EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

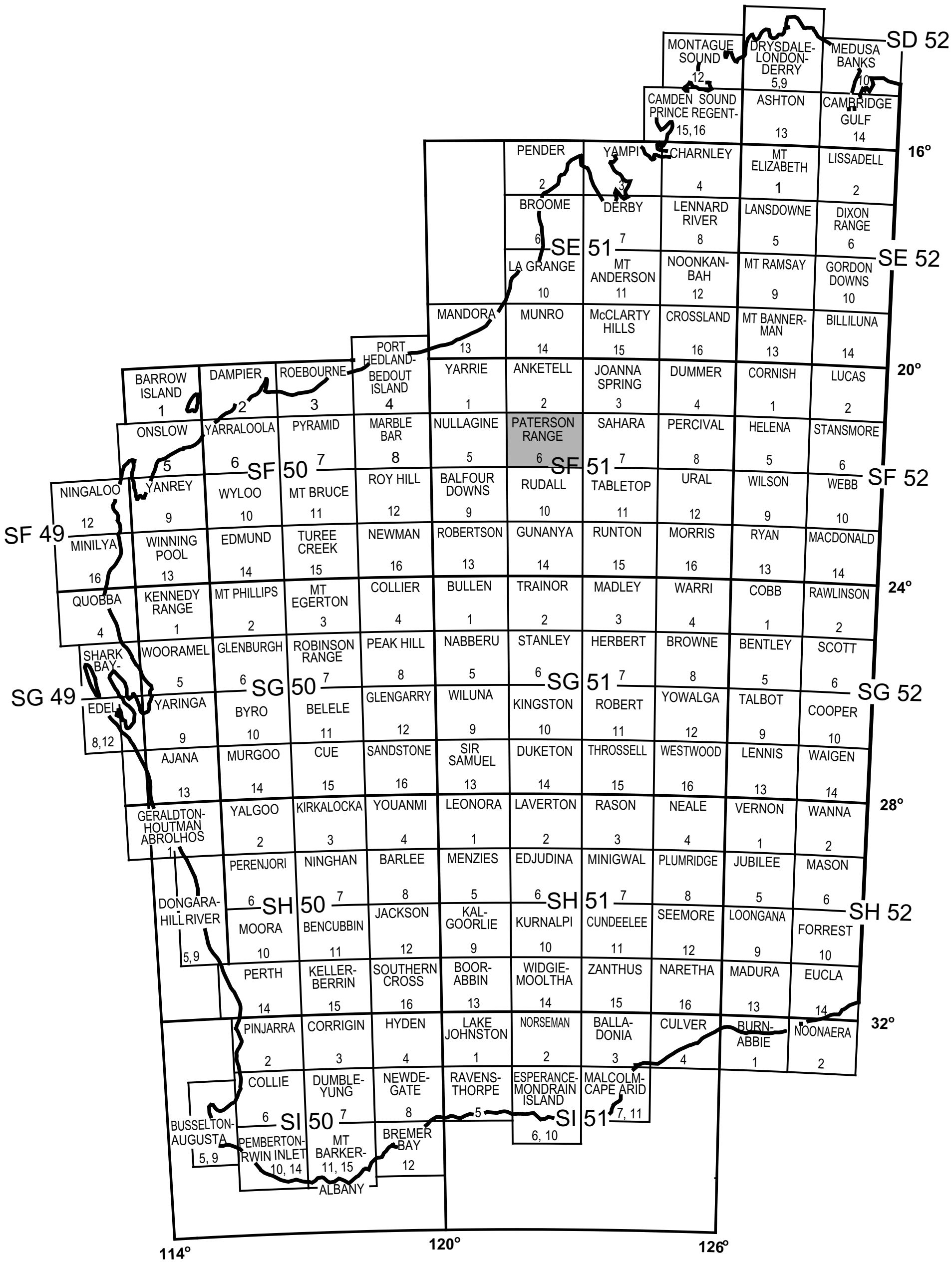
GEOLOGY OF THE PATERSON 1:100 000 SHEET

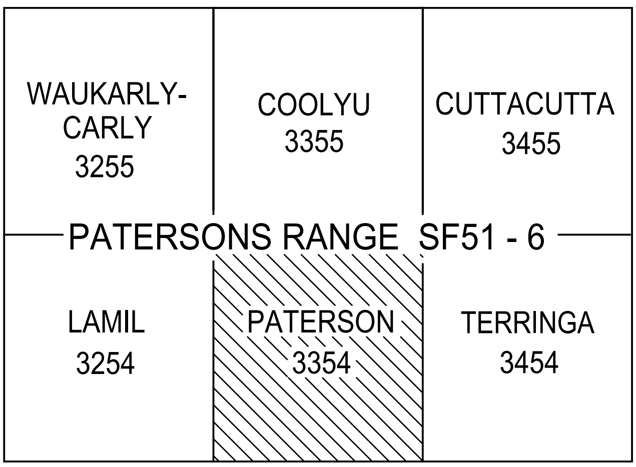
by L. Bagas

1:100 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY





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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY
OF THE PATERSON
1:100 000 SHEET

by
L. Bagas

Perth 2000

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The Main Dome at Telfer in the mid-1970s, before mining started. Photograph provided by Newcrest Mining (WA) Limited

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Geology of the Paterson 1:100 000 sheet

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L. Bagas

Abstract

The Paterson Orogen is a southeasterly trending belt of Proterozoic rocks that extends about 1200 km across the central part of Western Australia. The PATERSON 1:100 000 sheet, occupying the northern part of northwestern Paterson Orogen, comprises mainly the Neoproterozoic Lamil Group, and includes local outliers of sedimentary rocks of the Phanerozoic Canning Basin.

The Lamil Group is a sandstone–shale–carbonate (limestone and dolomite) succession that consists of the Malu, Puntapunta, and Wilki Formations, together with some unassigned sedimentary rocks. The group was deposited in an intracratonic setting that may have been either a pull-apart basin in a dextral strike-slip system, or a failed rift. The main deformation of the group involved northeast–southwest compression with upright folding and associated faulting. There is evidence that the main deformation event, which is here tentatively assigned to the Miles Orogeny, took place soon after the deposition of the group.

The Lamil Group is younger than c. 1070 Ma. The group was intruded by post-orogenic I-type monzogranites and syenogranites, which have SHRIMP U–Pb zircon ages of around 630 Ma and SHRIMP U–Pb titanite ages of up to 654 Ma.

Permian fluvioglacial sedimentary rocks, which form part of the Canning Basin succession, unconformably overlie the Proterozoic rocks and are exposed in the southern half of the map sheet.

PATERSON contains the Telfer mine, one of the richest gold deposits in Australia, which had produced about 175 t of gold by mid-1999. The current proven reserves at the mine are 1.9 million tonnes at 3.3 g/t Au and 0.4 million tonnes at 0.79% Cu.

KEYWORDS: Paterson Orogen, Lamil Group, Proterozoic, geological structures, metamorphism, mineralization

Introduction

The PATERSON* 1:100 000 sheet (SF 51-6, 3354) covers the southern and central parts of the PATERSON RANGE 1:250 000 sheet (SF 51-6), between latitudes 21°30' and 22°00'S and longitudes 122°00' and 122°30'E (Fig. 1). The area is situated in the northwestern part of the Paterson Orogen (Williams and Myers, 1990) and the southwestern part of the Canning Basin. It is included in the Marble Bar District of the Pilbara Goldfield, and part of the Great Sandy Desert falls within it.

The Telfer gold mine lies in the centre of PATERSON. It is closed to the public and permission to visit is required in writing from Newcrest Mining (W.A.). A well-formed gravel road in the northern part of the sheet area links Telfer with the Port Hedland – Woodie Woodie road (on the NULLAGINE 1:250 000 sheet) to the west. Numerous exploration tracks provide good access to the rest of the area.

* Capitalized names refer to standard map sheets. Where 1:100 000 and 1:250 000 have the same name, the 1:100 000 sheet is implied unless otherwise indicated.

Climate and vegetation

The region has an arid climate with a mean annual rainfall of approximately 250 mm. The rainfall is erratic and the area is subject to long periods of drought as well as localized floods during cyclonic activity. The wettest period is between November and March and is associated with cyclonic and thunderstorm activity. Average daily summer temperatures range from minima of about 25°C to maxima of 40°C, whereas average daily winter temperatures typically vary between minima of 5°C and maxima of 25°C. Average annual evaporation is about

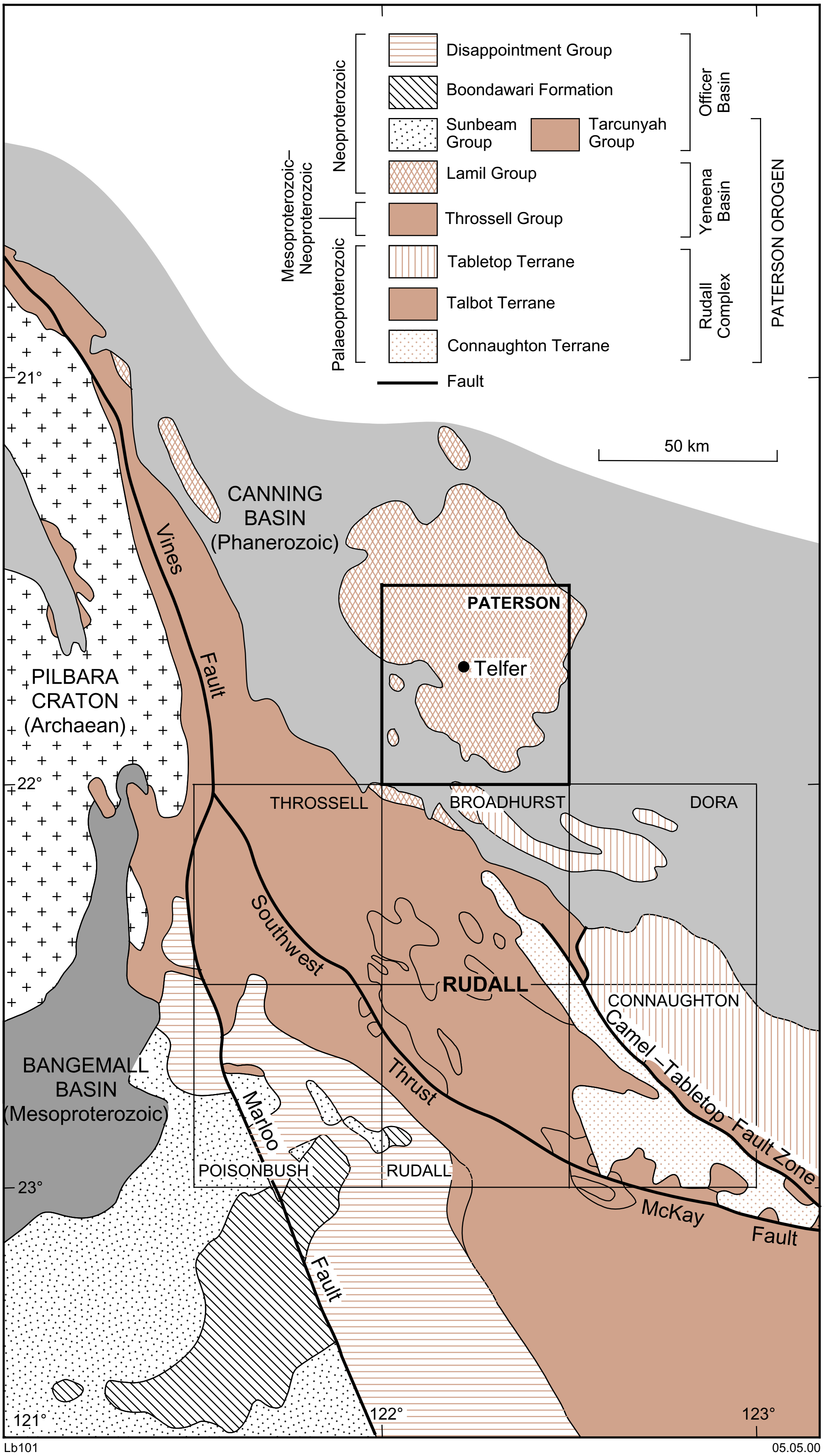


Figure 1. Regional geological setting of Paterson

4400 mm and prevailing winds blow from the east and southeast*.

PATERSON lies within the western part of the Great Sandy Desert (Beard, 1970; Beard and Webb, 1974). Spinifex (*Triodia*) is present across the entire area whereas other forms of vegetation are associated with different types of terrain. For example, sandplains also contain *Grevillea*, wattles (*Acacia*), soft shrubs (*Crotalaria*), eucalypts, and tea tree (*Melaleuca*). Creeks, such as those around the Wilki and Karakutikati Ranges, contain large eucalypts and grasses. Playa-lake margins contain salt bush (*Hemichron*, *Bassia*, *Frankenia*), samphire (*Arthrocnemum*), and spinifex. Areas of rock outcrop include small shrubs, grasses, mulga, and stunted eucalypts, whereas areas of outcrop and colluvium contain spinifex, small shrub, grasses, and *Acacia*.

Physiography

The most significant geological events that affected the physiography of PATERSON appear to be Permian glaciation, Tertiary peneplanation, and Cainozoic erosion and deposition (Fig. 2). The physiographic subdivision outlined below follows that of Bagas and Smithies (1998a).

Permian land surface

Remnants of areas originally covered by Permian fluvioglacial sediments of the Paterson Formation are present on PATERSON as dissected valley deposits that form benches and mesas (Fig. 2). It is suspected that most of PATERSON was once covered by Permian fluvioglacial sediments, as indicated by significant silicification of basement rocks below the Paterson Formation unconformity and remnant silicification elsewhere. However, although the silicification could be as old as Permian (Turner and McKelvey, 1981), it may be a result of more recent groundwater movement along the unconformity between the Paterson Formation and underlying Proterozoic basement rocks.

Tertiary land surface

Unmodified remnants of a Tertiary peneplain are present as cappings of ferruginous duricrust and silcrete. The precise age of the peneplain is unknown, although it may correlate with the Tertiary 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). Smaller areas of duricrust and silcrete that cap hills and ridges are typically preserved in areas underlain by sandstone. These are commonly bevelled to a height of about 300 m AHD (Australian Height Datum).

