3). It is also reported near Kalbarri, north of Geraldton. 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 Ranges, fossickers have collected fossil wood specimens from surface outcrops over an extensive area on several pastoral stations covering the central area of the 1:250 000 Kennedy Range map that incorporates the following 1:100 000 map sheets: MARDATHUNA (1849), and BINTHALYA (1848).

Fossil woods from the Southern Carnarvon Basin include some of the best-quality lapidary-grade material, and 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'.

Peanut wood

Mooka Creek *(BINTHALYA, 1848)*

Peanut wood is found in association with silicified Cretaceous Windalia Radiolarite. It occurs sporadically as detrital particles in the form of small subrounded cobbles and pebbles. At Mooka Creek, 32 km northwest of Gascoyne Junction, peanut wood detritus is located on the surface at various sites around the mookaite workings (Figs 35.3 and 35.4 in Chapter 35).

Peanut wood is petrified wood that has been formed by chalcedonic and opaline silica replacement after burial

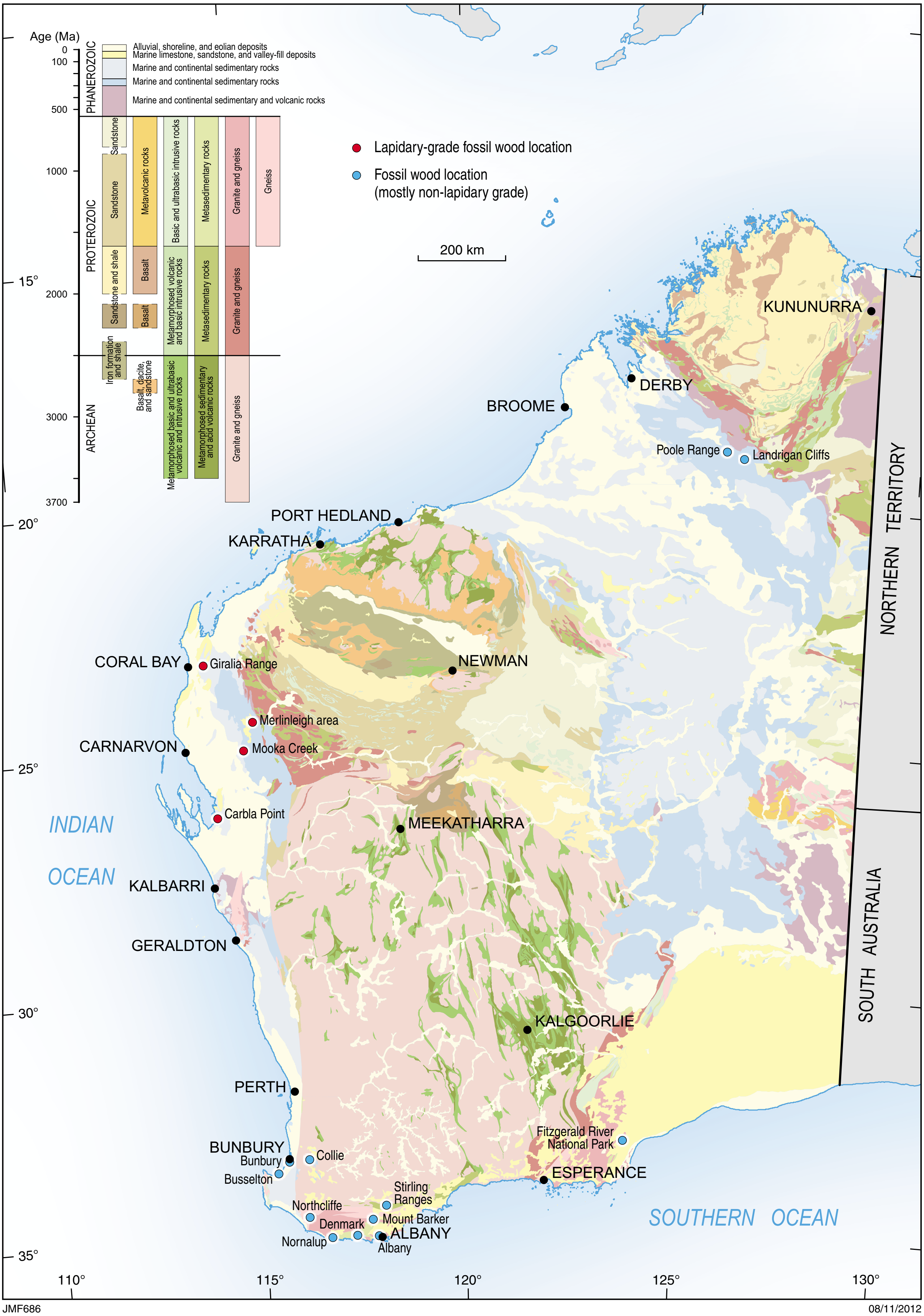

Figure 15.3 Approximate location of fossil wood sites in Western Australia

in fine-grained marine radiolarian siltstone, a silica-rich rock. Peanut wood has a distinctive light brown colour, often 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. 15.4).

Prior to silicification, the Teredo wood-boring bivalve molluscs of the families Teredinidae or Pholadidae made numerous burrows in the wood that were subsequently infilled by a white, radiolarian-rich mud and silt that constitutes the Windalia Radiolarite (Hocking et al., 1987). In transverse section, the burrows are round or oval, and 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 often show both transverse and longitudinal burrows, and in some specimens burrows are concentrated within particular sections of the original wood. Infilled burrows form white to cream colour patterns, which contrast with the translucent dark brown, near-black, or carnelian red banded wood in between (Fig. 15.5).

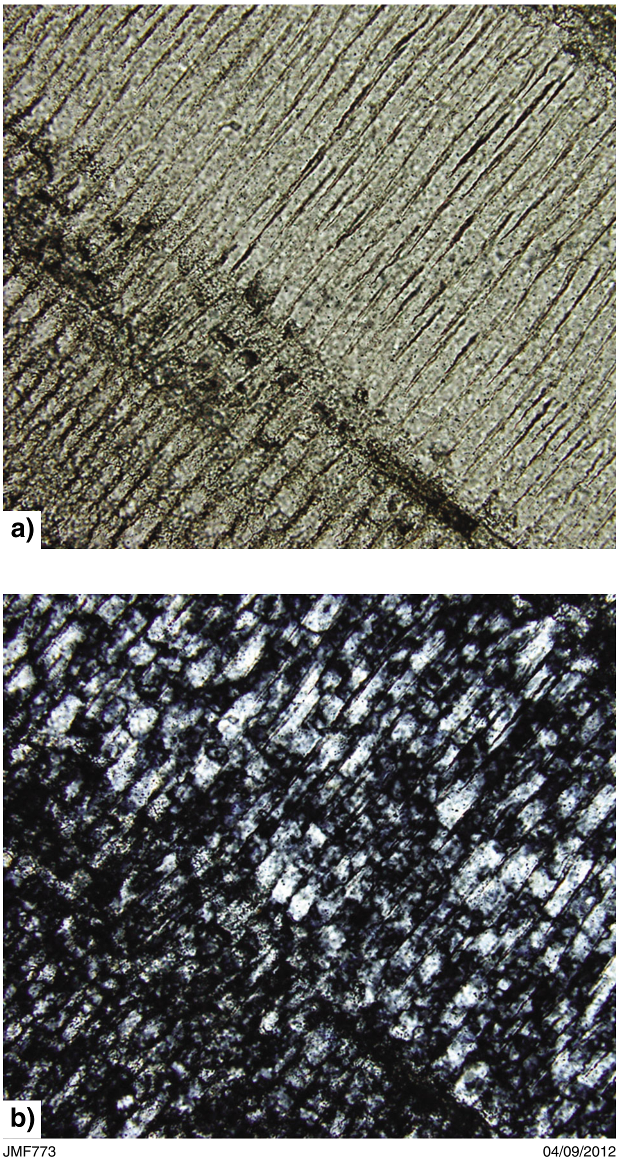

Figure 15.4 Photomicrographs of peanut wood (x200) showing the preserved, permineralized cellular structure: a) photomicrograph in plane-polarized light showing the compact, linear trains of fossil plant cells; b) photomicrograph of same view in crossed-polarizing light showing parallel trains of individual relict cells about 50 µm in length (Pontifex, 2011).

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 slabbed, polished pendants (Fig. 15.6).

Cardabia region

Giralia Range (Giralia, 1752; Mia Mia, 1751)

The Giralia Range, located about 35 km east of Coral Bay, consists of Cenozoic sedimentary rocks forming the north-trending Giralia Anticline (Fig. 15.3), which has a core of Cretaceous rocks.

In this area, fossil wood specimens (podocarp or araucarian conifers) are preserved within glauconite-rich beds and are permineralized by silica and phosphates from the Cretaceous Birdrong Sandstone and Cenozoic Windalia Radiolarite. 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 from various 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 but important cellular detail is often 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, which represent the first examples of fossilized saprophytic fungi recorded from Western Australia (McLoughlin, 1996).

Minnie Creek and Williambury Stations

Merlinleigh 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. 15.3). These fossils were derived from the Eocene

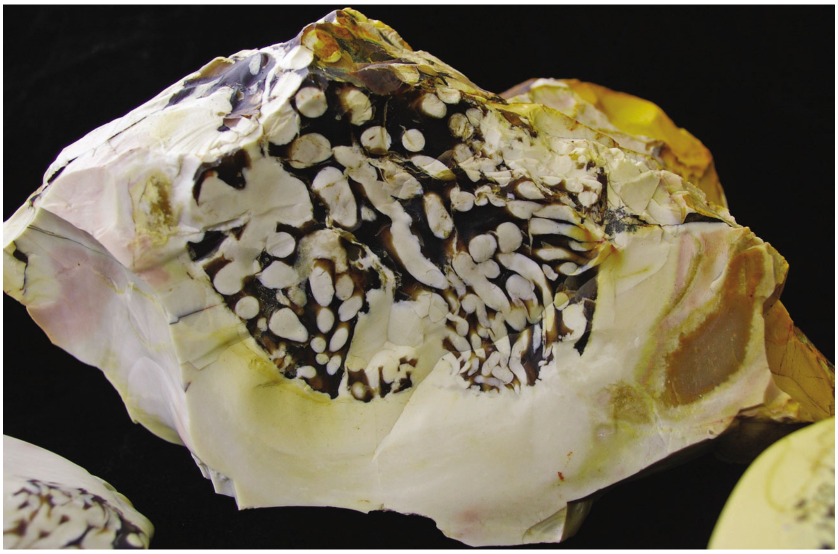

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Figure 15.5 **Peanut wood displaying irregular, white Teredo mollusc borings enclosed in a dark, siliceous, fossil wood matrix set in pale pink, resilicified Windalia Radiolarite (courtesy Judy Brewer)**

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Figure 15.6 **Peanut wood applications: a) a selection of tumble-polished pebbles (courtesy Judy Brewer); b) a slabbed and polished peanut wood pendant (courtesy Soklich Trading)**

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 sequence (generally <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 as well as abundant fossil wood (Hocking et al., 1987). The Merlinleigh Sandstone underlies much of the high-level sandplain on top of the Kennedy Ranges.

The fossil wood is commonly of a type displaying a finely striated texture in longitudinal sections and specimens are of variable quality as lapidary material. Precise specimen localities are not available, but the Western Australian Museum has recorded several sites on Mount Sandiman, Moogoorie, and the former Merlinleigh Stations (McNamara and Scott, 1983).

Southwest Western Australia

There are many specimens of fossil wood in the collections of the Western Australian Museum and The University of Western Australia 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, as well as other locations from around Northcliffe, Albany, Mount Barker, Denmark, Nornalup, Collie, Bunbury, and Busselton (Fig. 15.3). A number of these sites represent 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 are commonly 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, there are a number of sites where fossil wood is incorporated in 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 reaching 4 m in length, and farther west in the Poole Range is another area of silicified wood (Fig. 15.3). Precise locations for these sites are not available. Also, it has been established that 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 (Hocking, R, 2012, written comm.).

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Organic gems

High-quality, silver-white, South Sea cultured pearl from Western Australia, diameter 16.3 mm, weight 6.5 g (courtesy Nash Pearls)

Chapter 16 Pearls, periculture, and shells

An early history of pearling

Natural pearls have been appreciated and desired through historical time, although they have not been preserved from antiquity owing to their soft and chemically sensitive composition. In Ancient Egypt, evidence exists that pearls were buried with the dead, and mother-of-pearl inlay was part of Egyptian artistic culture. In China, there are records about pearls dating from 2300 BC that the Chinese had discovered the means of coating images with nacre by inserting them between the shell and mantle tissue of the Chinese freshwater mussel *Cristaria plicata*.

The finest and historically best-known natural pearls, termed 'oriental pearls', are produced by the pearl oyster *Pinctada radiata*. These pearls have been harvested from the Persian Gulf since 300 BC, especially off the island of Bahrain, but also extending from Kuwait southward to the Trucial Coast in the United Arab Emirates.

Pearl banks located in the Gulf of Mannar between India and the northwest coast of Sri Lanka have been worked for about 2500 years, and more recently were an important source of pearls, including seed pearls (<2 mm diameter), that were much in vogue in jewellery in the late 19th and early 20th centuries (Mahroof, 1997).

Pearls and pearl shell

Pearls are solid calcium carbonate concretions that develop naturally within living molluscs, with saltwater oysters and freshwater mussels being the most important hosts. Pearls tend to develop in various forms, commonly spherical or near-spherical, but other bizarre forms may also develop highly irregular shapes termed 'baroque pearls'. Pearls that are not attached to the shell but occur freely within the host are termed 'cyst pearls'. These varieties become larger by incremental, seasonal growth. By contrast, 'blister pearls' develop on the inside of the host shell, where they form convex protuberances and have to be removed from the shell by sawing. After harvesting, many pearls may be used in jewellery with no treatment required to reveal their beauty (Fig. 16.1a,b).

Although pearls can be formed within many species of molluscs, it is those pearls that possess a lustrous quality, termed nacreous pearls, that are of commercial importance. Nacre, also known as mother-of-pearl, is the hard, smooth, iridescent coating on the inner surface of specific mollusc shells. It is a composite material comprising microscopic layers of aragonite (a calcium carbonate polymorph) and conchiolin, an intergranular protein, that 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.

As mentioned above, a pearl develops by incremental and seasonal growth of successive layers of aragonite and conchiolin around a nucleation site. In natural pearls their development proceeds 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 in the alignment of crystals, results in non-nacreous lustre.

Marine pearl molluscs

Pearl-producing oysters and mussels belong to a class of molluscs known as Pelecypoda or bivalves in which the shell consists of two hinged parts. Pearls can also develop in gastropods (with a non-hinged shell) such as the non-nacreous baler shell (*Melo amphora*) found in Shark Bay. Pearl oysters most important to the pearling industry in Western Australia are from the genus *Pinctada* as well as *Pteria penguin*.

The silver-lipped pearl oyster, also termed the gold-lipped oyster (*Pinctada maxima*), is the largest living species and can grow to 30 cm diameter. It is harvested for its mother-of-pearl and is also the important host that produces Australian silver and white pearls as well as gold-coloured pearls from the Philippines and Japan. The large pearls produced by this species are commonly 10–20 mm, with the largest recorded attaining a diameter of 24 mm. Large cultured pearls of varied colours produced from *Pinctada maxima* are collectively termed 'South Sea Pearls' (SSP).

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Figure 16.1 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 together with a narrow mother-of-pearl border. The pendant is 40 mm in length (courtesy Joy Rogers)

Black-lipped pearl oysters (*Pinctada margaritifera*) produce 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 one of the host species used for culturing pearls off the west coast of Western Australia.

The oyster species *Pinctada fucata, Pinctada martensi* and *Pinctada imbricata* are the important hosts for the Japanese cultured pearl industry, the products of which are referred to collectively as Akoya pearls. Pearls are usually found in shades of white, yellow, pink and cream, but have overtones in many shades, with the white-rose and pink-rose being the most highly prized.

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 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.

Growing and seeding 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, but are developed on implanted, preformed nuclei. The culturing process is a surgical procedure and is performed under sterile conditions. It usually involves the grafting of a section of mantle tissue (saibo) from a sacrificial or donor oyster, together with a pearl nucleus, into a recipient oyster. 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 is an important part in determining pearl quality, and the nacre that develops will be the same colour as that of the host animal.

In spite of the care taken in all aspects of the implantation operations, mortality rates of host oysters 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%. Much of the technology and many of the procedures used in the cultured pearl industry are performed by experienced Japanese technicians.

The cultured pearl industry produces cultured 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, are attractive in appearance and 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, seeding it first at about two years old for spherical pearls and in its last year it may be used for mabe pearl production (Fig.16.2).

Natural freshwater pearls

Natural pearls from freshwater molluscs (*Margaritifera margaritifera*) and mussels (*Unio* sp.), termed 'river pearls', have been harvested and appreciated for some 2000 years. Especially well known in the jewellery trade are those from Scotland from the 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* sp.). 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 utilizes mother-of-pearl shell nuclei 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 lustre and colour. In Japan, freshwater cultured pearls are produced in Lake Kasumigaura using bead nucleated production to yield pearls 13–14 mm in diameter produced from hybrid mussels *Hyriopsis schlegeli* and *Hyriopsis cumingi* (Dillenburger, 2004). The freshwater pearl industry of China dominates the industry today with production of over 1500 t recorded in 2005 (Hui and Beili, 2005).

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Figure 16.2 Shells of the 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 diameter (courtesy Maggie Campbell Pedersen)

Quality of cultured pearls

Gem-quality pearls are initially assessed by growers and sorted into groups based on whether they are unmarked, have one major blemish, or more than one major blemish. Pearls are then graded using a sequence of quality criteria as follows:

- **Nacre thickness**
  This is largely determined by the length of time the nucleus remains in the host animal. Usually, the thicker the nacre, the higher the value and better the lustre. South Sea pearls (SSP) from *Pinctada maxima* are expected to have much thicker nacre than the accepted minimum thickness (0.6 – 1.0 mm) and are more likely to be about 3.5 mm thick.
- **Lustre**
  Lustre is the result of reflected and refracted light from the inner layers of nacre as well as 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**
  The size of a pearl is the smallest diameter measured in millimetres. For pearls of equivalent type and quality, the larger the pearl the greater its value.
- **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**
  Dimples, spots, circular markings, and other pinpoint imperfections are common on the surface of pearls. Categories of imperfection are generally classed in various grades between clean and spotted.
- **Colour**
  The most valuable pearls are white or pink, although different colours and shades of colour are acceptable and appreciated in different markets. Different designations of primary colour and overtones 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.

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 utilized.

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 centre of the Shark Bay pearling industry was located around Wilya Mia (formerly Wilyah Miah), along an 8 km stretch of the northeastern shore of Useless Inlet (Fig. 16.3). During this time, pearling activities were confined largely 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 *Pinctada albina albina*, *Avicula* (*meleagrina*) *fucata*, and *Pinctada cacharium* (Streeter, 1886). These shells were smaller and of lesser value than the silver- or gold-lipped pearl oyster (*Pinctada maxima*) that was found farther north in the Broome area.

At this time, pearl shell recovery was 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 located 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.

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 utilizing pearls, blister pearls, and mother-of-pearl were fashioned into brooches, pendants, bangles and other items forming the basis of an industry that was unique in style and content to Western Australia (Figs 16.4 and 16.5). Accordingly, blister pearls that appear to have been considered a semi-worthless material 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. A number of 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 workers employed included Aboriginal, Chinese, Japanese, Filipino, and Malay. 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 shell was discovered farther north, pearl fishing became centred in the Nickol Bay area where commercial pearling began in 1861 (Erickson, 2010; Fig. 16.3). This soon extended eastward to the area around Cossack. Here, *Pinctada maxima* shell

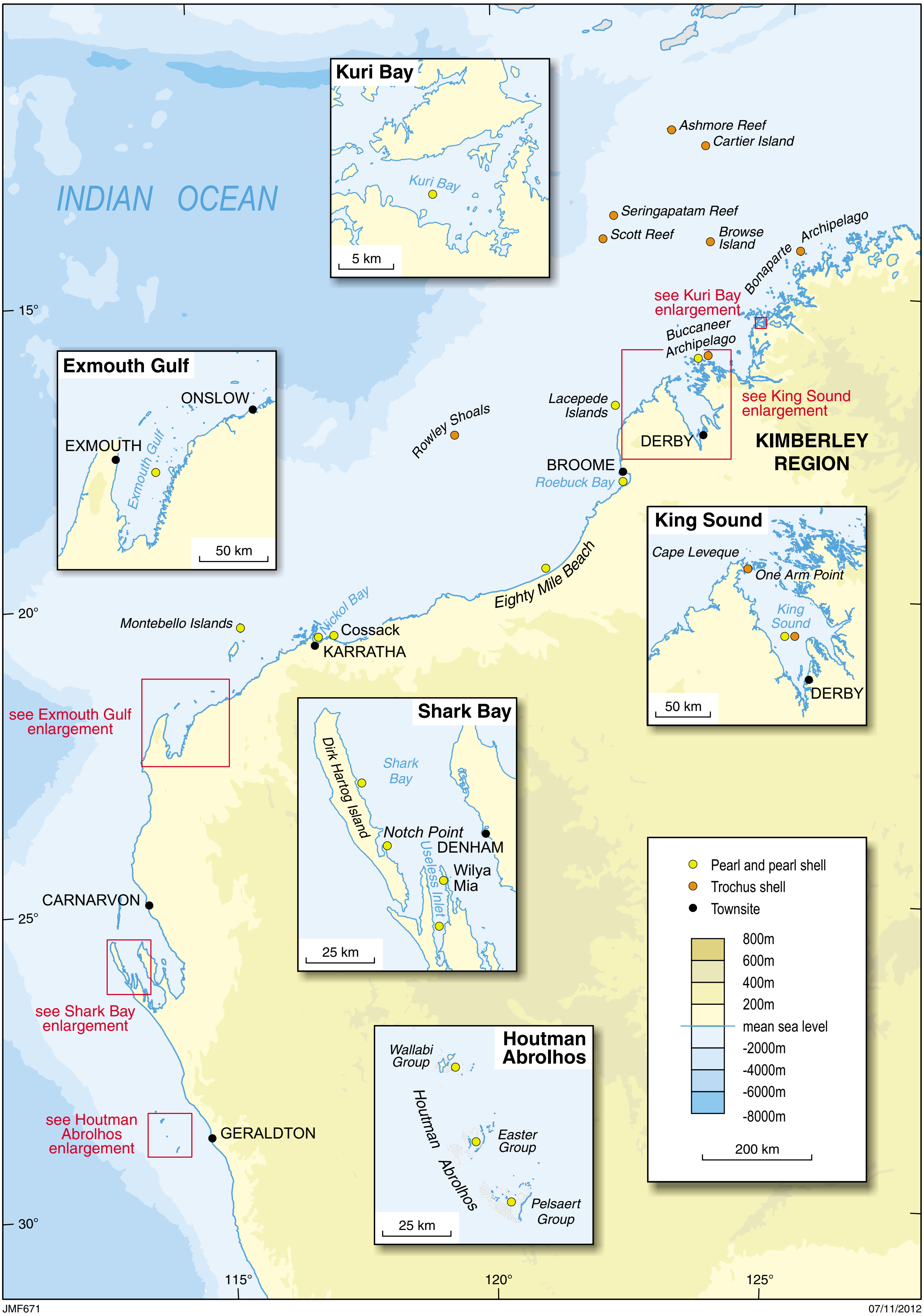

Figure 16.3 Map showing the location of pearl, pearl shell, and trochus shell sites in Western Australia

Figure 16.4 **A delicately carved pearl shell paperknife, 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, specimen CH 1970.972)**

and pearls were harvested in shallow waters by both white and Aboriginal 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 reports that in the season 1882–83 there were nineteen operating vessels, manned 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, 2006).

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 (irregularly shaped pearls) are produced in Western Australia. Broome is now the centre for the pearl industry and Paspaley Pearls currently 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).

The Western Australian pearling industry — current operations

Location of pearl-farming areas and hatcheries

The pearl industry in Western Australia currently uses several mollusc species, although most of the production is of large South Sea pearls in sites along the northern coastline utilizing *Pinctada maxima*. Off the west coast of the State other species used on pearl farms include *Pinctada margaritifera*, the winged oyster (*Pteria penguin*), the Akoya oyster (*Pinctada fucata*) and *Pinctada albina albina*.

Western Australian black pearls are currently produced from the Houtman Abrolhos Islands comprising the Wallabi, Easter, and Pelsaert Island groups, located 60 km west of Geraldton on the mainland, which is the commercial centre (Fig. 16.3). Pearls produced from this area (*Pinctada margaritifera*) display a range of colours including silver, green, peacock, and aubergine (Ministerial Media Statements, 2001).

The pearl-farm industry within Western Australia utilizes host oysters either captured in the wild as young oysters before they can seed and cultivate pearls, or 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 the Eighty Mile Beach near Broome and around the Lacepede Islands. Off the northern coast, oyster collection is principally of species *Pinctada maxima*. The industry has been restricted in the State by a quota system for shell collection to

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Figure 16.5 A 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, specimen H 1995.1371)

prevent overfishing; recent catches have been below the quota levels owing to low market demand. The quota is set by researchers at levels to ensure that stocks of oysters are sustained over the years (Malone et al., 1988). Also, there are major oyster hatcheries operating at Broome and King Sound.

Pearl-farm sites are located mainly along the Kimberley coast, particularly in the Buccaneer Archipelago, Roebuck Bay near Broome, and farther south around the Montebello Islands (Fig. 16.3). Farther south still, 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 *Pinctada maxima* spat (juvenile stock) to pearl farms in Exmouth Gulf and the Montebello Islands. Several hatcheries supply spat of the black-lipped pearl oyster (*Pinctada margaritifera* from a small number of wild Shark Bay brood stock oysters) to the black-pearl farms in the region (Fig. 16.3).

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, maturing earlier and making greater numbers of 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 centred on the feasibility of developing a pearl industry based on *Pinctada imbricata* and followed work conducted in NSW that established that quality cultured pearls using this oyster species could be produced in Australian waters (Cropp et al., 2011).

In Western Australia, all aspects of periculture operate under aquaculture pearling licences from the Department of Fisheries, where each licensee holds an approved quota for shell, and licences 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. Usually, technicians of 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 utilizes large vessels holding 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 then transported to sheltered waters at pearl farms where net panels are suspended on a floating line system from the surface of the sea and on which the oysters are permitted to mature. The oysters feed naturally and no artificial feeding or chemicals are required. Within the shell, encystation of the implanted nuclei (usually one per shell) by the host mantle-tissue deposits mother-of-pearl (nacre) on the nucleus and this process continues throughout the development time of the pearl, normally about two years (Brown, 2000).

Pearls cultured using *Pinctada maxima* hosts have a nacre thickness of over 2 mm and 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 termed '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 white and 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 to be negligible and Western Australia is currently the world's largest producer of white and silver South Sea cultured pearls, with the industry being valued at about $200 million per annum (Department of Fisheries, 2011).

Shells

Mother-of-pearl

The material termed mother-of-pearl is produced from nacreous shells of the same species that are hosts to pearls. Western Australia had a profitable mother-of-pearl shell industry established in the mid-19th century and the ready market for mother-of-pearl initiated additional pearling ventures. At that time, most shells were exported to Europe and used to make mother-of-pearl buttons. A small portion of the 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 often carved as well as pierced with fretwork and were frequently mounted in gold or gold backed. By the early 20th century, Broome supplied 80% of the world's shell which, at that time, was used not only for buttons but for items such as mother-of-pearl cutlery (dessert flatware), haircombs, and inlay work.

Trochus

Shells of the trochus species (*Trochus niloticus*) currently provide a small export commodity to serve the fashion industry with the raw materials for buttons (Fig. 16.6). 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. 16.3).

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 also included in the collection process such as *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 has been highlighted in recent years with less than 15 tpa of shell being reported compared with 135 t produced in 1980.

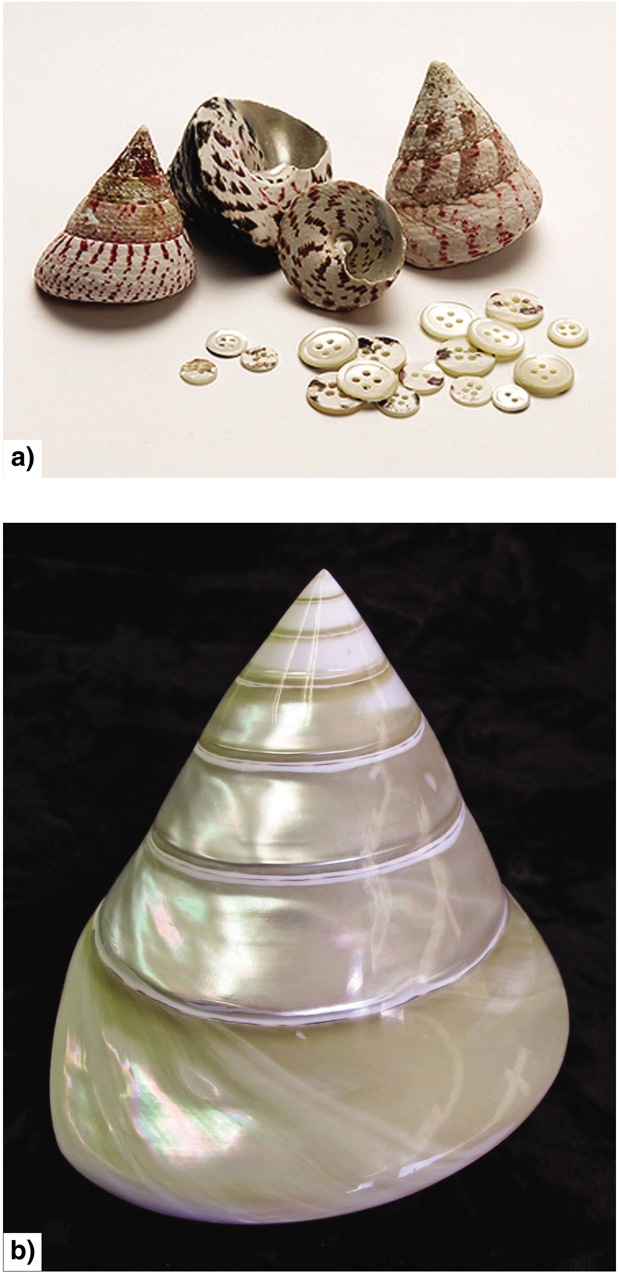

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Figure 16.6 **Trochus shell sourced from the northwest coast, offshore islands and reefs of Western Australia: a) trochus shells displaying their natural outer coating and application as shell buttons (courtesy Maggie Campbell Pedersen; b) a decorative trochus 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.**

Opercula

Opercula are unusual gemmological materials, being 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 function as a defensive structure against predators by sealing the shell. Opercula are composed of aragonite (a calcium carbonate polymorph) and they have a spiralling pattern on one surface and a convex and coloured surface on the reverse.

When first collected, opercula are an intense blue colour caused by a natural pigment but over time the colour fades. Opercula found in Western Australia originate from the mollusc *Astraea stellare* that inhabits the northern coastline from Exmouth Gulf and 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 were sometimes polished to remove any natural surface imperfections.

Opercula vary in size according to the variety of host shell; *Astraea* shells are the source of the small, oval opercula whereas the larger turban sea snail shells provide the larger and more or less circular opercula with a green-brown colouration. Opercula-mounted jewellery, especially from the 19th century, mainly made use of 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 that period (Fig. 16.7).

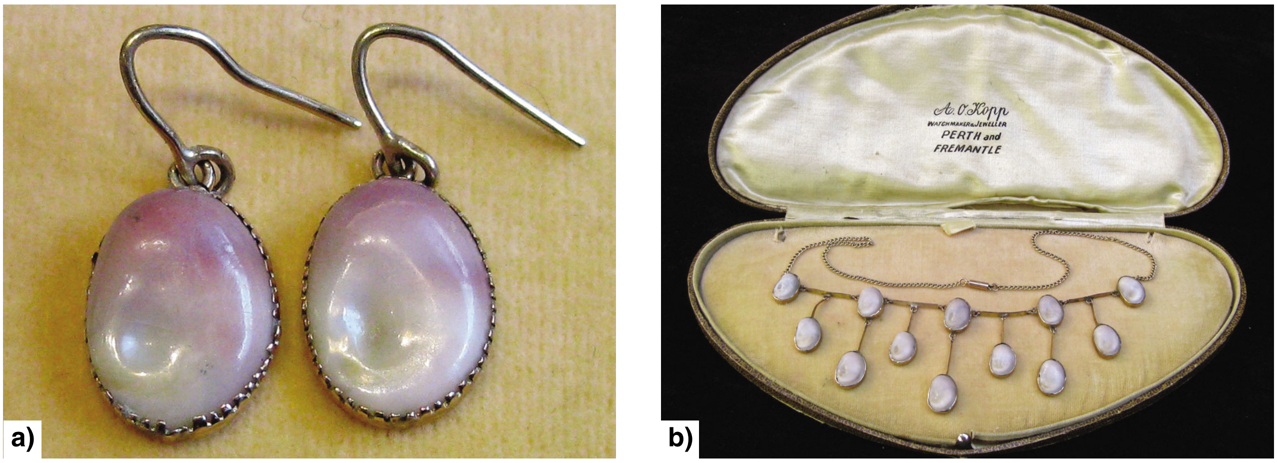

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Figure 16.7 Examples of opercula-mounted jewellery: a) opercula drop earrings in saw-tooth claw settings on gold backplates with hook fittings. The opercula are typical of those collected from the Shark Bay area and were probably set into earrings in the late 19th century. The subtle pink and blue colour tones shown by the opercula would have been more vivid when originally collected. Opercula are approximately 12mm in length (courtesy Trinity Antiques); b) a fringe necklace set with a collection of Western Australian opercula. It was crafted by jeweller AO Kopp who had businesses established in Fremantle and Perth between 1892 and 1905. The chain and connecting links are in 9 ct gold and the claw-set opercula form the accent of the necklace. It is likely that the necklace was made as a special commission around 1900 (courtesy Trinity Antiques).

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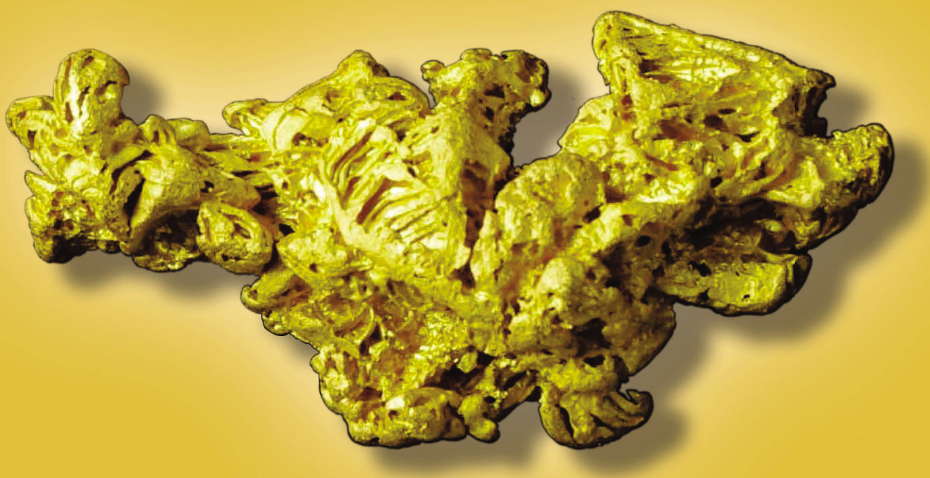
5

Precious metals



An example of a gold nugget (126 g) found using a metal detector in the Kalgoorlie region

Chapter 17 Gold and silver in jewellery

Gold

Pure gold is a soft, dense, yellow metal with a specific gravity of 19.3 and a melting point of 1063°C. It is the most malleable and ductile of all metals and also resists tarnishing, is insoluble in most acids, and readily forms an amalgam with mercury.

In the natural environment, gold is invariably alloyed with silver or copper. Native gold typically contains approximately 85–95% gold with the balance generally as silver. Gold containing at least 20% silver is referred to as electrum. Gold also occurs in combination 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 often associated with sulfides. Detailed studies indicate that vein gold occurs 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 these occur as relatively large masses), stockworks, and tiny grains intergrown with other sulfides. Crystalline gold is extremely rare. Primary gold ores fall into two groups. The first of these is free-milling gold in which the gold is recovered by simple crushing and extraction, and the second is refractory gold that is associated with telluride and sulfide ores, and which requires 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 may occur 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. Recent work by Hough (2010, written comm.) has suggested that the larger nuggets represent primary gold in situ in which the quartz matrix has been removed, leaving the gold.

Precious metals
Gold (Au)
Silver (Ag)

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 being displayed throughout Australia it was melted down by the Royal Mint in Perth into 29.461 kg (947.3 oz) of fine gold (Fig 17.1).

In Western Australia in 2010, by far the greatest gold production was derived from the Eastern Goldfields (63%, comprising 132.8 Moz) and 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).

Australian gold rushes

Gold was discovered in the eastern states much earlier than in the west, with the earliest verified discovery being in 1823 at Bathurst, NSW. In 1851, Edward Hargraves is commonly credited with the discovery of the first payable gold at Ophir (near Orange), leading to Australia's first gold rush. Gold was found in Victoria in 1848, with a gold rush in 1851, and subsequently in Tasmania in 1852, and Queensland in 1858.

Western Australia

In 1872, the Western Australian Government offered a reward of £5000 to the person who found the first payable goldfield in Western Australia. Although there were several applications for the reward, it was never paid out. Despite these claims, discoveries of gold at a number of 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 but there

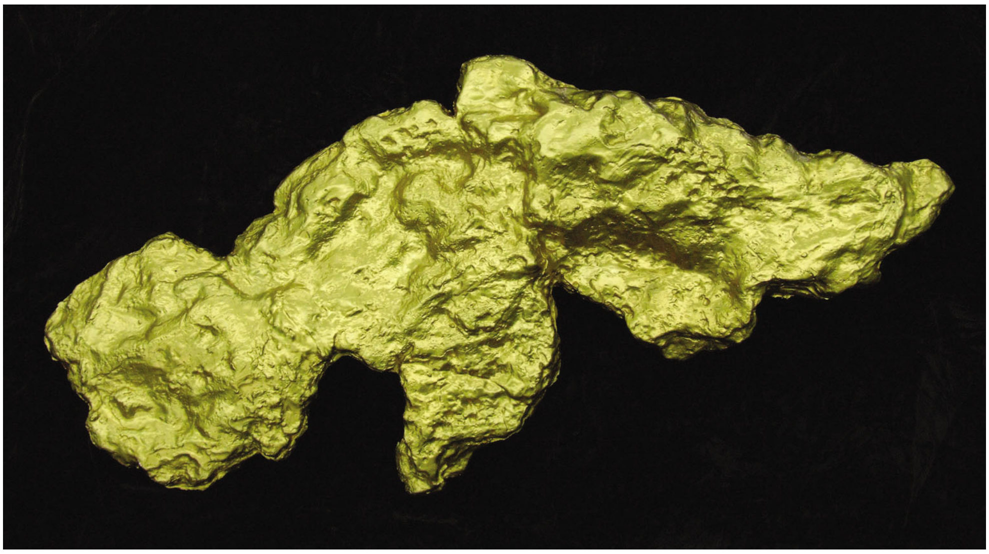


Figure 17.1 **A replica of the Golden Eagle, Western Australia's largest gold nugget. It measured approximately 630 mm in width and 260 mm in height and weighed 35.287 kg. It was found in 1931 by James Larcombe and his son at Larkinville about 60 km southeast of Coolgardie**

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.

- **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 and 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 ounces 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 ounces of gold at Coolgardie in 1892. This discovery marked the acceleration of the Western Australia 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 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'.

Gold in jewellery

Historical aspects

Gold has been utilized for jewellery manufacture for many thousands of years. Gold artefacts from the Paleolithic period (c. 40 000–10 000 years BC) have been found in Spanish caves.

The earliest gold jewellery found dates from around 3000 BC, from the Sumerian civilization that flourished between the Tigris and Euphrates Rivers in southern Iraq. From about 2600 BC 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' in many publications), with pure gold referred to as 24 carat. In addition to pure 24 ct gold, the most common gold grades are 22 ct (0.916 pure), 18 ct (0.750 pure), 14 ct (0.583 pure) and 9 ct (0.375 pure).

Gold can be readily alloyed with other metals to produce a variety of colours with differing hardnesses. It is the ratio of gold to other metals in the alloy that determines the carat value. For example, an alloy containing 14 parts gold to 10 parts alloy would create a 14 ct gold product. This carat value may also be expressed as the result of the ratio 14:24 that equals a purity of 0.583. Although the carat scale is used in jewellery, an alternative scale is used in mining that measures the 'fineness' of gold, where a value of 1000 corresponds to pure or 24 carat gold.

While gold has literally hundreds of possible alloys, in general the addition of metallic silver will colour gold white, and the addition of copper metal will colour it red. A mixture of around 50/50 copper and silver results in a range of yellow-gold alloys commonly seen in the marketplace (Fig. 17.2). In addition, a small amount of zinc (about 0.2%) may be added to the mixture to harden the alloy. A selection of gold alloys is given in the following list:

- **White gold**. An alloy of gold and at least one white metal, usually nickel, manganese or palladium.
- **Rose, pink or red gold**. A gold and copper alloy, also known as Russian gold.
- **Green gold**. Made by omitting copper from the alloy and just 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**. An alloy of gold and aluminium, also called amethyst gold or violet gold.
- **Blue gold**. An alloy of gold and indium.

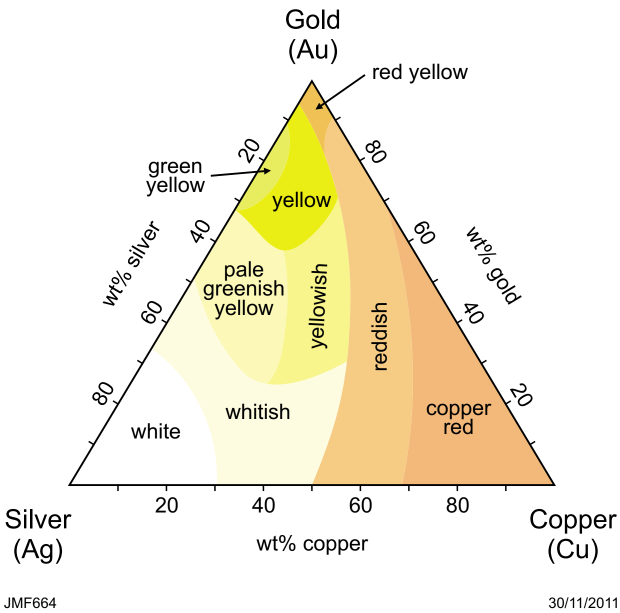


Figure 17.2 A ternary plot of the different colours of Ag–Au–Cu alloys (modified after Wikipedia, 2011)

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. 17.3a–c).

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.

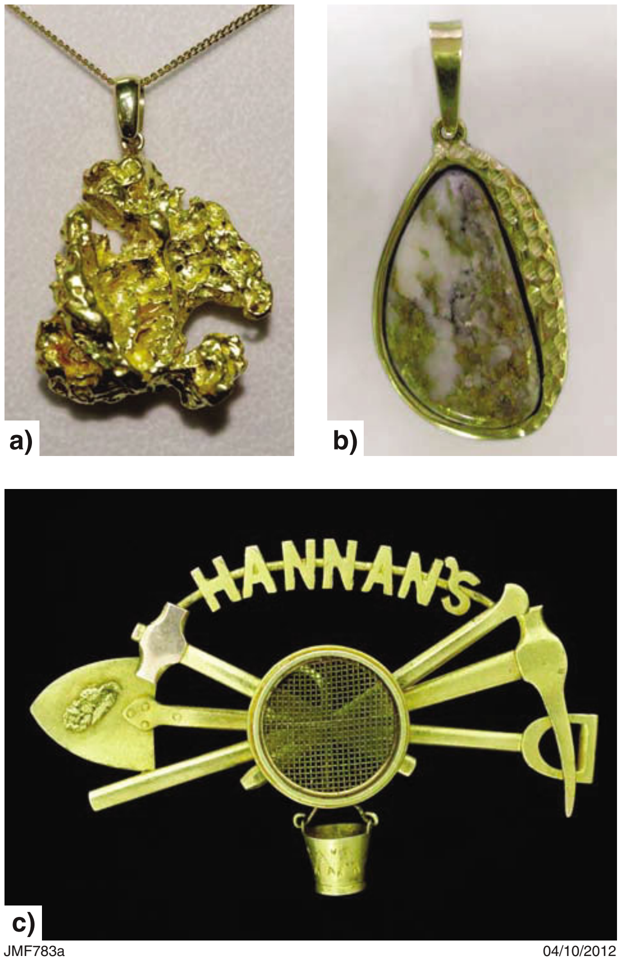


Figure 17.3 Three examples of gold jewellery: a) a 33.28 g gold nugget pendant (courtesy Perth Mint); b) a gold pendant encasing a gold–quartz cabochon (courtesy Gemrock Enterprises; c) gold prospectors' brooch, made in Kalgoorlie by GR Addis in about 1894. Western Australian Museum No. CH1970.772

Prospecting for gold in Western Australia

Early prospectors used panning and dry-blowing methods to locate surface or near-surface gold but these techniques have now been mostly replaced by the hand-held metal detector (Fig. 17.4).

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Figure 17.4 Prospecting for gold and precious metals using a hand-held metal detector

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. 17.5). Almost certainly, the best chance of finding these forms of gold would be in the vicinity of known gold deposits. Figure 17.6 shows the location of 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 GSWA.

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Figure 17.5 An example of a gold nugget (126 g) from the Kalgoorlie region found using a metal detector

Fossickers should remember that carrying out metal detecting for gold in Western Australia requires a Miner's Right as described in Chapter 4 and it is necessary to be aware of the relevant sections of the Mining Act. Also, most gold mining areas in the State are almost completely covered by mining and/or exploration tenements and it is necessary for persons 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.

In Western Australia, there are a number of metal-detecting clubs located 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 10.5 and melts at 962ºC. Silver is stable in pure air and water, but 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 utilized in artefacts, jewellery, high-value tableware, and coins. As early as 700 BC 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 has been mostly replaced by various metal alloys, although pure silver commemorative coins are still produced (Fig. 17.7). In 2001, 20% of total silver produced was used in jewellery and 3.5% for coins and medals.

Silver occurs 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, 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 matrix form that may be used for fashioning into cabochons for jewellery.

