EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

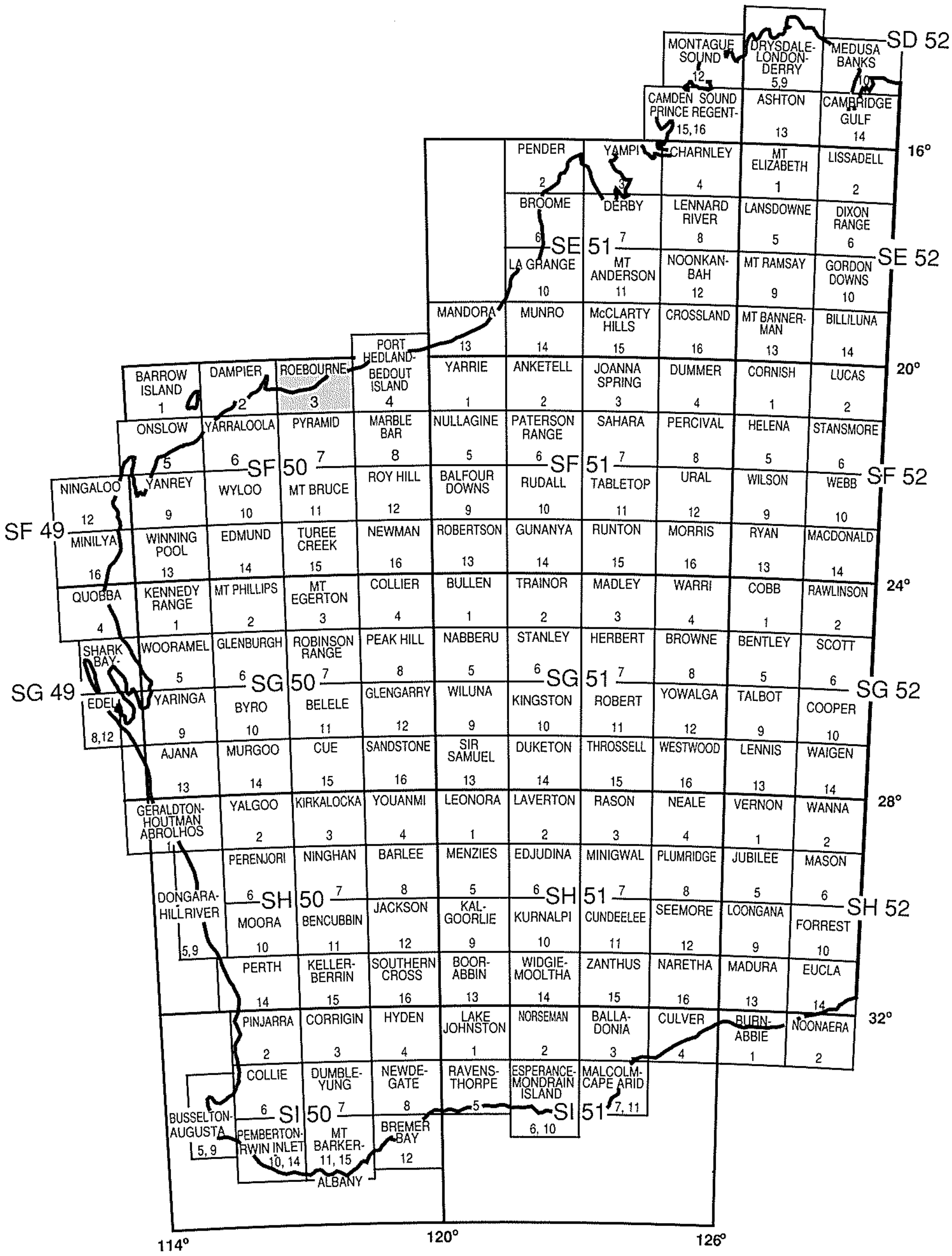
GEOLOGY OF THE SHERLOCK 1:100 000 SHEET

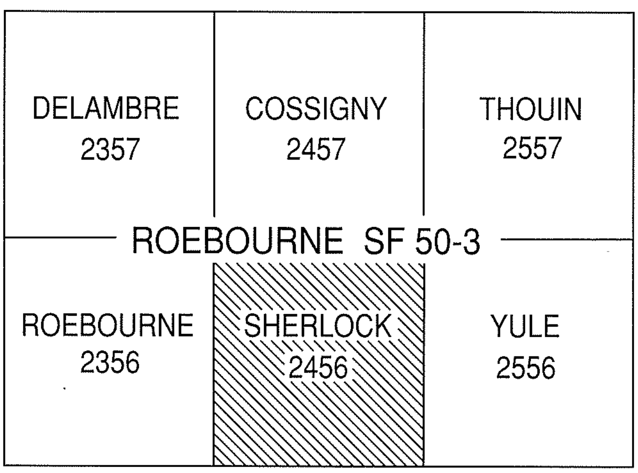
by R. H. Smithies

1:100 000 GEOLOGICAL SERIES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY





CAS53

26.03.98

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE SHERLOCK 1:100 000 SHEET

by
R. H. Smithies

Perth 1998

MINISTER FOR MINES
The Hon. Norman Moore, MLC

DIRECTOR GENERAL
L. C. Ranford

DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
David Blight

Copy editor: K. A. Blundell

REFERENCE

The recommended reference for this publication is:

SMITHIES, R. H., 1998, Geology of the Sherlock 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 29p.

National Library of Australia Card Number and ISBN 0 7309 6591 0

ISSN 1321–229X

Cover photograph:

Looking north down into the Whim Creek base-metal deposit, which is hosted by the Rushall Slate of the Whim Creek Group. Outcrop of the Mount Negri Volcanics forms the ridge in the background.

Contents

Appendix

Figures

Table

Geology of the Sherlock 1:100 000 sheet

by

R. H. Smithies

Abstract

The SHERLOCK 1:100 000 sheet lies on the northwest coastal margin of the Pilbara Craton and is dominated by the Archaean rocks of the Pilbara granite–greenstone terrane. The northeast-trending Whim Creek Belt contains greenstones that are in faulted contact with the Caines Well Granitoid Complex to the northwest and clastic sedimentary rocks of the De Grey Group (Mallina Formation) to the southeast. Recent geochronology has determined that the rocks of the Mallina Formation are younger than previously thought, while those of the Whim Creek Belt (the Whim Creek Group) are older; both sequences were deposited around 3000 Ma. The Whim Creek Belt was previously thought to represent a small and isolated ensialic pull-apart basin, but new data from the present study, especially structural observations, suggest that this is unlikely and point more to a simple rift setting.

A thick sequence of basalt and high-Mg basalt, previously thought to overly the Whim Creek Group, is now subdivided into a spinifex-textured lower unit — the Louden Volcanics — and an overlying variolitic unit — the Mount Negri Volcanics. Several lines of evidence, including the identification of spinifex-textured high-Mg basalts within the Whim Creek Group, now suggest that the Louden Volcanics may be part of this group.

A regionally important crustal structure (the Sholl Shear Zone) transects the sheet area and exhibits a late dextral strike-slip movement of 30–40 km. The present mapping has revealed that this movement post-dates deposition of the Whim Creek Group, which occurred both to the north and south of the shear zone. Mapping to the south of the Whim Creek Belt has identified another major zone of shearing that parallels the Sholl Shear Zone and is referred to here as the Mallina Shear Zone.

Mining has concentrated on base-metal mineralization within felsic volcaniclastic rocks (the Mons Cupri deposit) and shale (the Whim Creek deposit) of the Whim Creek Belt, and at the time of writing, plans were under way to reopen these mines. Gold has been mined in the southeastern part of the sheet at Toweranna, along the contact between clastic rocks of the Mallina Formation and an intrusive feldspar porphyry.

KEYWORDS: Archaean, Pilbara Craton, regional mapping, Whim Creek, base metals

Introduction

The SHERLOCK* 1:100 000 sheet (SF 50-03, 2456) occupies the central-southern part of the ROEBOURNE 1:250 000 sheet in the western Pilbara region. It is bounded by latitudes 20°30'S and 21°00'S and longitudes 117°30'E and 118°00'E (Fig. 1) and lies within the West Pilbara Mineral Field. The oldest rocks in the region form part of the granite–greenstone succession of the Archaean Pilbara Craton. Greenstones of this craton have been grouped into the Pilbara Supergroup (Hickman, 1983), the oldest parts of which have been dated at c. 3515 Ma.

The Whim Creek Group (Fitton et al., 1975) includes most of the well-preserved metavolcanic and metasedimentary succession (termed 'greenstone') on SHERLOCK and together with immediately overlying mafic volcanic rocks is thought to represent the youngest (c. 2950 Ma) component of the Pilbara Supergroup (Hickman, 1983, 1990). The group outcrops in an arcuate belt (Whim Creek Belt — Hickman, 1977) up to 10 km wide that stretches from the northeastern to the southwestern corner of SHERLOCK and further south and west onto ROEBOURNE, MOUNT WOHLER, and COOYA POOYA. The poorly outcropping rocks to the north and south of the belt are Archaean granites (chiefly the Caines Well Granitoid Complex) and metasedimentary rocks (Mallina Formation) respectively. Rocks of the late

* Capitalized names refer to standard map sheets.