The calcrete valley-floor deposits in the southwestern and northeastern parts of the map sheet, pre-date the sandplains that partially cover them, and are probably related to channels and lakes that were active during the Tertiary. These deposits form low mounds in low-lying areas, and are composed of massive, nodular, and vuggy limestone that is partly replaced by chalcedony.

Recent erosional land surface

The recent erosional land surface unit represents various stages of erosion of older units. For example, the unit includes low-relief hills and outcrop as well as sandstone strike ridges that rise up to 100 m above the sand plains (Fig. 2). Erosion is restricted to wind action and water movement in small streams, and represents an advanced stage in the formation of a new peneplain. Granite, carbonate, siltstone, and shale units typically underlie low-lying areas between the sandstone ridges.

Recent depositional land surface

The map area lies within sandplains that form the western part of the Great Sandy Desert. These sandplains include longitudinal (seif) dunes and minor areas of dune-free sandplains, which together cover about half of PATERSON (Fig. 2).

The seif-dune sandplains are predominantly flat with westerly to northwesterly trending longitudinal dunes that are many kilometres long, up to 3 km apart, and have an average height of 12 m. The longitudinal profiles are consistent with prevailing winds from the southeast. Many of the dunes are asymmetrical with steeper southern slopes. The dune-free sandplains on the western part of PATERSON are subjected to periodic flooding.

The scree, colluvium, sheetwash fans, and playa lakes units commonly flank sandplains, and represent locally derived clastic detritus from streams and channels that drain the hilly areas. Recent channels dissect some of these deposits.

Previous investigations

Mineral exploration on PATERSON was extremely limited until 1971 when the Telfer gold deposit was discovered. This stimulated interest in the region and many mineral exploration companies subsequently explored the map area. Details of this early phase of exploration are given in Chin et al. (1982) and Tyrwhitt (1995). A number of papers have since been published on the Telfer area (e.g. Dimo, 1990; Goellnicht, 1992; Goellnicht et al., 1989, 1991; Nelson, 1995, 1999; Rowins, 1994; Rowins et al., 1993, 1997, 1998; Tyrwhitt, 1995).

Reconnaissance mapping of the PATERSON RANGE 1:250 000 sheet was carried out between 1974 and 1977 as part of the systematic 1:250 000 geological mapping of Western Australia (Trendall, 1974; Chin et al., 1982) by the Geological Survey of Western Australia (GSWA). In 1989, the GSWA commenced a detailed 1:100 000-scale geological mapping program of the Paterson Orogen. By 1999, BROADHURST (Hickman and Clarke, 1993), CONNAUGHTON (Bagas and Smithies, 1996), RUDALL (Hickman and Bagas, 1996), THROSSELL (Williams et al., 1996), GUNANYA (Bagas, 1997), BLANCHE–CRONIN

* Climate data from Commonwealth Bureau of Meteorology website, 2000.

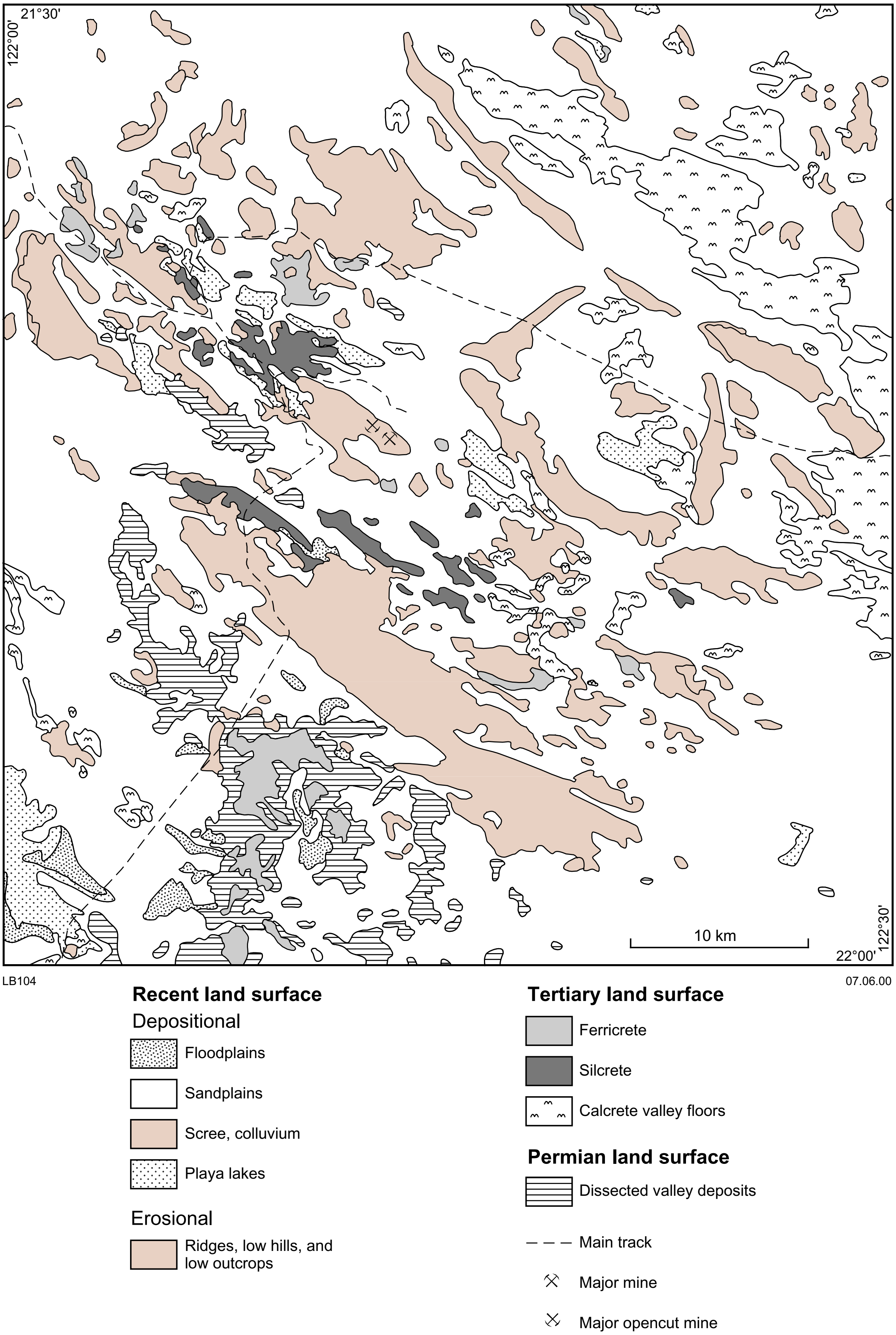


Figure 2. Physiography and access on Paterson

(Bagas and Smithies, 1998b), POISONBUSH (Williams and Bagas, 1998), and RUDALL (1:250 000; Bagas, 1999) were published.

This report and the accompanying PATERSON 1:100 000 geological map are based on detailed regional mapping undertaken during 1998 and the interpretation of regional magnetic and radiometric data.

Regional geological setting

PATERSON comprises rocks of the Proterozoic Paterson Orogen and Phanerozoic Canning Basin (Figs 1 and 3). Table 1 summarizes the history of deformation and metamorphism on PATERSON.

The Paterson Orogen is a southeasterly trending belt of Proterozoic rocks that extends about 1200 km across the central part of Western Australia (Williams and Myers, 1990). Rocks of the orogen are exposed in the north-western part along the eastern margin of the Pilbara Craton, and in the Musgrave Complex in the southeastern part. The northwestern exposure of the orogen was originally referred to as the Paterson Province (Daniels and Horwitz, 1969; Blockley and de la Hunty, 1975).

The Paterson Orogen consists of the Palaeoproterozoic Rudall Complex (comprising the Connaughton, Talbot, and Tabletop Terranes), the Meso- to Neoproterozoic Yeneena Supergroup, and the Neoproterozoic Tarcunyah Group (Bagas et al., 1995; Williams and Bagas, 1999). On PATERSON, the orogen is intruded by Neoproterozoic granites that range from c. 630 Ma in the Wilki Structure (Nelson, 1999) to c. 678 Ma at the Mount Crofton Granite (Dunphy, J., 1999, pers. comm.).

The Canning Basin, which contains Ordovician to Holocene sedimentary rocks, is the largest sedimentary basin in Western Australia (Middleton, 1990). On PATERSON, the basin sequence consists of the Permian Paterson Formation and the Cretaceous to Jurassic Callawa Formation.

Proterozoic rocks

Proterozoic rocks of the Paterson Orogen on PATERSON consist of the Neoproterozoic Lamil Group (c. 1070 Ma) and granitic rocks (c. 654 Ma).

Yeneena Supergroup

The Meso- to Neoproterozoic Yeneena Supergroup is composed of the Throssell and Lamil Groups of the Yeneena Basin (Williams and Bagas, 1999; Bagas et al., 1995, 1999). However, the validity of the terms Yeneena Supergroup and Yeneena Basin must be considered doubtful until more geochronological data are available and the stratigraphic relationship between the Throssell and Lamil Groups is established — nowhere is the contact between the two groups exposed. In the northern part of BROADHURST, Hickman and Clarke (1994) suggested that a fault or unconformity separates the two groups; however the contact is probably a northwestern extension of the Camel–Tabletop Fault Zone (Fig. 1).

The age of the Yeneena Supergroup has not been determined directly; however, isotopic ages and field relationships of igneous units indicate that the Throssell Group is probably younger than 1250 Ma and older than 900 Ma (Hickman and Bagas, 1999). As discussed below, the Lamil Group is between c. 1070 and 678 Ma.

On PATERSON, only the Lamil Group outcrops although the Throssell Group may be present under Phanerozoic cover in the southwestern corner of the area. A simplified map of the Proterozoic geology on PATERSON is presented in Figure 3.

Lamil Group

The Lamil Group (*PL*; Williams and Bagas, 1999) consists of the Malu, Puntapunta, and Wilki Formations, and unassigned sedimentary rocks (Table 2). The group is younger than c. 1070 Ma, the age of detrital zircons extracted from sandstones in the formations (Nelson, D. R., 2000, pers. comm.), and older than c. 630 Ma, the SHRIMP U–Pb zircon age of post-orogenic I-type monzogranites and syenogranites that intrude the group in the area of the Crofton Granite and the Wilki Structure (Nelson, 1995, 1999). However, coexisting titanite from three samples of the Mount Crofton Granite (Dunphy, J., 1999, pers. comm.) gave consistent, older, concordant, and more precise SHRIMP $^{206}Pb/^{238}U$ ages (639 ± 9 to 678 ± 12 Ma) than the U–Pb zircon-age data. The latter is the minimum age of the Lamil Group.

The Lamil Group is a sandstone–shale–carbonate (limestone and dolomite) succession, which includes an unnamed unit of interbedded carbonate and siltstone that is tectonically overlain by the Malu Formation in the Karakutikati Range (in the southern part of PATERSON). The interbedded carbonate and siltstone unit was previously assigned to the Isdell Formation (Chin et al., 1982), based on the similarity of these rocks with those of the Isdell Formation 10 km to the south on BROADHURST (see Hickman and Clarke, 1993). However, Permian rocks and Cainozoic sediments cover the area between these units, and their correlation is therefore tenuous. Elsewhere on PATERSON, the Malu Formation is conformably overlain by the Puntapunta Formation, which in turn is conformably overlain by the Wilki Formation (Williams and Myers, 1990).

Turner (1982) proposed an intracratonic basin setting for the deposition of the Lamil Group and suggested that deposition took place at a continental margin or within a failed rift. Harris (1985) suggested that the Lamil Group was deposited in a pull-apart basin developed in an extensional strike-slip system. This model is similar to that proposed for the Throssell Group on RUDALL (Hickman and Bagas, 1995, 1999).

The deformation history of the Lamil Group includes northeast–southwesterly directed compression and upright folding with associated faulting. Evidence suggests that

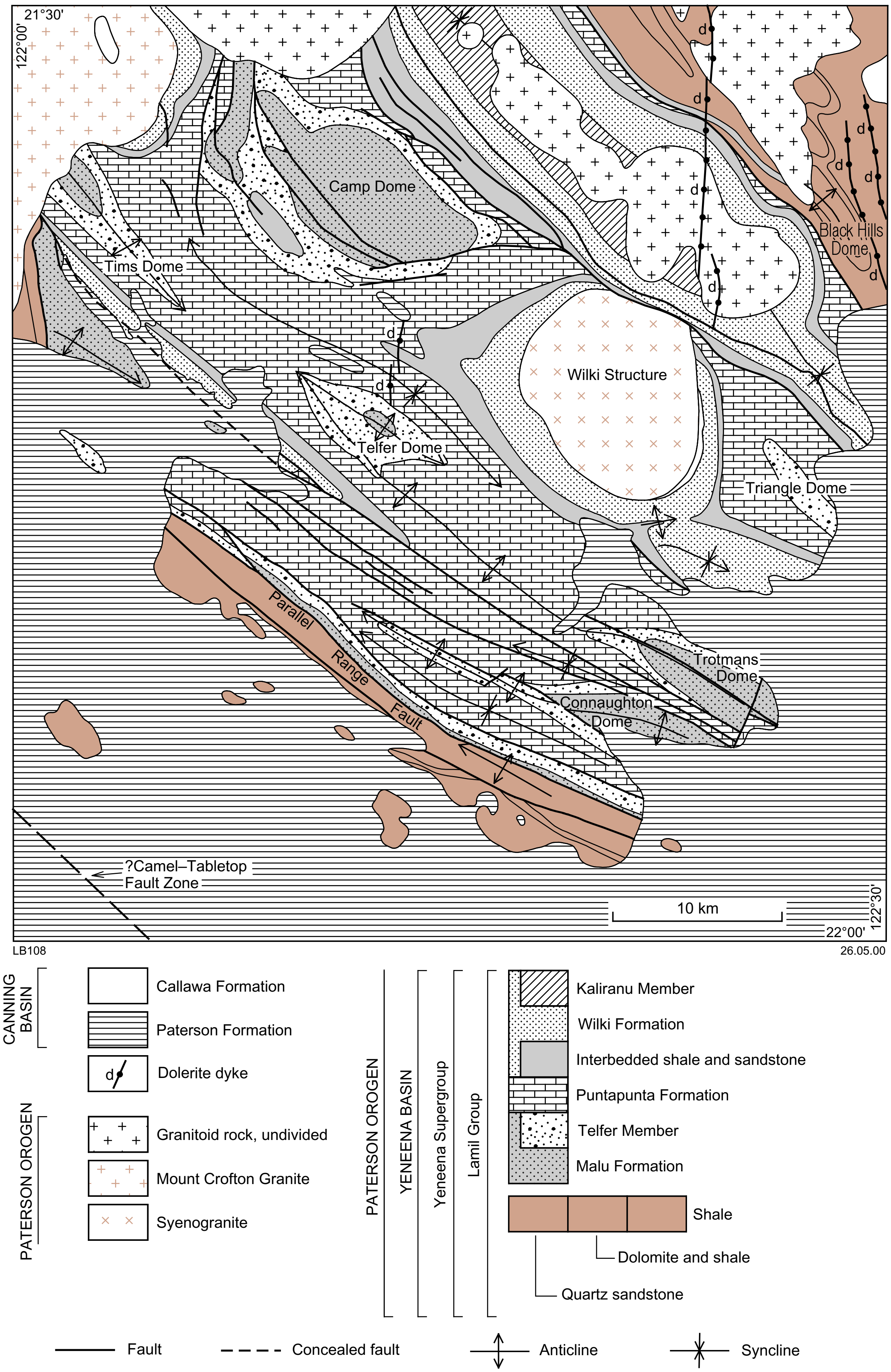


Figure 3. Simplified geological map of PATERSON, showing major structures

Table 1. Summary of geological events on PATERSON (after Bagas and Smithies, 1998a)