Pilbara Craton

Pinderi Hills area

Elizabeth Hill (*Pinderi Hills, 2255*)

The Elizabeth Hill mine was a small underground mine located in the Pinderi Hills area about 40 km south of Karratha (Fig. 17.8). The mine is situated to the west of the Maitland River and is best accessed via the Tom Price

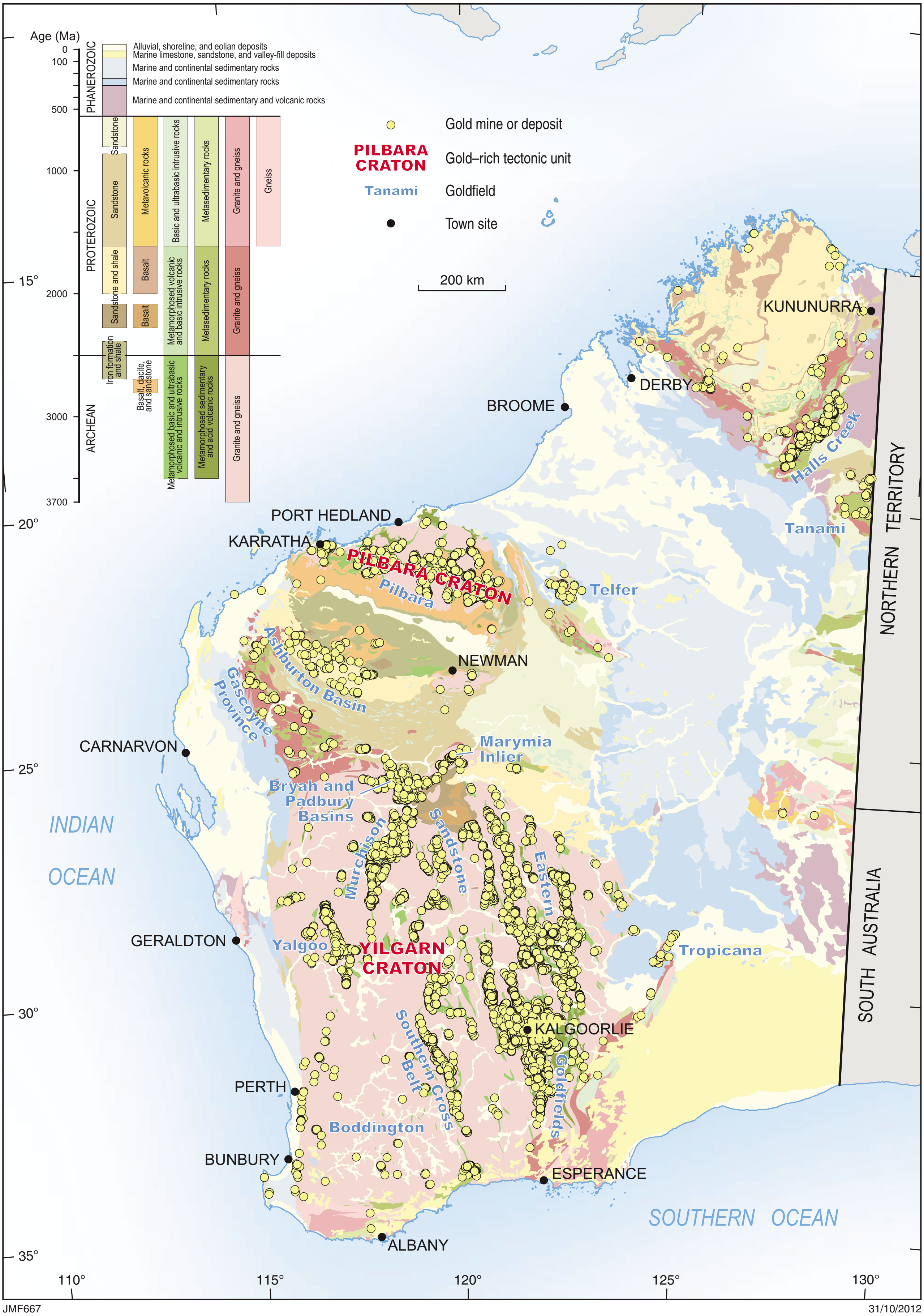

Figure 17.6 Principal gold-mining areas of Western Australia

Figure 17.7 **A 10 oz (311.03 g), pure silver kookaburra commemorative coin produced by the Perth Mint in 1993. Coin is 75 mm in diameter**

railway road that 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 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. A total of 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. More recently, in 2010 East Coast Minerals carried a drilling program of 17 drillholes targeting magnetic and EM anomalies. Unfortunately, assay results achieved a maximum grade of only 6.8 g/t over 4.0 m, which did not match the tenor of ore from the previous underground mining operation and the project has remained under assessment (East Coast Minerals, 2010).

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 Granite. The silver mineralization is situated 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. 17.9).

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 of thin wires or thicker ropy silver up to 60 mm long and weighing more than 10 kg were often encountered (Henry, 2007). The current situation relating to fossicking on the mine dumps is unknown.

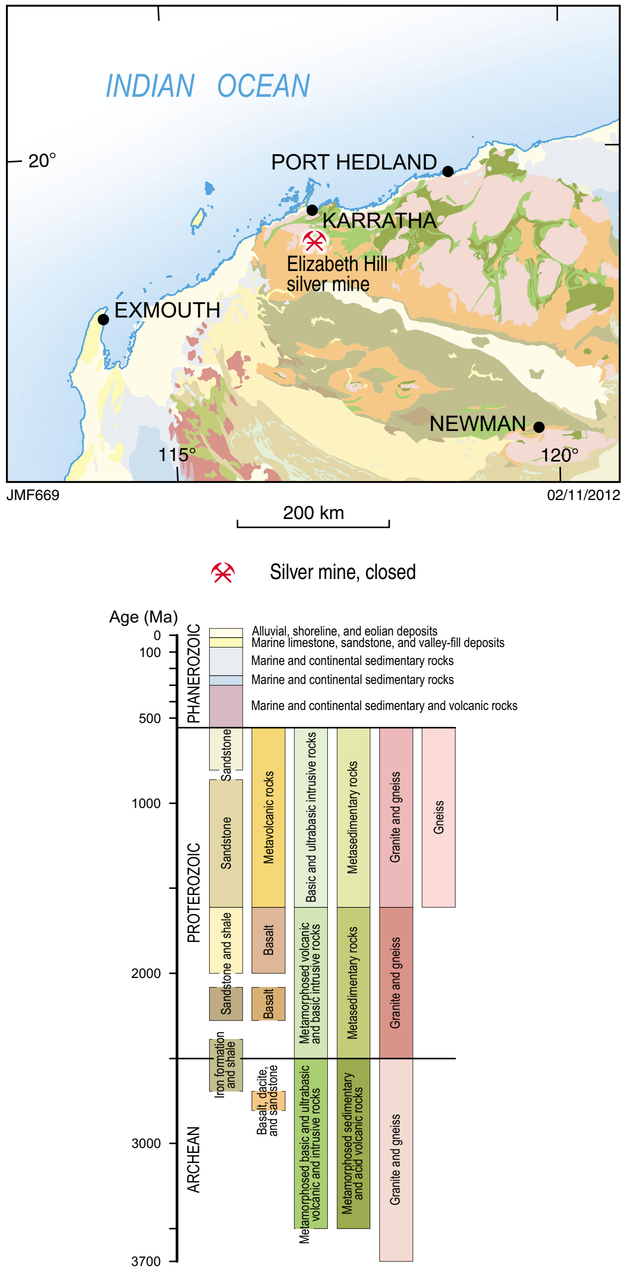

Figure 17.8 **Map of the Karratha region showing the location of the Elizabeth Hill silver mine in the Pinderri Hills area**

Figure 17.9 Four polished cabochons and an unpolished specimen displaying native silver enclosed in a calcium carbonate matrix from the Elizabeth Hill silver mine (courtesy Murray Thompson)

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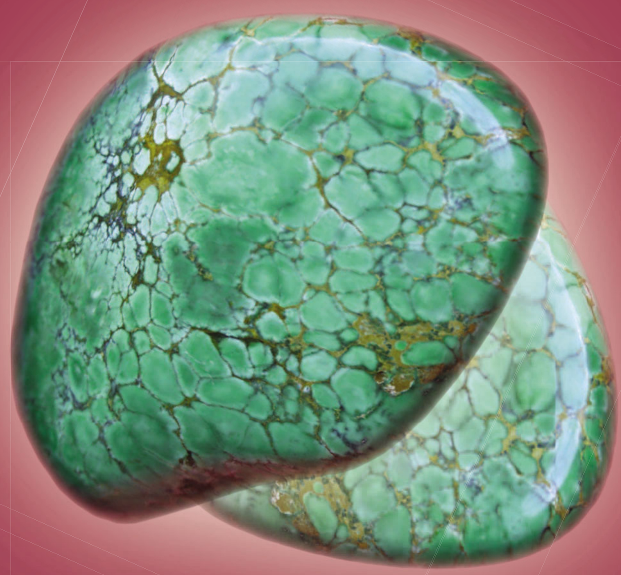
Other gemstones



Polished specimens of variscite from the Waldburg deposit on Woodlands Station, Meekatharra region.

Chapter 18 Andalusite and chiastolite

Andalusite

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 actually in the province of Guadalajara (Minerales y Minnas de España, 2012).

Andalusite is typically a metamorphic mineral and commonly forms as well-defined prismatic porphyroblasts (large crystals). More rarely, andalusite occurs 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 found 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 and exist as different mineral species with the same chemical formula. Although all can co-exist within rocks of the same metamorphic grade, kyanite and sillimanite are usually found in rocks formed under higher regional metamorphic grades. All three minerals contribute gemmological quality material.

Physical properties of andalusite

Crystal system	Orthorhombic
Habit	Prismatic crystals, vertically strained, square in section
Colour range	Light green to reddish-green, pink and yellowish-brown. Often 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
Hardness	7.5
Specific gravity	3.15 – 3.2
Cleavage	Distinct prismatic
Fracture	Subconchoidal
Varieties	Chiastolite displays a cross pattern of inclusions in transverse crystal sections. Viridine is manganiferous andalustie
Treatments	Resin-impregnated and oiled to conceal fractures and improve durability

Andalusite forms crystals that are of cylindrical form, described as cigar-shaped, and are square or rhomboid in section. Other varieties of andalusite include chiastolite, and a manganiferous type termed viridine. Andalusite can

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Figure 18.1 A row of faceted andalusite gems. The largest stone is 6 mm wide (courtesy Bill Moriarty)

Andalusite and chiastolite
Aluminium silicate polymorphs (Al_2SiO_5)

be faceted in its transparent light brown and green colour varieties and, as chiastolite, can be cabochon-cut to show its distinctive cross forms. In Western Australia, andalusite has been found in transparent small crystals suitable for faceting (Fig. 18.1).

Kyanite is faceted in attractive intense blue, green, and orange transparent varieties. Sillimanite is commonly cut to demonstrate chatoyant qualities but is also faceted in its violet, purple, and grey transparent coloured varieties. Neither kyanite nor sillimanite has been found in gem quality in Western Australia.

Table 18.1 Comparative physical and optical properties of andalusite, kyanite, and sillimanite

Properties	*Andalusite*	*Kyanite*	*Sillimanite*
Crystal system	Orthorhombic	Triclinic	Orthorhombic
Colour	Pink, red, grey, green, brown	Blue, green, white, orange	Grey, brown, yellow, violet
Habit and form	Stout prismatic crystals	Bladed, elongated, tabular crystals	Acicular, fibrous, silky
Refractive index	1.63 – 1.64	1.712 – 1.729	1.657 – 1.684
Hardness	7.5	4–7 (strongly directional)	6–7
Specific gravity	3.15 – 3.2	3.6	3.23
Varieties	Transparent and chatoyant, also opaque chiastolite	Transparent and chatoyant	Transparent and chatoyant

Chiastolite

Chiastolite crystals viewed down the length of the crystal show distinctive light and dark mineral zones that form tessellated patterns. Chiastolite is sectioned specifically for use in jewellery to display these cross-form patterns. It is also fashioned as cabochons or beads that have featured traditionally in rosaries and religious emblem jewellery, particularly in Europe.

The dark and light zones of chiastolite are the result of aggregated carbon, graphite, and dark mica grains between zones that are either transparent 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.18.2).

Viridine

Viridine, is a manganiferous variety of andalusite and has been recorded in the south of Western Australia in schists from the Mount Ragged, Mica Hills and Mount Dean areas. The viridine occurs 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, iron oxides) but are notable for displaying strong pleochroism from golden yellow, through yellow green, to emerald green. Refractive indices are greater (1.649 to 1.661) than those for the normal range of andalusite due to the presence of Mn^{3+} and Fe^{3+} (Prider, 1960). A specimen of viridine is displayed in the School of Mines Museum, Kalgoorlie (specimen 8615).

Figure 18.2 A 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 being worked today for gem minerals (Fig. 18.3). Rose quartz is currently exploited from the core of a pegmatite a few kilometres south of Spargoville on prospecting licence P15/5630. The site is of local interest to lapidaries as chiastolite crystals are found within the micarock aureole of this pegmatite (Fig. 18.4).

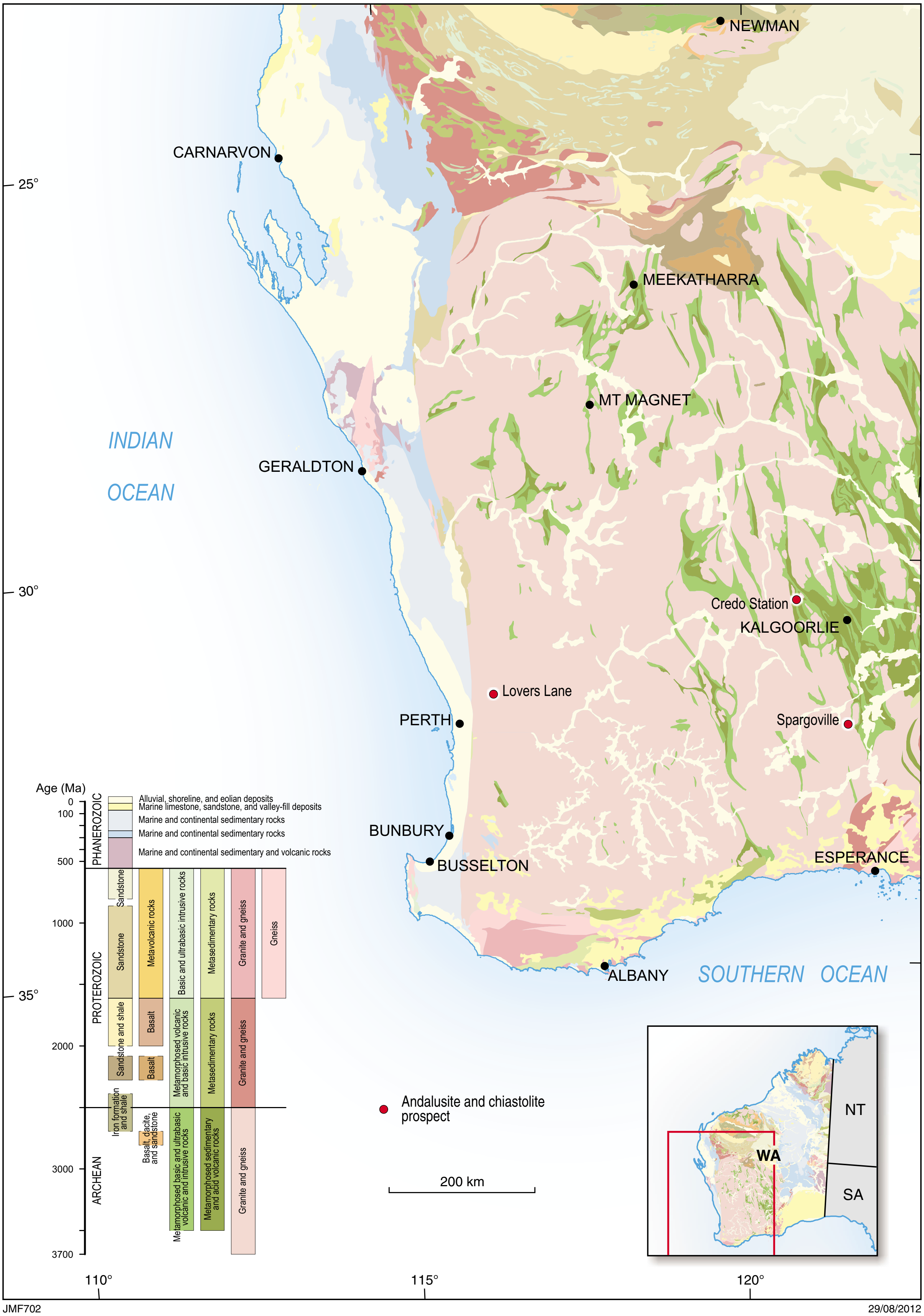

Figure 18.3 Location of andalusite and chiastolite prospects in Western Australia

Figure 18.4 A chiastolite crystal in greenstone schist south of Spargoville (courtesy Francine Payette)

Some of these crystals attain lengths of 100 mm with sections of approximately 30 mm. A specimen (325 mm long) at the School of Mines Museum in Kalgoorlie displays an incomplete crystal of andalusite-in-matrix (specimen 8390).

Staurolite, a red-brown to black orthorhombic silicate mineral, and garnets are encountered within the same schists and have also been collected from this area. The staurolite is commonly a dark red with an orange hue, a colour too dark for faceting. The fragments tend to be angular broken crystal pieces, 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. Well-crystallized but weathered staurolite can be found in situ in some of the outcropping andalusite schist and also on hill slopes as eluvial material.

Ora Banda area

Credo Station (*Davyhurst, 3037*)

An unpublished report (Trask, 1987) about andalusite from Credo Station covers an investigation to use andalusite as a refractory ore (Fig. 18.3). The area was investigated under exploration licence E16/26 and referred to three projects titled Rock Dam, Reptile Dam, and West Reptile Dam. The prospect was not progressed but the site is of interest for the occurrence of some facet-grade andalusite crystals, including chiastolite.

In one part of the prospect, scattered eluvial andalusite crystals extend over an area of approximately 600 x 200 m in a weathered rock described as fine-grained whitestone schist. In another part of the project area, andalusite exists within a silicifed laterite with crystals averaging 10 x 35 mm. West of the main occurrence (West Reptile Dam), a large number of ferruginous andalusite crystals were collected on a laterite surface at the time of the investigation (Trask, 1987).

Eluvial andalusite and chiastolite, some with adherent matrix, have been collected recently at Credo Station. The crystal fragments are generally less than 15 mm in length but finds include transparent quality material (Fig. 18.5).

South West Terrane

Toodyay area

Lovers Lane prospect (*Wooroloo, 2134*)

Andalusite and chiastolite occur at Lovers Lane prospect within schists of the Jimperding Metamorphic Belt that comprises metasedimentary rocks with subordinate mafic rocks (Fig. 18.3). The belt extends north-northwest for over 120 km and varies in width from 15 to 65 km, forming part of the Yilgarn Craton east of the Darling Fault. The rocks show a progressive eastwardly increase in metamorphic grade from lower amphibolite to granulite facies with the presence of andalusite, sillimanite, and cordierite indicator minerals.

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 (1948) describes 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 x 5 x 5 mm to 40 x 40 x 40 mm or 60 x 25 x 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 owing to 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 where individual crystals reach

Figure 18.5 Rough crystal fragments of andalusite from Credo Station. Maximum crystal length is 16 mm (courtesy Bill Moriarty)

larger sizes to 60 x 30 x 30 mm. A distinctive feature is the coating of coarse mica on the surfaces that is integral to the crystal and not part of the host mica schist. Simpson (1948) described many other localities within the Jimperding Metamorphic Belt.

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Chapter 19 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 generally 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 pseudo-hexagonal form. Transparent, high-quality chrysoberyl is usually faceted to form a hard, durable gemstone with a vitreous lustre.

Cats eye

Chrysoberyl may also exhibit chatoyancy. Chrysoberyl exhibiting this property is referred to as 'cats eye' (Fig. 19.1). This optical property is a phenomenon caused by light reflection from prolific needle-like inclusions developed parallel to the principal crystal axis (c or vertical axis). These inclusions are most commonly hollow tubules that develop on a microscopic scale. Cabochon-cut gemstones are often cut as oval-shaped, biconvex forms from chrysoberyl containing these inclusions that 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.

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 within 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 but gem-quality material is rarely found (Schmetzer et al., 2011). Also, 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 from Poona in Western Australia is an example of this mineralogical association.

Chrysoberyl and alexandrite
Beryllium aluminium oxide (Be Al_2O_4)

Physical properties of chrysoberyl

Crystal system	Orthorhombic
Habit	Tabular, commonly twinned
Colour ranges	Brown, yellow, golden-yellow, yellow-green, green, colourless
Colour cause	Yellow varieties: iron yellow to green varieties: 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 a number of 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 19.2 and more accurate sites are given in Appendix 1.

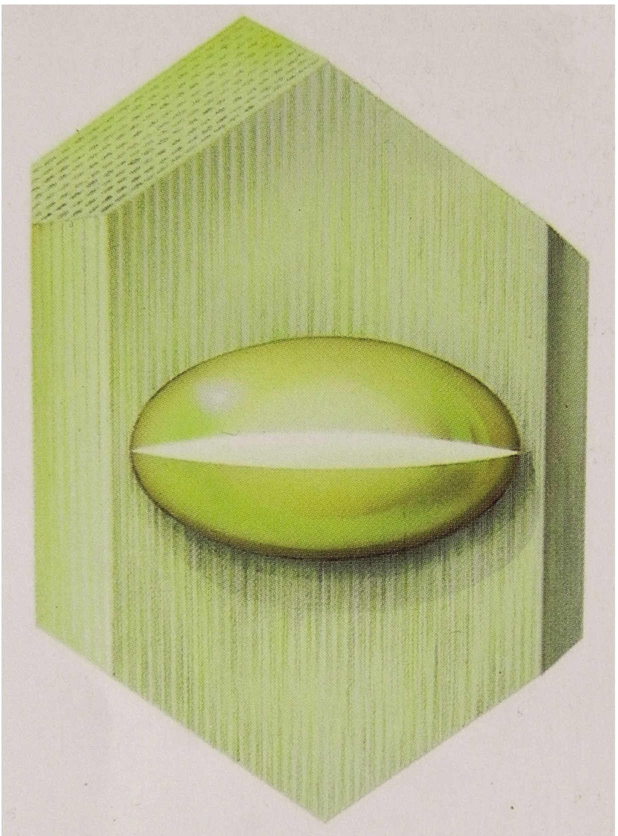

Figure 19.1 **Cats eye effect in chrysoberyl (after The Natural History Museum, 1993)**

Gascoyne Province

Yinnetharra area

Williamsons beryl mine (*Yinnetharra, 2148*)

Williamsons beryl mine (possibly the same as Lake Moore pegmatite mine), located 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. 19.2). This location has already been described in Chapter 6 (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 a disused mine located 16 km west-southwest of Bridgetown (Fig. 19.2). The deposit may be accessed via Tin Mines Road that 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 contained tin, tantalum, and lithium mineralization. Chrysoberyl is also recorded as being present in the pegmatite, but no further details are known (MDC 5778).

Dowerin

Dowerin pegmatite (*Dowerin, 2335*)

The Dowerin pegmatite is located about 1.6 km southeast of Dowerin township and about 200 m west of the Dowering–Meckering Road (Fig. 19.2). 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 was followed up by tracing subcrop material to a pegmatite in a local wheat field (Simpson, 1932). The Dowerin pegmatite was prospected for about three years before being abandoned in 1933 because all of the clear crystals recovered were assessed as being too small to be worth cutting. In 1991–92, DMP 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 andesine–quartz gneiss was intruded by pegmatitic veins during subsequent metamorphism to granulite facies. At the chrysoberyl openpit, the exposed rocks comprise pegmatite veins containing 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 that contain trace amounts of nickel (Bevan and Downes, 1997).

In the Dowerin deposit, crystals of chrysoberyl occur most commonly, but not exclusively, in the biotite-rich zones within the pegmatite, particularly in association with

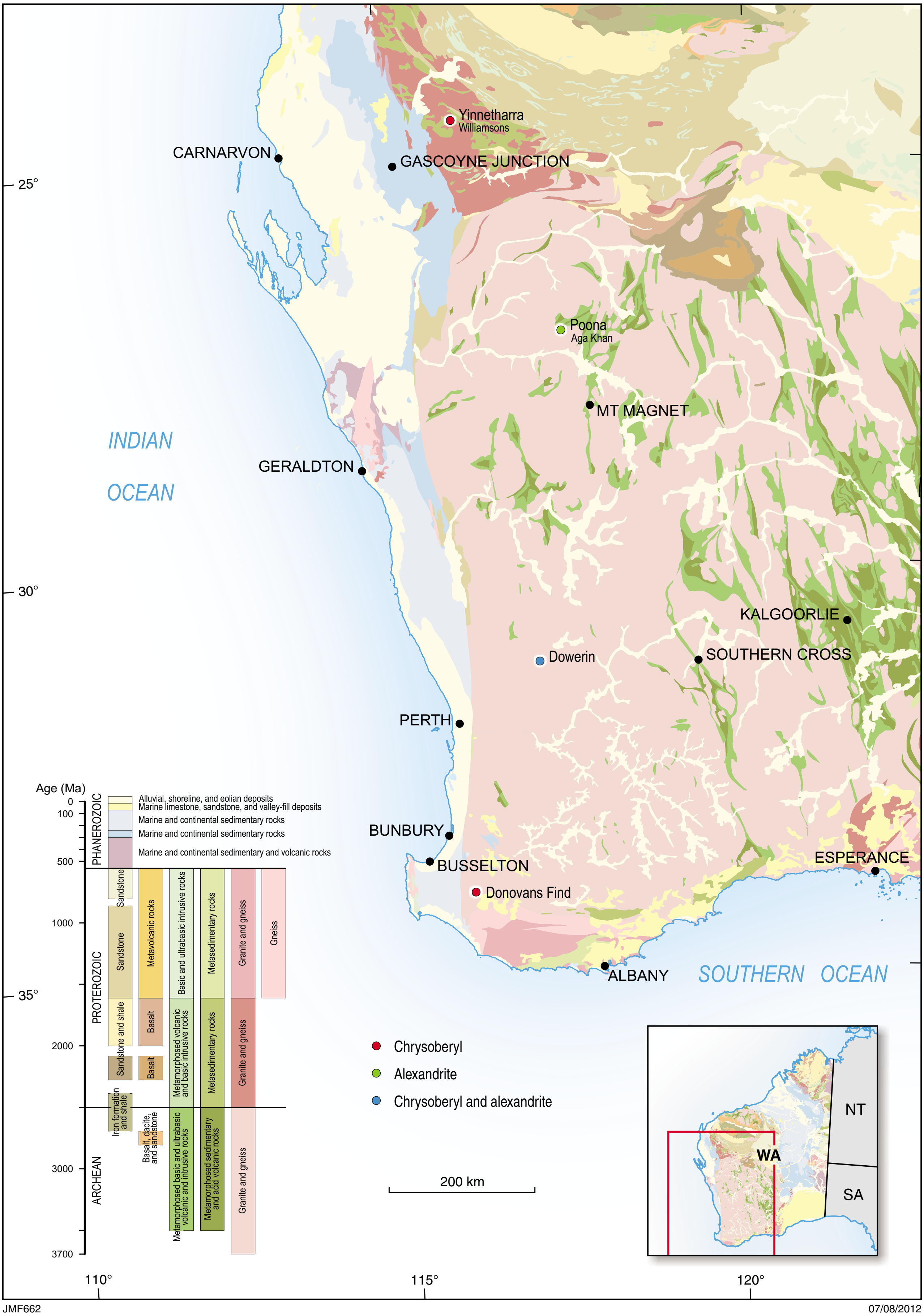

Figure 19.2 Location of chrysoberyl and alexandrite prospects in Western Australia

almandine garnet. Simpson (1932) described crystals of chrysoberyl ranging in size from less than 1 mm to more than 1 cm across and varying from colourless to yellow, through pale green, to a deep emerald-green. Most of the smaller crystals were generally transparent and a few of the deeper green crystals show the characteristic alexandrite colour change described in more detail below.

Common crystal forms of chrysoberyl present include tabular, striated and elongate crystals with some small cyclically twinned crystals (known as trillings). The largest crystals of chrysoberyl are generally poorly developed, translucent, and contain inclusions of other minerals. Some crystals have a bright yellow colour, The largest crystal found in recent times is a broken trilling 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 located approximately 55 km northwest of Cue (Fig. 19.2). These have been described in detail under emerald in Chapter 6. Simpson (1951) recorded 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 had small areas of gem-quality material.

In later years, Grundmann and Morteani (1998) 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; they are also 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 above 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. 19.3a). They recorded that few of the deeper green chrysoberyl crystals clearly showed the characteristic colour change present in alexandrite when viewed in daylight or incandescent light. Microprobe analyses show these crystals to have a detectable chromium content. Only two small alexandrites have been faceted, with the largest weighing only 0.15 ct (Fig. 19.3b).

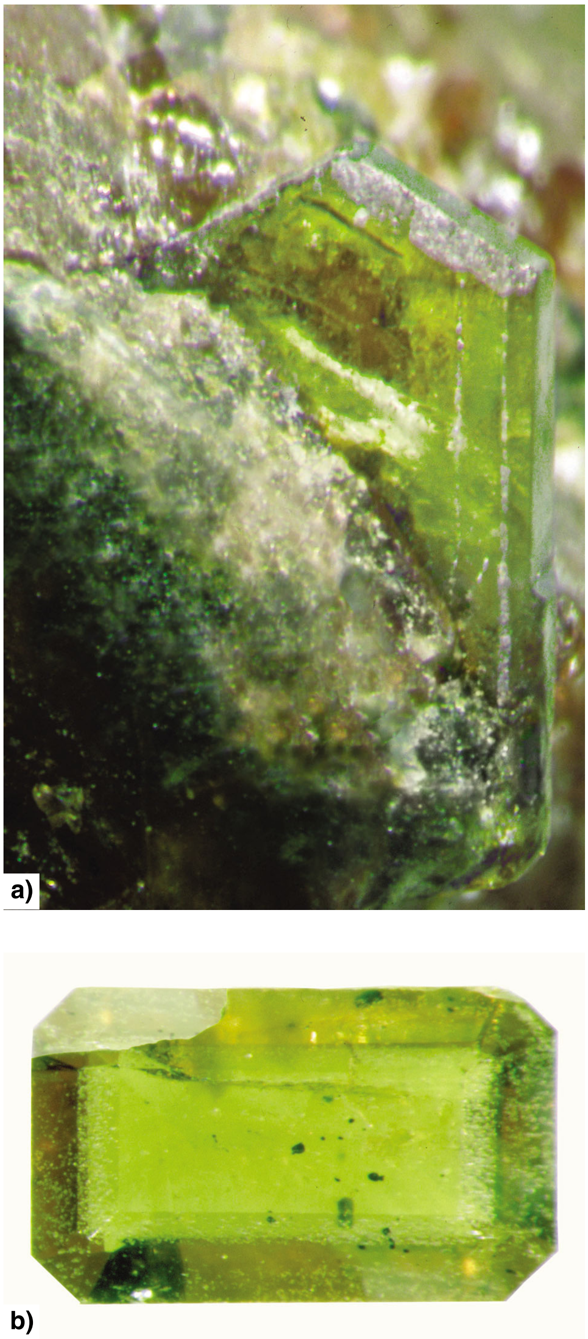

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Figure 19.3 **Alexandrite crystals from the Dowerin prospect: a) a pale green, tabular, euhedral alexandrite crystal, approximately 3 mm in length, showing many crystal faces; b) a very small, broken, lemon-green, faceted stone weighing only 0.15 ct (modified after Bevan and Downes, 1997)**

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Chapter 20 Corundum

Corundum gemstones

Corundum essentially comprises aluminium oxide (up to 99% Al_2O_3) with traces of iron (ferric and ferrous), 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, but it also occurs in silica-poor undersaturated igneous rocks with feldspathoids and in aluminous xenoliths in igneous rocks. Occurrences of corundum, as opaque and subtranslucent barrel-shaped crystals, are recorded from metasedimentary rocks, basic xenoliths, and eluvial finds from several sites within Western Australia.

Corundum, notably as emery, is utilized as an industrial mineral, but it is best known in gemmology as the important gem varieties ruby and sapphire.

Corundum 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 to the mineral. Traditionally, there are two significant gem varieties of corundum: the red variety, termed ruby, containing chromium; and blue, green, and yellow sapphires, with colour determined by the presence of iron and titanium.

Sapphire is usually considered to be blue (with others described specifically as yellow or green sapphire). Red gem corundum is invariably referred to as ruby.

Well-formed crystals of corundum, particularly sapphire, commonly possess a bipyramidal habit that is hexagonal in section and combined with twelve tapering faces, six above and six below. When viewed at right angles to the long dimension of crystals, hexagonal growth zoning is often apparent (Fig. 20.1).

Some crystals of sapphire and ruby contain geometric patterns of minute inclusions of exsolved fine acicular rutile. Gems from these that are fashioned in the correct orientation relative to specific crystal directions may produce chatoyancy, or a six- or twelve-ray star phenomenon.

Corundum
Aluminium oxide (Al_2O_3)

Figure 20.1 Cabochon-cut sapphires from the Pilbara. The sapphires show hexagonal zoning. Cabochons are up to 18 mm in length (courtesy Bill Moriarty)

Historically, the most important sources for ruby have been Burma (Myanmar), Afghanistan, and Sri Lanka, but ruby is now sourced from many other countries including Thailand, Madagascar, and Tanzania.

Blue sapphire from the Kashmir region of India and from Burma are considered to be the most desirable and valuable. Many other countries including the USA, Laos, Vietnam, Madagascar, Malawi, and Australia are producers of sapphire. Until recently, eastern Australia was the largest producer of yellow, green, and blue sapphires, mining 70% of the world's 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 used in industry; synthetic ruby was used as small bearings in watch movements following its commercial manufacture in the early 20th century. Currently, synthetic sapphire and ruby are utilized in a range of applications from scratch-resistant watch glasses to lasers.

Physical properties of corundum

Crystal system	Trigonal, rhombohedral
Habit	Commonly barrel-shaped crystals, also tabular rhombohedral
Colour range	Large range of colours: grey, brown, white, colourless, blue, red, green, yellow, orange, and purple
Colour cause	Trace iron, chromium, and titanium
Lustre	Adamantine to vitreous
Diaphaneity	Transparent to translucent
Refractive index	1.75 – 1.77
Birefringence	0.016
Hardness	9 (the standard of Mohs scale)
Specific gravity	3.95 – 4.10
Twinning	Common rhombohedral lamellar
Cleavage	Poor
Fracture	Uneven to conchoidal
Fluorescence	Unless quenched by iron, ruby displays strong red fluorescence in long wave UV

Corundum gemstones in Western Australia

Although Simpson (1951) recorded 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. 20.2) has been investigated on Williambury Station, approximately 200 km northeast of Carnarvon and 90 km north of Gascoyne Junction (Fig. 20.3). Access is via the Mount Sandiman to Williambury road and 4WD tracks.

The sapphire crystals occur as bladed sheaves, individual crystals and fragments are intergrown and associated with

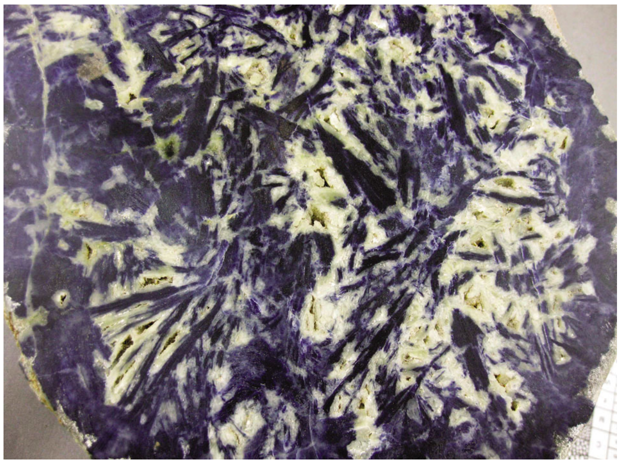

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Figure 20.2 Decorative rock with sapphire crystals in matrix, Williambury Station. Specimen is 12 cm in diameter (courtesy Barry Kayes)

muscovite. The sapphires are opaque and vary in colour from a dark to medium blue, some with a violet shade reminiscent of lapis lazuli. Selected sapphires were heat treated in Bangkok but 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 the Pincunyah prospect approximately 100 km south of Port Hedland, between the Mount Newman railway line and the southern branch of the Turner River (Fig. 20.3). This unconfirmed locality is likely to be within high-grade Archean metasedimentary rocks. Figure 20.1 shows cabochons cut from this material; all have been cut to display hexagonal zoning of the crystals.

Simpson (1951) recorded similar corundum crystals from a location about 8 km north of Abydos Homestead. He collected several specimens from this location, and 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 at Thoolmugga Well overlying amphibolite to lower granulite facies banded gneiss, calc-silicate gneiss, and mafic granofels after layered mafic bodies (Fig. 20.3; 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.

Yilgarn Craton — South West Terrane

Southwest Western Australia

Jacobs Well (*Brookton, 2333*)

The publication Gemstones in Western Australia (Geological Survey of Western Australia, 1994) recorded an interesting occurrence of translucent blue corundum at Jacobs Well in the South West of Western Australia. No

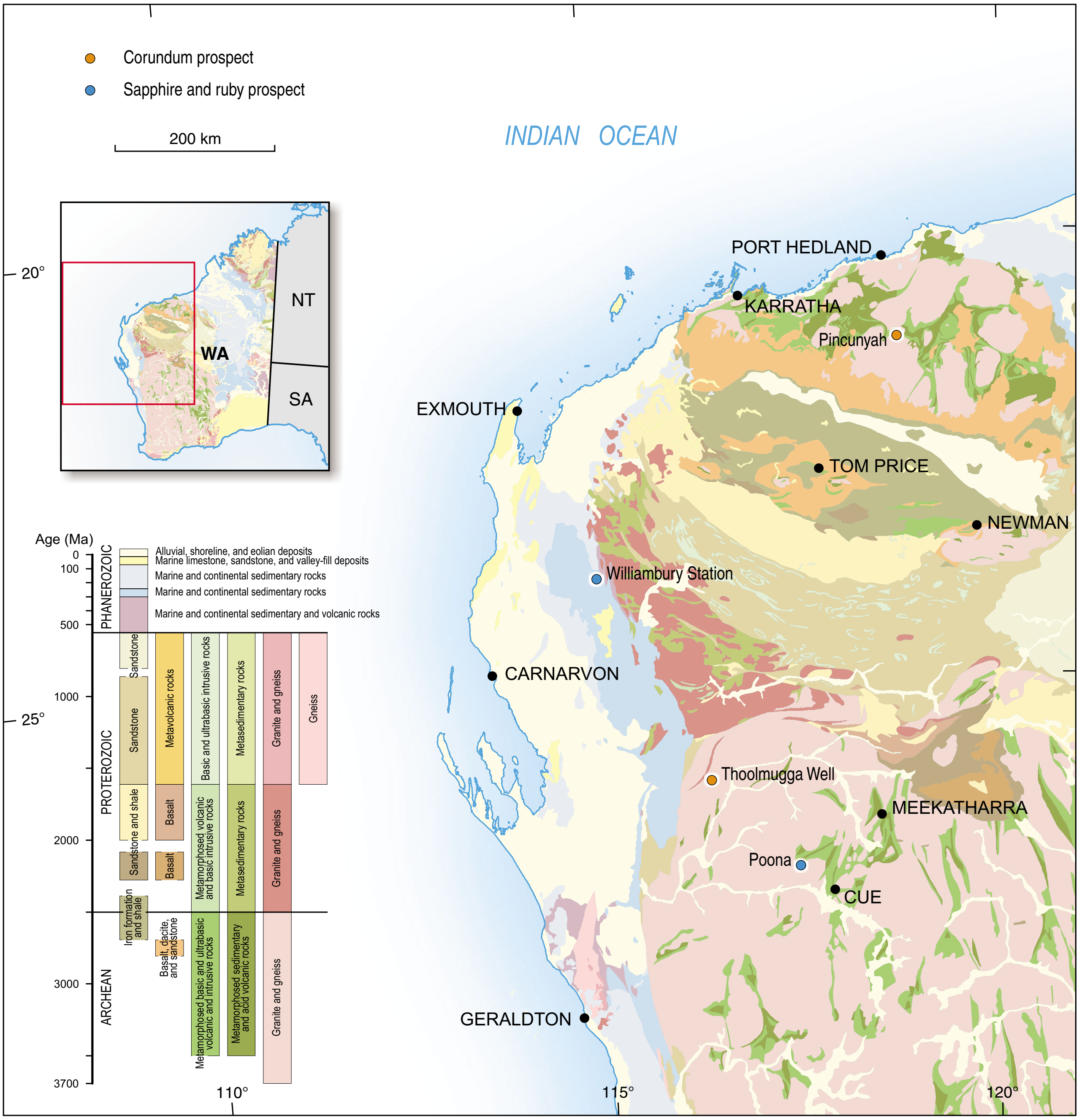

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Figure 20.3 Location of corundum mineral prospects in Western Australia

further information is given, but Simpson (1951) made the following observations.

The Jacobs Well eluvial deposit contained rounded and subangular corundum pebbles with strong rhombohedral twinning and parting. Crystals up to 120 mm in diameter were found, with the largest weighing 300 gm.The majority of crystals were grey to greyish-lilac, but 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 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 at the Aga Khan mine (Watkins et al., 1987; Fig. 20.3). These 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, ruby, and sapphire occur only as small crystals and not of facetable size.

According to Grundmann and Morteani (1998), the sapphires are more rare and smaller than the rubies. Subhedral to euhedral corundum crystals mostly display tabular habit and commonly form subparallel or radial aggregates. Individual crystal size ranges 1–5 mm in length; in some instances platy crystals have a diameter of up to 10 mm. Colourless or dark blue sapphire occurs in irregular patches, commonly in the centre of ruby crystals. Ruby and sapphire fragments are shown in Figure 20.4.

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Figure 20.4 Fragments of ruby and sapphire from Poona. Maximum particle size is approximately 5 mm (courtesy Guilio Morteani)

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Chapter 21 Copper gemstones

Turquoise

Turquoise is a soft, opaque mineral that ranges in colour from blue-green, to yellow-green with grey, black or brown veining. Turquoise 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 occurs as vein or fracture filling and is nodular or botryoidal in form. The blue-green colour is derived from copper.

Physical properties of turquoise

Crystal system	Triclinic
Habit	Cryptocrystalline crystal aggregates, nodular and botryoidal encrustations
Colour range	Blue-green and green
Colour cause	Colour from copper
Lustre	Vitreous to waxy
Diaphaneity	Opaque
Refractive index	Spot test: 1.62 (mean)
Birefringence	0.040
Hardness	5–6
Fracture	Conchoidal
Specific gravity	2.6 – 2.9
Cleavage	Good
Absorption spectrum	Spectral testing may show bands in the blue region
Lapidary application	Often fashioned together with host matrix material

Copper gemstones

Turquoise — hydrous copper aluminium phosphate $[CuAl_6(PO_4)_4(OH)_8.5H_2O]$

Malachite — copper carbonate $[CuCO_3.Cu(OH)_2]$

Azurite — copper carbonate $[2CuCO_3.Cu(OH)_2]$

Chrysocolla — hydrous copper silicate $(CuSiO_3.2H_2O)$

Turquoise is one of the oldest gemstones used for personal adornment as it features in many cultures in antiquity since at least 3000 BC, including those of the Egyptians, Persians, Aztecs, and Chinese.

Good-quality, fine-grained turquoise is rare and expensive. It is commonly impregnated with epoxy resins, colourless oil or wax to stabilize and enhance its colour and increase durability. Imitations of turquoise are common and much 'turquoise' jewellery and most beads commonly offered for sale are dyed forms of magnesite or howlite (a calcium borate). Turquoise may also be imitated using other natural minerals of similar colour, such as chrysocolla and hemimorphite (a zinc silicate). Verification of some of these minerals can be difficult.

Turquoise in Western Australia

Yilgarn Craton — Eastern Goldfields Superterrane

Kalgoorlie region

Lake Yindarlgooda copper–zinc prospect
(Kanowna, 3236)

An unnamed 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. 21.1), 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 suitable for cutting only small stones (Fig. 21.2).

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 commonly occur with azurite. Malachite is coloured green in varying intensities ranging from light to dark, and produces a green streak.

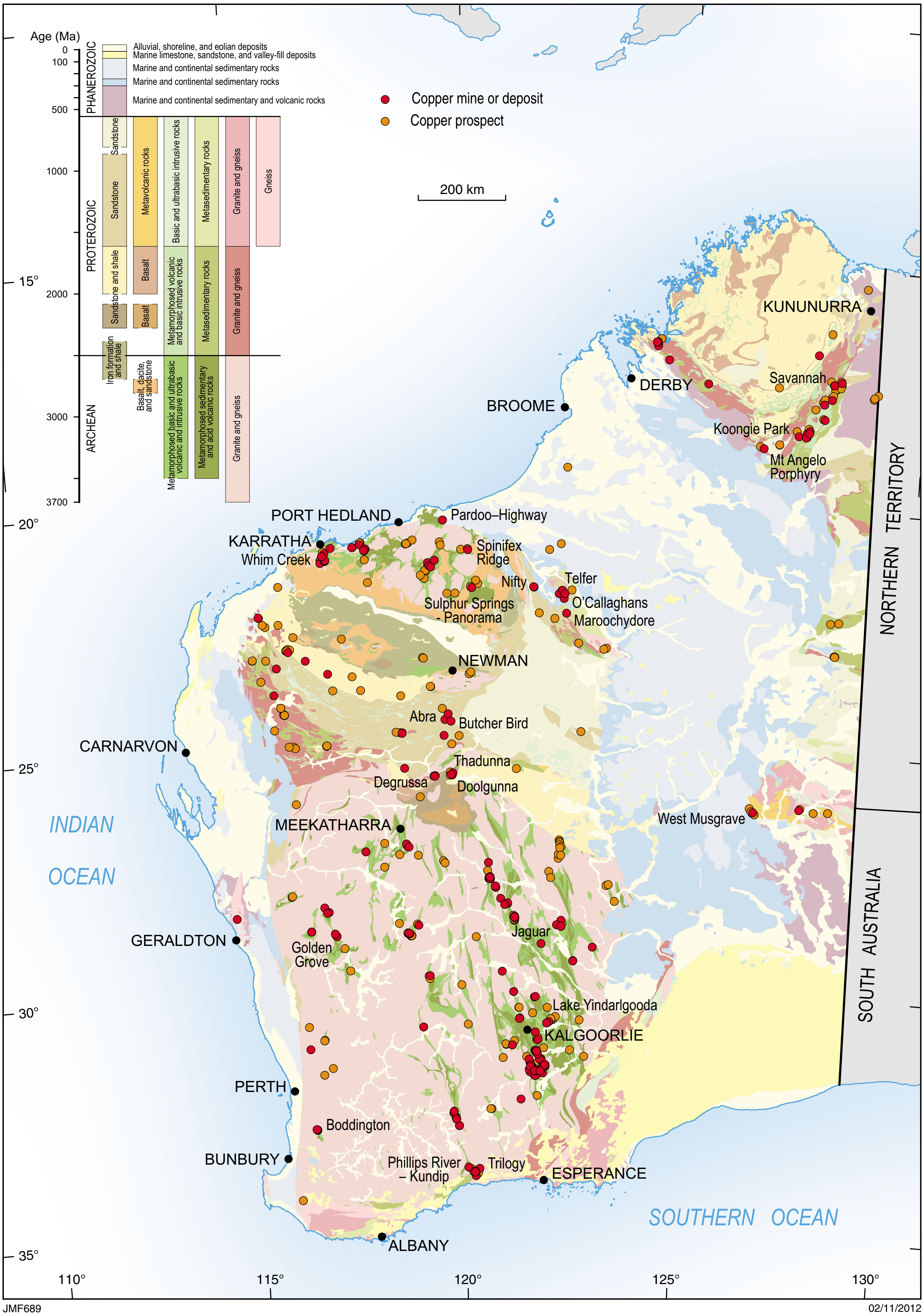

Figure 21.1 **Location of copper deposits and prospects in Western Australia (modified after Geological Survey of Western Australia, 2012)**

Chrysocolla can vary in colour from green, to bluish-green, and light blue, and produces a white streak.

Malachite is relatively soft but the stone is competent, with a hardness of 3.5 – 4, and generally occurs as massive to banded botryoidal encrustations, with crystals being less common. Western Australia has none of the spectacular ornamental malachite of the type found in the 19th century in the Ural Mountains at Nizhne Tagilsk in the Russian Federation. This material is featured in 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 Bwana Mkubwa mine, have been major sources of massive malachite.

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. 21.3).

Chrysocolla is softer than malachite, with a hardness of 2 – 2.4 and most typically occurs as botryoidal encrustations or vein fillings (Fig. 21.4). Chrysocolla is commonly cryptocrystalline with a translucent opal- or enamel-like texture, and its colour tends to be light blue. Micro-acicular chrysocolla crystals are rare.

For lapidary applications, chrysocolla is often used as an ornamental stone together with other copper minerals in its natural, silicified matrix. Like turquoise, chrysocolla may be resin-treated as treatment prevents discolouration and deterioration (Fig. 21.5).

