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MINERAL OCCURRENCES AND EXPLORATION POTENTIAL OF THE PATERSON AREA

by K. M Ferguson, L. Bagas, and I. Ruddock

Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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Cover photograph:
Coolbro Sandstone (foreground and background) in the Throssell Range about 12 km south-southwest of Nifty copper mine, looking east (MGA 348650E 7591950N). Coolbro Sandstone is overlain further east by poorly outcropping Broadhurst Formation that is highly prospective for stratabound base-metal mineralization; to the south the Coolbro Sandstone overlies the unconformity with the Rudall Complex that is highly prospective for vein and hydrothermal uranium mineralization

Contents

Appendices

Plate

Figures

Mineral occurrences and exploration potential of the Paterson area

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Abstract

The Paterson area is a remote part of Western Australia that was largely unexplored until the early 1970s when its mineral potential was demonstrated by the discovery of gold and copper at Telfer, which then became a world-class mine. Interest in the area continued and led to other significant discoveries, including copper at Nifty in 1981, and uranium at Kintyre in 1985. Nifty is also a major mine; the Kintyre deposits remain undeveloped.

The Paterson area includes rocks of the Paleoproterozoic to Mesoproterozoic Rudall Complex, the Neoproterozoic Officer and Yeneena Basins, and the Phanerozoic Canning and Gunbarrel Basins. The Rudall Complex consists of deformed and metamorphosed sedimentary and igneous rocks, and has been subdivided into the Talbot, Connaughton, and Tabletop tectono-stratigraphic terranes. The Officer Basin consists of sedimentary rocks dominated by fluvial–marine conglomerates, sandstones, and siltstones of the Tarcunyah Group. The Yeneena Basin contains sedimentary rocks of the Throssell Range Group, deposited in a shallow-water, fluviatile to marine-shelf environment, and overlying sedimentary rocks of the Lamil Group, which were deposited in a deeper water environment. Neoproterozoic deformation is associated with the intrusion of granites and ultramafic rocks. Carboniferous to Permian glacial and fluviatile sedimentary rocks are overlain by coarse- to fine-grained sedimentary rocks of Jurassic to Cretaceous age, which cover much of the area.

At Telfer, vein and hydrothermal gold mineralization in the Lamil Group takes the form of stacked reefs and linking stockwork zones that are located in domical structures, locally known as the Main and West Domes within the Telfer Dome. Recent redevelopment of the Telfer mine has led to the definition of additional resources and plans for annual production to increase to 800 000 ounces of gold and 30 000 tonnes of copper.

Stratabound clastic-hosted copper mineralization at Nifty is hosted by the Broadhurst Formation of the Throssell Range Group; similar base metal mineralization is present in other parts of the Yeneena Basin, such as at the Maroochydore prospect.

Uranium vein and hydrothermal mineralization at Kintyre is associated with gold, base metals, and platinum group elements in the Yandagooge Formation of the Talbot Terrane. The distribution of mineralization has probably been controlled by the unconformable or faulted contact with the Throssell Range Group.

The recently proposed equivalence of the Lamil and Throssell Range Groups further enhances the area's prospectivity for Telfer-type gold in the Throssell Range Group, particularly where it is concealed below Permian sedimentary cover southwest of the Telfer Dome area. Telfer-type mineralization may also be present in the Lamil and Throssell Range Groups beneath Permian cover north-northwest of the exposed Telfer area. Nifty-type base metal mineralization may be present in concealed Broadhurst Formation beneath the Permian cover, to the northeast and east of the known trend, particularly along the Camel–Tabletop Fault Zone. Similar prospective horizons may also be present in the Wilki Formation, which overlies the Puntapunta Formation.

The two major fault systems that transect the project area, the Camel–Tabletop and Vines–Southwest–McKay Fault Zones, have potential for vein-type mineralization in dilational zones, and for stratabound sedimentary types in graben structures created by faulting. There is also potential for concealed uranium mineralization in the Rudall Complex, below the unconformity separating it from the overlying Yeneena Basin.

The recent discovery of microdiamonds, possibly sourced from kimberlitic intrusions in sedimentary rocks of the Tarcunyah Group, represents a new type of exploration target in the southeast of the Paterson area.

Potential for nickel and platinum group element mineralization in mafic–ultrmafic intrusions may exist in concealed parts of the Rudall Complex within a continental-scale structural zone — the Anketell Regional Gravity Ridge. Such mineralization is known in the Musgrave Range area at the southeastern end of the Anketell Regional Gravity Ridge. Exploration for this type of concealed target would be restricted to areas where the cover of Phanerozoic rocks is relatively thin.

KEYWORDS: mineral exploration, mineral occurrences, mining, mineralization, Paterson Orogen, Rudall Complex, Yeneena Basin, Officer Basin, Gunbarrel Basin, Canning Basin, regolith, gold, base metals, uranium, platinum group elements, diamonds, speciality metals, steel industry metals, industrial minerals.

Present study

This study of the Paterson area aims to enhance and promote the mineral prospectivity of this remote region by presenting an up-to-date review of its geological setting, mineral exploration history, mineral occurrences, and controls on mineralization. The study collates information from all available published sources and, in particular, it incorporates information held in databases of the Geological Survey of Western Australia (GSWA) covering mineral exploration activity, mineral occurrences, and mineral resources.

Details of mineral exploration, mineral occurrences, and other geoscientific information for the study have been compiled from the following sources:

- the large dataset of open-file statutory mineral-exploration reports held in the Western Australian mineral exploration (WAMEX) database at the Department of Industry and Resources (DoIR);
- the database of Western Australia's mines and mineral deposits (MINEDEX) held at DoIR;
- books, journals, industry publications and datasets, Australian Stock Exchange reports and announcements, and company websites;
- regional geological surveys, and airborne geophysical and remote-sensing datasets.

Plate 1 shows the known mineral occurrences in the Paterson area, indicating commodity and mineralization style, on a geological map at 1:500 000 scale. The geology is based on the 1:250 000- and 1:100 000-scale GSWA maps listed under **Previous work**. A listing of the mineral occurrences shown on Plate 1 is provided in Appendix 1. Mineral occurrences are referred to in this Report using their Western Australian mineral occurrence database (WAMIN) 'deposit name' and 'deposit number', shown thus: Telfer West Dome (*9980*).

Appendix 2 defines the terms used in WAMIN and in the Western Australian mineral exploration activities database (EXACT). Appendix 3 gives a brief description of the digital datasets included on the CD-ROM accompanying this Report.

The CD-ROM includes all the data used to compile this Report and map. It includes files of geophysical, Landsat, topographic, and mining-tenement position data. The CD-ROM also contains files necessary for viewing the data with ArcView GIS software, and a self-loading version of GeoVIEWER software. Metadata statements on the geological, geophysical, and topographic datasets are also provided.

Location and access

The region covered in this Report includes the PATERSON RANGE*, RUDALL, TABLETOP, GUNANYA, and RUNTON 1:250 000 sheet areas (Fig. 1). The main population in the northern part of the region is at the Telfer and Nifty mines (Fig. 2), which are between 400 and 460 km southeast of Port Hedland. Both are 'fly in – fly out' operations. Access to these mines is closed to the general public. The only other settlement in the region is that of the Parnngurr (Cotton Creek) Aboriginal community on CONNAUGHTON.

Telfer is accessed by the Telfer road, which is a well-formed gravel and, in part, sealed road that connects with the sealed Ripon Hills road on NULLAGINE. A good graded road, used for ore cartage and transporting mine supplies, links the Nifty mine with the Woodie Woodie manganese mine to the west on NULLAGINE. A good-quality, four-wheel drive track connects the southern part of the region to Newman, via Balfour Downs and the Ethel Creek – Jigalong road. This road is connected to the Telfer road by a rough graded track through the Rudall River National Park. In 2004 a new gas pipeline connected Telfer to the North West Shelf pipeline network.

Climate and vegetation

The Paterson area has an arid climate, with evaporation exceeding precipitation. Average rainfall is approximately 220 mm/year, mainly from thunderstorms and cyclonic storms between November and March. Average daily summer temperatures range from about 25 to 40°C; average daily winter temperatures range from 5 to 25°C (Pink, 1992). Average annual evaporation is about 4000 mm, and prevailing winds are from the east and southeast (Pink, 1992).

The Paterson area forms part of the Great Sandy Desert and Little Sandy Desert natural regions of Beard (1970). Spinifex (*Triodia*) is present across the entire area. Other forms of vegetation are associated with different types of terrain; for example, sandplains also contain *Grevillea*, *Acacia*, *Crotalaria* (soft shrubs), eucalypts, tea-tree, and desert oak. Major riverbeds contain large eucalypts such as river gum (*Eucalyptus camaldulensis*) and paperbark (*Melaleuca* sp.), and various grasses. Playa-lake margins contain saltbush (*Hemichron*, *Bassia*, *Frankenia*) and samphire (*Arthrocnemum*). Areas of rock outcrop and colluvium contain low scrub, grasses, mulga, and sparse eucalypts (Beard, 1970).

Physiography

The most important erosional and depositional events that have influenced the physiography of the Paterson area appear to have been Carboniferous to Permian glaciation, and Cenozoic erosion and deposition. The physiographic subdivision outlined below follows that of Bagas and Smithies (1998).

Carboniferous to Permian land surface

Remnants of the Carboniferous–Permian land surface are present in areas covered by Carboniferous–Permian

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* Capitalized names refer to standard 1:100 000 map sheets unless otherwise indicated.

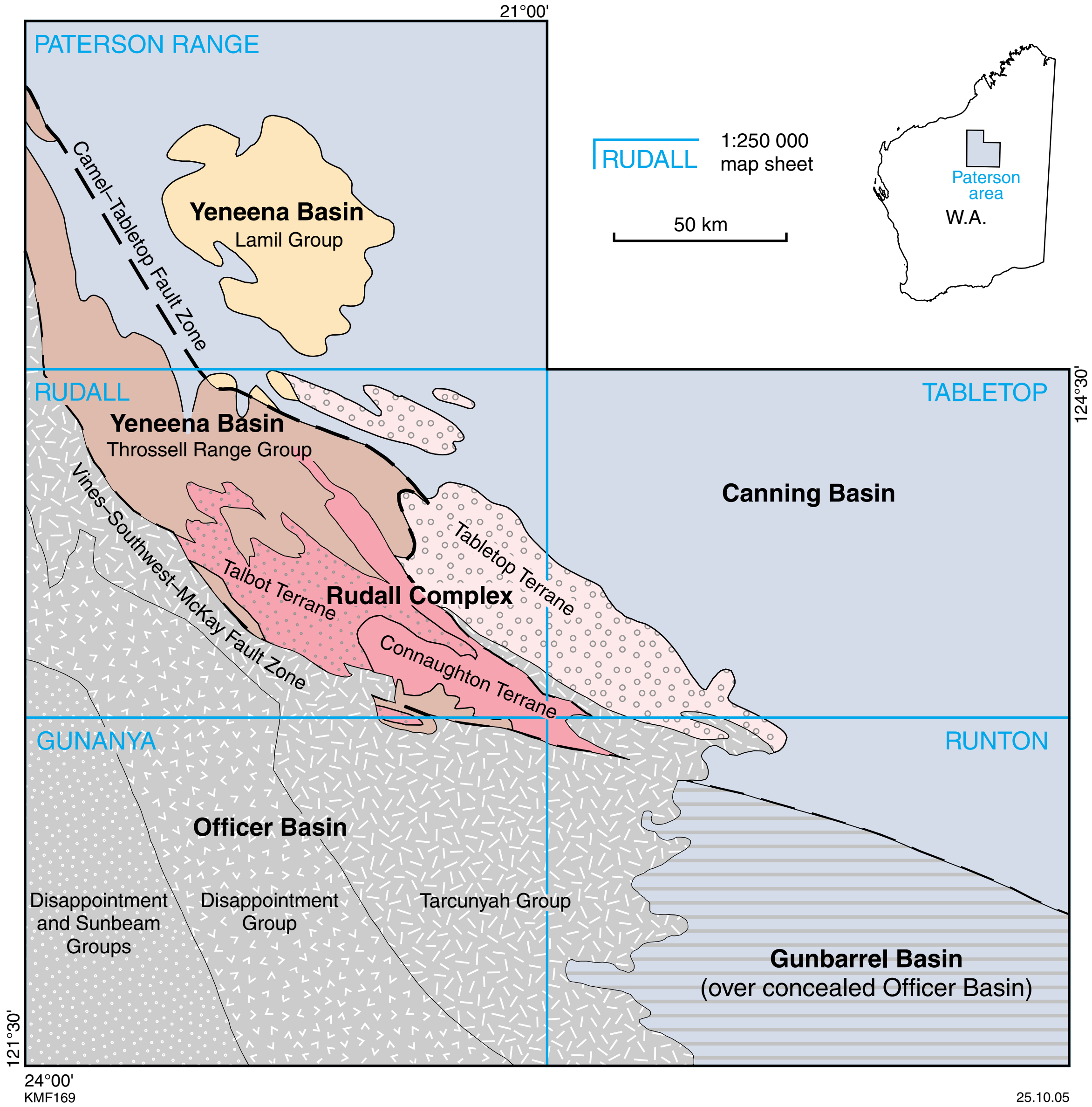

Figure 1. Tectonic units of the Paterson area, showing boundaries of the five included 1:250 000 geological maps

fluvioglacial sedimentary rocks of the Paterson Formation that represent sediments deposited during a glacial retreat. These remnants form dissected valley deposits with benches and mesas.

Cenozoic land surface

The Cenozoic land surfaces have been divided into erosional, relict or residual, and depositional land surfaces.

Erosional, relict or residual land surface

Units of this land surface represent various stages of erosion. Divisions include dissected plateaus, dissected ridges, low hills, rock pavements, and low-lying outcrop. Cliff lines, narrow gorges, and ravines commonly mark the edges of plateaus against more subdued landscape. Ridges rising to a height of 450 m above mean sea level are commonly separated by valleys developed in less-resistant rock types. These valleys are locally filled with thin Carboniferous–Permian sedimentary rocks, as seen in the southern part of RUDALL (Hickman and Bagas, 1996, 1998). Rock pavements and low outcrop are mainly found in sandplain areas, where erosion is restricted to wind action and water movement.

Depositional land surface

Sand-covered areas that form the southwestern part of the Great Sandy Desert, and the northern part of the Little Sandy Desert in the Paterson area, include westerly to northwesterly trending, mature longitudinal dunes, and

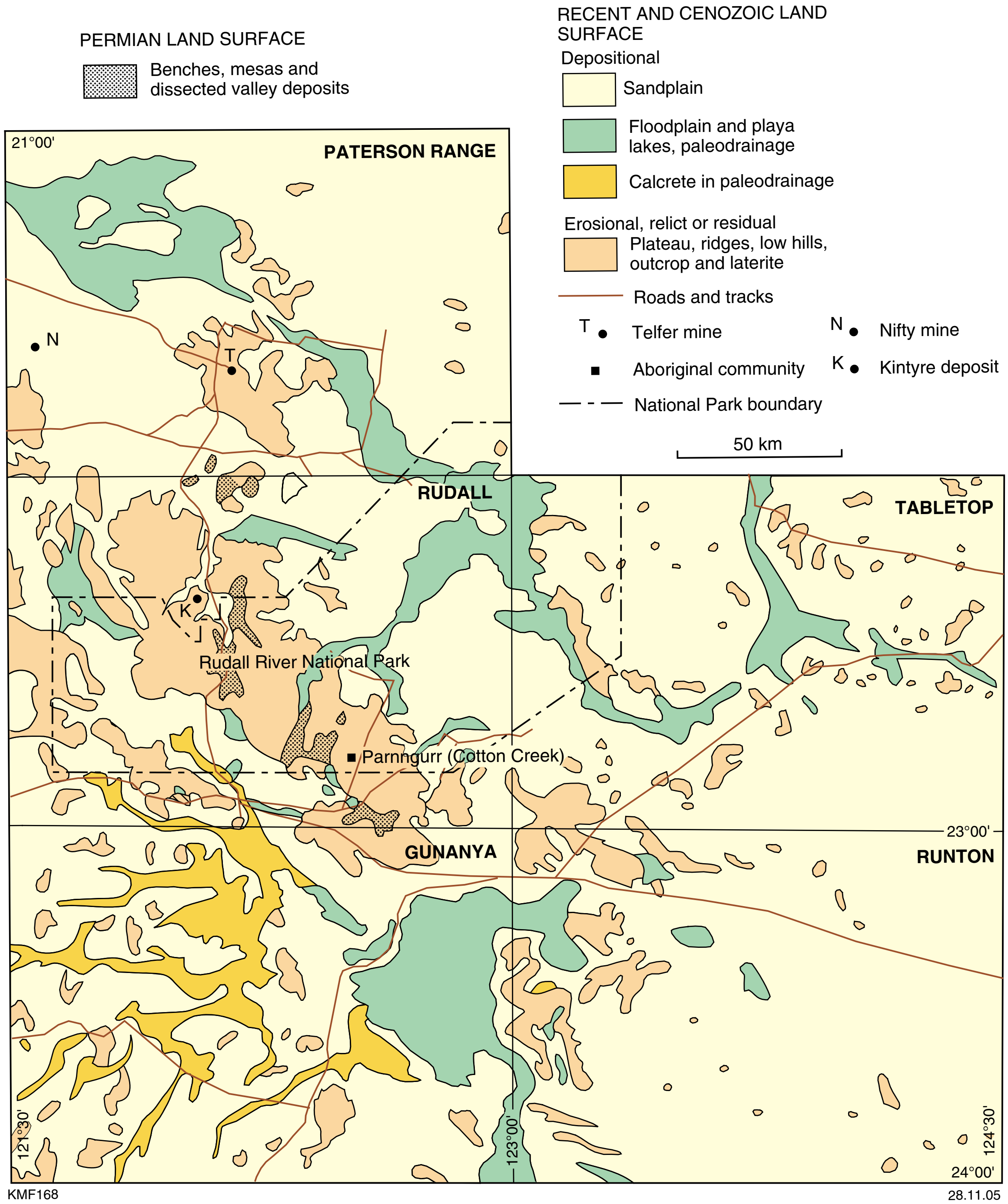

Figure 2. Location map showing physiographic units, settlements, roads, and tracks in the Paterson area, and boundaries of the Rudall River National Park

dune-free sandplains. The dunes are many kilometres long, up to 3 km apart, and average 30 m in height. The longitudinal profiles and their steep southern slopes are consistent with prevailing winds from the east-southeast. The dune-free sandplain areas are commonly subject to periodic flooding.

Scree, colluvium, sheetwash, fan, and playa-lake units that commonly flank the sandplains represent locally derived clastic detritus from streams and channels that drain the hilly areas.

Calcrete deposits pre-date the sandplains that partially cover them. They probably formed channels and lakes during the early Cenozoic. These deposits form low mounds composed of massive, nodular and vuggy limestone (partly replaced by chalcedony).

Unmodified remnants of a Cenozoic peneplain are present as ferruginous duricrust and silcrete cappings. The age of the peneplain laterite, ferruginous duricrust, and silcrete deposits that cap dissected plateaus may be correlated with the Hamersley Surface in the Hamersley

Ranges (Campana et al., 1964; Chin et al.,1982) or the Ashburton Surface of central Australia (Jennings and Mabbutt, 1971).

Previous work

W. F. Rudall wrote the first report on the region (Rudall, 1897) while searching unsuccessfully for the lost Wells expedition in 1896. F. H. Hann, who accompanied W. F. Rudall in 1896, returned during the following years searching for grazing land and prospecting for gold. In 1898, F. H. Hann named the Rudall River after his co-worker.

The first geological reconnaissance of the area was made by H. W. B. Talbot and A. W. Canning in 1908–09 along what is now known as the Canning Stock Route. Talbot (1910, 1919, 1920) described gneiss (Rudall Complex), the Nullagine Series (sedimentary units of the Mesoproterozoic Bangemall Supergroup, and the Neoproterozoic Officer and Yeneena Basins), and the Paterson Range Series (Carboniferous to Permian Paterson Formation).

F. Reeves (1949) investigated the southern part of the Canning Basin during a traverse from Mount Isdell to the Rudall River, making observations on the Yeneena Basin and Rudall Complex.

The Bureau of Mineral Resources (BMR), now named Geoscience Australia (GA), mapped a large part of the Canning Basin in 1954 (Traves et al., 1956) resulting in the publication of the Paterson Range and Tabletop 4-mile sheets. BMR also published preliminary Bouguer anomaly maps of the region in the 1970s, total magnetic intensity maps in the 1980s, and radiometric contour maps in the late 1980s. De la Hunty and Blockley of GSWA made reconnaissance trips in 1966 and 1969 to assist in the preparation of the 1966 and 1973 editions of the 1:2.5 million-scale State geological map (Blockley, 1972).

The isolation of the Paterson area, and the lack of a permanent surface water supply, impeded mineral exploration until 1971, when gold and copper were discovered at Telfer on PATERSON.

During the 1970s GSWA undertook systematic 1:250 000-scale geological mapping of RUDALL (Chin et al., 1980), GUNANYA (Williams and Williams, 1980), PATERSON RANGE (Chin et al., 1982), TABLETOP (Yeates and Chin, 1979), and RUNTON (Crowe and Chin, 1979). This work confirmed the unconformable relationship between the Rudall Complex and the (former) Yeneena Basin — which has since been redefined to include only the Neoproterozoic Throssell Range and Lamil Groups (Bagas et al., 1995, 1999; Williams and Bagas, 1999; Grey et al., 2005).

In 1989, GSWA began a program of 1:100 000-scale geological mapping of the Rudall Complex in the Paterson area, and published maps and Explanatory Notes for BROADHURST (Hickman and Clarke, 1994), CONNAUGHTON (Bagas and Smithies, 1998), RUDALL (Hickman and Bagas, 1998), THROSSELL (Williams and Bagas, 1999), GUNANYA (Bagas, 1998), BLANCHE–CRONIN (Bagas, 1999), POISONBUSH (Williams and Bagas, 2000), RUDALL 1:250 000 (Bagas et al., 2000), PATERSON (Bagas, 2000), and LAMIL (Bagas, 2005). A study of the evolution of the Talbot Terrane was undertaken by Hickman and Bagas (1999), which included an assessment of the distribution of mineralization.

In addition to these publications, regional overviews of the tectonic setting and mineralization of the northwestern part of the Paterson Orogen have been published by Bagas (2004a,b). These studies include a reinterpretation of the stratigraphy of the area that may impact on its prospectivity, and hence influence the direction of gold, base metal, and uranium exploration programs in the region.

Regional geology

Paterson Orogen

The Paterson area includes the northwestern part of the Proterozoic Paterson Orogen, part of the Neoproterozoic to Phanerozoic Officer Basin, and parts of the Phanerozoic Gunbarrel and Canning Basins (Fig. 1).

Williams and Myers (1990) defined the Paterson Orogen as ‘a belt of metamorphic, sedimentary, and igneous rocks that have a common tectonic history’. These metamorphosed Paleoproterozoic to Neoproterozoic sedimentary and igneous rocks extend over 2000 km, from the northwest of Western Australia across the central part of Western Australia, and into South Australia and the Northern Territory. The rocks are exposed in the northwest along the eastern margin of the Archean Pilbara Craton and in the Musgrave Complex of central Australia (Williams and Myers, 1990). Both areas were deformed during the c. 550 Ma Paterson and Petermann Orogenies (Bagas, 2004b). The two exposed areas are connected in the subsurface by a gravity high known as the Anketell Regional Gravity Ridge (Fraser, 1976) or the Warri Gravity Ridge (Iasky, 1990). The location of the gravity anomaly is shown in Figure 3.

The northwestern exposure of the Paterson Orogen was originally referred to as the Paterson Province (Daniels and Horwitz, 1969; Blockley and de la Hunty, 1975). It is flanked to the west by Archean to early Paleoproterozoic rocks of the Pilbara Craton, and to the east by the concealed Precambrian North Australian Craton (Myers et al., 1996).

The Paterson Orogen in this region includes the Paleoproterozoic to Mesoproterozoic Rudall Complex (Williams, 1990), the Neoproterozoic Yeneena Basin (Throssell Range and Lamil Groups), and the Neoproterozoic Tarcunyah Group and Disappointment Group of the Gibson and Wells Sub-basins of the northwestern Officer Basin (Williams and Bagas, 1999). The observed contacts between these regional subdivisions of the orogen are major faults. Other contacts are concealed by Phanerozoic rocks or sediments (Plate 1 and Fig. 1).

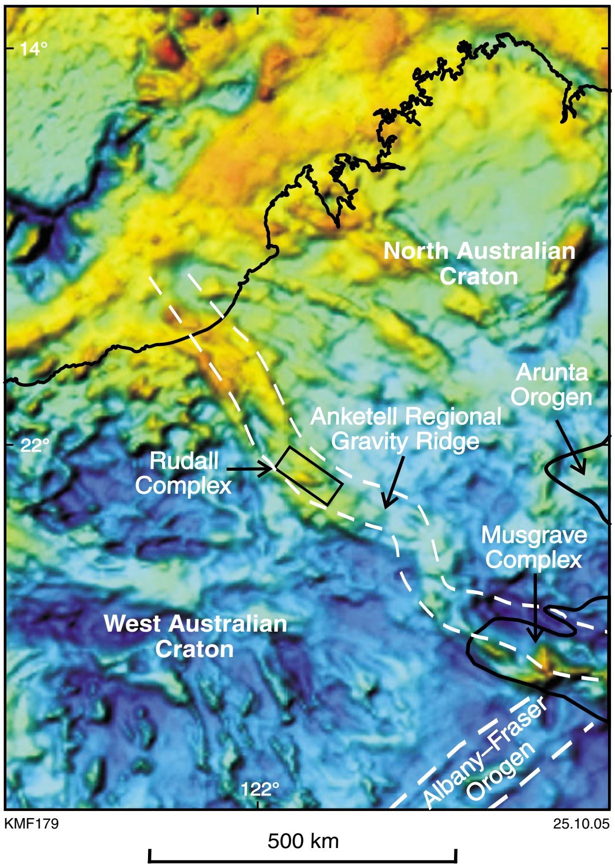

Figure 3. Northern part of Western Australia gravity image (Murray et al., 1997), showing the Anketell Regional Gravity Ridge and location of Rudall Complex

Paleoproterozoic to Mesoproterozoic Rudall Complex

The Rudall Complex outcrops in the centre of the Paterson area, and its relationship to the Pilbara and North Australian Cratons is obscured by sedimentary rocks of the Bangemall Supergroup, Yeneena Basin, Officer Basin, and Canning Basin (Plate 1).