Age (Ma)	*Geological event*
1290	Maximum possible age of the Throssell Group Maximum age of the Miles Orogeny ($D_{3\text{-}4}$) that affected the Rudall Complex and Throssell Group to the southwest of PATERSON
c. 1090	Maximum age of the Lamil Group, which was deposited in an intracratonic setting that may have been either a pull-apart basin in a dextral strike-slip system, or within a failed rift
820	Likely age of the southwesterly directed compression associated with the Miles Orogeny ($D_{3\text{-}4}$), which was accompanied by greenschist-facies metamorphism (M_4). The orogeny affected the Rudall Complex and Throssell Group to the southwest of PATERSON, and probably the Lamil Group. Structures attributed to the orogeny on PATERSON include northwesterly trending folds with a locally developed S_4 axial-planar cleavage, and normal and reverse faults with a component of either dextral or sinistral strike-slip transport
800–610	Poorly constrained age for the Blake Movement (D_5). Structures attributed to the Blake Movement on PATERSON are open folds with axial planes trending about 030°, which indicate a regional compression towards the northwest
630–678	Emplacement of post-D_4 monzogranites and syenogranites in the Lamil Group as laccolithic sheets in broad domal and synformal structures prior to the Paterson Orogeny (D_6). These Neoproterozoic granites appear to be unique to the Telfer region in the Paterson Orogen, and may be partly related to the genesis of gold and base-metal mineralization around Telfer
~550	Approximate age of the Paterson Orogen (D_6)
Post-D_6	Deposition of Phanerozoic sedimentary rocks in the Canning Basin

SOURCE: see text for references

the main deformation event, tentatively assigned to the poorly constrained Miles Orogeny of Bagas et al. (1995), commenced early in the history of the group, probably during diagenesis, in the area around Telfer. Soft-sediment deformation is commonly associated with structures that are attributed to the main deformation event, and lend support to the above interpretation.

It is probable that the Camel–Tabletop Fault Zone either played a major role in the deposition of the Lamil Group or brought an exotic terrane containing the Lamil Group into contact with the Paterson Orogen to the west. If the fault zone contributed significantly to the deposition of the Lamil Group, subsidence of, and deposition in, the Lamil intracratonic basin probably commenced during transpressional faulting along the northwestern extension of the Camel–Tabletop Fault Zone. This faulting would have taken place during the onset of the Miles Orogeny. The basin then deepened towards the northeast and tectonic instability led to the deposition of mass flow deposits of the Malu Formation (Turner, 1982). An increase in tectonic stability then resulted in deposition of outer carbonate-shelf deposits of the upper part of the Malu Formation and overlying Puntapunta Formation. The Wilki Formation was then deposited during shallowing of the basin.

Malu Formation (ⱣLm, ⱣLmh)

The Malu Formation (*ⱣLm*) is in faulted contact with an unnamed carbonate sequence to the south of Karakutikati Range, and is conformably overlain by the Puntapunta Formation (Table 2). The formation is here redefined to include the Telfer Formation of Chin et al. (1982) (as the Telfer Member) and the Malu Quartzite (Chin et al., 1982). Although the Telfer Member is similar to the rest of the Malu Formation, its higher proportion of interbedded siltstone and rare carbonate beds distinguishes it. Both units contain quartz-rich sandstone, siltstone, and shale, although the Telfer Member contains a higher proportion of siltstone, and rare carbonate rocks near its top. The sandstone consists of quartz, plagioclase (commonly altered to kaolinite), sericite, dolomite, iron oxide, and detrital zircon.

The Malu Formation varies in thickness from at least 1.2 km at the Karakutikati Range (where the lower part of the formation is faulted out), to at least 2 km at the Malu Hills and at depth in the Telfer mine. The exposed lower part of the formation at Malu Hills comprises shale interbedded with lesser sandstone (*ⱣLmh*), transitionally overlain by thickly bedded, moderately sorted, fine- to medium-grained quartz sandstone that is interbedded with thin beds of siltstone and shale. Elsewhere, the formation is interbedded with minor carbonate towards the top of the Telfer Member.

Although bedding is poorly preserved in outcrop, the Malu Formation has a distinctive banded pattern on aerial photographs. Sandstone beds are commonly less than 5 m thick and have rare sedimentary structures that include flute marks and coarsening upward sequences. In drillcore, bed thicknesses are similar, and in places the sandstones display trough cross-beds. Normal graded bedding is present at the top of sandstone beds where they are in contact with siltstone and shale. Turner (1982) interpreted the Malu Formation as deep-water turbidite deposits in northeasterly prograding submarine fans.

Table 2. Formations of the Lamil Group and their depositional environments

Formation (thickness)	*Rock type*	*Depositional environment*
Wilki Formation (previously the Wilki Quartzite) (1.4 km)	Fine- to medium-grained quartz sandstone; minor shale and siltstone	Shallow marine
Kaliranu Member (previously the Kaliranu beds) (≥200 m)	Silty dolomite, shale, and fine-grained sandstone; at the exposed upper part of the Wilki Formation	Shallow marine
	Conformable contact	
Puntapunta Formation (1.5 km)	Clastic carbonate rocks interbedded with siltstone, shale, and chert	Outer carbonate shelf
	Conformable contact	
Malu Formation (previously the Malu Quartzite) (about 2 km)	Fine- to medium-grained quartz sandstone; minor interbedded shale and dolomite	Alternating prograding submarine fan deposits and low-energy, deep-water marine deposits
Telfer Member (previously the Telfer Formation) (600 m)	Interbedded sandstone and shale; minor carbonate rocks; upper third of the Malu Formation	Transitional between deep water and outer carbonate shelf
	Faulted contact	
Unassigned carbonate rocks on the southern part of PATERSON (previously included in the Isdell Formation)	Interbedded dolomite and shale	Carbonate slope and outer carbonate shelf

SOURCE: after Chin et al. (1982); Turner (1982)

In the Telfer mine and in Camp Dome, mineral exploration geologists have previously thought that the Malu Formation is underlain by the Isdell Formation. Accordingly, mineralized reefs at depth within the mine have been called the ‘I-Series reefs’ (Richards, A., 1995, pers. comm.). However, drillcore that is reported to commence in the Malu Formation and end in the Isdell Formation, comprises a continuous alternating sequence of sandstone, siltstone, and shale (Hewson, 1996). Some siltstone is calcareous; however there are no thick carbonate interbeds that typify the Isdell Formation (Chin et al., 1982). The depositional base of the Malu Formation therefore remains undefined.

Telfer Member (ꝐLmt, ꝐLmtk)

The Telfer Member (*ꝐLmt*; redefined from the Telfer Formation of Chin et al., 1982) is a transitional sequence at the top of the Malu Formation and below the Puntapunta Formation. The base of the member is taken as the top of the massively bedded sandstone in the underlying part of the Malu Formation, and the top is taken as the uppermost sandstone bed. The member is about 600 m thick (Table 2).

The Telfer Member consists of fine- to medium-grained quartz sandstone interbedded with clayey sandstone, siltstone, and shale. Thinly bedded dolomitic shale and dolomite (*ꝐLmtk*) outcrops in the northwestern part of the Karakutikati Range (MGA 100906*) and in the Trotmans Dome (MGA 343830). Towards the top of the member, near to the Telfer mine, laminated dolomitic siltstone (dololutite) is interbedded with siltstone and shale, and is informally called the Outer siltstone and Middle Vale siltstone (Fig. 4).

The sandstone beds are typically well sorted, very fine- to fine-grained, and consist of quartz, plagioclase, sericite, and minor authigenic dolomite. Sedimentary structures are rarely preserved due to recent widespread silicification (*Czz*) of the region; however, flute marks and parallel laminations are present in the Karakutikati Range (MGA 173837), and cross-bedding with a palaeocurrent direction to the northeast is preserved at Tims Dome (MGA 046075).

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). Chlorite is found in hornfels zones. The dolomite beds are dololutite and consist of very fine-grained dolomite, minor plagioclase, tourmaline, sulfides (predominantly pyrite), and zircon.

Turner (1982) inferred that the Telfer Member represents a transition from deep water to an outer carbonate-shelf environment (represented by the overlying Puntapunta Formation).

Puntapunta Formation (ꝐLp, ꝐLpc, ꝐLph)

The Puntapunta Formation (*ꝐLp*; Chin et al., 1982) conformably overlies the Telfer Member of the Malu Formation (*ꝐLm*), and is conformably overlain by the

* Localities are specified by the Map Grid Australia (MGA) standard six-figure reference system whereby the first group of three figures (eastings) and the second group (northings) together uniquely define position, on this sheet, to within 100 m.

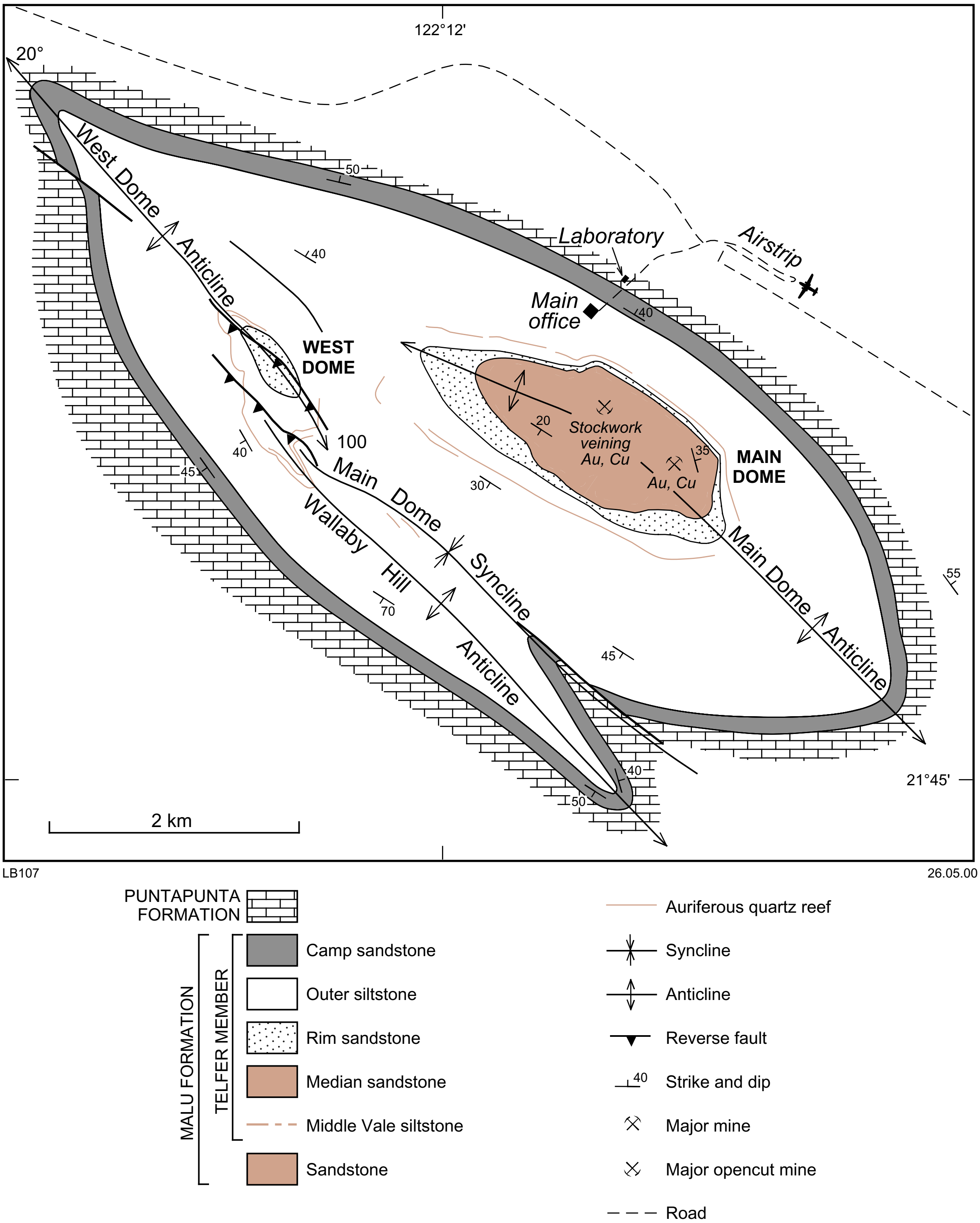


Figure 4. Simplified solid geology map of the Telfer Dome (only the major opencut area and mine are shown). The stratigraphy of the Telfer Member of the Malu Formation is after Dimo (1990)

Wilki Formation (Table 2). The upper contact of the Puntapunta Formation is the top of the last carbonate unit in the Puntapunta Formation or the base of the lowermost sandstone in the Wilki Formation (*ƁLw*), and its lower contact is the top of the last sandstone bed in the Malu Formation. The Puntapunta Formation is about 1.5 km thick in the area around Tims Dome, on the northwestern part of PATERSON.