Azurite

Azurite is characteristically an azure blue mineral, although it also occurs in varying shades of blue. Azurite is an idiochromatic gemstone, so called as its colour is determined from its essential copper composition. It is rarely found as discrete crystals such as 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. 21.6).

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Figure 21.2 A 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)

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Figure 21.3 **Carved and polished hippopotamus ornament in green-banded malachite from Zambia**

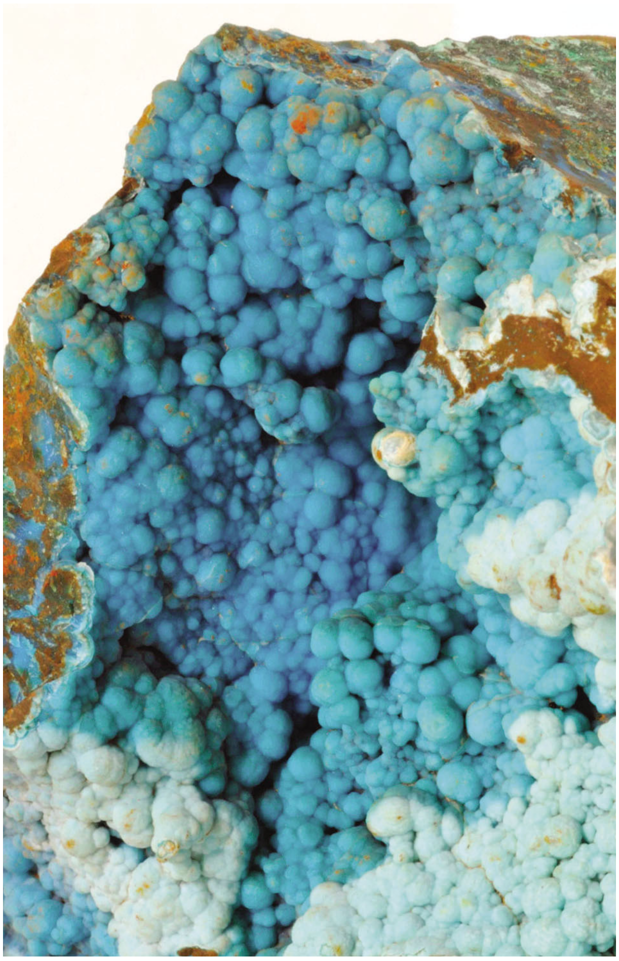

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Figure 21.4 **Botryoidal encrustations of blue chrysocolla forming a cavity wall lining. Degrussa copper–gold deposit, Peak Hill region (courtesy Murray Thompson)**

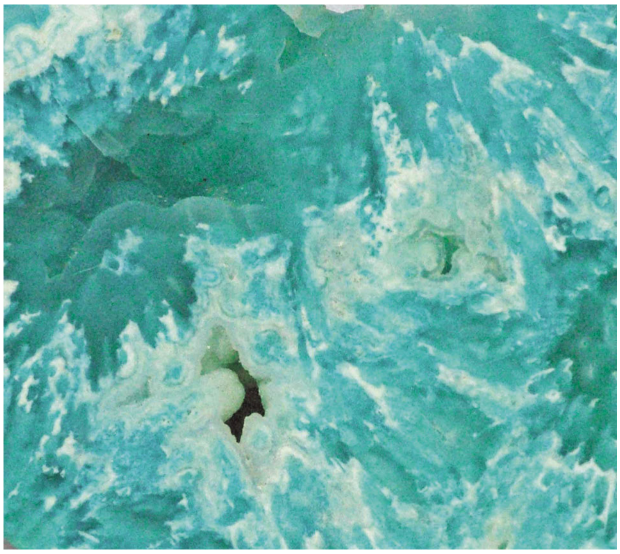

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Figure 21.5 **A silicified form of blue chrysocolla from the Degrussa mine, Peak Hill region. The specimen displays small cavities infilled by chalcedony within the radiating chrysocolla texture (courtesy Murray Thompson)**

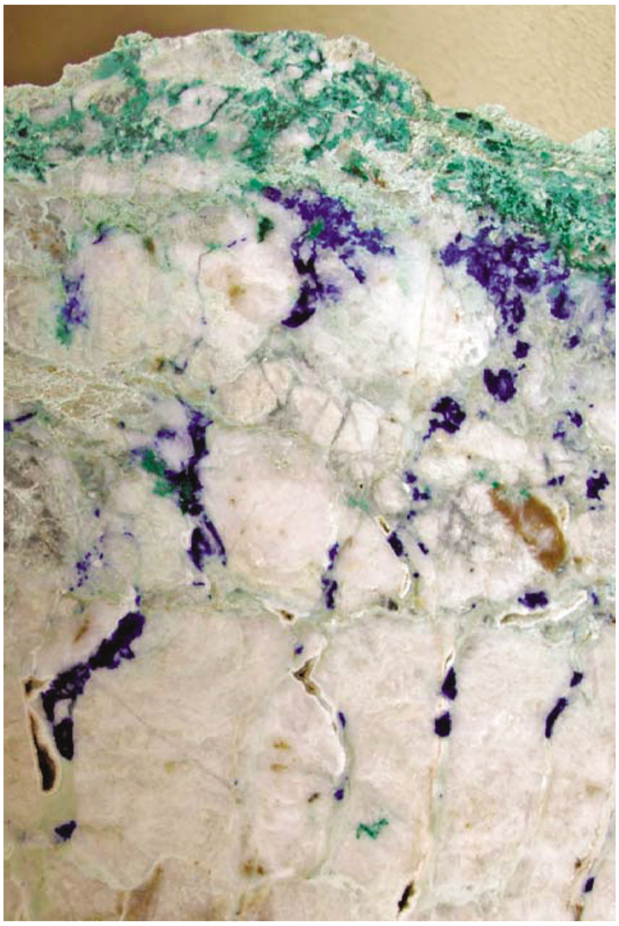

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Figure 21.6 **Blue azurite veins and other green copper minerals in quartz host rock. Thadunna copper prospect, Neds Creek Station (courtesy Barry Kayes)**

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	Massive, rare crystals
Colour range	Characteristic colour: light to dark green	Bright green, bluish-green, light blue	Characteristic colour: azure blue
Lustre	Vitreous to silky	Greasy, earthy to vitreous	Vitreous, also dull and earthy
Streak	Green	White	Blue
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
Mineral association	Other secondary copper minerals	Other secondary copper minerals	Other secondary copper minerals
Lapidary work	Carvings, cabochons, beads, inlay work	Often used together with its matrix minerals	Carvings, cabochons, beads, inlay work

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 mines, deposits and prospects in the State is shown in Figure 21.1. Some of these orebodies have associated secondary copper minerals suitable for gemstone applications.

Secondary copper minerals are found mostly 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, make visually attractive polished stone tiles or spectacular natural specimens. Examples of more massive secondary copper minerals of this type can 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 (Fig. 21.7). 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. 21.5).

Bryah Basin

Peak Hill region

Degrussa copper mine (DOOLGUNNA, 2746)

The Degrussa copper–gold deposits are located about 10 km east of the Great Northern Highway, some 140 km north-northeast of Meekatharra (Fig. 21.1). They lie within the Bryah Basin, part of the Paleoproterozoic Capricorn Orogen that separates the Archean Yilgarn and Pilbara Cratons. The Degrussa deposits were discovered by Sandfire Resources NL in the northeastern part of Doolgunna mining lease M52/1046. Drilling established substantial resources of copper–gold comprising four lenses of high-grade mineralization extending over 6 km, with the prospect of more discoveries.

At the Degrussa openpit, base metal and gold mineralization is hosted by the Narracoota Volcanics. This 2 km-thick sequence of volcano-sedimentary rocks extends over a strike length of 22 km. The Narracoota Volcanics consists of basalts, hyaloclastites, sediments, dolerite, gabbro, and minor mineralized quartz–carbonate breccias, jasper, and banded iron-formation.

The Degrussa volcanic-hosted massive sulfide ores are present as massive lenses of primary pyrite, chalcopyrite, and pyrrhotite with minor magnetite, sphalerite, galena, and arsenopyrite. The primary mineralization has been oxidized and the near-surface supergene enrichment has formed a zone with native copper together with a siliceous cap containing gold. The cap overlies a layer of oxide, carbonate copper, and a supergene chalcocite blanket.

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Figure 21.7 Broken clasts of green secondary copper minerals exposed in a mullock heap at the old Butcher Bird mine. Yanneri Pool area, south of Newman

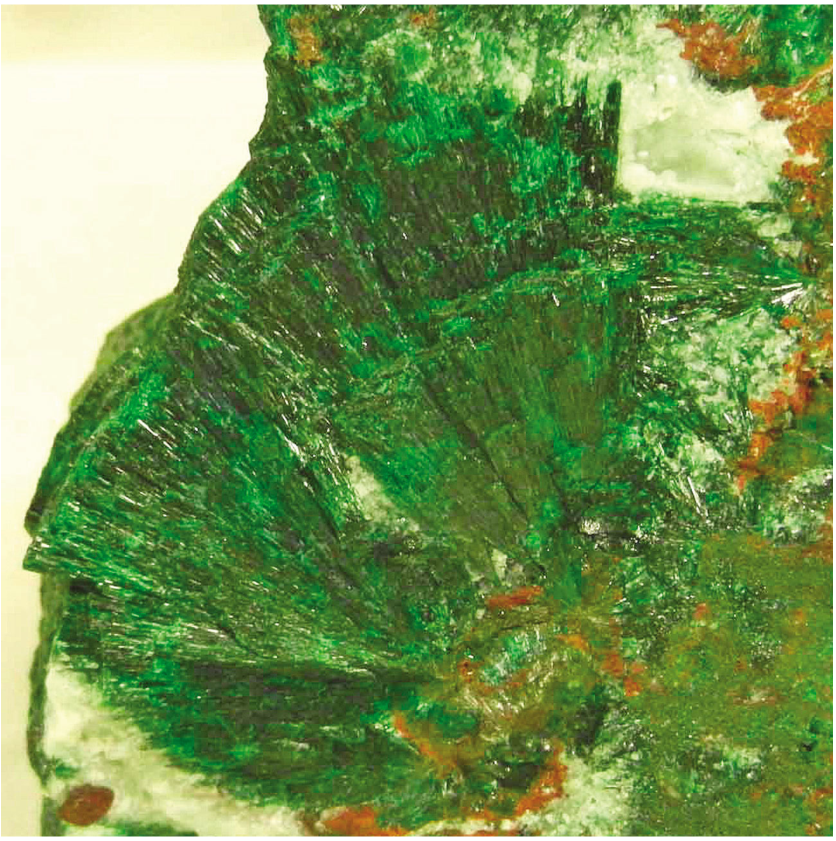

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Figure 21.8 Large, radiating masses of green, acicular crystalline clusters of malachite together with white calcite, Degrussa mine (courtesy Murray Thompson)

Large quantities of chrysocolla and malachite specimens have been sourced from the supergene zone by the company. Malachite is present as large, radiating masses of silky, acicular, crystalline clusters with similar specimens displaying narrow zones of azurite bordering the malachite (Fig. 21.8). At present, specimen material is not available to collectors but may prove a source of interest when the material is eventually released for sale.

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Chapter 22 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, sphene, grossular garnet, and scapolite.

Physical properties

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 ranges of optical and physical properties. Diopside itself 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.

Physical properties of diopside
(sourced from Yinnetharra)

Crystal system	Monoclinic
Habit	Prismatic
Colour range	Colourless, light to dark green
Colour cause	Green colour from 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
Specific gravity	3.32
Cleavage	Well-developed prismatic
Fluorescence	Inert
Absorption spectrum	Weak absorption band at ± 520 nm, general absorption at both red and violet spectral ends

Diopside
Calcium–magnesium silicate [$CaMg(SiO_3)_2$]

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 orientated patterns of exsolved iron minerals.

Applications

Diopside is used in jewellery as a green, faceted gem, particularly chromium diopside. Another variety of diopside is a dark green to black variety with its dark appearance caused by inclusions of exsolved magnetite grains. When cabochon cut, this type may display a four-ray star phenomenon. This material originates from India and is one of the few gems that is magnetic due to its magnetite inclusions.

Diopside in Western Australia

Simpson (1951) described the occurrence of 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 and commonly displaying schlieren-type 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.

Gascoyne Province

Yinnetharra area

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 situated on an isolated low hill, west of Thirty One River (Fig. 22.1).

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 that these were ultimately cemented within the silcrete.

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 but fractured, and measured 59 x 35 x 24 mm. Most crystals recovered had a length of about 20 mm.

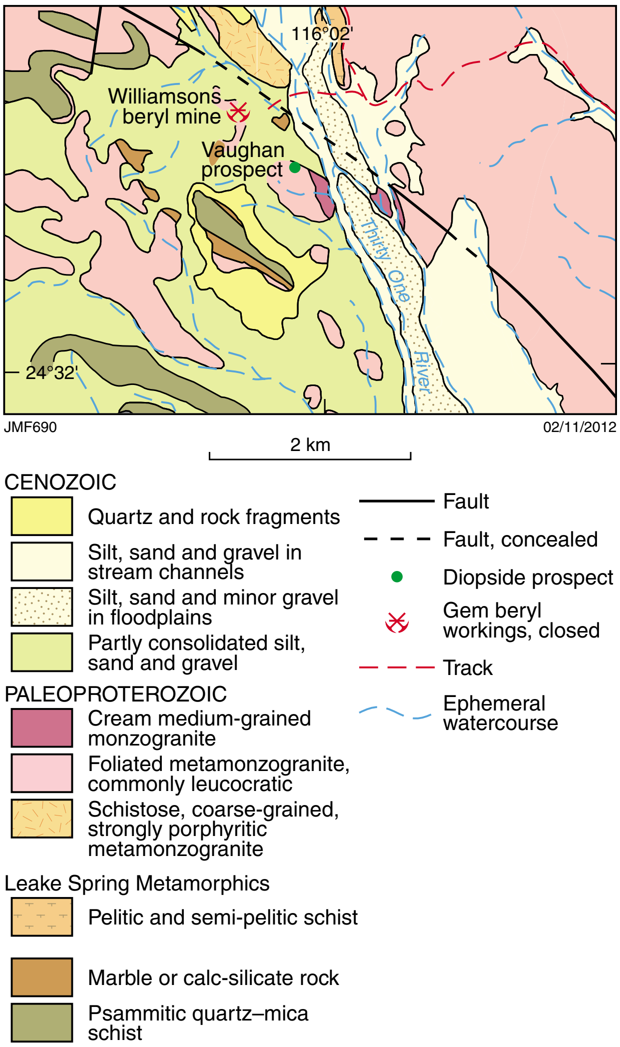

Figure 22.1 **Geology of the area around the Vaughan diopsite prospect, Yinnetharra area (modified after Sheppard et al., 2008)**

The operation yielded gem-quality rough crystals-in-matrix in excess of 100 ct and the transparent material was subsequently faceted (Fig. 22.2).

Figure 22.2 **Faceted, green diopside together with several rough diopside prisms from the Vaughan prospect. The gem is 6.21 ct and measures 14 x 8 mm (courtesy Gemrock Enterprises)**

Properties of the diopside from the Vaughan prospect are recorded in the highlight box above. It should be noted that the figures given for the range of refractive index and for specific gravity are at the higher end of established ranges and may indicate that this diopside contains some 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.

References

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Chapter 23 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, or brown, commonly appearing as contrasting coloured bands. Fluorite may occur as cubes or more rarely as octahedra and dodecahedra. It also occurs as massive and earthy forms, and as crusts or globular aggregates with radial fibrous texture (Fig. 23.1). Massive, banded blue, violet and purple fluorite from Derbyshire in England (Blue John) has been used for 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, celestite, sphalerite, chalcopyrite, other sulfides, and phosphates.

Under ultraviolet light, some fluorite varieties fluoresce in shades of yellow, green, blue, and violet. 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 due to inclusions of organic material.

Fluorite cleaves readily but cleavage surfaces are rarely perfect. They are marked by terracing that 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 used as a bead material and carved as small items (Fig. 23.2). As with calcite, fluorite is cut mainly for collectors.

Physical properties of fluorite

Crystal system	Isometric (cubic)
Habit	Cubic, octahedral, and massive
Colour range	Colourless, blue, green, pink, violet, commonly as banded colours
Lustre	Subvitreous, less commonly dull
Diaphaneity	Transparent to translucent
Refractive index	1.43 – 1.44
Hardness	4 (the standard on Mohs scale)
Specific gravity	3.0 – 3.2
Cleavage	Perfect octahedral in four directions, easily developed
Fracture	Irregular and conchoidal
Fluorescence	Commonly shows a blue or green response under long wave UV, and a weaker glow under short wave UV; some fluorite is inert

Fluorite
Calcium fluoride (CaF_2)

Figure 23.1 **Various forms of fluorite: a) a transparent, colourless mass of euhedral, cubic crystals up to 10 x 10 mm; b) a massive form displaying contrasting purple and pale greenish bands. Specimen is 5 cm wide**

Figure 23.2 **A bunch of grapes carved from colour-banded fluorite**

Environments of deposition

Fluorite occurs in a wide variety of geological environments with significant concentrations in areas of gravity lows and high heat flow. Abeysinghe and Fetherston (1997) recorded the following 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). A map showing the distribution of these deposits is shown in Figure 23.3. Some of the more significant deposits are discussed below and their locations 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 in the Archean Shaw River batholith area (Fig. 23.3). 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 the most common.

Nullagine region

Cookes creek (Nullagine, 2954)

The Cookes Creek fluorite prospect is located some 45 km east-northeast of Nullagine (Fig. 23.3). Fluorite veins are found in mafic and granitic rocks immediately east of Cookes Creek at a point approximately 3.5 km south-southeast of its confluence with the Nullagine River. The Nullagine 1:100 000 geological map (Bagas et al., 2004), indicates that the deposit lies in basalts immediately south of the Cookes Creek Monzogranite. At the prospect, fluorite is associated with tungsten minerals such as scheelite and wolframite.

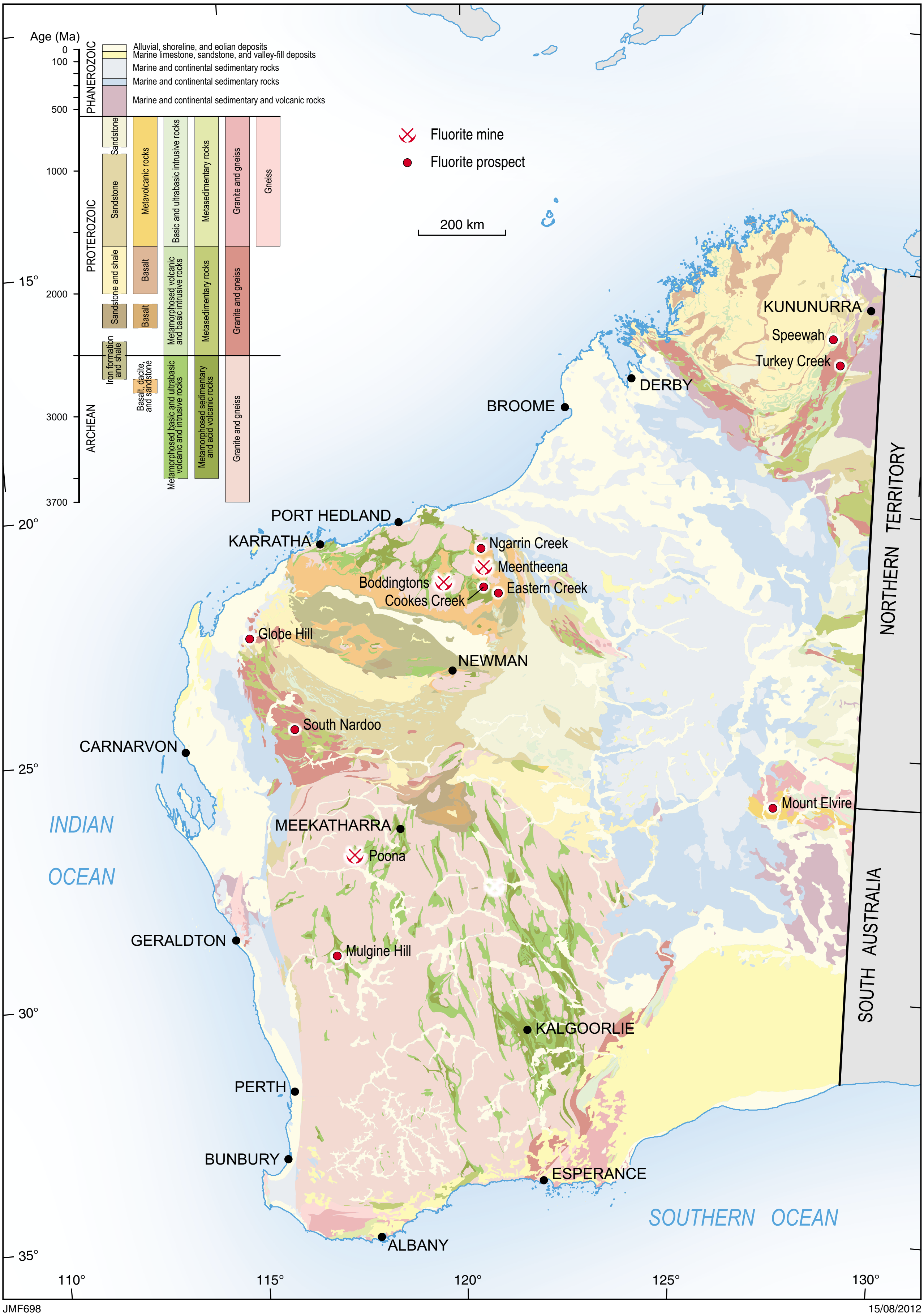

Figure 23.3 Location of fluorite mines and prospects in Western Australia

Meentheena (*Mount Edgar, 2955*)

The Meentheena fluorite deposit is situated on the Nullagine River, 75 km north-northeast of Nullagine, and about 6 km north-northeast of the abandoned Meentheena Homestead (Fig. 23.3). 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 thence south towards the old Meentheena 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 sediments 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 060º and 130º. Veins may reach 5 m in width and 1.6 km in length (Fig. 23.4). 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. Athough 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 located at Ngarrin Creek approximately 27 km south-southwest of Callawa Homestead (Fig. 23.3). At this site, fluorite occurs 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 to be 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 with phenocrysts 3 mm in diameter, which contain microcrystalline fluorite. This rock type occurs 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. 23.3). 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 from colourless to almost transparent milky-white, as well as less translucent, pale to deep amber-yellow, light brown, bottle-green, and lavender to dark violet varieties.

Kimberley Basin

Dunham River area

Speewah (*Dunham River, 4565*)

The Speewah fluorite prospects are located approximately 45 km west-southwest of Dunham River Homestead (Fig. 23.3).

The largest fluorite deposit in Western Australia is located at Speewah in the Kimberley Basin. The Speewah Valley lies within the Kimberley Basin close to the western edge

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Figure 23.4 Veins of purple fluorite crosscutting white quartz veins at Meentheena prospect (after Abeysinghe and Fetherston, 1997)

of the Halls Creek Orogen. The valley is incised into the Hart Dolerite, which occupies the core of the Speewah Dome. This north-trending structure is 32 km long by 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 but the most significant fluorite mineralization is confined to four areas: Main Zone, West Zone, Northwest Zone and Central Zone, which lie to the northeast, northwest, north-northwest, and north respectively of the abandoned Speewah Homestead (Fig. 23.5).

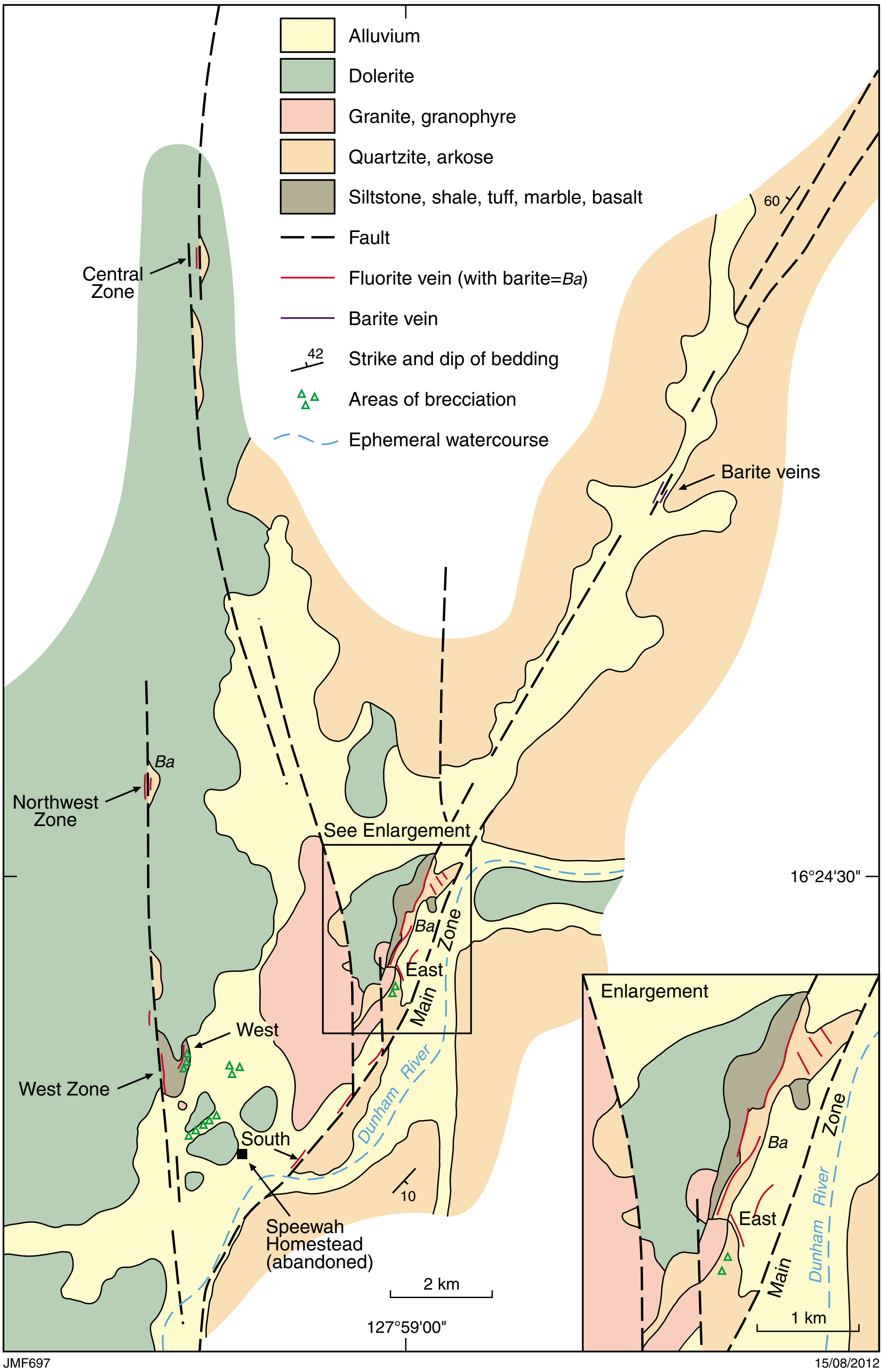

Figure 23.5 Geological sketch map of the Speewah area showing zones of fluorite and barite mineralization (modified after Abeysinghe and Fetherston, 1997)

Fluorite mineralization at Speewah comprises narrow, tabular, near-vertical veins that are present mostly in shear zones of variable width that are locally flanked by green, chloritically altered, lower grade material in stockworks and stringer veins. When fresh, the fluorite is grey or white, but weathers to pale green. Veins consist mainly of fluorite (20–80% in tabular veins), with quartz and local 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. 23.3). Specimens are coarsely crystalline, highly translucent, colourless, white, and various green tints including pale emerald. The fluorite is associated with small quantities of galena and quartz.

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 35 km west-southwest of the Nanutarra roadhouse (Fig. 23.3). The pegmatite contains 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, occur in felsitized acid volcanics of the Scamp volcanic association (Fig. 23.3).

Gascoyne Province

Yinnetharra area

South Nardoo prospect (YINNETHARRA, 2148)

Veins of fluorite over 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. 23.3). At this locality, fluorite is associated with galena, various copper minerals and orpiment in a quartz gangue. The mineralization is thought to be associated with the pegmatite phase of a Mesoproterozoic granite.

Yilgarn Craton — Murchison Terrane

Cue region

Poona (NOONDIE, 2343; CUE, 2443)

This fluorite prospect is located in the Poona emerald field, 55 km northwest of Cue (Fig. 23.3). 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 reaching 3 cm in diameter is associated with a pegmatite containing quartz, green beryl, and potassic oligoclase feldspar.

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. 23.3). 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 titanate.

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Chapter 24 Garnet group

Garnet group minerals

Garnet is the name given to a large group of minerals. Member species are defined by differences in their chemistry within the same basic formula, $A_3 B_2 (SiO_4)_3$, with Ca, Mg, Fe^{2+} or Mn^{2+} substituting in the A position, and Al, Fe^{3+}, Mn^{3+}, V^{3+} or Cr^{3+} in the B position.

The majority of the 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; andradite, grossular, and uvarovite are the end members of a second series.

Minor chemical changes between 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, termed hibschite) found in zones of metasomatized anorthosite and used as a green or pink ornamental rock best known as 'Transvaal jade'.

All garnet group minerals are isometric in form and commonly occur as euhedral (well-formed) crystals that are typically rhombic dodecahedra (12-sided crystals with each face rhomboid), trapezohedra (24-sided crystals with each face a trapezium) or combinations of these two forms (Fig. 24.1).

As a result of their variations in chemistry, garnets exhibit a wide range of constants and colours (see below). Garnets are sufficiently hard (approximately 7 on Mohs scale) to be eminently suitable for use as gems in jewellery. Their eligibility as gems is further enhanced by the absence of cleavage.

Garnet species of all types are of gemmological interest when 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, numerous intermediate species and encompasses a range of colours that includes red, orange, purple, black, yellow, brown, green, blue, colourless, and colour-change varieties.

Garnet group
Almandine, common red garnet $[Fe_3Al_2(SiO_4)_3]$

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Figure 24.1 **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)**

Almandine and spessartine garnets most commonly occur in gneisses, schists, and some granitic pegmatites. Pyrope is restricted to ultramafic rocks and grossular garnets are characteristically formed in calc-silicates and skarns. Andradite garnet can be found in 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 and is encountered in jewellery mostly 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 accordingly been termed 'Bohemian' garnet.

Garnet group minerals

Mineral	*Chemistry*	*RI*	*SG*	*Colour*	*Host rocks*
Almandine	$Fe_3\ Al_2\ (SiO_4)_3$	1.83	4.31	Red, violet-red, black	Igneous and metamorphic rocks (granites, schists, and gneisses)
Andradite	$Ca_3\ Fe_2\ (SiO_4)_3$	1.88	3.85	Green, brown, yellow, black	Metamorphosed ultramafic rocks and calc-silicates
Grossular	$Ca_3\ Al_2\ (SiO_4)_3$	1.73	3.59	Pink, green, colourless, yellow	Metamorphosed calc-silicates
Pyrope	$Mg_3\ Al_2\ (SiO_4)_3$	1.71	3.58	Red, purple-red	Ultramafic rocks (peridotite, kimberlite)
Spessartine	$Mn_3\ Al_2\ (SiO_4)_3$	1.80	4.19	Orange, orange-red, brown	Calc-silicates, granite pegmatites
Uvarovite	$Ca_3\ Cr_2\ (SiO_4)_3$	1.86	3.90	Bright green	Serpentinite and skarns
Hydrogrossular	$Ca_3\ Al_2\ (SiO_3OH)_3$	1.73	3.13	Green, pink, grey	Metasomatized anorthosite

The most valuable garnet is demantoid, a chromiferous bright green andradite. Demantoid was originally discovered in the Urals and the finest gems still originate from this source even though some are found in other countries, including Namibia.

Gem garnets are mined in many countries from alluvial gravels, although garnet sands are worked as a source of industrial garnet.

Garnets in Western Australia

In Western Australia, almandine garnet is mined from Pleistocene shoreline placer deposits at Port Gregory on the Hutt 1:100 000 map sheet (1741). The source of these garnet sands is the Proproterozoic Northampton Inlier.

Garnets are a feature of ornamental dimension stone, including gneisses, syenites, granites, and quartz monzonites. Garnets occurring 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 (Fetherston, 2010; Fig. 24.2).

Specimens of some large garnet crystals are in the collection of the Western Australian Museum; however, there are no records of facet-grade garnet in Western Australia.

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Figure 24.2 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

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. 24.3).

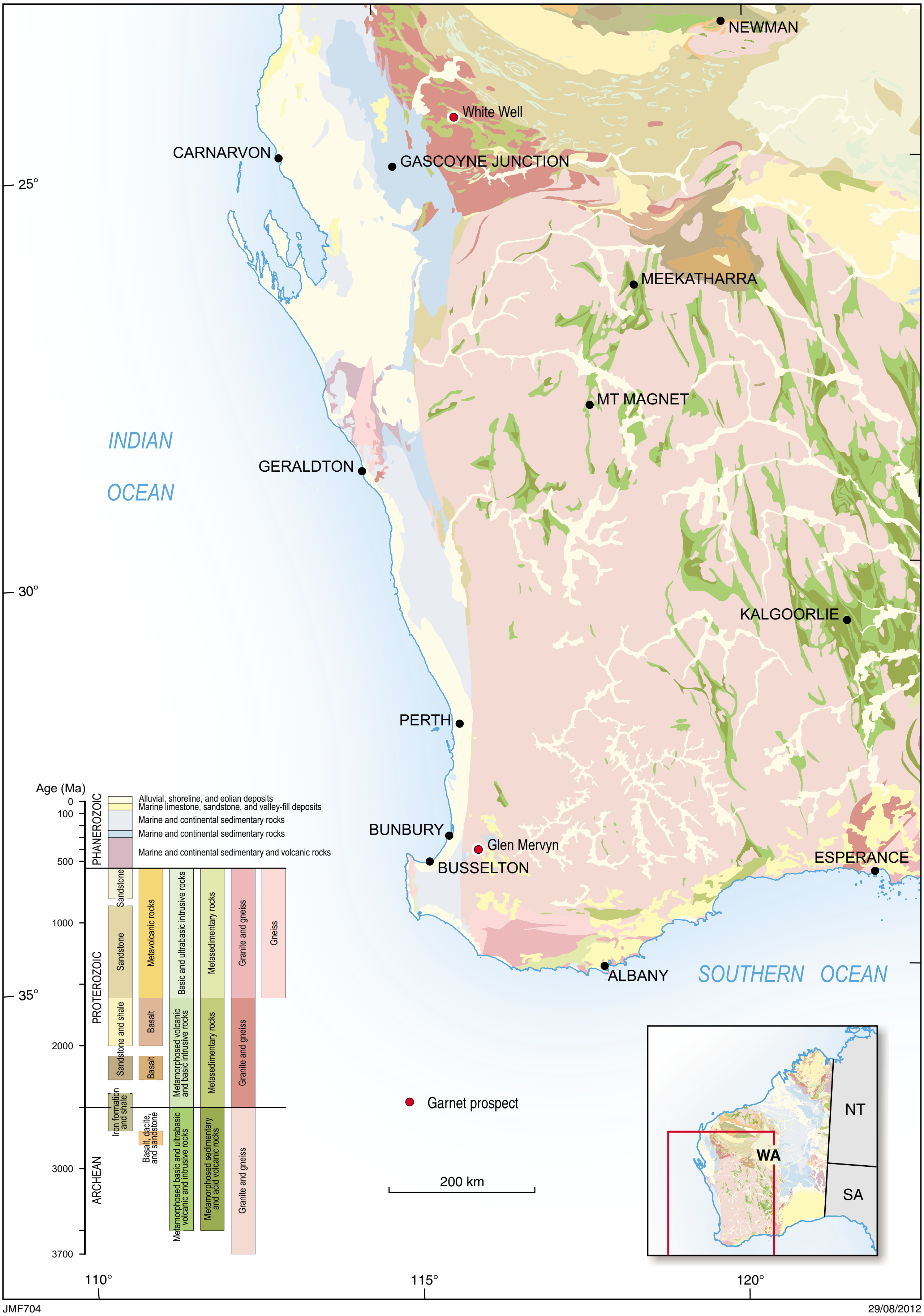

Figure 24.3 Location of garnet prospects in Western Australia

Lake King region *(King, 2831)*

Simpson (1952) records some fine specimens of crystallized dodecahedra and trapezohedra garnet up to 50 mm in diameter. They are reportedly dark brown and feebly translucent. Although the location of the garnet prospect is unknown, it may possibly be within the gneissic terrain located 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. 24.4). The approximate location is between White Well and Morrissey Creek on Mount Phillips Station, 30 km north-northeast of Yinnetharra (Fig. 24.3).

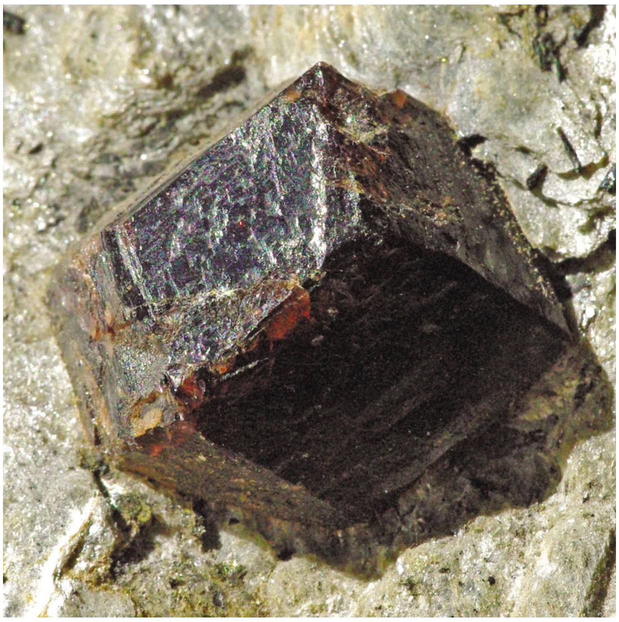

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Figure 24.4 Garnet dodecahedron in mica schist from Yinnetharra. Crystal is 10 mm in diameter. (courtesy David Vaughan)

References

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.

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Chapter 25 Gaspeite

Occurrence and physical 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 generally 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 occurs as 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. 25.1). 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. 25.2). 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 associated mainly with Archean rocks including volcanic peridotites, intrusive dunites, and various gabbroic rocks. Gaspeite has been recorded from a number of 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 25.3 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 to apple-green
Colour cause	Green colour from 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
Composition	Isomorphous with magnesite

Gaspeite deposits 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, located 5 km northwest of the small town of Widgiemooltha, 80 km south of Kalgoorlie on the Coolgardie to Esperance Highway (Figs 25.3 and 25.4).

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. Also, other rare nickel minerals from this mine are described in Nickel et al. (1994).

Figure 25.1 **Massive veins of bright green gaspeite within nickeliferous ore (courtesy Glenn Archer)**

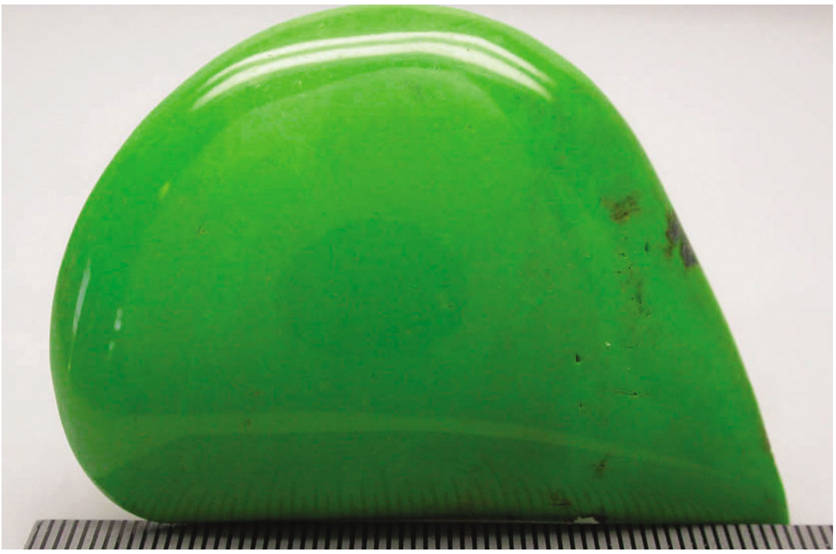

Figure 25.2 **A highly polished cabochon of bright apple-green gaspeite from Western Australia**

Gaspeite from Widgiemooltha is associated with talc-carbonated komatiite associated with nickel sulfide gossan and was probably formed by the substitution of nickel into carbonates such as magnesite. Nickel et al. (1994) describes the occurrence of 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 a range of nickel oxide (NiO) values from 34.9 to 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

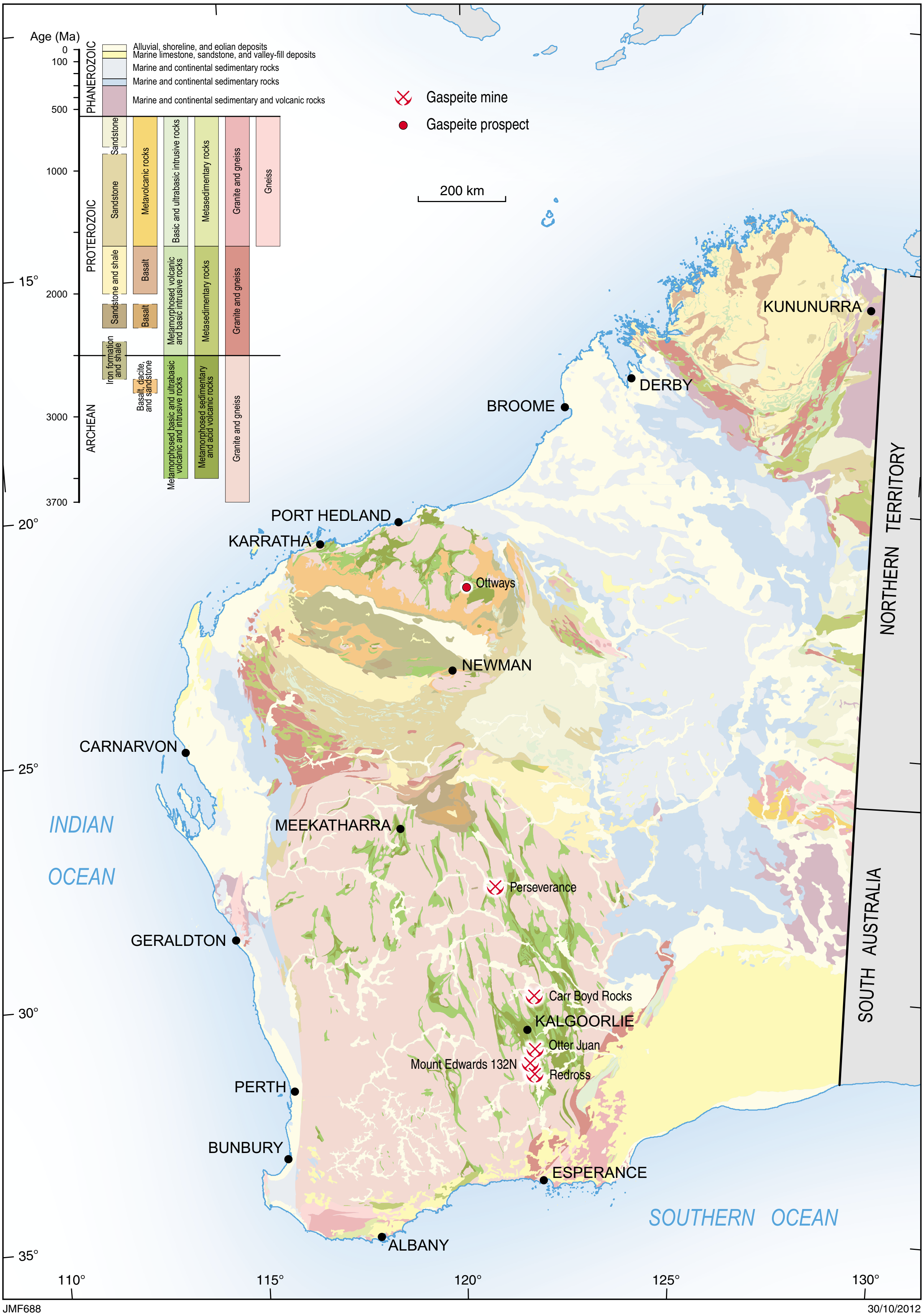

Figure 25.3 Location of gaspeite sites in Western Australia

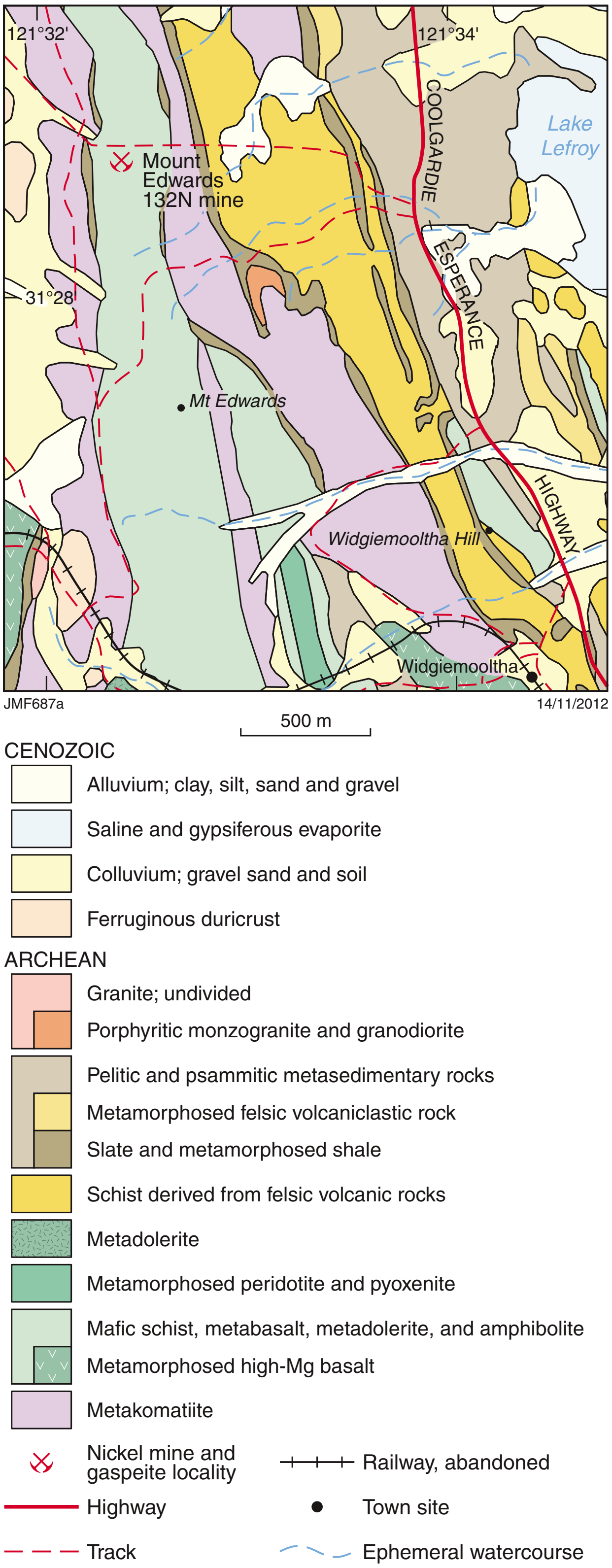

Figure 25.4 Geological map of the area around the gaspeite site at the Mount Edwards 132N nickel mine (modified after Griffin and Hickman, 1988)

a result, a large quantity of 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.

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. 25.3).