The complex consists of deformed and metamorphosed sedimentary and igneous rocks, and has been subdivided into three tectono-stratigraphic terranes: the Talbot, Connaughton and Tabletop Terranes (Bagas and Smithies, 1998; Plate 1 and Fig. 1).

Talbot Terrane

The Talbot Terrane is in the western part of the Rudall Complex (Plate 1; Figs 1 and 12) and is composed of sedimentary and igneous rocks that have been deformed and metamorphosed to amphibolite facies (Smithies and Bagas, 1997). Augen orthogneiss constitutes about half of the terrane (by area) and is the result of metamorphism of c. 1790 Ma monzogranitic, granodioritic and very rare tonalitic protoliths (Hickman and Bagas, 1998).

The Talbot Terrane is divided into eastern and western suites of supracrustal rocks. The western suite consists of quartzite, amphibolite, serpentinite, and banded iron-formation. These rocks form xenoliths, rafts, and lenses in a lithologically layered orthogneiss that is c. 2015 Ma in age (see **Paleoproterozoic orthogneiss**) and contains two early foliations — S_1 and S_2 (Hickman and Clarke, 1994; Hickman and Bagas, 1998). The lithologically layered orthogneiss also includes the c. 1790 Ma K-feldspar augen orthogneiss (Hickman and Bagas, 1998).

The eastern supracrustal suite is the most extensive. It consists of an approximately 5000 m-thick siliciclastic paragneiss succession comprising rocks of the Larry Formation, Fingoon Quartzite, Yandagooge Formation (including the Cassandra Member), Butler Creek Formation, and Poynton Formation (Hickman and Bagas, 1998, 1999). The youngest detrital zircons extracted from the Fingoon Quartzite indicate an age of 1790 ± 10 Ma (Nelson, 1995, GSWA sample 104989). This is similar in age to the oldest granitic protoliths of the augen orthogneiss that intrudes the sequence, which vary in age from c. 1800 to 1765 Ma. Early (D_2) shear zones within the Talbot Terrane contain sheared, serpentinized ultramafic and mafic bodies associated with pelitic schist and turbiditic metasedimentary rocks (Hickman and Bagas, 1998). These ultramafic and mafic bodies are interpreted to have been emplaced during early deformation (D_2; Hickman et al., 1994). Lithologically, they are considered to be similar to ophiolitic units in many of the world's orogenic belts. On the basis of platinum group element geochemistry and textural and field relationships, Carr (1989) concluded that they represent slices of Proterozoic oceanic crust.

The most extensively mineralized formation is the Yandagooge Formation, which is a dominantly pelitic to semi-pelitic succession of quartz–mica schist and hematite–biotite schist, with minor amounts of quartzite, felsic gneiss, pyritic graphitic schist, chert, and metamorphosed banded iron-formation. A 230 m-thick succession of iron-rich and graphitic pelite, banded iron-formation, and chert has been subdivided at the top of the formation as the Cassandra Member (Hickman and Bagas, 1998). Hickman and Bagas (1998) noted that most of the radiometric anomalies on RUDALL coincide with exposed uranium mineralization in the Cassandra Member.

Connaughton Terrane

The Connaughton Terrane (Figs 1 and 12) comprises a succession of mafic gneiss and schist derived from basalt, and paragneiss derived from chemical and clastic sedimentary rocks (Bagas and Smithies, 1998), all of which have been metamorphosed to amphibolite–granulite transitional facies (Smithies and Bagas, 1997). No maximum age constraints are available for these rocks, but a minimum age of 1777 ± 7 Ma has been derived from the granitic protoliths of the K-feldspar augen orthogneiss that intrudes the sequence (Nelson, 1995, GSWA sample 113035).

Paleoproterozoic orthogneiss

About half of the exposed Rudall Complex in the Talbot and Connaughton Terranes is composed of orthogneiss derived from granitic protoliths. A large proportion of the orthogneiss is a microcline–quartz–plagioclase–biotite gneiss, which is characterized by K-feldspar augen (or deformed megacrysts). A smaller proportion of the orthogneiss is a lithologically layered gneiss with rafts and xenoliths of amphibolite, serpentinite, banded iron-formation, and paragneiss. Various (although minor) types of orthogneiss in the Talbot and Connaughton Terranes in the area are described elsewhere (Hickman and Bagas, 1998; Bagas and Smithies, 1998; Bagas et al., 2000).

The lithologically layered orthogneiss has a layer-parallel foliation (S_1) that is tightly folded (F_2). This unit is extensively intruded by sheets and veins of the K-feldspar augen orthogneiss. The K-feldspar augen orthogneiss is the only orthogneiss that outcrops in both the Talbot and Connaughton Terranes, and its protoliths were mainly biotite monzogranite. Typically it has a foliation (S_2) defined by the alignment of biotite, and microcline augen are often stretched within the foliation plane. No earlier deformation event is evident.

Two samples of the lithologically layered orthogneiss gave sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon dates of 2015 ± 26 Ma (Nelson, 1995, GSWA sample 104932) and 1972 ± 4 Ma (Nelson, 1995, GSWA sample 112310). The age of the K-feldspar augen orthogneiss ranges from 1802 ± 14 Ma to 1765 ± 15 Ma (Nelson, 1995, GSWA samples 104934, 104981, 110056, 111843, 111854, 112310, 112341, 112379, 112397). The K-feldspar augen orthogneiss forms a compositionally coherent group, despite its age range between c. 1800 and 1765 Ma.

Paleoproterozoic deformation and metamorphism in the Talbot and Connaughton Terranes

The history of Proterozoic igneous, deformational, and metamorphic events in the Talbot and Connaughton Terranes have been described in Bagas (2004b) and summarized in Figure 4.

Structures associated with the Yapungku Orogeny (D_{1-2}; Bagas and Smithies, 1998) in the Talbot and Connaughton Terranes can be linked to those of the Arunta Inlier in central Australia (Fig. 3), and partly with the Paleoproterozoic Capricorn Orogen in central Western Australia (Bagas, 2004a). The similarities in deformation and metamorphic histories for these widely separated regions indicate Paleoproterozoic collision of the Paleoproterozoic West Australian and North Australian Cratons between c. 1830 and 1765 Ma. This event, in the Paterson area, is expressed as the Yapungku Orogeny (Bagas and Smithies, 1998). The orogeny involved thrust stacking of older clastic sedimentary and volcanic rocks, and deposition of the protoliths for a c. 1790 Ma siliciclastic paragneiss succession, all of which was contemporaneous with granitic intrusion and regional metamorphism up to granulite facies (Smithies and Bagas, 1997).

Tabletop Terrane

The Tabletop Terrane (Figs 1 and 12) is distinguished from the strongly deformed and highly metamorphosed Talbot and Connaughton Terranes by the presence of granitic rocks that are not metamorphosed above greenschist facies. Supracrustal rocks are rare in the Tabletop Terrane but, where present, include quartzite, calc-silicate rocks, amphibolite, banded iron-formation, and intrusive ultramafic rocks.

Late (c. 1300 Ma) igneous rocks, including tonalite, monzogranite, leucocratic monzogranite, and syenogranite, have been recognized in the Tabletop Terrane (Bagas et al., 2000). The only strongly foliated granitic rocks are found close to the major northwesterly trending Camel–Tabletop Fault Zone, which corresponds approximately to the northern edge of the Anketell Regional Gravity Ridge. Tonalite is dominant in the Tabletop Terrane, whereas monzogranite is dominant elsewhere in the Rudall Complex.

The available geochronological data (Nelson, 1995, 1996) suggest that the voluminous tonalite was intruded at c. 1500–1300 Ma (Bagas and Smithies, 1998; Nelson, 1995). A contemporaneous igneous event is unknown in the Connaughton Terrane, while rare c. 1450 Ma monzogranite occurs in the Talbot Terrane (Nelson, 1996, GSWA sample 112102).

The Camel–Tabletop Fault Zone (Figs 1 and 12) separates the Tabletop Terrane from the Connaughton and Talbot Terranes (Bagas and Smithies, 1998). The fault zone is interpreted to have formed during the c. 750–720 Ma Miles Orogeny, and later reactivated (during the c. 550 Ma Paterson Orogeny) as a strike-slip system (Bagas and Lubieniecki, 2000). Aeromagnetic data indicate that the fault zone probably continues northwest, forming the concealed contact between the Throssell Range and Lamil Groups (Bagas, 2000).

Pungkuli–Taliwanya Formations

The Taliwanya Formation, the Pungkuli Formation, and unassigned sandstone are of uncertain ages, and are found in the central part of the Paterson area (Plate 1). The Taliwanya and Pungkuli Formations, which outcrop on the southern part of CONNAUGHTON near the Connaughton Terrane, were tentatively assigned, on lithological grounds, to the Yeneena Basin (Bagas et al., 2000). However, this correlation is uncertain because of the lack of age constraints and outcrop in intervening areas. For this reason these formations are excluded here from the Yeneena Basin pending availability of geochronological data.

Taliwanya Formation

The Taliwanya Formation (Bagas and Smithies, 1998), is up to 170 m thick and is predominantly arkosic sandstone containing local thick beds of polymictic conglomerate, and rare, thin interbeds of fine-grained lithic wacke, sandstone, and shale. The shale beds become more abundant towards the overlying Pungkuli Formation (Bagas and Smithies, 1998).

Pungkuli Formation

The Pungkuli Formation (Bagas and Smithies, 1998) is about 900 m thick and consists of interbedded, laminated,

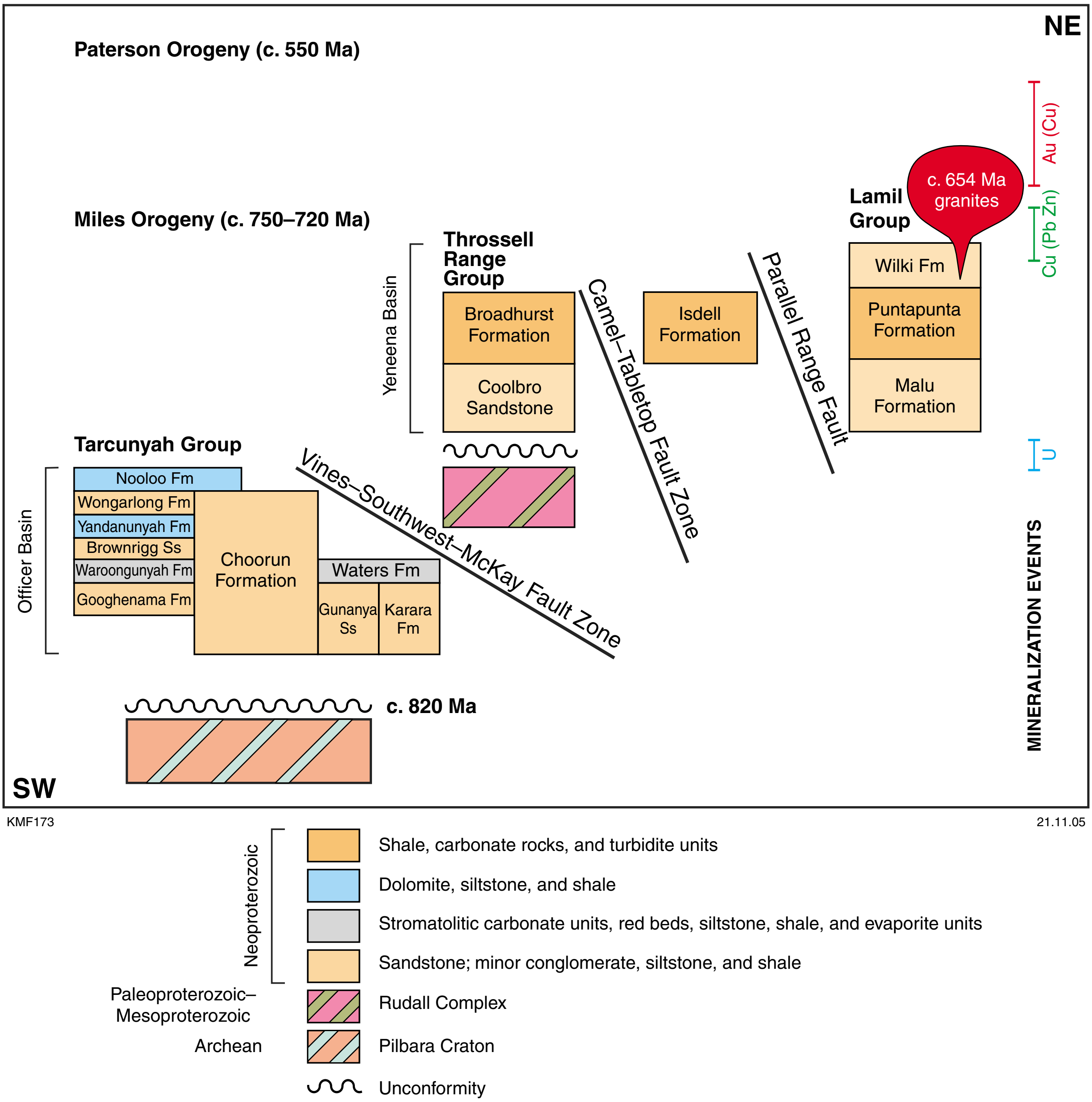

Figure 4. Simplified stratigraphy and tectonic events for the Neoproterozoic sequences of the Yeneena and northwest Officer Basins; proposed mineralization events shown on the right (modified from Bagas, 2004a)

slightly micaceous, grey to dark-brown to black shale, locally carbonaceous shale and siltstone, thin units of sulfidic shale and sandstone, and minor amounts of carbonate and chert (Bagas and Smithies, 1998).

Unassigned sandstone

The unassigned sandstone outcrops in the southern part of Blanche–Cronin and consists of cross-bedded to laminated, medium- to coarse-grained sandstone, interbedded with minor amounts of siltstone and shale (Bagas, 1999). Rare matrix-supported granule and pebble conglomerate outcrops near the base of the unit where it unconformably overlies the Rudall Complex. The sandstone is unconformably overlain by the Tarcunyah Group (Bagas, 1999).

Neoproterozoic northwestern Officer Basin

The northwestern Officer Basin in the Paterson area comprises the Neoproterozoic Tarcunyah Group, Sunbeam Group, Boondawari Formation, Disappointment Group, and Durba Sandstone (Bagas et al., 1995, 1999; Williams and Bagas, 1999; Grey et al., 2005).

Tarcunyah Group

The Tarcunyah Group consists of shallow-water, fluvial–marine conglomerate and sandstone; shallow-marine siltstone, shale and carbonate; and supratidal evaporites that are exposed to the west of the Vines–Southwest–McKay Fault Zone (Plate 1 and Fig. 1).

The Tarcunyah Group unconformably overlies the Archean Pilbara Craton, the Mesoproterozoic Bangemall Supergroup, and the Rudall Complex (Hickman and Bagas, 1998; Williams and Trendall, 1998). Grey and Stevens (1997) and Stevens and Grey (1997) correlated the c. 800 Ma *Acaciella australica* and *Baicalia burra* stromatolite assemblages in the group with fossils from Supersequence 1 of the Centralian Superbasin (Walter et al., 1995). Geochronological studies of detrital zircons from sandstone confirmed a Neoproterozoic age for the Tarcunyah Group on GUNANYA and CRONIN (Bagas, 2003).

Sunbeam Group

The Sunbeam Group (Bagas et al., 1999) includes the Watch Point, Coondra, Spearhole, Mundadjini, and Skates Hills Formations (Williams, 1992) and was named after Sunbeam Creek on TRAINOR. Of these formations, only the Mundadjini Formation is present in the Paterson area. The Mundadjini Formation (Williams and Tyler, 1991) extends through the central part of the northwestern Officer Basin. The formation is a fine- to medium-grained, sandstone-dominated unit with lesser amounts of interbedded siltstone, shale, and dolomite that is in part stromatolitic, and minor amounts of coarse-grained sandstone and conglomerate. Bedding ranges from rippled, with flat-topped and ladderback forms present, through parallel bedded to cross-bedded. Williams (1992) reported mud cracks, eolian adhesion surfaces, and various ripple forms. Gypsum and halite pseudomorphs are locally common, but no evaporite minerals are known in outcrop. Williams (1992) documented the lithology of the formation in detail.

The Sunbeam Group is equivalent to Williams' (1992) Depositional Sequence B. Most formations now placed in the Salvation Group (Hocking and Jones, 2002) were originally included in the Sunbeam Group (Bagas et al., 1999), but were excised after radiometric dating indicated they were part of an older succession. The Sunbeam Group incorporates most of the older part of the former Savory Group (Williams, 1992, 1994). The cumulative thickness of the Sunbeam Group is about 4000–5000 m.

The age of the Sunbeam Group is based on stratigraphic position and the recognition of the c. 800 Ma *Acaciella australica* and *Basisphaera irregularis* stromatolite assemblages in the Skates Hills Formation near the top of the group, which indicate correlation with the Browne Formation of the southwestern Officer Basin, the Bitter Springs Formation of the Amadeus Basin, the Yackah beds of the Georgina Basin, and the Coominaree Dolomite of the Adelaide Rift Complex (Grey, 1995; Hill et al., 2000).

Boondawari Formation

The Sunbeam Group is overlain by the Boondawari Formation, which has an inferred age of about 600 Ma by correlation with Marinoan glaciation elsewhere in Australia (Walter et al., 2000). The Boondawari Formation (Williams and Tyler, 1991) has been described in detail by Williams (1992, 1994) and Walter et al. (1995). The formation consists of diamictite, fine- to coarse-grained sandstone, conglomerate, siltstone, mudstone, dolomitic siltstone, and dolomite that is, in part, stromatolitic. A crystallization age of 508 ± 5 Ma for intrusive dolerite in the Boondawari Formation (Wingate, M. T. D., 2002, written comm.) is similar to other radiometric ages for the Table Hill and Antrim Plateau Volcanics and provides a minimum age for deposition (Veevers, 2000; Hanley and Wingate, 2000).

The Boondawari Formation is disconformable on the Mundadjini Formation, is unconformably overlain by the McFadden Formation, and is part of Williams' (1992) Depositional Sequence C. The Boondawari Formation was derived from widespread sources lying mainly to the west and south of the northwest Officer Basin. Williams (1987, 1992) interpreted the diamictites as glacigenic and deposited in a shallow-marine environment, distant from the ice source. Paleocurrent directions for sandstones interbedded with, and overlying, the diamictite are from the northwest to east, with a minor southwest component indicating supply from the Paterson Orogen.

Disappointment Group

The Disappointment Group (Bagas et al., 1999) includes the McFadden Formation, Tchukardine Formation, and Woora Woora Formation, and was named after Lake Disappointment. The Durba Sandstone (described below) is not included in the group because its age and relationship to the McFadden Formation remain equivocal. The Durba Sandstone is probably part of the same sedimentary package, but may be significantly younger. The Disappointment Group extends mostly around the northeastern margin of the northwest Officer Basin, and is found mainly east of the Marloo Fault on RUDALL, TRAINOR, and western MADLEY. The group includes those formations that demonstrate predominantly southwesterly paleocurrents, as shown by Williams (1992) for his Depositional Sequence D. The Disappointment Group consists of sandstone, siltstone, and conglomerate. It overlies, or is in faulted contact with, older rocks. The Disappointment Group overlies the Sunbeam Group and Boondawari Formation, and is overlain by Carboniferous–Permian Paterson Formation, but is otherwise poorly constrained. Its extent and possible correlatives are uncertain. Williams (1992) described the group as being associated with the onset of tectonism during the c. 550 Ma Paterson Orogeny (Fig. 4). The Disappointment Group probably corresponds to the Lungkarta Formation in the Officer Basin to the east and southeast.

Durba Sandstone

The Durba Sandstone (Williams et al., 1976) has been described by Williams and Williams (1980), and Muhling and Brakel (1985). This formation may be part of, or significantly younger than, the Officer Basin succession (as defined by Hocking, 1994), but there is no firm evidence as to its age.

The Durba Sandstone outcrops in widely separated areas parallel to the northeast margin of the northwestern Officer Basin. Its main exposure is at Durba Hills. The upper surface of the formation is everywhere eroded, and the maximum preserved thickness is less than 100 m (Williams, 1994). The formation is an overall upward-fining succession that consists of a basal pebble and cobble, sandy conglomerate up to 3 m thick and discontinuous, overlain by medium- to coarse-grained conglomeratic sandstone and medium- to fine-grained, well-sorted sandstone (Williams, 1992). Conglomerate commonly fills channels cut in underlying rocks. The sandstone is thick bedded and, in places, medium to coarse grained near the base of the formation, becoming medium to fine grained and flaggy upwards, and locally has a clay matrix. It is commonly cross-bedded to rippled, with scattered indicators of emergence and desiccation (Williams, 1992).

Neoproterozoic Yeneena Basin

The Yeneena Basin comprises the Neoproterozoic Throssell Range and Lamil Groups (Fig. 4; Bagas et al., 1995; Williams and Bagas, 1999; Grey et al., 2005).

Throssell Range Group

The Throssell Range Group (Williams and Bagas, 1999; Grey et al., 2005) is a sandstone–shale–carbonate succession that unconformably overlies, and is locally faulted against, the Rudall Complex (Plate 1 and Fig. 1). The group is interpreted, on sedimentological grounds, to have been deposited in a shallow-water, fluviatile to marine-shelf environment (Hickman and Clarke, 1994; Bagas and Smithies, 1998; Hickman and Bagas, 1999) probably within a strike-slip basin, intracontinental rift, or sag basin.

The Throssell Range Group consists of the Coolbro Sandstone, and Broadhurst and Isdell Formations (cf. Bagas et al., 2000). The Isdell Formation outcrops on northeastern BROADHURST, and probably under cover in the northeastern part of THROSSELL (Hickman and Clarke, 1994; Williams and Bagas, 1999). Stratigraphic contacts between the Broadhurst Formation and structurally overlying Isdell Formation have not been recognized in the field (Hickman and Clarke, 1994). However, the greater proportion of carbonate units in the upper part of the Broadhurst Formation on BROADHURST (Hickman and Clarke, 1994) and LAMIL (Bagas, 2005) suggests that the Isdell Formation may be a facies equivalent of the Broadhurst Formation. For this reason, the Isdell Formation is here tentatively included in the Throssell Range Group.

Coolbro Sandstone

The Coolbro Sandstone (Williams et al., 1976) is a fine- to coarse-grained, and massive to well-bedded quartz sandstone, with minor amounts of conglomerate, siltstone, and shale. Individual beds, where they are recognized, are commonly less than 5 m thick. The formation is found west of the Camel–Tabletop Fault Zone (Bagas and Smithies, 1998) and thins rapidly to the southwest near the Vines–Southwest–McKay Fault Zone (Plate 1 and Fig. 1) where it is reduced in thickness from about 4000 m on BROADHURST (Hickman and Clarke, 1994) to less than 30 m on THROSSELL (Williams and Bagas, 1999).

Broadhurst Formation

The Broadhurst Formation (Williams et al., 1976) conformably overlies the Coolbro Sandstone, and is characterized by poorly outcropping, metamorphosed, grey carbonaceous (graphitic) shale and siltstone, sandstone, poorly sorted sandstone, and dolomite (Plate 1). The formation includes minor interbeds of sandstone, and rare basalt. A strong magnetic signature, due to magnetite, pyrite, and pyrrhotite in shale units, characterizes the formation (Bagas et al., 2000). Like the Coolbro Sandstone, it appears to thin from 2000 m thick on BROADHURST (Hickman and Clarke, 1994) to metres thick on THROSSELL (Williams and Bagas, 1999) towards the Vines–Southwest–McKay Fault Zone.

Isdell Formation

The Isdell Formation (Williams et al., 1976) is exposed around Mount Isdell on BROADHURST (Hickman and Clarke, 1994; Plate 1). The formation is composed of carbonate rocks interbedded with relatively thin beds of calcareous siltstone and shale (Hickman and Clarke, 1994). The total thickness of the formation is at least 1000 m (Hickman and Clarke, 1994).

Lamil Group

The Lamil Group was deposited in deeper water than the Throssell Range Group, and consists of sandstone, siltstone, and carbonate rocks (Bagas, 2000; Bagas et al., 2002). The group comprises the Malu, Puntapunta, and Wilki Formations, and unassigned sedimentary rocks (Bagas, 2000).

In the northeastern part of the exposed Lamil Group, fine- to medium-grained quartz sandstone is interbedded with carbonate beds that grade into marble where granite is near the surface. The marble contains tremolite, diopside, and scapolite, in a fine-grained matrix of quartz, calcite, and feldspar, rare tourmaline, epidote, and titanite (Bagas, 2000). The sandstone is generally massive but includes rare thinly bedded sandstone intervals, with minor interbeds of partially dolomitized siltstone and shale. The proportion of siltstone and shale is greatest towards the base of the unit where it underlies carbonate units. On magnetic images and aerial photographs this sandstone resembles the Wilki Formation or the Malu Formation. However, it has not been included in either of these formations because of major concealed structural breaks, interpreted from magnetic images. These units remain unassigned pending further work in the area.

Malu Formation

The Malu Formation (Bagas, 2000) includes the Telfer Member at its top. Both units contain quartz-rich sandstone, siltstone, and shale, although the Telfer Member contains a higher proportion of siltstone, and rare dolomite near its top. The Malu Formation is at least 2 km thick at the Malu Hills locality, and at depth in the Telfer mine on PATERSON (Bagas, 2000).

Telfer Member

The Telfer Member (Bagas, 2000) is a transitional sequence between the Malu Formation and the overlying Puntapunta Formation (Plate 1). The base of the member is at the top of the massively bedded sandstone in the underlying part of the Malu Formation, and the top is at the uppermost sandstone bed (Bagas, 2000). The Telfer Member is about 600 m thick.