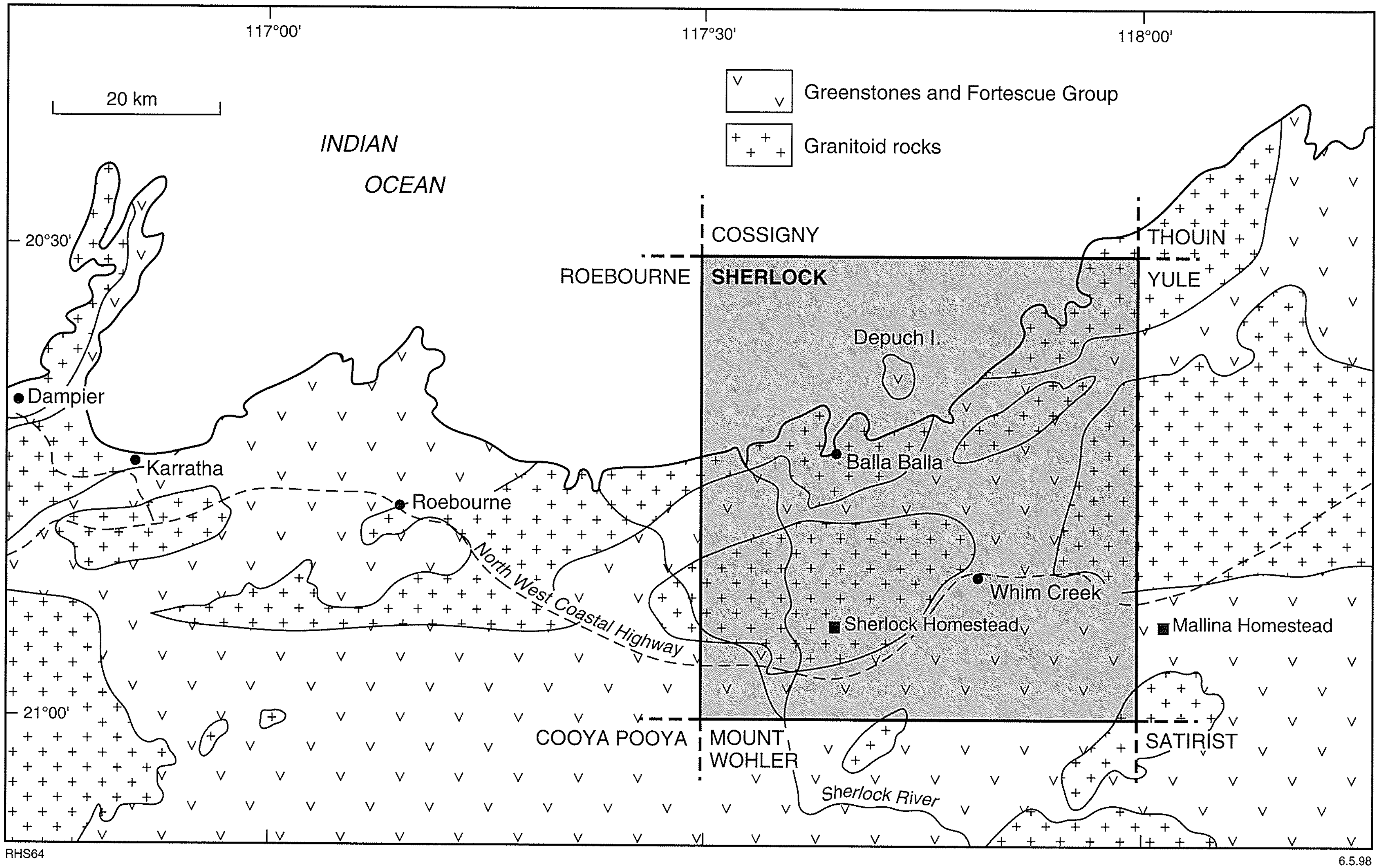


Figure 1. Location of Sherlock within the northeast Pilbara region

Archaean Fortescue Group locally overlie the greenstones.

Access and land use

The North West Coastal Highway passes through SHERLOCK, linking the towns of Roebourne and Port Hedland (Fig. 2). The only permanent settlements are Sherlock Homestead and the Whim Creek Hotel, the latter located on the highway at the site of the Whim Creek copper mine. Sherlock Station covers the western part of SHERLOCK, while the eastern part is divided between Mallina Station to the north and Croydon Station to the south. Farm tracks are generally well maintained and provide access to much of the area. A well-maintained gravel road links the Whim Creek Hotel to the abandoned Balla Balla Harbour, situated at the mouth of the Balla Balla River.

Grazing is the primary agricultural activity on all three stations on SHERLOCK. Although there are no operating mines at present, gold, base metals, and asbestos have been extracted from the area. The copper mine at Whim Creek, perhaps the most famous deposit in the area, yielded about 11 500 t of copper from 91 500 t of ore. The harbour at Balla Balla was constructed for shipping the ore. Copper mining also took place on a small scale at Mons Cupri, about 5 km southwest of Whim Creek. Gold was extracted at the Toweranna mining centre, about 15 km southeast of Whim Creek, where a total of 161.8 kg of gold was recovered from 4052 t of ore. About 830 t of asbestos (chrysotile) was mined from a small deposit near Green Hill Bore, about 3 km southwest of Sherlock Homestead.

Previous investigations

Woodward (1911) assigned all sedimentary components of the Whim Creek Group to the 'Nullagine Beds' — a unit containing all the older, post-granite sedimentary and volcanic rocks of Western Australia considered to be Palaeozoic in age. David (1932) reassigned the beds to the Proterozoic, while Finucane and Sullivan (1939) correlated the upper sedimentary part of the Whim Creek Group with the Archaean 'Mosquito Creek Series'.

Ryan and Kriewaldt (1964) suggested that the volcano-sedimentary stratigraphy of the western Pilbara region developed as a single subsiding trough in which clastic material was derived from essentially contemporaneous stable volcanic margins. The northwestern margin lay in the Mons Cupri – Roebourne region, while the Teichmans region (on SATIRIST) represented the southeastern margin. The entire volcano-sedimentary sequence was redefined as the Roebourne Group and appears as such on the ROEBOURNE 1:250 000 sheet (Ryan et al., 1965). The group was equated with the 'Warrawoona succession' of the east Pilbara.

Further mapping of the western Pilbara region (Fitton et al., 1975) led to a major revision of the stratigraphy. Felsic to intermediate volcano-sedimentary rocks on SHERLOCK were considered to be much younger than those of the 'Warrawoona succession' and were redefined as the 'Whim Creek Group'. Voluminous basalts (including high-Mg basalts of the Negri Volcanics) that overlie felsic to intermediate rocks in the Whim Creek area were excluded from the group based on locally unconformable contact relationships. An angular unconformity was identified in the southeastern part of the Whim Creek Belt, between low-grade metamorphic rocks (Warambie Basalt) considered to represent the base of the Whim Creek Group and amphibolite facies rocks considered to correlate with the Warrawoona Group of Hickman and Lipple (1975).

A thick but poorly outcropping sequence of shale and fine- to coarse-grained sandstone, immediately south of the Whim Creek Belt, was called the Mallina Formation and correlated with shale around the Whim Creek mine in the upper part of the Whim Creek Group (Fitton et al., 1975). Sandstone beneath the Mallina Formation was called the Constantine Sandstone and thought to be a facies equivalent of the tuffaceous and clastic units below the shale at Whim Creek. This increased the outcrop extent of the Whim Creek Group beyond the confines of the (later defined) Whim Creek Belt. The group was given regional significance when Horwitz (1979, 1990) suggested a correlation between the Mallina Formation and the Mosquito Creek Formation (Hickman and Lipple, 1975) of the eastern Pilbara.

Hickman (1977, 1983) remapped the Whim Creek area and redefined the Whim Creek Group. He noted that the Mallina Formation was virtually devoid of volcanic intercalations and ranged from 2.5 to 5 km in thickness, whereas the shale at Whim Creek (Fitton et al., 1975) contained thin volcanic units and was only about 100 m thick. Hickman (1977) suggested that the Mallina Formation and the Constantine Sandstone were older than the Whim Creek Group and assigned them to the Gorge Creek Group; this separated the redefined Whim Creek Group from the Warrawoona Group. Subsequent studies (Krapez, 1984; Horwitz and Guj, 1987) confirmed earlier suggestions (Fitton et al., 1975) of a regional unconformity within the Gorge Creek Group, leading Hickman (1990) to relocate the Mallina Formation and Constantine Sandstone into what he termed the 'De Grey Group'.

Hickman (1977) further indicated that the (redefined) Whim Creek Group was, at that time, limited in areal extent to a fault-bounded graben structure that he termed the 'Whim Creek Belt'. Although adopted in general by most workers (Barley, 1987), the basis for Hickman's redefinition of the Whim Creek Group was rejected by Horwitz (1979, 1990) in favour of the earlier interpretations of Fitton et al. (1975).

Hickman (1977) also noted that the Negri Volcanics (Fitton et al., 1975), which overlie the Whim Creek Group, could be subdivided into an upper variolitic basalt and a lower sequence dominated by quench-textured mafic and ultramafic flows. In subsequent publications, Hickman (1983, 1990) separated the quench-textured rocks into the 'Louden Volcanics' and referred to the variolitic basalts as the 'Mount Negri

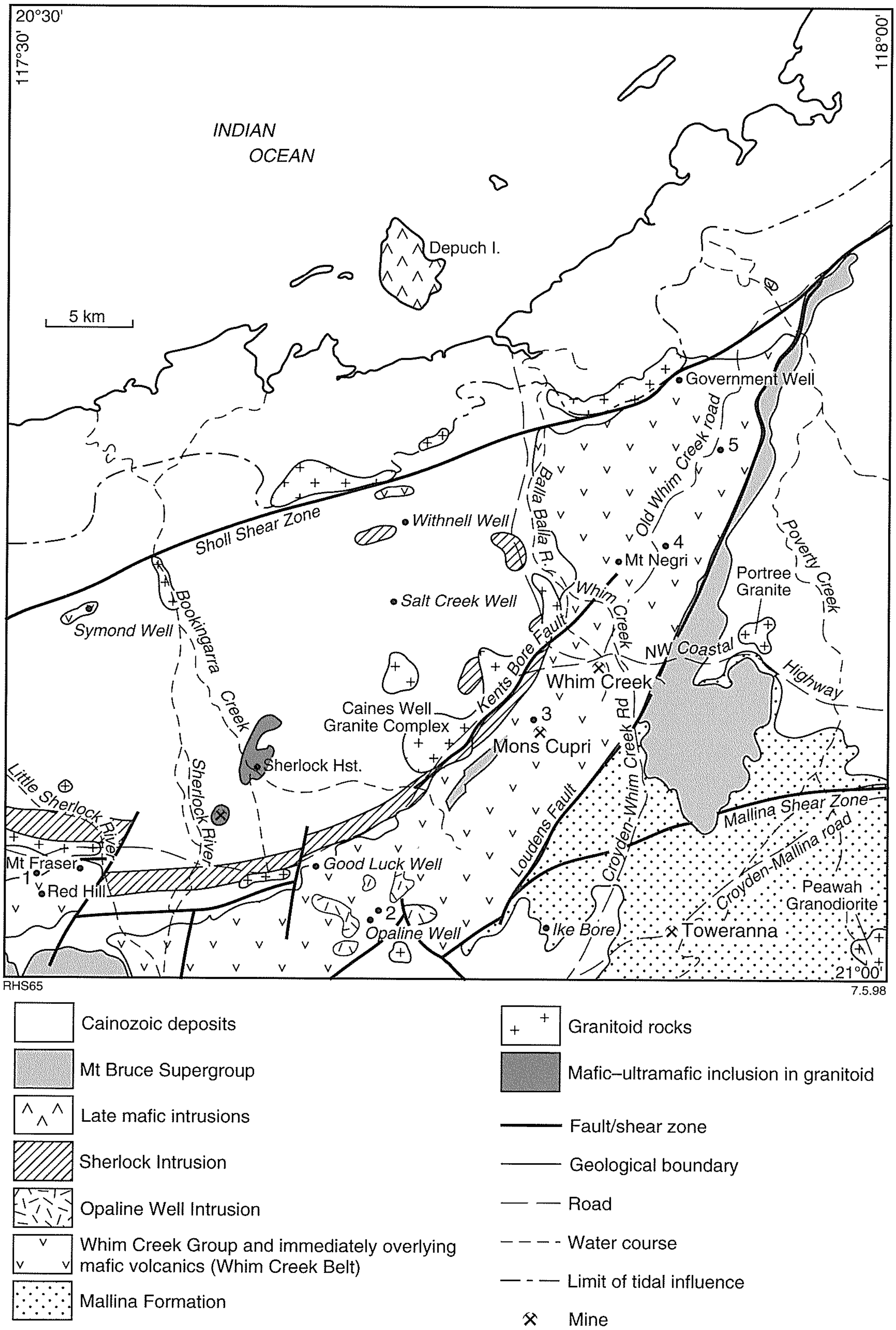


Figure 2. **General geology, location names, and major access roads on Sherlock. Numbers 1–5 refer to general localities of stratigraphic sections presented in Figure 5**

Volcanics'. The Louden Volcanics were said to be separated from the Whim Creek Group below, and the Mount Negri Volcanics above, by low-angle unconformities. Nevertheless, geochemical studies (Barley, 1986; Glikson et al., 1986b) indicated that the two rock types have similar geochemical characteristics, and both have been collectively referred to as the Negri Volcanics (Horwitz, 1979; Barley, 1987).