Other gaspeite sites in Western Australia

Gaspeite has also been recorded at a number of other nickel mines and prospects in the Eastern Goldfields Superterrane and Pilbara Terrane (Fig. 25.3).

Yilgarn Craton — Eastern Goldfields Superterrane

- Redross mine, 20 km south-southeast of Widgiemooltha (Cowan, 3234)
- Carr Boyd Rocks mine, 51 km northeast of Broad Arrow (Gindalbie, 3237)
- Perseverance mine, 11 km north of Leinster (Sir Samuel, 3042).

Pilbara Craton

- Ottways prospect, 26 km north of Nullagine (Nullagine, 2954).

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Chapter 26 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-formation (BIF) units, located in the Archean–Paleoproterozoic Hamersley Basin, and to a lesser degree in the Archean Yilgarn and Pilbara Cratons. The BIFs, 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 lava. The best-developed BIF units are situated in the Hamersley Basin where they cover an area of approximately 75 000 km^2. Smaller, linear BIF occurrences 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, iron oxide from these enrichment deposits is the source of gem material such as highly polished, blue-black to jet-black hematite. Enriched hematite may also be altered through metasomatic processes into specularite, which has been utilized as an attractive ornamental material.

Within BIF units chert bands are mostly pale coloured, but in some areas they may contain minute, hematite inclusions that colour the stone blood-red and are referred to as 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 utilized 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 26.1 and listed in 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. 26.1). Physical properties of hematite are listed below.

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
Fracture	Subconchoidal to uneven
Specific gravity	4.9 – 5.3
Cleavage	None

Hematite may be cut and polished into a lustrous blue-black to jet-black gemstone that is particularly attractive in silver settings (Fig. 26.2). Despite the fact that 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 complex of iron and other oxides to yield an opaque black mass that displays a silvery metallic lustre on polished

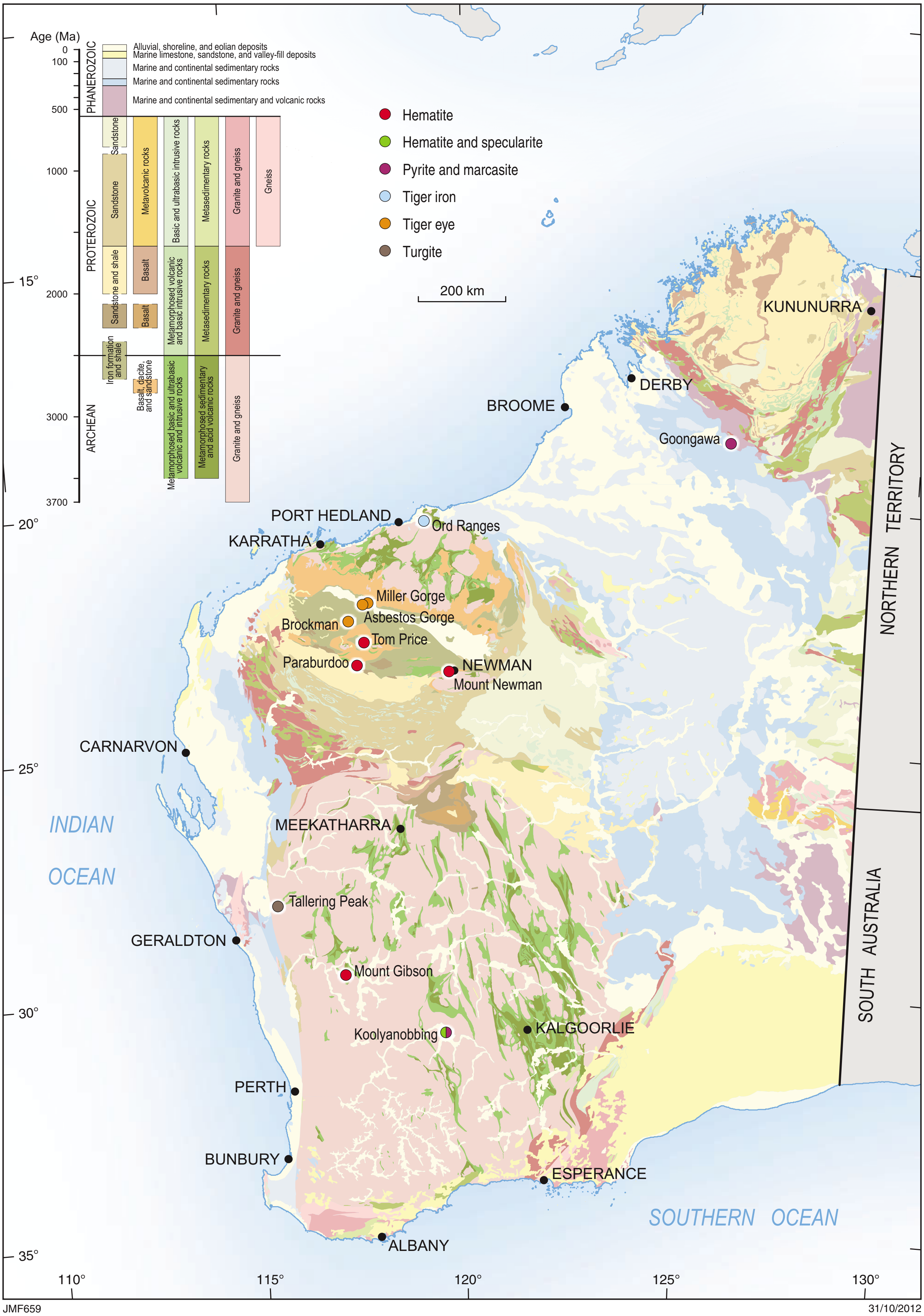

Figure 26.1 Location of iron-rich gemstones in Western Australia

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 composed of hematine.

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Figure 26.2 Polished, black hematite bead necklaces (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 generally small and commonly occur as bands in more massive forms of hematite, they can also be relatively large (to a maximum of 15 cm in length). Large crystals can be cut and polished to make attractive ornamental pieces such as bookends (Fig. 26.3).

Yilgarn Craton — Southern Cross Domain

Southern Cross region

Koolyanobbing *(Seabrook, 2836)*

Impressive specularite crystals can be obtained from iron ore mines around Koolyanobbing town site, located about 50 km north-northeast of Southern Cross (Fig. 26.1).

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. 26.4). Originally described from the Ural Mountains in Russia, it is also found in Western Australia at the T6 Pit, part of the Tallering Peak iron ore mine to the east of Geraldton and about 50 km north-northeast of Mullewa.

Specimens of turgite show bright and varicoloured iridescence and are collected for display only, as polishing would remove the iridescent film (C Bosel, 2012, written comm.; Fig. 26.1).

Pyrite and marcasite

Pyrite, or iron pyrites, is probably the most common of all

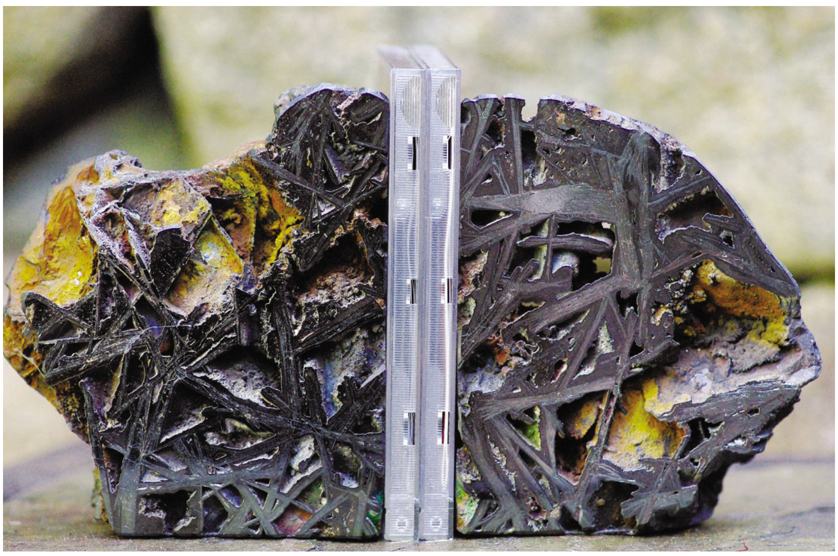

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Figure 26.3 A pair of specularite bookends made from material sourced from the Koolyanobbing iron ore mine

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Figure 26.4 **Turgite, an iridescent mixture of hematite and goethite from Tallering Peak iron ore mine, north of Mullewa (courtesy C Bosel)**

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. 26.5). Pyrite also occurs as massive, reniform, and nodular forms. When fresh, it is a pale yellow, brassy mineral that bears 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'.

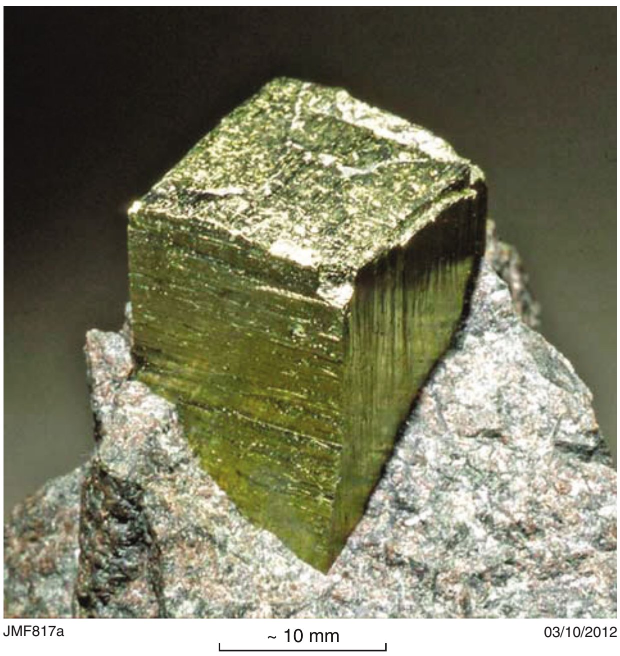

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Figure 26.5 **A brassy-yellow, cubic form of pyrite developed within original host rock. The pyrite clearly shows striated crystal faces. Sourced from the Dampier area (courtesy Western Australian Museum)**

Marcasite, sometimes called white iron pyrite, is iron sulfide with an orthorhombic crystal structure and is physically and crystallographically distinct from pyrite. It is paler and more brittle than pyrite. On fresh surfaces marcasite is pale yellow to almost white, tarnishes to a yellowish or brownish colour, and has a black streak.

Pyrite is used commercially both in the production of sulfur dioxide for use in the paper industry and in the manufacture of sulfuric acid. When exposed to air and water pyrite decomposes into iron oxides and sulfate, with reactions occurring more rapidly when the pyrite is in the form of fine crystals or dust-sized particles. The sulfate released from decomposing pyrite combines with water to yield sulfuric acid, which may produce acid groundwater.

In jewellery manufacture, pyrite is termed marcasite, and so-called 'marcasite' jewellery is actually set with cut pieces of pyrite. Pyrite has been used for ornament since prehistory, early evidence of which are the pyrite beads found in ancient Egypt, but the widespread decorative use of pyrite in jewellery is more recent and dates back to mid-18th century Europe. Diamond jewellery was in high demand at that time and the main attraction of faceted pyrite was its use as a simulant for diamond. The 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, as well as pyritized fossils, especially ammonites.

Pyrite and marcasite in Western Australia

Pyrite and marcasite are widely distributed throughout Western Australia and Simpson (1952) devotes over 35 pages to pyrite occurrences. This reference should be consulted if necessary as 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 to be 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 occurs together 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, silver deposit (Figs 26.1 and 26.6).
- Banded iron-formations. Massive pyrite is often found in association with iron oxides in BIFs throughout the Yilgarn Craton. For example, at Koolynobbing in the Southern Cross Domain pyrite was evaluated as a potential source of sulfur (Fig. 26.1).
- 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. 26.7).
- Pyritic replacement of organic material, including coal, in a reducing environment.

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

Tiger eye

Tiger eye is golden-brown, chatoyant, silicified crocidolite with the fibres perfectly preserved to a compact mass with hardness between 6.5 and 7. The mineral exhibits a constantly changing pattern of reflected light as a result of its fibrous nature (Mayer, 1976). Consequently, carefully cut cabochons exhibit silky lustre and spectacular cats eye effects. In the 19th century, Griquatown and Niekershoop

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Figure 26.6 Large, tabular, pale brassy masses of marcasite together with white calcite aggregates. Goongawa lead, zinc and silver mine, 60 km south-southeast of Fitzroy Crossing in the southern Kimberley region (courtesy Western Australian Museum)

Figure 26.7 Pyrite sphere formed within the Mount McRae Shale, Millstream area, Hamersley Basin (courtesy Mark Rheinberger)

in South Africa were the principal sources of tiger eye that 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.

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. 26.8).

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 referred to as '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.

It should be noted that in the literature 'tiger eye' (the current, preferred spelling of the golden-brown variety) has been spelled in a number of 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

Figure 26.8 Silicification and oxidation of blue crocidolite (at top) to yellow tiger eye (beneath)

converts contained limonite to hematite and the resultant red material is referred to as 'bull's eye'.

While 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 tiger eye opal) from Yarra Yarra Creek and from Lionel mining area indicate that the material in these deposits is composed of silicified chrysotile and is discussed in Chapter 13 under 'Cats eye and siliciophite'.

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 is made up of 2–20 bands of crocidolite fibres that comprise between a quarter and half the thickness (Trendall and Blockley, 1970). Tiger eye localities in the State are shown in Figure 26.1.

Prospectors and fossickers should note that crocidolite is an asbestiform mineral with serious personal health risks associated with breathing the dust. Accordingly, crocidolite outcrops, prospects, disused mines, stockpiles, and tailings dumps should be avoided.

Although silicified tiger eye is not considered to be 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 this asbestiform mineral.

Pilbara Craton — Hamersley Basin

Mount Brockman area

Brockman tiger eye (Jeerinah, 2353)

The Brockman tiger eye prospect is located 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 thence southward along rough station tracks. The prospect is located within the Archean–Paleoproterozoic Marra Mamba Formation, which comprises chert, BIF, and pelitic rocks (Fig. 26.9).

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 (Fig. 26.10a). The boulder was removed by heavy machinery and transported to Perth for cutting into thick slabs approximately 3.5 m in length by 0.5 m in height, and the costean backfilled and rehabilitated.

Polishing of this visually attractive rock revealed its truly spectacular structure comprising multiple bands of green, blue, red, and orange jasper interspersed with extensive bands and large, triangular-shaped blebs of golden-brown tiger eye (Fig. 26.10b). 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).

Mount Margaret area

Miller and Asbestos Gorges (Mount Billroth, 2454)

Kriewaldt and Ryan (1967) reported poor-quality tiger eye in the Brockman Iron Formation within the Pyramid 1:250 000 map sheet (SF 50-7). More recently, Smithies and Hickman (2004) recorded two occurrences of crocidolite at Miller and Asbestos Gorges, approximately 1.5 km north and 5 km west-southwest respectively of Mount Margaret some 80 km north of Tom Price (Fig. 26.1). It is probable that the tiger eye reported in 1967 is present at one or more of these localities.

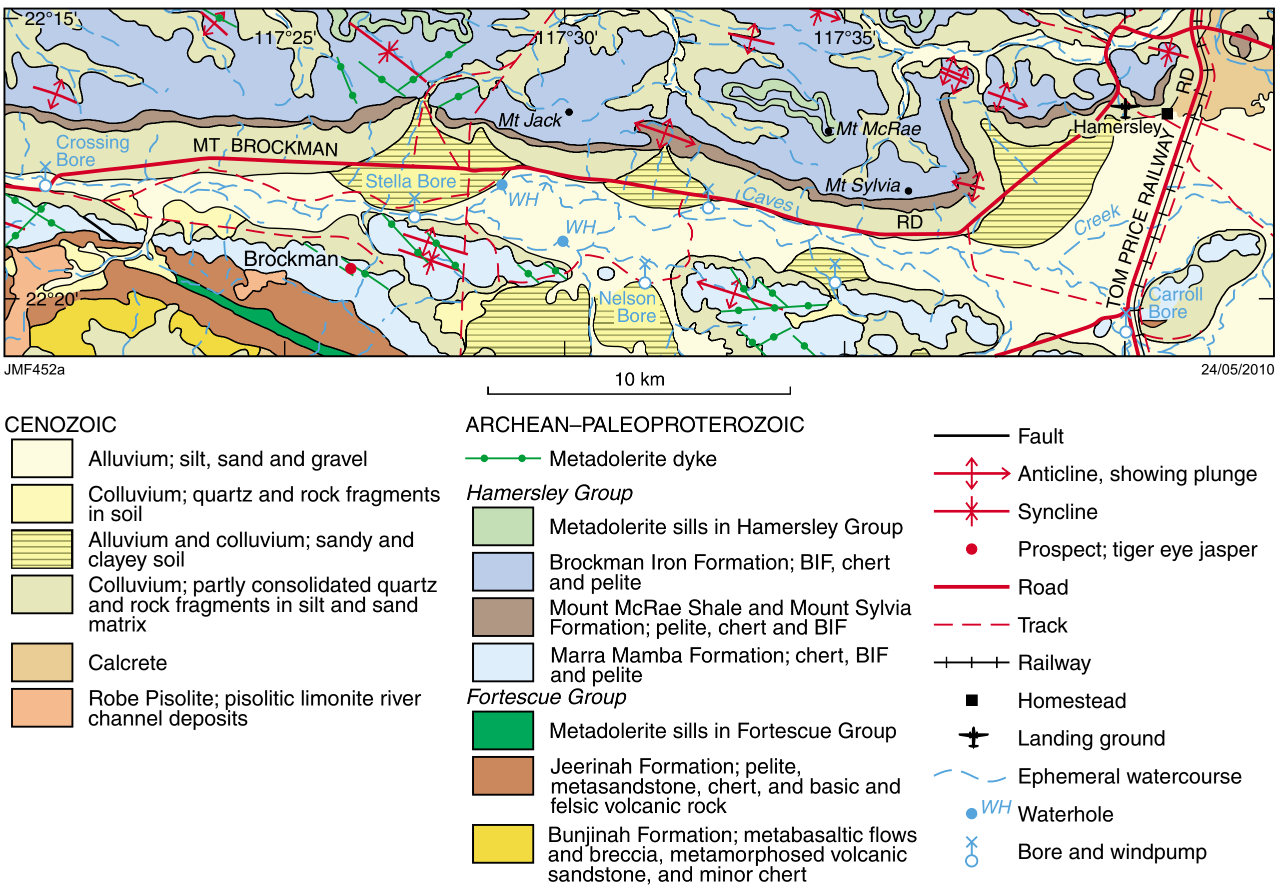

Figure 26.9 **Geology of the Mount Brockman area (modified after Blight et al., 1996)**

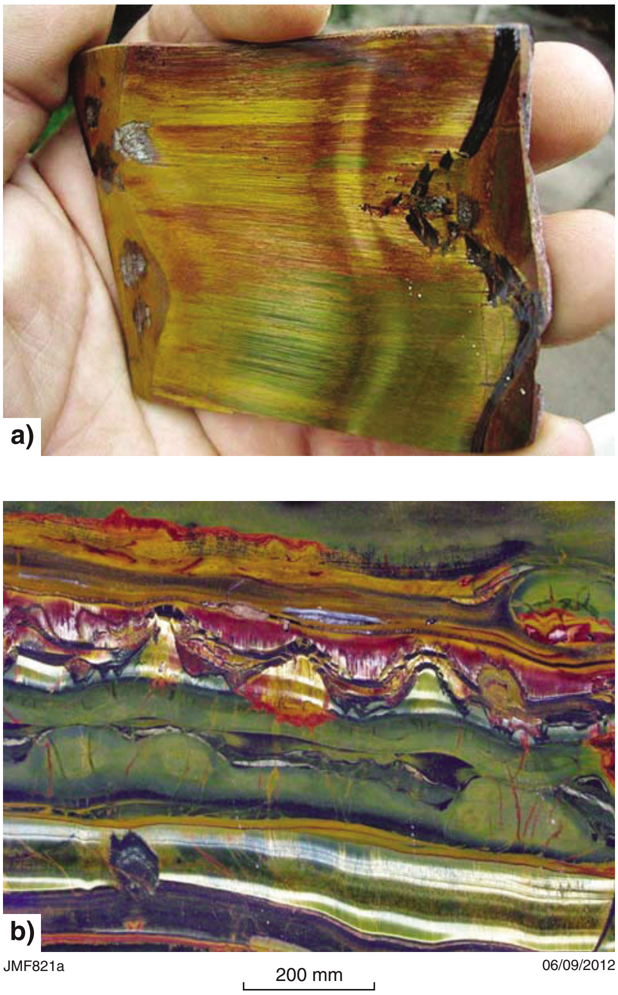

Figure 26.10 Brockman tiger eye from the Mount Brockman area, Hamersley Basin: a) detail of a small polished slab of Brockman tiger eye clearly showing the silicified crocidolite fibres (courtesy Glenn Archer); b) polished section of a large slab of Brockman tiger eye. The section shows bands and triangular blebs of golden-brown tiger eye interspersed with multiple bands of green, blue, red, and orange jasper

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.

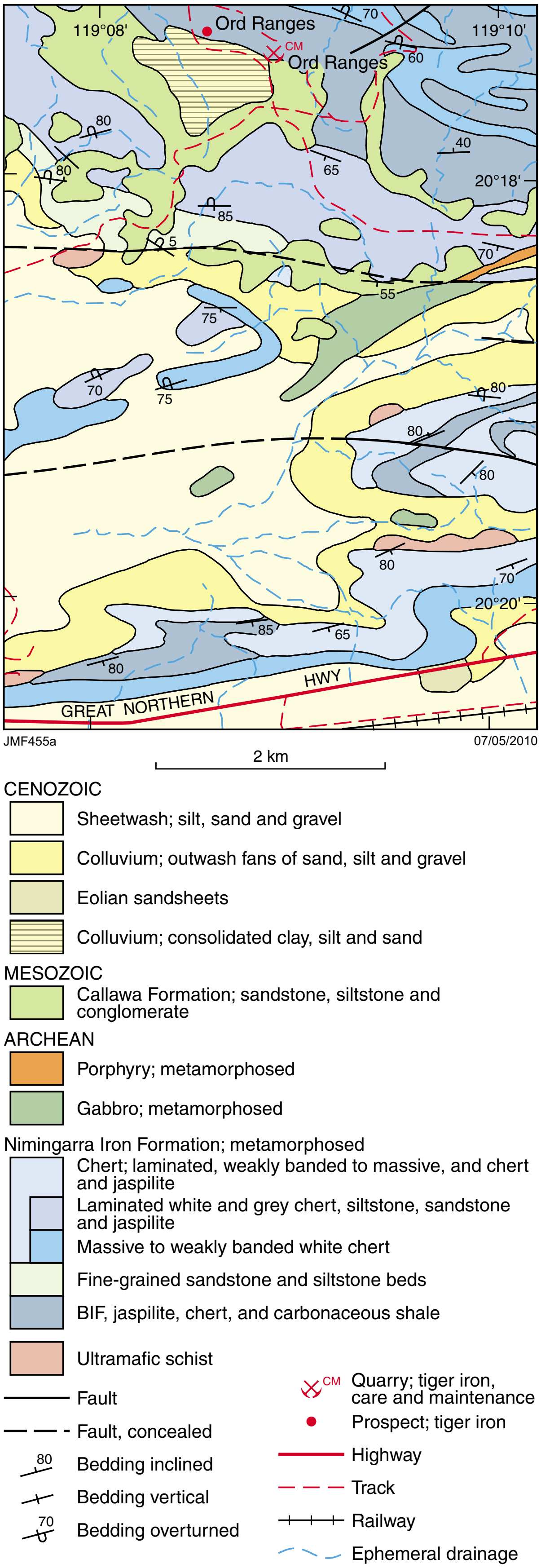

Figure 26.11 Geology around the Ord Ranges tiger iron quarry and prospect (modified after Smithies, 2002)

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Figure 26.12 A pair of polished tiger iron book-ends showing folded bands of hematite, cherty quartz, and golden-brown tiger eye (courtesy Barry Kayes)

Pilbara Craton

De Grey River region

Ord Ranges (*De Grey, 2757*)

The Ord Ranges tiger iron deposits are located about 60 km east of Port Hedland and immediately west of the north-flowing De Grey River (Fig. 26.1). In this area, tiger iron deposits are present within a highly folded BIF, jaspilite, chert, and shale unit within the metamorphosed Archean Nimingarra Iron Formation (Fig. 26.11). In past years, tiger iron has been mined intermittently from this site.

The ornamental tiger iron, shown in Figure 26.12, 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, table tops and in a diverse range of ornaments (Fetherston, 2010).

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Chapter 27 Prehnite

Prehnite is recorded as the first eponymous mineral, being named in 1790 after Colonel Von Prehn, who served in the Cape of Good Hope (South Africa).

Occurrence and properties

Prehnite is a common hydrothermal mineral found in cavities in igneous rocks, particularly basalts, and commonly occurs 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 its structure. It is usually green or yellowish green with a waxy to vitreous lustre but may also be colourless, white, bluish green, yellow, brown and, rarely, orange. It is mostly translucent but rare transparent forms may be found.

Since prehnite occurs naturally in a massive form, refractive index tests are usually 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 moderately tough property (Fig. 27.1).

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, brown
Lustre	Waxy, pearly, and vitreous
Diaphaneity	Translucent to semitransparent
Refractive index	1.616 – 1.649
Birefringence	0.022 – 0.033
Pleochroism	Nil
Hardness	6 – 6.5
Specific gravity	2.80 – 2.95
Cleavage	Good

Prehnite
Hydrated calcium aluminium silicate $Ca_2Al_2Si_3O_{10}(OH)_2$

Figure 27.1 **Detail of globular prehnite showing its fibrous, radiating texture (courtesy Barry Kayes)**

Applications for prehnite

Since the early 1990s, prehnite has been supplied to international markets from sources in western Mali in West Africa, and has been used in the manufacture of beads and carvings as well as mineralogical specimens. Attractive specimen material may feature spherical aggregates of prehnite together with epidote. Prehnite may also be accompanied by andradite garnet and vesuvianite sourced from zones of dolomitic marble and calc-silicates.

Prehnite is a relatively common material available to local lapidaries. Owing to its translucent to semitransparent diaphaneity, prehnite may be faceted. However, it is more usually cut as cabochons, or used as a bead material, and is often displayed in these forms at local gem fairs (Fig. 27.2).

Because of its pale green colour, prehnite appears similar to bowenite (a serpentine mineral) and both minerals are used as imitants of jade. For example, at Wave Hill in the Northern Territory, yellow to yellow-green prehnite is mined from basaltic lava in the Antrim Plateau Volcanics, and after carving and polishing is marketed under the name 'SunJade'® (Openallday, 2012).

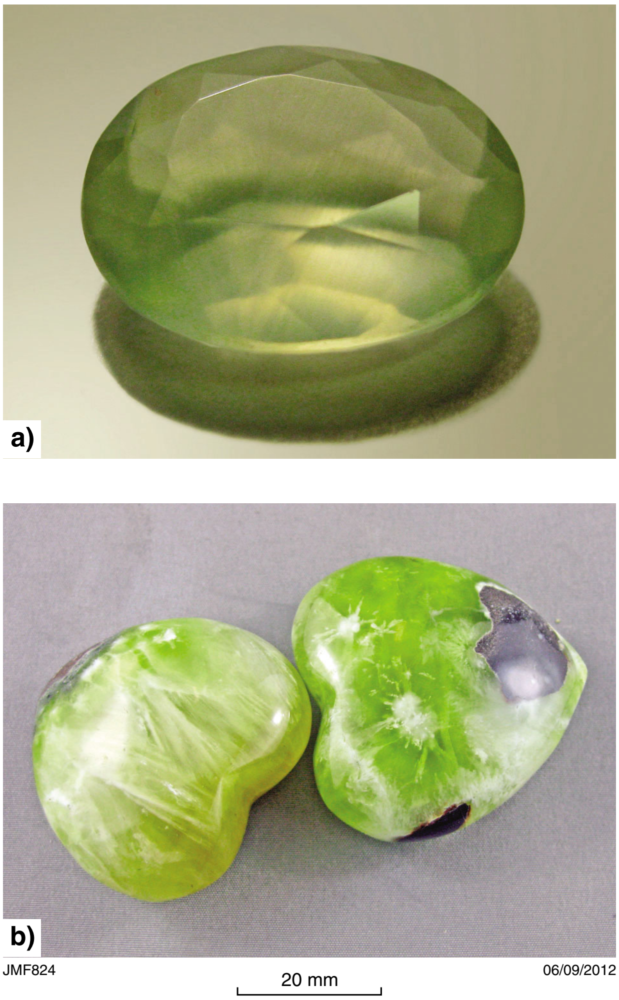

Figure 27.2 **Prehnite applications: a) 4 ct, faceted stone exhibiting prehnite's typical milky translucency, sourced from the Kimberley region (courtesy WA Branch, Gemmological Association of Australia; b) mid-green prehnite cut and polished as decorative hearts. Flora Valley prehnite prospect area, east Kimberley region (courtesy Barry Kayes)**

Prehnite in Western Australia

Most prehnite marketed in Western Australia comes from the Antrim Plateau Volcanics in the east Kimberley region of the State. It is also recorded in pegmatites, accompanying copper minerals, and associated with calcite and gypsum in some gold veins (Simpson, 1952). The Western Australian School of Mines Museum in Kalgoorlie features a specimen of quartz and prehnite from the Londonderry pegmatite south of Coolgardie.

In Western Australia it is associated mainly with the Antrim Plateau Volcanics, which covers large areas that extend over 400 km along the State border in the east Kimberley region.

The Lower Cambrian Antrim Plateau Volcanics is Australia's largest Phanerozoic flood-basalt province and outcrops extensively in the east Kimberley region of Western Australia as well as the Victoria and Daly River basin areas of the Northern Territory. The present area of exposure covers about 35 000 km^2 but there is evidence that the field extends as far eastwards as the Northern Territory – Queensland State border. Outliers of these lavas are also found west of Halls Creek, which suggests that the Antrim Plateau volcanic field occupied an original area of up to 400 000 km^2 (Pirajno, 2000).

The Antrim Plateau Volcanics is predominantly tholeiitic basalt that shows a remarkably uniform chemistry. This unit has a maximum thickness of over 1000 m in the west, generally exhibits very gentle dips, and appears 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 virtually anywhere in the Antrim Plateau Volcanics, but 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, in some specimens, the mineral's radiating texture may be observed.

Ord Basin

Flora Valley area

Prehnite prospects (ANTRIM, 4561)

Between Halls Creek and the State border, the Antrim Plateau Volcanics, which comprises the lowermost unit of the early Paleozoic Ord Basin, forms extensive outcrops of basalt (Mory and Beere, 1988). 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 respectively, several prehnite sites have been evaluated intermittently over the last 20 years. At these sites, known as the Mound and Flora Valley prospects, prehnite occurs either in amygdales or veins, and is also commonly found scattered as nodules on the surface (Fig. 27.3). 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. 27.4). No further information relating to these prospects is available.

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie region

Londonderry feldspar pegmatite (YILMIA, 3135)

The Londonderry feldspar pegmatite is located about 20 km south-southwest of Coolgardie via the Nepean road (see Fig. 11.5 in Chapter 11).

In the Londonderry feldspar pegmatite quarry, prehnite occurs as light green, prehnite–quartz pseudomorphs after petalite displayed as fine- to coarse-grained masses with a faint relict (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 x 2 mm. Masses of light green prehnite crystals 3–4 cm in size are common in mullock heaps and debris within the southwestern pegmatite pit. Local vugs up to 5 mm in diameter are present in masses containing radiating euhedral green prehnite crystals (Jacobson et al., 2007).

Edmund Basin

Paraburdoo region

Mount Vernon (MOUNT VERNON, 2549)

In the Mount Vernon area, about 110 km south-southeast of Paraburdoo, there are unconfirmed reports of a prehnite occurrence to the north of Mount Vernon. No precise information is available on the exact location or size of this deposit, but a large cut and polished specimen of prehnite purporting to be from this locality has been reported by Cyril Richter (Fig. 27.5).

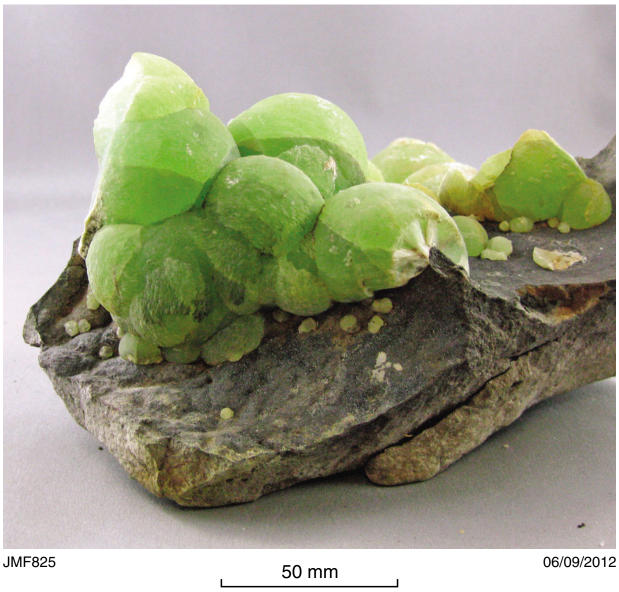

Figure 27.3 (left) Prehnite crystals, showing rosette structure, attached to a portion of an inside wall of an amygdale in basaltic lava at Flora Valley, east Kimberley (courtesy Barry Kayes)

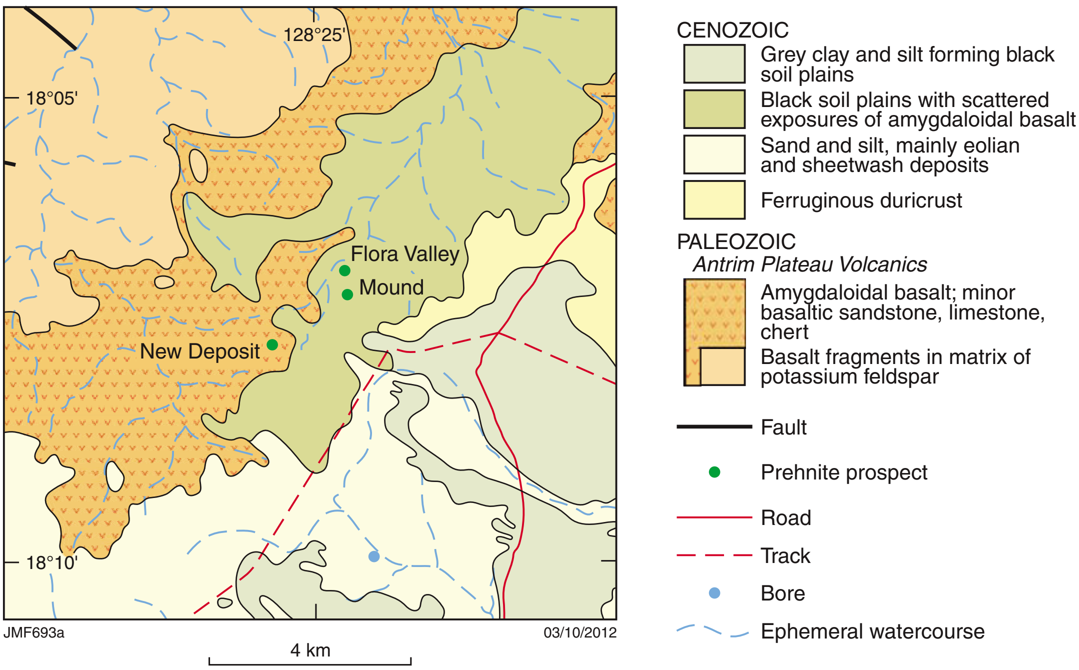

Figure 27.4 Geological map of the area surrounding the Flora Valley prehnite prospects (modified after Blake et al., 2000)

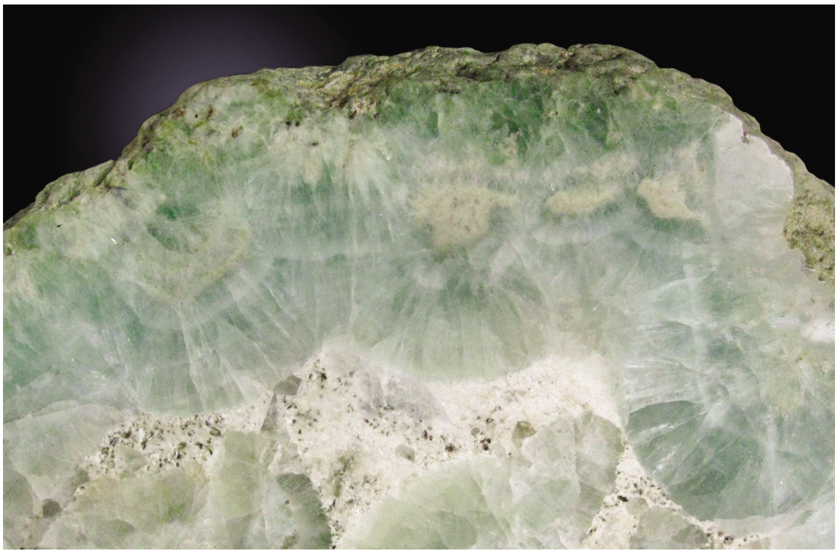

Figure 27.5 **Pale blue prehnite from an unknown locality north of Mount Vernon (courtesy Cyril Richter)**

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Chapter 28 Rhodonite

Properties

Rhodonite consists of manganese silicate ($MnSiO_3$) with variable quantities of calcium, with the calcium-rich variety known as bustamite. Also, rhodonite may contain a little ferric iron and up to 14.5% FeO as ferrous iron.

Rhodonite is normally pale pink to red, although yellow and grey varieties have been reported. It is often 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. 28.1). Spectacular rhodonite crystals have been found in the Broken Hill mine in New South Wales.

Physical properties of rhodonite

Crystal system	Triclinic
Habit	Prismatic, 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 commonly exists together with tephroite (Mn_2SiO_4) and hausmannite (Mn_3O_4) among others. This type is especially common in New South Wales, where most manganese occurs 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 rocks, and can also form 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 more brightly coloured than material from regionally metamorphosed deposits. The most significant rhodonite occurrences in Australia are in New South Wales, particularly in the New England region.

Rhodonite
Manganese silicate [$(Mn,Fe,Ca)SiO_3$]

Rhodonite in Western Australia

Even though there are numerous deposits of manganese in Western Australia, most are of the oxide type and rhodonite is rare. Gemstones in Western Australia (Geological Survey of Western Australia, 1994) reported only one occurrence, in the Pilbara region.

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Figure 28.1 Pink rhodonite patterned with black veinlets and dendrites of secondary manganese from Tamworth, NSW (courtesy Barry Kayes)

Pilbara Craton

Roebourne area

Five Mile Well (ROEBOURNE, 2356)

Rhodonite has been reported from Five Mile Well, approximately 7 km northeast of Roebourne (Fig. 28.2a). No further information is available.

Albany–Fraser Orogen

Hopetoun area

Hamersley Gorge (COCANARUP, 2830)

Simpson (1952) reported an occurrence of 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 Jeramungup and Ravensthorpe and flows through the Fitzgerald River National Park into the ocean immediately to the west of Edwards Point. De la Hunty (1963) reported on an occurrence of syngenetic manganese from the Hamersley Gorge about 18 km west-northwest of Hopetoun (Fig. 28.2b). This prospect may possibly be the location of the rhodonite samples.

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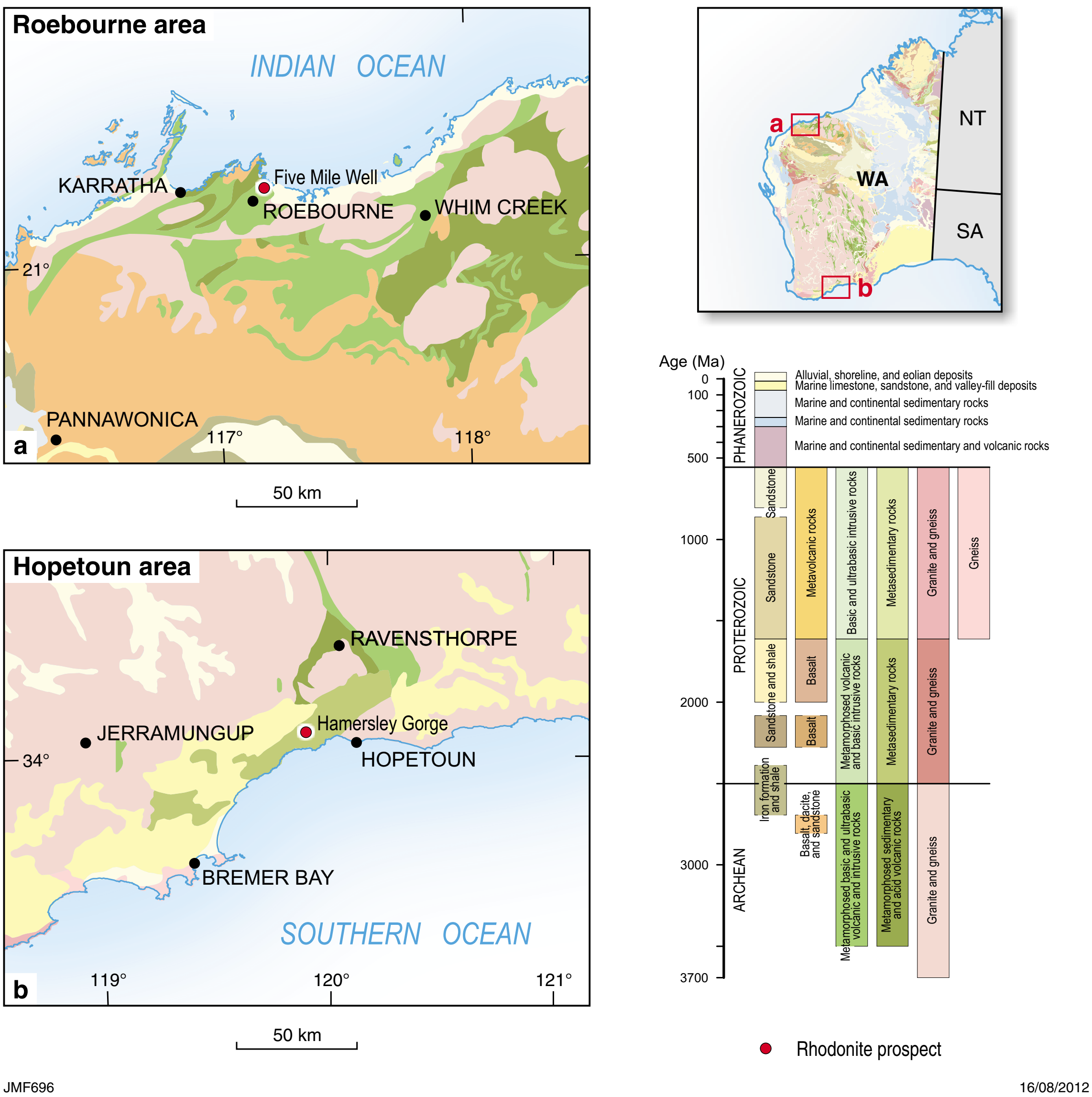

Figure 28.2 **Location of rhodonite prospects in Western Australia: a) Roebourne area; b) Hopetoun area**

Chapter 29 Variscite

Variscite — gemstone properties

Ornamental variscite, a hydrated aluminium phosphate, is a visually attractive, fine-grained, massive mineral generally yellow-green to blue-green, but may also be white to light brown. Variscite is often closely associated with turquoise, the best known ornamental phosphate gem material, commonly bright blue and comprising hydrated copper–aluminium phosphate. These two minerals have a number of 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 often 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 its monoclinic dimorph metavariscite. It commonly forms as veins and nodular encrustations both within and over a variety of rock types. Variscite may also occur as a replacement mineral formed 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 but, owing to its moderate hardness and the porous nature of its associated matrix materials, it is often impregnated with synthetic resins to minimize damage and staining (Fig. 29.1).

Variscite in Western Australia

Variscite deposits and prospects in Western Australia are comparatively few in number and are mostly located 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 farther south in the northern Murchison Domain, part of the Archean Yilgarn Craton. Also, small variscite occurrences, mostly from unknown sites, have been recorded 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 that the total production of variscite was about 850 t over a 14-year period 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 29.2 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, often fibrous, forms 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
Fracture	Splintery (massive forms), uneven (glassy forms)
Specific gravity	3.68 – 3.78
Associated minerals	Metavariscite, crandallite, wardite, and other hydrated phosphate and iron-bearing minerals
Processing and display	Sometimes impregnated with synthetic resins to stabilize colour and matrix material. Cut, polished, and carved. Often used together with host rock matrix.

Source: Willing et al. (2008)

Figure 29.1 **A pendant of green variscite on a background of natural, pale blue-green variscite in a brown rock matrix (pendant diameter 30 mm)**

Bryah Basin

Robinson Ranges

Dimble Creek 1 and 2 (*Padbury, 2546*)

Dimble Creek 1 and 2 variscite prospects are located immediately 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. 29.2).

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, it is suggested by Elias and Williams (1980) that the variscite, being located only at the summit of a prominent hill, 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 located immediately south of the Gascoyne River on Milgun Station, about 175 km north-northwest of Meekatharra (Fig. 29.2).

In this area, variscite is found in the Paleoproterozoic–Mesoproterozoic Jillawarra Formation that comprises siltstone and shale with minor chert. At the main site, variscite occurs as 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*)

Located 180 km north-northwest of Meekatharra and approximately 15 km north-northwest of Milgun Station, the Mount Deverell and Mount Deverell East deposits were, until now, the main production sites for variscite in Western Australia (Fig. 29.2). As previously mentioned, between 1992 and 2005 these opencut mines produced about 850 t of variscite.

The Mount Deverell deposits are located within shale and mudstone of the Mesoproterozoic Kiangi Creek Formation close to the adjoining dolomite of the Irregully Formation (Fig. 29.3). The variscite occurs in narrow, near-surface, fault-controlled veins less than 100 mm wide, which cut irregularly silicifed shale and mudstone. Associated minerals include wardite (Na–Al phosphate mineral), crandallite, turquoise, alunite, gypsum, and rare magnesian collinsite (Bridge and Pryce, 1974).

Woodlands Station

Waldburg deposit (*Mount Egerton, 2448*)

The Waldburg variscite deposit (also known as Woodlands variscite) was discovered by prospectors in 2005 in the Waldburg Range approximately 230 km north-northwest of Meekatharra, and 47 km west-northwest of Woodlands Station (Fig. 29.2).