The Telfer Member consists of fine- to medium-grained quartz sandstone, interbedded with clayey sandstone, siltstone, and shale. The sandstone beds are typically well sorted, very fine to fine grained, and consist of quartz, plagioclase, and sericite, with minor amounts of authigenic dolomite. Siltstone beds are laminated and commonly spotted with authigenic dolomite grains. The siltstone consists of quartz, carbonate, plagioclase, sericite, tourmaline, zircon, and sulfides (mostly pyrite).

Puntapunta Formation

The Puntapunta Formation (Chin et al., 1982) is a laminated to thinly bedded sequence of dolarenite, interbedded with dolomite, siltstone, and shale. It conformably overlies the Malu Formation, and is conformably overlain by the Wilki Formation (Plate 1). The Puntapunta Formation is about 1500 m thick (Bagas, 2000).

Wilki Formation

The Wilki Formation (Wilki Quartzite of Chin et al., 1982) is about 1400 m thick and appears to conformably overlie the Puntapunta Formation, although the contact between the two formations is nowhere exposed. Much of the Wilki Formation is a monotonous sequence of silicified fine- to medium-grained sandstone, and minor recessive shale and laminated sandstone. The sandstone is moderately sorted, quartz rich, with subrounded to well-rounded quartz grains in a matrix of quartz and sericite. Hornfelsed sandstone north of the Mount Crofton Granite contains recrystallized and interlocking quartz grains with minor chlorite, muscovite, and tourmaline. Sedimentary structures are rarely preserved in this formation.

Age of the Throssell Range and Lamil Groups

No diagnostic stromatolite or acritarch fossils have been identified that could give precise ages for the Throssell Range and Lamil Groups.

SHRIMP U–Pb zircon ages from detrital zircons confirm the Neoproterozoic age for the Throssell Range and Lamil Groups (Nelson, 1999; Bagas et al., 2002). Monzogranite and syenogranite, which intrude the Lamil Group (discussed below), indicate a minimum depositional age of c. 654 Ma for the Lamil Group (Dunphy and McNaughton, 1998). Strata of the Lamil and Throssell Range Groups have similar zircon age distributions (Bagas et al., 2002), which suggests the same provenance, and possible stratigraphic correlation.

Miles Orogeny

The Neoproterozoic Throssell Range and Lamil Groups were deformed during the c. 720 Ma Miles Orogeny (D_{3-4}; Bagas and Smithies, 1998; Bagas, 2004b; Fig. 4). The orogeny produced a northwesterly trending fold and fault system of tight to isoclinal upright and overturned folds and thrust faults, possibly contemporaneous with the c. 750–720 Ma Areyonga tectonic movement, which deformed the lower Neoproterozoic succession of the Amadeus Basin in central Australia, and the Officer Basin in Western Australia (Moors and Apak, 2002).

Mount Crofton Granite and associated granitic rocks

The Lamil Group is metamorphosed and intruded by granite, including the Mount Crofton Granite, in the northern part of PATERSON (Bagas, 2000), the northeastern part of LAMIL (Bagas, 2005), and the northern half of the PATERSON RANGE 1:250 000 sheet area (Chin et al., 1982; Plate 1 and Fig. 1). Narrow contact aureoles are present around the granites on LAMIL and PATERSON, but the width of aureoles increases further north. Outcropping granitic rocks range in composition from monzogranite to syenogranite, and are usually massive and undeformed. They are highly fractionated (average SiO_2 content >71 wt% and Rb/Sr ratios up to 20.5), metaluminous, and I-type in nature (Goellnicht et al., 1991; Goellnicht, 1992). The development of contact metamorphic aureoles is variable and hard to recognize due to the silica-rich sandstone units that the granite intrudes. The aureoles are up to 2 km wide and reach the pyroxene-hornfels facies (Chin et al., 1982); country rocks contain veinlets of quartz and biotite, and cordierite porphyroblasts are present in pelitic rocks.

Two samples from the Mount Crofton Granite gave titanite SHRIMP U–Pb ages of 640 ± 8 and 654 ± 8 Ma (Dunphy and McNaughton, 1998). These ages are regarded as the most valid for constraining the true crystallization age of the samples, despite the high to extremely high concentration of uranium in the zircons, which has largely destroyed their structure and resulted in significant lead loss (Dunphy and McNaughton, 1998). The zircon ages for the same samples range from c. 630 to 600 Ma (Nelson 1995, 1999), and are therefore minimum ages for the granitic rocks — not their crystallization ages (Dunphy and McNaughton, 1998).

Paterson Orogeny

The last major Proterozoic event recorded in the Paterson Orogen was the late Neoproterozoic (c. 550 Ma) intracratonic Paterson Orogeny (D_6; Bagas and Smithies, 1998, fig. 45) which, in the Paterson area, reactivated earlier structures (Hickman and Bagas, 1998). This event is probably equivalent to the c. 550 Ma Petermann Orogeny (Camacho and Fanning, 1995) of the Musgrave Complex in central Australia, and synchronous with the King Leopold Orogeny of the Kimberley region of northern Western Australia (Shaw et al., 1992).

Several northeasterly trending open folds with southeasterly dipping axial planes and strike-slip faults have been mapped in the northwestern Officer Basin (Bagas and Smithies, 1998; Williams and Bagas, 1999) and in the Rudall Complex (Hickman and Bagas, 1998). These structures, which indicate northwest shortening against the Archean Pilbara Craton, have been assigned to D_5, and have been associated with the Blake Movement (Williams, 1992). These structures may be associated with a transpressional folding event with dextral strike-slip faulting (southwest block to the northwest) during the Paterson Orogeny (Bagas and Smithies, 1998).

Possible kimberlite dykes

Possible kimberlite intrusions, forming a dyke complex, have been intersected during exploration drilling within sandstone units of the Tarcunyah Group on southeast BLANCHE–CRONIN (Jackson, M., 2004, written comm.); their age is uncertain (see **Diamonds**).

Phanerozoic Canning and Gunbarrel Basins

The Canning Basin is the largest sedimentary basin in Western Australia, and contains sedimentary rocks from Ordovician to Cretaceous in age. Occupying a largely unexplored area of about 550 000 km^2, it extends south from the Fitzroy River in the northwest to the De Grey River in the west, and from the coast southeast to around 128°E longitude (Middleton, 1990). The basin underlies the western part of the Great Sandy Desert.

The Canning Basin unconformably overlies rocks included in the Paterson area. Outcropping Canning Basin successions are Carboniferous to Permian, and Jurassic to Cretaceous in age. These are the Late Carboniferous to Early Permian Paterson Formation, Permian Poole Sandstone, Noonkanbah Formation, and Liveringa Group; Jurassic to Cretaceous Callawa Formation; and Cretaceous Anketell Sandstone (Yeates et al., 1984; Middleton, 1990).

The Gunbarrel Basin (Hocking, 1994) is a poorly exposed Phanerozoic succession that overlies the northwestern Officer Basin in the eastern part of the Paterson area. The Gunbarrel Basin was defined by Hocking (1994) as the Paleozoic and Mesozoic successions that are floored by the Cambrian Table Hill Volcanics, which were originally included in the Officer Basin. The rocks included in the Gunbarrel Basin are correlatives of those in the Canning Basin, and the Gunbarrel Basin probably forms a sub-basin of the Canning Basin. The Gunbarrel Basin in the Paterson area consists of the Late Carboniferous to Early Permian Paterson Formation, Jurassic to Cretaceous Callawa Formation, and Cretaceous Anketell Formation.

The boundary between the Gunbarrel and Canning Basins is ill-defined, and reflects magnetic trends related to underlying Neoproterozoic and possibly older rocks. Deposition of Permian and Cretaceous rocks appears to have been continuous over the boundary, although there may have been a ridge between the two basins in the Ordovician. The Permian succession thickens and is more complete in the Canning Basin (Hocking, R. M., 2005, written comm.).

Carboniferous to Permian rocks

Paterson Formation

Remnants of the Carboniferous to Permian Paterson Formation outcrop in northerly trending glacial paleovalleys throughout the Paterson area. These fluvioglacial and diamictic sedimentary rocks form mesas or partially dissected benches that flank the larger hills, and consist of pebble and boulder conglomerate, cross-bedded and coarse-grained sandstone, siltstone and shale (Bagas, 2000). The basal part of the formation contains rounded and striated pebbles and boulders indicating a widespread source that is largely outside the region. The conglomerate is overlain by coarse-grained, poorly sorted, medium to coarse, cross-bedded sandstone and siltstone, with ripple marks and graded laminae — which is the dominant exposed lithology of the formation.

Poole Sandstone and Noonkanbah Formation

Shallow-water fluvial and marine sandstone and siltstone of the Permian Poole Sandstone is conformably overlain by the Noonkanbah Formation, which is made up of marine mudstone interbedded with sandstone. These formations disconformably overlie the Paterson Formation.

Liveringa Group

The Permian Liveringa Group (Yeates et al., 1984) is found in the northeastern part of the Paterson area, and consists of undivided shallow-marine to fluvial–deltaic conglomerate, sandstone, siltstone, and mudstone. A full description of the group has been given by Yeates et al. (1984), which describes the constituent formations and environments of deposition.

Jurassic to Cretaceous rocks

Late Jurassic to Early Cretaceous sedimentary rocks cover much of the Paterson area. These were previously shown as Jurassic to Cretaceous, but may well be entirely Cretaceous, based on recent paleontological re-evaluation.

Callawa Formation

The Late Jurassic to Early Cretaceous Callawa Formation and its equivalents are confined to isolated areas in the northern part of the PATERSON RANGE and TABLETOP 1:250 000 sheet areas (Chin et al., 1982; Yeates and Chin, 1979). The formation is a fluvial succession of conglomerates, fine- to coarse-grained and poorly sorted sandstones, and siltstone (Bagas, 2000).

Anketell Sandstone

The Cretaceous Anketell Sandstone and its equivalents (Yeates et al., 1984) consist of a fluvial succession of thin-bedded siltstone, and fine-grained sandstone interbedded with lenticular units of cross-bedded coarse-grained sandstone and minor amounts of granular conglomerate. This unit disconformably overlies the Callawa Formation and forms mesas, breakaways and isolated hills.

Regolith

Regolith covers most of the eastern and northeastern part of the Paterson area and is the product of weathering, mass wasting, erosion, and transport. A digital dataset of the regolith layer (1:500 000) is included in the CD-ROM that accompanies this Report. This digital map is an extract from the 1:500 000-scale State regolith map of Western Australia. The various regolith units identified on the map are lacustrine (*L*), alluvium (*A*), slope deposits (*C*), sandplain (*S*), calcrete (*calcrete)*, and exposed rock (*X).*

Cenozoic deposits

On Connaughton, Bagas and Smithies (1998) identified the effects of ferruginization, leaching, and silicification that are typical of laterite profiles. These processes resulted in the formation of duricrust caps, ferricrete or ironstone deposits, and various forms of silcrete developed over sandstone and orthogneiss. Some silcrete cover, such as near Telfer, may be Carboniferous or Permian in age (Bagas, 2000).

Colluvium and talus, sheetwash, fan, and calcrete deposits are also present. Calcrete, consisting of massive, vuggy, or nodular sandy limestone, is usually only a few metres thick and is found in drainage channels.

Quaternary deposits

Quaternary deposits, mainly alluvium and eolian sands, cover most of the rocks in the Paterson area. Alluvium is present in drainage courses and related floodplains. Playa lake deposits tend to be confined to the major paleodrainage courses and interdunal areas. Areas of sheetwash are typically developed in areas of low relief where mature red-earth soils dominate.

Eolian sands cover most of the low-lying areas, and form the most common and widespread regolith unit. Areas dominated by long, densely grouped longitudinal (seif) dunes form sandplains in the broad areas between playas, drainage courses, and the areas of rock outcrop. The dunes are up to about 50 m high and many kilometres long, and are aligned on the west to northwest orientation defined by the prevailing winds.

Exploration and mining history

Due to its isolation, poor access and lack of permanent water supply, there was very little prospecting and mineral exploration in the Paterson area until the early 1970s, when major exploration programs commenced for gold and base metals, and later for uranium. These programs were initially triggered by the discovery of significant gold mineralization at Telfer.

Gold in the Yeneena Basin

Gold was discovered by Phillippe Koehn and Ron Thomson of Day Dawn Minerals in July 1971, in gossans on low sandstone ridges of the Lamil Group in the Paterson Range (Royle, 1990; Tyrwhitt, 1995; Sheppard, 2002). Due to the low gold price at that time, the company decided not to apply for tenements. Prior to this, in October 1970, prospector Jean Paul Turcaud was the first to discover mineralization in the same area when he found copper in gossanous outcrops. During 1970–71 Turcaud approached several major exploration companies, but none of them decided to take up an interest in his discovery. His gossan samples and those collected by two companies who conducted field inspections were only analysed for base metals, and not for gold (Tyrwhitt, 1995; Sheppard, 2002)[*].

In 1972 Thomson interested his new employers, Newmont Pty Ltd, in the auriferous outcrops in the area later to be called the Telfer Dome. Newmont intersected high-grade gold during exploratory drilling in June–July 1972 and initially considered the gold–copper mineralization to be stratiform and syngenetic in nature (Tyrwhitt, 1995). Further studies indicated that mineralization was structurally controlled. The vertically stacked, stratabound vein-type reef mineralization represents linked zones of intense stockwork in sheeted vein sets that are associated with domical structures. The initial RC drilling program in the Telfer Dome established a reserve of 3.8 Mt at 9.6 g/t Au (Tyrwhitt, 1995).

The Telfer discovery set in motion further regional exploration in the mid-1970s by Newmont Australia Ltd (later Newcrest), and to a lesser extent by Geopeko, that led to the discovery of further gold–copper prospects in the Thomson, 17 Mile and other domes.

Mining production commenced at Telfer in 1977, and six million ounces of gold were mined over the next 15 years. Later, in 1993, production was boosted by mining of the stacked reef system beneath the Telfer Dome. In 2000 Newcrest Mining Ltd curtailed production because of high costs related to the processing of ore containing cyanide-soluble copper in the Main Dome. From then until 2004, the mineral resource and ore reserve base was increased by deeper exploration drilling, which located new mineralized zones known as the Telfer Deeps and the West Dome Deeps. There have also been substantial improvements in the infrastructure at Telfer. A new gas pipeline now delivers North West Shelf gas to Telfer and there has been a major upgrade to the access road. Mining recommenced in November 2004.

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[*] The two companies were Australian Anglo American and Western Mining Corporation, who carried out separate inspections a few months before investigations by Day Dawn's geologists. During the early 1970s it was not usual for gold to be routinely assayed in base metal exploration programs.

Uranium, with associated base metals and other commodities, in the Rudall Complex

The earliest uranium exploration in the Paterson area was in 1974, when Esso Exploration carried out helicopter-borne radiometric surveys, but no significant anomalies were found. In 1977, CRA Exploration (CRAE, now Rio Tinto Exploration) explored for uranium during its gold and base metals programs (Jackson and Andrew, 1988, 1990).

Drilling by Otter Exploration in 1972 located subeconomic base metals, with associated minor uranium, at Camel Rock and Mount Cotton (Bagas and Smithies, 1998; Ferguson, 1999). Otter also explored the Yandagooge – Lead Hills area in 1972 targeting pelitic, carbonaceous or carbonate schist within the Rudall Complex (Hickman and Clarke, 1994). Exploration by Newmont in the South Rudall Dome area in 1974–75, in a gossanous, graphitic and carbonate-rich schist–BIF horizon, obtained relatively low base-metal values during drilling (Ferguson, 1999). In the period 1981–84, Agip Exploration and CRAE explored in the same area in a farm-in agreement. They also tested the Connaughton Dome, with a best drilling intersection at Mount Cotton of 0.38 m at 1.5% U_3O_8.

In the early 1980s, CRAE carried out ground surveys to investigate the sources of geophysical anomalies interpreted from airborne surveys carried out during a program of diamond exploration. As a follow up in 1983, they undertook an electromagnetic INPUT survey in areas of base metal anomalies, and of uranium indicator minerals in the drainage system (including the Yandagooge uranium anomaly). Helicopter-borne and ground radiometric surveys were carried out during 1984–85 and these located anomalies that later became the Kintyre and Tracy (Yandagooge) prospects. Here, vein-type uranium mineralization was identified in an area of graphitic schist, beneath unconformably overlying sandstones of the Coolbro Sandstone of the Yeneena Basin.

Drilling at Kintyre followed in 1985 and continued into 1988, identifying intersections up to 70 m thick with 2.5 – 6.3 kg/t U_3O_8. Two blind deposits (Pioneer and Whale) were located in 1985 (700 m northeast and 500 m east-northeast of Kintyre, respectively) beneath the cover of Permian glacial deposits. A third deposit (Nerada) was identified later. Other uranium prospects located included Wellington, 11 km south of Kintyre in the Yandagooge Inlier; Jackpot in unassigned psammitic gneiss of the Rudall Complex; Sunday Creek in the Yandagooge Formation; and Fandango in the unconformably overlying Throssell Range Group.

CRAE located other base metal prospects with associated uranium within the Rudall Complex at Lead Hills, Minder, Cassandra, Bilbo, and Dione. The company also discovered a small, subeconomic copper deposit called the Wanderer prospect (in sulfidic chlorite schist and quartzite of the Rudall Complex) 4 km north-northwest of the Wellington uranium prospect. Drill testing a deep magnetic target in 1988 gave best one-metre assays at 5.18% Pb, 0.43% Cu, 0.22% Zn and 13.4 g/t Ag.

GSWA carried out rock-chip sampling in the Connaughton Dome area as part of their 1:100 000-scale geological mapping program (Bagas and Smithies, 1998). Results from the Connaughton Syncline at Mount Cotton East showed up to 19.4% Cu and 2260 ppm Pb, suggesting good potential for stratabound, fault controlled, supergene-enriched base metal mineralization, similar to that described above in the work of Otter Exploration (Ferguson, 1999).

Further details of this period of uranium, base metal, and other mineral exploration are provided by Hickman and Bagas (1999) and Bagas (2000).

Base metals in the Yeneena Basin

As discussed in the previous section, Jean Paul Turcaud was the first to discover base metals in the Lamil Group in 1970. However, as a consequence of the spectacular success of Newmont's gold exploration at Telfer in 1972, exploration for other commodities was temporarily overlooked. In the late 1970s, WMC Resources (WMC) realised the potential of the Throssell Range Group for sediment-hosted base metal deposits of Zambian style. In 1981, exploration led to the discovery of copper mineralization (with subordinate zinc and lead) at Nifty in the Broadhurst Formation, as a result of a lag sampling program. An important part of WMC's successful exploration strategy in the Throssell Range Group was the idea that the underlying basal arenaceous Coolbro Sandstone was a possible source rock for copper mineralization that later accumulated in the overlying thinly bedded, pyritic, dolomitic siltstone and shale of the host Broadhurst Formation. This is further discussed under **Mineralization controls and exploration potential**. Haynes et al. (1993) considered the Nifty mineralization to be a new style of sediment-hosted copper deposit with similarities to stratiform lead–zinc orebodies such as those at Mount Isa. WMC commenced openpit mining of secondary (oxide) mineralization at Nifty in 1993, with heap leach extraction of the copper ore.

WMC sold its interests in Nifty to Straits Resources in 1998. In March 2003, Straits Resources sold the project to a wholly owned subsidiary of the Aditya Birla Group of India. The new owner carried out additional drilling and a feasibility study into underground mining of the deep-sulfide mineralization. The company plans to reopen the mine in August 2005 and to increase production from 1.5 to 2.5 Mt per year.

Elsewhere, Amax Exploration (Australia) discovered uranium and base metal mineralization at Cottesloe in the late 1970s. This deposit, also referred to as Eva Well, is at the southern end of a basin-shaped syncline, in sulfidic shale of the Broadhurst Formation.

Occidental Minerals also explored the Yeneena Basin for uranium and base metals along the Coolbro Sandstone – Broadhurst Formation contact zone in 1978. At that time no economic mineralization was found, despite drilling of geochemical anomalies in the Mount Sears Range, Sunday Creek and Coolbro Creek, and Broadhurst Range areas.

In 1984 Esso discovered the Maroochydore copper mineralization at about the same stratigraphic level as the Nifty deposit. This further confirmed the potential of the Yeneena Basin, particularly the graphitic–sulfidic, carbonate-rich Broadhurst Formation, for syngenetic–epigenetic base metal mineralization (Ferguson, 1999).

Other metalliferous commodities (PGE and REE mineralization)

The ultramafic rocks in the Rudall Complex were explored for platinum group elements (PGE) in 1971 by North West Oil and Minerals (Taylor, 1971). The company considered the rocks to be prospective for PGE, chromite, or cumulate-associated nickel deposits. Drilling results included 6.65 ppm Pt at depths of up to 240 m. Blockley (1972) carried out follow-up surface investigations, but was unable to obtain significant PGE results in rock-chip sampling near the drillhole collars, and in natural concentrates of black sands collected from small streams draining the ultramafic body. Platinum and palladium have also been detected in the Kintyre uranium deposit, and in other uranium – base metal prospects in the Rudall Complex (Hickman and Bagas,1999).

Exploration for PGE and diamond, targeting ultramafic rocks, was carried out by Australian Platinum Mines between 1995 and 2000 in the Camel–Tabletop area of the Rudall Complex. Only amphibolite (as opposed to ultramafic) bodies were found, and there were no kimberlitic indicators.

Bagas and Smithies (1998) reported anomalous concentrations of rare earth elements in gossans within amphibolite, schist, orthogneiss, and banded iron-formation of the Rudall Complex on CONNAUGHTON.

Diamonds

In the southeast of the Paterson area, diamond potential has recently been identified in the Runton area by Caldera Resources. In 2003 twenty microdiamonds were discovered at Runton in a sandstone host rock which may be interpreted to be a quartz-rich tuff or crater-facies lithology. This may represent the upper portion of a diamondiferous kimberlite or lamproite dyke-like body that intrudes Proterozoic sandstones (Resource Information Unit, 2004). Other indicator minerals were also found, including a diamond–moissonite intergrowth grain, chrome spinels, and baddeleyite. A near-surface intrusive kimberlitic or lamproitic body, of at least 600 m depth extent, is suggested by a subtle linear magnetic anomaly. Potential for further intrusive rocks of this type has been suggested by Jackson (Jackson, M., 2004, written comm.).

Industrial minerals

Minor occurrences of barite have been found in mica schist and orthogneiss of the Rudall Complex. Gypsum has been found as lake-bed kopi at Watrara Creek, Lake Disappointment, and Lake Waukarlycarly.

Mineralization

There are 130 mineral occurrences recorded in the WAMIN database for the Paterson area; their locations are shown on Plate 1 and Figure 5. The mineral occurrences are also grouped in Appendix 1 (and on Plate 1) according to commodity (colour) and mineralization style (symbol). In the following sections the occurrences are grouped by mineralization style and then by commodity groups under various subheadings. Mineral occurrences referred to below are identified by the WAMIN 'deposit name' and 'deposit number', shown thus: Telfer West Dome (*9980*). Mineralization is discussed in terms of the major geological events that have shaped the Paterson area. The temporal relationship between geological evolution and mineralization is shown in Figure 4.

The largest number of mineral occurrences (91) are in the vein and hydrothermal mineralization category. Of these, 40 are Telfer-style gold occurrences in the Lamil Group (in the broad Telfer Dome area) and four are base metals, also in the Lamil Group. Most of the remaining mineral occurrences are base metals associated with uranium, gold, and PGE in the Rudall Complex.

A total of 15 mineral occurrence sites represent stratabound, clastic-hosted base metal mineralization (of the Nifty-type), found predominantly in the Broadhurst Formation of the Throssell Range Group. The remaining WAMIN sites include minor occurrences of industrial minerals, speciality minerals, and steel industry minerals — predominantly in the Rudall Complex and in the regolith.

Kimberlite and lamproite mineralization

Precious minerals (diamonds)

Twenty microdiamonds, and other indicator minerals, have been found in a possible crater-facies sandstone at Runton (*17670*) in an area of a subtle linear magnetic anomaly that Caldera Resources have interpreted to be a kimberlitic dyke complex intruding Neoproterozoic sandstones.

Orthomagmatic mafic and ultramafic mineralization

In the Paterson area there are only two mineral occurrences exhibiting this style of mineralization: both are platinum group elements.