According to Barley (1987), the Whim Creek Group accumulated over a sialic basement within the bounds of an Archaean rift or pull-apart basin. It was suggested that the bounding faults — the Kents Bore Fault to the north and the Loudens Fault to the south — were active during deposition of the sequence but have since become part of the regional pattern of strike-slip faulting (Barley, 1987).

Recent studies (Horwitz and Pidgeon, 1993; Hickman, 1997) have established that the Warrawoona Group does not extend to the west Pilbara (as suggested by Hickman, 1983) and that greenstones in the Roebourne–Karratha area belong to the c. 3270 Ma Roebourne Group and, south of the Sholl Shear Zone, to the c. 3120 Ma Whundo Group.

Physiography

About one-third of SHERLOCK consists of ocean and tidal flats (Fig. 3). The non-tidal land surface on SHERLOCK is dissected by a series of rivers and creeks (Fig. 2) that are dry for most of the year but flow northward during the summer wet season. The majority of the non-tidal land surface comprises low-lying spinifex plains and gilgai of alluvial and diluvial origin. Tidal mudflats, including mangrove swamp along the coastline and watercourse outlets, are up to 8 km wide.

Outcrop on SHERLOCK is predominantly of Archaean rocks, which form an arcuate range up to 15 km wide that stretches from the northeast to the southwest corners of the sheet. This is mainly represented by the 'Range' and 'Low hills' divisions on Figure 3. Late Archaean rocks of the Fortescue Group, however, form a prominent land surface ('Plateau' and 'Dissected plateau' — Fig. 3) at an elevation of 130–180 m, representing a Tertiary peneplain referred to by Campana et al. (1964) as the 'Hamersley Surface'.

Regional geological setting

The Pilbara Craton represents the oldest exposed crustal element of Australia. The Archaean rocks can be divided into two components: a granite–greenstone terrane that formed between c. 3600 and c. 2800 Ma (Barley, 1997) and the unconformably overlying volcano-sedimentary sequences (Mount Bruce Supergroup) of the 2770 to 2300 Ma Hamersley Basin (Arndt et al., 1991). Archaean granite–greenstone terrane is predominantly exposed in the north and northeast, where erosion has removed all but local remnants of the Mount Bruce Supergroup.

Hickman (1983, 1990) grouped the volcano-sedimentary rocks of the granite–greenstone terrane into a single stratigraphic sequence — the Pilbara Supergroup. The distribution of the principal stratigraphic subdivisions are presented in Figure 4. The stratigraphy relies mainly on rock relationships established from the eastern Pilbara (Hickman and Lipple, 1975). Parts of the sequence appear to be locally and regionally replicated in the western Pilbara, establishing the concept of a craton-wide layer-cake stratigraphy (Hickman, 1983, 1990). Hickman (1990), however, notes that although the succession appears to extend across the Pilbara, lateral interdigitation of felsic, sedimentary, and mafic units is commonly important at the member scale. This stratigraphic sequence has been criticized, both in terms of the relative chronology of specific units (Horwitz, 1979, 1990; Horwitz and Pidgeon, 1993), hence the terrane-wide stratigraphic correlations, and in terms of concept (Krapez, 1993). It nevertheless remains the foundation for most regional and local studies of the Pilbara greenstones and is used in these Notes.

Krapez and Barley (1987) and Krapez (1993) subdivided the Pilbara granite–greenstone terrane into five fault-bounded tectono-stratigraphic domains (Fig. 4). Krapez (1993) applied the principles of sequence stratigraphy to the rocks of the Pilbara Supergroup and showed how the inferred tectono-stratigraphic units related to the five domains. This model-driven approach is fraught with the uncertainties regarding the recognition of time-bounding surfaces in deformed rocks of Archaean age, the interpretation of (proportionally significant) volcanic successions (Krapez, 1993), and the applicability of modern plate-tectonic processes to the Archaean. Krapez (1993), nevertheless, found that the Pilbara greenstone sequence fits well with sequence-stratigraphic theory, and identified two 'first-order chronostratigraphic sets' (analogous to Wilson Cycles): an older set for the eastern Pilbara and a younger set for the western Pilbara. The approach gives valuable insight into how the various stratigraphic components of the Pilbara greenstones may fit into a rational tectonic framework. Implicit in this approach, and in the recognition of tectono-stratigraphic domains, is the rejection of the earlier craton-wide lithostratigraphic correlations made by Hickman (1983, 1990), although Krapez (1993) does recognize that some supersequences are represented in more than one domain. The geochronological and detailed stratigraphic data required to resolve this conflict are not yet available.

The oldest units within the Pilbara Supergroup are mafic metavolcanic rocks and subordinate felsic metavolcanic and metasedimentary rocks of the Warrawoona Group. The age of the basal rocks is poorly constrained, but felsic rocks in the Salgash Subgroup, near the top of the Warrawoona Group, have been dated at c. 3450 Ma (Thorpe et al., 1992). Felsic volcanic rocks of the Wyman Formation were initially included in the Warrawoona Group (Hickman and Lipple, 1975; Hickman, 1983), but subsequent dating (3325 Ma — Thorpe et al., 1992) found them to post-date the Euro Basalt by about 125 million years. The Wyman Formation is now placed between the

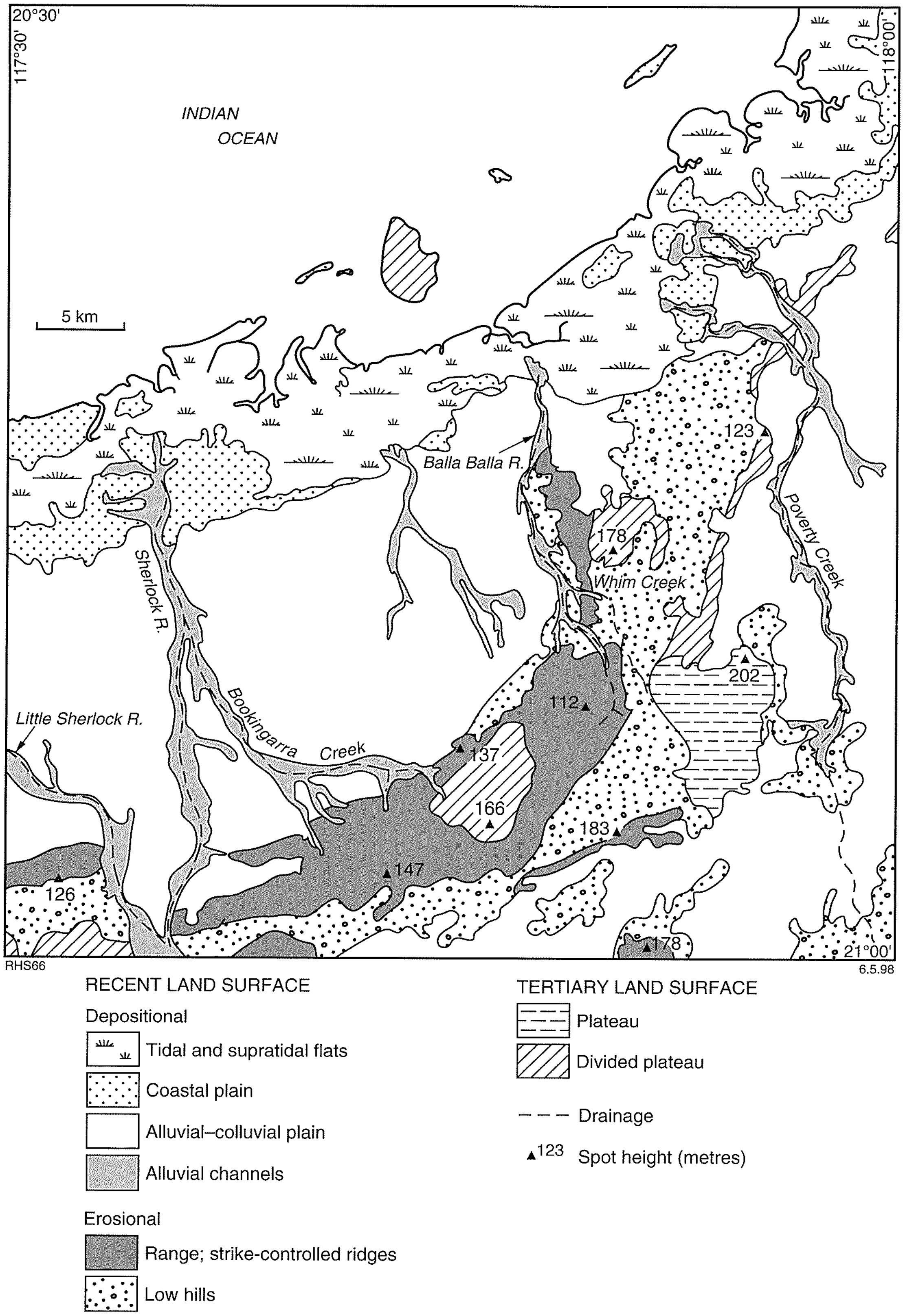


Figure 3. Physiography on SHERLOCK (subdivisions after Hickman, 1983)

Warrawoona Group and the overlying Gorge Creek Group.

Previous studies suggested that, at least in the eastern Pilbara, deposition of the lower units of the Gorge Creek Group — clastic sediments of the Corboy Formation and banded iron-formation (BIF) of the Cleaverville Formation — pre-dated emplacement of regional granite batholiths (Hickman, 1981; Horwitz, 1990; Krapez, 1993). More-recent studies, however, show that at least some of the granite–greenstone contacts are tectonized unconformities (Dawes et al., 1995).

A substantial sequence of clastic rocks that was originally placed at the top of the Gorge Creek Group (Hickman, 1983) was subsequently proven to be separated from that group by a regional unconformity (Krapez, 1984) and was accordingly redefined as the De Grey Group (Hickman, 1990). Included in the De Grey Group are the Lalla Rookh Sandstone, the Mosquito Creek Formation, and the Mallina Formation. The Mallina Formation was thought to be separated from the overlying c. 2950 Ma Whim Creek Group by an unconformity (Hickman, 1977, 1990). Horwitz (1979, 1990), however, did not recognize the De Grey Group; he regarded the Mosquito Creek Formation as the upper part of the Gorge Creek Group and considered the Lalla Rookh Sandstone, Mallina Formation, and Constantine Sandstone to belong to the overlying Whim Creek Group, which was then given a craton-wide distribution.