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 occurs in a 0.5 m-wide zone as a number of 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. 29.4). Veins comprise both massive and spindle-shaped aggregations of variscite together with other phosphate minerals: metavariscite, turquoise, crandallite, apatite, wardite, as well as 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, whereas at other sites conformable

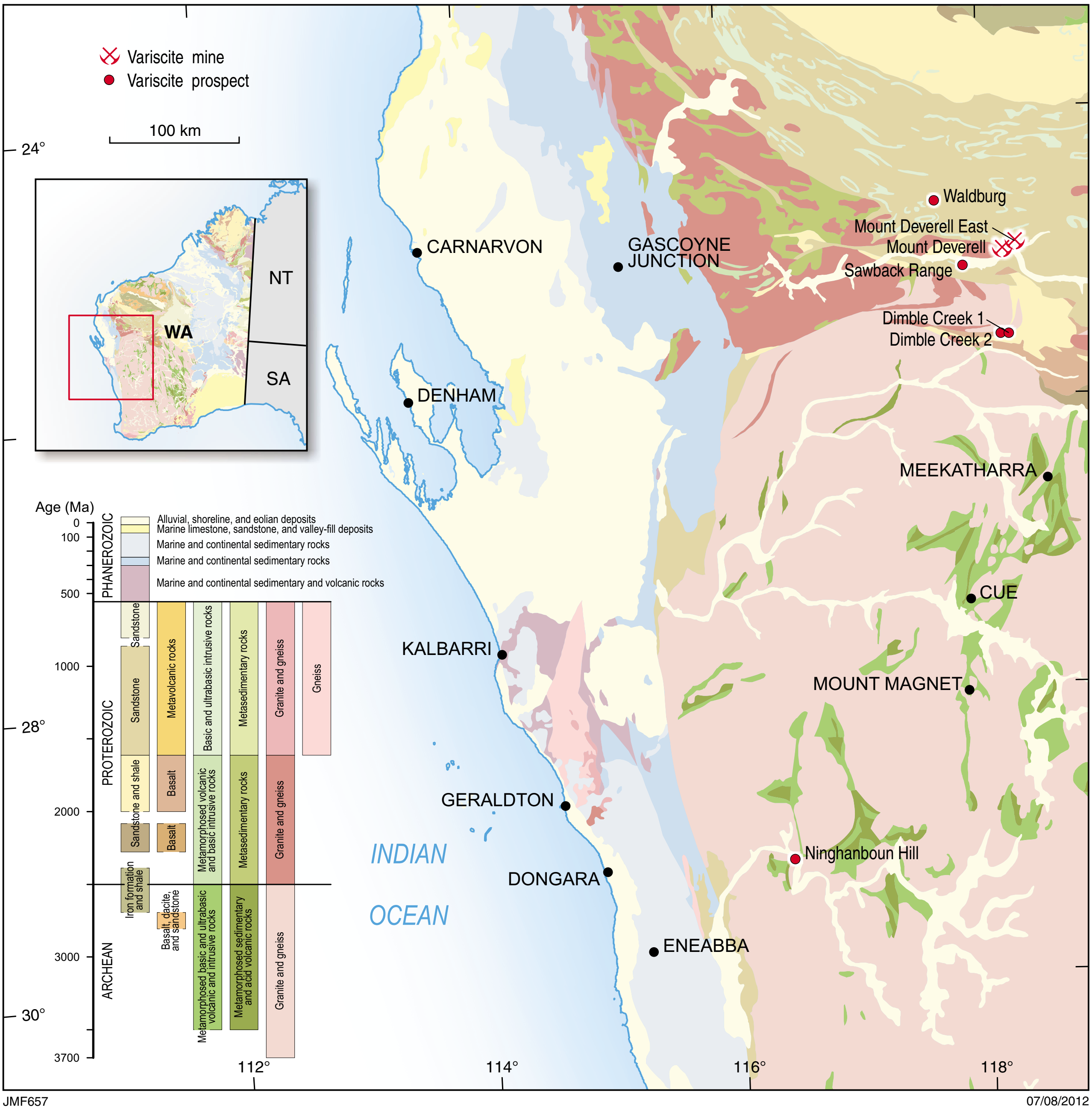

Figure 29.2 **Location of variscite mines and prospects in Western Australia**

seams comprise mostly porous, bluish-turquoise and small inclusions of apatite, and larger, nodular, intergrown masses of variscite, quartz, and apatite. By contrast, the thicker, discordant main vein differs markedly from the thinner conformable veins in that 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 29.5 and 29.6).

The discordant main vein is of principal gemmological interest in that it contains gem-quality, translucent variscite commonly dark emerald-green. It has been demonstrated by Nickel et al. (2008) that the chromophore element chromium (up to 0.2% by weight) is responsible for the colour zonation present in the variscite ranging from light to dark emerald-green.

Diverse textures present in the variscite of the main vein include:

- relatively massive blocks of colour-zoned green variscite (Fig. 29.7)
- finely fractured, spindle-shaped masses up to 1–2 cm in diameter of colour-zoned variscite displaying a

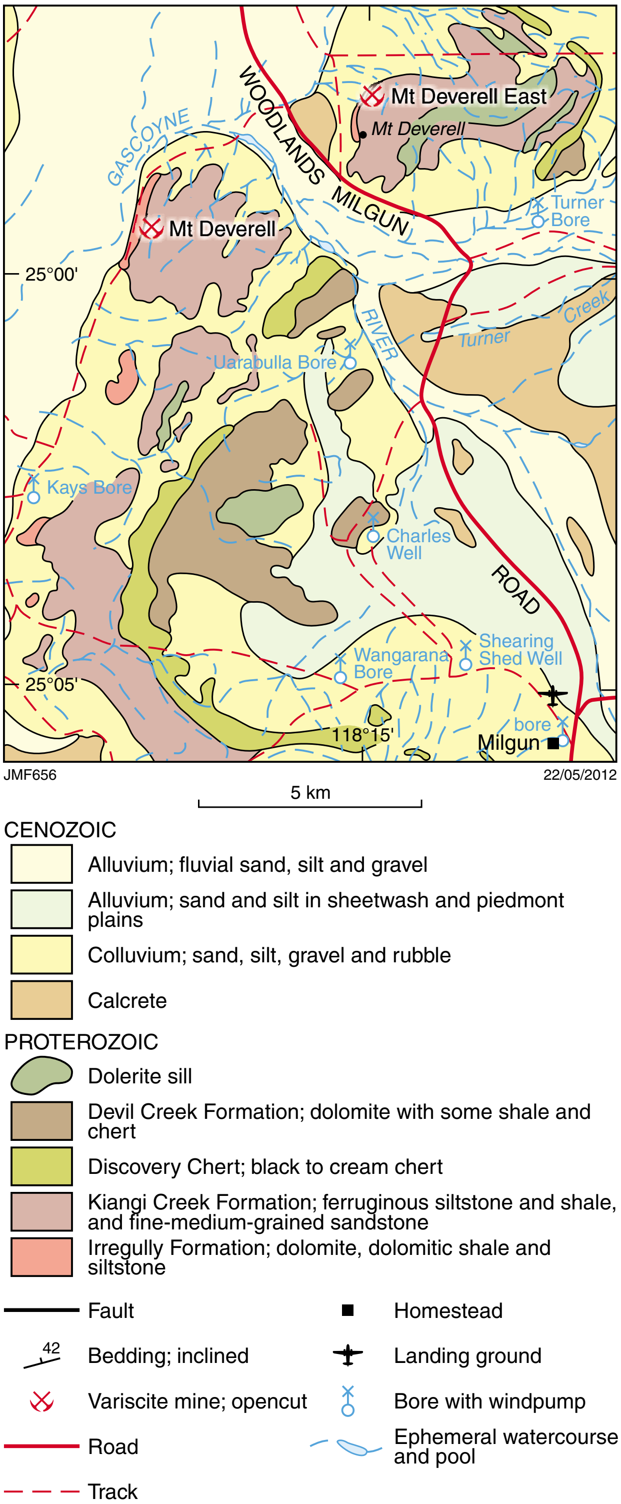

Figure 29.3 Geological map of the area around the Mount Deverell variscite mines (modified after Muhling et al. (1977) and Occhipinti et al. (2002)

spiderweb fracture pattern infilled with pale brown crandallite commonly intermixed with yellow alunite–jarosite and kaolinite (Fig. 29.8)

- 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, the main vein variscite has been shown to have an association with irregularly dispersed gold particles that vary from visible spongy grains, some with dendritic growths, present on boundaries and fractures in the variscite, to micrometre-sized particles with a delicate, lace-like texture (Nickel et al., 2008).

Trial batches of polished Waldburg variscite mainly as slabs, cabochons and carvings were displayed to some acclaim at the 2006 international gem trade fair in Tucson, Arizona (Fig. 29.9).

The Waldburg (Woodlands) variscite deposit is also discussed in some detail in a recent paper by Willing et al. (2008).

Yilgarn Craton — Murchison Domain

Weelhamby Lake

Ninghanboun Hill (Perenjori, 2139)

Variscite is found in two, narrow, easterly 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. 29.2).

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 due to the presence of chromium. Simpson (1952) also states that the redonite occurrence, located 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 (Tieraco, 2545)

Brown and green variscite have 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 colour due to the presence of chromium.

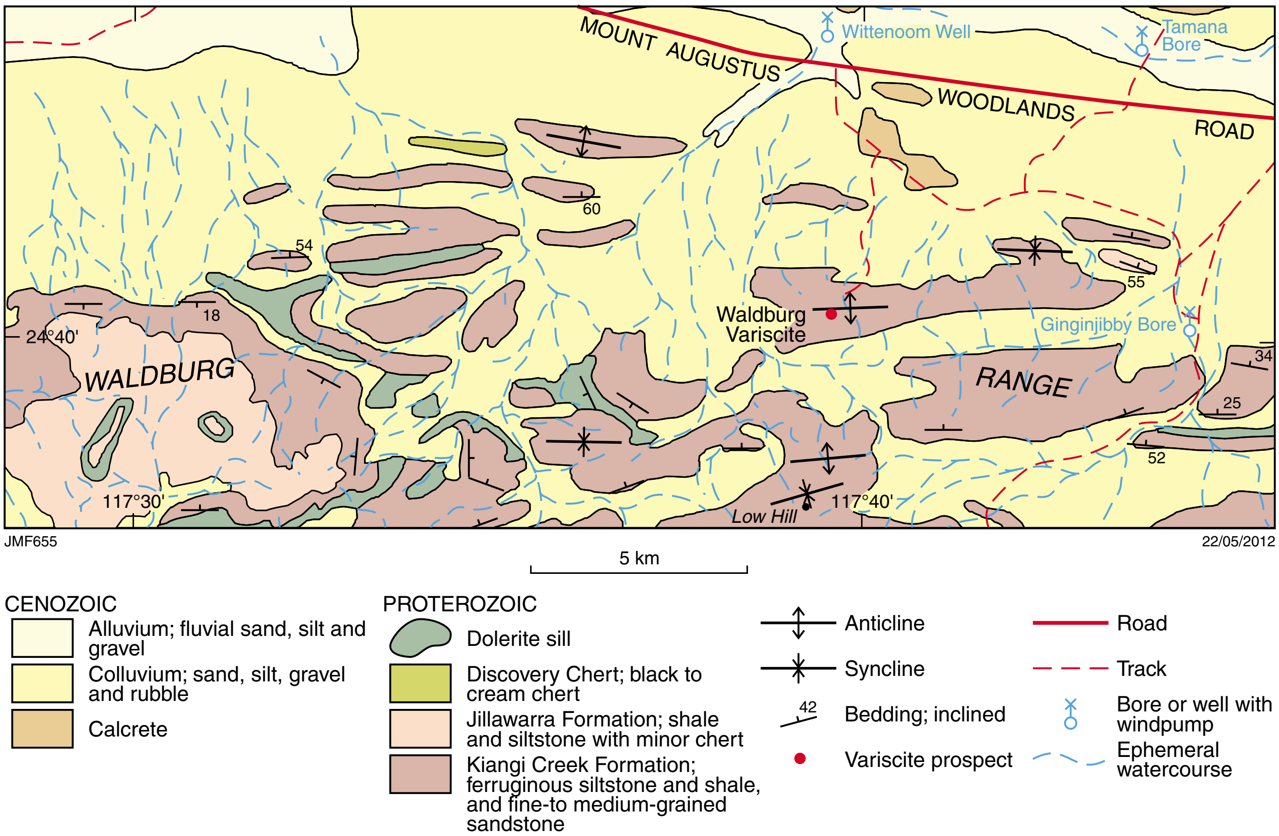

Figure 29.4 Geological map of the area around the Waldburg variscite deposit (modified after Muhling et al., 1977)

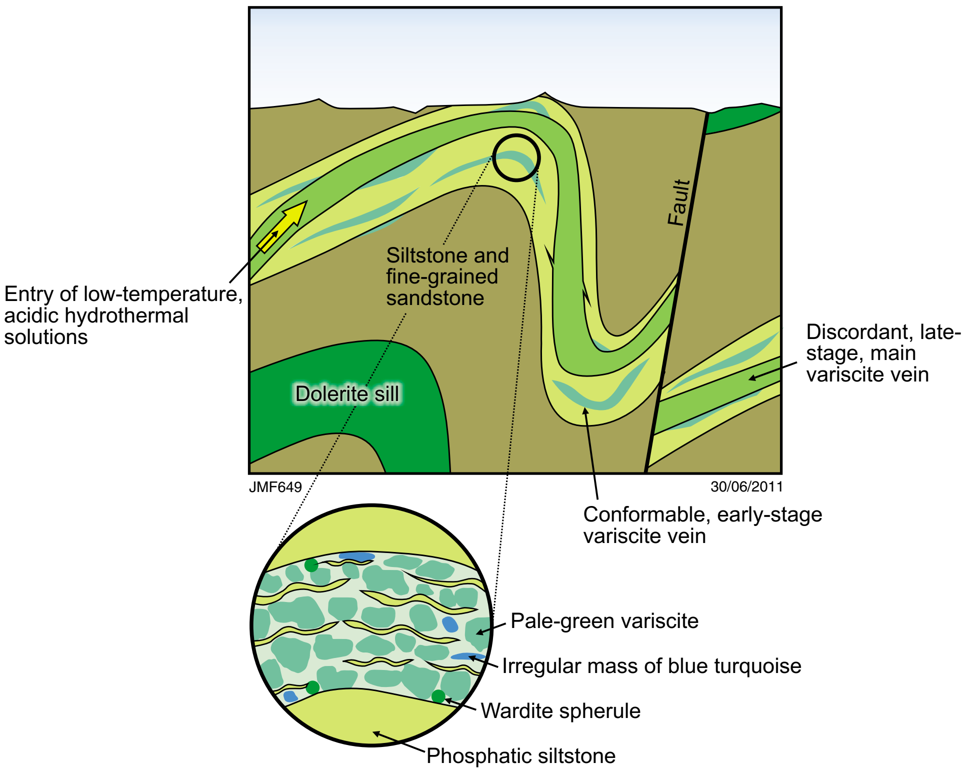

Figure 29.5 Schematic cross section of the Waldburg variscite deposit (modified after Nickel et al., 2008)

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~ 250 mm

Figure 29.6 Mineralized variscite zone exposed in the Waldburg opencut (courtesy Glenn Archer, Australian Outback Mining)

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Figure 29.7 A 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)

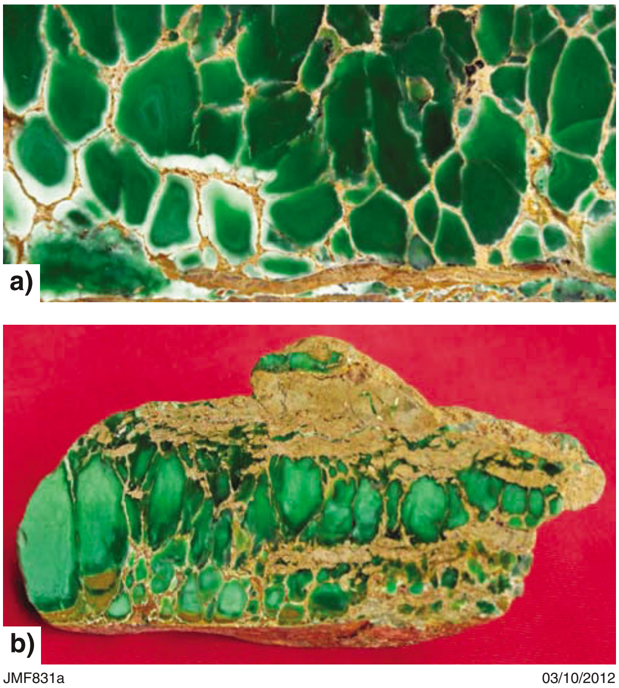

Figure 29.8 **Spindle-shaped masses of main vein, deep green, colour-zoned variscite: a) distinctive spiderweb fracture pattern surrounding variscite spindles 1–2 cm in diameter with fractures filled with pale brown crandallite sectioned parallel to main vein upper surface; b) cross section of variscite spindles in a crandallite matrix, normal to the surface of the main vein**

Figure 29.9 **Artistically carved, translucent, emerald-green variscite displaying a distinctive, yellow-brown, spiderweb fracture pattern (approximate height 7 cm) (courtesy Australian Outback Mining; cutting and photography by Dalan Hargrave)**

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7

Decorative stones

A visually attractive selection of highly polished decorative stones.

Chapter 30 Carbonate group

The carbonate group

The minerals listed below are the most common in the anhydrous carbonate group. These minerals all crystallize in the trigonal (rhombohedral) system, whereas aragonite (also $CaCO_3$) crystallizes in the orthorhombic system. Ferruginous magnesite, $FeMg(CO_3)_2$, is known as breunnerite and commonly occurs 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. 30.1). Carbonate rocks (limestone, marble, dolomite, and magnesite) are all employed as carving and bead materials as well as being cut and polished to make small decorative items. Limestone and dolomite are quarried on a large scale and utilized 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. They are also porous and commonly dyed for jewellery use.

By contrast, rare carbonate minerals including gaspeite (a green nickel carbonate, see Chapter 25), and stichtite (a purple magnesium–chromium carbonate) are collectors' items, and specimens featuring azurite and malachite (secondary copper carbonate minerals, see Chapter 21) are sometimes set into jewellery as crystal aggregations or used as display items and collected for micromount examination.

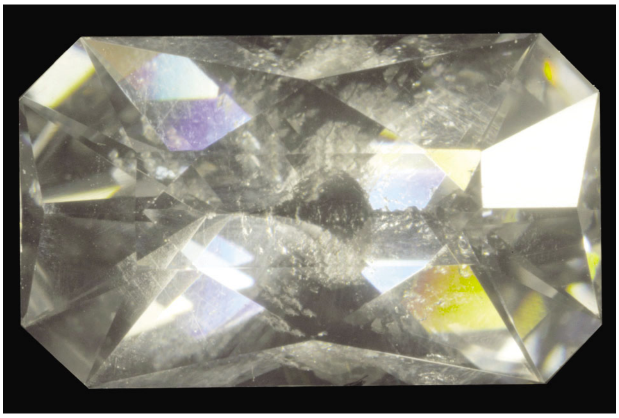

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Figure 30.1 Faceted, colourless magnesite showing a doubling effect of facets and inclusions. Dimensions: 12.25 x 7.77 mm (Courtesy Brian Jackson, image by Bill Crighton)

Calcite

Although calcite (calcium carbonate) may occur as spectacular crystals in vein fillings and cavities, it is relatively soft (3 on Mohs hardness scale) and has three

Carbonate group
Calcite – $CaCO_3$
Dolomite – $CaCO_3.MgCO_3$
Ankerite – $CaCO_3.(MgFe)\ CO_3$
Magnesite – $MgCO_3$
Siderite – $FeCO_3$

Physical properties of calcite

Crystal system	Trigonal
Habit	Commonly as rhombohedral crystals
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
Cleavage	Highly perfect in three rhombohedral directions, easily developed and producing 'cleaved rhomb crystals'
Fracture	Conchoidal
Fluorescence	Commonly shows a variable and patchy pink or white response under ultraviolet light

perfect directions of rhombohedral cleavage, which severely limits 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 that are especially dramatic using twinned crystals (Fig. 30.2). 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, these have been replaced by synthetic plastic polarizers.

Aragonite is a dimorphous form of calcite, crystallizing in the orthorhombic system. It is best known in gemmology as the biogenic carbonate of pearls. Aragonite crystals are appreciated as display specimens and are sometimes faceted as collectors' gems.

Simpson (1948) recorded numerous occurrences of calcite crystals in vein and amygdale fillings throughout Western Australia.

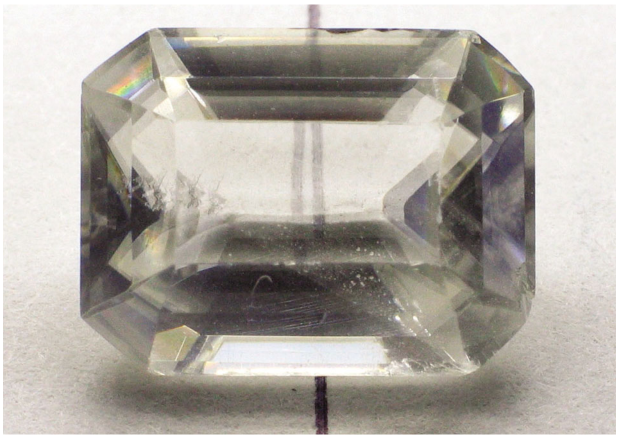

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Figure 30.2 Faceted, 5.19 ct colourless calcite demonstrating the doubling effect of a line (courtesy Peter Groenenboom)

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):

- Residual magnesite in Archean, altered serpentine-rich, ultramafic rocks that are widespread throughout the State. Good examples are located at Bulong, Coolgardie, and Ravensthorpe.
- Secondary magnesite in Paleogene sedimentary rocks that are known only from deposits at Bandalup near Ravensthorpe.

Residual magnesite deposits are developed over Archean serpentinite, amphibolite, quartzite, and schist. Faulkner (1962) defined two discrete varieties, 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 lenticular lumpy bodies with well-defined margins and occurs in low-lying to intermediate physiographic levels 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, and locally 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 as dyed blue beads and inexpensive jewellery marketed as 'turquenite', imitating turquoise. A more attractive form of this mineral is nickeliferous magnesite that is commonly light green and often referred to as 'citron' or 'lemon' magnesite. This commonly occurs in association with apple-green chrysoprase, and in this association may be referred to (incorrectly) as citron or lemon chrysoprase. It is commonly found as surface cappings on weathered nickel-rich ultramafic rocks where the magnesite generally forms as rounded structures or loose boulders (Fig. 30.3). This attractive rock is commonly found in the Eastern Goldfields area of Western Australia in a belt of nickel-rich ultramafic rocks that extends 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).

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Figure 30.3 Rough boulders of citron magnesite (nickeliferous magnesite) sourced from Marshall Pool mine (courtesy Barry Kayes)

Nickeliferous magnesite takes a good polish and, when veined with brown limonite, makes attractive tumbling and cabochon material and may also be carved into attractive objets d'art (Fig. 30.4). Some of the better known localities are recorded below.

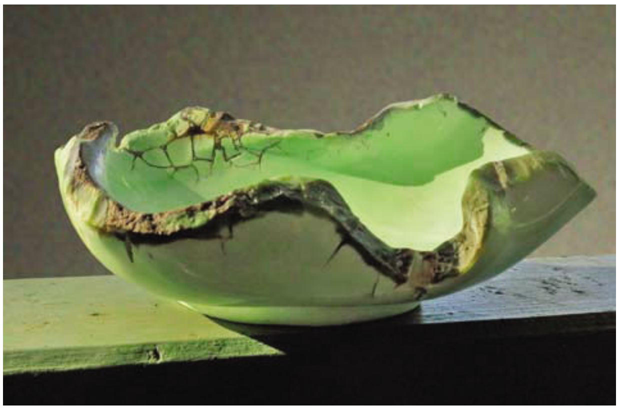

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Figure 30.4 **Carved and polished bowl in citron magnesite from Marshall Pool (courtesy Glenn Archer)**

Yilgarn Craton — Eastern Goldfields Superterrane

Lake Rebecca area

Duck Hill and Jump Up Dam prospects (EDJUDINA, 3338)

The booklet Gemstones in Western Australia (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 but Chen (1999) reports that chrysoprase has been mined from several small openpits west of Jump Up Dam and at Duck Hill (Fig. 30.5). 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, on mining leases M31/104 and M31/112, is approximately 145 km north-northeast of Kalgoorlie and 13 km south of Yerilla Homestead (Fig. 30.5). The mine area can be accessed via the well-maintained Kookynie–Yarrie gravel road and is immediately 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-striking zone of mafic and ultramafic units with a total strike length of over 70 km (Ahmat, 1995). The centre of the complex lies some 35 km east of Kalgoorlie in an area containing numerous gold and nickel mines (Fig. 30.5).

In this area, magnesite is found as a surface or near-surface weathering product over most ultramafic rocks on the KANOWNA 1:100 000 geological map, with the best deposits occurring over 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) reports that nickeliferous magnesite has been found within the Bulong Complex and on the shores of Lake Rebecca.

Goongarrie Hill area

Goongarrie (BARDOC, 3137)

Citron magnesite is reported at Goongarrie, approximately 100 km to the north of Kalgoorlie (Fig. 30.5). The BARDOC 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 have reported that nickeliferous magnesite occurs 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. 30. 5). Access from Leonora is along the graded Leonora to Agnew road and thence northward along station and mining roads.

Musgrave Province

Wingellina area

Wingellina prospect (BELL ROCK, 4645)

The booklet Gemstones in Western Australia (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. 30.5). Much of this area is underlain by the extensive mafic/ultramafic Giles Complex. Weathering is deep in places and nickel laterites are locally well developed and abundant surface magnesite has been recorded. Chrysoprase has also been

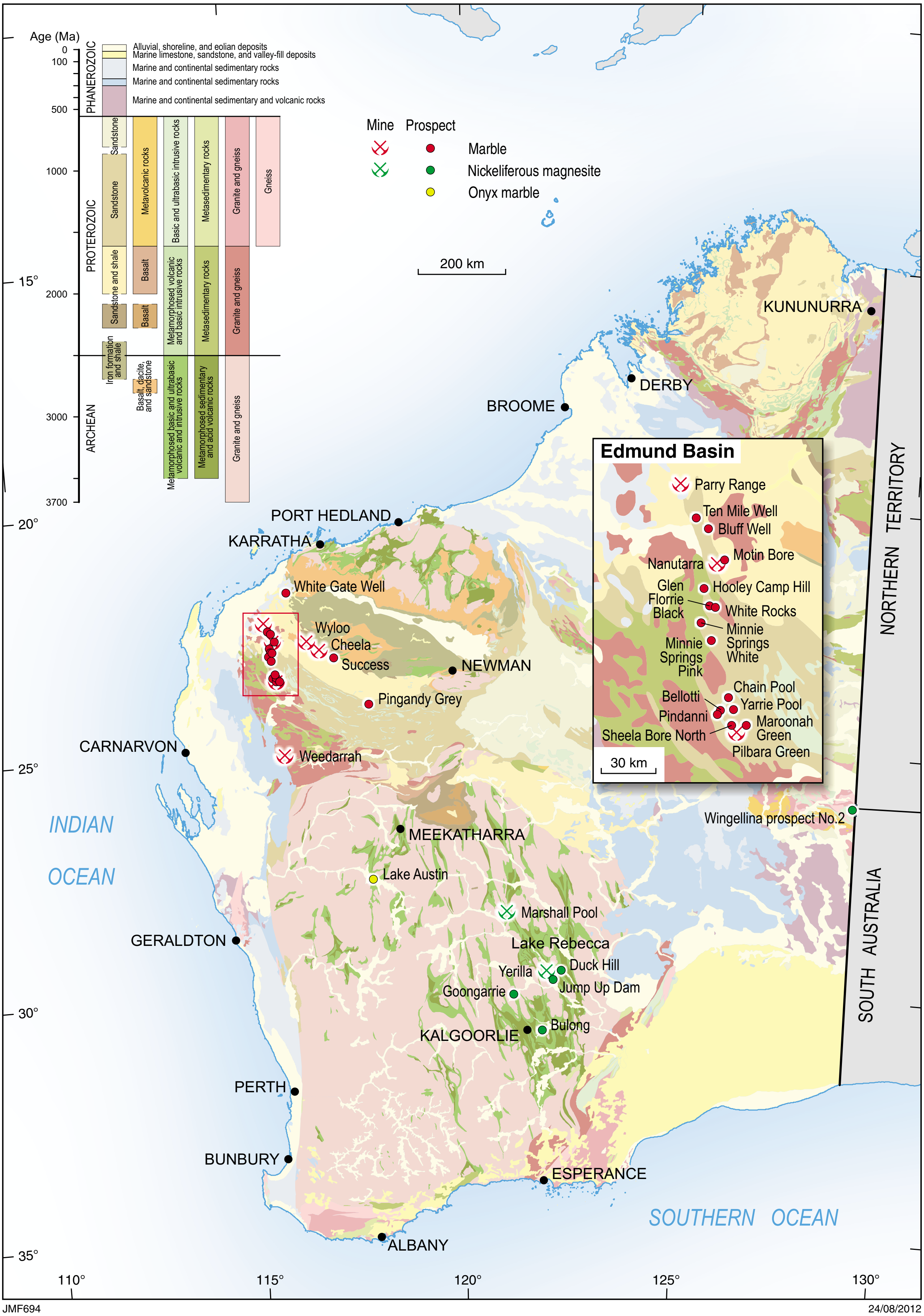

Figure 30.5 Location of carbonate group decorative stones in Western Australia

mined in this area and it is highly likely that nickeliferous magnesite would be found here.

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 often incorrectly referred to as onyx (a type of banded chalcedony) or as 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, but they are commonly veined by coloured fractures or by areas containing metallic oxides. This gives rise to a delicate banding of amber, orange, and green which, together with their translucence, makes them popular as a sculpting medium.

Yilgarn Craton — Murchison Domain

Lake Austin (Wynyangoo, 2542)

The booklet Gemstones in Western Australia (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. 30.5). 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 marbles 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 located within the western end of the Palaeoproterozoic Ashburton Basin and the western part of the overlying Paleoproterozoic–Mesoproterozoic Edmund Basin. Outside 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 marbles in the region are designated as dolomitic marbles with chemical contents ranging from 24–41% CaO, and 11–22% MgO. The marbles display 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 from pure white through cream, yellow, orange, pink to deep red, and brown as well as green, mauve, grey, and black. It appears that trace element values bear little relationship to the colour of the marbles.

Thin-section work revealed the presence of green serpentine minerals in many of the marbles as well as iron-rich minerals such as hematite and limonite. Also, it is possible that the dark colouration of a number of marbles 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. It should be noted that these quarries are not the only sources of marble and specimens could be obtained from almost anywhere in the 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 30.5 and 30.6). All are hosted within the Duck Creek Dolomite of the Wyloo Group, dated at about 1830 Ma.

Locations are shown in Appendix 1, and details are summarized in Table 30.1.

Edmund Basin

Of the 20 dolomitic marble deposits located in the western end of the Edmund Basin almost all are located in three discrete areas: western Glen Florrie Station, Maroonah Station, and Nanutarra, with one located south of Paraburdoo (Figs 30.5 and 30.7). All Edmund Basin marble deposits are hosted by the Irregully Formation. Locations are shown in Appendix 1 and details are summarized in Table 30.2.

Gascoyne Province

Weedarrah marble (Daurie Creek, 2047)

The Weedarrah marble quarry is located 60 km east of Gascoyne Junction and about 6 km south-southeast of Weedarrah Homestead (Fig. 30.5). The Paleoproterozoic, coarsely crystalline, white marble lens is enclosed by dark green, weathered mica schist, amphibolite, and minor quartzite (Fig. 30.8). The marble is penetrated in places by steeply dipping, anastomosing veins of pale green, schistose serpentine.

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 between 5 and 40% the rock becomes a dolomitic limestone and, at over 40%, the rock is classified as a dolomite. In many instances, limestone and dolomite grade into each other. Limestone containing a high proportion of sand-sized carbonate grains is known as calcarenite. Calcitic rocks precipitated around hot and cold calcareous springs are termed calcareous tufa and travertine. Oolitic limestone may be formed in shallow-water environments by inorganic carbonate precipitation.

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, that fringe the southwestern coastline are soft, porous and contain abundant quartz grains and shell fragments. These are commonly calcareous dunal and, less commonly, beach deposits.

Finer grained, more competent limestone and dolomite units 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.

Table 30.1 Summary of marble quarries and prospects in the Ashburton Basin

1:100 000 map sheet	*Quarry/prospect*	*Location*	*Colour*
Pannawonica 2154	White Gate Well – prospect	25 km WSW of Pannawonica	Red and 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 – position doubtful	Black
Hardey 2252	Gala Mauve – prospect	Cheela Area – position doubtful	Pinkish-grey
Hardey 2252	Cheela Grey – prospect	Cheela Area – position doubtful	Dark grey
Hardey 2252	Beasley Pearl – prospect	Cheela Area – position doubtful	Dark grey
Hardey 2252	Wonangara Rose – prospect	Cheela Area – position doubtful	Rose-pink
Wyloo 2152	Wyloo Smoky Pink – prospect	Wyloo Area – position doubtful	Pink and white
Wyloo 2152	Kooline Opal – prospect	Wyloo Area – position doubtful	Green-grey

Table 30.2 Summary of marble quarries and prospects in the Edmund Basin

1:100 000 map sheet	*Quarry/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

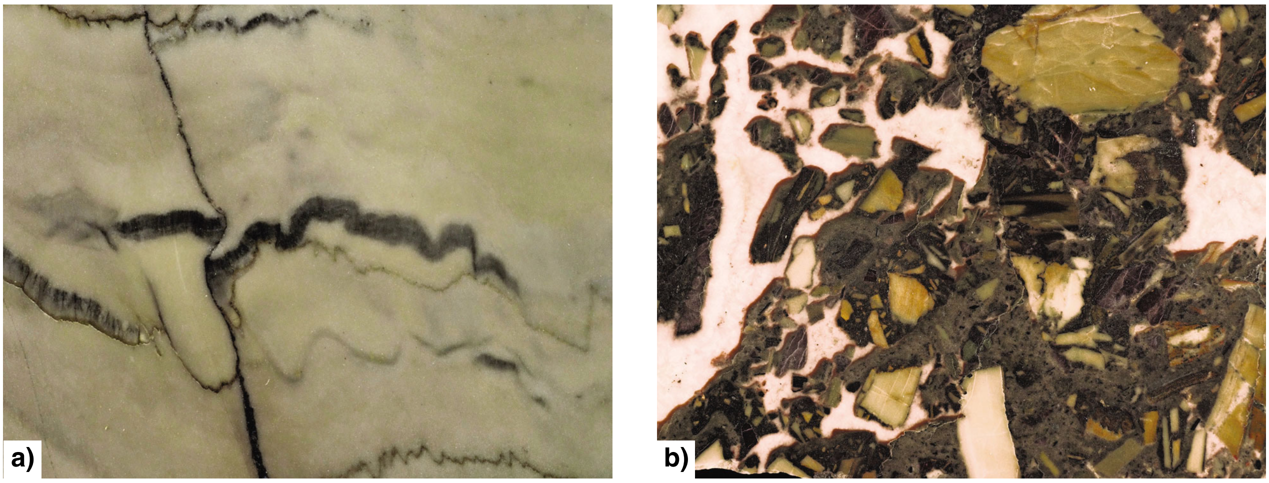

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Figure 30.6 **Marbles from the Ashburton Basin: a) pale grey Cheela marble with dark green veins and stylolites; b) brecciated, grey-green Wyloo marble with pink veins of coarse-grained sparry carbonate**

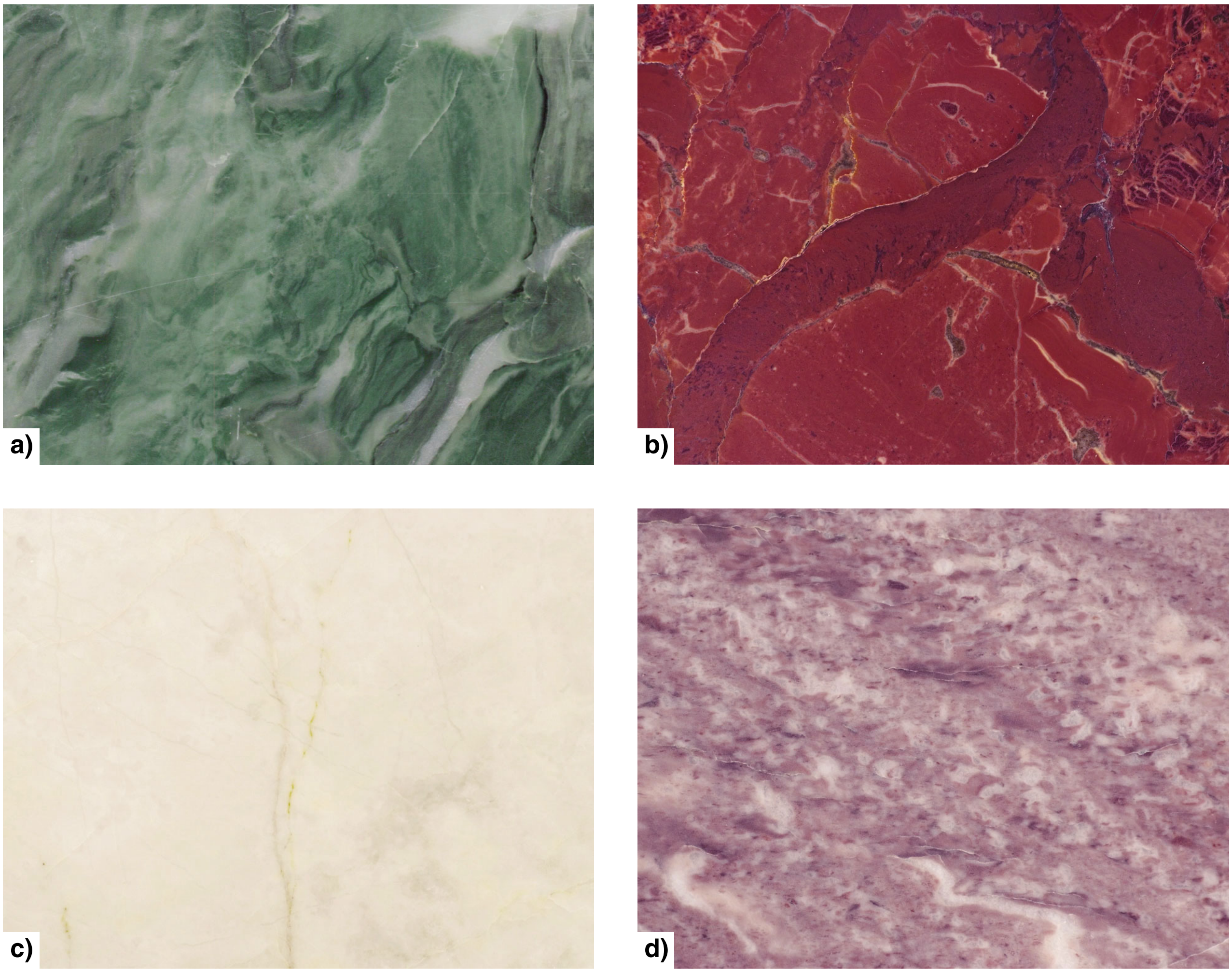

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Figure 30.7 **Marbles from the Edmund Basin: a) Pilbara Green marble from Maroonah; b) Rosso Venezia red marble from Nanutarrra; c) Austral Pearl cream marble from Nanutarra; d) mauve-coloured marble from Hooley Camp Hill. Polished slabs average 90 mm in width**

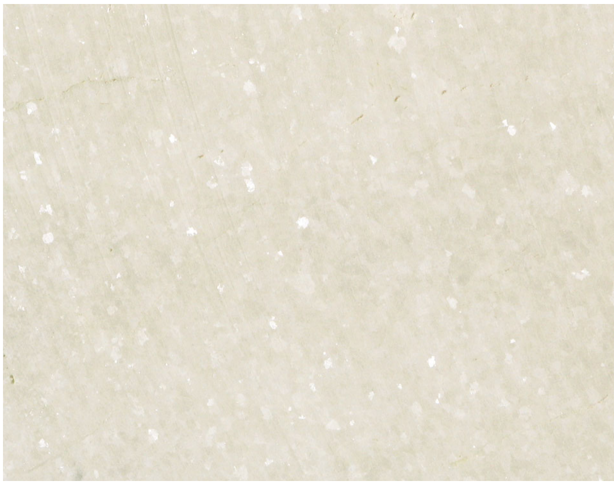

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Figure 30.8 Coarsely crystalline white marble from Weedarrah

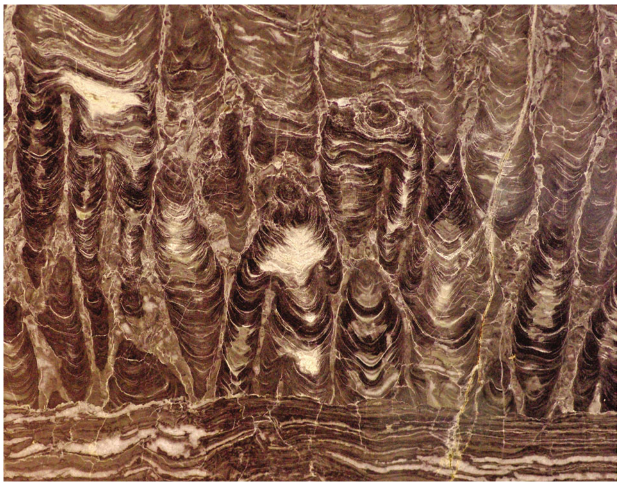

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Figure 30.9 Columnar stromatolites from the Three Springs area. Image is about 425 mm wide (Courtesy Glenn Archer)

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. 30.9). 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 often 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, which differ 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 are of a coarse structure that is poorly laminated; these grow to about 1 m in height (Monroe, 2011).

Stromatolites are common as fossils and have been found in rocks formed 3.45 billion years ago, 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 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. 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 (Fig. 30.10).

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 members of DMP prior to any fossil collecting trip.

Lapidary applications

Stromatolites are commonly slabbed and made into small objects such as book ends, cutting boards, and table tops. Also 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 containing fragmented stromatolites has been used for making cabochons (Fig. 30.11).

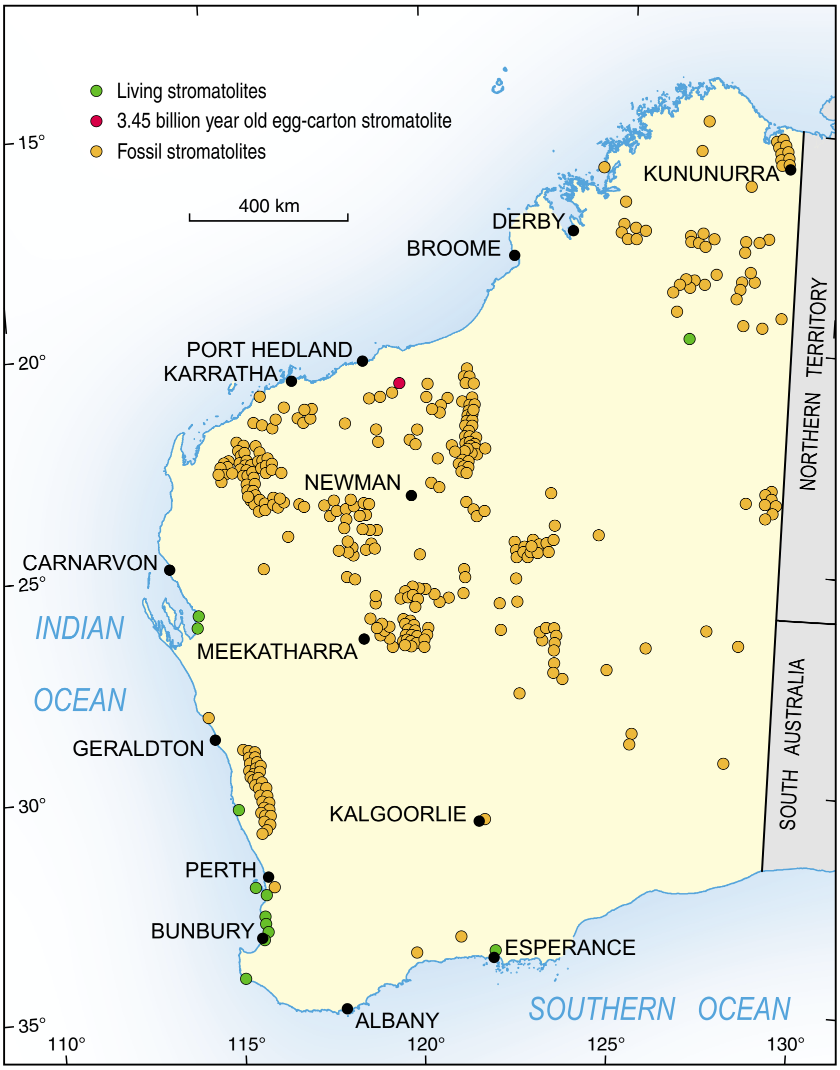

Figure 30.10 Map showing distribution of stromatolite locations in Western Australia

Figure 30.11 Cabochon of Noondine Chert, a silicified fragmented stromatolitic limestone. Cabochon is 5 cm in diameter

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Chapter 31 Chinese writing stone

Description

Chinese writing stone is a trade name used to describe decorative rocks that have a porphyritic texture with white or light-coloured crystals (phenocrysts) forming contrasting patterns scattered throughout a fine-grained dark groundmass. In Western Australia this term is applied to these structures in porphyritic basalts although in similar igneous rocks worldwide, they are referred to by a variety of terms. 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, usually less than 10 mm in length, form a distinctive texture. In some groups the crystals diverge to form rosette patterns (Fig. 31.1). 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 by 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.

Decorative stone properties

Chinese writing stone is a tough material with a variable range of hardness according to alteration and mineralogy. Unaltered material is hard and takes a high polish, whereas altered rock is generally softer, may be easily scratched, and does not take a high polish. In some instances, surface

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Figure 31.1 Chinese writing stone showing clusters and rosettes of lath-shaped, light-coloured feldspar crystals up to about 10 mm in length

Chinese writing stone
Porphyritic basalt

pitting on polished stones may be caused by changes in differential hardness between mineral types within the rock mass.

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 basal formation 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. The stone is also present in a number of 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 being in Port Hedland.

Langwell Gorge prospect (MOUNT WOHLER, 2455)

The Langwell Gorge chinese writing stone prospect is located 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. 31.2). 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.

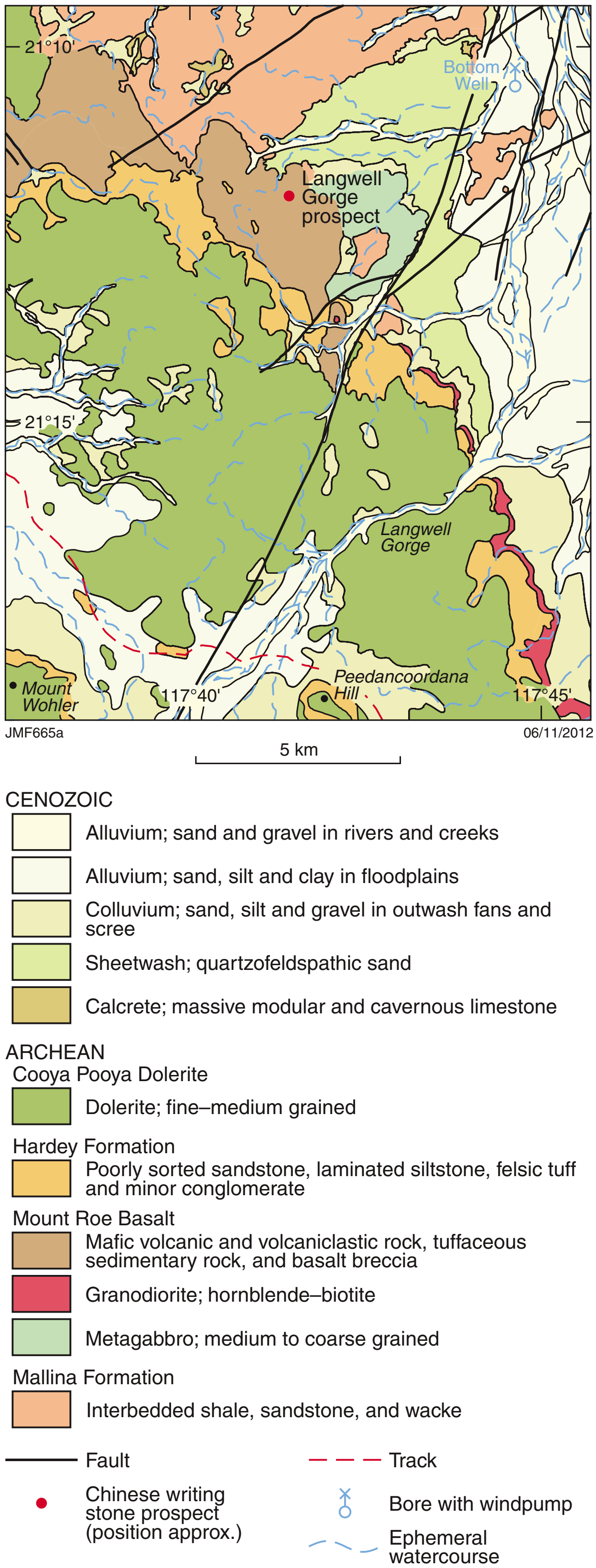

Figure 31.2 Geological map of the area around the Langwell Gorge chinese writing stone prospect (modified after Smithies, 1998)

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Chapter 32 Epidote group

Epidote group

Epidote is a group name for a variety of related hydrous calcium–aluminium silicate minerals. Only a few coloured epidote varieties are classified as gems or visually attractive ornamental stones and these are described in this chapter. 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%) and this 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 in calc-silcates, contact metamorphic rocks (especially at granite–greenstone contacts) and as a result of saussuritization and epidotization of calcic feldspars in mafic rocks. Epidote also exists in the vesicles of lavas.