Precious metal (platinum group elements)

Platinum group element mineralization is known at Tom Tit (*9958*) and Jason (*9960*) within fragments of an ultramafic body in the Talbot Terrane of the Rudall

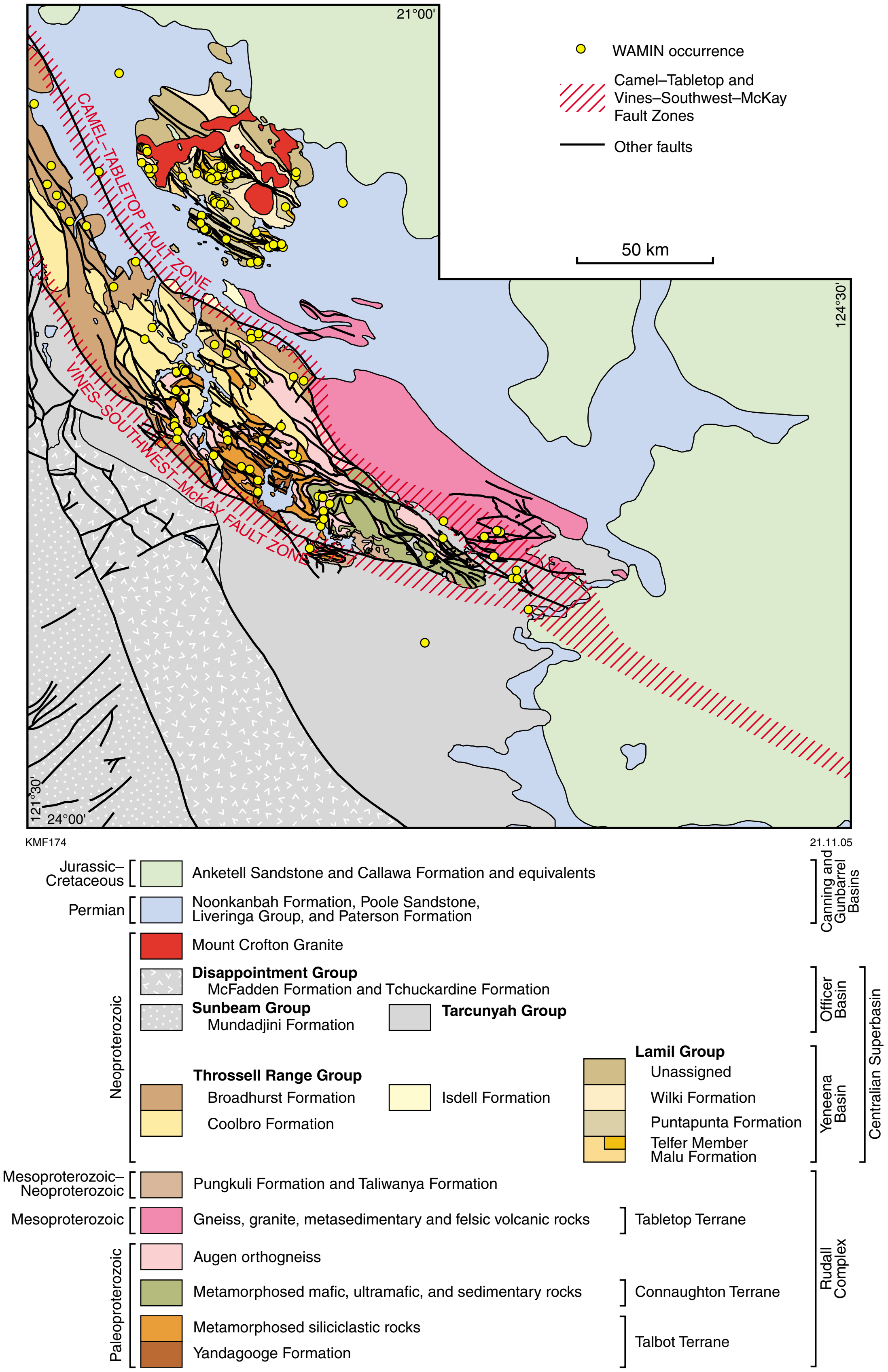

Figure 5. Distribution of 130 WAMIN occurrences in the Paterson area

Complex (Blockley, 1972). The ultramafic rocks appear as a number of small lenses of metamorphosed serpentinite in the Talbot Terrane, and are associated with orthogneiss. Carr (1989) examined the geochemistry and PGE distribution of these ultramafic bodies. Carr suggested that they represented a dismembered and deformed peridotitic slice of a larger ultramafic body of komatiitic affinity, and that they had a low potential for economic sulfide mineralization.

Stratabound sedimentary mineralization

There are 19 occurrences of stratabound sedimentary mineralization in the Paterson area. All are hosted within sedimentary rocks of the Yeneena Basin (Fig. 6). Of these, 15 are clastic-hosted (base metals), one is carbonate-hosted (base metals), and the remaining three are less clearly defined in style and are categorized as stratabound sedimentary – undivided (base and precious metals).

Clastic-hosted mineralization

Base metals — copper, lead, zinc (silver, nickel, cobalt)

Clastic-hosted base metal mineralization has been found predominantly within the Throssell Range Group, mostly within the graphitic–sulfidic, carbonate-rich facies of the Broadhurst Formation (Hickman and Clarke, 1994; Ferguson, 1999; Ferguson and Ruddock, 2001). The Broadhurst Formation is a transgressive shallow-marine deposit, probably formed under euxinic conditions (Williams and Trendall, 1998).

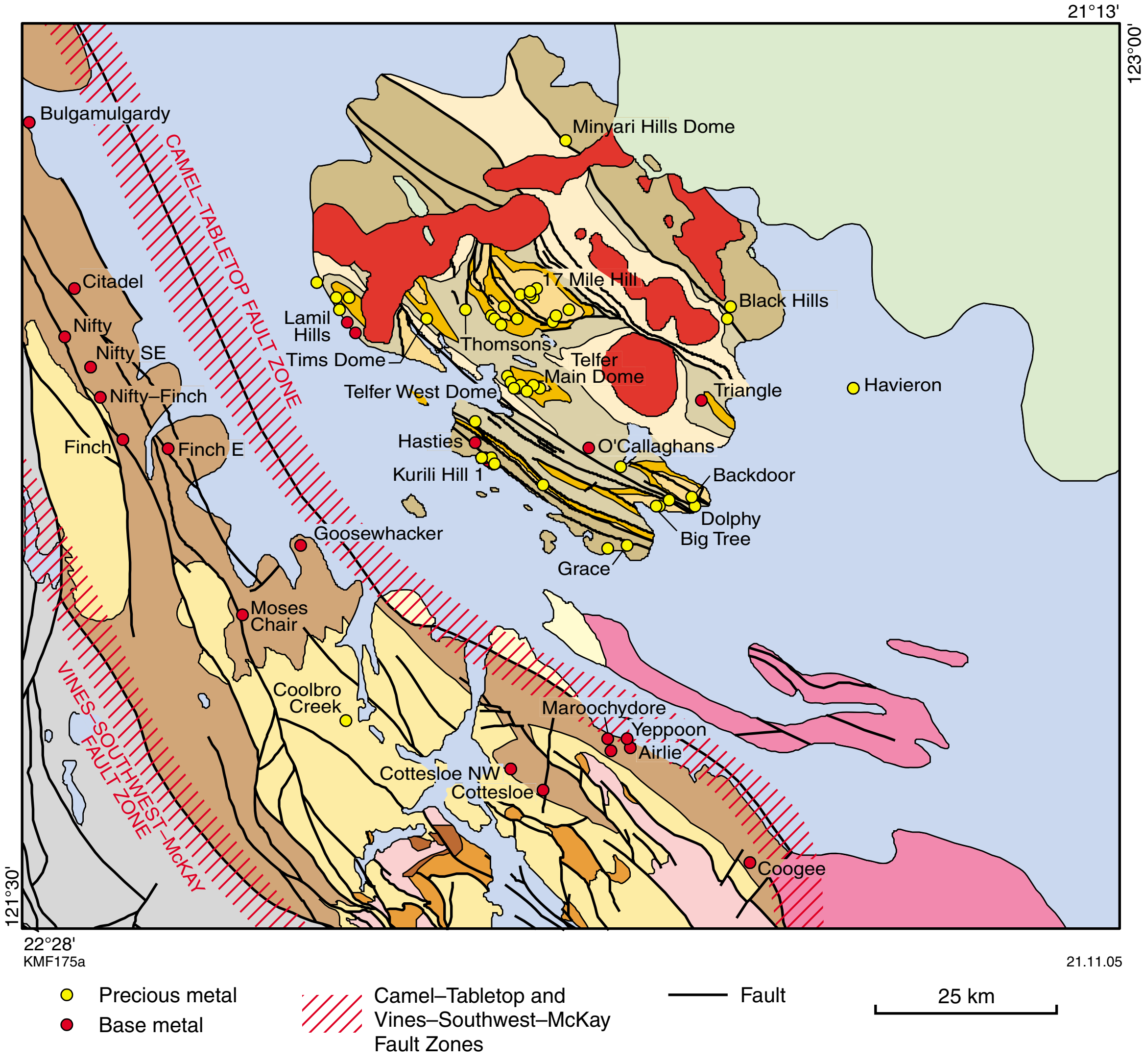

Figure 6. Vein and hydrothermal, skarn, and stratabound sedimentary gold and base metal mineralization in the Yeneena Basin (refer to Figure 5 for geological legend)

At Nifty (*10038*) a stratabound, epigenetic deposit within the Broadhurst Formation is enriched within a groundwater-related supergene zone.

Nifty

Copper is the only metal recovered at the Nifty mine, but minor amounts of sphalerite, galena, and silver are present, together with traces of gold and uranium minerals (Hickman et al., 1994).

There are three types of copper mineralization in the Nifty area (Fig. 7): primary chalcopyrite; secondary, silicified carbonate-hosted copper; and secondary shale-hosted mineralization. Most of the mineralization is structurally controlled in the F_4 Nifty Syncline; this forms the primary style of mineralization and is confined to highly silicified and dolomitized rocks locally known as the 'pyrite marker bed' and the 'Nifty member'. Primary mineralization includes chalcopyrite, pyrite, sphalerite, and galena, but most of the ore is disseminated to massive chalcopyrite. High-grade ore appears to be best developed in carbonate beds below shale beds, and there is a strong stratigraphic control (Hickman et al., 1994).

Carbonate-hosted secondary (oxide) mineralization is confined to shallow depths and is characterized by a vertical zonation from malachite–azurite passing downwards to malachite–cuprite–tenorite–native copper, and then down to a chalcocite-rich supergene zone. This type of ore also contains erratically anomalous gold (Hickman et al., 1994).

Shale-hosted remobilized secondary (oxide) mineralization is confined to a 15 m-thick zone that is between 40 and 80 m below the present watertable and above the base of the oxidation front, and consists predominantly of malachite with minor amounts of azurite. This style of mineralization is interpreted to have formed by supergene enrichment or precipitation at the paleowatertable (Hickman et al., 1994).

Production from secondary (oxide) mineralization has been from an opencut operation, and the copper has been extracted using heap leach, solvent extraction, and electrowinning techniques. Underground development commenced in early 2005 to access the deeper sulfide mineralization. A standard flotation process is planned to recover chalcopyrite ore (95% project recovery) to produce concentrate for export to India. Oxide ore will continue to be processed on site to produce copper cathode.

The mine produced 25 103 t of copper cathode in 2003, and has a cumulative production of 151 467 t of copper cathode for the period between 1994 and 2003 (Department of Industry and Resources production records). At March 2005, sulfide resources were 27.1 Mt at an average grade of 3.18% Cu; this includes sulfide reserves of 24.1 Mt at an average grade of 2.84% Cu (1.5% cutoff grade for resources and reserves). The remaining leachable oxide resources were 13.8 Mt at an average grade of 1.15% Cu; this includes reserves of 9.1 Mt at an average grade of 1.28% Cu (0.4% cutoff grade for resources and reserves). Contained copper was 1 022 280 t in total resources; this includes 815 556 t in total reserves (Birla Nifty Pty Ltd, 2005, written comm.).

Haynes et al. (1993) considered that the carbonate member formed in a local basin transected at the eastern end by a synsedimentary fault, and that mineralization formed prior to the earliest diagenetic folding, with pyrite–sphalerite–galena, and then chalcopyrite, replacing the algal-laminated carbonate. More recent studies by Anderson et al. (2001) concluded that Nifty is a structurally controlled deposit (c. 750–720 Ma Miles Orogeny, D_4; Fig. 4), where chalcopyrite–quartz–dolomite has replaced carbonaceous and dolomitic shale. Fluids were focused by thrust faulting in the tightening Nifty Syncline, and the main phase of copper mineralization was associated with a zoned sequence of hydrothermal alteration exhibiting styles similar to those in copper orebodies at Mount Isa (Waring et al., 1998; Anderson et al., 2001).

In this model the hot, saline, reduced hydrothermal fluid has been focused in the hinge zone at the core of the syncline by thrust faults acting as conduits (Fig. 7). Mineralization has developed where the fluids have access to a carbonaceous and dolomitic shale unit. Oxidized and supergene-enriched mineralization is also developed in silicified carbonate beds and shales, and further remobilized from the carbonate beds.

In the vicinity of Nifty, WMC discovered smaller deposits at Citadel (*10541*), Nifty SE *(10545*), Nifty–Finch (*10544*), Finch (*10542*) and Finch East (*10543*). Similar mineralization that is hosted by the Broadhurst Formation is also present: a minor occurrence about 30 km to the southeast at Moses Chair (*10042*); and several others 80 km to the southeast on the northeastern flank of the Rudall Complex, in tightly folded Broadhurst Formation at Maroochydore (*9971*), Yeppoon (*9972*), Maroochydore South (*10002*), Airlie (*9973*), Cottesloe (*10001*) and Cottesloe NW (*10046*). The Citadel prospect (*10541*), north-northeast of Nifty, is in rocks of similar lithology, but has been identified as occupying an anticlinal structure. The mineralization is patchy, with drill intersections and grades of 14 m at 0.36% Zn and 8 m at 0.7% Pb. Other prospects extend in a south-southeasterly direction in rocks of similar lithology. These include Nifty Southeast (*10545*), with up to 4 m at 2.95% Cu; Finch (*10542*) with up to 2 m at 1.5% Cu and 24 m at 0.4% Pb; Finch East (*10543*) with 18 m at 0.3% Zn, 2 m at 0.4% Pb and 0.35% Zn; and Moses Chair (*10042*) with 8 m at 0.27% Zn, 45 km south-southeast of Nifty.

Cottesloe (*10001*), also known as Eva Well, and Cottesloe NW (*10046*) occurrences are in the southeasterly trending Cottesloe Syncline, which is a doubly plunging structure in the central part of BROADHURST (Hickman and Clarke, 1994). Gossan drilling by Amax gave results of up to 3.8% Pb and 80 g/t Ag over 4 m in stratiform sulfides in a shale–carbonate unit. Amax also found weak, low-grade mineralization over a 12-km strike length at a similar stratigraphic level in the Broadhurst Formation. The northwest exposure of the same unit produced a rock-chip sample that assayed 1.44% Pb.

The Broadhurst Formation, northwest of the Cottesloe Syncline, hosts the Maroochydore (*9971*) deposit, and

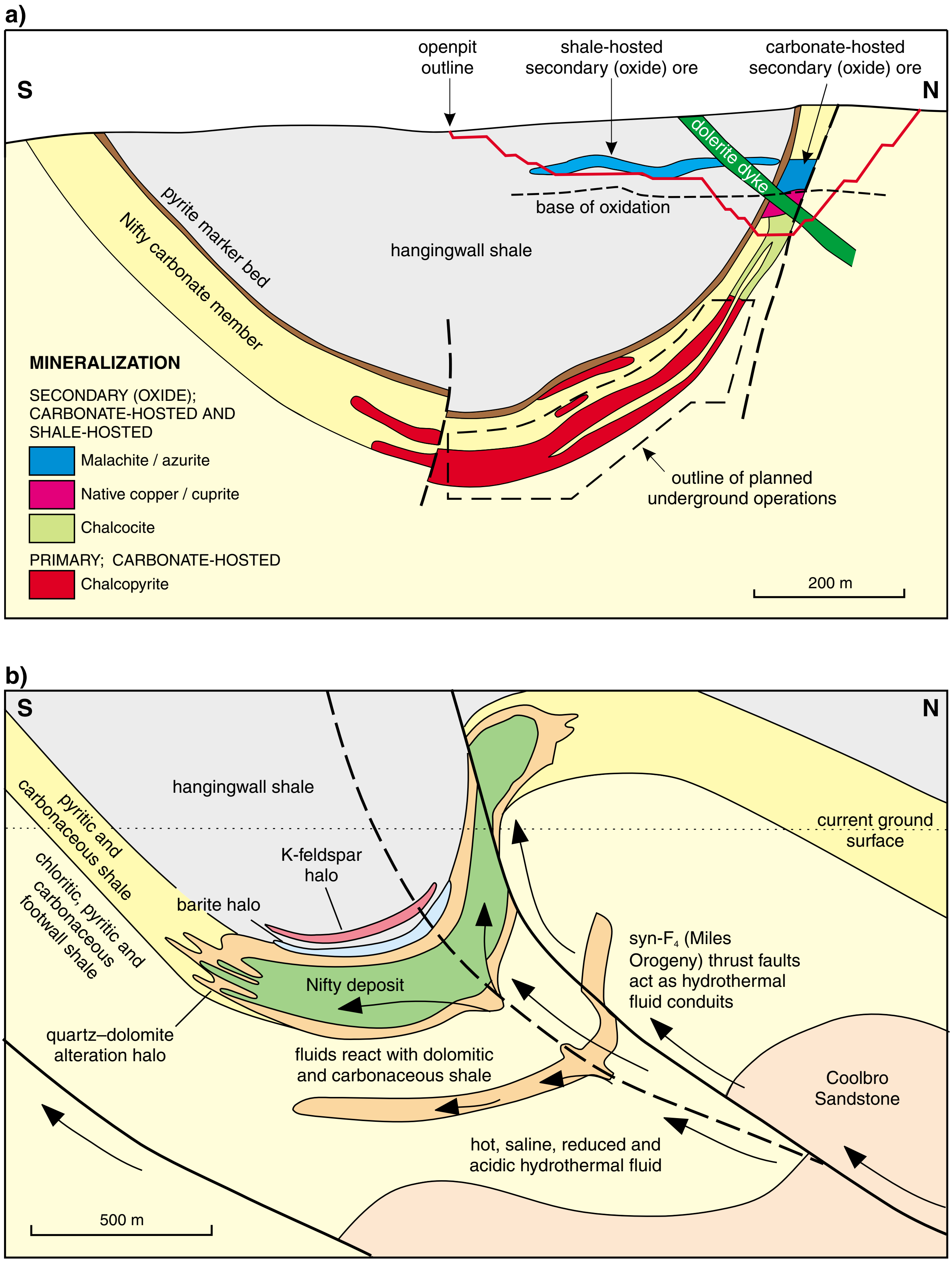

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Figure 7. a) Diagrammatic cross section of Nifty mine (courtesy Birla Pty Ltd); b) genetic model for Nifty mineralization (modified from Anderson et al., 2001)

the Yepoon (*9972*) and Airlie (*9973*) prospects. Each of these are hosted in weathered, interbedded shale, pyritic carbonaceous shale, siltstone, and sandstone, and confirm the formation's potential for significant base metal mineralization (Ferguson, 1999).

Copper occurrences (*10029–30*, *10059*) in the Tarcunyah Group in central Blanche–Cronin have further enhanced the prospectivity of the Neoproterozoic succession in the northwestern Officer Basin. One of these, at Copper Lake (*10059*), is a stratabound base metal prospect hosted in mudstone, tuffaceous siltstone, and sandstone in the basal part of the Karara Formation. Mineralization is in a graben (Fig. 8) with exposed dimensions of 3 by 10 km, within the regional-scale Camel–Tabletop Fault Zone (Bagas, 1999).

Carbonate-hosted mineralization

Mineralization at Coogee (*10043*), southeast of the Mount Sears Range (on Broadhurst) consists of veins of coarse sparry dolomite containing traces of galena and sphalerite. Base metals are hosted in a massive dolomite unit within a mainly clastic component of the Broadhurst Formation. Another base metal occurrence, possibly of this type, is at Bulgamulgardy (*10576*) where BHP diamond drillhole BMD-1 intersected 57.5 m at 0.264% Zn. Mineralization is in fractured, brecciated dolomite within a fault zone in the Broadhurst Formation. BHP explained the broad intersection as being the result of drilling down a fault zone, or downdip through a sedimentary breccia (Davis and Kerr, 1995).

Vein and hydrothermal mineralization

Of the 91 vein and hydrothermal mineral occurrences in the Paterson area, 43 gold and seven base metals occurrences are in the Yeneena Basin. The Rudall Complex is host to 41 occurrences, which include 17 uranium occurrences (and an associated suite of base and other metals, and platinum group elements), 15 occurrences of base metals, three of gold, and four of industrial minerals.

Precious metal (gold) in the Yeneena Basin

The 43 vein-gold occurrences in the Paterson area are hosted by sandstones, shales, and minor carbonate sedimentary rocks, predominantly in the Lamil Group of the Yeneena Basin (Fig. 6). Most gold occurrences are in the Telfer Member of the Malu Formation at the transition zone with the overlying Puntapunta Formation.

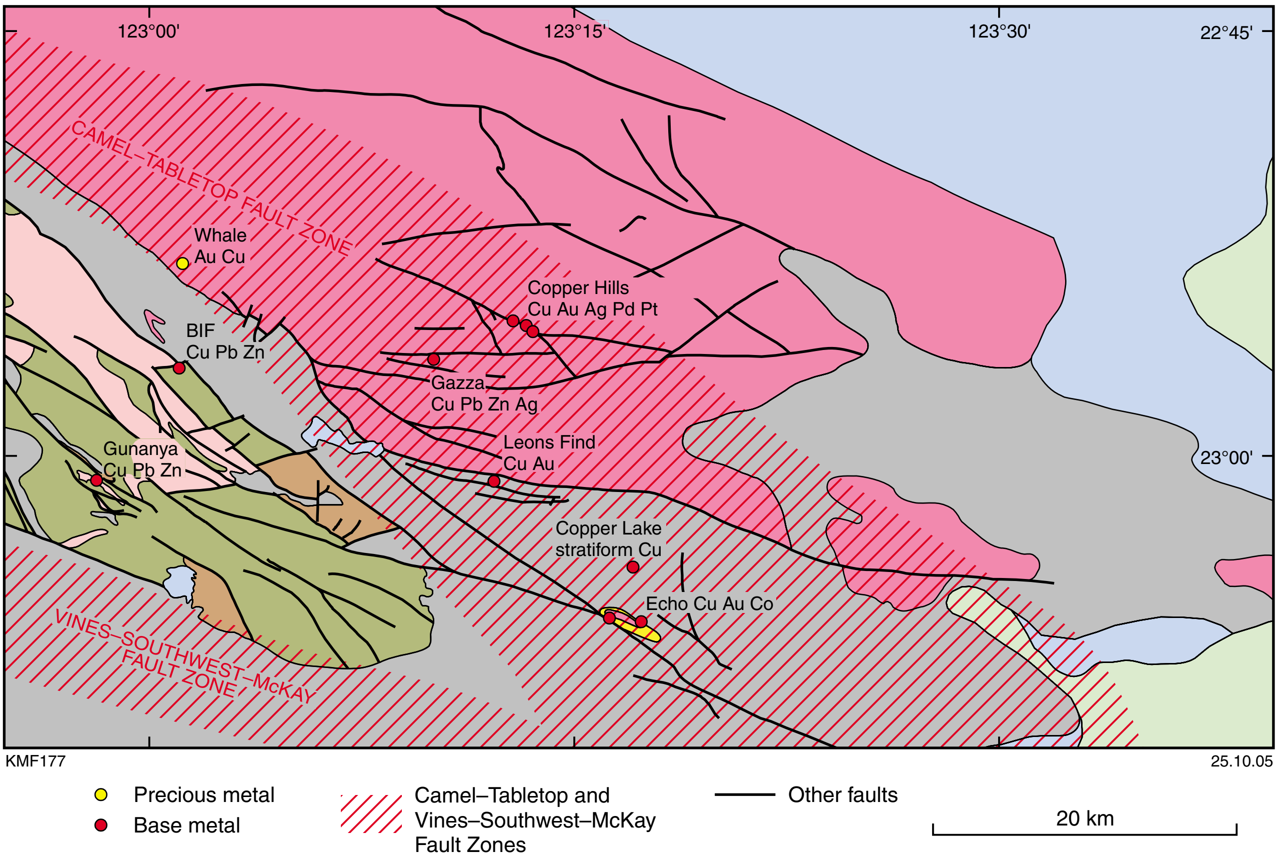

Figure 8. Stratiform and vein-style base metal and polymetallic mineralization in the Camel–Tabletop Fault Zone (refer to Figure 5 for geological legend)

Telfer

Mineralization in the Telfer mine area (Fig. 9) is in extensive, vertically stacked, stratiform to stratabound quartz–carbonate sulfide reefs developed in the Telfer Dome (Fig. 10). The Telfer Dome has been subdivided by Newcrest Mining Ltd (Dimo, 1990) into the Main Dome (*9978*, *9981*) and West Dome (*9980*).

The stratiform to stratabound quartz–sulfide reefs are laterally extensive, and are locally named the Middle Vale reefs, and the E-, M-, and I-Series reefs (Dimo, 1990). The reefs are several metres thick, mostly conformable, and hosted by calcareous or carbonaceous siltstone interbedded with massive sandstone of the Malu Formation. The reefs are commonly linked by intensive stockworks of quartz–sulfide veins, pods, and sheeted vein sets in faults (Dimo, 1990; Rowins et al., 1997; Fig. 11).

The sulfide minerals are mainly pyrite, chalcopyrite, and pyrrhotite, and form either aggregates or disseminations in carbonate and argillic veins in the quartz reefs. Gold is found in the pyrite as small inclusions, and in fractures, and is commonly associated with small amounts of chalcopyrite and trace amounts of pyrrhotite (Dimo, 1990). Wallrock silica–dolomite(–sericite–tourmaline–rutile–xenotime–monazite) alteration is restricted to narrow zones at the reef margins, which contain disseminations of fine-grained gold with disseminated euhedral to subhedral pyrite, and minor amounts of chalcopyrite and galena.

High-grade mineralization is commonly due to supergene enrichment that extends to 300 m below the surface (Dimo, 1990). Extensive montmorillonitic and kaolinitic alteration, with clay veining, is common in this zone, and this causes difficult mining conditions. The weathered reefs contain chalcocite, goethite, hematite, limonite, bornite, enargite, malachite, azurite, unidentified iron oxides, and numerous other secondary minerals (Dimo, 1990; Rowins et al., 1997).

The genesis of the Telfer mineralization has been explained by either a syngenetic exhalative model (Turner, 1982; Tyrwhitt, 1995) or an epigenetic model (Goellnicht et al., 1989, 1991; Goellnicht, 1992; Dimo, 1990; Rowins et al., 1997). The syngenetic model was based on observations that the mineralization is stratabound, and that pyrite is commonly laminated (Turner, 1982). It assumes that the mineralization is hosted entirely within the Malu Formation. This model influenced the style of exploration in the region until the epigenetic models gained acceptance in the late 1980s.

The epigenetic models emphasize the importance of structural controls on mineralization within the domes. They propose that various lithological and structural traps have been provided for ascending mineralizing fluids, to produce stratabound, vein-hosted, shear-hosted, and breccia-hosted deposits.