Studies by Krapez (1984), Barley (1987), and Krapez and Barley (1987) suggest that the Lalla Rookh Sandstone and Whim Creek Group were individually deposited within fault-bounded basins of about the same extent as their present outcrop. Their findings support Hickman's (1977) view that the felsic and mafic volcanic units that comprise the bulk of the Whim Creek Group (and overlying Mount Negri and Louden Volcanics) cannot be correlated across the Pilbara Craton.

The age of the Louden and Mount Negri Volcanics is constrained between that of the Whim Creek Group (c. 3000 Ma) and the base of the Mount Bruce Supergroup (2770 Ma — Arndt et al., 1991). Galena extracted from mineralized fractures within the Mount Negri Volcanics gives a Pb–Pb model age of 2920 Ma (Thorpe et al., 1992). Fitton et al. (1975) suggested that some phases of the 'Millindinna Complex' (referred to here as the Sherlock Intrusion) — a regional mafic and ultramafic suite that locally intrudes the Whim Creek Group — may represent stocks and feeders for the Mount Negri Volcanics. Korsch and Gulson (1986) obtained a Sm–Nd whole-rock and mineral age of 2830 ± 30 Ma and a Pb–Pb whole-rock age of 2960 ± 20 Ma for rocks of the 'Millindinna Complex'. These authors considered an age of 2900 Ma to be consistent with the geology of the area.

Granitoid rocks with a range of compositions and intrusive ages are exposed as domal features of batholithic scale and together constitute about 60% of the granite–greenstone terrane. The majority of the granitoid rocks in the eastern Pilbara were emplaced between c. 3500 Ma and c. 3000 Ma, with peaks of magmatism at 3450–3500 Ma, c. 3300 Ma, and 2950–3000 Ma (Bickle et al., 1983, 1989; Williams and Collins, 1990). The oldest ages are from banded tonalitic gneiss and foliated granodiorite–monzogranite. The 'batholiths' of the western Pilbara are less well studied but appear to comprise younger intrusive phases. Passively intruded 'post-tectonic' monzogranite to granite is found throughout the craton and has been dated in the east at 2850–2830 Ma (Pidgeon, 1978; Bickle et al., 1989).

The structural and stratigraphic evolution of the Pilbara greenstones is intimately linked to the formation of the batholithic granitoid domes. The origin of the domes has been ascribed to a process of solid-state diapiric uprise of basement, consisting essentially of the 3500–3400 Ma granitoid rocks (Hickman, 1983, 1984; Collins, 1989), or diapirism following substantial collision-related crustal thickening and heating (Bickle et al., 1985). According to Hickman (1984), solid-state diapirism was a progressive or repetitive process that commenced prior to the complete accumulation of the Gorge Creek Group and outlived accumulation of the Whim Creek Group. Periods of diapirism resulted in downwarping and deformation of overlying greenstones, with the resulting topography influencing further accumulation of greenstones. Hickman (1990) recognized distinct phases of diapirism and deformation before and after deposition of the Gorge Creek Group and both during and after deposition of the De Grey Group. Resultant recumbent folds, confined to rocks of the Warrawoona Group, were ascribed to D_1, while major upright folds in pre–Whim Creek Group rocks were grouped into a complex and protracted second deformation event (D_2). A third deformation event (D_3) was apparently unrelated to diapirism but reflected a Pilbara-wide phase of horizontal deformation that resulted in the development of strike-slip faults, conjugate folds, kink folds, and crenulation cleavages. The Whim Creek Group, at the top of the Pilbara Supergroup, contains D_3 structures but is otherwise little deformed, and primary layering typically dips at less than 30°.

The Mount Bruce Supergroup is a volcano-sedimentary succession, typically less than 10 km thick, and is separated from the youngest rocks of the Pilbara Supergroup by an unconformity that marks a hiatus in the order of 100 million years. According to Thorne (1990), the Mount Bruce Supergroup has three principal stratigraphic components, including, in order of decreasing age, the Fortescue, Hamersley, and Turee Creek Groups. Only the lower part of the Fortescue Group is preserved on SHERLOCK.

The Fortescue Group comprises mainly mafic volcanic and volcaniclastic rocks, with subordinate felsic volcanic, siliciclastic, and carbonate rocks and locally important mafic and felsic intrusive rocks (Thorne, 1990).

Archaean rocks

The most conspicuous geological feature on SHERLOCK is the greenstone sequence of the Whim Creek Belt. The belt trends in a northeasterly direction, adjacent to the Caines Well Granitoid Complex, and partly wraps around

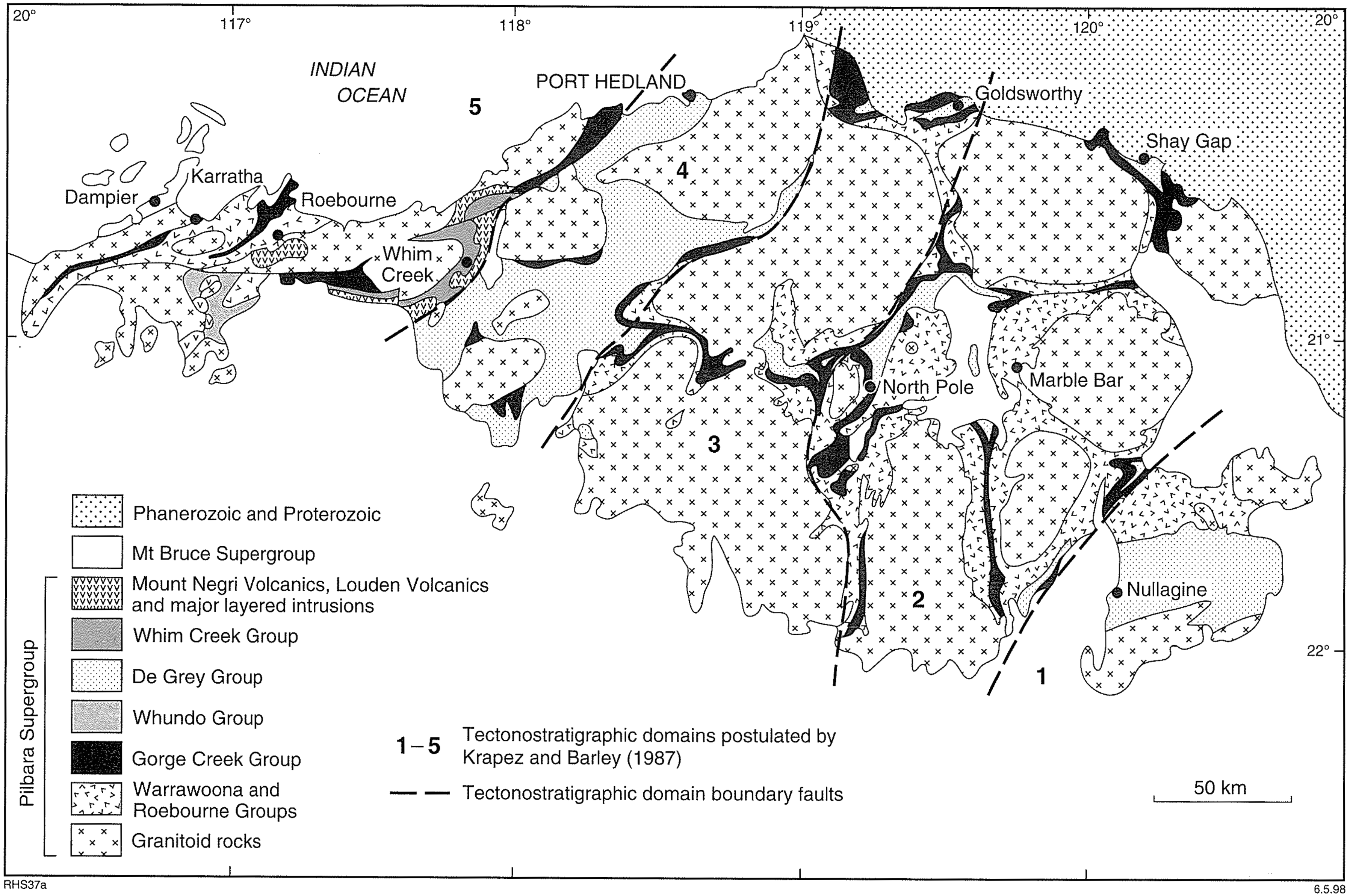


Figure 4. Principal stratigraphic subdivisions of the north Pilbara granite–greenstone terrane. Adapted from Hickman (1990, 1997)

that complex to the north where both the belt and the complex are truncated by the Sholl Shear Zone (Fig. 2). The Caines Well Granitoid Complex forms a broad domal feature with a northeast-plunging axis; the typically shallowly dipping rocks of the Whim Creek Belt conform to this structure. Contacts with the granite are commonly sheared (Kents Bore Fault — Barley, 1987) and have been intruded by gabbro, which Fitton et al. (1975) correlated with the 'Millindinna Complex' (here named the Sherlock Intrusion). The Loudens Fault forms the southeastern boundary of the belt and juxtaposes mafic volcanic rocks of the belt with sedimentary rocks of the Mallina Formation (De Grey Group).

De Grey Group

On SHERLOCK the De Grey Group is subdivided into the Constantine Sandstone and Mallina Formation. The Constantine Sandstone comprises quartzite (*ADcq*) and arkose and shale (*ADcs*) and outcrops in the southeastern part of the sheet. This unit is overlain by arkose and shale (*ADm*) and rare feldspar porphyries (*ADmf*) of the Mallina Formation, which dominate outcrops to the southeast of the Whim Creek Belt.

Constantine Sandstone (*ADcq, ADcs*)

The nose of the 'Croydon Anticline', a prominent structure on MOUNT WOHLER, lies about 2 km southwest of Toweranna Well in the southeastern part of SHERLOCK. The anticline is outlined by quartzite and sandstone of the Constantine Sandstone (Fitton et al., 1975), which conformably underlies the Mallina Formation.

The Constantine Sandstone is dominated by moderately well sorted, medium- to coarse-grained quartzite (*ADcq*). Grains of quartz and subordinate feldspar are angular to subrounded and typically supported by a matrix of quartz, sericite, feldspar, and clay minerals. Fragments of fuchsitic chert and black chert are locally common. Grain-size grading is uncommon and usually poorly developed. Towards the top of the Constantine Sandstone, medium-grained, poorly sorted arkose and shale (*ADcs*) are interbedded with quartzite. The shale is laminated on a scale of 1–5 mm. The proportion of shale and arkose increases upward towards a gradational contact with the Mallina Formation.