Epidote

The mineral epidote may occur as a green rock-forming mineral or as single crystals that are commonly of prismatic habit, green or brown in colour, and may be faceted as gems (Fig. 32.1). Epidote may vary in colour if chemical substitution with chromium, manganese or vanadium has taken place. A rare chromium epidote variety is very 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 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 — manganian zoisite; hydrous manganese calcium aluminium silicate $[(Ca\ Mn)_2Al_3(SiO_4)_3(OH)]$
Unakite — an epidote-rich hydrothermally altered granite
Marshmallow rock — porphyritic dolerite containing pink clinozoisite (clinothulite)
Epidote–quartz–axinite rock (axinite, a complex borosilicate)

Physical properties of epidote

Crystal system	Monoclinic and orthorhombic varieties
Habit	Prismatic or granular
Colour range	Grey, colourless, yellow, green, pink
Colour cause	Iron, chromium, manganese, 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

Epidote is known in Western Australia only 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 known as unakite.

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 sourced only from several deposits in this region. Zoisite gemstones and crystals are found in various colours of blue, green, yellow, pink, brown, and khaki. All these colours may be altered to blue by heat treatment, a process routinely used.

Clinozoisite

Clinozoisite, typically a grey or colourless mineral of the epidote group, may also occur as a strong pink

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Figure 32.1 Typical light green epidote rock

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Figure 32.2 Photo showing unakite as natural rock, and polished beads and cabochon applications

colour if it contains trace amounts of manganese. Pink clinozoisite is termed clinothulite and it is this form that occurs as phenocrysts in the decorative Western Australian porphyritic dolerite marketed as 'marshmallow rock' (described below). The pink crystals within the dolerite result from metamorphic alteration of the primary feldspars, a process known as saussuritization.

Thulite

The term thulite refers to both a manganian zoisite and 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, that has proven to be excellent for carving and polishing. It is recorded from Norway, Greenland, and several sites in the USA.

Thulite rock is composed essentially 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 USA. It is essentially an altered granite composed of pink orthoclase feldspar, green epidote, and colourless quartz.

Unakite is a relatively low temperature, hydrothermally altered granite in which the orthoclase feldspar has developed a pinkish colour due to the presence of minute hematite inclusions, and the original plagioclase feldspar has been converted in part to green epidote. The colourless quartz remains unaffected. The result is an attractive mottled pink-green rock that can be cut into cabochons or made into beads (Fig. 32.2).

Epidote minerals in Western Australia

Unakite

In Western Australia, unakite occurrences are not common. The best localities lie 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 located 17 km southeast of Denmark (Fig. 32.3). At this site, a unakite vein has cut the local coarse-grained, porphyritic, microcline-bearing quartz monzonite.

Cheyne Bay area

Cape Riche (*Cheyne, 2628*)

The booklet Gemstones in Western Australia (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. 32.3). Nothing further is known about this occurrence.

Thulite

Pilbara Craton

Roebourne area (*Roebourne, 2356*)

Tayler (1967) reported on the occurrence of thulite from an unknown locality near Roebourne (Fig. 32.3). The thulite

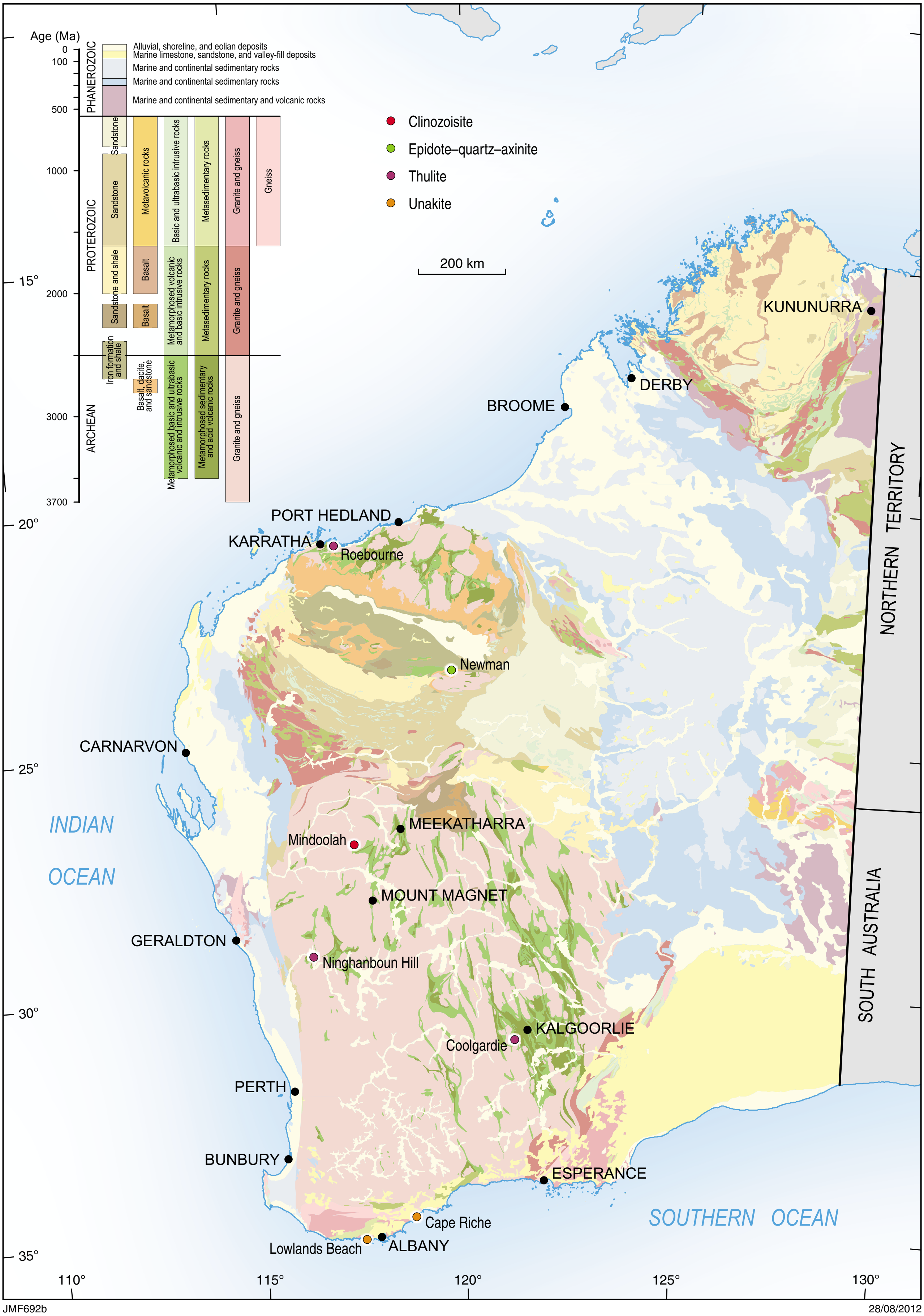

Figure 32.3 Location of epidote group minerals and rocks in Western Australia

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 occurs in grain sizes from very fine (10–15 µm) to relatively coarser euhedra (0.2 – 0.4 mm). In contrast, the clinozoisite grades into a deeper rose colour that may have a mauve tinge. The pink and rose clinozoisite are recorded as having an Fe_2O_3 content of 0.48 – 0.59% and a MnO_2 content of 0.09 – 0.30%. Honey-coloured and grey grossular garnet is commonly present as veins, and also 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)

Mindoolah is located on prospecting licence P20/2122 some 75 km northwest of Cue and about 1.5 km east of Mardoonganna Hill (Fig. 32.3). At this site, the steeply dipping, east-northeasterly trending Mindoolah porphyritic dolerite dyke has intruded Archean basalt (Fig. 32.4).

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. 32.5). 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 tables and polished spheres.

Lake Weelhamby area

Ninghanboun Hill (Perenjori, 2139)

Simpson (1951) records the presence of thulite at Ninghanboun Hill located 30 km north-northeast of Perenjori (Fig. 32.3). At this site, a relatively large pale pink to grey inclusion a few metres in length is

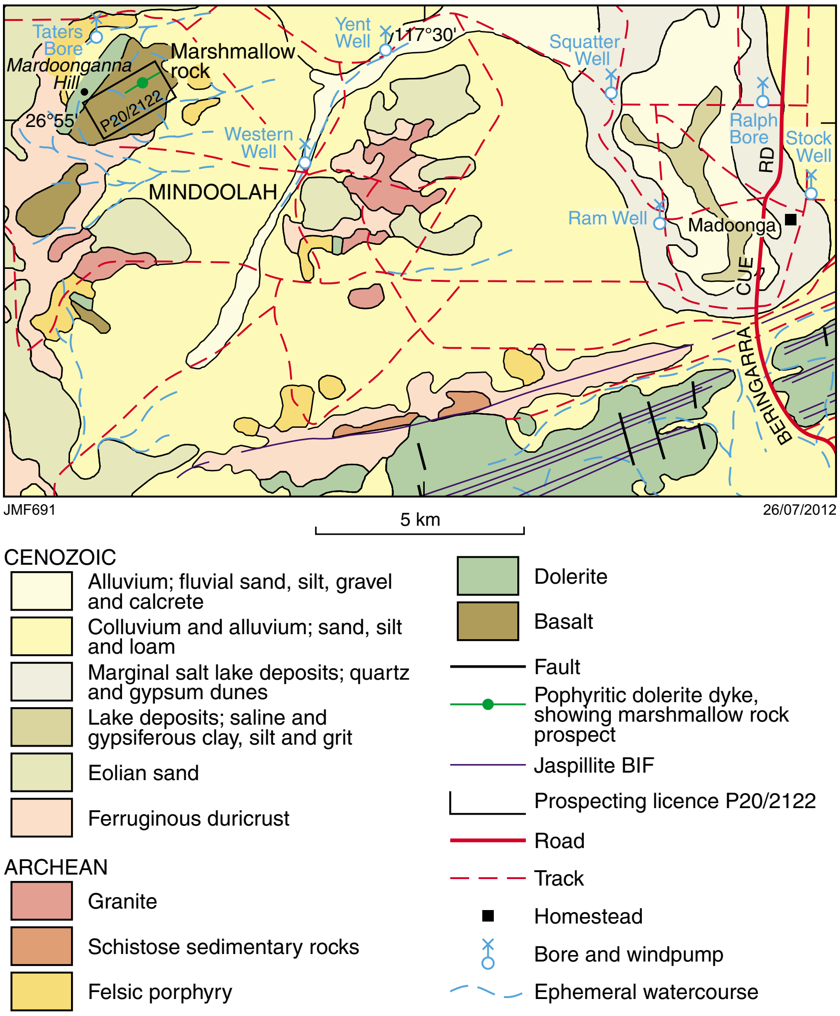

Figure 32.4 **Geology of the Mindoolah area, northwest of Cue (modified after Elias et al., 1983)**

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 have specific gravity values ranging from 3.28 to 3.32, and contain minor minerals including feldspar, amphibole, titanite, and zircon.

Yilgarn Craton — Eastern Goldfields Superterrane

Coolgardie area *(Kalgoorlie, 3136)*

The Western Australian Branch of the Gemmological Society of Australia possesses a sample of thulite reportedly originating from an unknown locality near Coolgardie (Fig. 32.3). Nothing further is known about the origins of this sample, shown in Figure 32.6.

Epidote–quartz–axinite rock

Pilbara Craton — Hamersley Basin

Newman area *(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 possibly 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 has recently reported the discovery of a single occurrence of epidote–quartz–axinite rock at an unknown site on Turee

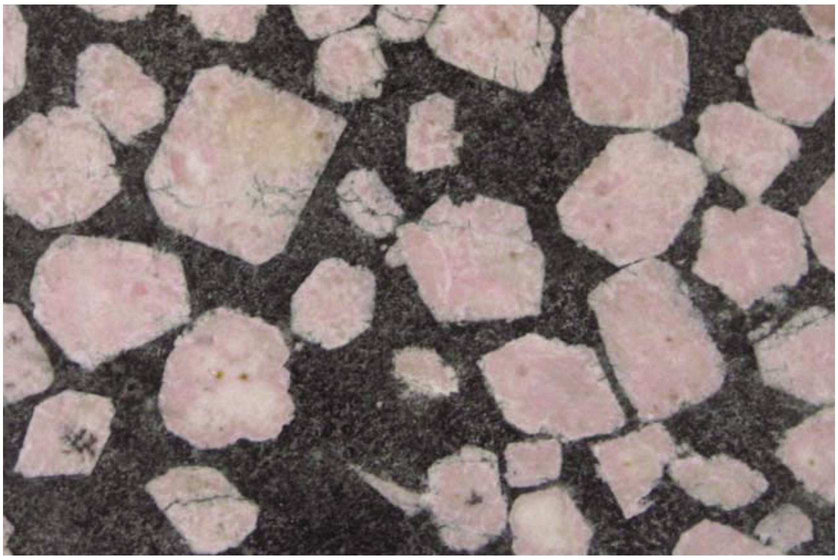

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Figure 32.5 'Marshmallow rock', a metamorphosed porphyritic dolerite containing hard, pink clinozoisite megacrysts, 20–40 mm in diameter

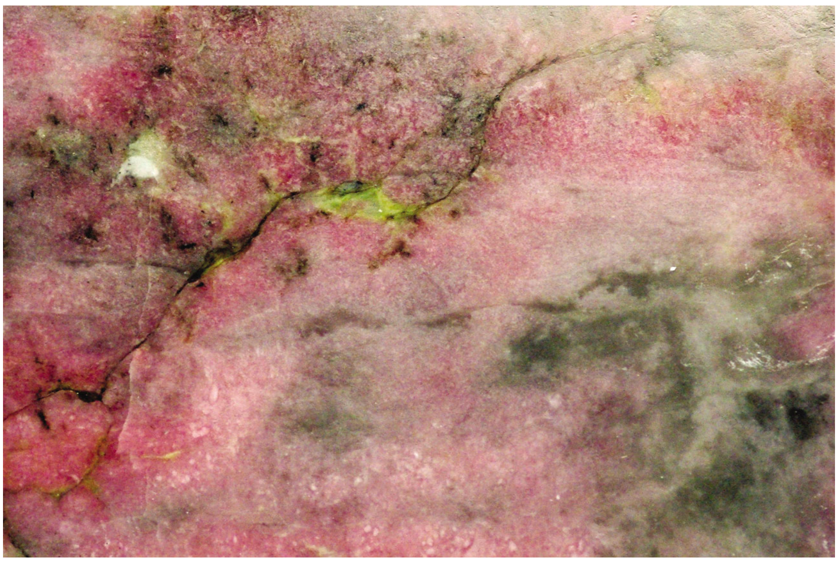

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Figure 32.6 Polished specimen of pink thulite reportedly from the Coolgardie area. Collection of the Western Australian Branch of the Gemmological Society of Australia

Creek Station, about 110 km west-southwest of Newman in the Archean–Paleoproterozoic Hamersley Basin. The occurrence comprises a vein of epidote–quartz–axinite, generally no thicker than 25 cm, that intersects the Weeli Wolli Formation (Fig. 32.7). The Weeli Wolli Formation is composed of banded iron-formation intruded by numerous concordant dolerite sills. It is proposed that the epidote–quartz–axinite (a complex borosilicate mineral) mineralization was formed as a product of hydrothermal alteration (Australian Outback Mining, 2012).

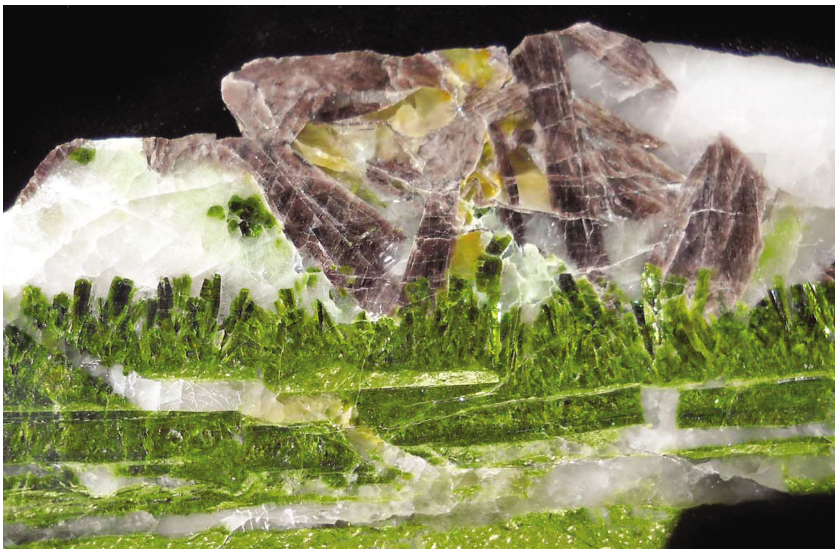

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Figure 32.7 Polished epidote–quartz–axinite rock showing green epidote crystals, milky quartz, and brown axinite crystals from Turee Creek Station west-southwest of Newman. Slab is approximately 15 cm wide (courtesy Glenn Archer)

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Chapter 33 Grunerite

Pilbara Craton

Abydos area

Desert gold prospect *(Wodgina, 2655)*

‘Desert gold’ is the local prospectors’ name applied to the golden-brown grunerite–quartz rock composed mainly 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 located on Kavir Downs Station on mining lease M45/1134, owned by Mr B Kayes, about 33 km southeast of the Wodgina Mining Centre (Fig. 33.1).

The prospect is on a low hill, possibly 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 to be 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 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. 33.2). The stone also contains quartz and is sufficiently hard (6.5 on the Mohs scale) to be suitable for cutting and polishing as a decorative stone (Fig. 33.3).

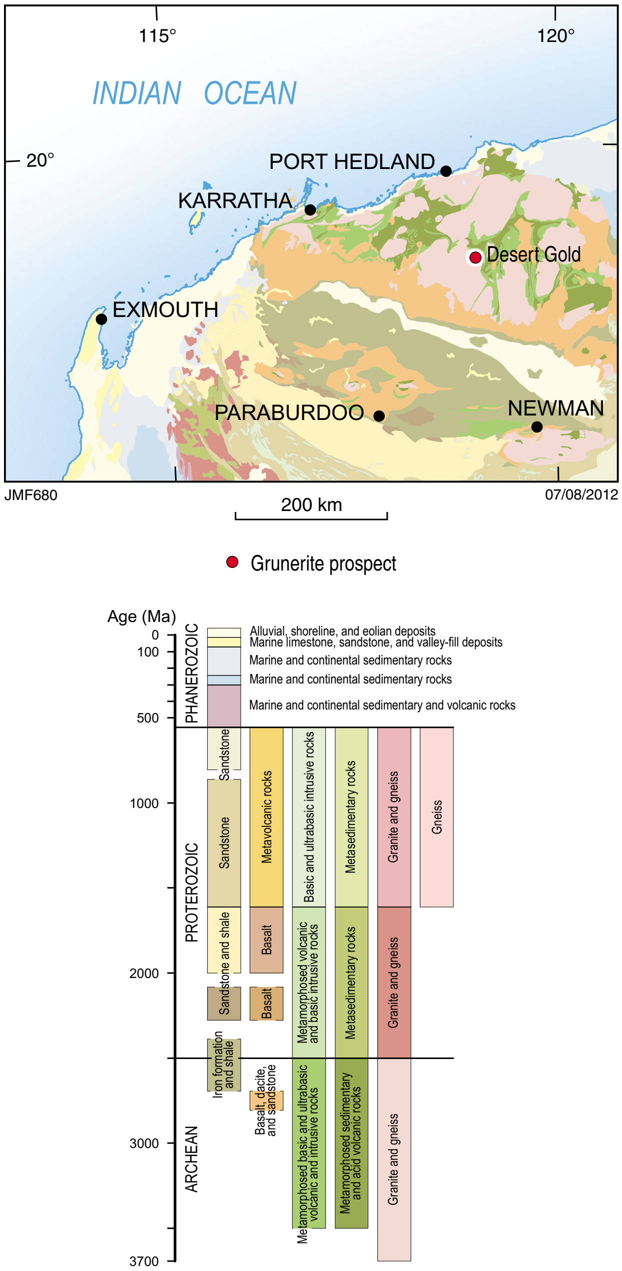

Figure 33.1 Location of the Desert Gold grunerite deposit

Grunerite
Iron-rich amphibole $[Fe^{2+}_2(Fe^{2+},Mg)_5Si_8O_{22}(OH)_2]$

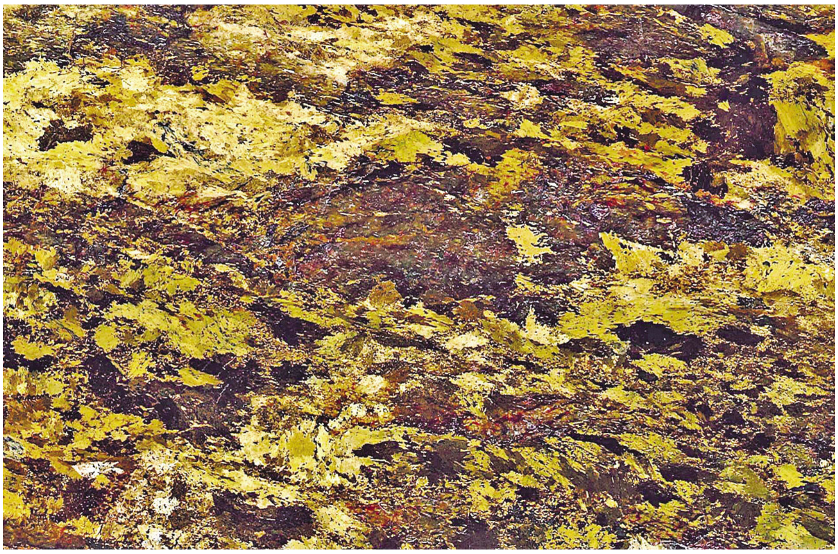

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Figure 33.2 A polished specimen of desert gold displaying masses of golden-bronze grunerite with individual crystal laths up to 15 mm in length

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Figure 33.3 A polished desert gold cabochon, 20 mm in diameter, with coarse laths of golden-brown grunerite clearly visible (courtesy Murray Thompson)

Chapter 34 Jade

Jade

Jade is a non-specific term used for a number of different fine-grained, hard rocks, commonly of green or white colour, used for jewellery and ornamental purposes. Jadeitite and nephrite are the only two rocks considered to be true jades and each has specific mineralogical compositions and textural properties.

Jadeitite or jadeitic jade is the rarest and most valuable form of jade, found mainly in Burma, Guatemala, and Japan. It is composed of the clinopyroxene mineral jadeite, with small amounts of feldspar or feldspathoids and formed under high-pressure metamorphism (Fig. 34.1).

Nephrite or nephritic jade contains the 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, Alaska, New Zealand, and Cowell in South Australia (Fig. 34.2a). In New Zealand, nephrite is known as 'pounamu' by the Maori people who carve it into prized artworks. Found in the Hokitika district on the west coast of New Zealand's South Island, the nephrite is translucent and bright to dark green, with black spots and other inclusions (Fig. 34.2b).

Both jadeitic jade and nephrite have random, finely felted or granular textures that result in their notable toughness. Nephrite jade generally has a finer texture and greater toughness, whereas jadeitic jade may also have a fine texture, but its prismatic pyroxenes are usually coarser grained.

Although both jades may appear similar they can be readily distinguished by differences in refractive index and specific gravity:

	Jadeite	*Nephrite*
Refractive index	1.666 – 1.68	1.606 – 1.632
Specific gravity	3.34	2.95

Both varieties of jade have been used and revered in many ancient cultures from Paleolithic times (>4500 BC) to the present day and are especially well represented in sculptural works and artefacts from ancient Chinese dynasties.

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Figure 34.1 Pale green jadeite carved pendant from Burma

Jade in Western Australia

No true jades have been recorded as being mined from Western Australia although there are unconfirmed reports of nephrite jade having been sampled from unknown locations in the Pilbara, Eastern Goldfields, and Ashburton regions (see below).

a)

b)

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Figure 34.2 **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 from the Hokitika district in New Zealand's South Island. Pendant is 45 mm in length (courtesy Te Koha Gallery, Franz Josef)**

There are also a number of different ornamental stones that have been mined and marketed under the term 'jade'. These ornamental stones include:

Common or trade name	Mineral or rock type
Ninghan black jade	Metamorphosed magnesian tholeiite (subalkaline metabasalt)
Pilbara jade or Marble Bar jade	Serpentine/chlorite
Indian jade	Aventurine
Karratha jade or Mount Regal jade	Microcrystalline quartz or chalcedony with green fuchsite mica
Pear Creek jade	Cryptocrystalline silica (chalcedony) possibly with green fuchsite mica
Australian jade (or Queensland jade)	Chrysoprase (an apple-green variety of chalcedony)

Stones from this table marketed as Indian, Karratha, and Pear Creek jades are discussed in Chapter 37; Australian jade (chrysoprase) is discussed in Chapter 14. The locations of Ninghan black jade and Pilbara jade are shown in Figure 34.3 and more accurate locations are given in Appendix 1.

Ninghan black jade

Yilgarn Craton — Murchison Domain

Yeoh Hills (NINGHAN, 2339)

Black jade, a metamorphosed magnesian tholeiite (a subalkaline metabasalt), is the trade name given to a hard, very dark, greenish-black, massive rock that is finely crystalline, tough and able to take an excellent polish (Fig. 34.4).

The Ninghan black jade deposit is located at Yeoh Hills, about 40 km west of Paynes Find. Access is via the gravel Yalgoo–Ninghan Road that intersects the Great Northern Highway adjacent to the Ninghan Station turnoff. The Yeoh Hills lie to the east of the gravel road and can be reached by narrow, rough tracks made by miners about 14 km from the highway turnoff (Fig. 34.3).

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 comprising 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 sequence and can be easily identified by its distinct outcrop pattern. In outcrop, the more massive material comprises

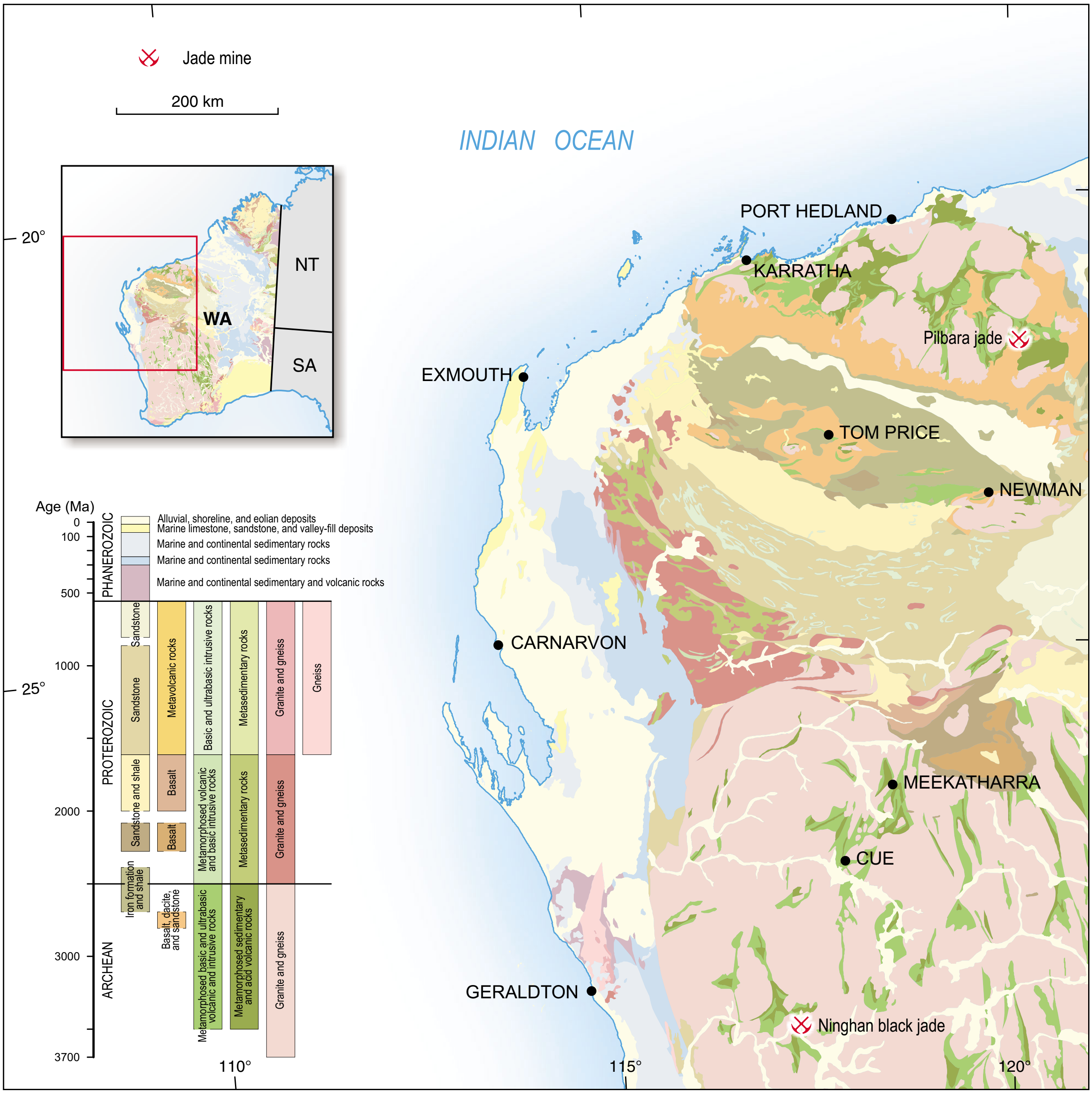

Figure 34.3 Location of jade deposits in Western Australia

Physical properties of Pilbara jade

Mineralogy	Dominantly massive chlorite		
Minerals	**Chlorite**	**Al-serpentine**	**Chrysotile serpentine**
Colour range	Green to grey-green	White	Pale yellow-green
Habit	Massive to microbanded	Fibrous	Asbestiform
Diaphaneity	Turbid to smoky translucence		Translucent
Lustre	Waxy		
Refractive index			
(min)	1.570	1.553	1.530
(max)	1.572	1.555	1.536
Birefringence	Low		
Hardness		2.5 – 3	
Fracture	Subconchoidal		
Specific gravity	2.58 – 2.71		
Weathering	Weathers to a brown to brownish-red, subvitreous, irregular surface		

Source: Hudson (1974)

large, sharply angular blocks coated with a thin red-brown iron oxide weathering rind (Fig. 34.5). In more deformed areas, the black jade becomes foliated or fractured and is 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 but can reach 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. Assaying has shown the jade to contain 157 ppm Ni, 998 ppm Cr, 51 ppm Co, 37 ppm Cu, 286 ppm V, and 7.32% Fe. These data are consistent with a magnesian tholeiite.

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Figure 34.4 A fish carved in Ninghan black jade from Yeoh Hills in the Paynes Find area (courtesy Soklich Trading)

Pilbara jade (or 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 it is 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 some 25 km north of Nullagine. The probable location is approximately 4.5 km northeast of the old Hales Grave Well where there are two mining leases, M46/63 and 44. Access is northward along the Nullagine to Marble Bar road and then along a track that leads northeast from the abandoned Hales Grave Well.

The Pilbara jade deposit is situated 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

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Figure 34.5 **Angular shards of massive Ninghan jade showing its characteristic thin, red-brown iron oxide weathering rind**

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Figure 34.6 **A sample of Pilbara jade (~30 cm wide) showing green chlorite surrounding white Al-serpentine cut by narrow fibres of asbestiform serpentine (courtesy Cyril Richter)**

green to grey-green rock composed almost entirely of chlorite. The rock weathers to produce a brown to brownish-red irregular surface, whereas freshly broken surfaces have a waxy lustre with subconchoidal fractures. Microscopic banding can be seen on some polished faces but the purest specimens are generally massive, displaying a slightly turbid to smoky translucence when held against the light.

Hudson (1974) also stated that a characteristic feature of 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. 34.6).

Pilbara jade occurs 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 that was probably introduced along channelways during the alteration process.

Mineable Pilbara jade occurs in kidney-shaped bodies (usually fractured in the near-surface environment) that are contained in what appears to be narrow dykes of ‘jade’ in

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Figure 34.7 **Handcrafted pendant of Pilbara jade inset with an 18 mm diameter Broome mabe pearl (courtesy Marion Egger)**

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 34.7.

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 indices between 1.612 and 1.618, and 1.620 and 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 sourced from the Nunyerry Station area, approximately 115 km south-southeast of Roebourne. This material was very difficult to diamond saw, and the colour unsuitable for gems, but the stone may prove ideal for base work in box making and overlay work (WR Moriarty, 2011, written comm.).

Yilgarn Craton — Eastern Goldfields Superterrane

- Grey-green to yellow-green, opaque and fibrous material found in an area known as Lindin, in the Eastern Goldfields (WR Moriarty, 2011, written comm.).

Ashburton region

- Pale grey-green to pale green, flaky and milky translucent material sourced from an unknown locality somewhere in the Ashburton region (WR Moriarty, 2011, written comm.).

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Chapter 35 Mookaite and pink opal

Mookaite

Mookaite is a commercial name for the varicoloured ornamental stone 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. These include a wide range of colours with attractive, mottled patterns, a general lack of directional weaknesses and a very fine grained nature combined with adequate hardness. These properties make it very suitable for cutting and polishing.

Mookaite is found within the Lower Cretaceous Windalia Radiolarite, part of the Winning Group of the Southern Carnarvon Basin. The Windalia Radiolarite consists of a series of sedimentary lithologies formed in a marine-shelf setting during times of high sea levels when siliceous microfauna (zooplankton) were abundant. The resultant rocks are fine grained, dominantly siliceous in nature and comprise radiolarian siltstones, sandy radiolarite, siltstone, and chert. Casts of ammonites, belemnites, and bivalves are also locally present (Hocking et al., 1985; Hocking et al., 1987).

The Windalia Radiolarite is a uniform white-weathering rock with poor, blocky bedding that rarely displays bedding structures. Fresh exposures are medium to dark grey, ranging to grey-brown when carbonaceous, and green-grey or olive-black when glauconitic. Although the Windalia Radiolarite is regionally widespread, it appears that mookaite is found only 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.

Physical properties of mookaite

Mineralogy	Dominantly massive ultrafine silica
Crystal system	Amorphous
Colour range	Varicoloured: white, cream, light brown, grey, orange-red, purple-red, yellow, and mauve
Colour cause	Concentrations of iron oxide/ 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: SG is variable due to compositional changes and variable porosity
Patterning	Variable: mostly rounded forms of mottles and blebs. Colour is commonly variable along microfissures and fractures

Properties and applications

Examination of thin sections shows mookaite to be dominantly composed of cryptocrystalline silica with a finely banded texture and coloured by hematite/goethite granules of varying concentrations. Throughout the groundmass are scattered tiny spheroidal and ellipsoidal particles (0.05 – 0.2 mm in diameter) that are poorly preserved microfaunal structures, predominantly radiolaria (Stocklmayer and Stocklmayer, 2010).

Coloured mookaite shows a wide range of hues and shades including yellow, red, brown, purple, and light mauve with each hue varying in intensity, tone, and shade (Fig. 35.1). The colours result from iron oxide-rich groundwater that has penetrated along conduits of fractures and micro-fissures 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. Thus, colourless zones indicate low concentrations of iron-rich granules and, accordingly, 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.

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. 35.2).

Mookaite and pink opal

Silicified, iron-stained radiolarite

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Figure 35.1 **A selection of tumbled, polished mookaite stones showing a wide range of colours and patterns (courtesy Judy Brewer)**

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Figure 35.3 **Polished, multicoloured, mookaite slices inlaid into a commercially manufactured, decorative table top**

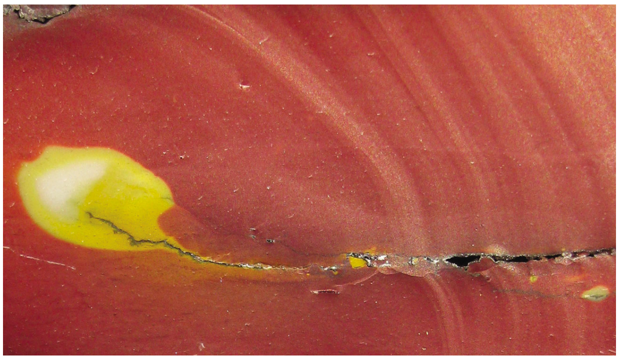

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Figure 35.2 **Fine liesegang red/pink banding in mookaite reflecting lighter and darker iron oxide zones**

Surface lustres of natural unpolished mookaite vary with freshly broken surfaces having a matte or earthy appearance with low reflection, whereas mookaite exposed at the surface may often show bright reflections resulting from a natural patina or desert varnish. Polished mookaite artworks and ornaments, generally display a high vitreous lustre, although at times some unpolished patches of matte appearance may remain (Fig. 35.3).

Mookaite in Western Australia

Southern Carnarvon Basin

Upper Gascoyne region

Mooka Creek (*Binthalya, 1848*)

Mookaite is mined on the former Mooka Station from several closely spaced sites on Mooka Creek adjacent to the Mardathuna track, about 32 km northwest of Gascoyne Junction, and 13 km north of the Gascoyne River (Fig. 35.4). In this area, surface mining of mookaite slabs is carried out on a campaign basis from three contiguous mining leases; M09/86 (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 Lower Cretaceous Windalia Radiolarite partially exposed by erosion of Cenozoic unconsolidated, alluvial sediments on Mooka Creek and 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. Scenes of surface mining of mookaite slabs may be seen in Mookaite (2011).

Fossickers should note that the best mookaite localities in the area are located within the area of the three mining leases mentioned above and permission for fossicking must be sought from individual tenement owners. The location of mookaite mines is shown in Figure 35.4 and more accurate positions are given in Appendix 1.

Pink opal

'Pink opal' is a prospectors' name applied to a different variety of mookaite that outcrops as a persistent bed of extremely bright pink opalized radiolarite near Binthalya Pool, which is located approximately 1 km downstream from the Archer mookaite mine on Mooka Creek (Fig. 35.4). This site, known as the Binthalya prospect, is contained within an exploration licence held by G Archer.

At this site, pink opal is present as a dominant, horizontal bed within zones of coloured porcellanites located beneath a surface-brecciated zone in which angular fragments of pink porcellanite have been cemented by iron and silica solutions to produce 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. 35.5a,b).

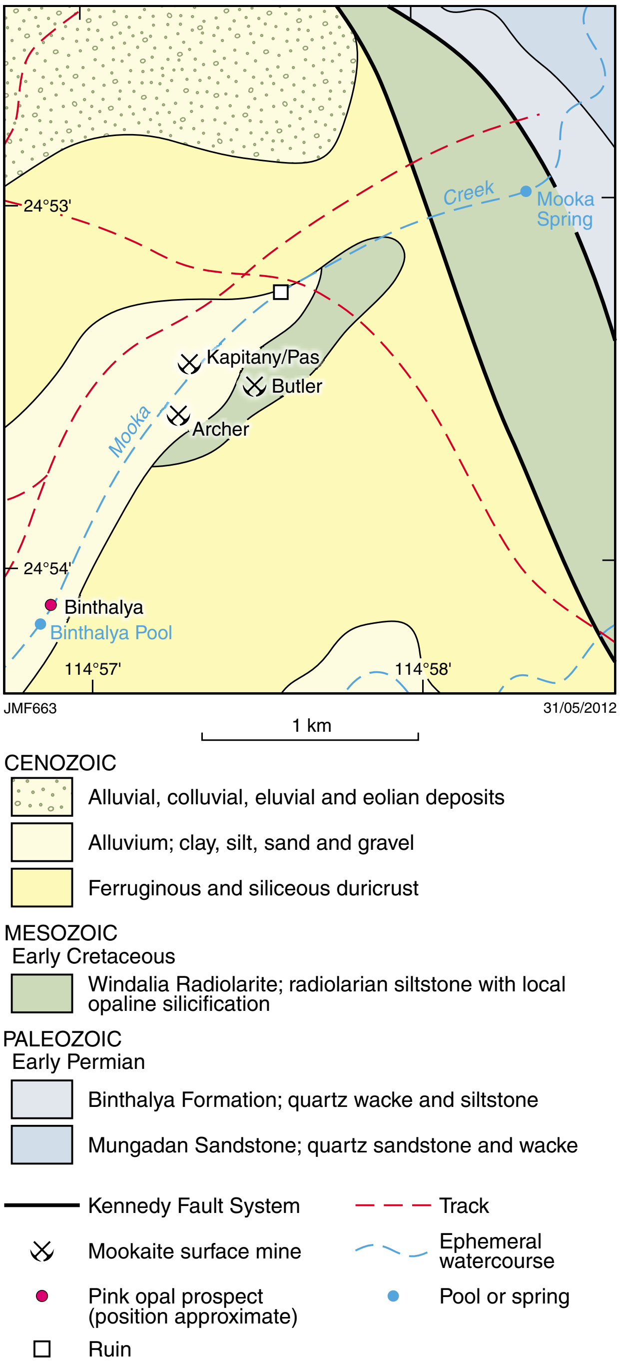

Figure 35.4 Sketch map of mookaite mining operations and pink opal prospect at Mooka Creek (modified after Denman et al., 1985)

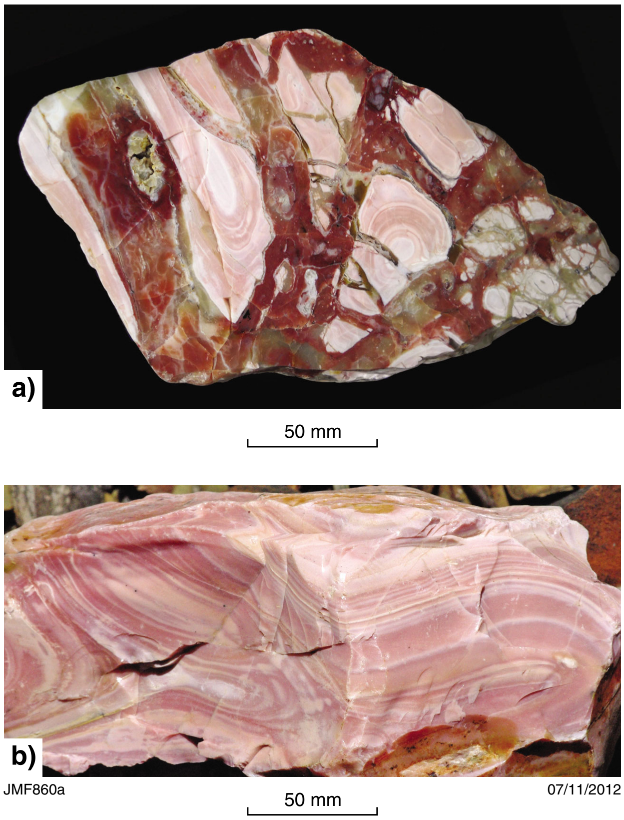

Figure 35.5 Pink opal specimens from the Binthalya prospect at Mooka Creek: a) angular fragments of brecciated pink opal, cemented by iron and silica, from the near-surface zone; b) visually attractive, banded pink opal, from the lower pink zone, showing its distinctive conchoidal fracture pattern (courtesy Glenn Archer)

Examination of pink opal thin sections has confirmed the rock is radiolarite with a dominantly isotropic, fine-grained mineral composition. Although not verified by XRD analysis, the pink opal's physical and visible optical properties suggest it is predominantly opaline silica, having a lower bulk density than the locally porcellanized mookaite material. Pink opal commonly shows liesegang banding and often contains small vugs and fine fractures infilled with microcrystalline quartz. Microscopic, lustrous grains within the rock result from reflections of granular quartz where it has infilled pores and replaced radiolarian structures.

The photomicrograph shown in Figure 35.6 shows two types of radiolarians with the conical form assigned to the Nassellarian Order, and the circular object with one spine protruding in the upper right-hand corner is identified as part of the Spumellarian Order (D Haig, written comm.).

In a manner similar to the origin of mookaite, the re-silicification of the Windalia Radiolarite forming 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 35.5b). 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. 35.7).

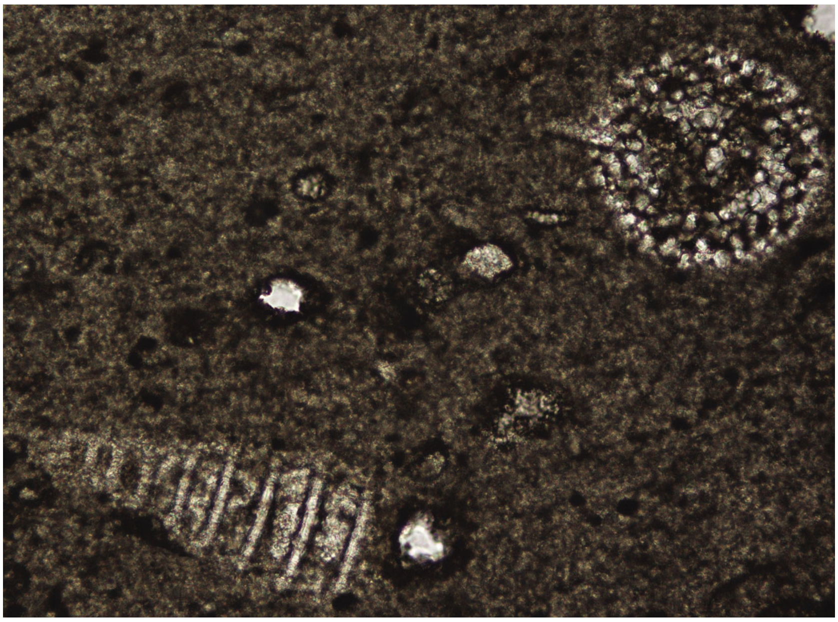

Figure 35.6 **Photomicrograph of a section of pink opal showing two varieties of radiolarian with the conical form assigned to the Nassellarian Order, and the circular object with one protruding spine, in the upper right-hand corner, is from the Spumellarian Order.**

Figure 35.7 **Colourful, polished cabochons of pink opal (upper left) and mookaite (lower right) (courtesy Judy Brewer)**

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Chapter 36 Orbicular granite

Orbicular granite

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. These include 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 twelve 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 having less-defined outlines, to larger, multilayered varieties with mafic outer shells (Fig. 36.1).

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Figure 36.1 A 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)

A generalized succession from the centre of an orbicule consists of a coarsely radiating mix of hornblende and plagioclase with the different shells fairly sharply defined by crystal aggregation, crystal shape, and differing granularity. The outer radiating shells commonly have a coarser texture and greater proportion of mafic minerals, including opaques and titanite. Green biotite is commonly a dominant mineral in the orbicule outer shells, where it appears as a replacement mineral owing to later changes in magma chemistry. Pockets and veins of complex sulfide intergrowths may also be found associated with the 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 (sphene) with lengths reaching 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 book ends and coasters, as well as slabbed and polished tiles, have been made from the rock.