The Puntapunta Formation is well exposed as low-lying outcrops, which are commonly silicified (*Czz*) or ferruginized (*Czf*). It consists of a laminated to thinly bedded sequence of dark-grey dolomitic sandstone, grey dolomitic siltstone, and rare limestone, very fine-grained light-brown dolomitic sandstone, chert (*ƁLpc*), and shale (*ƁLph*). Very rare and thin beds of dolorudite, which form lensoid channels that are around 2 m wide and 0.5 m thick, have also been observed (e.g. about 5 km south of Punta Punta Hill, at MGA 218815). The dolorudite comprises angular clasts of dolomite in a dolomitic matrix.

The dolomite (dolarenite and dololutite) beds are commonly less than 300 mm thick, have slightly undulating contacts, and contain flame structures and scour channels. The rock consists of interlocking calcareous silt grains with various amounts of subrounded quartz and minor sericite. The dolarenite tends to form thicker beds than the dololutite, and both rock types are commonly pitted on the surface. The dololutite is commonly parallel laminated, although cross-bedding has been observed in places. The cross-bedding includes 20–50 mm-thick planar cross-sets and approximately 10 cm-thick trough cross-sets. Cross-bedding measurements indicate a palaeocurrent direction towards the northeast.

Banded chert (*ƁLpc*) interlayered with shale (*ƁLph*) is present towards the top of the formation (e.g. around MGA 260946). The chert is tens of metres thick and is probably a silicified shale or carbonate. These units, as suggested by Chin et al. (1982), probably represent a change in the depositional environment preceding the deposition of the Wilki Formation.

Turner (1982) interpreted the Puntapunta Formation as an outer carbonate-shelf deposit.

Wilki Formation (ƁLw, ƁLwk, ƁLwh)

The Wilki Formation (*ƁLw*; Chin et al., 1982) is the youngest exposed stratigraphic unit of the Lamil Group. It includes the informally named Kaliranu beds of Williams (1990) as the Kaliranu Member (*ƁLwk*). The formation is about 1.4 km thick and appears to conformably overlie the Puntapunta Formation (Table 2); however the contact between the two formations is not exposed.

The basal part of the Wilki Formation is poorly exposed and dominated by graphitic shale and siltstone, interbedded with fine-grained silty sandstone (*ƁLwh*). This unit is about 250 m thick and seems to be transitional with the underlying Puntapunta Formation.

Much of the Wilki Formation is a monotonous sequence of silicified sandstone. Bedding comprises laterally extensive, fine- to medium-grained sandstone and recessive silty sandstone. The sandstone is moderately sorted, fine- to medium-grained, quartz-rich, with subrounded to well-rounded quartz grains in a matrix of quartz and sericite. Hornfelsed samples from Wilki Range contain recrystallized and interlocking quartz grains with minor chlorite, muscovite, and tourmaline. Sedimentary structures are not preserved.

A shallow-marine environment is tentatively inferred for the Wilki Formation (Turner, 1982).

Kaliranu Member (ƁLwk)

The Kaliranu Member (*ƁLwk*) is a poorly exposed sequence towards the top of the Wilki Formation that includes interbedded shale, siltstone, fine-grained sandstone, and silty dolomite. The member is at least 200 m thick (Table 2).

Unassigned sedimentary rocks (ƁL(k), ƁL(km), ƁL(a), ƁL(sh), ƁL(h), ƁL(c))

In the northeastern and southern parts of PATERSON, dolomite is interbedded with siltstone and rare intraformational conglomerate (*ƁL(k)*). Very rare light-grey chert (*ƁL(c)*) is also interbedded with dolomite near Trotman Hills (MGA 260749). The dolomite is yellow, pink, and brown, thinly bedded, and fine- to medium-grained. The conglomerate forms thin beds within the dolomite and consists of elongate, angular to rounded pebbles of dolomite, in a poorly sorted sandstone matrix (e.g. south of Karakutikati Range at MGA 136857). On the northeastern part of PATERSON, carbonate beds grade into marble (*ƁL(km)*) where granite is near the surface — highly weathered, medium-grained granite (*Ɓg*) outcrops in this area (MGA 434155). The marble contains tremolite, diopside, and scapolite, in a fine-grained matrix of quartz, calcite, and feldspar, rare tourmaline, epidote, and titanite.

Chin et al. (1982) correlated carbonate beds just south of the Karakutikati Range, with the Isdell Formation that outcrops 10 km further to the south on BROADHURST. This correlation was based on both outcrop areas having thin bedding and a similar colour. However, Permian rocks and Cainozoic sediments separate the unassigned carbonate unit from the Isdell Formation to the south, thereby making the correlation tenuous. Furthermore, the contact between the Malu Formation and the carbonate beds south of the Karakutikati Range is a fault, and therefore the stratigraphic relationship between the two units is uncertain. The unassigned carbonate unit is similar to rocks of the Puntapunta Formation and therefore it may be a facies variant of the formation.

Fine- to medium-grained quartz sandstone (*ƁL(a)*) is exposed south of the Karakutikati Range and in the northeastern part of PATERSON. The unit includes massive and rare thinly bedded sandstone, 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 (*ƁL(k)* and *ƁL(km)*), and is labelled as *ƁL(sh)*. On magnetic images, aerial photographs, and in outcrop, the sandstone in the northeastern part of PATERSON resembles the Wilki Formation. However, the unit has not been included in the Wilki Formation because a major concealed structural break, interpreted from magnetic images, separates it from the Wilki Formation. The stratigraphic relationship between the two is therefore not known. To the south of the Karakutikati Range, the sandstone unit appears to be thin and within a carbonate succession. This sandstone was previous correlated with the Telfer Formation (now the Telfer Member of the Malu Formation) by Chin et al. (1982).

A poorly exposed shale unit (*ƁL(h)*), commonly ferruginized and cleaved, outcrops to the west of the Malu Formation near Lamil Hills (MGA 980068). It has not been included in the Wilki Formation, as it was by Chin et al. (1982), because of possible structural complications in the area inferred from magnetic images.

Granitoid rocks

The Lamil Group is intruded by granitoid rocks near Mount Crofton, to the north of the Wilki Range, and in the northeastern part of PATERSON. Narrow contact aureoles are found around granitic bodies in the Malu Hills and around the Hasties prospect (MGA 101895). A contact aureole is also recognized at O'Callaghans prospect (around MGA 231899).

Outcropping granitoid rocks range in composition from monzogranite to syenogranite, and are usually massive and not deformed. They are highly fractionated (with average SiO_2 contents > 71 wt% and Rb/Sr ratios of up to 20.5), metaluminous, and I-type in nature (Goellnicht et al., 1991). The development of contact metamorphic aureoles is variable. They are up to 2 km wide (Goellnicht, 1992), and reach the pyroxene-hornfels facies grade (Chin et al., 1982).

The distribution of granitoid rock on PATERSON, based on the interpretation of magnetic images, is shown in Figure 3.

Mount Crofton Granite (Ꮑgcr, Ꮑgcry, Ꮑgcrm)

The Mount Crofton Granite (*Ꮑgcr* — on simplified geology map; Chin et al., 1982) is well exposed as boulders in several prominent hills in the northwestern corner of PATERSON and the northeastern corner of LAMIL. On PATERSON, this granite is predominantly medium- to coarse-grained, biotite monzogranite (*Ꮑgcrm*), with areas of fine-grained leucocratic syenogranite (*Ꮑgcry*) in places. The monzogranite grades into porphyritic phases, which are considered local variants. The monzogranite consists of perthitic K-feldspar (orthoclase and minor microcline), which is megacrystic in places, quartz, minor biotite, plagioclase with myrmekitic rimming, apatite, titanite, zircon, allanite, and opaque minerals, and rare hornblende. The syenogranite is an equigranular and medium-grained rock that consists of perthitic K-feldspar, lesser zoned plagioclase, minor biotite, titanite, zircon, apatite, and opaque minerals.

Three samples from the Mount Crofton Granite have titanite SHRIMP U–Pb ages that range between 639 ± 9 and 678 ± 12 Ma. These ages are regarded as the most valid for constraining the true crystallization age of the samples, given the high to extremely high concentration of uranium in the zircons that has essentially destroyed their structure and resulted in significant lead-loss (Dunphy, J., 1999, pers. comm.). The zircon ages for the same samples, which range from c. 600 to 630 Ma, are therefore minimum ages for the granitic rocks and not their crystallization ages (Dunphy, J., 1999, pers. comm.).

Minor dykes of aplite and pegmatite (with chilled aplitic margins) intrude the granite. The pegmatite contains quartz, biotite, and muscovite.

Unassigned granitoid rocks (Ꮑg, Ꮑgsl, Ꮑgsls, p)

Small outcrops of highly weathered granitoid rock (*Ꮑg*) are found in the northeastern and central parts of PATERSON. Thin pegmatite veins (*p*), associated with granitic intrusions at depth, are found at Trotmans Stockwork (MGA 315855). Low-lying and scattered boulders of syenogranite and monzogranite (*Ꮑgsl*) are present 15 km to the east of Telfer mine in the Wilki Structure. A sample of monzogranite (MGA 325005) has a SHRIMP U–Pb zircon age of 628 ± 19 Ma (Nelson, 1999). The monzogranite outcrop is sheared (*Ꮑgsls*) on its eastern edge where it is in contact with the Wilki Formation, and has lineations that plunge down-dip along the foliation. The syenogranite consists of megacrystic microcline and orthoclase in a coarse-grained matrix of euhedral plagioclase (with euhedral zones, myrmekitic intergrowths, and sericitic alteration), biotite that is altered to chlorite in places, quartz, apatite, zircon, titanite, and opaque minerals.

Mafic intrusions and quartz veins (*d*, *q*, *qt*)

Northerly trending dolerite dykes (*d*) crosscut the early structures that affect the Lamil Group, thereby indicating that the dykes are relatively young. Hornfelsed dolerite, observed in diamond drillcore from hornfels zones around the Mount Crofton Granite and in the Malu Hills area, suggests that the dolerite was intruded before, or synchronously with, the Mount Crofton Granite. The hornfelsed dolerite at the Hasties Prospect (MGA 101895) is fine- to medium-grained and consists of microphenocrysts of plagioclase altered to sericite and anhedral epidote, and clinopyroxene (augite) altered to chlorite. The matrix comprises fine- to medium-grained interlocking lath-like plagioclase, and ragged to bladed actinolite that probably replaced the original clinopyroxene. Fine-grained leucoxene and minor magnetite also comprises the matrix.

Quartz (*q*) veins are commonly located in faults and shear zones. Some veins are limonitic, particularly along their margins, and indicate wallrock sulfidation reactions. Other quartz veins contain limonite and goethite in late fractures, suggesting precipitation from groundwater during Cainozoic lateritization. Some veins in the Malu Hills area also contain tourmaline (*qt*).

Permian and Jurassic–Cretaceous rocks

The distribution of Permian and Jurassic–Cretaceous rocks are shown in Figure 3. These rocks form part of the Canning Basin succession.

Paterson Formation (Pa)

The Paterson Formation (*Pa*; Traves et al., 1956) is widespread to the south of Karakutikati Range and west of Telfer mine. It appears to have been deposited in a palaeoglacial valley that developed in Proterozoic basement rocks. Outliers of the formation overlie the Puntapunta Formation to the north of Telfer mine.

The Paterson Formation contains fluvioglacial and diamictite deposits that comprise pebble and boulder conglomerate, cross-bedded and coarse-grained sandstone, siltstone, and shale. The base of the formation is a diamictite that consists of mudstone with striated pebbles and boulders of quartzite, orthogneiss, gabbro, schist, chert, dolomite, and sandstone. This unit passes upwards into a normally graded, medium- to coarse-grained, poorly sorted, cross-bedded sandstone, overlain by siltstone and mudstone. South of Telfer mine and the Karakutikati Range, siltstone and well-bedded sandstone are commonly folded, faulted, and steeply dipping, and overlain by shallowly dipping beds of sandstone and siltstone. These structures probably resulted from sediment slumping either during the melting of ice, or by the movement of glaciers (Chin et al., 1982).

Callawa Formation (JKc)

The Callawa Formation (*JKc*; Traves et al., 1956) is confined to isolated areas in the northeastern and northwestern corners of PATERSON. The formation is a Jurassic to early Cretaceous (Chin et al., 1982; Middleton, 1990) fluvial succession of conglomerate, fine- to coarse-grained and poorly sorted sandstone, and siltstone.

Cainozoic deposits

On PATERSON, Cainozoic deposits comprise dissected and variably cemented sediments that mantle Proterozoic to Mesozoic rocks. Areas of active sedimentation are mapped as Quaternary deposits. Individual Cainozoic and Quaternary units have been mapped from aerial photographs and limited field observations.

Gently undulating duricrust surfaces, which include ferricrete or ironstone deposits (*Czf*) and silcrete deposits (*Czz*), contain areas of exposed underlying bedrock where dissected. The ferricrete grades downward into leached and kaolinized deeply weathered rock. The duricrust represents remnants of Cainozoic or older weathering profiles in which the original rock structures or textures are poorly preserved. Silcrete is widespread on PATERSON and is commonly developed over carbonate rocks, which were previously identified as sandstone by Chin et al. (1982), for example, west of the Telfer gold mine (MGA 123986). The silcrete is probably Tertiary or older in age and may represent a Tertiary continent-wide weathering event (Idnurm and Senior, 1978), or are silicified and leached zones developed at the base of Permian rocks. Flat-lying glacigenic conglomerate and pebbly sandstone locally overlie the silcrete, implying that at least some of the silcrete could be as old as Permian (Turner and McKelvey, 1981).

Colluvium, sheetwash, alluvial fan deposits, and talus (*Czc, Czcg*), are composed of boulders, gravel, sand, and silt. These units are derived from various rock types, but are mainly from those lithologies that are relatively resistant to weathering and erosion and form the adjacent hilly areas. Colluvium that is derived from Permian fluvioglacial rocks and diamictite (*Czcg*), comprises erratics of granite, orthogneiss, and quartzite.