Mallina Formation (*ADm, ADmf*)

The area east of the Loudens Fault and south of the North West Coastal Highway is dominated by rocks of the Mallina Formation (*ADm*). This formation is of regional significance south and east of SHERLOCK and, along with possible correlatives (such as the Mosquito Creek Formation), has been either placed stratigraphically below the Whim Creek Group (Hickman, 1977, 1983, 1990) or correlated with that group (Fitton et al., 1975; Horwitz, 1979, 1990).

The Mallina Formation comprises a succession of interbedded greywacke and shale considered to be of turbiditic origin (Hickman, 1977; Barley, 1987; Horwitz, 1990). Fitton et al. (1975) estimated a maximum thickness of about 2.5 km from a section near Mallina Homestead, immediately east of SHERLOCK. On SHERLOCK the formation is typically dominated by shale, although arkose rarely constitutes less than 20% of any outcrop and is locally dominant. Graded bedding is locally well developed.

Shale within the Mallina Formation is typically laminated and ferruginous. Angular silt-sized grains of chert and quartz are common, and rare grains of ?plagioclase have been pseudomorphed by calcite. Clay minerals constitute the bulk of the groundmass and are accompanied by abundant chlorite, sericite, and quartz, and minor amounts of zoisite. The rocks show a prominent slaty cleavage defined by alignment of mica. Some samples are strongly carbonated; carbonate overprints the slaty cleavage and may constitute up to 50% of some rocks.

The greywacke component of the Mallina Formation ranges in grain size from sand to silt, and individual beds commonly fine upward. The rocks are typically poorly sorted and grains range from angular to subrounded. The abundance of quartz typically exceeds that of plagioclase. Lithic fragments, which are particularly abundant in the coarser grained rocks, are usually grey chert, but fragments of fine-grained and tuffaceous felsic volcanic rocks, shale, and basalt are also found. The matrix is rich in clay minerals and chlorite, with subordinate quartz, plagioclase, biotite, epidote, zoisite, and pyrite. The rocks are commonly iron stained and some are strongly carbonated.

To the south of Opaline Well, sedimentary rocks of the Mallina Formation outcrop in the contact aureole of a late granitoid intrusion, adjacent to the Loudens Fault. Contact metamorphism has resulted in biotite-rich rocks that contain abundant rosettes of sillimanite and less common porphyroblasts of cordierite. Close to the Peawah Granodiorite in the southeastern part of SHERLOCK, shale of the Mallina Formation also shows the effects of contact metamorphism, with garnetiferous spotted hornfels being most conspicuous.

The Mallina Formation contains minor amounts of high-Mg basalt and diorite (*Abm*), which outcrop very poorly throughout the sequence. Although mafic rocks and shale appear to be 'mixed' together at some outcrops (AMG 860806*), it is never clear whether the high-Mg basalt lies conformably within the Mallina Formation, is folded into that formation, or intersects bedding as dykes or fault slices. For this reason the mafic rocks are discussed in **Unassigned units.**

Feldspar(–hornblende) porphyry (*ADmf*) is interleaved with sedimentary rocks of the Mallina Formation in the southeastern part of SHERLOCK. It consists of subhedral to euhedral phenocrysts of hornblende (up to 3 mm

* Localities are specified by the Australian Map Grid (AMG) 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.

in size and commonly rimmed by biotite) and plagioclase (up to 5 mm in size) in a medium- to fine-grained groundmass of quartz, plagioclase, and biotite. A weak to moderate mineral foliation that parallels bedding in the surrounding sedimentary rocks may be a flow foliation. Hornblende is variably altered to chlorite and actinolite, and plagioclase and groundmass phases have been variably altered to sericite, carbonate, chlorite, and epidote. Many units of the porphyry are probably intrusive, but fragmental textures, flattened shard-like features, and angular lithic clasts point to a possible pyroclastic origin for some units.

Whim Creek Group

The Whim Creek Group (Fitton et al., 1975) is a sequence of felsic volcanic, volcaniclastic, and fine- to coarse-grained clastic rocks, with minor amounts of basalt, which reaches a maximum of 1.6 km in thickness. It outcrops almost continuously along the northwestern edge of the Whim Creek Belt, adjacent to the Caines Well Granitoid Complex. Miller and Smith (1975) described a sequence of felsic to mafic volcanic rocks from Symond Well in the northwest that may also belong to the Whim Creek Group, as may small outcrops of highly sheared felsic volcanic and volcaniclastic rocks found north of the Sholl Shear Zone near Peawah Hill (AMG 972172). Figure 5 shows stratigraphic columns typical of the northeastern, central, and southwestern portions of the Whim Creek Belt.

Felsic volcanic rocks of the Mons Cupri Volcanics (*ACf*) form the base of the Whim Creek Group throughout most of the Whim Creek Belt, except in the west where the Warambie Basalt (*ACw*) is locally interleaved with the basal portion of the felsic volcanic rocks. The Mons Cupri Volcanics is overlain by tuffaceous epiclastic, volcaniclastic, and clastic rocks of the Cistern Formation (*ACc*), which also includes thin layers of basalt. Well-laminated pelitic rocks of the Rushall Slate (*ACr*) conformably overly the Cistern Formation and represent the uppermost unit of the Whim Creek Group.

Mons Cupri Volcanics (*ACf, ACft, ACfr, ACfrp*)

The basal unit of the Whim Creek Group is the Mons Cupri Volcanics (Fitton et al., 1975). Although commonly sheared along the Kents Bore Fault, the basal contact of the Whim Creek Group is an unconformity against rocks of the Caines Well Granitoid Complex. The unconformity is exposed along the southern base of a hill, 1 km northeast of the point where Bookingarra Creek intersects the North West Coastal Highway. It is also found along the southern base of a hill, about 300 m west of the point where the Croydon – Whim Creek road crosses Whim Creek.

The Mons Cupri Volcanics (*ACf*) is subdivided into an upper sequence of felsic volcanic rocks and subordinate volcaniclastic rocks (*ACft*) and the lower 'Mount Brown Rhyolite Member' (Fitton et al., 1975). The latter mainly consists of porphyritic felsic tuff and lava (*ACfr*) but also includes some intrusive rocks; some rocks (*ACfrp*) are distinctly more phenocryst rich. The Mons Cupri Volcanics reaches a maximum thickness of about 1 km in the Mount Brown area but thins towards the west.

The felsic volcanic and volcaniclastic unit (*ACft*) appears to be of only local extent or was locally removed soon after deposition. However, mineralogical gradations sometimes make the distinctions between that unit and the Mount Brown Rhyolite Member (*ACfr, ACfrp*) difficult. Close proximity to the top of the Mons Cupri Volcanics, the presence of thin (less than 10 m) and discontinuous lenses of volcaniclastic rocks, a typically very fine grained equigranular texture, and a white shade in hand specimen constitute the field criteria used to identify the felsic volcanic and volcaniclastic rock unit.

Light-grey to white felsic volcanic rocks (*ACfr*) of the Mount Brown Rhyolite Member, containing relatively few feldspar(–quartz) phenocrysts, can be distinguished from dark-grey, phenocryst-rich rocks of that member (*ACfrp*); however, these two units are frequently interleaved on a scale of less than 10 m and hence mapped according to the dominant rock type.

Felsic volcanic rocks comprising the phenocryst-poor Mount Brown Rhyolite Member (*ACfr*) typically contain less than 10% phenocrysts. Plagioclase is the dominant phenocryst phase and forms euhedral to subhedral grains, up to 5 mm in length, that are usually partially resorbed. Anhedral grains of quartz are the only other phenocryst phase. Lithic fragments are locally abundant and consist of felsic volcanic rocks and rare pumice and volcaniclastic rocks. Some samples of the Mount Brown Rhyolite Member are highly spherulitic, with individual spherulites up to 3 mm in diameter. The spherulitic rocks are typically more vesicular than non-spherulitic rocks. The matrix of most samples comprises clay minerals, sericite, carbonate, chlorite, and iron oxide and is a microcrystalline alteration product of devitrified glass. Well-developed perlite textures are commonly preserved. The presence of perlite textures and rare pumice fragments indicates a tuffaceous origin. In some samples the matrix comprises very fine grained feldspar, quartz, magnetite, and chlorite (possibly after biotite) and probably crystallized from a lava rather than forming as a pyroclastic deposit.

Tuff and lava units of the phenocryst-rich variety of the Mount Brown Rhyolite Member (*ACfrp*) contain more than 15% phenocrysts, which are dominated by plagioclase and subordinate quartz, with rare microcline. Abundant spherulites and well-developed perlitic and fragmental textures reflect a pyroclastic origin. Some units may be crystal-lithic tuffs, whereas the less spherulitic samples, which lack perlite textures, may be lava flows or high-level intrusive rocks.

The volcanic component of the volcanic and volcaniclastic unit (*ACft*) is lithologically indistinguishable from the phenocryst-poor Mount Brown Rhyolite Member (*ACfr*). The volcaniclastic component is typically poorly sorted, matrix-supported, fine- to