Joint sets in the core of domical structures host the stockwork veins, which include quartz–sulfide veins and laminated quartz–carbonate–sulfide veins. The quartz veins are up to 20 mm thick and contain up to 10 g/t Au; the laminated veins are up to 0.3 m thick with grades up to 160 g/t Au. Fluid inclusion studies show that the ore fluids were rich in H_2O–CO_2–CH_4–NaCl, and reached temperatures between 225 and 450°C (Dimo, 1990; Goellnicht et al., 1991; Rowins et al., 1997). Goellnicht et al. (1989, 1991) suggested that the mineralizing fluid was a mixture of fluids derived from magma and host or basin rocks, and mineralization is related to a distal gold halo of a giant porphyry copper–gold system. Rowins et al. (1997), however, suggested that the ore fluids were dominantly derived from a sedimentary source, with minimal magmatic contribution. Both models indicate that the mineralization event was at about 650 Ma (Fig. 4), which is the approximate time that the post-tectonic, highly fractionated I-type granitic rocks intruded the Lamil Group (Nelson, 1999).

Recent feasibility studies included deep diamond drilling below known mineralization during 2000–01. This led to the discovery of new stockwork vein systems, known as the Telfer Deeps, that contain high grades of gold and copper, particularly in breccia zones. Deep mineralization is also present in two pods beneath the West Dome in an anticlinal core (known as the Western Deeps). The Telfer mine, following this recent re-evaluation of the mineralized system, has an ore reserve of 18 Moz of gold and 685 kt of copper, with a mineral resource of 26 Moz of gold and 960 kt of copper. Planned annual production is 800 000 ounces of gold and 30 000 tonnes of copper (Newcrest Mining Limited, 2004).

Further dome-related gold mineralization occurs in the Malu Formation, north of Telfer; in the Camp Dome area (*10096*); at 17 Mile Hill (*9976*, *9993–4*, *11339*); and in the Thomsons Dome (*9974–5*, *10091*, *10093–5*, *10640–1*). To the east and southeast of Telfer other occurrences are in the Triangle Dome (*9977*), Trotmans Dome (*9986*, *9991*, *16978*) and Connaughton Dome (*16979*), as well as at Big Tree and Big Tree West (*9992*, *9997*).

Other gold occurrences

The Trotmans Dome group of occurrences includes the Backdoor prospect (*9991*) where drilling by Newcrest has located mineralization in a large breccia zone that is open at depth. The area also contains the Dolphy deposit (*16978*) 1.4 km southeast of the Backdoor prospect, where a small resource has been delineated at about 100 m depth; and the Connaughton Dome prospect (*16979*) about 3 km west of Backdoor.

To the southwest of Dolphy, gold is present in the Trotman Hills at Grace and Grace East (*9987* and *10444*) where the host rocks are unassigned dolomite and shale in narrow fault-bounded anticlines.

The Hasties group of gold and base metal prospects, southwest of Telfer, are in the Karakutikati Range in the northwestern part of a fault-bounded and tight, west-northwesterly trending anticline (Fig. 6). The group includes gold and base metal occurrences in narrow northwesterly trending domes northeast of Kurili Hill (gold at *10148*, *10153–4*, *10167*, *11336* and base metals at *9988*, *9998–9*, *10000*). These include the copper-dominant Hashes–Hasties area where chalcocite, chrysocolla, and malachite are present in unassigned fractured dolomite

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Figure 9. Photographs of Telfer Dome: a) prior to mining in 1976; b) Telfer mining operations in 1988 (taken from the air looking north-northwest). Photographs courtesy Newcrest Mining Limited

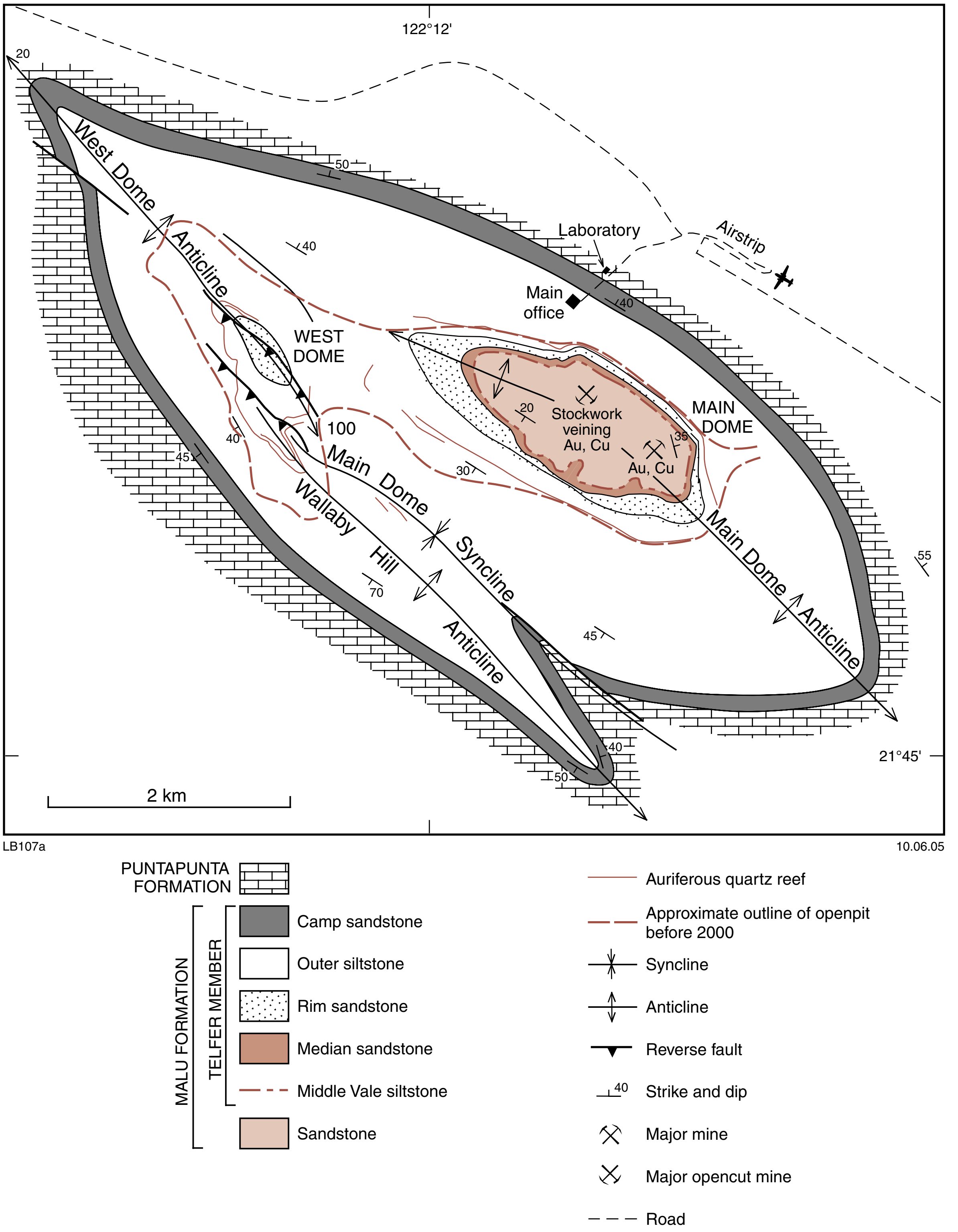

Figure 10. Main structures at Telfer Dome (adapted from Dimo, 1990)

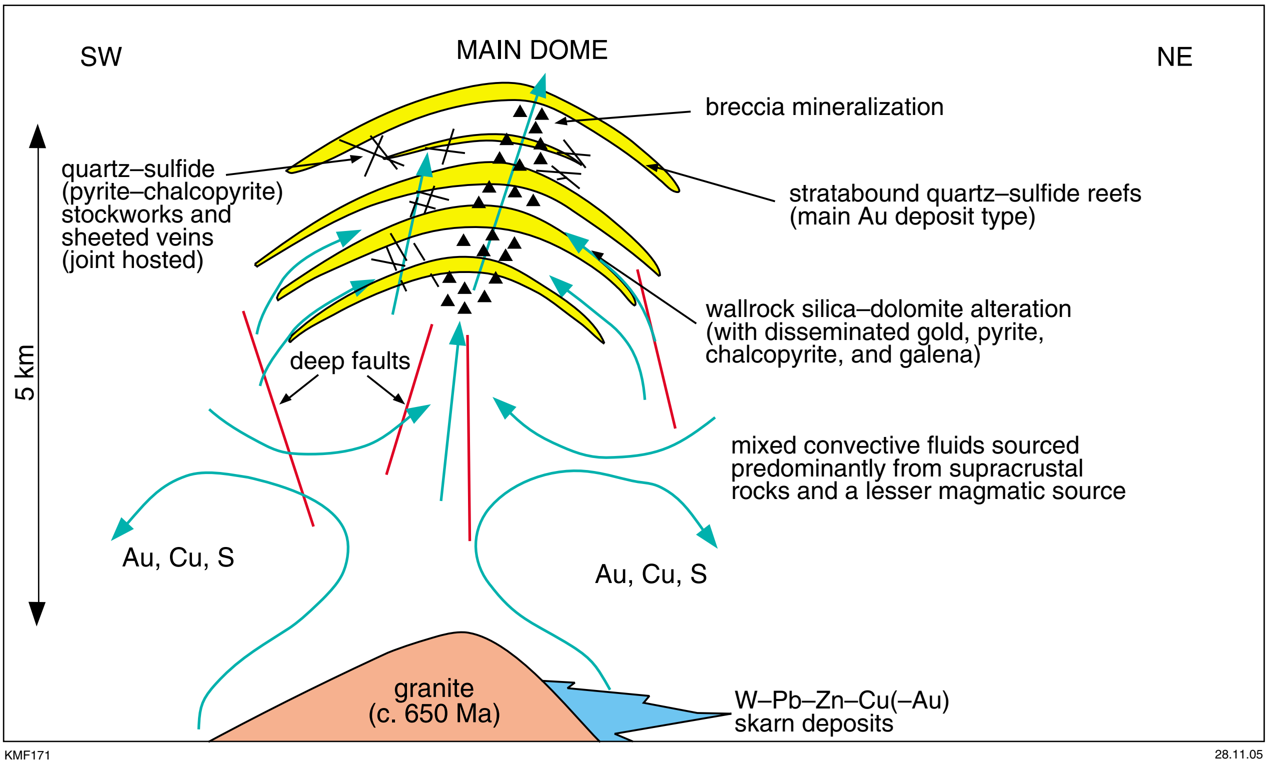

Figure 11. Schematic cross section of the Telfer mineralization model (Rowins et al., 1997)

and shale. Mineralization is in stringers and massive nodules related to breccias developed in faults and fold axial planes in the Malu Formation (*9988*, *10148*, *10153*). Surface enrichment is suggested by high grades in sampling results: 26 g/t Au and 32.6% Cu. A pre-resource estimate of 2.3 Mt at 0.9 g/t Au has been reported (Bagas, 2000).

On LAMIL, about 30 km northwest of the Telfer mine, there are four gold occurrences along a narrow domal axis at Lamil Hills South (*10450*, *10597*, *13042*). About 20 km to the north-northeast of Telfer on COOLYU, gold mineralization at Minyari Hill (*10167*) represents a bulk-leach extractable gold sample collected by Newcrest with 7.45 g/t Au in quartz veining within carbonate-rich rocks in an anticlinorium of the Isdell Formation. Just north-northwest of this zone, the Fallows Field deposit (*9982*) is within a narrow dome in carbonate-rich rocks of the Puntapunta Formation.

A small, isolated gold occurrence known as Rudall River 2 (*10068*) is present at the northeast corner of RUDALL. Alluvial gold at Tabletop (*12453*) may be derived from vein-hosted gold mineralization in Coolbro Sandstone to the southwest (Williams and Bagas, 1999).

About 50 km east of Telfer at Haveiron (*10908*), below 420 m of Permian cover rocks, Newcrest intersected copper–gold mineralization (12 m at 2.2 g/t Au) in carbonate-rich rocks of the Puntapunta Formation during drill testing of coincident magnetic and gravity anomalies (Henderson, 1993).

Uranium, base metals, and precious metals in the Rudall Complex

A total of 41 vein and hydrothermal mineral occurrences have been identified in the Rudall Complex. About half of these contain uranium in association with all, or some, of the following commodities: gold, silver, lead, zinc, copper, arsenic, nickel, cobalt, bismuth, tungsten, cerium, lanthanum, and platinum group elements. Of the 41 occurrences, 26 are within the Talbot Terrane, with eight in the Tabletop Terrane and seven in the Connaughton Terrane (Fig. 12).

Talbot Terrane

The vein and hydrothermal mineral occurrences in the Talbot Terrane are predominantly hosted by pelitic and graphitic schist, chert, and banded iron-formation of the Yandagooge Formation. Jackson and Andrew (1990) suggested that mineralization resulted from metal enrichment that was enhanced and focused in mineralizing fluids near or along the unconformity with the overlying Throssell Range Group, and by the reducing nature of the carbonaceous host rocks in the Rudall Complex. These occurrences have been classified as unconformity-associated or related occurrences (Jackson and Andrew 1988, 1990; Hickman and Bagas, 1999; and Bagas and Lubieniecki, 2000).

According to Hickman and Bagas (1998) most of the radiometric anomalies on RUDALL coincide with exposed uranium mineralization in the Cassandra Member of the Yandagooge Formation (Fig. 13).

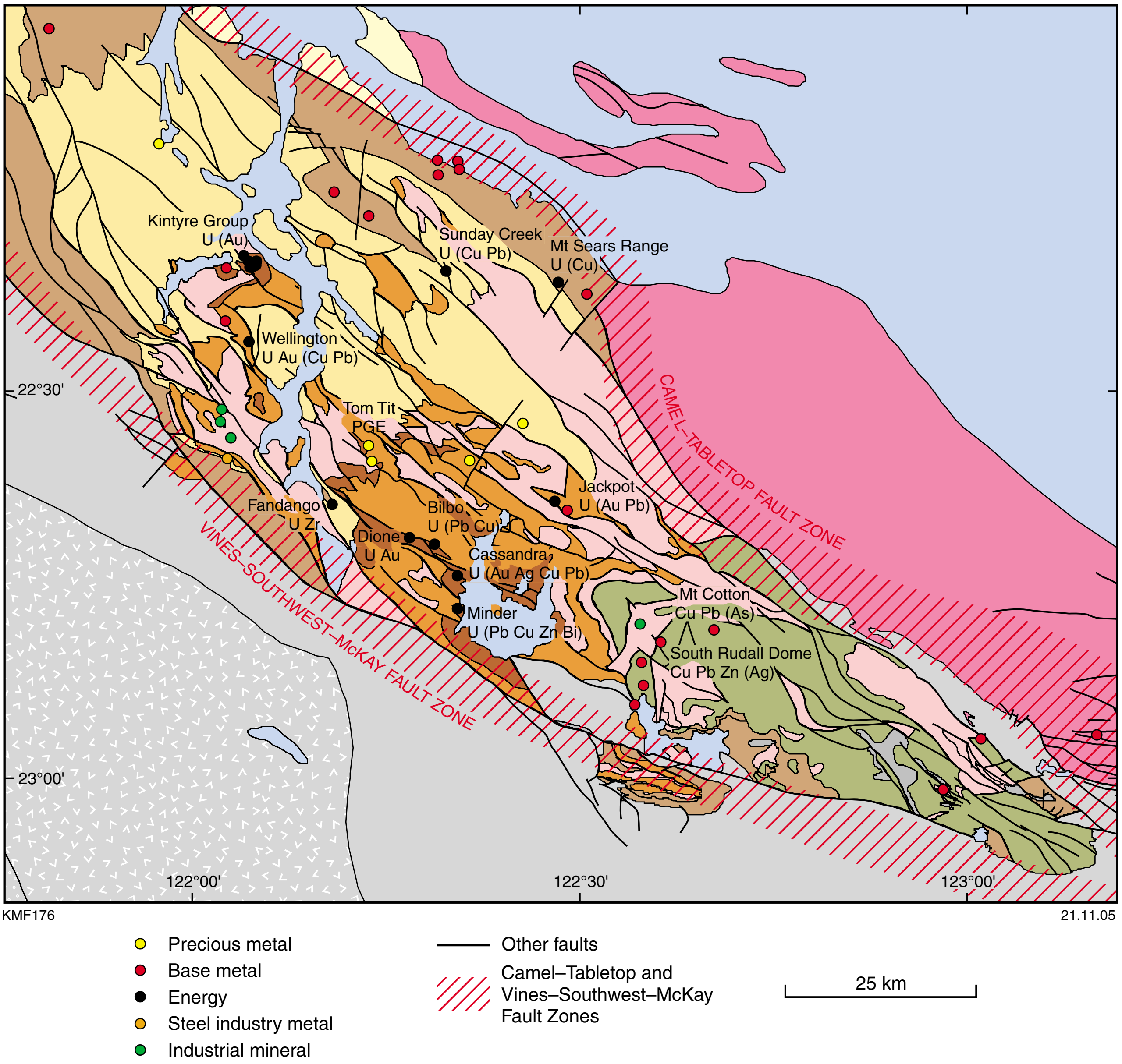

Figure 12. Geology and mineralization in the Talbot, Tabletop, and Connaughton Terranes of the Rudall Complex (refer to Figure 5 for geological legend)

Kintyre uranium deposits

Uranium mineralization at Kintyre is present in seven orebodies: the main Kintyre deposit (*9966*) and six concealed deposits known as Kintyre East (*17470*), Whale (*17471*), Whale East (*17472*), Pioneer (*17473*), Pioneer East (*17474*) and Nerada (*17475*).

The combined identified mineral resource for three of these deposits (Kintyre, Whale, and Pioneer) is estimated at 36 000 t of contained U_3O_8, with grades averaging between 1.5 and 4.0 kg/t U_3O_8 at a 0.5 kg/t U_3O_8 cutoff grade (Jackson and Andrew, 1990). Of this resource, 24 000 t is indicated and more than 11 000 t is inferred. The uranium mineralization is associated with bismuth, gold, platinum, and palladium, the value of which is yet to be ascertained.

The Kintyre orebody forms a shallow-dipping lens to a depth of about 150 m and is hosted by sheared chlorite(–carbonate)–quartz schist and chert in contact with dolomitic limestone and graphitic schist. The mineralization is confined to axial-planar cleavage in the axial region of an F_2 antiform. The main vein-ore mineral is pitchblende, and gangue minerals are chlorite, dolomite, ankerite, and calcite, with accessory bismuthinite, chalcopyrite, bornite, and galena, and locally significant gold and platinum group elements (Jackson and Andrew, 1990). The gold locally grades up to 15 g/t near, or in, the pitchblende veins. The mineralization is considered to have formed early in the history of the Yeneena Basin (at c. 800 Ma; Fig. 4)) and it appears to have been affected by a later widespread thermal event in the region at c. 650 Ma (Durocher et al., 2003).

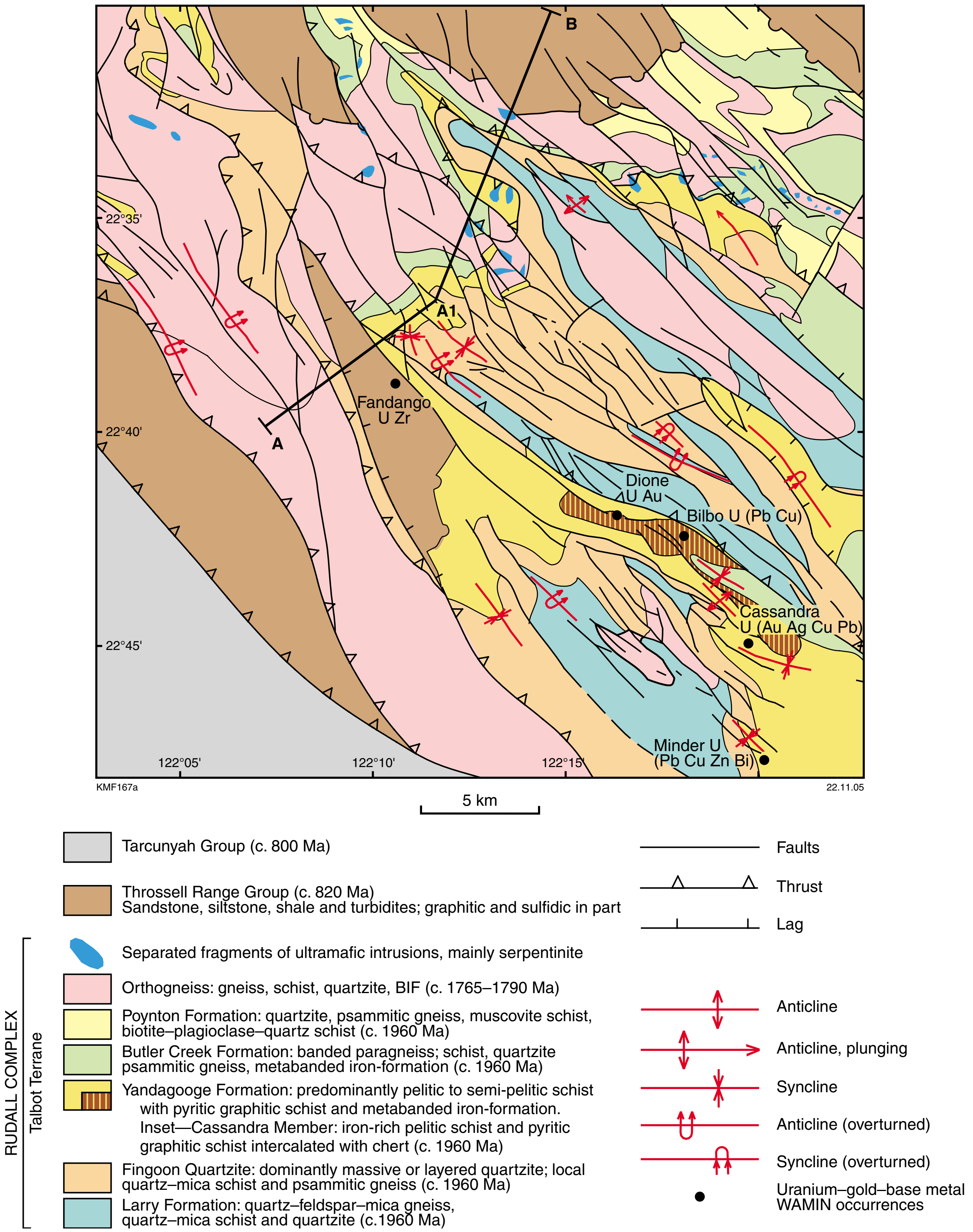

Figure 13. Vein and hydrothermal uranium occurrences in the central part of the Talbot Terrane (adapted from figure 3 of Hickman and Bagas, 1998). Cross section for line A–A1–B is shown in Figure 15

Other uranium occurrences (with base metals and precious metals)

Other uranium vein and hydrothermal occurrences in the Talbot Terrane are Minder (*9950*), Cassandra (*9952*), Bilbo (*9954*), Dione (*9955*), Fandango (*9957*) (Fig. 13), Sunday Creek (*9962*), Wellington (*9963*), Tracy (*9968*), Mount Sears Range (*10003*), and Jackpot (*10661*). Seven of these sites are predominantly uranium mineralization, including Cassandra and Minder (*9950*, *9952*, *9954*, *9955*, *9963*, *9968*, *10661*), while three are predominantly base metals found at Lead Hills, Wanderer, and Gasher (*9949*, *10603*, *10662*). One at Rudall River 1 (*10025*) is mainly precious metal (gold).

Tabletop Terrane

In the Tabletop Terrane, there are a group of gold and base metal prospects at Whale (*10055*), Echo (*10029*), Echo ESE (*10030*), Gazza (*10058*), and Leons Find (*10024*) within a 10 × 3 km graben in the Camel–Tabletop Fault Zone that also affects sedimentary rocks of the Tarcunyah Group of the Officer Basin (Fig. 8). Whale and Echo are classified as unconformity-related occurrences (Bagas and Lubieniecki, 2000). Copper Hills 1 and 2 (*10022–3*) and Copper Hills PM (*10021*) are vein-hosted in dolomitic, carbonaceous and graphitic chlorite schist, on a 2 km-long curvilinear shear zone. The remarkably rich mineralization occurs in dilational jogs, with surface samples assaying up to 11% copper, 3.5% silver, 0.23% gold, 0.49% palladium, and 0.34% platinum (Bagas and Lubieniecki, 2000).

Connaughton Terrane

In the Connaughton Terrane, mineral occurrences are predominantly base metals, silver, and gold in sulfidic, graphitic schist and banded iron-formation. They include South Rudall Dome (*10013*, *10015*; Bagas and Smithies, 1998) and Mount Cotton East (*10018*). Of similar style are both the significant Mount Cotton prospect (*10009*) (Cu–Pb–Zn–U–Ag), which is in ferruginous schist, with up to 1.5% U_3O_8, 11.4% Cu and 2.6% Pb at the surface, and 1.8% Cu, 1.6% Pb, and 1.1% Zn, with 27 ppm Ag in narrow drilling intercepts; and the base metals prospect at BIF (*10057*) (Cu–Pb–Zn). At Mount Cotton NW1 and 2 (*10019–20*) lanthanum and lead are present in gossanous zones within orthogneiss.

Industrial minerals in the Rudall Complex

Barite

Vein-hosted barite occurs in mica schist in the Talbot Terrane of the Rudall Complex at Rudall 1 and 2 (*10005–6*) and at Watrara Pool (*10070*) where it is associated with strontium, molybdenum, and cerium.

Skarn mineralization

Base, steel industry and precious metals

The O'Callaghans deposit (*9985*) is developed within the Telfer Member of the Lamil Group. Goellnicht (1992) considered it to be a granite-associated skarn. Mineralization includes copper, lead, zinc, tungsten, bismuth, molybdenum, and tin.

At Lamil Hills South there are three prospects where Newcrest intersected skarn mineralization during drill testing of magnetic anomalies near the western margin of the Mount Crofton Granite. One prospect is auriferous (*10449*); two are non-auriferous and contain copper and tungsten (*16942–43*).

Mineralization controls and exploration potential

The substantial potential of the Paterson area was not evident until the discoveries of gold at Telfer Dome in 1971, and base metals at Nifty in 1984, highlighted the prospectivity of the Mesoproterozoic–Neoproterozoic Yeneena Basin for vein and hydrothermal and stratabound clastic-hosted mineralization. The discovery of uranium at Kintyre followed in 1985, and highlighted the prospectivity of the Paleoproterozoic Rudall Complex for unconformity-related vein and hydrothermal mineralization.