Orbicular granite in Western Australia

Yilgarn Craton — Murchison Domain

Mount Magnet area

***Boogardie** (Mount Magnet, 2441)*

The Boogardie Orbicular granite deposit is located on Boogardie Station, 35 km west of Mount Magnet. At the Boogardie minesite, the central tenement Mining Lease M59/28 owned by Mr K Seivwright, encloses the Boogardie quarry, which is currently in care and maintenance. Although the quarry is not in production, there is abundant stockpiled material (Fig. 36.2). 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

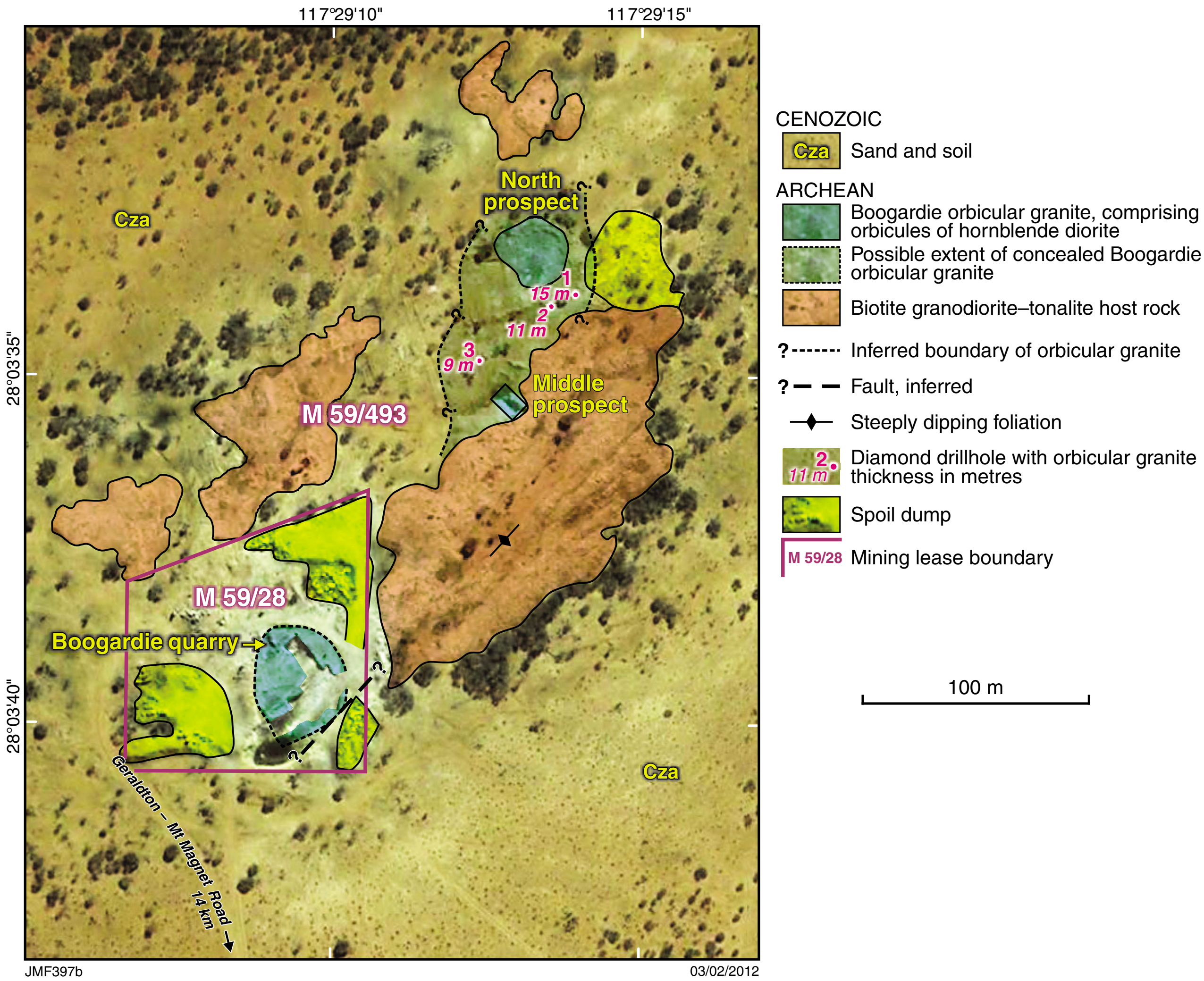

Figure 36.2 **Geological sketch map of the Boogardie orbicular quarry and exploration areas (modified after Fetherston, 2010)**

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 appears to have been no significant mining operations since the late 1990s, whereas exploration has proceeded in more recent times at the North and Middle prospects to the north of the quarry (Fig. 36.2).

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. 36.2; 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 in shape but also contain near-spherical, irregular and broken shapes. Orbicules have an average diameter in the longest axis of around 140 mm, but may extend to 200 mm. Individual orbicules are generally separated from the enclosing granodiorite–tonalite matrix by an outer shell of up to 10 mm in thickness comprising hornblende, biotite, and plagioclase feldspar with minor opaque oxide and titanite. Within this shell, orbicules contain five to seven (or more) well-defined zones of variable width, structural complexity, and mineralogy. Well-developed orbicules may have a central core, most commonly coarse-grained plagioclase feldspar, but also mafic xenoliths or fragments of previously formed orbicules (Fig. 36.3; Bevan, 2007).

Figure 36.3 Boogardie orbicules enclosed in a granodiorite–tonalite matrix. The rock mass, including orbicules, has been cut by a late-phase, pink pegmatite vein approximately 120 mm thick (Fetherston, 2010)

The distribution and morphology of the orbicules suggests a multi-stage history of nucleation and development. It appears that orbicules developed during early crystallization, forming on seed crystals, xenolith material or fragments of previously formed orbicules. 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).

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Chapter 37 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. Firstly, 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, opal, and chalcedony.

The quartz classification is represented by three groups: macrocrystalline quartz, microcrystalline quartz, and amorphous silica materials. It should be noted that many siliceous gems and decorative stones are commonly found as mixtures of more than one form of silica, such as a mix of chalcedony and opal. 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, praseolite, and quartz varieties that contain other mineral inclusions as in sagenitic quartz, 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.

Microcrystalline quartz

These minerals require 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, patches or in radiating or spherulitic groups. The fibrous variety is referred to as chalcedony, a quartz variant with optical and physical properties differing slightly from quartz, such as having a lower refractive index. Many of these fine-grained quartz varieties contain a mixture of silica polymorphs (other forms of SiO_2) including microquartz, chalcedony, and opal. 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 owing to other mineral impurities. Chert commonly forms extensive horizons in sedimentary rock formations, mostly 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, many in the form of agate and carnelian. Other chalcedonies show evidence of their origin by replacement of existing mineralogy, such as chrome chalcedony after serpentinite.

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.

Opaline silica, which may be distinguished only by XRD techniques, is mostly found associated with coarser silica polymorphs such as chalcedony and microquartz as well as the quartz polymorphs cristobalite, tridymite, and moganite.

Siliceous decorative stones

Siliceous decorative stones (SiO_2 and $SiO_2.n\ H_2O$)

Green decorative stones in Western Australia

There are many occurrences of green ornamental stones throughout the State. Some are quarried for dimension stone (dressed building stone) such as Toodyay quartzite and 'Karratha jade', whereas others are collected from numerous occurrences and used to make small decorative items such as book ends, coasters, table tops, carvings, sculptural works, cabochons, and beads.

Quartz is the dominant rock component of most of these green ornamental rocks but will also be found in its fine-grained varieties chalcedony and chert (impure cryptocrystalline types). The green colour in these ornamental rocks derives from minor mineral content; most common and important is the green chromiferous muscovite mica, fuchsite.

Colour is the most important feature of these rocks and includes many hues and intensities of greenness (sometimes described as malachite-green). Some rocks additionally show variation of colours caused by banding, schistosity, and veining.

Aventurine

Some green quartzites exhibit a glistening sheen effect caused by light reflection from platelets of included green fuchsite. This effect is enhanced when the mica inclusions occur in planes, which is commonly the case in schists. These glistening, speckled, and metallic effects are termed aventurescence. A quartzite showing this effect is termed aventurine quartzite. Aventurine quartzite is a rock but some minerals, for example feldspars and cordierite, can demonstrate this reflection effect from their inclusions. Aventurescent materials are mostly green, but are known in other colours including blue, brown, white, and yellow. The colour is dependent on the particular mineral inclusions (iron oxides, copper, fuchsite, mica etc.) of the rock or mineral. The best aventurine effects are seen when the host rock or mineral is colourless, 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 will range between 2.64 and 2.69, and hardness is lower than quartz at about 6.5. Fuchsite quartzite will give a positive Chelsea filter (a green filter that transmits only green and red light) response; showing red indicates the presence of chromium.

Fuchsite

Fuchsite is a muscovite mica in which chromium substitutes for aluminium in its formula; one analysis reports 4.81% Cr_2O_3 in a fuchsite rock although it may be as much as 6% (Deer et al., 1962). In some whole rock analyses, Simpson (1952b) recorded various percentages for the chromium content; from 1.10% Cr_2O_3 from a fuchsite schist at Nullagine to 2.20% Cr_2O_3 from a rock with andalusite and corundum at Burbanks.

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 fuchsite is associated with corundum and kyanite. Simpson also noted that fuchsite is 'a marked feature of the metamorphosed sediments (quartzites) of the early Precambrian succession'.

Chrome-rich chert in Western Australia

Pilbara Craton

Karratha area

Mount Regal mine (Dampier, 2256)

The Mount Regal chrome chalcedony mine is situated on mining lease M47/363 located 12 km southwest of Karratha on the Pilbara coast (Fig. 37.1). The mine is sited on a ridge of folded, moderately dipping Archean beds of green, chrome-rich chert in the vicinity of ultramafic rocks that are 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 care has to be exercised in stone removal through the exclusive use of large excavators. This operation produces 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' (Fig. 37.2).

Laboratory testing has shown that this rock is possibly an altered ultramafic lithology. It consists mainly of massive, extremely fine grained quartz–sericite–kaolinite, together with fuchsite, which colours the rock green, and 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.

Pear Creek area

Pear Creek jade prospect (Coongan, 2856)

The Pear Creek jade deposit is located 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. 37.1).

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. 37.3). The Pear Creek jade deposit is associated with Archean mafic and ultramafic schists.

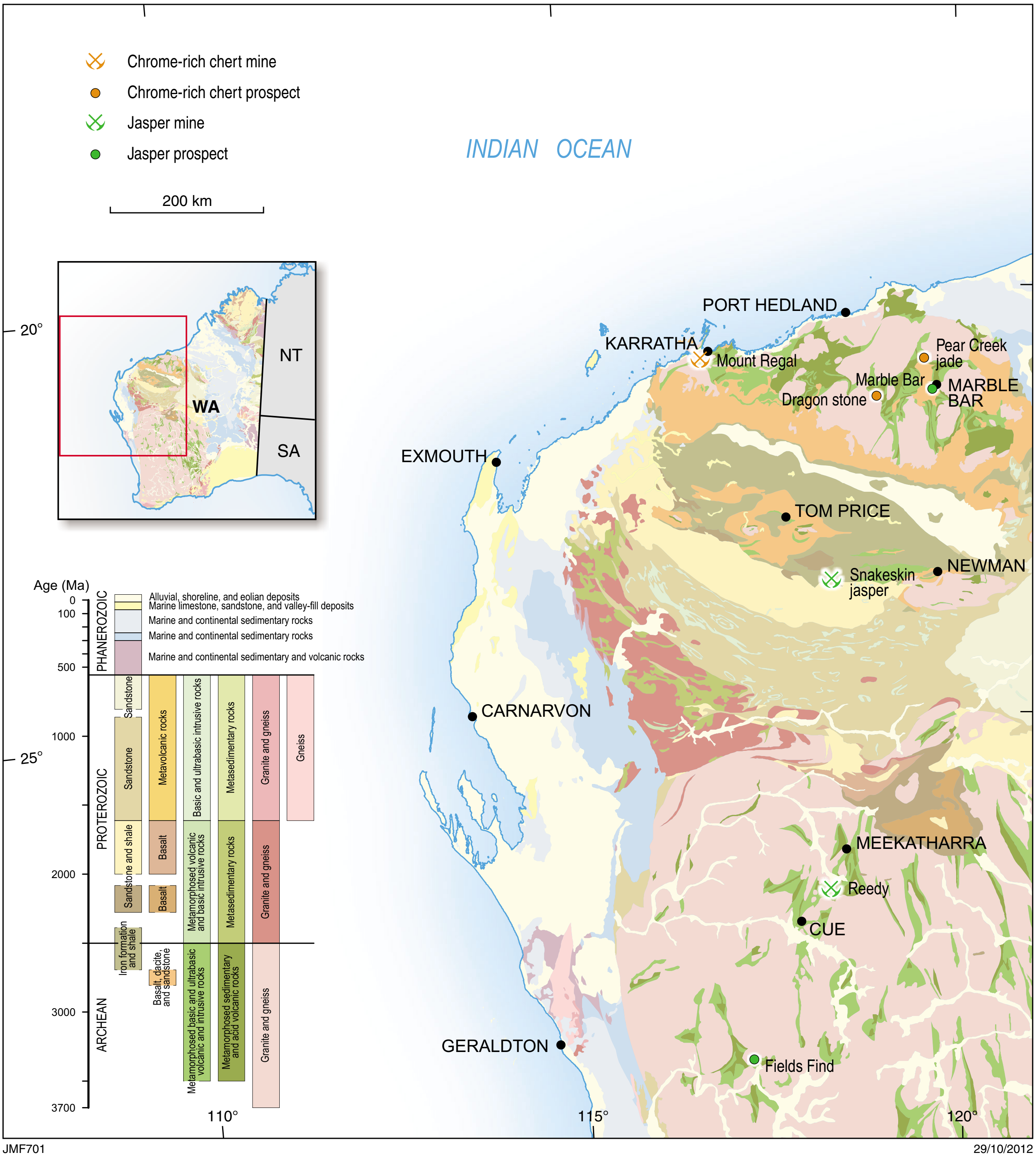

Figure 37.1 Location of other siliceous stones in Western Australia

Laboratory examination showed the rock to be dominated by cryptocrystalline silica, partly 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 ?chromite grains. This suggests 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 located on Kavir Downs Station within mining lease M45/1004, about 35 km east-southeast of the Wodgina Mining Centre (Fig. 37.1).

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 located in an area of Archean schist and quartzite adjacent to an intrusion of metamorphosed ultramafic rock, the possible source of the chromium.

X-ray diffraction analysis of this rock has shown that it is composed largely of microcrystalline quartz in the form of chert together with small amounts of muscovite and fuchsite, with the latter probably being responsible for the overall green colouration.

Visually, dragon stone has a mid-green cherty matrix, often interspersed with fine red, probably ferruginous-rich bands and red blebs, hence the name dragon's blood stone (Fig. 37.4). 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. 37.5).

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 due to 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), as well as green jasper. Green jasper, of a uniform colour is sometimes referred to as prase, and lighter green as plasma (Webster, 1975). It should be noted the term prase is nowadays also used in describing other green-coloured rocks, especially fuchsitic quartzites.

It is widely agreed that most of the sediment in 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 ten nanometres impart the red colour to the red jaspers. Cherts may also form by the silicification of fine-grained calcareous rocks, siltstones, and shales. Cherts are predominantly paler than the more intensely coloured jaspers.

Jasper is opaque and has a dull lustre, which are the two most significant features that distinguish it from chalcedony. The microstructure of both is similar although jaspers are formed of a heterogeneous mass of fibrous chalcedonic silica, commonly as spherulitic aggregates, interspersed with fine-grained quartz crystals. Metamorphosed jaspers may consist almost totally of granular quartz.

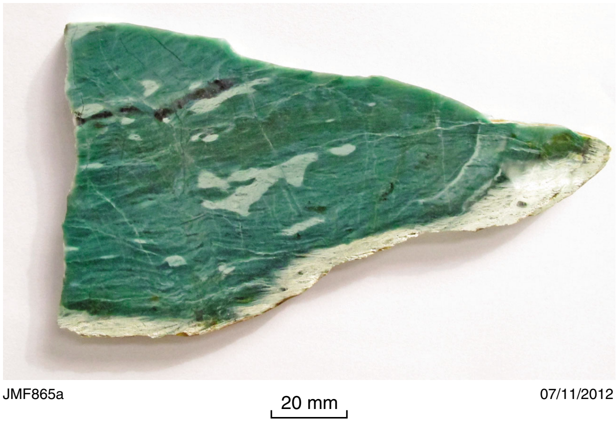

Figure 37.2 Polished slab of mid-green Karratha jade

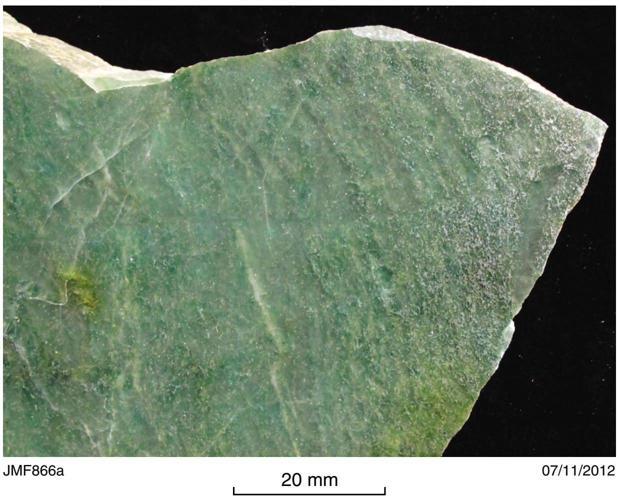

Figure 37.3 Siliceous, dark green Pear Creek jade

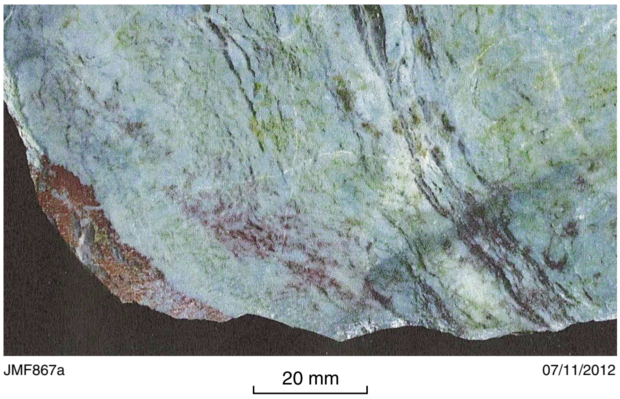

Figure 37.4 Mid-green dragon stone displaying fine red bands and blebs of ferruginous material

Figure 37.5 Carving of a fabulous beast in dragon stone (courtesy Soklich Trading)

The physical properties of jasper occupy a wide range owing to variable mineral impurities. Refractive indices measure approximately 1.54 (as spot readings) and specific gravity lies mostly between 2.58 and 2.91. Hardness is just below that of quartz (7 on Mohs scale), but jasper is a tougher material.

Jaspilite comprises thin bands of iron oxides alternately bedded with red jasper and is present in BIFs. A good example of jaspilite is shown in Figure 26.12 (Chapter 26) in the form of tiger iron from the Ord Ranges in the Port Hedland region.

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, book ends, and polished slabs. Polished slabs of brightly coloured banded jaspilite will mostly reveal the fineness of the original sedimentary bedding, commonly as waved and contorted layering with microfolding and other small-scale structural features such as fracturing, brecciation, and secondary cementation.

For commercial reasons, the term ‘jasper’ is also used as a suffix in describing many ornamental rocks of unspecified type that are not mineralogically true jasper or jaspilite. They comprise rock types that are distinctive in some way, with some named after their place of origin and others for a distinctive texture. Several of them have attractive colour patterns caused by secondary iron staining by iron oxide and iron hydroxide minerals in the form of irregular fracture fillings, blebs, bands with fretted patterns, and concentric varicoloured leisegang banding.

Jasper misnomers specific to Western Australia include picture jasper, outback jasper, Noreena jasper, Turee Creek jasper, convoluted jasper, Duck Creek jasper and black jasper conglomerate.

Jasper and jaspilite are common throughout the Yilgarn and Pilbara Cratons and can be found in many of the BIF units. Because they are composed of hard and tough material resistant to weathering, pebbles and cobbles of jasper and jaspilite 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 this State is described in Simpson (1951). Gemstones in Western Australia (Geological Survey of Western Australia, 1994) lists locations in which jaspers can be found. These include;

- Red-and-black banded jasper can be collected from about 76 km south-southwest of Kalgoorlie (KALGOORLIE, 3136)
- Some good jasper, suitable for tumbling, has been found in the Lake Rebecca area (MULGABBIE, 3337)
- Finely banded jaspilite can be found 3 km east of Linden (LAKE CAREY, 3339)
- Striking red-and-white banded jasper is found in the Wiluna district (WILUNA, 2944)
- A breccia, composed of fragments of jasper in a siliceous matrix is found on the eastern side of Pinyalling Hill (NINGHAN, 2339)
- The hills around Mount Jackson are a favourite collecting area for jasper (JACKSON, 2737)
- Weld Range is one of the best collecting localities for black-and-red ribbon jasper (MADOONGA, 2444).

Pilbara Craton

Marble Bar area

Marble Bar chert (MARBLE BAR, 2855)

The Marble Bar chert site is located 3.5 km west-southwest of the town of Marble Bar (Fig 37. 1). This chert is a visually attractive red-and-white chert (a jasper) that 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. 37.6a). 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 located on mining lease M52/32 about 80 km east-southeast of Paraburdoo in the Archean–Paleoproterozoic Hamersley Basin (Fig. 37.1). The jasper lies within BIF 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. 37.6b). 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 at the Reedy area, approximately 60 km northeast of Cue (Fig. 37.1). At this site, a finely banded and folded, dark red jasper is intersected by a network of white quartz veins (Fig. 37.6c). No other information is available.

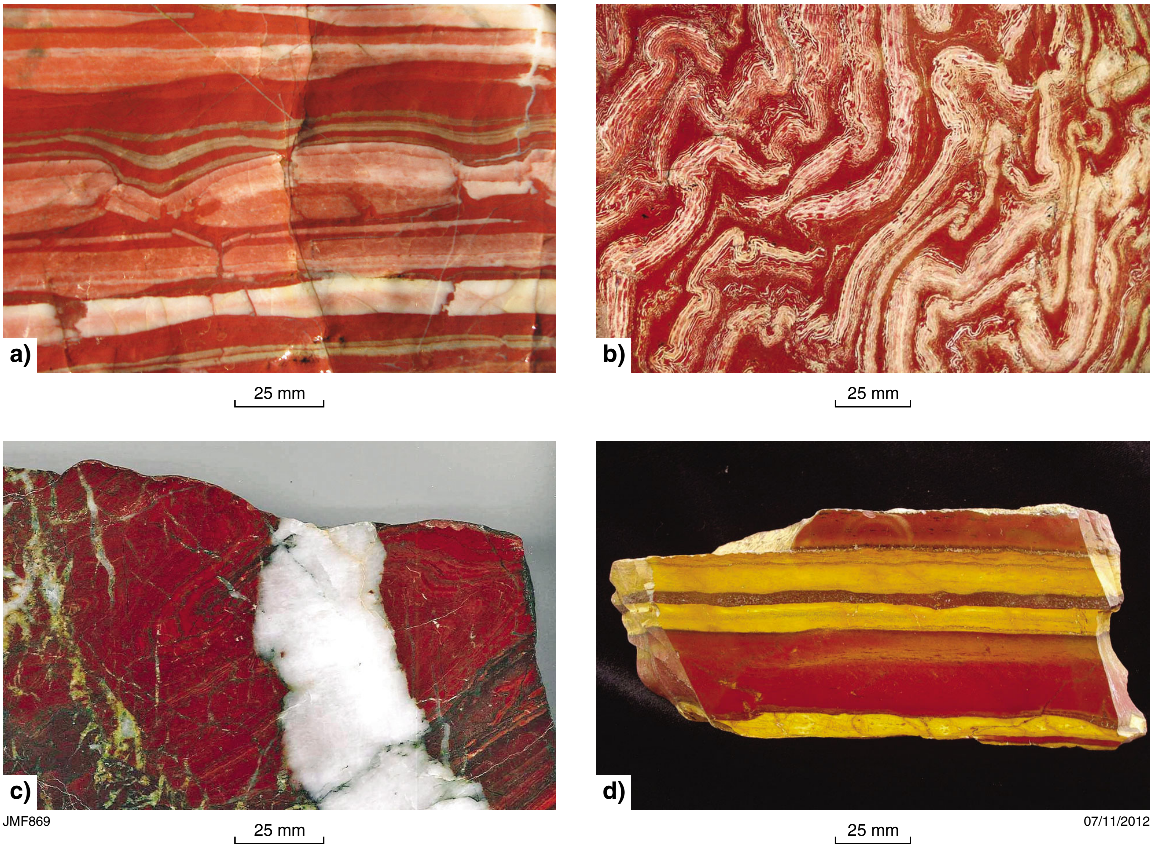

Figure 37.6 **A selection of Western Australian jaspers: a) Marble Bar chert (red-and-white banded jasper) (after Van Kranendonk and Johnston, 2009); b) orange-red Snakeskin jasper from the Hamersley Basin, showing its 'snakeskin' texture; c) red-banded jasper intersected by a white quartz vein from 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)**

Fields Find area

Desert Sunset (Ninghan, 2339)

The Desert Sunset banded jasper is located on pending mining lease M59/723 in the Fields Find area, about 50 km northwest of Paynes Find (Fig. 37.1).

At this site, the mining lease application covers interlayered Archean mafic, felsic, and metasedimentary rocks containing steeply dipping BIFs. These outcrop discontinuously in a southwesterly direction over a distance of about 2 km and range from a few metres to tens of metres in thickness. The BIFs 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. 37.6d; Fetherston, 2010).

In 2008, polished specimens of Desert Sunset were exhibited at the Marmomacc international trade fair in Italy and received some strong interest.

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Chapter 38 Serpentine and talc

Serpentine and talc, related members of the mineral group of hydrous magnesium silicates, 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. Suitable varieties are used for ornamental carving of high-quality sculptures and other visually attractive pieces of ornamental stone such as clockfaces and coasters.

Serpentine group

The serpentine group of minerals comprises a number of polymorphic forms with the general formula $Mg_3Si_2O_5(OH)_4$, the most important being chrysotile, lizardite, and antigorite. Their differences are minor and almost indistinguishable in hand specimen although chrysotile is more likely to have an asbestiform habit, and antigorite and lizardite are usually found as cryptocrystalline masses. Lizardite is the most common serpentine variety. There is relatively little chemical substitution in the serpentine minerals by other elements except nickel and aluminium.

The serpentine group of secondary metamorphic minerals are derived mainly from ultramafic rocks such as dunites, pyroxenites, and peridotites by a process of 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 those in contact with dolerite intrusions, when 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 often conspicuous, and black, opaque grains of relict chromite or magnetite are commonly preserved.

Serpentine and talc

Hydrous magnesium silicates

Gemmological materials

Serpentine minerals and serpentinite rocks have a wide variety of colours and are usually grouped into two categories as gemmological materials:

- **Precious or noble serpentine**

  This material is light to dark green in colour and translucent, even in thick pieces. The most distinctive and important variety is bowenite, a massive, fine-grained variety of antigorite that is light yellowish-green, with a waxy lustre, and 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 often speckled with black opaque minerals, commonly 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 according to mineral composition from about 2 to 5 on the Mohs scale.

Applications

Because serpentine minerals are relatively soft, and occur in an extensive range of attractively patterned colours, they are a popular medium for sculpting, carving into small artefacts and trinkets or for the manufacture of pendants, beads, and other items of jewellery. Serpentine can be easily distinguished from nephrite jade by its lower hardness and refractive indices.

Physical properties of serpentine minerals

	Chrysotile	Lizardite	Antigorite
Crystal system	Monoclinic	Monoclinic	Monoclinic
Habit	Fibrous	Lamellar	Fibrous
Colour range	Yellow, white, grey-green	Green, white	Green, green-blue, 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 – 4.0
Specific gravity	2.22	2.55	2.60
Cleavage	Prismatic	Perfect basal	Perfect basal

Serpentine 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 over 60 different occurrences of serpentinite (a rock consisting almost entirely of serpentine group minerals) within the State, and since that time detailed field mapping has identified many more. It seems that most serpentinite sites have never been investigated for their ornamental stone attributes. Accordingly, only the more significant and better documented serpentine occurrences are discussed below and these are shown in Figure 38.1.

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, situated about 25 km north of Nullagine township (Fig. 38.1). The probable location is approximately 4.5 km northeast of the old Hales Grave Well, where two mining leases M46/63 and 44 are located. Access is northward along the Nullagine to Marble Bar road and thence 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 occurrence 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 (see Fig. 34.6 in Jade, Chapter 34).

Tambourah region

Soanesville Mining Centre (*TAMBOURAH, 2754*)

Soanesville Mining Centre is located about 70 km southwest of Marble Bar (Fig. 38.1). 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 located near the northern edge of the TAMBOURAH 1:100 000 map sheet and extending over a northerly direction for some 7 km (Van Kranendonk and Pawley, 2002). Immediately west of Soanesville Mining Centre is a series of peridotites and ultramafic schists that are probably the source of serpentinite rock in the vicinity. There are reports stating that chrysotile was mined from Soanesville to the end of 1977 (Van Kranendonk, 2003).

The publication Gemstones in Western Australia (Geological Survey of Western Australia, 1994) described the occurrence of 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 often tinted by ferric oxide. Such specimens, which show all tints from bronze through golden yellow to various shades of green, exhibit a chatoyancy due to 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 is probably located in an isolated area approximately 45 km south-southeast of Whim Creek and about 10 km south-southwest of Mount Satirist (Fig. 38.1).

In this area, a number of relatively narrow, northerly-trending linear ultramafic outcrops are present (Smithies and Farrell, 2000). These rocks comprise chlorite–actinolite–serpentine–epidote schist altered after a sequence of high-Mg basalt and komatiite. Gemstones in Western Australia also records occurrences of 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. 38.1). The Nunyerry mine workings are located close to Nunyerry Spring and may be accessed by a track that leads northward from the Roebourne–Wittenoom road at a point a few kilometres north of Mount Florence Homestead.

The old chrysotile mine inhabits a narrow, northeast-trending lens of altered komatiite ultramafic rock comprising serpentine–talc–tremolite (Smithies and Hickman, 2004). It is reported that over 6000 t of chrysotile were obtained from serpentinite and it has been suggested that this area could potentially supply material for use as a semiprecious stone (Kriewaldt and Ryan, 1967). The area surrounding the Nunyerry mine site 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. 38.2).

Dampier region (Dampier, 2256)

The Dampier 1:100 000 geological map (Hickman, 2001) shows a relatively wide belt of serpentinite rock trending easterly and centred on Mount Princep adjacent to the Tom Price railway road about 14 km south-southwest of Karratha (Fig. 38.1).

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.

It would appear that this area may have some potential as a source for ornamental serpentinite stone but this is yet to be demonstrated.

Talc

Talc is a hydrated magnesium silicate with the formula $Mg_3Si_4O_{10}(OH)_2$ that generally shows little variation in composition but sometimes contains small amounts of aluminium and titanium that may substitute for silicon, and also small amounts of iron, manganese, and aluminium that may substitute for magnesium. It is an extremely soft, sectile mineral with a hardness of 1 (the standard on the Mohs scale). It has a characteristic soapy or greasy feel and a pearly lustre, and is commonly found as scaly, foliated, or massive aggregates. The scaly aggregates form laminae that are commonly flexible but not elastic. The colour of talc varies from white through greenish-white to grey or pale brown.

Physical properties of talc

Crystal system	Monoclinic or orthorhombic
Habit	Massive, foliated or fibrous, rare crystals
Colour range	Apple-green to silvery-white, greenish-grey, brown
Lustre	Pearly
Diaphaneity	Subtransparent to translucent
Refractive index	1.539 – 1.589
Birefringence	0.05
Pleochroism	Rare
Hardness	1 (some local talc = 1.5)
Specific gravity	2.7 – 2.8
Cleavage	Perfect basal

Massive forms of talc are steatite and soapstone. 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.

Two common occurrences of talc result from the hydrothermal alteration of ultramafic rocks, generally referred to as ‘steatitization’, and from the metamorphism of siliceous dolomites. Talc may also result from the hydrothermal alteration of mafic lithologies, a considerably rarer process.

Steatitization is commonly, but not invariably, associated with the serpentinization process, although some talc schists may form directly from unserpentinized ultramafic rocks. In other environments it has been shown that the steatitization actually took place after 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 give rise to large and high-grade talc deposits, such as the Three Springs and Mount Seabrook deposits in Western Australia.

Talc is a popular medium in the sculpting and carving industry where soft and reasonably competent forms such as steatite and soapstone are often preferred. Also, material displaying attractive patterns and colour variations is sought after. A set of carved talc vases in different colours from the Three Springs talc mine is shown in Figure 38.3.

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. 38.1). Deposits are

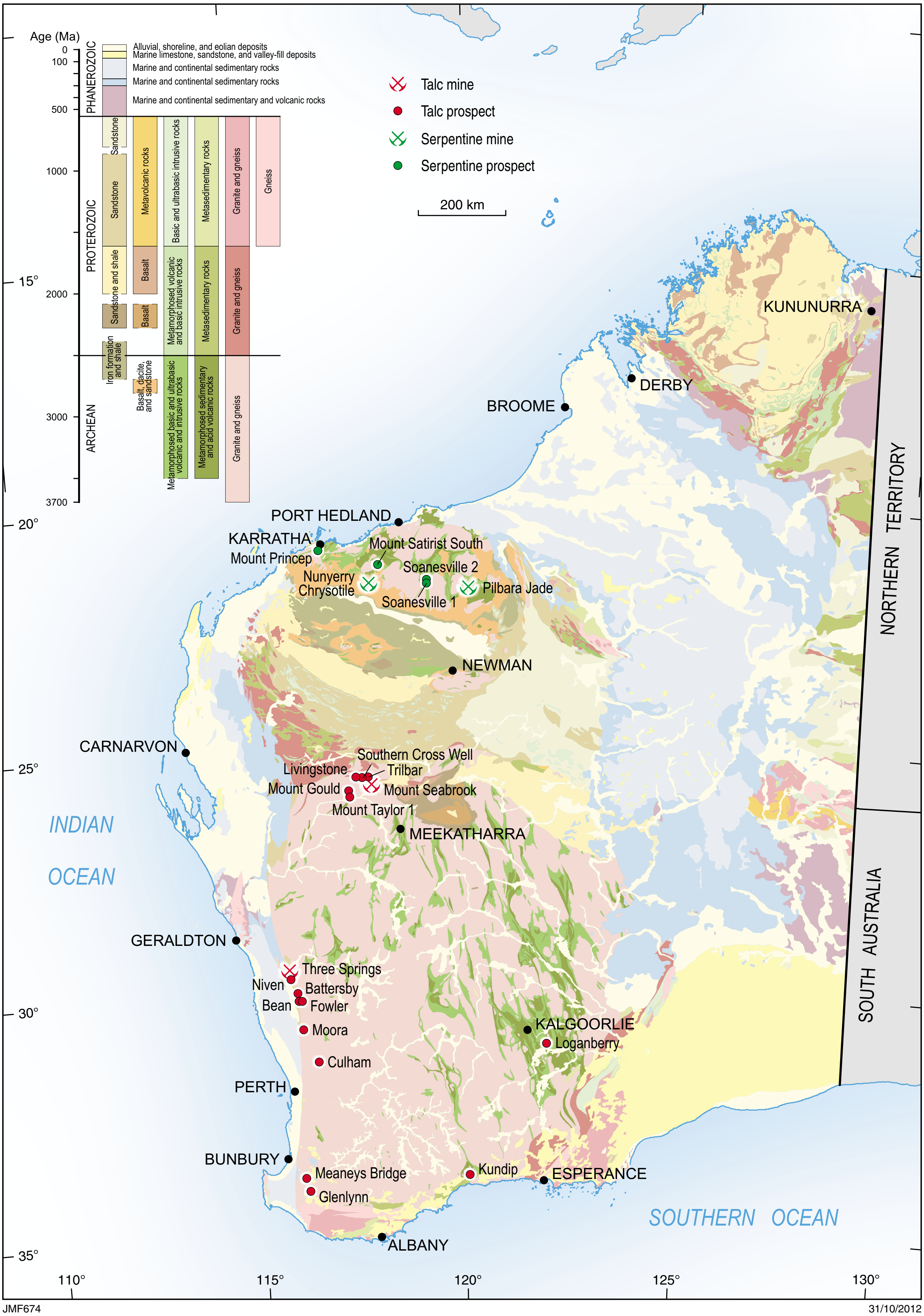

Figure 38.1 **Location of ornamental-grade serpentine and talc deposits in Western Australia**

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Figure 38.2 **A finely carved fish in serpentinite from the Nunyerry chrysotile deposit (courtesy Archean Gems)**

JMF871a 04/10/2012

Figure 38.3 **A set of carved talc vases in different colours from the Three Springs talc mine (courtesy Imerys Talc Australia)**

found mainly in altered ultramafic bodies within greenstone belts and, to a lesser extent, within sedimentary rock sequences containing dolomite. Numerous talc localities have been recorded by Simpson (1952), and Abeysinghe (1996) has described the larger deposits in some detail and also lists many of the smaller ones. This publication is referred to in many of the following descriptions of the larger and more significant occurrences.

Deposits derived from dolomite

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).

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 that extends for about 70 km south from the Three Springs talc mine to the area around Marchagee and contains a number of significant deposits (Fig. 38.4).

Three Springs area

Three Springs talc mine *(CARNAMAH, 2038)*

The Three Springs talc mine is located 12 km northeast of the Three Springs town site and about 330 km north-northeast of Perth (Fig. 38.4). Talc was first discovered at this site in the 1940s by a local farmer and underground mining commenced in 1948. In 1959, Western Mining acquired a 50% share of the project and subsequent 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 again, to Imerys Talc, currently the world's largest talc producer.

At Three Springs, the talc occurs as a subhorizontal orebody, trending north with a maximum width of 200 m and a thickness varying from a few metres to over 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.

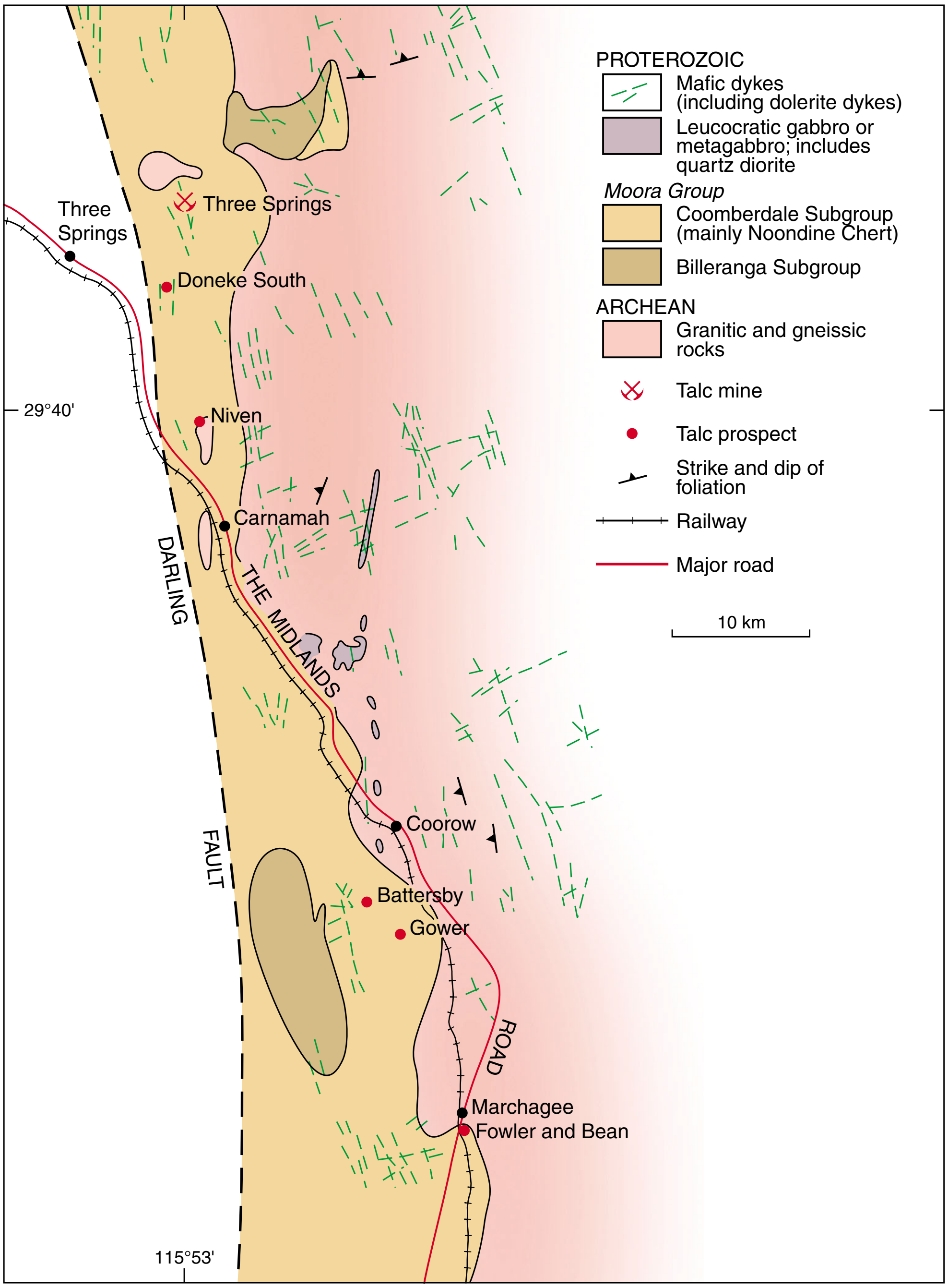

Figure 38.4 **Map showing the location of Three Springs talc mine and associated talc prospects in the Three Springs – Marchagee belt (modified after Fetherston et al., 1999)**

The mine is currently in operation and access to the mine site would only be with permission from the mine operators, Imerys Talc Australia, who can be contacted at their mine office at Three Springs.

Niven deposit (Carnamah, 2038)

The Niven deposit is approximately 8 km north-northwest of Carnamah (Fig. 38.4). Exploratory drilling by various companies between the 1970s and 1991 identified a zone of talc mineralization in altered dolomitic sedimentary rocks close to mafic dykes with dimensions 30 m wide, 200 m long, and 1–10 m thick. Drill samples from five drillholes confirmed the presence of high-quality 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 some 50 km south-southeast of Three Springs (Fig. 38.4).

Initial interest in the area stemmed 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 but did not locate talc of commercial grade.

Fowler and Bean deposits (Watheroo, 2137)

The Fowler and Bean deposits are situated on properties immediately south of the town of Marchagee where the original exploration by Western Mining Corporation delineated talc mineralization (Fig. 38.4). Follow-up drilling by a variety of companies concentrated on the Fowler deposit and a northerly striking talc body exceeding 500 m in length with a maximum width of about 180 m was delineated. A cross section of the Fowler talc deposit is shown in Figure 38.5.

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. 38.6). Weathering has also resulted in iron-oxide staining, mainly along fractures and joints.

In contrast to the Three Springs deposit, where talc mineralization is found adjacent to dolerite dykes, a younger granite is considered to be 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 located 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 sequence that was intruded by granite of the Moorarie Supersuite.

Mount Seabrook talc mine (Moorarie, 2446)

The Mount Seabrook talc mine, operated by Imi Fabi (Aust.) Pty Ltd on a campaign basis, is located on mining lease M52/58 about 1.5 km north-northeast of Mount Seabrook (Fig. 38.1). 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 the period 1969 to 1972.

Rock types within the mine and adjoining area consist of metamorphosed sandstone, dolomite, quartzite, pebble conglomerate, and quartz–muscovite schist together with biotite- and chlorite-bearing lenses of white to light

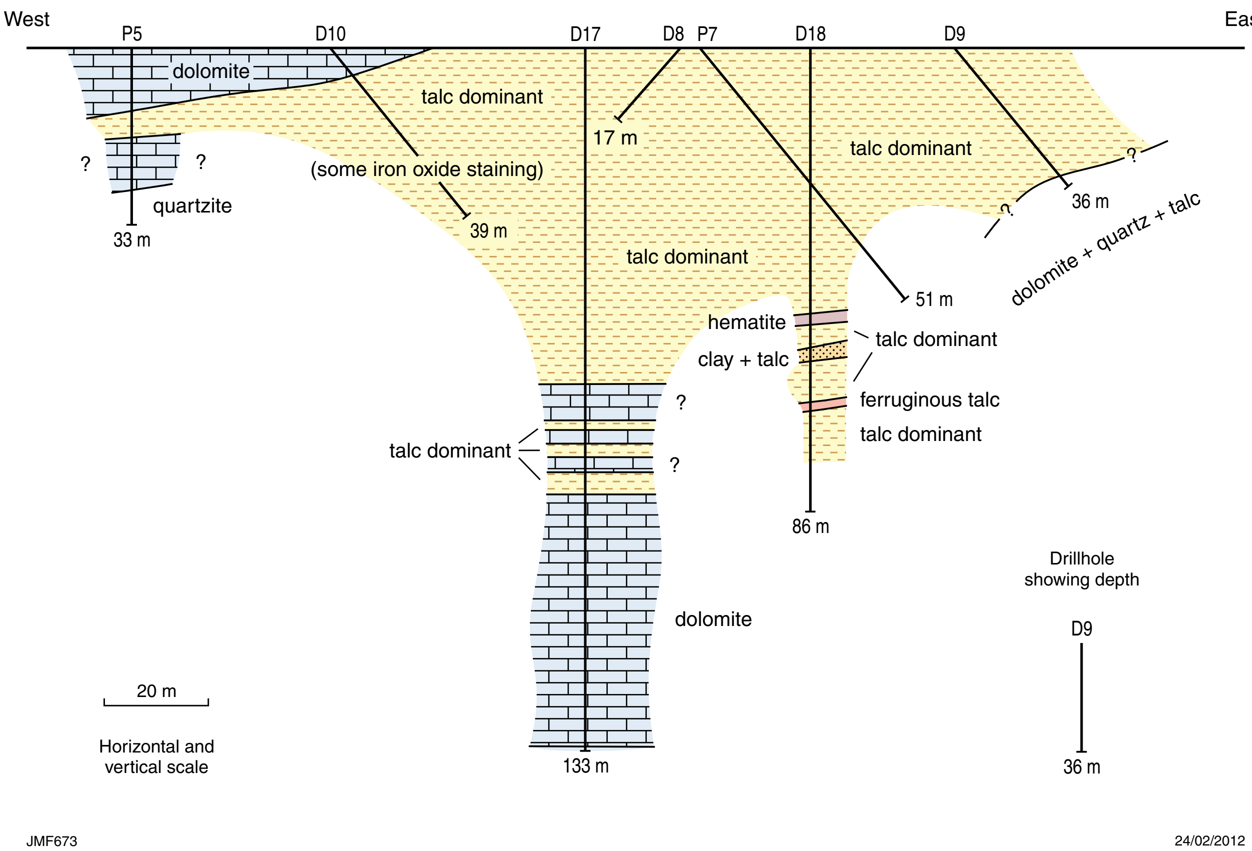

Figure 38.5 Cross section through the Fowler talc deposit at Watheroo (modified after Fetherston et al., 1999)

Figure 38.6 White massive talc excavated from a costean at the Fowler deposit

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 at temperatures between 200 and 250ºC. In general, the talc from Mount Seabrook is massive, white to pale green, fine grained, opaque to locally translucent, and contains quartz inclusions (Fig. 38.7). 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 mine site would only be with permission of the owners of the mining lease.

Livingstone talc prospect *(Moorarie, 2446)*

Discovered in 1983, the main Livingstone talc prospect is located 7 km northwest of Mount Seabrook (Fig. 38.1). By 1986, a second high-grade deposit plus 12 other talc sites had been discovered in the Livingstone area. These prospects comprise sequences 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 situated about 3 km north-northeast of Mount Seabrook (Fig. 38.1). At this site the talc occurs in subvertical lenses to 8 m in true thickness (average 2–5 m) within a Paleoproterozoic metasedimentary rock sequence. Drilling intersected high-quality talc in several exploratory drillholes.