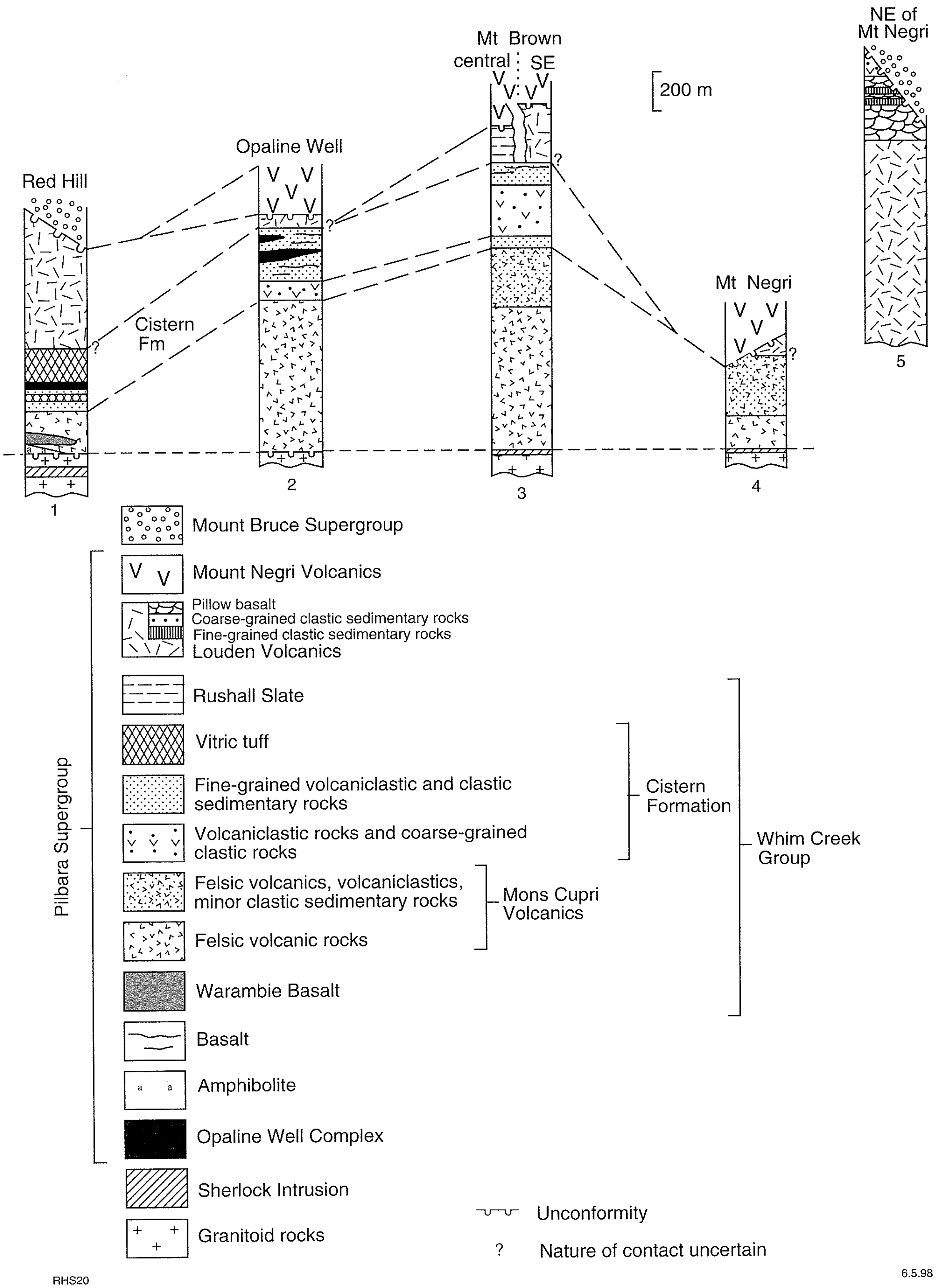


Figure 5. Stratigraphic columns showing stratigraphic variations across the Whim Creek Belt (numbers refer to localities in Figure 2). Modified from Smithies (1996)

medium-grained arkose, containing angular to subangular grains of quartz, feldspar (dominantly plagioclase), and locally derived lithic fragments.

The cryptocrystalline to microcrystalline groundmass of many felsic lavas and tuffs of the Mons Cupri Volcanics causes problems in the modal classification of the rocks. Phenocrysts in the Mons Cupri Volcanics are predominantly plagioclase, and alkali feldspar is rare to absent. However, chemical analyses prove most of the rocks to be of rhyolitic composition (see **Geochemistry**).

Warambie Basalt (*ACw, ACwx, ACwy*)

Between the Sherlock River and Mount Fraser, the Mons Cupri Volcanics appears to be interleaved with basalt, and mafic breccia and conglomerate of the Warambie Basalt (Fitton et al., 1975). Although considered by Fitton et al. (1975) to represent the lowest formation of the Whim Creek Group, evidence gained here reveals that the basalt association is interleaved with the Mount Brown Rhyolite Member. The Mons Cupri Volcanics pinches out immediately west of this region, where the Warambie Basalt sits unconformably on amphibolite (*Aba*). In places, the basalt directly overlies granite-boulder conglomerate that marks the unconformity between the Caines Well Granitoid Complex and the Whim Creek Group.

The Warambie Basalt (*ACw* — fully subdivided into *ACwx* and *ACwy* on SHERLOCK) includes vesicular and glomeroporphyritic tholeiitic basalts (*ACwy*). These rocks commonly show a moderate degree of alteration, with intergranular patches of carbonate, chlorite, serpentine, and zoisite enclosed by an interlocking network of sericitized and carbonated plagioclase. The glomeroporphyritic basalt is distinguishable from the Mount Roe Basalt, which has larger and better formed aggregates of feldspar phenocrysts. Blocky flow tops are commonly preserved in the Warambie Basalt.

Fragmental basalt, mafic breccia, and conglomerate units (*ACwx*) are interleaved with basalt flows. They contain an altered matrix of chlorite, quartz, and iron oxides. Angular clasts in the breccia are up to 15 cm in size and are either compositionally similar to the matrix or composed of plagioclase porphyry. Some of the breccia units may be flow-top breccias. Conglomerate is matrix supported and contains subangular to subrounded clasts up to 1 m in diameter. Some units are essentially oligomictic conglomerates derived from a source petrographically similar to the Warambie Basalt. One notable conglomerate (AMG 548828) lies between the Caines Well Granitoid Complex and a thin interval of the Mons Cupri Volcanics (*ACfr*). Adjacent to the granitoid complex it contains subrounded boulders of granite up to 1 m in diameter, but closer to the felsic volcanic rocks it contains only basalt clasts. Most of the conglomerates are distinctly polymictic, containing basaltic clasts and abundant boulders of felsic plagioclase porphyry that are petrographically identical to the Mount Brown Rhyolite Member (*ACfr, ACfrp*). Polymictic conglomerate is locally overlain by flows of Warambie Basalt.

Cistern Formation (*ACco, ACcf, ACct*)

The Mons Cupri Volcanics, as originally defined by Fitton et al. (1975) and Hickman (1977), include a locally thick (200–300 m) package of felsic tuff and reworked tuff, conglomerate, poorly sorted sandstone, siltstone, and laminated shale, which forms a generally fining-upward sequence. However, this tuffaceous sequence overlies and can be differentiated from the felsic volcanic and less common volcaniclastic rocks of the Mons Cupri Volcanics (*ACft*) — it contains few felsic lavas or spherulitic tuffs and abundant vitric (both crystal and lithic) tuffs, the tuffs and associated epiclastic and volcaniclastic rocks show well-developed graded beds, and it contains coarse-grained clastic rocks. The unit hosts the base-metal mineralization at Mons Cupri and is reassigned here to the Cistern Formation, a term originally used by Miller and Gair (1975) in reference to a thin (about 30 m) sandstone at the top of the Mons Cupri Volcanics. The (redefined) Cistern Formation thus includes the original arkose and the upper portion of the Mons Cupri Volcanics of Fitton et al. (1975). The Cistern Formation is locally absent and, in such areas, the Rushall Slate lies conformably or disconformably on the Mons Cupri Volcanics.

The Cistern Formation is best represented north of Opaline Well. Contacts between the formation and the Mons Cupri Volcanics may be transitional (rare lenses of spherulitic, crystal-rich tuff are found in the lower portion of the Cistern Formation) but are commonly marked by an oligomictic, matrix-supported boulder conglomerate (*ACco*). Boulder conglomerate also forms discontinuous lenses, a few metres thick, throughout the formation. South of Good Luck Well, the boulder conglomerate reaches a thickness of about 200 m and successions at least that thick are present east of Mons Cupri. Clasts in the boulder conglomerate are usually subrounded to subangular, reach a maximum of 30 cm in diameter, and are dominantly locally derived — overwhelmingly from the Mount Brown Rhyolite Member (*ACfr, ACfrp*); rare granite and basalt clasts may have been derived from the Caines Well Granitoid Complex and the Warambie Basalt respectively.

A lithologically variable package of rocks, comprising poorly sorted tuffaceous layers interbedded with poorly sorted sandstone and shale (*ACcf*), overlies the conglomerate. The tuffaceous layers are up to 3 m thick and commonly show well-developed grain-size grading, from coarse grit to silt-sized (?ash) particles. Crystal-lithic tuff is locally a dominant component and consists of a glassy matrix that has been devitrified and altered to a cryptocrystalline mass of clay minerals supporting lithic fragments and poorly sorted and angular grains of plagioclase and quartz. Most of the lithic fragments are from similar tuff (i.e. locally derived) or the underlying Mons Cupri Volcanics, but basaltic fragments are also found. Some tuff is clast supported and shows evidence of welding. Some of the more quartz-rich layers show clear evidence for reworking. They form medium-grained units that are matrix supported and poorly sorted, with lithic fragments and angular to subrounded grains of feldspar and quartz. They fine upward to well-laminated mudstone and shale.

At a few localities (e.g. AMG 728822 and AMG 560820), a thick sequence of black, glassy fragmental volcanic rocks (*ACct*), andesite to dacite in composition (see **Geochemistry**), is present either interbedded with or overlying the mixed unit (*ACcf*). Some samples of glassy fragmental volcanic rocks show well-developed flow textures. Near Red Hill, the unit forms a series of well-developed cooling layers, each up to 10 m thick, with a combined thickness of about 200 m. The rock varies from matrix (devitrified glass) rich to matrix poor and crystal-lithic tuff to lithic-crystal tuff. Partial resorbed subhedral grains of plagioclase are the main crystal component with subordinate anhedral quartz. Lithic fragments are locally more abundant than phenocrysts and include fragments of Mons Cupri Volcanics, basalt, pumice, and other rocks from the Cistern Formation (*ACcf*).

North of Opaline Well, the Cistern Formation includes rare basalt units up to 50 m thick. These units are conformable within the formation, commonly vesicular, and locally connected to stratigraphically lower mafic igneous intrusions via thin dykes. The basalt units are probably flows, but have been included in a series of generally intrusive mafic rocks called the Opaline Well Intrusion (*Aaob*, see below).

Barley (1987) considered the sequence of conglomerates, tuffs, and debris-flow deposits, grouped here into the Cistern Formation, to be characteristic of subaqueous fanglomerate deposits, typical of steep-sided, fault-bounded sedimentary basins. While such an origin would explain the restricted or local development of the formation, the evidence indicates that at least some of the tuffaceous deposits, and particularly the vitric and welded tuffs described here, are subaerial in origin.

Rushall Slate (*ACr, ACrc*)

The Rushall Slate (*ACr*) is locally preserved on the northeastern and southwestern sides of a domal feature that lies between Whim Creek and Mons Cupri and is also found immediately south of Mount Negri and on the northeastern and southwestern sides of a domal feature that lies between Good Luck Well and Opaline Well. Contacts with the Cistern Formation are conformable. Contacts with the Mons Cupri Volcanics are mostly fault bounded, but sharp and conformable or disconformable contacts are observed (e.g. AMG 778837). The Rushall Slate reaches a maximum thickness of about 200 m and is relatively uniform throughout most of its stratigraphic thickness. It consists mostly of well-laminated shale, but minor, thin (mainly 0.5–1.5 cm, but up to 30 cm) interlayers of medium-grained sandstone lie near the base, as do thin layers of basalt. The shale comprises very fine grained sericite, chlorite, and quartz, heavily dusted with iron oxides and pyrite, and is iron stained. Graded bedding is locally well developed. The rock shows a prominent schistosity defined by the alignment of micas. At Whim Creek and Salt Creek, Marston (1979) and Barley (1987) noted the presence of tuffaceous interbeds and chert within the shale, with associated massive sulfide mineralization. The Rushall Slate was considered by Barley (1987) to be a distal facies equivalent of the fanglomerate deposits assigned here to the Cistern Formation. However, deposition in local sediment-starved basins is also consistent with the restricted distribution of the shale.