Calcrete (*Czk*), consisting of massive, vuggy, or nodular sandy limestone with local opaline caprock, is a few metres thick and present in drainage channels in the eastern and western parts of PATERSON. The calcrete is transgressed and overlain by longitudinal dunes.

Quaternary deposits

Gently sloping scree and outwash fans alongside ridges and hills are composed of colluvial sand, soil, and gravel (*Qc*). Extensive colluvial fans locally grade into alluvium downstream.

Flat to undulating sandplains and variably spaced longitudinal (seif) dunes (*Qs*), cover large parts of PATERSON. The sandplains and seif dunes consist of dark-red eolian sand and clayey sand. The sand comprises iron-stained quartz grains that have diameters of up to 0.5 mm. The dunes are up to 30 m in height, many kilometres long, and have a westerly to northwesterly orientation that parallels the prevailing wind direction. Sand movement is confined to the dune crests, and a cover of spinifex (*Triodia* sp.) and small eucalypt bushes stabilizes their sides. Some dunes terminate on the eastern side of outcrops or where drainage channels cut them. The depth of the sand between dunes is commonly less than 2–3 m, as revealed by exposed pediments and an absence of trees.

The sand unit (*Qp*) is common throughout PATERSON, and is characteristically dark brown on aerial photographs. The unit is a mixture of residual and transported ferricrete granules, pebbles, and eolian sand. The residual ferruginous component indicates a high iron content in the bedrock. It commonly overlies shale, pelitic schist, or nodular laterite. There is a lithological gradation between *Qs* and *Qp*, and the distinction between these two unit is difficult in places.

Poorly developed red-earth soils (*Qw*) are covered with dense mulga that has grown in a distinctive curved pattern. The unit has formed either over mature, deeply weathered plains, or after older alluvium of unknown age. The unit contains ferricrete granules (*Qwf*) and, in places, calcareous soils.

Poorly developed drainage courses and associated floodplains contain alluvium (*Qa*), which consists of unconsolidated clay, silt, sand, and gravel. The floodplain deposits also contain sand and clay mixed with eolian sands.

Playa lake deposits (*Ql*) consist of clay, silt, and evaporites. The unit is found in low-lying areas marginal to drainage channels, or at the termination of creeks against sand dunes. Lake sediment comprises a mixture of black to brown mud, evaporites, and sand. Seasonal grasses and scattered eucalypts are the only types of vegetation on the lake surface. Mixed lacustrine and eolian deposits that can not be divided are labelled *Qd* on the map sheet.

Structure

Interpretations of the structural history of the Paterson Orogen have been presented by Chin et al. (1980), Myers (1990a,b), Clarke (1991), Hickman and Clarke (1994), Hickman et al. (1994), Myers et al. (1996), Hickman and Bagas (1998, 1999), Bagas and Smithies (1998a), and Bagas et al. (2000). These authors recognized four phases of deformation (D_3–D_6) in the Throssell Group to the west and south of PATERSON (Table 1). Numerous structural studies have been undertaken on the Lamil Group and each incorporated northeast–southwesterly directed compression in an intracratonic basin setting (Chin et al., 1982; Goellnicht, 1992; Hickman and Bagas, 1999).

The structural evolution of the Lamil Group on PATERSON is discussed within the general structural framework for CONNAUGHTON to the south, as outlined by Bagas and Smithies (1998a). However, assigning deformation events observed on PATERSON to these orogenies defined for the south, assumes that the rocks of the Lamil Group experienced the same orogenic events. This assumption is tentatively adopted here because the orogenic events observed in the Lamil Group and elsewhere have not yet been proven synchronous. Furthermore, a major concealed, northwesterly trending magnetic lineament separates the Lamil Group from the Throssell Group near the Paterson Range area on the southwestern part of PATERSON. This lineament may correspond to a northwesterly extension of the Camel–Tabletop Fault Zone (Fig. 3). To the southeast on CONNAUGHTON, the fault zone in the Rudall Complex is a long-lived shear zone that acts as the boundary between the Tabletop Terrane to the east, and the Connaughton and Talbot Terranes to the west (Bagas and Smithies, 1998a).

The Miles Orogeny (D_{3-4}; Bagas and Smithies, 1998a) is an orogenic event observed in both the Rudall Complex and Throssell Group on RUDALL (1:250 000; Bagas et al., 2000). The D_3 and D_4 events represent southwesterly directed compression and were interpreted by Bagas and Smithies (1998a) as sequential during the Miles Orogeny. The age of the orogeny is poorly constrained between 1300 and 800 Ma (Bagas et al., 1995). Galena from the Throssell Group on LAMIL and RUDALL (1:250 000) has provided lead-model ages of between 940 and 520 Ma (Blockley and Myers, 1990; Hickman and Clarke, 1994). The $^{207}Pb/^{206}Pb$ model ages, however, indicate that the timing of galena mineralization is about 940–820 Ma, the minimum age of the Throssell Group is c. 900 Ma, and D_4 is older than c. 800 Ma.

On BROADHURST, there are locally developed D_3 thrusts, recumbent fold axes, and associated axial-planar cleavage (Hickman and Clarke, 1994). The D_3 fabrics are crenulated, cleaved, and faulted by D_4 structures. The D_4 event produced large folds that trend between 300° and 345°, normal and reverse faults with a component of either dextral or sinistral strike-slip transport, and a well-developed S_4 foliation. The event is also associated with retrogressive greenschist metamorphism (M_4) in the Rudall Complex, and prograde metamorphism (M_4) in the Throssell Group (Bagas et al., 2000).

Northeasterly trending folds affect the Tarcunyah Group in the northwestern part of the Officer Basin (formally the Savory Basin of Williams, 1992, 1994) on THROSSELL (Williams and Bagas, 1999), and CONNAUGHTON (Bagas and Smithies, 1998a). These folds are assigned to the Blake Movement (D_5), which is interpreted as a fault and fold event connected with basin inversion along the northwestern margin of the Officer Basin (c.f. Williams, 1992, 1994).

The Paterson Orogeny, as redefined by Bagas and Smithies (1998a), is the D_6 event that post-dates the glacigenic Boondawari Formation of the Officer Basin (Williams, 1992; Williams and Tyler, 1991), and is a correlative of the Petermann Orogeny in central Australia (Myers, 1990b; Bagas et al., 1995). These Officer Basin structures formed after the D_4 event and are younger than 610 Ma, the probable depositional age of the Boondawari Formation (Williams, 1992; Tyler et al., 1998). The orogeny produced shears and faults that have marked lateral and vertical movement components, as well as tight to open northwesterly to west-northwesterly trending folds. These long-lived structures, which were probably active during the Miles Orogeny or earlier, have been reactivated several times during the geological history of the area. They are classified as D_6 structures because they now truncate or offset earlier structures.

Both D_{3-4} and D_6 structures indicate major northeasterly directed compression. Myers et al. (1996) proposed that the Miles Orogeny coincided with the assembly of Australian cratons as part of Rodinia, whereas the Paterson Orogeny was the product of intracratonic deformation during fragmentation of Rodinia.

Miles Orogeny

Chin et al. (1982) recognized two folding events in the Telfer region (Table 3). The first deformation (D_4) produced isoclinal upright folds (F_4) with northwesterly trending axial planes (S_4), and associated faults. The F_4 folds are non-cylindrical, open to tight, and doubly plunging. The cleavage is best preserved in siltstone and shale units where it is a spaced-crenulation or slaty cleavage. Also present, is cleavage related to bedding-plane slip that is equated to early F_4. Cleavage is not readily recognizable in sandstone units. The second folding event is present in the Malu Hills (MGA 144125) where a north-northeasterly trending fold crosscuts F_4 folds.

Harris (1985) and Goellnicht (1987) interpreted regional Landsat lineaments and the curvature of fold axes, combined with structural studies on the Telfer deposit, as evidence for a north-northwesterly trending dextral strike-slip fault system in the basement that deformed overlying rocks of the Lamil Group. Harris (1987) also interpreted that the direction of compression was from the north. He further proposed that the two crosscutting folds observed by Chin et al. (1982) at Malu Hills, represented a single folding event in the Lamil Group, produced during progressive dextral displacement in the basement (Harris, L., 1998, pers. comm.).

Table 3. Summary of previously proposed structural histories for the Lamil Group

Chin et al., 1982	*Goellnicht et al., 1991*	*Hewson, 1996*
		Weak monoclinal recumbent folding (D_1) with a coarsely spaced axial-planar cleavage (S_1)
Regional folding (D_1) with isoclinal, upright, and doubly plunging folds that trend northwestward, and associated axial-planar cleavage	Upright domal folding (D_1) with two associated cleavages (S_1 at a low angle to S_0, and S_2 axial-planar to folding)	Upright folding (D_2) with doubly plunging axes and associated penetrative axial-planar cleavage (S_2)
		Weak, heterogeneously developed, recumbent folding (D_3) of S_0 and S_2
Weak, high-angle cross-folding (D_2), with folds trending east-northeast	Mica overgrowth of S_2 cleavage, defining a weak overprinting cleavage	Upright, northerly trending cross-folding (D_4) of F_2 folds, rare coarsely spaced crenulation cleavage (S_4)
		Small-scale asymmetric monoclinal kink folding (D_5), with a weakly developed crenulation cleavage (S_{5a})
		Progressive reorientation of the stress field to N–S (D_{5b})

The fold and fault pattern in the Lamil Group has also been attributed to fold and thrust belts developed in a compressional regime that trends in a northeast–southwesterly direction (Vearncombe and Hill, 1993). Goellnicht et al. (1991) proposed that the granitoid rocks in the Telfer region are late- to post-tectonic and are related to the c. 690 Ma collision between the West Australian Craton (Myers, 1993) to the southwest, and the North Australian Craton to the northeast.

Hewson (1996) proposed a deformation history for the region that involved multiple (at least five) and progressive events, which resulted in subvertical and subhorizontal foliations, similar to modern examples of gravity-collapse orogenies (Table 3).

In the central part of PATERSON, the Telfer, Trotmans (MGA 370835), and Tims (MGA 025090) Domes form a series of moderately plunging, upright, antiformal structures in the Malu Formation. Carbonate and shale of the Puntapunta Formation envelop these domes. The domal structures were formed by a progressive northeast–southwesterly directed deformation event (D_4), and were then further deformed by the intrusion of laccolithic granites (discussed below) and by high-angle reverse and normal faulting (D_4 and D_6).

The Telfer Dome is a southeasterly trending, doubly plunging D_4 structure (Fig. 4), which is moderately to steeply inclined. The northeast limb dips up to 55° and the southwest limb dips at about 20°. The structure is simple and in detail comprises two en echelon, open, and asymmetrical anticlines with tight closures, called the Main and West Domes. These are separated by a poorly exposed and faulted syncline (Dimo, 1990). The anticlines are concentric folds with a poorly developed axial-planar cleavage. Normal and reverse faults parallel to bedding are present. The gently dipping southwestern limbs display bedding-plane slip that is characterized by cleavage and drag folds. Dome formation is interpreted to be the product of a single and progressive deformation event.

Later compression, presumably during the Paterson Orogeny, and minor movement along the faults in response to local competency variations, have modified and tightened the Telfer Dome. Axial-planar cleavage (S_4) to these folds is difficult to recognize due to the extensive silicification in the region, but it can be observed in siltstone units where it is weakly developed. The cleavage dips steeply to either the southwest or northeast, and is refracted through units of different competency. Bedding-plane slip in the anticlinal hinge zones typically forms saddle-reef structures, which are commonly mineralized with gold–copper ore. Rock failure along these slip planes has resulted in reverse and normal faulting, with displacements of up to tens of metres. The faults dip parallel to the bedding, have down-dip lineations, and are commonly accompanied by limited drag folding with a cleavage that is at a low angle to bedding.

Drag folds are common in carbonate units of the Puntapunta Formation (e.g. 18 km northwest of Telfer mine at MGA 065115) and in unassigned carbonate units south of the Karakutikati Range (e.g. 15 km south of Telfer mine at MGA 152842). Hewson (1996) has interpreted these structures as evidence for an earlier deformation event associated with recumbent monoclinal folds.

The Parallel Range Fault (Fig. 3) forms the contact between the Malu Formation and the unassigned carbonate unit to the south of the fault. Beds within the carbonate unit are complexly folded and terminate at the fault, which is at low angles to bedding. This locally complex area can be simply explained as the product of folding and faulting during D_4. The fault was probably reactivated during the Paterson Orogen (D_6).

Blake Movement

Open folds with axial planes trending about 030° have been recognized at Wilki Range (MGA 316935), Fallows Field (about 10 km southwest of Telfer mine at MGA 114924), and Karakutikati Range (e.g. at MGA 149864 and 224804). These upright open folds with subvertical axial planes, indicate compression towards the northwest.

Similar northeasterly trending open to tight (F_5) folds with southeasterly dipping axial planes, have been mapped in the Tarcunyah Group (Bagas and Smithies, 1998a; Williams and Bagas, 1999), and the Rudall Complex (Hickman and Bagas, 1998). These structures have been assigned to the Blake Movement (D_5), which was defined in the northwestern Officer Basin (formally the Savory Basin) by Williams (1992, 1994). The age of this folding event is poorly constrained between about 800 and 610 Ma (Williams, 1992). The relationship between F_5 folds and the granites that intrude the Lamil Group on PATERSON, is not known.

Structures related to granitic intrusions

Sandstone assigned to the Wilki Formation (*ⱣLw*) form steeply dipping synformal structures around late Neoproterozoic granitic rocks. Such outcrops are found along the southeastern edge of the poorly exposed Mount Crofton Granite, around the Wilki Structure (Fig. 3), and are evident from drilling and aerial magnetic surveys in the northwesterly trending calcrete-covered region, north of Wilki Range. Geophysical data also suggest that these granite bodies are thin laccolithic sheets with subhorizontal tops (Dimo, 1990).

Hornfelsed sandstone of the Malu Formation, which forms a broad domal structure circumscribed by the Puntapunta Formation at Malu Hills, overlies a granitic intrusion at depth (as indicated by exploration drilling in the area). In the Paterson Orogen, the association of broad domal and synformal structures with granite intrusions is present only in this part of the Paterson Orogen.