Southern Cross Well prospect *(Moorarie, 2446)*

The Southern Cross Well prospect lies about 11 km northwest of Mount Seabrook (Fig. 38.1). 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 varying 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 the Kundip township (Fig. 38.1). 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.

Figure 38.7 Export-grade, fine-grained, white to pale green, cosmetic-grade talc from Mount Seabrook.

At the Kundip site, a significant deposit of high-grade, coarsely crystalline talc is present. The talc is a pale sea-green colour and is strongly foliated. More recent exploration identified a number of areas of talc mineralization within dolomitic sedimentary rocks extending from the surface to approximately 45 m 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 located in the Jack Hills, about 135 km west-northwest of Meekatharra, and 0.5 km north of Mount Taylor (Fig. 38.1). The Jack Hills consist of a north-northeasterly trending belt of an Archean ultramafic and mafic sequence 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, and a parcel of talc was 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 located within mining lease M52/236 on the slopes of Mount Gould, approximately 14 km north-northwest of Mount Taylor (Fig. 38.1). Massive talc of very high quality is contained in a north-northeasterly trending ultramafic and mafic Archean sequence 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 resulting from hydrothermal alteration of ultramafic rocks, especially serpentinite, and numerous small occurrences are known although large deposits are rare.

Mount Monger area

Loganberry prospect (Lake Lefroy, 3235)

The Loganberry deposit is located 1.5 km north-northwest of Mount Monger and some 60 km southeast of Kalgoorlie (Fig. 38.1). At this site, foliated talc lenses within serpentinites are present in mafic and ultramafic rocks forming part of a north-northwesterly trending Archean sequence.

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, 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 located 8 km south-southeast of Bridgetown (Fig. 38.1). The deposit was first mined in 1942 and features a series of shallow costeans that were 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, but 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 located 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. 38.1).

Records are incomplete, although it is recorded that 10 t of soapstone was mined from the deposit in 1942. Simpson (1952) also reported the occurrence of massive talc at a location approximately 8 km east of Balingup, which is possibly the same location as the Meaneys Bridge deposit. This report stated that the talc is pale greenish-grey and scaly with no prominent foliation.

Bolgart area

Culham prospect (CHITTERING, 2135)

The Culham talc prospect, is located 8 km south-southwest of Bolgart township (Fig. 38.1). The deposit was mined in 1952 from a number of shallow pits and costeans 1–3 m deep. Some of the talc was massive, fine grained and pale green in colour but other samples were darker green and coarser grained. There are no rock outcrops in the area, but there are altered ultramafic rocks in the general region that 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 located on the western side of a low hill some 11 km east-southeast of the town of Moora (Matheson, 1945; Fig. 38.1). 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 suggests 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).

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Chapter 39 Tektites

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 found in only four 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 USA 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)
- Thailandites (Thailand)
- Javaites (Java)
- Bediasites (Texas, USA)
- Georgiaites (Georgia, USA)
- Indochinites (Thailand and Cambodia)
- Philippinites and Rizalites (Philippines)
- Billitonites (Billiton Island, Indonesia)
- Moldavites (Czech Republic and Slovakia)
- Irgizites (Irgiz, Kazakhstan).

Tektites
Silica glass [SiO_2 (68 to 82%)]

Origin

Numerous theories have been advanced on the formation of tektites but 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 falling to earth.

In Europe, tektites found in Miocene sediments (15 Ma ago) have been linked to the Nordlinger Ries crater in western Bavaria that 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 to 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 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 that have been dated 34–35 Ma (McNamara and Bevan, 2001). In Australia, australites are considerably younger with an age of around 800 000 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. Results of this research produced a mean age for two fractions of 796 ka ± 10 (ka = thousand years) that agrees with the estimated age of impact of 793 ka (Fieldnotes, 2012).

Composition

Chemically, tektites are similar to silica-rich igneous rocks and some sedimentary rocks, especially greywackes (lithic sandstones) with a high silica content of 68–82%, alumina 10–14%, together with lesser quantities of iron, magnesium, calcium, potassium, and titanium. One major difference is the almost total lack of water in tektite glass.

Shapes

Tektites occur 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 dumb-bells, boats, canoes, lenses, ovals, and teardrops.

European tektites (moldavites)

Moldavites from the Czech Republic are green or greyish-green tektites and were the first tektites to be studied in a scientific manner by gemmologists. When first discovered in the late 18th century, moldavites were considered to be glassy remains from an early glassworks plant, a theory maintained until similar pieces were found in other parts of the world.

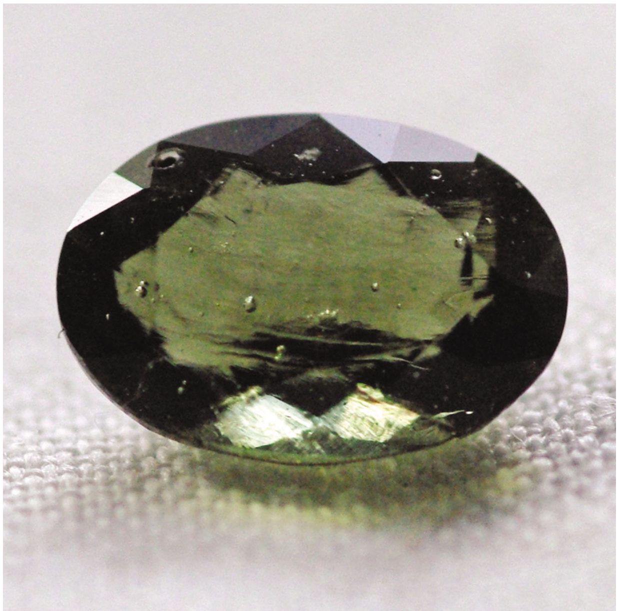

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Figure 39.1 A faceted moldavite gemstone displaying gas bubbles and swirled interior. The stone measures 7 x 5 mm

Moldavites have been used in jewellery commonly in their natural form, preserving both their shapes and characteristic surface textures. Moldavites occur as irregular fragments ranging from 10 to 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 a variety of names such as 'bottle stone', obsidian, and boueillenstein (Konta and Saul, 1976; Fig. 39.1).

Physical properties of moldavites include a hardness of 5.5, specific gravity of 2.34 – 2.39, and a refractive index of 1.488 – 1.503. Internal examination of moldavite glass often 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 be concentrated 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 utilized them for tools and weapons. Percussion flaking of tektites produces very sharp pointed fragments and flakes and these have been used as scrapers, knives, points, and ceremonial implements. Currently, tektites found on the Nullarbor Plain are generally quite small and flakes are plentiful, which indicates that larger tektites from the region may have been utilized 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, dumb-bells, 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 related to whether the blob was rotating and the actual speed of rotation
- Secondary modification in flight caused by frictional heating at hypersonic velocities resulting in the loss of frontal material of blobs travelling in steadily orientated flight

- More recent terrestrial modification by weathering and transportation processes.

Examples of variations in australite shapes are shown in Figure 39.2.

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 each 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 showing the distribution of australite sites in Western Australia is shown in Figure 39.3.

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). Specific gravity range is largely dependent 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 generally preserved in their natural state. They are enthusiastically collected and appreciated by fossickers. A sample of some Western Australian australites is displayed in Figure 39.4.

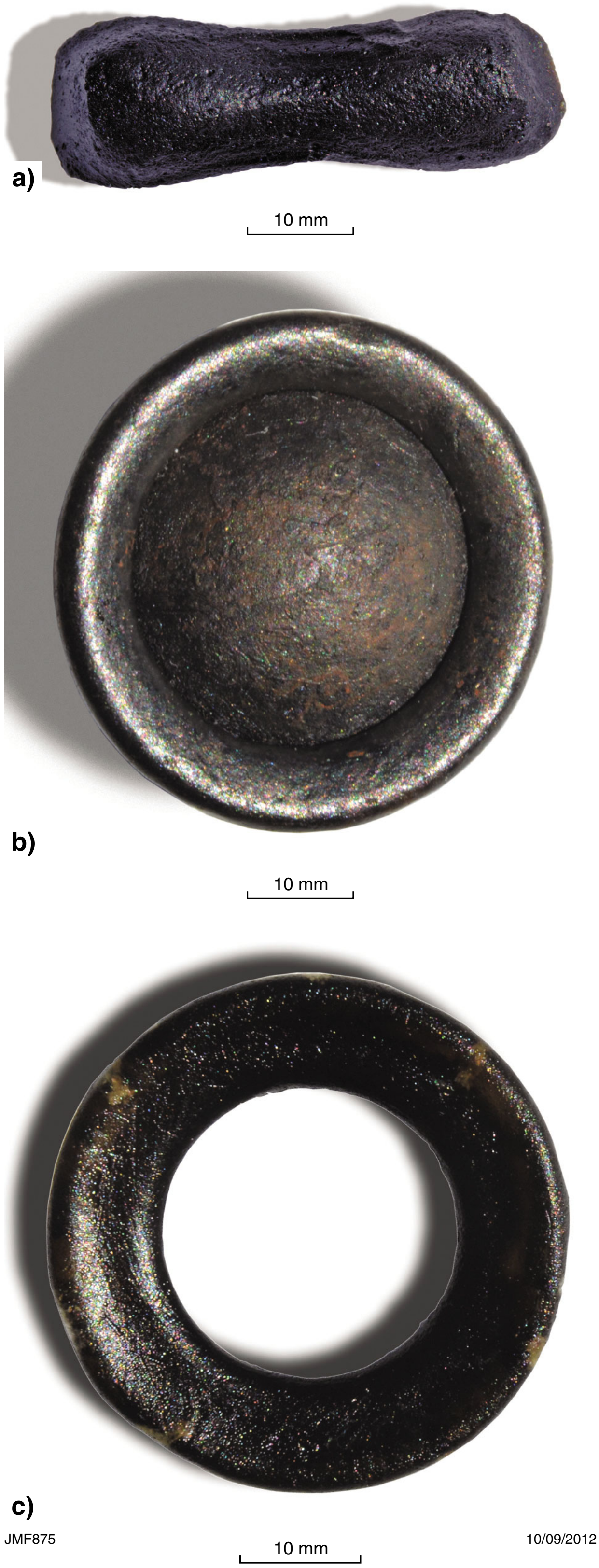

Figure 39.2 Three examples of Western Australian australite shapes: a) dumb-bell; b) button; c) doughnut

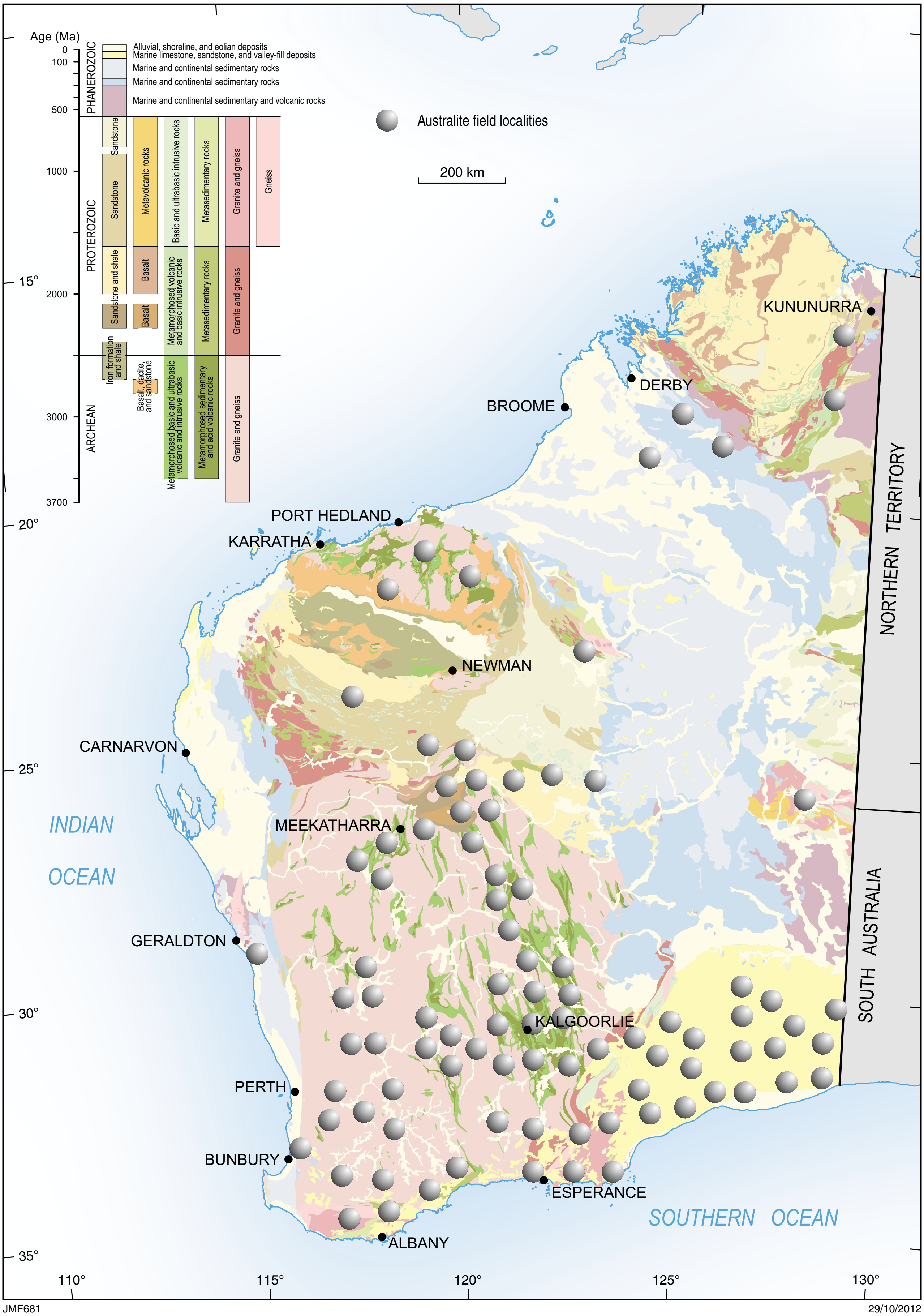

Figure 39.3 **Distribution of australite sites in Western Australia (modified after McNamara and Bevan, 2001)**

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Figure 39.4 A sample of Western Australian australites from southeast of Kalgoorlie (after Fieldnotes, 2012)

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Chapter 40 Decorative stones from the Kununurra region

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 (approximately 600 Ma) Duerdin Group of rocks (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 stone and other patterned rocks including ribbon stone, okapi stone, primordial stone, and astronomite.

Decorative stones from the Kununurrra region

Zebra stone

(Argyle Downs, 4665)

Zebra stone was first discovered by T Blachford in 1924 at a site not far from the old Argyle Downs Homestead, now submerged beneath the northern extremity of Lake Argyle. Later exploration revealed that the stone could be found in lens-like structures within in the upper part of the Neoproterozoic Ranford Formation from the Snappy Gum Ridge deposit in the south extending in a north-northeasterly direction for over 50 km to the Northern Territory border. Today, a number of known deposits are submerged below the surface of Lake Argyle.

Currently there are three openpit zebra stone operations; two in the south of the area in Lake Argyle at Snappy Gum Ridge and Remote Island, at Zebra Stone 1 and 2 pits respectively, and in the north of the area at the Kununurra Zebra Stone pit. These operations are worked on a campaign basis during the dry season according to demand for stocks of raw material. Also, two other zebra stone prospects, identified by Hancock (1969), are located on the northern end of Hagan Island in Lake Argyle, and close to the lake shore on Spider Point, approximately 7 km to the northeast. These prospects may also be subject to seasonal inundation. Zebra stone sites are shown on Figure 40.1 and more detailed locational information is given in Appendix 1.

Decorative stones from the Kununurra region
Micaceous, iron-rich siltstone

Zebra stone 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 Stone 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 Stone 1 openpit. Even during the dry season, access for the openpit operators, together with the removal of quality zebra stone, is only by boat.

At the Lake Argyle sites, zebra stone 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 stone 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 stone occurs in a variety of forms, the most common of which is 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 thickness 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 bandwith 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. 40.2).

Other zebra stone 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. 40.3).

Laboratory studies by Loughnan and Roberts (1990) showed that zebra stone is composed largely of fine-grained quartz and sericite (white mica). Other minerals

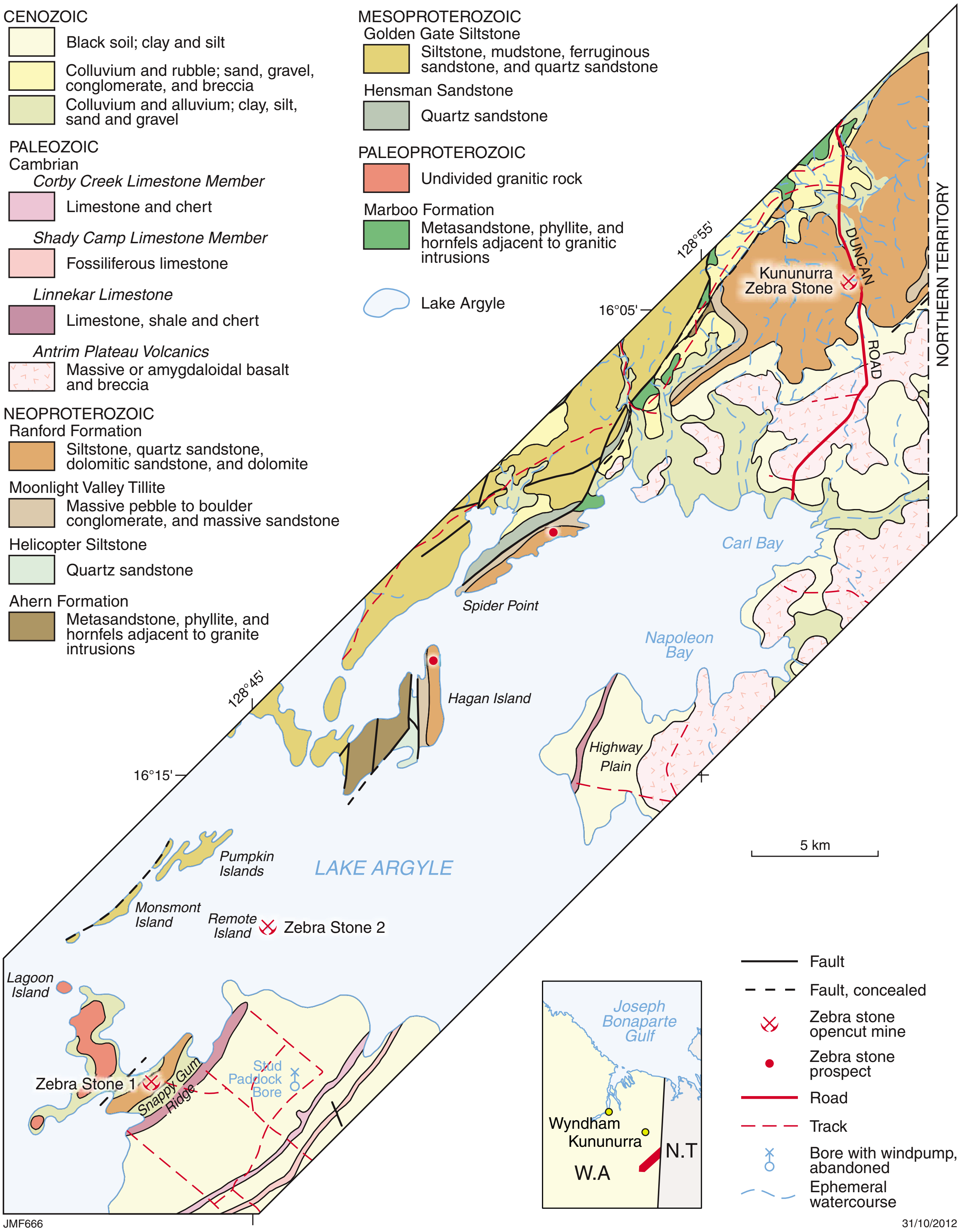

Figure 40.1 **Distribution of zebra stone deposits within the Ranford Formation, Lake Argyle area (modified after Thorne et al., 1998)**

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Figure 40.2 **Vertical zebra stone bed, estimated at 60 mm width, in the Zebra Stone 1 openpit at Snappy Gum Ridge, Lake Argyle. Note the comparatively thin, arcuate, brown bands extending from top to bottom of the bed (courtesy John Read)**

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Figure 40.3 **Zebra stone rods from Remote Island in Lake Argyle. Sectional view shows ovoid-shaped rods approximately 8 mm wide x 17 mm along the longest axis**

present included alunite, kaolinite clay and its polymorph, dickite. Loughnan and Roberts' work indicated that the colour banding seen in the zebra stone 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 (Bevan, 2001).

Zebra Stone 1 openpit

The zebra stone 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. 40.1). Situated within mining lease M80/185, this openpit has produced the traditional white-and-brown banded material for which the stone is renowned (Fig. 40.4).

Depending on demand for the stone, up to eight miners have worked the openpit at times during the dry season. Until recently, zebra stone 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 employed to expose the seams before hand removal. Despite the reduction in stone removal time, mining 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 stone is removed by boat after each mining campaign.

Zebra Stone 2 openpit

Situated on tiny Remote Island, about 8 km to the northeast, Zebra Stone 2 openpit is enclosed within mining lease M80/442 (Fig. 40.1). Also operated mainly by the Read family using the same extraction techniques as for Zebra Stone 1, the operation on Remote Island is one of the main sources of high-quality, rod-shaped material. At this location, the stone also occurs in relatively narrow, near-vertical beds within the openpit (Fig. 40.5).

Kununurra zebra stone area

The Kununurra zebra stone area is located in the northern part of the Ranford Formation that extends from the northern end of Lake Argyle northeast to the Northern Territory border (Fig. 40.1). This area contains the Kununurra Zebra Stone openpit located 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 stone at this site although the material appears to be similar to that at Lake Argyle. In 2011, a proposal was made to remove up to 200 t of rock to extract zebra stone as the target mineral.

Previously, it has been observed that zebra stone block size within the Ranford Formation from sites closer to the Northern Territory border tended to be 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 stone quality tended to be of a poorer grade in some samples.

Figure 40.4 High-quality zebra stone from Snappy Gum Ridge, Lake Argyle. Bands and rods are approximately 5–6 mm wide

Figure 40.5 Zebra stone rods enclosed in a vertical bed in Zebra Stone 2 openpit on Remote Island, Lake Argyle (courtesy John Read)

Zebra stone properties and applications

Zebra stone is essentially a compact, argillaceous (clay-rich), fine-grained siltstone and as such is sufficiently soft to permit precise cutting and carving using hand tools. The stone has a smooth, silky texture that enables it to be finished using ultra-fine wet and dry emery paper resulting in an extremely smooth and semi-gloss finish. Sealing the stone is carried out using talcum powder or warm clear vaseline. Final colour enhancement is achieved by the application of up to several coats of polyurethane solvent to obtain either satin or gloss finishes as required. Products fashioned from zebra stone include jewellery, bowls, jugs, and many other attractive artefacts (Fig. 40.6).

Other ornamental stones from the 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, there are several unidentified, closely spaced sites containing other visually attractive ornamental stones. These stones are located in the upper part of the Ranford Formation at roughly the same stratigraphic horizon as the zebra stone and a number of these stones are clearly similar to zebra stone itself. According to prospector Johan Pas, ‘astronomite’ generally occurs 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’ is seen to overlie the zebra stone while astronomite and primordial stone are absent from this location (J Pas, 2011, written comm.).

Ribbon stone

Ribbon stone is considerably harder than zebra stone and consequently more difficult to work. Colours are highly variable, ranging through white, cream, orange, pink, burgundy red, beige, light to dark grey, and black. There is a wide range of textures present including stripes, spots, and streaks or combinations of all three. Also, welded displaced fractures are a common highlight of this stone, and crystal imprints are seen in places. The combination of random colour patches and textures may often create the illusion of landscape pictures in the stone.

Okapi stone

In terms of composition, okapi stone is quite similar to zebra stone, being a fine-grained, thin-bedded, iron-rich siltstone. By contrast, okapi stone lacks zebra stone's extremely regular reddish-brown banding on a white clayey matrix (Fig. 40.7). Instead, the banding present in okapi stone is not regular, being of variable thicknes and irregular spacing, and colours vary from a rich dark or 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 lens-shaped 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 but has physically stronger properties.

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. The orbicules consist of concentric, ferruginous siltstone rings with the majority 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 but 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. 40.8). The overall effect of these circular structures set in a dark brown matrix is to create a visually attractive decorative stone.

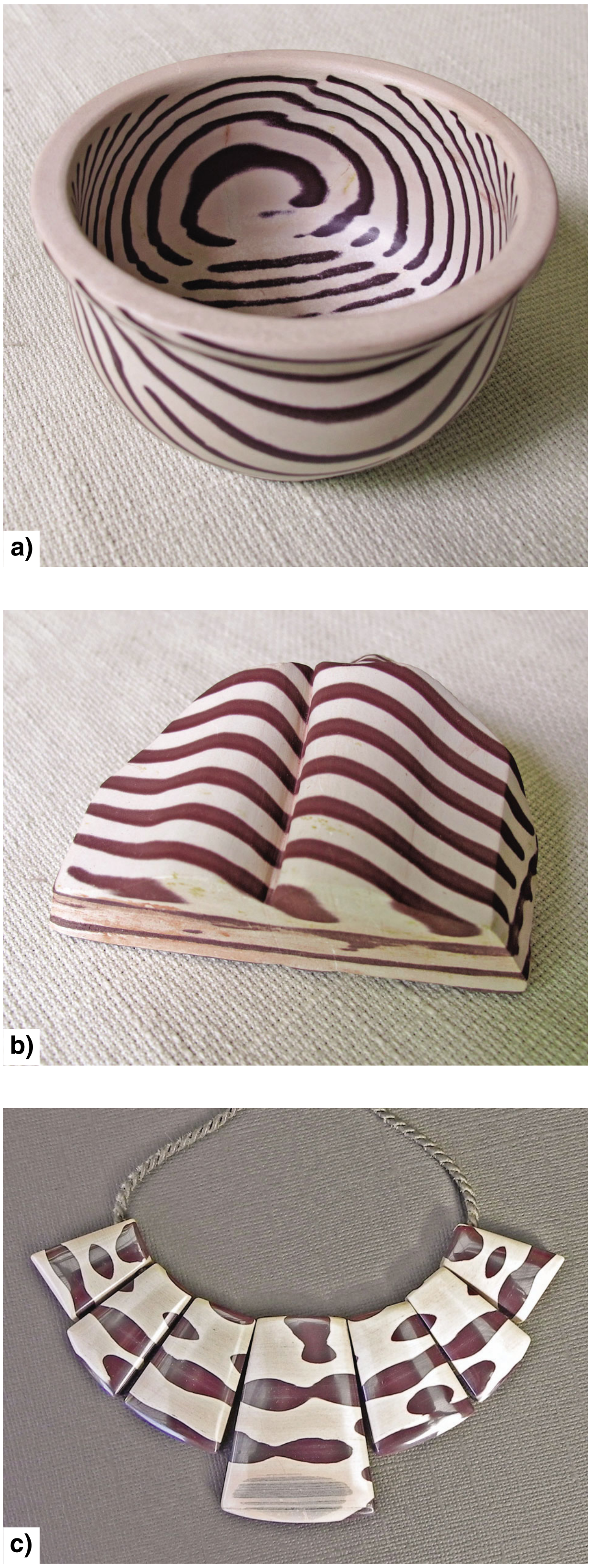

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Figure 40.6 Examples of high-quality artefacts produced from Lake Argyle zebra stone: a) a semi-gloss bowl featuring dark brown banding; b) a carved open book in the well-known white and mid-brown colours (courtesy John Read); c) zebra stone necklace with a gloss finish (courtesy Gloria Nanini)

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Figure 40.7 Okapi stone is similar to zebra stone but lacks the extremely regular reddish-brown banding on a white clayey matrix (courtesy Arcgems)

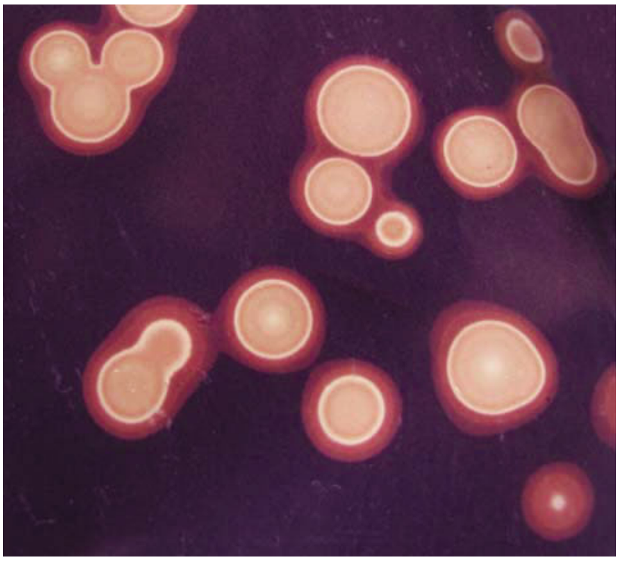

Figure 40.8 **Concentric astronomite orbicules set in a dark brown siltstone matrix. Maximum orbicule diameter is 10 mm**

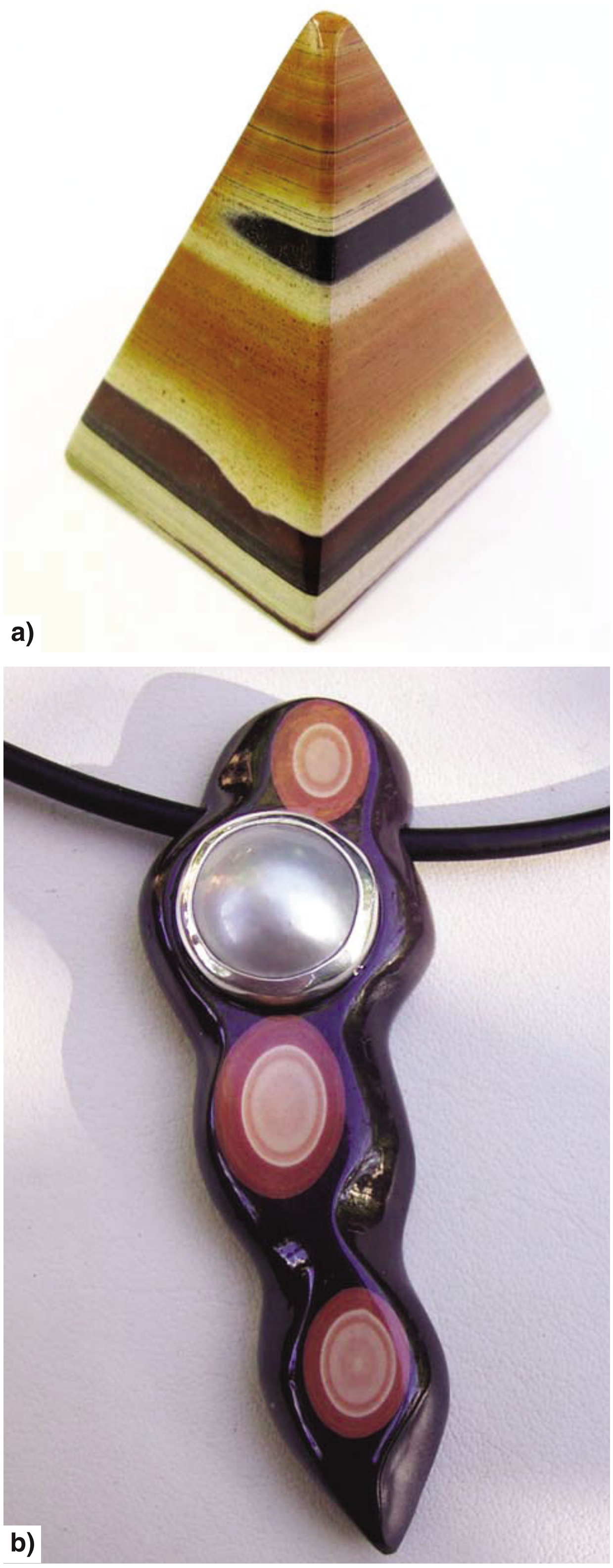

Figure 40.9 **Applications for other decorative stones from the Ranford Formation: a) a carved and lacquered pyramid of Okapi stone (height 70 mm); b) a carved piece of astronomite designed to highlight the oval-shaped orbicules and incorporating a Broome mabe pearl (courtesy artisan Marion Egger)**

Applications for other ornamental stones from the Ranford Formation

In addition to zebra stone, most of the ornamental stones mentioned above are processed and carved in the Kununurra area for sale in Kununurra or distribution to other rock shops around the State and farther afield. Most applications relate to jewellery, especially in attractive pendants and earrings, or the stones may be transformed into polished shapes such as pyramids (Fig. 40.9). In the case of ribbon and other stones, these may be used in the creation of impressionistic landscape pictures in stone.

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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 5 – Diamond									
	Halls Creek Orogen — Lamboo Complex	East Kimberley diamond province	n/a	Diamond – colourless, yellow, brown and pink	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 mine	435748	8155569	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	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 – fancy yellow, colourless, etc.	Ellendale 9 mine	697466	8057122	51	
				Diamond – fancy yellow, colourless, etc.	Ellendale 4 mine	704095	8045029	51	
				Diamond – fancy yellow, colourless, etc.	Ellendale 7 mine	697221	8053499	51	
				Diamond	Ellendale 11 prospect	695400	8057420	51	
				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	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*[†]
				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	
	Nabberu Basin	Mount Throssell	n/a	Diamond	Mount Throssell prospect	464963	7123032	51	
Chapter 6 – Beryl group									
Emerald	Yilgarn Craton — Murchison Domain	Poona	Poona	Emerald, aquamarine, morganite	Aga Khan mine	545707	6999444	50	
		Yalgoo	Noongal (Melville)	Emerald, beryl	Emerald Show prospect	475530*	6888080*	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	
	Pilbara Craton	Tambourah	n/a	Emerald, beryl	Curlew mine	737822	7612573	50	
			Tambourah pegmatite field	Emerald	prospect	709300^	7602500^	50	
		Wodgina	Mount Cassiterite pegmatite field	Emerald	prospect	671700*	7658700*	50	
			Mount Francisco pegmatite field	Beryl, emerald ?	prospect	661400*	7636300*	50	
			Pilgangoora pegmatites	Emerald	prospect	698060*	7671630*	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	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
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	Olivers 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 7 – 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	
	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	766770*	6272870*	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	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*†
			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 8 – Tourmalite and warrierite									
	Yilgarn Craton — Murchison Domain	Lake Mongers tourmalite island	n/a	Tourmalite (warrierite)	Tourmalite mine	524875	6778075	50	
Chapter 9 – 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	Calcalling 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 10 – 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
		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

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
			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	328200^	6360290^	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 11 – Minor pegmatite gemstones									
	Yilgarn Craton — Murchison Domain	Yalgoo	Melville pegmatite field	Lepidolite	Carliminda Blue mine	470146	6880590	50	
		Paynes Find	Mount Edon pegmatite field	Phenakite	Goodingnow northern pegmatite	566507	6757653	50	
	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	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number[†]
		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	Catlin Creek pegmatites	Spodumene	Catlin 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 12 – 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	341190*	6549970*	51	
		Binneringie	n/a	Quartz	Binneringie prospect	420104	6513397	51	
			n/a	Citrine	Saint John pegmatites prospect	419810*	6516820*	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	
	Yilgarn Craton — Murchison Domain	Mukinbudin	n/a	Quartz and K-feldspar	Mukinbudin mine	609432	6581594	50	
			n/a	Quartz and K-feldspar	Calcaling mine	636704	6578725	50	
		Paynes Find	Mount Edon pegmatite field	Quartz, beryl and feldspar	Goodingnow mine	566665	6757369	50	
		Bencubbin region	n/a	Quartz	Beacon prospect	571350*	6642190*	50	
		Southern Cross region	n/a	Citrine	Grace Road prospect	724040*	6501420*	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	Northam area	n/a	Quartz	Toodyay Road prospect	463030^	6498750^	50	
		Beverley area	n/a	Quartz	Morbinning Road prospect	503130*	6447270*	50	S 3849
	Pilbara Craton	Wodgina area	n/a	Quartz	Kangan quartz prospect	656090*	7666780*	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	454980*	7291700*	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*	7267180*	50	
			n/a	Amethyst and 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 13 – Opal									
	Collier Basin	Mundiwindi area	n/a	Fire opal	Mundiwindi prospect	218960*	7365780*	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	794320*	7639770*	50	S 3826
	Yilgarn Craton — Eastern Goldfields Superterrane	Ora Banda area	n/a	Common opal	Grants Patch prospect	320110*	6629870*	51	
		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 and moss opal	Norseman opal mine	377310*	6444210*	51	MDC 3322, 4832
		Laverton region	n/a	Fire opal	Adam Range prospect	460200*	6861740*	51	S 1602 (a & b)

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
		Yundamindera area	n/a	Fire opal	Bulla Rock Well opal mine	396940*	6778890*	51	
		Yundamindera area	n/a	Fire opal	French Soak prospect	394240*	6779700*	51	
		Kalgoorlie region	n/a	Fire opal	Smithfield prospect	345780^	6623220^	51	
		Ora Banda area	n/a	Green opal	Ora Banda 1 prospect	315412	6633349	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
		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 and common opal prospect	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	438400*	7119030*	50	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*[†]
		Byro area	n/a	Tiger eye and green opal	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	699150*	6577990*	50	S 1606
		Poison Hills area	n/a	Moss opal and common opal	Poison Hills prospect	700000^	7004600^	50	MDC 3323
		Bullfinch area	n/a	Siliciophite	Morlands Find mine	710110*	6554530*	50	
	Yilgarn Craton — South West Terrane	Northam	n/a	Fire opal and common opal	Mount Dick 2 prospect	468960*	6506010*	50	S 1604, 1610, 3797, 3830
		Moora area	n/a	Siliciophite	Bindi Bindi prospect	437300*	6611180*	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	418560*	6605090*	50	S 3808
		Northam	n/a	Siliciophite and common opal	Meenaar prospect	488860*	6497620*	50	
		Goomalling	n/a	Siliciophite and common opal	Thomas and Truscotts mine	484405	6537010	50	S 3761 (a & b)
Chapter 14 – Chalcedony Group									
	Pilbara Craton	Balfour Downs region	n/a	Agate	Prospects on Noreena Downs Station	209200*	7532220*	51	
	Pilbara Craton — Hamersley Basin	Roy Hill region	n/a	Agate	Marillana Station mine	763204	7488744	50	
	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	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
		Boyce Creek area	n/a	Chrysoprase	Yerilla mine (Boyce Creek East)	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*	6602040*	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	
	Musgrave Province	Wingellina area	n/a	Chrysoprase	Wingellina prospect No. 2	494702	7120461	52	
Chapter 15 – Fossil wood									
	Southern Carnarvon Basin	Mooka Creek	n/a	Peanut wood	Mooka Creek prospecting area	293830*	724532*	50	4953
		Giralia Range	n/a	Fossil wood	Giralia Range prospecting area	206400*	7440700*	50	
		Merlinleigh 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 18 – Andalusite and chiastolite									
	Yilgarn Craton — Eastern Goldfields Superterrane	Kambalda region	n/a	Chiastolite	Spargoville prospect	357533	6545286	51	
		Ora Banda area	n/a	Andalusite and chiastolite	Credo Station prospect	283698	6624480	51	
	South West Terrane	Toodyay area	n/a	Andalusite and chiastolite	Lovers Lane prospect	439900	6503700	50	
Chapter 19 – Chrysoberyl and alexandrite									
	Gascoyne Province	Yinnetharra	Thirty One River	Chrysoberyl	Williamsons mine	401322	7288920	50	
	Yilgarn Craton — South West Terrane	Manjimup	Smithfield	Chrysoberyl	Donovans Find mine	408288	6231457	50	
		Dowerin	n/a	Chrysoberyl and alexandrite	Dowerin chrysoberyl prospect	504313	6547815	50	
	Yilgarn Craton — Murchison Domain	Poona	Poona emerald field	Alexandrite	Aga Khan mine	545707	6999444	50	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
Chapter 20 – Corundum									
	Gascoyne Province	Gascoyne Junction region	n/a	Sapphire	Williambury Station prospect	297710*	7359850*	50	
	Pilbara Craton	Wodgina area	n/a	Corundum	Pincunyah prospect	685120^	7652830^	50	
	Yilgarn Craton — Narryer Terrane	Mardagee Station area	n/a	Corundum	Thoolmugga Well prospect	436068	7105632	50	
	Yilgarn Craton — South West Terrane	Brookton area	n/a	Corundum	Jacobs Well	520571	6457084	50	
	Yilgarn Craton — Murchison Domain	Cue region	Poona emerald field	Sapphire, ruby	Aga Khan mine	545707	6999444	50	
Chapter 21 – 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	
Chaapter 22 – Diopside									
	Gascoyne Province	Yinnetharra	Thirty One River	Diopside	Vaughan prospect	401797	7288427	50	
Chapter 23 – 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	
	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	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number[†]
Chapter 24 – 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 25 – 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 26 – 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*	7413490*	50	
		Tom Price	n/a	Hematite	Tom Price mine	579190*	7482160*	50	
		Paraburdoo	n/a	Hematite	Paraburdoo mine	561530*	7430330*	50	
		Mount Brockman	n/a	Tiger eye jasper	Brockman prospect	544356	7531082	50	
		Mount Margaret	n/a	Tiger eye	Miller Gorge prospect	586530*	7571470*	50	
		Mount Margaret	n/a	Tiger eye	Asbestos Gorge prospect	582040*	7568060*	50	
	Yilgarn Craton — Southern Cross Terrane	Koolyanobbing	n/a	Hematite, specularite and pyrite	Koolyanobbing mine	740990*	6590180*	50	
	Yilgarn Craton — Murchison Terrane	Mount Gibson	n/a	Hematite	Mount Gibson mine	515600*	6728200*	50	
		Mullewa area	n/a	Turgite	Tallering Peak mine	364500	6889299	50	
	Canning Basin	Lennard Shelf	n/a	Marcasite	Goongawa mine	801564	7937802	51	
Chapter 27 – 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	

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	Prehnite	Londonderry feldspar mine	316605	6556300	51	
	Edmund Basin	Paraburdoo region	n/a	Prehnite	Mt Vernon prospect	604970^	7329240^	50	
Chapter 28 – 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	768090*	6244190*	50	
Chapter 29 – 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	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 30 – 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	388460*	6597670*	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	
	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 prospect area	586520*	6944130*	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	

Appendix 1 (continued)

Mineral	*Tectonic unit*	*Locality*	*Mineral field*	*Gemstone*	*Mine or prospect*	*MGA Easting*	*MGA Northing*	*Zone*	*WAM number*[†]
	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 31 – Chinese writing stone									
	Pilbara Craton	Whim Creek	n/a	Chinese writing stone	Langwell Gorge prospect	571600*	7655600*	50	
Chapter 32 – Epidote group									
	Albany–Fraser Orogen	Denmark area	n/a	Unakite	Lowlands Beach prospect	545743	6119894	50	
		Cheyne Bay	n/a	Unakite	Cape Riche prospect	663170*	6168880*	50	
	Pilbara Craton	Roebourne	n/a	Thulite	Roebourne prospect	515090^	7703100^	50	
	Yilgarn Craton — Murchison Domain	Mindoolah area	n/a	Clinozoisite (thulite)	Marshmallow rock prospect	543334	7023786	50	
		Lake Weelhamby	n/a	Thulite	Ninghanboun Hill prospect	443290*	6770450*	50	
Chapter 33 – Grunerite									
	Pilbara Craton	Abydos area	n/a	Grunerite	Desert Gold prospect	703464	7638587	50	

Appendix 1 (continued)

Mineral	Tectonic unit	Locality	Mineral field	Gemstone	Mine or prospect	MGA Easting	MGA Northing	Zone	WAM number†
Chapter 34 – Jade									
	Yilgarn Craton — Murchison Domain	Yeoh Hills	n/a	Black jade	Ninghan mine	526462	6765027	50	
	Pilbara Craton	Marble Bar area	n/a	Pilbara jade	Pilbara jade prospect	201200*	7601570*	51	
Chapter 35 – Mookaite and pink opal									
	Southern Carnarvon Basin	Mooka Creek	n/a	Mookaite	Archer M09/86 mine	293405	7245342	50	
			n/a	Mookaite	Butler M09/18 mine	293795	7245491	50	
			n/a	Mookaite	Kapitany & Pas M09/109 mine	293463	7245603	50	
			n/a	Pink opal	Binthalya prospect	292720*	7244450*	50	
Chapter 36 – Orbicular granite									
	Yilgarn Craton — Murchison Domain	Mount Magnet area	n/a	Orbicular granite	Boogardie mine and prospect	547729	6895980	50	
Chapter 37 – Siliceous decorative stones									
	Pilbara Craton	Karratha area	n/a	Cr-rich chert	Mount Regal mine	475386	7698008	50	
		Pear Creek area	n/a	Cr-rich chert	Pear Creek jade prospect	769308	7691957	50	
		Abydos area	n/a	Cr-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	
	Yilgarn Craton — Murchison Domain	Cue region	n/a	Jasper	Reedy area mine	627800^	7007400^	50	
		Fields Find area	n/a	Jasper	Desert Sunset mine	524857	6787660	50	
Chapter 38 – Serpentine and talc									
	Pilbara Craton	Marble Bar area	n/a	Serpentine	Pilbara jade mine	201200*	7601570*	51	
		Tambourah region	n/a	Serpentine	Soanesville 1 prospect	727040*	7617610*	50	
			n/a	Serpentine	Soanesville 2 prospect	726990*	7618460*	50	
		Whim Creek region	n/a	Serpentine	Mount Satirist south prospect	614900*	7657900*	50	
			n/a	Serpentine	Nunyerry chrysotile 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	

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	Mount Monger area	n/a	Talc	Loganberry prospect	397130*	6567430*	51	
	Yilgarn Craton — South West Terrane	Bridgetown area	n/a	Talc	Glenlynn prospect	422380*	6234780*	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	416570*	6606060*	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	410980*	6670760*	50	
	Albany–Fraser Orogen	Kundip area	n/a	Talc	Kundip prospect	229010	6262717	51	
Chapter 40 – Decorative stones from the Kununurra region									
	Duerdin Group	Snappy Gum Ridge	n/a	Zebra Stone	Zebra Stone 1 mine	469339	8191161	52	
		Remote Island	n/a	Zebra Stone	Zebra Stone 2 mine	474038	8197463	52	
		Kununurra area	n/a	Zebra Stone	Kununurra Zebra Stone mine	496487	8223319	52	
		Hagan Island	n/a	Zebra Stone	Prospect	480660*	8207930*	52	
		Spider Point	n/a	Zebra Stone	Prospect	485250*	8213170*	52	

* position approximate
† Western Australian Museum number
^ position doubtful
n/a not applicable

From the time of formal inception in 1896, the Geological Survey of Western Australia (GSWA) has, until now, never produced a substantial and systematic work on the subject of gemstones to be found in this State. Mineral Resources Bulletin 25, Gemstones of Western Australia, redresses this deficiency. In this joint publication by GSWA and the Gemmological Association of Australia (GAA), the authors have assembled a comprehensive resource on virtually all gemstones and decorative stones used in jewellery and ornamental sculpture known in the State. Although diamonds command a certain pride of place among the industries of Western Australia, far less is known about occurrences of beryl, topaz, tourmaline, tektites, gem-quality quartz and associated siliceous gems. Material peculiar to this State, such as zebra stone, orbicular granite and mookaite are discussed, as are pearls, fossil wood, and precious metals. Geographical locations are indicated where possible, and abundant references to earlier work given.

Whilst systematically sound and scientifically authoritative, 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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