A thin band of basalt is exposed near the base of the Rushall Slate at, and about 8 km southwest of, Mons Cupri. It has been referred to as the Comstock Andesite Member by Miller and Gair (1975), but it is here referred to as the Comstock Member (*ACrc*). The basalt is compositionally diverse, and at Mons Cupri it is heavily chloritized and ferruginized. The rocks are fine grained and many are vesicular, suggesting that the unit is extrusive. Most of the rocks contain carbonate–chlorite pseudomorphs after pyroxene. The original pyroxene crystals were of two generations: euhedral cores now altered to chlorite and rims of a later generation now altered to carbonate. The pseudomorphs probably reflect early orthopyroxene rimmed by clinopyroxene; similar features are seen in basalt within the Cistern Formation and the Louden Volcanics (*Aey*).

Mafic volcanic rocks overlying the Whim Creek Group

A mafic volcanic succession overlies the Rushall Slate, apparently separated from that unit by an unconformity (Fitton et al., 1975; Hickman, 1977, 1983, 1990; Barley, 1987). Hickman (1977) recognized that this sequence could be subdivided and subsequently (Hickman, 1983) described a lower spinifex-textured (and locally pillowed) unit — the Louden Volcanics — and an upper variolitic unit — the Negri Volcanics, later renamed the Mount Negri Volcanics (Hickman, 1990). However, textural and compositional differences between the Louden Volcanics and the Mount Negri Volcanics have been considered insufficient to justify the separation of the two units (Barley, 1987).

The units, as defined by Hickman (1977), were readily identified during the mapping of SHERLOCK. The Louden Volcanics comprises a diverse sequence of aphyric to coarsely spinifex-textured basalts, while the Mount Negri Volcanics forms massive flows of variolitic basalt. Vesicular basalt is a component of both the Louden Volcanics and Mount Negri Volcanics and at some localities cannot be assigned to either formation (*Aby*).

Contacts between the Mount Negri Volcanics and both the Whim Creek Group and the Louden Volcanics are locally unconformable. Very few stratigraphic contacts between the Louden Volcanics and the Whim Creek Group are exposed, and none seen by the author can be confirmed as unconformable. Field relationships from the Mount Fraser – Copper Bore area in the most southwesterly part of SHERLOCK suggest that the contact is either conformable or disconformable.

Louden Volcanics (*Ae, Aep, Aeq, Aes, Aec, Ael, Aey, Aeb, Aed, Aet, Aem, Aeh, Aeo*)

Most outcrops of the Louden Volcanics (*Ae*) are confined to the southeastern and southern portions of the Whim Creek Belt (adjacent to the Loudens Fault) and along the contact between the Whim Creek Belt and Sholl Shear Zone. The volcanics are best developed in the northeast, where they are up to 1.3 km thick and include an upper unit of clastic rocks.

Units that constitute the Louden Volcanics are predominantly extrusive. Mafic to ultramafic rocks with a well-developed, coarse pyroxene spinifex texture (*Aem*) are differentiated from those with fewer and randomly orientated acicular pyroxene phenocrysts (*Aeh*). Rocks showing an olivine spinifex texture are associated with the pyroxene spinifex-textured rocks but form layers that are not sufficiently thick or continuous to be represented at map scale. Some rocks have been altered and sheared by movement along the Loudens Fault and are now serpentine–chlorite schists (*Aet*). Aphyric basalt (*Aeb*) is common near the top of the sequence, forming cooling units up to 10 m thick. Most units of the Louden Volcanics contain some vesicular examples, and some units near the top of the sequence are characteristically vesicular (*Aey*). Units of both aphyric basalt and vesicular basalt are locally associated with hyaloclastite. Pillowed basalt (*Ael*) is also present at the top of the sequence, where it is locally interlayered with, and conformably overlain by, chert and clastic rocks including conglomerate. The transition upward from basalt that contains no pillows but is hyaloclastite bearing to pillowed basalts indicates submergence of a land surface. Some dioritic units (*Aed*) and ultramafic cumulates (*Aeo*) within the Louden Volcanics may be sills or dykes or may represent thicker flows.

Most samples contain a very fine grained groundmass comprising devitrified glass, pyroxene, and plagioclase partially altered to chlorite, carbonate, iron hydroxides, and clay minerals. Phenocrysts are commonly acicular pyroxene (up to 4 cm in length), but olivine is abundant in some samples. In many cases, pseudomorphs after euhedral pyroxene phenocrysts show a distinct chloritized core, rimmed by carbonate or clinopyroxene. The original mineralogy was probably of orthopyroxene or olivine, rimmed by clinopyroxene. Some ultramafic cumulates (*Aeo*) contain abundant phenocrysts of olivine, commonly enclosed in orthopyroxene that is in turn rimmed by clinopyroxene. Most rocks show well-developed pyroxene spinifex textures indicative of rapidly cooled high-Mg basalts or of pyroxene-rich portions of komatiite flows. However, rocks showing olivine spinifex textures are not abundant, suggesting that the Louden Volcanics predominantly consists of high-Mg basalt, with minor amounts of komatiite. Evolved plagioclase-rich samples are rare (some *Aed*) and some contain interstitial quartz or granophyric intergrowths of feldspar and quartz. Most rocks are partially chloritized and carbonated and may also contain actinolite and epidote; some are completely altered.

In the northeastern part of SHERLOCK, adjacent to the Loudens Fault, clastic rock and minor amounts of chert appear to lie within the upper part of, and overly, the Louden Volcanics. Both the sedimentary rock and pillow basalt (*Ael*) of the Louden Volcanics are poorly exposed and are locally extensively sheared by movement along the Loudens Fault. Nevertheless, the sedimentary rock locally appears to be interbedded with the basalt (e.g. AMG 965132) and, accordingly, has been included within the Louden Volcanics.

Poorly sorted, medium- to fine-grained sandstone (*Aes*), containing interbeds and lenses of shale and polymictic conglomerate, dominates the sedimentary horizon within the upper part of the Louden Volcanics. Grains are matrix supported, subrounded to subangular, and dominantly composed of quartz with lesser amounts of plagioclase and lithic fragments. The fine-grained matrix comprises quartz, feldspar, chlorite, sericite, and clay minerals. Some samples show extensive carbonate replacement of plagioclase and matrix minerals. Polymictic conglomerate within the sandstone unit (*Aes*) is poorly sorted, matrix supported, and contains locally derived clasts of sandstone, shale, chert, quartzite, and high-Mg basalt. Chert (*Aec*) forms only a very minor portion (less than 10 m) of the sedimentary unit within the Louden Volcanics. It is thinly banded, red to grey, and sometimes brecciated.

Coarse-grained and locally trough cross-bedded quartzite (*Aeq*) forms prominent ridges within the sedimentary sequence that overlies the Louden Volcanics. The rock is a moderately well sorted, grain-supported quartz arenite containing subrounded grains in a matrix of quartz and clay minerals. A distinctive feature of the rock is the presence of clasts of black chert.

A distinctive polymictic conglomerate layer (*Aep*), up to 100 m thick and separate from other clastic rocks, overlies pillow basalts of the Louden Volcanics adjacent to the Sholl Shear Zone. The conglomerate is coarser grained than that found within the sandstone unit (*Aes*) but is similar in all other respects.

Mount Negri Volcanics (*At, Atv, Aty*)

The Mount Negri Volcanics (*At* — fully subdivided into *Atv* and *Aty* on SHERLOCK) occupies two main areas at Mount Negri and between Hill Well and Mons Cupri. The volcanic rocks comprise variolitic basalt (*Atv*) and vesicular basalt (*Aty*). Variolitic basalt forms individual flows up to 15 m thick and reaches an accumulated thickness of more than 150 m in the vicinity of Mount Negri. The basalt contains abundant dark-green, pea-sized varioles composed of acicular clinopyroxene and interstitial plagioclase and glass in a light-green groundmass consisting of clinopyroxene, plagioclase, and glass. Euhedral clinopyroxene phenocrysts up to 2 mm in length are distributed randomly throughout varioles and groundmass. Epidote, actinolite, carbonate, and chlorite are common replacement minerals. A combination of rare scoria deposits including bombs up to 20 cm in diameter, a lack of pillow structures, and the presence of hyaloclastite suggest a locally emergent environment of extrusion.

Unassigned units (*Asq, Abm, Aby, Aba, Aus, Aux*)

Coarse-grained quartzite (*Asq*) outcrops as a prominent east-northeasterly trending ridge in the southeastern part of SHERLOCK. The quartzite is locally associated with high-Mg basalt (*Abm*), fault bounded on both sides against rocks of the Mallina Formation, and truncated to the west by the Loudens Fault. The outcrop marks the trace of an east-northeasterly trending structure referred to here as the Mallina Shear Zone. The rock is a moderately well sorted, grain-supported quartz arenite, containing subrounded quartz grains and clasts of black chert in a matrix of quartz and clay minerals. Trough cross-bedding is locally well developed.

Thin and discontinuous layers of high-Mg basalt and diorite (*Abm*) are in sheared contact along the southern edge of the quartzite ridge (*Asq*) described above and outcrop very poorly throughout the Mallina Formation. At some outcrops (e.g. AMG 860806), the mafic rocks and shale of the Mallina Formation appear to be mixed together; however, it is not clear whether the high-Mg basalt and diorite lie conformably within the Mallina Formation, are folded into that formation, or were emplaced either as dykes or as fault slices. The mafic rocks are extensively replaced; plagioclase is altered to calcite, sericite, and zoisite, and clinopyroxene is altered to carbonate (?dolomite) and chlorite. A few samples contain carbonate (?dolomite) pseudomorphs after olivine phenocrysts. At some localities, vesicular basalt (*Aby*) similar to that of the Louden and Mount Negri Volcanics can not be assigned to either formation.

Amphibolite (*Aba*) unconformably underlies the Whim Creek Group in the southwestern part of SHERLOCK. It is a medium-grained granoblastic rock composed of hornblende, plagioclase, and/or epidote. Serpentinized ultramafic rock (*Aus*) derived from metaperidotite and metapyroxenite (*Aux*) form large xenoliths, up to 5 km long and 2 km wide, within the Caines Well Granitoid Complex or adjacent to the southwestern and northeastern margins of that complex. The metaperidotites range from olivine-rich samples containing serpentine (after ?metamorphic forsterite) to granoblastic assemblages of cummingtonite, orthopyroxene, olivine (now serpentine), and spinel (hercynite). Metapyroxenite shows a granoblastic texture and consists of clinopyroxene, hornblende, and minor amounts of serpentine (after olivine). Adjacent to the northeastern margin of the granitoid complex, the metapyroxenite has been extensively ferruginized.

Mafic intrusive rocks

Millindinna Intrusion (*AaMo*)

Medium- to coarse-grained gabbro (*AaMo*) intrudes rocks of the Mallina Formation in the southeastern part of SHERLOCK and are assigned to the Millindinna Intrusion.