Bedding-plane slip has developed in the Wilki Formation around the Wilki Structure and is best recognized to the west and east of the synform where the formation gradually thins northwards and is faulted parallel to bedding. Granite, exposed on the eastern side of Wilki Range, is sheared (*Ɀgsls*), has a foliation parallel to bedding of the contact metamorphosed Wilki Formation, and lineations that plunge downdip. Around the Wilki Structure, the dip of the Wilki Formation steepens close to the contact with its granitic core. A gradual thinning of units is present towards the northern side of the structure.

Circular synclinal structures of the type described above, have elsewhere been explained by meteorite

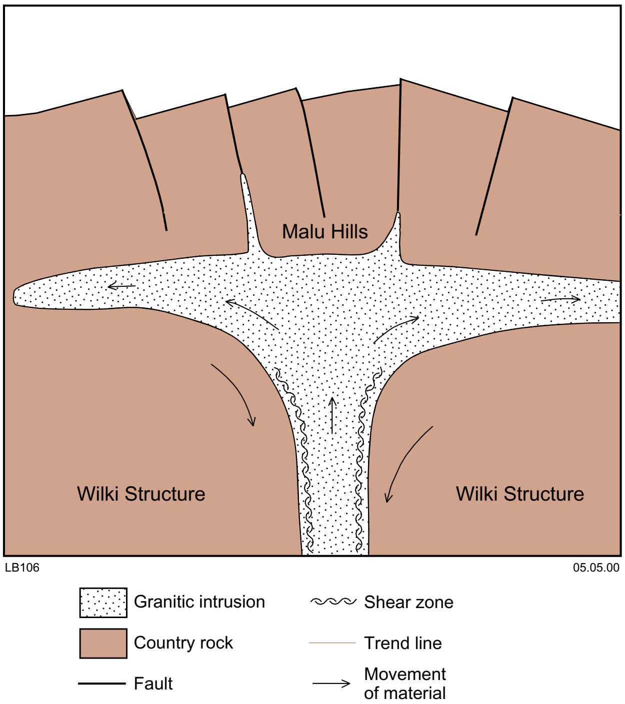


Figure 5. Proposed model for the formation of the Wilki Structure. The relative downward movement of the layered country rocks, leads to attenuation of individual units and the shearing of the uprising intrusion close to its margin (adapted from Bridgwater et al., 1974)

impact. However, no shatter cones, diaplectic glass, planar deformation features, and pseudotachylyte have been recognized in the structures on PATERSON. An alternative model is that proposed by Bridgwater et al. (1974) for the emplacement of post-orogenic, oval, granitic intrusions in South Greenland. This model proposes that intrusion of a laccolith would cause updoming of overlying rocks (such as at the Camp Dome) and downfolding of rocks (Wilki Structure) adjacent to the stem margins of the granitic intrusion (Fig. 5). At the lower levels of the intrusion in the Greenland example, the country rocks at the contact with the intrusive body are inward dipping and strongly foliated with a steeply plunging lineation, and the intrusive stem is funnel-shaped. In this model, downfolding and bedding-plane slip would play important roles in the evolution of such structures.

During the later stages of emplacement, or during the Paterson Orogeny (D_6), the granitoid rock acts as a rigid body, thereby forcing the surrounding sedimentary rocks outwards and locally refolding pre-existing structures (Fig. 6). On PATERSON, this is suggested by the curvilinear nature of the northwesterly trending F_4 fold-axes around the structures (Fig. 6). Later disruption by reverse faulting took place during the Paterson Orogeny (D_6).

Paterson Orogeny

Northerly to northwesterly striking dextral faults and east-northeasterly striking sinistral faults with minor displace-

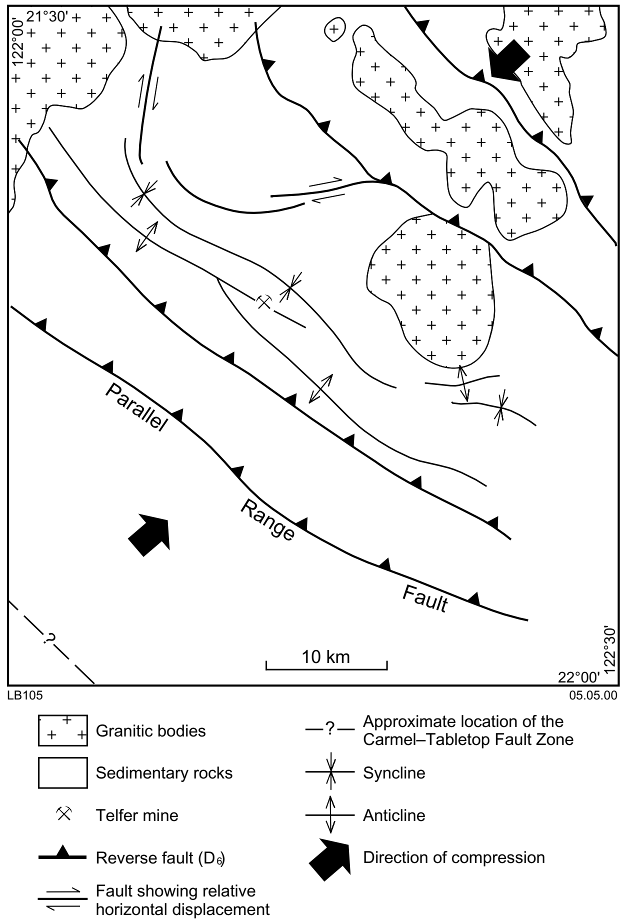


Figure 6. Simplified sketch showing the NE–SW-directed compression associated with the Paterson Orogeny (D_6). The D_6 reverse faults shown are most probably reactivated D_4 structures. Note how the F_4 folds are refolded around the granites, which acted as solid bodies either during the later stages of their emplacement or during the Paterson Orogeny

ments, affect the Karakutikati Range. These are near-vertical conjugate strike-slip faults that indicate maximum compression from the north or northeast. The north-westerly trending Parallel Range Fault and the major fault on the northeastern edge of the Wilki Structure, are interpreted as reactivated high-angle reverse faults that were active during the late structural history of the region (Fig. 6). These structures are consistent with the stress regime assigned to the Paterson Orogeny (D_6) on BROADHURST (Hickman and Clarke, 1994) and RUDALL (Hickman and Bagas, 1998).

Metamorphism and hydrothermal alteration

The Miles Orogeny on PATERSON is characterized by low-grade regional metamorphism. The lower greenschist-facies mineral assemblage consists of quartz, plagioclase (albite), sericite, muscovite, epidote, carbonate (dolomite and calcite), and rare biotite and chlorite. Combinations of these minerals are present in the early weak penetrative foliation (S_4) of siliciclastic sedimentary rocks at the Telfer mine. Epidote and chlorite have also crystallized in the matrix. Some samples contain porphyroblasts that are composed of dolomite crystals rimmed with fine-grained albite and quartz.

The regional metamorphic mineral assemblage is overprinted by contact metamorphism that is associated with granitic and mafic intrusions into the Lamil Group, and also by later hydrothermal alteration that crosscuts all metamorphic fabrics. The contact aureoles are around 2 km wide but are wider in the northeastern part of PATERSON. Here, the calcareous units have been metamorphosed to marble, which contains calcite, diopside, scapolite, and chlorite (*PL(km)*). Sandstone in this area (*PLw*, e.g. at MGA 420090) is recrystallized, and consists of closely interlocking quartz crystals and rare muscovite.

Elsewhere (e.g. around the 17 Mile Hill area, MGA 175120), hornfelsed pelitic rocks contain poikiloblastic mica (biotite or muscovite) in a matrix that contains K-feldspar and scapolite. Goellnicht (1992) documented an early microcline–biotite (greisen) assemblage that is overprinted by quartz–muscovite–scheelite(–tremolite–scapolite–fluorite–apatite) in a carbonaceous skarn, hosted in the O'Callaghans prospect area (around MGA 233898).

Partially dolomitic sandstone and siltstone (*PL(a)*) in the Black Hills area of northwestern PATERSON (around MGA 460100), contains quartz–biotite(–muscovite–cordierite–tourmaline–?amphibole–hedenbergite–sulfide) veins that crosscut layering or infill shear zones and brittle fractures. The hedenbergite is partly replaced by dolomite. The biotite is intergrown with veinlets of quartz and dolomite or is finely disseminated in the matrix. The cordierite is found as porphyroblasts in pelitic rocks that consist of quartz, biotite, and muscovite. The porphyroblasts contain fine biotite and tourmaline, and are rimmed by biotite. Tourmaline is also present as disseminated fine needles within the matrix. This mineral assemblage is indicative of hornblende-hornfels metamorphic facies, and is probably associated with concealed granitoid rocks nearby to the north and west (Fig. 3).

Calcareous shale from the Hasties area (around MGA 100895) contains an anhedral mosaic of plagioclase (albite) intergrown with granular carbonate and rare sericite, which is crosscut by quartz veinlets. Xenoblastic tourmaline is also present in the matrix and is compositionally zoned from cores of bluish schorl to rims of brown dravite. Granular leucoxene is aligned parallel to bedding. This albite–carbonate–tourmaline–leucoxene(–sericite–quartz) assemblage represents a metasomatic overprint, probably associated with mafic intrusive rocks found at depth in the area by exploration companies.

Hydrothermal alteration is common around quartz veins at the Telfer mine. The host rocks are altered to muscovite, and are commonly accompanied by pink dolomite and disseminated pyrite, chalcopyrite, tourmaline, monazite, and rare sphalerite, galena, pyrrhotite, and gold. Hydrothermally altered shale at the Trotmans prospect (around MGA 310855) and Grace prospect (MGA 292735), contain veins of dolomite–sericite–albite–quartz with tourmaline and anhedral rutile. The matrix consists of a mosaic of anhedral plagioclase and dolomite with interstitial quartz, and tourmaline.

Economic geology

The Telfer deposit, a major Australian gold deposit since the late 1970s, had produced about 175 t (5.6 million ounces) of gold by mid-1999. The production from the Fallows Field deposit, 8 km south of Telfer, was about 1.5 t (50 000 ounces) of gold (Langsford, N., 1999, pers. comm.). The current proven reserves at the Telfer mine are 1.9 million tonnes at 3.3 g/t Au and 0.4 million tonnes at 0.79% Cu (Newcrest Mining Ltd, 1999). Little published information on other prospects on PATERSON is available (Table 4).

The origin of the Telfer mineralization has been explained by a syngenetic exhalative model, based on the observation that the mineralization is stratabound and that pyrite is commonly laminated (Turner, 1982), and epigenetic models (e.g. Goellnicht et al., 1989; Dimo, 1990; Rowins et al., 1998). The epigenetic models emphasize the importance of structural controls on the mineralization that is hosted by a series of vertically stacked, stratabound quartz–carbonate–sulfide reefs, and centred on the anticlinal hinge zone of Telfer Dome. Other styles of mineralization include stockworks, pods, and vein systems in faults (Richards, A., and Russell, P., 1993, pers. comm.).

The stratabound quartz–sulfide reefs are laterally extensive, and are locally named the Middle Vale reefs, and the E-Series, M-Series, and I-Series reefs. The reefs are up to several metres thick, mostly conformable, and are hosted by calcareous or carbonaceous siltstone interbedded with massive sandstone. The reefs are commonly linked by stockworks of quartz–sulfide veins and sheeted vein sets. The sulfide minerals are predominantly pyrite and chalcopyrite, 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 chalcopyrite and galena.

Joint sets in the core of the domal structures host the stockwork veins, which include quartz–sulfide veins and laminated quartz–carbonate–sulfide veins (Richards, A., and Russell, P., 1993, pers. comm.). 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 and have grades of up to 160 g/t Au. Other stockwork deposits that comprise gold–copper–arsenic(–lead–zinc) include Big Tree, Hasties, Lamil, and Thomsons, which are all characterized by phyllic alteration (Goellnicht, 1992).

Fault-hosted veins have low to moderate grades of gold mineralization, and are commonly parallel to the axial planes of the domes. These faults contain breccia-hosted quartz–carbonate–sulfide mineralization. Also present are linear and tabular lenses of mineralization, which are hosted by faults, fold hinges, and limbs. Other fault-related deposits include Grace and Trotmans East.

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 derived from magma, and host rock or basin rocks, and that the mineralization is related to a distal gold-halo of a giant porphyry copper–gold system. The 17-mile Hill and Hasties prospects are examples of a porphyry-style copper deposit close to a granite. Another style of mineralization, which appears to be associated with granitoid rocks, is the tungsten–copper–bismuth skarn at O'Callaghans prospect (Goellnicht, 1992). Rowins et al. (1997, 1998) suggested that the ore fluids were

Table 4. Mineral occurrences on PATERSON

Prospect (metals)	*Location (MGA)*	*Resource/grades*
Big Tree (Au)	357796	2.23 Mt@1.56 g/t Au (indicated; Richards, A., 1993, pers. comm.)
Black Hills (Au, Ag, Cu, Pb, Zn)	461102	0.8 Mt@1.79 g/t Au (indicated; Richards, A., 1993, pers. comm.)
Fallows Field (Au)	113924	1.5 t produced (Newcrest Mining Ltd, 1999)
Grace (Au, As, Cu)	292735	unknown
Hasties area (Au, Cu, As)	100895	2.3 Mt@0.9 g/t Au (pre-resource; Richards, A., 1993, pers. comm.)
O'Callaghans (W, Zn, Cu, Pb, Bi, Mo, Sn)	232898	unknown
Telfer Dome area (Au, Cu, Ag)	165985	175 t Au produced (Langford, N., 1999, pers. comm.)
Thompsons (Au, Cu)	085092	unknown
Thompsons Dome East (Au)	125084	unknown
Tims Dome area (Au)	017102	unknown
Triangle (Cu, Au)	421960	unknown
Trotmans Stockwork (Au, Sn, Bi, W, Pb, Cu)	309855	unknown
Trotmans Dome area (Au, Ag, Cu, As, Bi, Pb, Zn)	365835	unknown
17 Mile Hill (Cu, Au, W, Pb, Zn, As, Bi, Ag, Co)	178125	8.5 Mt @ 0.63% Cu (inferred; Richards, A., 1993, pers. comm.)

dominantly derived from a sedimentary source with a minimal magmatic contribution. Both these models indicate that the mineralization event was at about 630 Ma, which is the approximate age that the post-tectonic, highly fractionated I-type granitic rocks, intruded the Lamil Group (Nelson, 1999).