Vein and hydrothermal mineralization

Gold–copper in the Yeneena Basin

Gold–copper mineralization at Telfer is found in sedimentary rocks of the Lamil Group in the Yeneena Basin, particularly within the Malu Formation and the included Telfer Member. Most of the mineralization is hosted by northwesterly trending D_4 structures of the Miles Orogeny (c. 750–720 Ma), and is therefore syn- to post-D_4 in age. The main structures are domical and anticlinal — such as Telfer Dome, Tims Dome, Thomsons Dome, and Trotmans Dome (Bagas, 2000). An interesting characteristic of the gold–copper deposits is that they are all within 10 to 15 km of outcropping late Neoproterozoic monzogranite (c. 650 Ma).

Solomon and Groves (1994) suggested that the Telfer deposit 'appears to have formed within or above contact metamorphic aureoles during emplacement and cooling of high-level granites.' They consider that 'the relatively high temperatures involved in the gold-related mineralization … suggest a magmatic fluid input, or fluid circulation, early in the cooling history of the related plutons'.

Goellnicht et al. (1989) suggested that a range of salinities and temperatures may have resulted from a mixing of magmatic and non-magmatic fluids. They also suggested that the mineralizing fluid for Telfer-type mineralization was a mixture of magmatic and host-rock fluids related to the distal gold halo of a giant porphyry copper–gold system (Goellnicht et al., 1989; 1991) and that some of the areas of mineralization, such as that in the Hasties area, are examples of porphyry-style copper deposits having a close association with granites (Bagas, 2004b). Proximity to the granites, therefore, affects the style of the mineralization with, for example, the proximal skarn prospect at O'Callaghans (*9985*) containing base and steel industry metals.

Using carbon, oxygen, boron, lead, and sulfur isotope data from ore sulfides and alteration minerals, in conjunction with the geochemistry of tourmaline and pyrite, Rowins et al. (1997) concluded that the source of the mineralization at Telfer is chiefly the Mesoproterozoic–Neoproterozoic sedimentary host rocks, with the c. 650 Ma granites acting primarily as regional heat sources for thermal convection cells that allowed heated saline fluids at depth to transport and concentrate gold, copper, and sulfur. This implies that any Mesoproterozoic–Neoproterozoic successions that are within 15 km of younger granite are prospective for Telfer-style gold and copper mineralization in areas that are structurally favourable for the precipitation of metals from ascending fluids. Rowins et al. (1997) also suggested the north-northwesterly trending Telfer lineament facilitated the focusing of these fluids to higher stratigraphic levels.

Figure 11 shows the interpreted relationship between granite-driven convection beneath the Telfer Dome, and the structural, stratigraphic, and lithological controls within the Main Dome. Skarn and porphyry mineralization types near granites are also shown.

As discussed earlier (**Regional geology**), the probable equivalence of the Lamil and Throssell Range Groups highlights the possibility of gold mineralization in the Throssell Range Group, particularly in the Coolbro Sandstone, which may now be correlated with the Malu Formation. Target zones in the Throssell Range Group would be those that show similar structural settings to those of the Telfer deposits in the Lamil Group. These include the presence of domical structures, locally pyritic and carbonaceous units (such as those in the Telfer Member), and proximity to late Neoproterozoic (c. 650 Ma) monzogranites at depth to drive the fluid convection of the mineralizing process.

To the west and southwest of the Telfer area, for about 40 km, the outcrop of the Lamil and Throssell Range Group sedimentary rocks is obscured by the overlying cover of Permian Paterson Formation and Quaternary eolian sands. These partially obscure the northwesterly trending Broadhurst Formation with its associated base metal mineralization of the Nifty type. West and southwest of the Broadhurst Formation, the Coolbro Sandstone is present in an area of relatively poor outcrop. The 1:100 000-scale mapping by GSWA suggests that fairly tight anticlinal structures, with northwesterly to north-northwesterly trends, are present in this area. They could offer similar mineral potential to the Hasties – Kurili Hill – Mathews Dome area to the south-southwest of Telfer. Elongated domical features are also present in the Throssell Range Group between Moses Chair and Kintyre. The Tabletop occurrence (*12453*) in this area is proximal to an anticlinal axis, and represents visible gold extracted from gravels in the headwaters of Coolbro Creek (Williams and Bagas, 1999). However, there are no direct indications of c. 650 Ma Mount Crofton-style granites in this area at, or near, the surface.

In the north of the area, there is high potential for Telfer-type mineralization beneath Paterson Formation cover. This has already been demonstrated during exploration at Gindalbie Gold's 'Paterson West Gold–Copper Project', about 100 km northwest of Telfer (outside this study area). Two doubly closed domical structures have been identified in Neoproterozoic rocks beneath the Paterson Formation, and copper and gold mineralization has been discovered at the Magnum prospect (Peiris, 2004).

Uranium and related commodities in the Rudall Complex

Uranium mineralization is hosted in the Talbot Terrane (mainly within the Yandagooge Formation) in hydrothermal veins which developed from mineralizing fluids that passed along, or close to, the unconformity with the overlying Coolbro Sandstone of the Throssell Range Group (Jackson and Andrew, 1990). The occurrences have been classified as unconformity-associated, with similarities to those in the Alligator Rivers region of the Northern Territory, and the Athabaska region of Canada (Jackson and Andrew 1988, 1990; Hickman and Bagas, 1999; Bagas and Lubieniecki, 2000). The mineralizing process may have been related to fluid convection at depth early in the history of the Yeneena Basin (c. 800 Ma), and the mineralization appears to have been affected by a later thermal event in the Kintyre region at c. 650 Ma (Durocher et al., 2003).

Gold in the Rudall Complex

The age of gold veins in the Rudall Complex is difficult to constrain because, even though early (D_2) structures may be mineralized, these structures were commonly reactivated during the Miles Orogeny, or as growth faults during deposition of the Neoproterozoic sedimentary rocks.

Stratabound sedimentary (clastic-hosted) mineralization

Base metals

The Throssell Range Group is highly prospective for structurally controlled Nifty-type epigenetic copper(–lead–zinc–silver–nickel–cobalt) in the Broadhurst Formation. These base metal occurrences are structurally controlled (D_4), and are generally related to hydrothermal alteration with metal sulfide and quartz–dolomite replacement of graphitic–sulfidic, carbonate-rich rocks.

There are some base metal prospects that may be of somewhat different origin to the Nifty type. For instance, Haynes et al. (1993) considered the Rainbow prospect, a small stratiform chalcopyrite occurrence 30 km north of Nifty, to be an example of the type of stratiform copper mineralization that was initially targeted by exploration companies in the Paterson area during the early 1980s.

Hickman and Clarke (1994) invoked Mount Isa-style lead–zinc base metal models in relation to the Yeneena Basin deposits, noting that carbonate in the host rocks is a common factor. The Mount Isa sequences are interpreted in terms of intercontinental rifting and D_2 structures.

The probable equivalence of the Lamil and Throssell Range Groups suggests there may also be potential for the discovery of Nifty-type stratabound–stratiform mineralization within the Lamil Group. The Lamil Group – Throssell Range Group correlation infers that the Puntapunta Formation may be an approximate lithological equivalent to the Broadhurst Formation.

The Puntapunta Formation consists of dolomitic sandstone and siltstone with rare limestone; it also includes dolomite and ferruginized shale. Banded chert and shale are present towards the top of the formation.

Mineral occurrences recorded in the Puntapunta Formation include Fallows Field (*9982*) and Mathews Dome (*11336*), both vein and hydrothermal gold occurrences; Thompsons (*9974*) vein and hydrothermal gold and copper occurrence; Trotmans Stockwork (*9986*) vein and hydrothermal occurrence for gold, tin, bismuth, tungsten, lead, and copper; and O'Callaghans (*9985*), a skarn deposit with copper, lead, zinc, tungsten, molybdenum, bismuth, and tin. While none of these are stratabound in style, most show the presence of base metals.

A more favourable environment for the formation of Nifty-type mineralization may be found in the Wilki Formation (which directly overlies the Puntapunta Formation) since it includes graphitic shale and siltstone interbedded with fine-grained silty sandstone, in its basal part (Plate 1). Also, the enigmatic Isdell Formation, possibly equivalent to the Broadhurst and Puntapunta Formations, is indicated as being locally sulfidic. The known outcrop of the Isdell Formation on BROADHURST is close to, and northwest of, the Maroochydore group of base metal prospects, and is also bisected by the Camel–Tabletop Fault Zone. Outcrop of the Isdell Formation is limited in this area due to a cover of overlying Paterson Formation and Quaternary dunefields.

Another unit containing sulfidic host sedimentary rocks is the Pungkuli Formation, which is exposed at the southeastern extremity of the Rudall Complex – South Rudall Dome and at McKay Range (Bagas and Smithies, 1998). This formation is reported to include reddish-brown shale, minor sandstone, dolomite, and sulfidic rocks (pyritic shale).

Significance of major fault zones for mineralization

Stratabound base metal occurrences in the Broadhurst Formation occupy a northwesterly trending corridor in the Yeneena Basin near the Camel–Tabletop Fault Zone (e.g. Nifty and Maroochydore deposits). The fault zone is a major northwesterly trending regional structure that separates the Talbot and Tabletop Terranes of the Rudall Complex (Figs 1, 8 and 12).

Bagas and Lubienecki (2000) discussed copper and polymetallic mineralization within the Camel–Tabletop Fault Zone where it affects the Rudall Complex and the northwestern (Tarcunyah Group) part of the Officer Basin. They considered that vein and hydrothermal-style occurrences predominate in dilational openings, while stratabound sedimentary-style occurrences are within graben structures created by faulting (Fig. 8). The latter occurrences (found to date) are all within the Tarcunyah Group of the Officer Basin. However, similar mineralization styles may be present in the Yeneena Basin marginal to, and within, the fault zone. Bagas (2000) suggested that stratabound base metal mineralization in the Broadhurst Formation may also (in part at least) be associated with this 300 km-long structural zone. The mineral potential of the Isdell Formation (mentioned above in relation to Nifty-type base metals) may also be enhanced where it is close to the regional fault zone.

There may be potential for similar base metal mineralization within, and close to, the Vines–Southwest–McKay Fault Zone (the other major regional structural zone in the area). This is a major sinistral structure controlling the 400 km displacement of the allochthonous Rudall Complex and Yeneena Basin from their Musgrave–Arunta associations in central Australia. Vein and hydrothermal mineralization might be expected in association with such a regional structure, particularly in open, stress-relieving combinations of fractures and faults in geochemically and lithologically favourable zones, within and marginal to the main fault zone.

In the Talbot Terrane, the influence of major structures on mineral potential is evident in Figure 14, where the distribution of WAMIN sites is combined with the distribution of geochemically anomalous rock samples discussed by Hickman and Bagas (1999). These samples were collected from rocks which might be expected to show indications of mineralization: quartz veins, ferruginous quartz veins, gossans, chert, ironstones, and banded iron-formation. In Figure 14, polygons have been broadly defined for particular target element groups to outline areas with potential for four broad types of mineralization: gold dominant; uranium dominant; steel-industry metal dominant; and base metal dominant. The polygon outlines generally follow the northwesterly structural trend, except that the uranium-dominant polygons also show the influence of the Cassandra Member of the Yandagooge Formation and the overlying unconformity with the Coolbro Sandstone.

Exploration targets for uranium mineralization in the Rudall Complex are likely to be concealed beneath sedimentary rocks of the Yeneena Basin, as shown in the interpreted cross section in Figure 15 (after Hickman and Bagas, 1995, 1996). The Yeneena Basin – Rudall Complex unconformity has been tightly folded and faulted, and therefore presents a complex exploration target. The main requirement for mineralization is the proximity of the

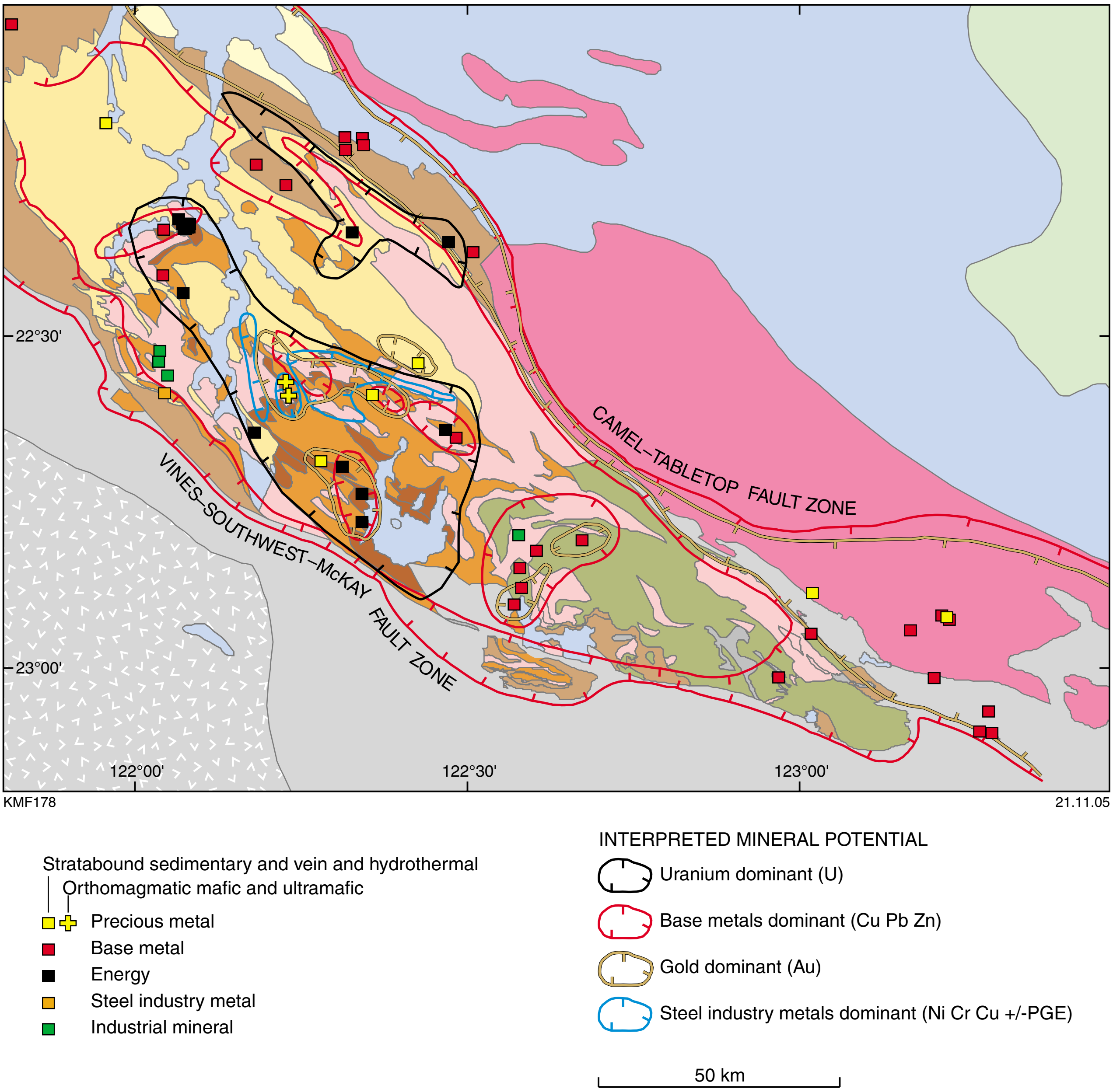

Figure 14. Distribution of mineral occurrences, and mineral exploration potential in the Rudall Complex (modified from Hickman and Bagas, 1999; refer to Figure 5 for geological legend)

Yandagooge Formation and its prospective Cassandra Member, combined with the presence of subvertical faults accessing the favourable rocks through to, and through, the Yeneena Basin cover, as at Fandango.

Kimberlite intrusions

The discovery of microdiamonds at Runton, associated with a linear magnetic anomaly, may indicate a concealed kimberlite or lamproite dyke complex intruding Tarcunyah Group sedimentary rocks. This discovery highlights this relatively underexplored area, south and southeast of the Rudall Complex, as a new prospective area for diamonds.

Orthomagmatic mafic and ultramafic mineralization in the Rudall Complex

Metamorphosed dunite, peridotite, and pyroxenite in the Talbot Terrane of the Rudall Complex have a moderate prospectivity for orthomagmatic-style mineralization. These ultramafic bodies are found in the northeastern part of Rudall and extend into the northwestern part of Connaughton (Fig. 13). They are commonly best preserved in the hinge zones of F_2 folds, and represent fragments of larger intrusive bodies that have become dislocated and scattered during the metamorphic history of the terrane (Hickman and Bagas, 1998).

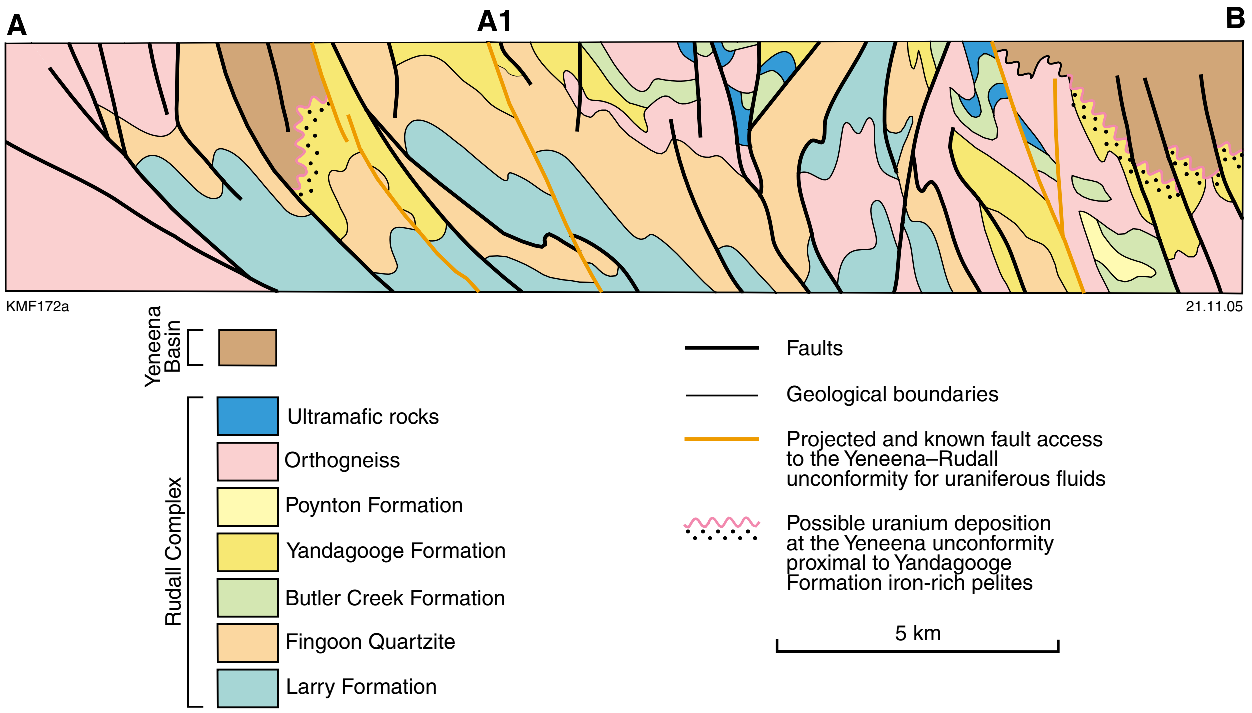

Figure 15. Interpreted cross section showing possible uranium zones and structural complexity of the Throssell Range Group – Rudall Complex unconformity. Location of section line shown on Figure 13 (modified from cross section on Rudall 1:100 000 geological map; Hickman and Bagas, 1996)

There is potential for nickel–copper, PGE, vanadium, and chromium mineralization (similar to that in the Musgrave Complex) within mafic–ultramafic intrusions that may exist in concealed parts of the Rudall Complex where it forms part of a continental-scale structural zone — the Anketell Regional Gravity Ridge. However, the feasibility of exploring for this type of concealed target would be restricted to areas where the cover of Phanerozoic rocks is relatively thin.

Conclusions

The Paterson area is host to three world-class deposits at Telfer (a major gold–copper mine in the Yeneena Basin), Nifty (a major copper mine also in the Yeneena Basin), and Kintyre (an undeveloped uranium deposit in the Rudall Complex). Telfer is classified as vein and hydrothermal mineralization related to structurally controlled fluid convection and circulation during Neoproterozoic thermal events associated with granite intrusion at c. 650 Ma. Nifty is classified as stratabound clastic-hosted mineralization involving sediment replacement related to structurally controlled fluid circulation during the Neoproterozoic Miles Orogeny at c. 750–720 Ma. Kintyre is considered to be unconformity-related vein and hydrothermal mineralization that formed during the early history (c. 800 Ma) of the Yeneena Basin and was later affected by a thermal event at c. 650 Ma.

There is high potential for further discoveries of gold, copper, and uranium deposits of similar mineralization styles. The results from recent GSWA work continue to provide a better defined geological framework for the timing and location of mineralization processes in the Yeneena Basin and Rudall Complex. In particular, the correlation of the Lamil Group and Throssell Range Group within the Yeneena Basin extends the potential for stratabound base metal mineralization of the Nifty type into the Lamil Group; and in addition potential for Telfer-style gold mineralization may extend into the Throssell Range Group.

Recognition of the structural complexity of the unconformity between the Rudall Complex and Yeneena Basin also suggests potential for further concealed uranium mineralization.

On a continental scale, regional structures have been recognized that are related to the displacement of much of the Paterson Orogen from its original association with the Arunta Orogen and Musgrave Complex in central Australia. These structures offer the potential for mineralization controlled by large-scale, regional geological events in a continental framework.

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Appendix 1

List of mineral occurrences in the Paterson area

* KEY TO OPERATING STATUS

Bold numbers	Operating mine
Bold and italic numbers	Abandoned pit
Plain numbers	Mineral deposit
Italic numbers	Mineral occurrence or prospect

KEY TO COMMODITY CODES

Ag	Silver	Co	Cobalt	Mo	Molybdenum	Sn	Tin
As	Arsenic	Cu	Copper	Ni	Nickel	Sr	Strontium
Au	Gold	Dmd	Diamond	Pb	Lead	U	Uranium
Bi	Bismuth	Gp	Gypsum	Pd	Palladium	W	Tungsten
Brt	Barite	Gvl	Gravel	PGE	Platinum group elements	Zn	Zinc
Cd	Cadmium	La	Lanthanum			Zr	Zirconium
Ce	Cerium	Mn	Manganese	Pt	Platinum		

KEY TO LOCATIONS

EAST	MGA Easting
NORTH	MGA Northing

No*	COMMODITY	EAST	NORTH	NAME
PRECIOUS MINERAL				
☆	**Kimberlite and lamproite intrusions**			
17670	Dmd	533755	7433200	Runton
PRECIOUS METAL				
✚	**Orthomagmatic mafic and ultramafic — undivided**			
9958	PGE	420940	7501660	Tom Tit
9960	PGE	420500	7503900	Jason
◆	**Vein and hydrothermal — undivided**			
9974	Au Cu	408650	7609300	Thomsons
9975	Au	412750	7608600	Thomsons Dome E
9976	Au Cu W Pb Zn As Bi Ag Co	417950	7612400	17 Mile Hill
9978	Au Cu	419300	7597500	Telfer Mine UG
9980	Au Cu	415700	7597600	Telfer West Dome
9981	Au Cu	418650	7598000	Telfer Open Pit
9982	Au	410500	7592500	Fallows Field OP
9986	Au Sn Bi W Pb Cu	431050	7585650	Trotmans Stockwork
9987	Au As Ag Cu	429220	7573450	Grace
9990	Au Ag Cu Pb Zn	446300	7610200	Black Hills
9991	Au	440850	7581100	Backdoor
9992	Au	436500	7579650	Big Tree
9993	Au	417850	7611650	17 Mile Hill 1
9994	Au	418800	7612550	17 Mile Hill 2
9995	Au	445950	7608400	Black Hills S
9997	Au	435950	7579800	Big Tree W
10025	Au	433900	7501850	Rudall River 1
10047	Au	416600	7598200	Telfer Pit 8
10048	Au	417000	7597700	Telfer Pit 14
10049	Au	415400	7598500	Telfer E Reefs N
10050	Au	416100	7597700	Telfer E Reefs S
10051	Au	414800	7599300	Bot Flat Telfer Pit 11
10055	Au Cu	502000	7469000	Whale
10068	Au	440950	7507200	Rudall River 2
10091	Au	416350	7608350	Trig Ironstone
10093	Au Pb Zn Ag	414350	7609800	H 3 Gossan
10094	Au	423600	7609350	Wobbleys Gossan
10095	Au	421500	7608600	282 Reef

No*	COMMODITY	EAST	NORTH	NAME
◆	**Vein and hydrothermal — undivided**			
10096	Au	416750	7612050	Camp North
10103	Au	422800	7635400	Minyari Hills Dome
10121	Au	392350	7546950	Coolbro Creek
10148	Au Cu As	411400	7586900	Hastie Advance
10153	Au Cu As	413100	7586050	Hastie Retreat
10154	Au Cu	412600	7587200	Frenchmore
10167	Au	413000	7586000	Minyari Hill
10444	Au Cu As	432000	7573800	Grace E
10450	Au As	390450	7611250	Egg
10640	Au	414100	7607400	Thomsons Fold Closure
10641	Au	413200	7608100	Thomsons Dome E (SE)
10908	Au Cu Zn Pb	463936	7597761	Havieron
11334	Au	418550	7611150	17 Mile Hill C9
11336	Au	420000	7583000	Mathews Dome
11339	Au	421200	7607500	Bean Counters Gossan
13042	Au	392300	7611250	Stuttgart
13045	Au	417850	7596950	Nick MH
16978	Au	441398	7579872	Dolphy
16979	Au	437200	7580000	Connaughton Dome
17319	Au	403300	7608000	Tims Dome
⬢	**Skarn**			
10449	Au	391120	7609450	Lamil Hills South 1
■	**Stratabound sedimentary — undivided**			
10597	Au	387800	7613650	North Magnetic
⬭	**Regolith — alluvial to beach placers**			
12453	Au	389400	7542300	Tabletop
STEEL INDUSTRY METAL				
◆	**Vein and hydrothermal — undivided**			
10007	Mn	401750	7502000	Rudall
⬭	**Regolith — residual and supergene**			
10014	Mn	455500	7468100	South Rudall Dome 1
10017	Mn	451750	7457950	McKay Range