High-grade mineralization is commonly due to supergene enrichment that extends to 300 m below the surface (Dimo, 1990). Extensive kaolinization and montmorillonitic alteration and clay veining are common in this zone. The weathered reefs contain chalcocite, limonite, goethite, hematite, unidentified iron oxides, and numerous other secondary minerals (Dimo, 1990).

Water resources

On the northern and western parts of PATERSON, areas of calcrete along palaeodrainage systems may contain large, although saline, groundwater supplies. Significant groundwater supplies are likely to be found in fractured and sheared sandstones of the Wilki and Malu Formations.

References

BAGAS, L., 1997, Gunanya, W.A. Sheet 3451: Western Australia Geological Survey, 1:100 000 Geological Series.

BAGAS, L., 1999, Rudall, W.A. Sheet SF51-10 (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series.

BAGAS, L., GREY, K., and WILLIAMS, I. R., 1995, Reappraisal of the Paterson Orogen and Savory Basin: Western Australia Geological Survey, Annual Review 1994–95, p. 55–63.

BAGAS, L., GREY, K., HOCKING, R. M., and WILLIAMS, I. R., 1999, Neoproterozoic successions of the northwestern Officer Basin: a reappraisal: Western Australia Geological Survey, Annual Review 1998–99, p. 39–44.

BAGAS, L., and SMITHIES, R. H., 1996, Connaughton, W.A. Sheet 3452: Western Australia Geological Survey, 1:100 000 Geological Series.

BAGAS, L., and SMITHIES, R. H., 1998a, Geology of the Connaughton 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 38p.

BAGAS, L., and SMITHIES, R. H., 1998b, Blanche–Cronin, W.A. Part Sheets 3551 and 3552: Western Australia Geological Survey, 1:100 000 Geological Series Special.

BAGAS, L., WILLIAMS, I. R., and HICKMAN, A. H., 2000, Rudall, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 50p.

BEARD, J. S., 1970, The natural regions of the deserts of Western Australia: Journal of Geology, v. 57, p. 677–711.

BEARD, J. S., and WEBB, M. J., 1974, The vegetation of the Great Sandy Desert area: Vegetation Survey of Western Australia, 1:100 000 Vegetation Series, Explanatory Notes to Sheet 5: Perth, University of Western Australia Press, 66p.

BLOCKLEY, J. G., and de la HUNTY, L. E., 1975, Paterson Province, *in* The geology of Western Australia: Western Australia Geological Survey, Memoir 2, p. 114–118.

BLOCKLEY, J. G., and MYERS, J. S., 1990, Proterozoic rocks of the Western Australian Shield — geology and mineralization, *in* Geology of the mineral deposits of Australia and Papua New Guinea *edited by* F. E. HUGHES: Australasian Institute of Mining and Metallurgy, Monograph 14, p. 607–615.

BRIDGWATER, D., SUTTON, J., and WATTERSON, J., 1974, Crustal downfolding associated with igneous activity: Tectonophysics, v. 21, p. 57–77.

CAMPANA, B., HUGHES, F. E., BURNS, W. G., WHITCHER, I. G., and MUCENIEKAS, E., 1964, Discovery of the Hamersley iron deposits (Duck Creek – Mt Pyrton – Mt Turner area): Australasian Institute of Mining and Metallurgy, Proceedings, v. 210, p. 1–30.

CHIN, R. J., HICKMAN, A. H., and TOWNER, R. R., 1982, Paterson Range, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 29p.

CHIN, R. J., WILLIAMS, I. R., WILLIAMS, S. J., and CROWE, R. W. A., 1980, Rudall, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 22p.

CLARKE, G. L., 1991, Proterozoic tectonic reworking in the Rudall Complex, Western Australia: Australian Journal of Earth Sciences, v. 38, p. 31–44.

DANIELS, J. L., and HORWITZ, R. C., 1969, Precambrian tectonic units of Western Australia: Western Australia Geological Survey, Annual Report 1968, p. 37–38.

DIMO, G., 1990, Telfer gold deposits, *in* Geology of the mineral deposits of Australia and Papua New Guinea *edited by* F. E. HUGHES: Australasian Institute of Mining and Metallurgy, Monograph 14, p. 643–651.

GOELLNICHT, N. M., 1987, Constraints on the timing and source of gold mineralization at Main Dome, Telfer, Western Australia: University of Western Australia, BSc (Hons) thesis (unpublished).

GOELLNICHT, N. M., 1992, Late Proterozoic fractionated granitoids and their role in the genesis of gold and base-metal mineralisation in the Telfer district, Western Australia: University of Western Australia, PhD thesis (unpublished).

GOELLNICHT, N. M., GROVES, D. I., and McNAUGHTON, N. J., 1991, Late Proterozoic fractionated granitoids of the mineralized Telfer area, Paterson Province, Western Australia: Precambrian Research, v. 51, p. 375–391.

GOELLNICHT, N.M., GROVES, D. I., McNAUGHTON, N. J., and DIMO, G., 1989, An epigenetic origin for the Telfer gold deposit, *in* The geology of gold deposits: the perspective in 1988 *edited by* R. R. KEAYS, W. R. H. RAMSAY, and D. I. GROVES: Economic Geology Monograph 6, p. 151–167.

HARRIS L. B., 1985, Structure of the Telfer deposit and its regional tectonic setting: initial observations: Newmont (Australia) Ltd, Report (unpublished).

HARRIS L. B., 1987, A tectonic framework for the Western Australian shield and its significance to gold mineralization: a personal view, *in* Recent advances in understanding Precambrian gold deposits *edited by* S. E. HO and D. I. GROVES: University of Western Australia, Geology Department and University Extension, Publication 11, p. 1–27.

HEWSON, S. A. J., 1996, A structural examination of the Telfer gold-copper deposit and surrounding region, northwest Western Australia: the role of polyphase orogenic deformation in ore-deposit development and implications for exploration: James Cook University of North Queensland, PhD thesis (unpublished).

HICKMAN, A. H., and BAGAS, L., 1995, Tectonic evolution and economic geology of the Paterson Orogen — a major reinterpretation based on detailed geological mapping: Western Australia Geological Survey, Annual Review 1993–94, p. 67–76.

HICKMAN, A. H., and BAGAS, L., 1996, Rudall, W.A. Sheet 3352: Western Australia Geological Survey, 1:100 000 Geological Series.

HICKMAN, A. H., and BAGAS, L., 1998, Geology of the Rudall 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 30p.

HICKMAN, A. H., and BAGAS, L., 1999, Geological evolution of the Palaeoproterozoic Talbot Terrane and adjacent Meso- and Neoproterozoic successions, Paterson Orogen, Western Australia: Western Australia Geological Survey, Report 71, 91p.

HICKMAN, A. H., and CLARKE, G. L., 1993, Broadhurst, W.A. Sheet 3353: Western Australia Geological Survey, 1:100 000 Geological Series.

HICKMAN, A. H., and CLARKE, G. L., 1994, Geology of the Broadhurst 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 40p.

HICKMAN, A. H., WILLIAMS, I. R., and BAGAS, L., 1994, Proterozoic geology and mineralization of the Telfer–Rudall region, Paterson Orogen: Geological Society of Australia (W.A. Division), 12th Australian Geological Convention, Perth, W.A., 1994, Excursion guidebook 5, 56p.

IDNURM, M., and SENIOR, B. R., 1978, Palaeomagnetic ages of late Cretaceous and Tertiary weathering profiles in the Eromanga Basin, Queensland: Palaeography, Palaeoclimatology, Palaeoecology, v. 24, p. 263–277.

JENNINGS, J. N., and MABBUTT, J. A., 1971, Landform studies from Australia and New Guinea: Canberra, Australian National University Press, 434p.

MIDDLETON, M. F., 1990, Canning Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 425–457.

MYERS, J. S., 1990a, Precambrian tectonic evolution of part of Gondwana, southwestern Australia: Geology, v. 18, p. 537–540.

MYERS, J. S., 1990b, Geological Evolution, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 735–755.

MYERS, J. S., 1993, Precambrian history of the West Australian craton and adjacent orogens: Earth and Planetary Science, Annual Review, v. 21, p. 453–485.

MYERS, J. S., SHAW, R. D., and TYLER, I. M., 1996, Tectonic evolution of Proterozoic Australia: Tectonics, v. 15, p. 1431–1446.

NELSON, D. R., 1995, Compilation of SHRIMP U–Pb zircon geochronology data, 1994: Western Australia Geological Survey, Record 1995/3, 244p.

NELSON, D. R., 1999, Compilation of geochronology data, 1998: Western Australia Geological Survey, Record 1999/2, 222p.

NEWCREST MINING LTD, 1999, Report to shareholders: Newcrest Mining Ltd, Annual Report, 1999, 92p.

ROWINS, S. M., 1994, A geochemical study of Late Proterozoic gold and copper mineralization in the Telfer district, Western Australia, with a special emphasis on porphyry copper–gold-style deposits: University of Western Australia, PhD thesis (unpublished).

ROWINS, S. M., GROVES, D. I., and McNAUGHTON, N. J., 1998, Neoproterozoic Telfer-style Au (Cu) deposits: Australian Geological Survey Organisation, Journal of Australian Geology and Geophysics, v. 17, p. 217–223.

ROWINS, S. M., GROVES, D. I., McNAUGHTON, N. J., BROWN, P. E., McLEOD, R. L., and HALL, D., 1993, Evidence of unusually carbonic and reduced ore fluids in the Late Proterozoic Seventeen Mile porphyry copper-style deposit, Telfer district, Western Australia, *in* Geological Society of Australia, 2nd National Meeting of the Specialist Group in Economic Geology, Abstracts, v. 34, p. 68–69.

ROWINS, S. M., GROVES, D. I., McNAUGHTON, N. J., PALMER, M. R., and ELDRIDGE, C. S., 1997, A reinterpretation of the role of granitoids in the genesis of Neoproterozoic gold mineralization in the Telfer Dome, Western Australia: Economic Geology, v. 92, p. 133–160.

TRAVES, D. M., CASEY, J. N., and WELLS, A. T., 1956, The geology of the southwestern Canning Basin, Western Australia: Australia BMR, Canberra, Report 29, 76p.

TRENDALL, A. F., 1974, The age of a granite near Mount Crofton, Paterson Range Sheet: Western Australia Geological Survey, Annual Report 1974, p. 134–138.

TURNER, C. C., 1982, The Telfer gold deposits, Western Australia: stratigraphy, sedimentology and gold mineralisation of the Proterozoic Yeneena Group: University of New England, PhD thesis (unpublished).

TURNER, C. C., and McKELVEY, B. C., 1981, A Palaeozoic silcrete near Telfer, Western Australia: Search, v. 12, p. 411–412.

TYLER, I. M., PIRAJNO, F., BAGAS, L., MYERS, J. S., and PRESTON, W. A., 1998, The geology and mineral deposits of the Proterozoic in Western Australia: Australian Geological Survey Organisation, Journal of Australian Geology and Geophysics, v. 17, p. 223–244.

TYRWHITT, D. S., 1995, Desert Gold, the discovery and development of Telfer: Louthean Publishing Pty Ltd, Western Australia, 56p.

VEARNCOMBE, J. R., and HILL, A. P., 1993, Strain and displacements in the Middle Vale Reef at Telfer, Western Australia: Ore Geology Reviews, v. 8, p. 189–202.

WILLIAMS, I. R., 1990, Yeneena Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 277–282.

WILLIAMS, I. R., 1992, Geology of the Savory Basin, Western Australia: Western Australia Geological Survey, Bulletin 141, 115p.

WILLIAMS, I. R., 1994, The Neoproterozoic Savory Basin, Western Australia, *in* The sedimentary basins of Western Australia *edited by* P. G. PURCELL and R. R. PURCELL: Petroleum Exploration Society of Australia, West Australian Basins Symposium, Perth, 1994, Proceedings, p. 841–850.

WILLIAMS, I. R., and BAGAS, L., 1998, Poisonbush, W.A. Sheet 3252: Western Australia Geological Survey, 1:100 000 Geological Series.

WILLIAMS, I. R., and BAGAS, L., 1999, Geology of the Throssell 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 24p.

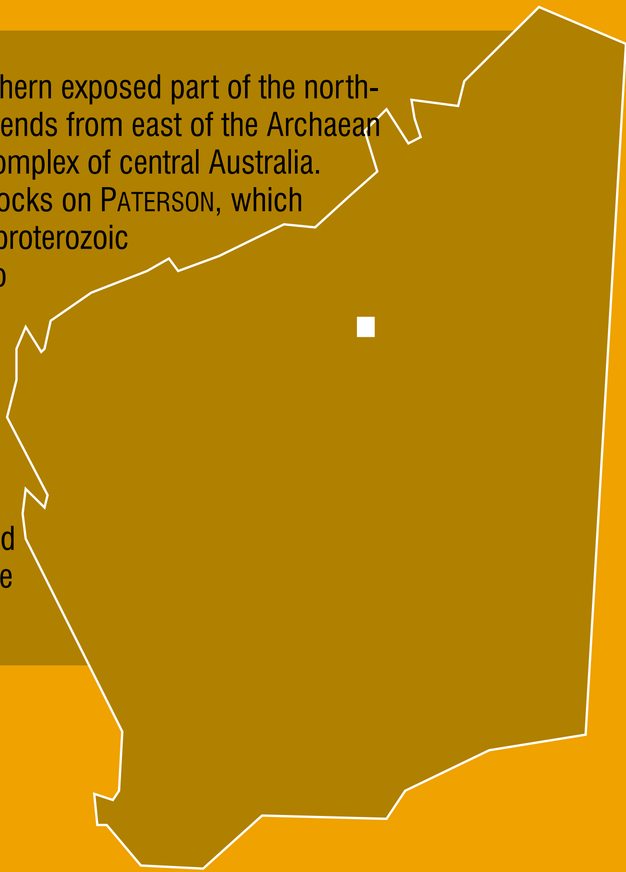
WILLIAMS, I. R., BAGAS, L., and SMITHIES, R. H., 1996, Throssell, W.A. Sheet 3253: Western Australia Geological Survey, 1:100 000 Geological Series.

WILLIAMS, I. R., BRAKEL, A. T., CHIN, R. J., and WILLIAMS, S. T., 1976, The stratigraphy of the Eastern Bangemall Basin and Paterson Province: Western Australia Geological Survey, Annual Report 1975, p. 79–83.

WILLIAMS, I. R., and MYERS, J. S., 1990, Paterson Orogen, *in* Geology and Mineral Resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 274–275.

WILLIAMS, I. R., and TYLER, I. M., 1991, Robertson, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 36p.

The PATERSON 1:100 000 map sheet occupies the northern exposed part of the north-western component of the Paterson Orogen, which extends from east of the Archaean Pilbara Craton in Western Australia to the Musgrave Complex of central Australia. These Explanatory Notes describe the geology of the rocks on PATERSON, which includes the Neoproterozoic Lamil Group and late Neoproterozoic granitoid rocks of the Paterson Orogen, and Permian to Jurassic–Cretaceous rocks of the Canning Basin. The Lamil Group is younger than c. 1070 Ma and was deformed by the Miles Orogeny before the intrusion of post-orogenic I-type monzogranites and syenogranites, which are younger than 654 Ma. These rocks were then deformed by the c. 550 Ma Paterson Orogeny. PATERSON is prospective for gold and base metals, and contains the Telfer mine, which is one of the richest gold deposits in Australia.



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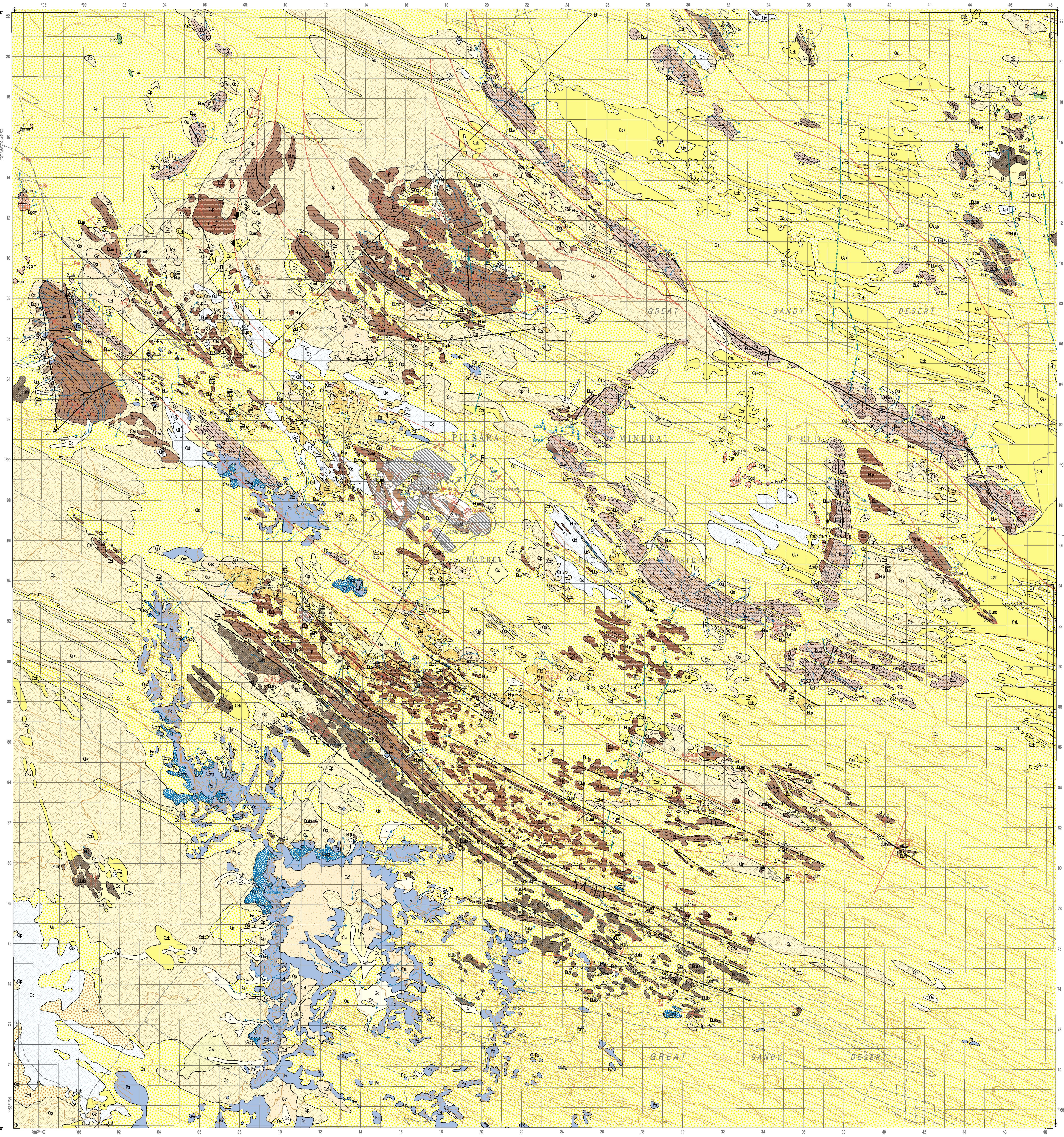
PATERSON

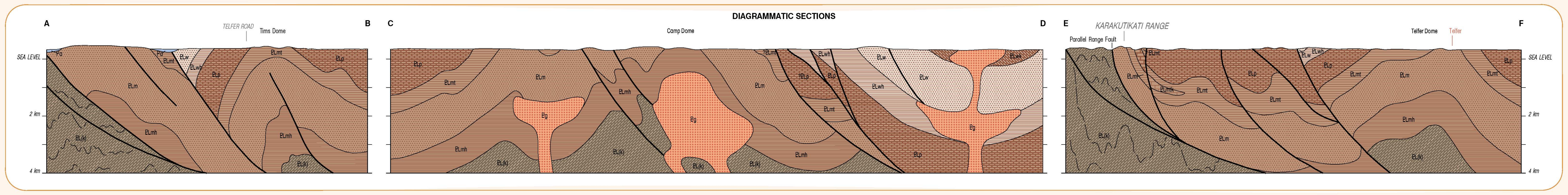
AUSTRALIA 1:100 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 3354



DIAGRAMMATIC SECTIONS



Legend

PHANEROZOIC — CAINOZOIC

Qa Alluvium — silt, sand, and gravel; in drainage channels and on floodplains
Qc Colluvium — locally derived sand and gravel; in scree and outwash-fan deposits
Ql Lacustrine deposits — clay, silt, and silty sand; playa and claypan deposits
Qd Mixed lacustrine and eolian deposits — clay, silt, and sand
Qs Eolian deposits — sand; includes sheets, and dunes with intervening sandy valleys
Qp Lag and eolian deposits — ferricrete sand and pebbles
Qw Colluvial and alluvial deposits — clay, silt, sand, and gravel; in distal outwash deposits in poorly drained areas; numerous small claypans
Qwf Ferruginous lag gravel or gibber plain; ferricrete rubble, clay, silt, and sand; in distal outwash deposits in poorly drained areas

Czc Colluvium — variably cemented outwash talus; dissected by present-day drainage
Czcg Colluvial and eluvial pebbly sand, silt, and clay; partly consolidated; derived from the PATERSON FORMATION
Czk Calcrete — massive, nodular, and cavernous sandy limestone; locally silicified
Czz Silcrete — siliceous caprock with angular quartz grains
Czf Ferricrete — ferruginous duricrust

MESOZOIC — JURASSIC - EARLY CRETACEOUS (CANNING BASIN)

JKc **CALLAWA FORMATION:** fine- to coarse-grained, cross-bedded sandstone, and conglomerate; minor siltstone; fluviatile deposit

PALAEOZOIC — PERMIAN (CANNING BASIN)

Pa **PATERSON FORMATION:** sandstone, claystone, conglomerate, and boulder beds; tillite and other fluvioglacial deposits

d Dolerite dyke; dashed where interpreted from aeromagnetic data
q Quartz vein
qt Quartz–tourmaline vein

p Pegmatite

PROTEROZOIC — NEOPROTEROZOIC (PATERSON OROGEN)

Eg Granitoid rock, undivided

c. 621 Ma — **MOUNT CROFTON GRANITE**
Egcry Leucocratic syenogranite; medium-grained, equigranular
Egcrm Biotite monzogranite; medium- to coarse-grained

c. 628 Ma
Egsl Leucocratic syenogranite and monzogranite; coarse-grained, equigranular
Egsls Leucocratic syenogranite and monzogranite, sheared

MESOPROTEROZOIC – NEOPROTEROZOIC — Yeneena Supergroup, Lamil Group (YENEENA BASIN, PATERSON OROGEN)

ELwk **Kaliranu Member:** silty dolomite, shale, and fine-grained sandstone
ELw **WILKI FORMATION:** fine- to medium-grained quartz sandstone, massive to bedded; minor shale and laminated sandstone
ELwh Interbedded shale, silty dolomite, and sandstone
ELp **PUNTAPUNTA FORMATION:** dominantly clastic carbonate rocks interbedded with siltstone and shale; commonly dolomitic and arenaceous; cross-bedded and scour-marked
ELpc Chert
ELph Shale; commonly ferruginized
ELmt **Telfer Member:** interbedded sandstone and shale; locally pyritic; minor carbonate rock
ELmtk Thinly bedded dolomitic shale and dolomite
ELm **MALU FORMATION:** fine- to medium-grained quartz sandstone, massive to bedded; minor interbedded shale and dolomite
ELmh Interbedded shale and sandstone

EL(k) Interbedded dolomite and shale; thinly bedded, fine- to medium-grained
EL(km) Marble; hornfelsed carbonate rock
EL(a) Fine- to medium-grained quartz sandstone and minor siltstone; massive to bedded
EL(sh) Interbedded sandstone and shale
EL(h) Shale; commonly ferruginized
EL(c) Chert

Symbols

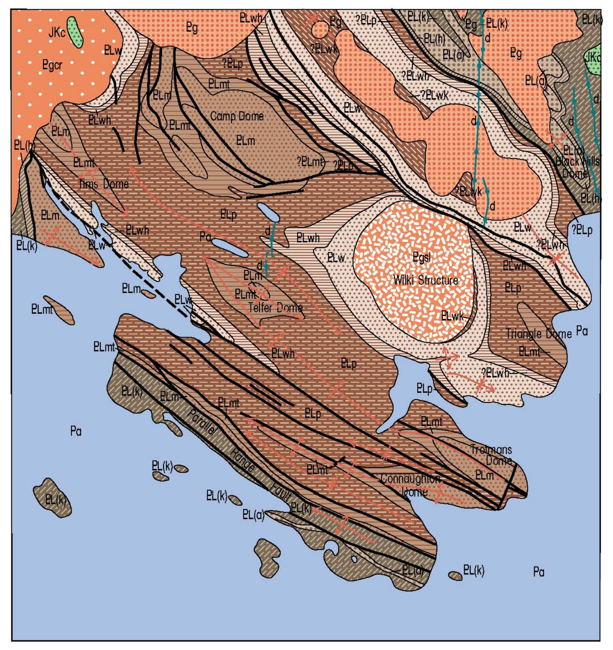
Geological boundary
- exposed
Fault
- exposed
- concealed
- strike-slip, showing relative horizontal displacement
- concealed, interpreted from aeromagnetic data
Fold, showing axial trace and plunge
- anticline; exposed, concealed
- syncline; exposed, concealed
Small-scale fold axis, showing trend and plunge
- anticline
- syncline
- S-vergence
- Z-vergence
- M-vergence
Bedding, showing strike and dip
- inclined
- overturned
- trend of bedding
Palaeocurrent, showing trend and sense of direction
- from asymmetrical ripple marks, direction known
- from cross-bedding, direction known
Glacial striae, showing trend and sense of ice movement
- sense of movement known
Foliation, showing strike and dip
- inclined
- vertical
Cleavage, showing strike and dip
- inclined
- vertical
Lineation, showing trend and plunge direction
- axis of crenulation
Fracture or joint, showing strike and dip
- inclined
Airphoto lineament
- structural or prominent, unspecified
- fracture pattern
Isotopic age determination site with identification number — 118916

Formed road
Major track
Track
Powerline
Building
Microwave repeater station
Horizontal control, minor
Breakaway
Sand dune
Contour line, 20 metre interval — 240

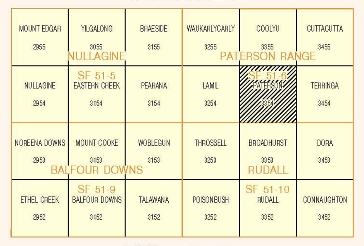
Watercourse, with ephemeral pool
Bore — Bore
Windpump
Tank — Tank
Abandoned — (abd)

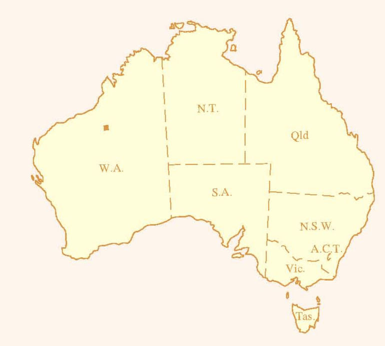
Mining centre — TELFER
Major mine — Telfer
Major opencut
Opencut
Quarry or pit
Prospect
Battery or treatment plant
Opencut
Tailings or stockpile
Mineral occurrence
- Gold — Au
- Bismuth — Bi
- Copper — Cu
- Road materials — Rm
- Tin — Sn
- Tungsten — W

SIMPLIFIED GEOLOGY



SHEET INDEX





Geology by L. Bagas 1997

Edited by F. Eddison, K. Greenberg, and G. Loan

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DEPARTMENT OF MINERALS AND ENERGY
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GOVERNMENT OF WESTERN AUSTRALIA
HON. NORMAN MOORE, M.L.C.
MINISTER FOR MINES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
DAVID BLIGHT, DIRECTOR

SCALE 1:100 000

1000 Metres 0 1 2 3 4 5 6 7 8 9 10 Kilometres

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

Grid lines indicate 1000 metre interval of the Map Grid Australia Zone 51

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

Reference points to align maps based on the previous datum, AGD84, have been placed near the map corners

PATERSON

SHEET 3354 FIRST EDITION 2000