No*	COMMODITY	EAST	NORTH	NAME
SPECIALITY METAL				
◆	**Vein and hydrothermal — undivided**			
10020	La Pb	456600	7478550	Mt Cotton NW 2
⬬	**Regolith — residual and supergene**			
10019	La Pb	455000	7478900	Mt Cotton NW 1
BASE METAL				
⬢	**Skarn**			
9985	Cu Pb Zn W Bi Mo Sn	423350	7590000	O’Callaghans DO
16942	Cu W	391900	7609400	Lamil Hills South 2
16943	Cu W	392250	7608500	Lamil Hills South 3
◆	**Vein and hydrothermal — undivided**			
9947	Cu Pb Zn	496800	7454900	Gunanya
9949	Pb Zn Ag Cu U Cd	401450	7529250	Lead Hills
9977	Cu Au	442350	7596050	Triangle
9988	Cu Au	410200	7589500	Hashes
9998	Cu	411650	7587050	Kurili Hill 1
9999	Cu	412100	7586700	Kurili Hill 2
10000	Cu	412500	7586650	Kurili Hill 3
10009	Cu U Zn Ag Au Pb	459350	7476000	Mt Cotton
10013	Cu Pb Zn Ag	457050	7469800	South Rudall Dome 4
10015	Cu	455950	7467000	South Rudall Dome 2
10018	Cu Pb As	466400	7477750	Mt Cotton E
10021	Cu Ag Au Pd Pt	522750	7464950	Copper Hills PM
10022	Cu	521950	7465250	Copper Hills 1
10023	Cu	523150	7464550	Copper Hills 2
10024	Cu Au	520800	7454800	Leons Find
10029	Cu Au Co	527750	7445900	Echo
10030	Cu	529650	7445650	Echo ESE
10057	Cu Pb Zn	501800	7462200	BIF
10058	Cu Pb Zn Ag Au Ni	517150	7462750	Gazza
10603	Pb Cu Zn Ag	401370	7521640	Wanderer
10662	Pb Cu Ce La	446900	7494800	Gasher
■	**Stratabound sedimentary — carbonate-hosted**			
10043	Pb Zn	449400	7525750	Coogee
■	**Stratabound sedimentary — clastic-hosted**			
9971	Cu Pb Zn Ag Co	429450	7544800	Maroochydore
9972	Cu Pb Zn	432150	7544700	Yeppoon
9973	Zn Cu Pb Ni Co	432350	7543500	Airlie
10001	Pb Zn Ag	420350	7536800	Cottesloe
10002	Cu	429550	7542700	Maroochydore S
10038	Cu Pb Zn Ag Au	352191	7604746	Nifty
10042	Zn Pb	377600	7563300	Moses Chair
10046	Pb	415700	7540200	Cottesloe NW
10059	Cu	529150	7449200	Copper Lake
10541	Zn Pb	353600	7612150	Citadel
10542	Cu Pb	360820	7589650	Finch
10543	Pb Zn	367120	7587950	Finch E
10544	Cu	357620	7595880	Nifty–Finch
10545	Cu	355820	7600150	Nifty SE
10576	Zn	346920	7637250	Bulgamulgardy

No*	COMMODITY	EAST	NORTH	NAME
■	**Stratabound sedimentary — undivided**			
10010	Cu	456800	7473100	South Rudall Dome 3
16946	Cu	385839	7573591	Goosewhacker
ENERGY				
◆	**Vein and hydrothermal — unconformity**			
9950	U Pb Cu Zn Bi	432400	7480700	Minder
9952	U Au Ag Cu Pb	432400	7485400	Cassandra
9954	U Pb Cu	429300	7489900	Bilbo
9955	U Au	426000	7490800	Dione
9957	U Zr	415700	7495500	Fandango
9962	U Cu Pb	430650	7428950	Sunday Creek
9963	U Au Cu Pb	404500	7518700	Wellington
9966	U Au	404600	7529350	Kintyre
9968	U Pb Zn Cu	403750	7531000	Tracy
10003	U Cu	445600	7527400	Mt Sears Range
10661	U Au Pb	445250	7496100	Jackpot
17470	U	404825	7529365	Kintyre East
17471	U	405145	7529610	Whale
17472	U	405380	7529660	Whale East
17473	U	405065	7529840	Pioneer
17474	U	405455	7530230	Pioneer East
17475	U	404360	7530190	Nerada
INDUSTRIAL MINERAL				
◆	**Vein and hydrothermal — undivided**			
10005	Brt	402200	7504950	Rudall 1
10006	Brt	400800	7507250	Rudall 2
10070	Brt Sr Mo Ce	400950	7509000	Watrara Pool
⬬	**Regolith — lacustrine**			
3858	Gp	495000	7419800	Lake Disappointment
3861	Gp	379000	7649800	Lake Waukarlycarly
3867	Gp	411000	7509800	Watrara Creek
CONSTRUCTION MATERIAL				
▽	**Undivided**			
16939	Gvl	389885	7618146	
16940	Gvl	389485	7619352	
16941	Gvl	388869	7619474	
16944	Gvl	387584	7620014	
16945	Gvl	371639	7609883	

Appendix 2

WAMIN and EXACT databases

WAMIN database (mineral occurrences)

The WAMIN (Western Australian mineral occurrence) database of the Geological Survey of Western Australia (GSWA) contains geoscience attribute information on mineral occurrences in Western Australia. The database includes textual and numeric information on the location of the occurrences, location accuracy, mineral commodities, mineralization-style classification, order of magnitude of resource tonnage and estimated grade, ore and gangue mineralogy, details of host rocks, and both published and unpublished references. Each of the occurrences in WAMIN is identified by a unique ‘deposit number’.

The WAMIN database uses a number of authority tables to constrain the essential elements of a mineral occurrence, such as the operating status, the commodity group, and the style of mineralization. These and other attributes were extracted either from open-file mineral exploration reports in WAMEX (Western Australian mineral exploration database) or from the published literature.

Those elements of the database that were used to create the symbols for mineral occurrences and tabular information displayed in Plate 1 and Appendix 1 of this Report are:

- occurrence number and name (deposit number and name)
- operating status (font style of deposit number)
- position and spatial accuracy (symbol position)
- commodity group (symbol colour)
- mineralization style (symbol shape).

The elements of the database used for symbology in Plate 1 and Appendix 1 are operating status, commodity group, and mineralization style. These parameters have previously been defined for the GSWA mineralization mapping projects that have been completed for prospectivity enhancement studies of southwest Western Australia (Hassan, 1998), the north Eastern Goldfields (Ferguson, 1998), the Bangemall Basin (Cooper et al., 1998), the west Pilbara (Ruddock, 1999), the east Kimberley (Hassan, 2000), the east Pilbara (Ferguson and Ruddock, 2001), the north Kimberley (Ruddock, 2003), and the west Kimberley (Hassan, 2004).

Operating status

The database includes mineralization sites (referred to as deposits) ranging from small, but mineralogically significant, mineral occurrences up to operating mines. The classification includes all MINEDEX sites with established resources: MINEDEX is the Department of Industry and Resources’ (DoIR’s) mines and mineral deposits information database (Townsend et al., 1996, 2000; Cooper et al., 2003). All occurrences in the WAMIN database are assigned a unique, system-generated number (deposit number). The font style of this number (bold, italicized, and plain) is used as the coding to indicate operating status both on the face of the map and in Appendix 1 of this Report. The system used is:

- Mineral occurrence — any outcropping mineralization or gossan or any drill intersection of an economic mineral exceeding an agreed concentration and size found in bedrock or regolith (italic serif numbers, e.g. *1212*).
- Prospect — any mineralized zone that has not been sufficiently sampled at the surface, or in the subsurface, to enable a resource to be identified. A prospect may also be old workings (italic serif numbers, e.g. *1138*).
- Mineral deposit — economic mineralization for which there is an established resource figure (serif numbers, e.g. 1137).
- Abandoned mine — workings that are no longer operating, or are not on a care-and-maintenance basis, and for which there is recorded production, or where field evidence suggests that the workings were for more than prospecting purposes (bold–italic sans serif numbers, e.g. ***2321***).
- Operating mine — workings that are operating, including on a care-and-maintenance basis, or that are in development leading to production (bold sans serif numbers, e.g. **1106**).

The names of the occurrences, and any synonyms that may have been used, are mainly derived from the published literature and from open-file reports (in WAMEX); others are assigned according to the nearest geographical feature. Names that appear in the MINEDEX database have been used where possible, although there may be differences created because MINEDEX uses site names based on overall production and resources, where WAMIN may show names of several individual occurrences at one MINEDEX site.

Commodity group

The WAMIN database includes a broad grouping that is based on the potential end-use or typical end-use of the principal commodities comprising a mineral occurrence. The commodity group, as listed in Table 2.1, determines the particular colour for the mineral occurrence symbols in Plate 1 and Appendix 1. The commodity groupings are based on those published by the Mining Journal (1998) with modifications, as shown in Table 2.2, to suit the range of minerals and end-uses for the mineral output of Western Australia.

Table 2.1. WAMIN authority table for commodity groups

WAMIN commodity group	*Typical commodities*	*Symbol colour*
Precious mineral	Diamond, semi-precious gemstones	⬜
Precious metal	Ag, Au, PGE	🟨
Steel industry metal	Co, Cr, Mn, Mo, Nb, Ni, V, W	🟧
Speciality metal	Li, REE, Sn, Ta, Ti, Zr	🟩
Base metal	Cu, Pb, Sb, Zn	🟥
Iron	Fe	🟦
Aluminium	Al (bauxite)	🟫
Energy mineral	Coal, U	⬛
Industrial mineral	Asbestos, barite, fluorite, kaolin, talc	🟪
Construction material	Clay, dimension stone, limestone	🟦

Mineralization style

There are a number of detailed schemes for classifying mineral occurrences into groups representing different styles of mineralization, with the scheme of Cox and Singer (1986) probably being the most widely used. The application of this scheme in Western Australia would necessitate modifications to an already complex scheme, along the lines of those adopted by the Geological Survey of British Columbia (Lefebure and Ray, 1995; Lefebure and Hoy, 1996). Representing the style of mineralization on the face of a map cannot be simply and effectively achieved if the scheme adopted is too complex.

The Geological Survey of Western Australia has adopted the principles of ore deposit classification from Evans (1987) with some modifications based on Edwards and Atkinson (1986). This scheme works on the premise that ‘If a classification is to be of any value it must be capable of including all known ore deposits so that it will provide a framework and a terminology for discussion and so be of use to the mining geologist, the prospector and the exploration geologist’. The system above is based on an environmental–rock association classification, with elements of genesis and morphology where they serve to make the system simpler and easier to apply and understand (Table 2.3).

To fully symbolize all the mineralization style groups would result in a system that is too complex. As the full details of the classification are preserved in the underlying WAMIN database, the chosen symbology has been reduced to nine shapes (Table 2.3).

Table 2.2. Modifications made to the Mining Journal Ltd (1998) commodity classification

Commodity group (Mining Journal Ltd, 1998)	*Commodities*	*Changes made for WAMIN commodity group (see Table 2.1)*
Precious metals and minerals	Au, Ag, PGE, diamonds, other gemstones	Diamond and other gemstones in precious minerals group; Au, Ag, and PGE in precious metals group
Steel industry metals	Iron ore, steel, ferro-alloys, Ni, Co, Mn, Cr, Mo, W, Nb, V	Fe in iron group
Speciality metals	Ti, Mg, Be, REE, Zr, Hf, Li, Ta, Rh, Bi, In, Cd, Sb, Hg	Sn added from major metals; Sb into the base metals group
Major metals	Cu, Al, Zn, Pb, Sn	Cu, Pb, and Zn into the base metals group; Al (bauxite) into aluminium group; Sn in speciality metals
Energy minerals	Coal, U	No change
Industrial minerals	Asbestos, sillimanite minerals, phosphate rock, salt, gypsum, soda ash, potash, boron, sulfur, graphite, barite, fluorspar, vermiculite, perlite, magnesite/ magnesia, industrial diamonds, kaolin	No change

Table 2.3. WAMIN authority table for mineralization styles and groups

Mineralization style	*Typical commodities*	*Group symbol*[(a)]
Carbonatite and alkaline igneous intrusions	Nb, Zr, REE, P	☆
Kimberlite and lamproite	Diamond	
Disseminated and stockwork in plutonic intrusions	Cu, Mo, Au	⬡
Greisen	Sn	
Pegmatitic	Sn, Ta, Nb, Li	
Skarn	W, Mo, Cu, Pb, Zn, Sn	
Orthomagmatic mafic and ultramafic — komatiitic or dunitic	Ni, Cu, Co, PGE	✙
Orthomagmatic mafic and ultramafic — layered-mafic intrusions	Ni, Cu, Co, V, Ti, PGE, Cr	
Orthomagmatic mafic and ultramafic — undivided	Ni, Cu, Co, V, Ti, PGE, Cr	
Vein and hydrothermal — unconformity	U	◇
Vein and hydrothermal — undivided	Au, Ag, Cu, Pb, Zn, Ni, U, Sn, F	
Stratabound volcanic and sedimentary — volcanic-hosted sulfide	Cu, Zn, Pb, Ag, Au, Ba	△
Stratabound volcanic and sedimentary — sedimentary-hosted sulfide	Pb, Zn, Cu, Ag	
Stratabound volcanic and sedimentary — volcanic oxide	Fe, P, Cu	
Stratabound volcanic and sedimentary — undivided	Pb, Zn, Cu, Ag, Au, Fe, Ba	
Stratabound sedimentary — carbonate-hosted	Pb, Zn, Ag, Cd	□
Stratabound sedimentary — clastic-hosted	Pb, Zn, Cu, Au, Ag, Ba, Cd, U	
Stratabound sedimentary — undivided	Pb, Ba, Cu, Au	
Sedimentary — banded iron-formation (supergene enriched)	Fe	
Sedimentary — banded iron-formation (taconite)	Fe	
Sedimentary — granular iron formation	Fe	
Sedimentary — undivided	Mn	
Sedimentary — basin	Coal, bitumen	○
Regolith — alluvial to beach placers	Au, Fe pisolites, Ti, Zr, REE, diamond, Sn	⬭
Regolith — calcrete	U, V	
Regolith — lacustrine	Gypsum, halite	
Regolith — residual and supergene	Al, Au, Ni, Co, Mn, V, Fe crustals, Fe scree	
Regolith — residual to eluvial placers	Au, Sn, Ti, Zr, REE, diamond	
Undivided	Construction materials, various	▽

NOTE: (a) The white symbol colour used in this table does not indicate the commodity group in Table 2.1

Mineral occurrence determination limits

Any surface expression of mineralization (gossan or identified economic mineral) is an occurrence. Subsurface or placer mineralization is included as an occurrence where it meets the criteria given in Table 2.4.

Professional judgement is used if shorter intercepts or surface occurrences at higher grade (or vice versa) are involved. Any diamonds or gemstones would be mineral occurrences, including diamondiferous kimberlite or lamproite.

EXACT database (exploration activities)

The EXACT* database is a GIS-based spatial index, for exploration activities in WAMEX, which has been developed by GSWA to improve access to information in open-file mineral exploration reports (Ferguson, 1995). A major limitation to data retrieval in WAMEX, in its current form, is the difficulty in selecting reports that cover a specific area and, further, in precisely locating various individual exploration activities described within a selected report.

In the current WAMEX database, when spatial parameters are used to make data searches, the results of searches are constrained to very large areas. The smallest search polygon that can be effectively used to locate reports in WAMEX is the area of a 1:50 000-scale sheet. Even though a query may be entered as a single point (either MGA or latitude/longitude coordinates), the resulting search will produce all reports for the 1:50 000-scale sheet in which that single point is located. Hence, for example, it is not possible to restrict report selection to small areas of prospective ground of particular interest to the user. As a consequence these WAMEX searches are time consuming, and they have become more time consuming as the number of open-file reports has increased with continuing releases of data.

The EXACT spatial index overcomes this problem and allows easy access to data on specific areas of previous exploration activity. It also provides a spatial

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* The EXACT database is a GIS-based spatial index of **EX**ploration **ACT**ivities. This term supersedes the acronym SPINDEX (Spatial Index) used in Cooper et al. (1998), Ferguson, (1998), and Hassan (1998).

Table 2.4. Suggested minimum intersections for mineral occurrences in drillholes or trenches

Element	*Intersection length (m)*	*Grade*
Hard rock and lateritic deposits		
Gold	>1	>0.5 ppm
Silver	>1	>35 ppm
Platinum	>1	>0.7 ppm
Lead	>1	>1%
Zinc	>1	>0.5%
Copper	>1	>0.25%
Nickel	>1	>0.2%
Cobalt	>1	>0.02%
Chromium	>1	>5% Cr_2O_3
Vanadium	>5	>0.1%
Tin	>5	>0.02%
Iron	>5	>40% Fe
Manganese	>5	>25%
Uranium	>2	>300 ppm U
Diamonds	na	any diamonds
Tantalum	>5	>200 ppm
Tungsten	>1	>1000 ppm (0.1%)
Placer deposits		
Gold	na	>300 mg/m^3 in bulk sample
Diamonds	na	any diamonds
Heavy minerals	>5	>2% ilmenite

NOTE: Modified from Rogers and Hart (1995)
na: not applicable

representation of the intensity of past exploration, thereby highlighting prospective areas that may have been lightly or inadequately tested by various earlier exploration methods.

The spatial index consists of an attribute database, developed in Microsoft Access, which is linked to ArcView for spatial representation. In the CD-ROM, the dataset includes tabulated textual and numeric information that has been retrieved from open-file mineral exploration reports and attached to individual exploration activities. The areas of exploration activity are digitized (as polygons, lines, or points) using the computer-assisted drafting (CAD) system Microstation, converted into Arc/Info, and then transferred into ArcView to enable an interactive display of EXACT. The positional data are digitized from hardcopy maps and plans in mineral exploration reports, using various published sources (geological maps, topographic maps, Landsat images, and TENGRAPH — DoIR's electronic tenement-graphics system) for georeference purposes. The types of exploration activity detailed are essentially those used in WAMEX, with some rationalization, and these are listed in Table 2.5. In the table, the 27 activities are grouped as follows:

- Geological activities (and remote sensing activities)
- Geophysical activities
- Geochemical activities
- Mineralogical activities
- Drilling activities
- Mineral resources
- Hydrogeological activities.

Table 2.5 Types of exploration activity detailed in the EXACT database

Activity type	*Description*
Geological	
GEOL	Geological mapping
AMS	Airborne multispectral scanning
LSAT	Landsat TM data
Geophysical	
AEM	Airborne electromagnetic surveys
AGRA	Airborne gravity surveys
AMAG	Airborne magnetic surveys
ARAD	Airborne radiometric surveys
MAG	Magnetic surveys
EM	Electromagnetic surveys (includes TEM, SIROTEM)
GEOP	Other geophysical surveys (includes IP, resistivity)
GRAV	Gravity surveys
RAD	Radiometric surveys (includes downhole logging)
SEIS	Seismic surveys
Geochemical	
SOIL	Soil surveys
SSED	Stream-sediment surveys
REGO	Regolith surveys (includes laterite, pisolite, ironstone, and lag)
NGRD	Non-gridded geochemical surveys (includes chip, channel, dump, and gossan)
ACH	Airborne geochemistry
GCDR	Geochemistry drilling (includes auger and RAB drilling for deep sampling)
Mineralogical	
HM	Heavy mineral surveys (ilmenite, zircon, monazite, garnet, gold, tin, tantalum)
DSAM	Diamond sampling surveys (stream sediment, loam)
Drilling	
DIAM	Diamond drilling
ROT	Rotary drilling (predominantly percussion drilling)
RAB	RAB drilling (includes other shallow geochemical drilling such as auger)
RC	RC drilling
Mineral resources	
MRE	Mineral resource estimate
Hydrogeological	
HYDR	Groundwater surveys

The above groups relate to those specified in the statutory guidelines for mineral exploration reports (Department of Minerals and Energy, 1995).

For each separate exploration activity the following statistics have been compiled:

- description of activity including prospect name and brief summary of results where appropriate
- sample types and numbers
- elements analyzed and whether the element is anomalous or not
- metres of drilling and number of holes
- scales of presentation of data in reports.

The activity data are also linked in the dataset to the following related information taken from WAMEX:

- A-numbers (WAMEX accession numbers for individual reports)
- I-numbers (WAMEX item numbers for single or groups of reports on microfiche or CD)
- company or companies that submitted reports
- period of exploration (years)
- mineral commodities sought
- summaries (annotations) of exploration projects included in individual item numbers.

In ArcView the exploration activities are included as spatial themes that are displayed as polygons, lines, or points on the interactive on-screen map known as the view. The table of contents (i.e. map legend) provided alongside the view allows access to the themes, so that any theme or combination of themes may be displayed. Details (taken from attribute tables) of any theme can be accessed on screen, and queries can be carried out either as spatial queries through a view or as textual queries direct from the attribute tables. Further details (with examples) of displays, queries, charts, and view layouts are provided by Ferguson (1995).

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Appendix 3

Description of digital datasets on CD-ROM

There are three principal components of this study, which are this Report, Plate 1, and a CD-ROM containing digital datasets for use with database or GIS software. The CD-ROM includes all the data used to compile the map and Report, and also includes files of exploration and mining activity, geophysical, remote sensing, and topographic data. The CD-ROM also includes the files necessary for viewing the data in the ArcView GIS environment, and a self-loading version of the GeoVIEWER.WA software package modified to suit this particular dataset.

Mineral occurrences (WAMIN)

The mineral occurrence dataset (from WAMIN, the Western Australian mineral occurrence database) as used in this Report and on Plate 1 is described in Appendix 2. The dataset on the CD-ROM includes textual and numeric information on:

- location of the occurrences (MGA coordinates, latitude and longitude, geological province, location method, and accuracy)
- commodities and commodity group
- mineralization classification and morphology
- order of magnitude of resource tonnage and estimated grade
- mineralogy of ore and gangue
- details of host rocks
- both published and unpublished references.

EXACT

The EXACT dataset (from EXACT, Geological Survey of Western Australia's spatial index of exploration activities) as used in this Report is described in Appendix 2 (Ferguson, 1995). The dataset on CD-ROM contains spatial and textual information (derived from open-file reports) defining the locations and descriptions of exploration activities in the area. EXACT, for the Paterson area, was compiled between 2002 and 2004, and contains information on types of mineral exploration activity such as statistics relating to:

- report numbers
- sample types and numbers
- elements assayed
- metres of drilling and number of holes
- scales of presentation of the data.

Positional data were taken from hardcopy maps of various scales, from company reports (in the Western Australian mineral exploration, WAMEX, database), located from coordinate and/or geographical information (from topographic maps or Landsat images), and then digitized. Table 2.5 (in Appendix 2) lists the exploration activity types.

The activity data are linked to more general data concerning the individual open-file reports (commonly defined in WAMEX by accession A-numbers) and individual exploration projects (commonly defined in WAMEX by open-file item I-numbers). This information includes the company or companies involved in the project, the commodities explored for, the timing of the project, names of localities in the project, and a summary (annotation) of the project, including exploration concept, activities, and a synopsis of results.

WAMEX

All relevant open-file company mineral exploration reports for the area, indexed in the WAMEX* database held by the Department of Industry and Resources (DoIR), were referred to for this study. Information extracted from these reports was used to analyse the historical trends in exploration activity and target commodities.

MINEDEX

The MINEDEX* (DoIR's mines and mineral deposits information) database (Cooper et al., 2003) has current information on all mines, process plants, and deposits, excluding petroleum and gas, for Western Australia. Mineral resources included in MINEDEX must conform to the Joint Ore Reserves Committee (JORC) (2004) code to be included in the database. The database contains information relevant to WAMIN under the following general headings:

- commodity group and minerals
- corporate ownership and percentage holding
- site type and stage of development
- location data (a centroid) including map, shire, mining district, and centre
- current mineral resource estimates
- mineralization type
- tectonic unit
- tenement details.

MINEDEX contains all the relevant resource information and WAMIN uses the unique MINEDEX site number as a cross-reference for this information. WAMIN may contain pre-resource global estimates that do not conform to the JORC (2004) code, and are not included in MINEDEX.

TENGRAPH

The TENGRAPH* database (DoIR's electronic tenement graphics system) shows the position of mining tenements

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* The WAMEX, MINEDEX, and TENGRAPH databases are available on the DoIR website at <http://www.doir.wa.gov.au>.

relative to other land information. TENGRAPH provides information on the type and status of the tenement and the name(s) and address(es) of the tenement holders (Department of Minerals and Energy, 1994). It should be borne in mind that the tenement situation is constantly changing and that current tenement plans should be consulted before making any landuse-based decisions or applying for tenements.

Solid geology and regolith

The solid geology and regolith incorporates an interpretation of the study area, at 1:500 000 scale, based on compilation of the Geological Survey of Western Australia (GSWA) mapping. The full details of the solid geology and regolith are on the CD-ROM. The CD-ROM also includes a large number of solid geology and regolith units that are smaller than 250 000 m^2 in area that were omitted from Plate 1 for simplicity.

Geophysics (GUNANYA, RUDALL, and RUNTON)

The aeromagnetic and radiometric data covering the area are presented in the form of pseudocolour images. The data used to create these images is a composite of regional survey data, flown at 1600 m line spacing (PATERSON RANGE and TABLETOP 1:250 000 map sheets) acquired by Geoscience Australia (GA) in 1992 and 1969, respectively, and 1500–3000 m line spacing (GUNANYA, RUDALL, and RUNTON) acquired by Geoscience Australia in 1984. The data have been merged to single datasets; total magnetic intensity and total count radiometric, with a grid cell size of approximately 20 m.

Regional gravity data collected by GA at 11 km station interval are presented as a Bouguer anomaly image, in pseudocolour, with a grid cell size of approximately 800 m.

The colour images presented show variations of blue through to red representing low to high values. The data are disparate due to variations in line spacing, flying height and spectrometer crystal size.

Digital data for these surveys, in either point located or gridded formats, can be downloaded free of charge from the GA website at <http://www.ga.gov.au/adds>.

Landsat

Landsat TM imagery has been acquired for all the 1:250 000-scale map sheets in the Paterson study. The raw data are available commercially through the Remote Sensing Services section of the Department of Land Information (DLI). Images are included in the digital package that preserve the original 25 m pixel size, but these cannot be reverse-engineered back to any bands or band ratios of the original 6-band dataset.

Both image datasets comprise a patchwork of 1:250 000-scale map tiles. The simplest of the two uses the first principal component of bands 1, 2, 3, 4, 5, and 7, written out as an 8-bit dataset that can be viewed as a monochrome image. The second, more complex, image can be viewed in colour, and was created using a decorrelation stretch of bands 4, 5, and 7.

Cultural features

Selected roads and tracks are given as a single dataset, and range from sealed highways through shire roads to major station tracks. The digital data in this file were captured by digitizing from Landsat imagery.

Place names for the area, in a separate file, are given for major hills, stations, and communities. More comprehensive topographical and cultural data, including drainage, can be obtained from the Australian Land Information Group (AUSLIG).

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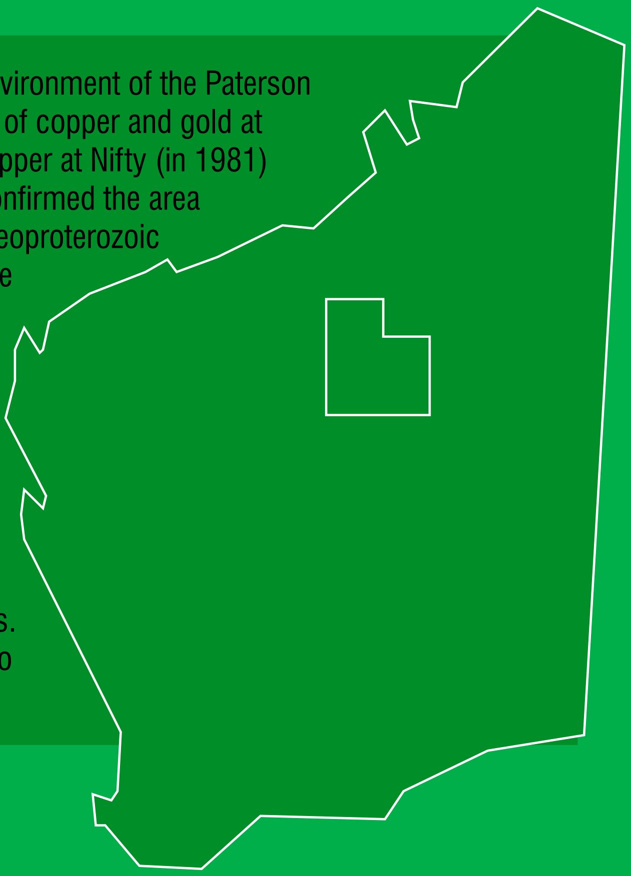
The mineral potential in the remote and harsh environment of the Paterson area was virtually unknown until the discoveries of copper and gold at Telfer in the early 1970s. Later discoveries of copper at Nifty (in 1981) and uranium at Kintyre (in 1985) have further confirmed the area to be a highly prospective Mesoproterozoic to Neoproterozoic mineral province. Production from the Telfer mine commenced in 1977 and it has become one of the world's largest gold mines. Nifty is also a major copper mine, whereas the uranium deposits at Kintyre remain undeveloped. This Report reviews the geology, mineralization, and exploration potential of the area and is an explanatory note to the digital dataset on the accompanying CD-ROM that includes new data on mineral occurrences and exploration activities. A 1:500 000-scale map of the Paterson area also accompanies the Report.



This Report is published in digital format (PDF) as part of a digital dataset on CD. It is also available online at: www.doir.wa.gov.au/gswa/onlinepublications. Laser-printed copies can be ordered from the Information Centre for the cost of printing and binding.

Further details of geological publications and maps produced by the Geological Survey of Western Australia are available from:

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Department of Industry and Resources
100 Plain Street
East Perth, WA 6004
Phone: (08) 9222 3459   Fax: (08) 9222 3444

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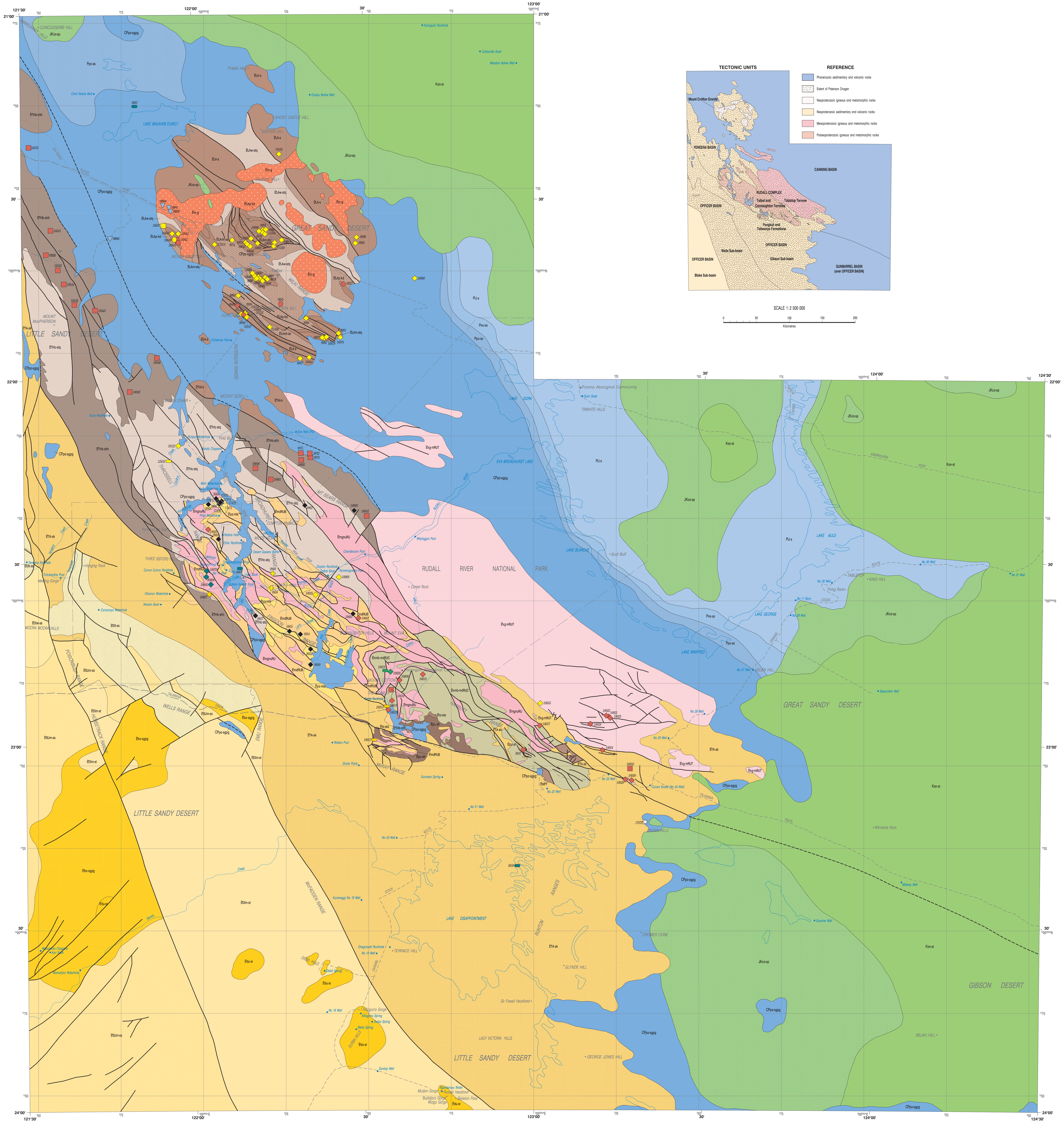
FERGUSON et al.

Mineral occurrences and exploration potential of the Paterson area

REPORT 97



TECTONIC UNITS

REFERENCE

- 🟦 Phanerozoic sedimentary and volcanic rocks
- ▨ Extent of Paterson Orogen
- ☐ Neoproterozoic igneous and metamorphic rocks
- 🟨 Neoproterozoic sedimentary and volcanic rocks
- 🟪 Mesoproterozoic igneous and metamorphic rocks
- 🟫 Palaeoproterozoic igneous and metamorphic rocks

SCALE 1:2 500 000

0 50 100 150 200
Kilometres

PHANEROZOIC

MESOZOIC

CRETACEOUS

Kan-st **ANKETELL SANDSTONE** (and **SAMUEL FORMATION, PARDA FORMATION, FREZIER FORMATION,** and **EMERIAU SANDSTONE**)**:** sandstone, and minor siltstone and conglomerate

JURASSIC–CRETACEOUS

JKca-sp **CALLAWA FORMATION** (and **MELLIGO SANDSTONE, BROOME SANDSTONE,** and **CRONIN SANDSTONE**)**:** fine- to coarse-grained, cross-bedded sandstone and conglomerate, and minor siltstone

GUNBARREL and CANNING BASINS

PALEOZOIC

PERMIAN

PLl-s **Liveringa Group:** undivided; sandstone, mudstone, conglomerate, and minor coal; includes **TRIWHITE SANDSTONE, LIGHTJACK FORMATION, CONDREN SANDSTONE,** and **HARDMAN FORMATION**

Pno-ss **NOONKANBAH FORMATION:** mudstone and sandstone

Ppo-ss **POOLE SANDSTONE:** sandstone and siltstone

CANNING BASIN

CARBONIFEROUS–PERMIAN

CPpa-sgpg **PATERSON FORMATION:** conglomerate with sandstone and siltstone; generally of glacigene origin

GUNBARREL and CANNING BASINS

PROTEROZOIC

NEOPROTEROZOIC

Paterson Orogeny (c. 550 Ma) [1]

Ᵽdu-sr **DURBA SANDSTONE:** sandstone, pebbly in places; minor conglomerate

Disappointment Group

Ᵽdlw-ss Ᵽdlt-ss Ᵽdlm-st

Ᵽdlw-ss **WOORA WOORA FORMATION:** medium-grained ferruginous sandstone, lithic sandstone, quartz wacke, and siltstone

Ᵽdlt-ss **TCHUKARDINE FORMATION:** medium- to coarse-grained sandstone, quartz wacke, siltstone, and shale; minor conglomerate

Ᵽdlm-st **McFADDEN FORMATION:** sandstone; minor siltstone and conglomerate

c. 600 Ma [2]

Ᵽbo-sgpg **BOONDAWARI FORMATION:** conglomerate, sandstone, siltstone, diamictite, and dolomite; fluvial and fluvioglacial origin

Sunbeam Group

ᵽSUm-ss **MUNDADJINI FORMATION:** sandstone, siltstone, and minor conglomerate, shale, mudstone, and dolomite (locally stromatolitic); evaporite pseudomorphs

<1064 Ma [7]

ᵽTA-sk **Tarcunyah Group:** undivided; sandstone, siltstone, mudstone, and stromatolitic and non-stromatolitic dolomite; minor conglomerate; evaporite pseudomorphs

OFFICER BASIN

c. 654 Ma [3]

Ᵽcr-g **MOUNT CROFTON GRANITE** and associated intrusions: syenogranite and monzogranite

Miles Orogeny (c. 750–720 Ma) [4]

Throssell Range Group

<1070 Ma [5] [6]

ᵽTHb-shh **BROADHURST FORMATION:** carbonaceous shale and siltstone, pyritic and pyrrhotitic shale, siltstone, and fine-grained sandstone

ᵽTHc-stq **COOLBRO SANDSTONE:** massive to thick-bedded quartz sandstone and minor siltstone and shale; local basal conglomerate

ᵽTHi-k **ISDELL FORMATION:** thinly bedded carbonate rock, calcareous siltstone, and minor shale; locally sulfidic

Lamil Group

ᵽLA-s Unassigned; quartz sandstone, conglomerate, carbonate rock, siltstone, and shale; minor pyritic shale

ᵽLAw-stq **WILKI FORMATION:** fine- to medium-grained quartz sandstone; minor shale, laminated sandstone, and dolomite

ᵽLAp-kd **PUNTAPUNTA FORMATION:** dolarenite interbedded with dolomite, siltstone, and shale; thinly bedded, fine to medium grained

ᵽLAmt-ss **Telfer Member:** fine- to medium-grained quartz sandstone interbedded with clayey sandstone, siltstone, and shale; minor carbonate rock

ᵽLAm-stq **MALU FORMATION:** fine- to medium-grained quartz sandstone

YENEENA BASIN

CENTRALIAN SUPERBASIN

MESOPROTEROZOIC–NEOPROTEROZOIC

Ᵽpu-sh **PUNGKULI FORMATION:** reddish brown to grey shale, locally carbonaceous; minor sandstone, dolomite, and sulfidic shale and sandstone

Ᵽta-sta **TALIWANYA FORMATION:** arkose to arkosic sandstone, with local thick beds of polymictic conglomerate and rare thin interbeds of lithic wacke, siltstone, and shale

ᵽstPT Medium- to coarse-grained sandstone; well bedded; minor siltstone, shale, and conglomerate

MESOPROTEROZOIC

1476–1222 Ma [8]

Ᵽxg-mRUT Granitic rock, amphibolite, metamorphosed ultramafic rock, metamorphosed banded iron-formation, quartzite, and orthogneiss

Tabletop Terrane

PALEOPROTEROZOIC

Yapungku Orogeny (1830–1765 Ma) [9]

2015–1765 Ma [8]

ᵽmgnuRU Augen orthogneiss derived from porphyritic biotite granite to monzogranite; includes minor lithologically layered gneiss derived from granite, mafic, ultramafic, and metasedimentary rocks

ᵽxmb-mdRUC Amphibolite, metamorphosed banded iron-formation, chert, metamorphosed carbonate rock, quartzite, pelitic schist, and metamorphosed ultramafic rock

Connaughton Terrane

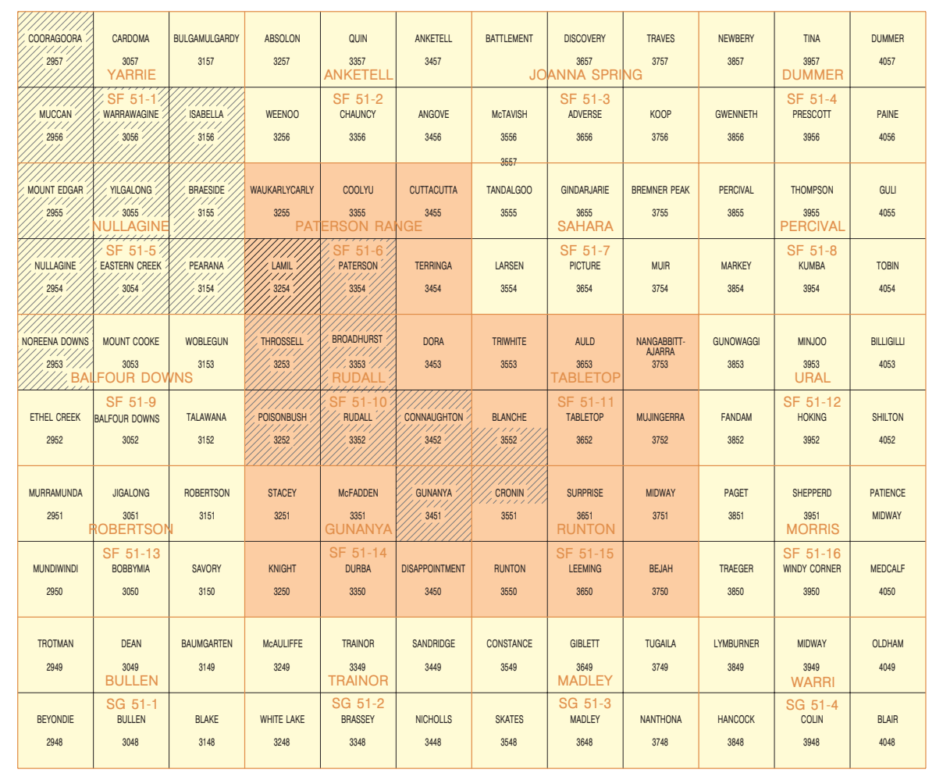
ᵽmdRUB Quartzite, psammitic paragneiss, banded paragneiss, and pelitic schist; includes **LARRY FORMATION, FINGOON QUARTZITE,** and **BUTLER CREEK** and **POYNTON FORMATIONS**

ᵽya-mls **YANDAGOOGE FORMATION:** pelitic to semi-pelitic quartz–mica schist and hematite–biotite schist; minor quartzite, felsic gneiss, pyritic graphitic schist, chert, and metamorphosed banded iron-formation

Talbot Terrane

RUDALL COMPLEX

SHEET INDEX



COORAGOORA 2957	CARDOMA 3057 YARRIE	BULGAMULGARDY 3157	ABSOLON 3257	QUIN 3357 ANKETELL	ANKETELL 3457	BATTLEMENT	DISCOVERY 3657 JOANNA SPRING	TRAVES 3757	NEWBERY 3857	TINA 3957 DUMMER	DUMMER 4057
MUCCAN 2956	SF 51-1 WARRAWAGINE 3056	ISABELLA 3156	WEENOO 3256	SF 51-2 CHAUNCY 3356	ANGOVE 3456	McTAVISH 3556	SF 51-3 ADVERSE 3656	KOOP 3756	GWENNETH 3856	SF 51-4 PRESCOTT 3956	PAINE 4056
MOUNT EDGAR 2955	YILGALONG 3055 NULLAGINE	BRAESIDE 3155	WAUKARLYCARLY 3255	COOLYU 3355 PATERSON RANGE	CUTTACUTTA 3455	3557 TANDALGOO 3555	GINDARJARIE 3655 SAHARA	BREMNER PEAK 3755	PERCIVAL 3855	THOMPSON 3955 PERCIVAL	GULI 4055
NULLAGINE 2954	SF 51-5 EASTERN CREEK 3054	PEARANA 3154	LAMIL 3254	SF 51-6 PATERSON 3354	TERRINGA 3454	LARSEN 3554	SF 51-7 PICTURE 3654	MUIR 3754	MARKEY 3854	SF 51-8 KUMBA 3954	TOBIN 4054
NOREENA DOWNS 2953	MOUNT COOKE 3053 BALFOUR DOWNS	WOBLEGUN 3153	THROSSELL 3253	BROADHURST 3353 RUDALL	DORA 3453	TRIWHITE 3553	AULD 3653 TABLETOP	NANGABBITT-AJARRA 3753	GUNOWAGGI 3853	MINJOO 3953 URAL	BILLIGILLI 4053
ETHEL CREEK 2952	SF 51-9 BALFOUR DOWNS 3052	TALAWANA 3152	POISONBUSH 3252	SF 51-10 RUDALL 3352	CONNAUGHTON 3452	BLANCHE 3552	SF 51-11 TABLETOP 3652	MUJINGERRA 3752	FANDAM 3852	SF 51-12 HOKING 3952	SHILTON 4052
MURRAMUNDA 2951	JIGALONG 3051 ROBERTSON	ROBERTSON 3151	STACEY 3251	McFADDEN 3351 GUNANYA	GUNANYA 3451	CRONIN 3551	SURPRISE 3651 RUNTON	MIDWAY 3751	PAGET 3851	SHEPPERD 3951 MORRIS	PATIENCE MIDWAY
MUNDIWINDI 2950	SF 51-13 BOBBYMIA 3050	SAVORY 3150	KNIGHT 3250	SF 51-14 DURBA 3350	DISAPPOINTMENT 3450	RUNTON 3550	SF 51-15 LEEMING 3650	BEJAH 3750	TRAEGER 3850	SF 51-16 WINDY CORNER 3950	MEDCALF 4050
TROTMAN 2949	DEAN 3049 BULLEN	BAUMGARTEN 3149	McAULIFFE 3249	TRAINOR 3349 TRAINOR	SANDRIDGE 3449	CONSTANCE 3549	GIBLETT 3649 MADLEY	TUGAILA 3749	LYMBURNER 3849	MIDWAY 3949 WARRI	OLDHAM 4049
BEYONDIE 2948	SG 51-1 BULLEN 3048	BLAKE 3148	WHITE LAKE 3248	SG 51-2 BRASSEY 3348	NICHOLLS 3448	SKATES 3548	SG 51-3 MADLEY 3648	NANTHONA 3748	HANCOCK 3848	SG 51-4 COLIN 3948	BLAIR 4048

1:100 000 maps shown in black
▨ Published 1:100 000 maps used in compilation
▨ Published 1:100 000 maps
1:250 000 maps shown in brown
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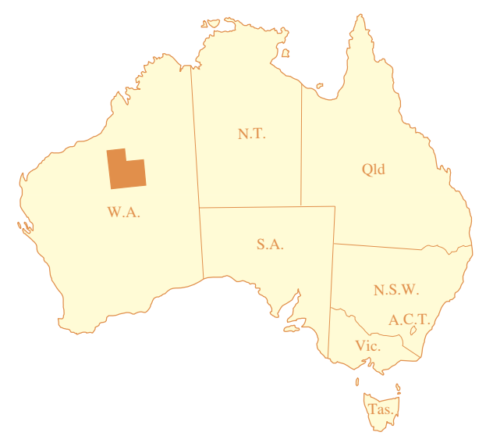

Mineral occurrence data compiled by K. M. Ferguson 2004

Geology compiled by L. Bagas 2004–05 from 1:500 000 State Interpreted Bedrock Geology and GSWA maps (see sheet index)

Geochronology by:
- (3) J. M. Dunphy and N. J. McNaughton, 1998, Geological Society of Australia, Abstracts, no. 49, p. 127.
- (5) D. R. Nelson, 2001, GSWA geochronology dataset, GSWA 169118.
- (6) D. R. Nelson, 2002, GSWA geochronology dataset, GSWA 169117, 169119, 169120.
- (7) D. R. Nelson, 2004, GSWA geochronology dataset, GSWA 177101.

Interpreted geochronology:
- (1) L. Bagas, 2003, GSWA Annual Review 2002–03, p. 43–52.
- (2) M. R. Walter et al., 2000, Precambrian Research, v. 100, p. 371–433.
- (4) L. Bagas, 2004, Lamil (sheet 3254): GSWA 1:100 000 Geological Series map.
- (8) L. Bagas, 2004, Precambrian Research, v. 128, p. 475–496.

Edited by C. Strong and C. Brien

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Published by the Geological Survey of Western Australia. Digital and hard copies of this map are available from the Information Centre, Department of Industry and Resources, 100 Plain Street, East Perth, WA, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444

Web www.doir.wa.gov.au Email geological.survey@doir.wa.gov.au

The recommended reference for this map is:
FERGUSON, K. M., and BAGAS, L., 2005, Mineralization and geology of the Paterson area (scale 1:500 000), *in* Mineral occurrences and exploration potential of the Paterson area *by* K. M. FERGUSON, L. BAGAS, and I. RUDDOCK: Western Australia Geological Survey, Report 97, Plate 1.

MINERAL OCCURRENCES

The detailed list of mineral occurrences is in Appendix 1 of Report 97

MINERALIZATION STYLES

- ☆ Kimberlite and lamproite
- ⬡ Skarn
- ✚ Orthomagmatic mafic and ultramafic
- ◇ Vein and hydrothermal
- ☐ Stratabound sedimentary and/or sedimentary banded iron-formation
- ▭ Regolith hosted
- ▽ Undivided

MINERAL AND ROCK COMMODITY GROUPS

- ○ Precious mineral
- 🟡 Precious metal
- 🟠 Steel industry metal
- 🟢 Speciality metal
- 🔴 Base metal
- ⚫ Energy
- ● Industrial mineral
- 🔵 Construction material

Mineral occurrences and numbers are from the GSWA WAMIN database

OPERATING STATUS AND SITE IDENTIFICATION NUMBER

Operating mine	e.g. 9978
Abandoned mine	e.g. *11653*
Mineral deposit	e.g. 11699
Mineral occurrence or prospect	e.g. *11326*

Geological boundary
Fault
exposed
concealed
Road; unsealed
Track
Gas pipeline
Landing ground
Airfield
Townsite; less than 1 000 .... Telfer
Aboriginal community .... ■ Parnngurr Aboriginal Community
National park boundary
Watercourse with ephemeral pool or waterhole
Lake
Pool, rockhole, waterhole, claypan .... ● *Pool* ● *Rockhole* ● *Waterhole* ● *Claypan*
Soak, spring .... ● *Soak* ● *Spring*
Bore, well .... ● *Bore* ● *Well*
Position doubtful .... *(PD)*

DATA DIRECTORY

Theme	Data Source	Data Currency	Agency
Geology	1:500 000 Interpreted Bedrock Geology of WA*	2003 – 2004	Dept of Industry and Resources
Mineral occurrences (non-confidential)	MINEDEX*	AUG 2005	Dept of Industry and Resources
	WAMIN	AUG 2005	Dept of Industry and Resources
Cadastre	TENGRAPH	2004	Dept of Industry and Resources
Topography	DLI and GSWA field survey	2004	Dept of Land Information

*GSWA and DoIR databases are viewable online (www.doir.wa.gov.au/aboutus/geoview_launch.asp) or can be downloaded from the GSWA Data and Software Centre (www.doir.wa.gov.au/GSWA/downloadcentre)

Department of
Industry and Resources

Geological Survey of
Western Australia

ALAN CARPENTER, M.L.A.
MINISTER FOR STATE DEVELOPMENT

JIM LIMERICK
DIRECTOR GENERAL

TIM GRIFFIN
EXECUTIVE DIRECTOR

SCALE 1:500 000

5000 0 5 10 15 20 25 30 35 40 45 50
Metres Kilometres

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

Grid lines indicate 25 000 metre interval of the Map Grid Australia Zone 51

GDA
The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94)
GDA94 positions are compatible within one metre of the datum WGS84 positions

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 97 PLATE 1

MINERALIZATION AND GEOLOGY
OF THE
PATERSON AREA

Version 1.0 — November 2005