Sherlock Intrusion (*AaSo, AaSl, AaSoy*)

Gabbro (*AaSo*) sills and dykes of the Sherlock Intrusion are found at the contact between the Caines Well Granitoid Complex and the Whim Creek Group and marginal sections of the granitoid complex close to that contact. The rock is medium to coarse grained and ranges from massive to well foliated close to the Kents Bore Fault. Subhedral to euhedral clinopyroxene is the main mafic phase and commonly lies within an interlocking network of plagioclase euhedra or, less commonly, displays a subophitic texture. It is sometimes rimmed by hornblende. In rare cases, early formed subhedral to euhedral phenocrysts of orthopyroxene are found. Quartz and patches of quartz–plagioclase granophyric intergrowth are intergranular phases that become common in plagioclase-rich leucogabbro (*AaSl*) and abundant in granophyric gabbro (*AaSoy*). Most of the rocks show at least partial recrystallization to epidote, actinolite, and chlorite.

Opaline Well Intrusion (*AaO, AaOb, AaOo, AaOd, AaOv*)

Rocks that constitute the Opaline Well Intrusion (*AaO*) intrude the Whim Creek Group and lie at the contact between that group and rocks of the Sherlock Intrusion. At the contact with the Sherlock Intrusion, rocks of the Opaline Well Intrusion are commonly sheared, while those of the Sherlock Intrusion are massive. This relationship may reflect the typically more mafic composition of the former rocks, but it may also suggest that intrusion of the Opaline Well Complex pre-dates that of the Sherlock Intrusion. Contacts with rocks of the Whim Creek Group are mostly with the Cistern Formation, particularly in the Opaline Well area. No contacts with the Rushall Slate are observed, although this may reflect the very restricted outcrop extent of the shale rather than imply that intrusion pre-dates deposition of the shale. Where the intrusions are in contact with rocks of the Cistern Formation, the sedimentary rocks locally dip steeply towards the contacts. Some contacts are sheared and transgress bedding within the Cistern Formation. Many of the intrusions are dykes that probably utilized fault planes related to local block faulting of the Whim Creek Group, although some are sills.

The coarser grained gabbroic rocks of the Opaline Well Intrusion (*AaOo*) differ from the rocks of the Sherlock Intrusion in that they contain slightly more clinopyroxene, showing a notably acicular habit. Also, the texture is distinctly inequigranular, with intergranular spaces between clinopyroxene and plagioclase euhedra filled with very fine grained plagioclase, clinopyroxene, quartz, and clay minerals. Such textures probably reflect high levels of intrusion, and quenching of a crystal-rich magma. In some samples, intergranular quartz and quartz–feldspar granophyric intergrowth constitute up to

10% of the rock, although proportions of less than 5% are most common.

Medium-grained and fine-grained rocks of the Opaline Well Intrusion are dolerite or fine-grained gabbro (*AaOd*) and basalt (*AaOb*). These rocks differ from the coarser grained gabbro (*AaOo*) in that pyroxene and plagioclase euhedra are medium to fine grained and range in habit from stumpy to acicular. In some samples, pyroxene grains contain a chlorite core that may reflect altered orthopyroxene or olivine. The fine-grained (intergranular) groundmass is commonly glassy and forms up to 60% of the rock. The basalt is petrographically similar to vesicular basalt of the Louden Volcanics (*Aey*).

Gabbroic rock of the Opaline Well Intrusion grades into peridotitic gabbro and peridotite (*AaOv*), with an increase in the proportion of clinopyroxene and the addition of olivine and minor amounts of orthopyroxene. Some of these peridotitic rocks closely resemble peridotite of the Louden Volcanics (*Aeo*). Many outcrops show 1 to 10 m-scale igneous layering that is conformable with the dip of nearby sedimentary rocks and defined by alternating layers of gabbro or olivine gabbro and peridotite. Most rocks of the Opaline Well Intrusion, and particularly the peridotitic rocks, show partial recrystallization to epidote, actinolite, chlorite, and serpentine.

Granitoid rocks (*AgR, AgRn, AgRg, Ang, Agpo, Agm, Agpe, Agl, Apto*)

Granitoid rocks outcrop discontinuously over a large proportion of SHERLOCK (Fig. 2). The Caines Well Granitoid Complex (*AgR*) outcrops between the Sholl Shear Zone and the Kents Bore Fault, forming an elliptical feature rimmed by mafic rocks of the Sherlock Intrusion. Rocks of the granitoid complex range from foliated (Bookingarra Granite — *AgRg*) in the east to gneissic (*AgRn*) in the west. Granitoid rock accounts for most of the outcrop north of the Sholl Shear Zone; weakly foliated to well-foliated granitoid rock (*Agm*) outcrops to the east, while gneiss (*Ang*) is found to the west. East of the Whim Creek Belt, the Portree Granite (*Agpo*) forms rare outcrop to the north of the North West Coastal Highway, while the Peawah Granodiorite (*Agpe*) outcrops in the far southeastern corner of SHERLOCK. Leucogranite (*Agl*) forms a small stock to the south of Opaline Well and locally intrudes at the margin of the Caines Well Granitoid Complex, often within the Kents Bore Fault.

Granitoid gneiss north of the Sholl Shear Zone (*Ang*) consists of at least two phases: a homogeneous phase that is typically coarse grained and porphyritic and a phase that shows well-developed compositional banding on a 1 to 10 cm-scale. Neither phase shows a strong mineral foliation except close to the Sholl Shear Zone, where the rocks are strongly sheared and a mylonitic fabric may be developed. The porphyritic phase is clearly less deformed (younger) than the well-banded phase, but both provide clear evidence for migmatization. The porphyritic phase has been dated using Sensitive High-Resolution Ion Microprobe (SHRIMP) U–Pb zircon analyses at 3014 ± 3 Ma (Nelson, 1997 — see **Geochronology**). Both phases contain biotite as the sole mafic mineral and are classified as monzogranite.

Gneiss within the Caines Well Granitoid Complex (*AgRn*) is petrographically similar to the well-banded gneiss north of the Sholl Shear Zone. It outcrops very poorly, exposed mainly in the bed of the Sherlock River or as xenoliths within the Bookingarra Granite (*AgRg*). Amphibolite facies ultramafic rocks (*Aus, Aux*) at Sherlock Station are probably xenoliths within the gneiss. The gneiss has been dated (SHRIMP U–Pb zircon age) at 3093 ± 4 Ma (Nelson, 1997 — see **Geochronology**).

The Bookingarra Granite (*AgRg*) of the Caines Well Granitoid Complex is a medium- to coarse-grained porphyritic rock containing subhedral to euhedral phenocrysts of perthite (or microcline perthite) up to 1 cm in size in a seriate-textured groundmass. The rock contains less than 5% mafic minerals and ranges from hornblende- and biotite-bearing monzogranite to biotite-bearing syenogranite. The foliated granitoid rock has been dated (SHRIMP U–Pb zircon age) at 2925 ± 4 Ma (Nelson, 1997 — see **Geochronology**).

The only part of the Portree Granite (*Agpo*) exposed on SHERLOCK is medium-grained tonalite to granodiorite (rather than granite). Hornblende is the only primary mafic mineral; it constitutes less than 5% of the rock and has been partially to totally altered to chlorite. The rock is weakly foliated to massive. Contact relationships with the Mallina Formation are not sufficiently exposed to indicate the relative age of the granitoid rock, although reconnaissance mapping to the east, on YULE, clearly shows that the granites intrude the Mallina Formation.

The Peawah Granodiorite (*Agpe*) clearly shows intrusive contacts with the Mallina Formation. The granitoid rocks range in composition from tonalite to granodiorite but are distinctly more mafic than the granodiorite associated with the Portree Granite, with up to 15% combined hornblende and biotite (both partially altered to chlorite). The Peawah Granodiorite has been dated (SHRIMP U–Pb zircon age) at 2948 ± 5 Ma (Nelson, 1997 — see **Geochronology**). A small porphyry stock (*Apto*) at Toweranna is possibly related to the Peawah Granodiorite.

Fortescue Group (*AFr, AFry, AFrg, AFrb, AFrc, AFrs, AFh, AFdc*)

The Fortescue Group is a c. 2770–2680 Ma, dominantly basaltic succession that extends across much of the Pilbara Craton. In all areas where the group is in contact with the granite–greenstone terrane, this contact is an angular unconformity. On SHERLOCK the Fortescue Group unconformably overlies the Mallina Formation to the south of the North West Coastal Highway, but contacts with the Mount Negri Volcanics are rare. Contacts between the Fortescue Group and the Louden Volcanics are unconformable. A poorly sorted, matrix-supported polymictic conglomerate, containing subrounded clasts locally derived from the Mallina Formation and the Whim Creek Group locally marks the base of the Fortescue Group but is too thin and lenticular to be represented at map scale.

On SHERLOCK, most rocks of the Fortescue Group belong to the Mount Roe Basalt (*AFr*), and the majority of these are either vesicular basalt (*AFry*) or glomeroporphyritic basalt (*AFrg*). The former contain rare stumpy subhedral phenocrysts of plagioclase and clinopyroxene and quartz–calcite-filled vesicles, all in a groundmass rich in plagioclase laths with interstitial chlorite and epidote (after mafic phases and glass). The glomeroporphyritic rocks differ from the vesicular variety only in that they contain abundant clots of plagioclase up to 2 cm in size. Both the vesicular and glomeroporphyritic basalts show local development of pillows. Some outcrops of basalt (*AFrb*) show extensive brecciation and development of hyaloclastite that, together with the presence of pillowed basalt, indicate a subaerial to shallow-marine environment of extrusion essentially unchanged from that in which the Mount Negri Volcanics accumulated.

Sedimentary rocks are interlayered with the basalts and include well-laminated mudstone and siltstone and fine- to medium-grained, poorly sorted arkose and subarkose (*AFrs*), commonly with well-developed grading, ripple cross-bedding, and mudcracks. Matrix-supported polymictic conglomerate (*AFrc*), containing clasts derived from the Pilbara Supergroup and Mount Roe Basalt, is locally interlayered with the finer grained sedimentary rocks (*AFrs*). About 3 km southwest of Mons Cupri, interbedded coarse-grained (*AFrc*) and fine-grained (*AFrs*) sedimentary rocks form a narrow outcrop up to 500 m wide and 6 km long. The outcrop is fault bounded against the Mount Negri Volcanics, follows the general trend of the Whim Creek Belt, and probably represents a local graben infill.

Conformably overlying the Mount Roe Basalt are poorly to moderately sorted, medium- to coarse-grained arkoses and interbedded fine- to medium-grained tuffaceous sediments of the Hardey Formation (*AFh*). In the southwestern corner of SHERLOCK, these sedimentary rocks have been intruded by mafic magma of the Cooya Pooya Dolerite (*AFdc*), represented in that area by medium-grained olivine, orthopyroxene, clinopyroxene, plagioclase cumulate, and fine- to medium-grained plagioclase-rich and biotite-bearing dolerite.

Late Archaean dykes and mafic intrusive rocks (*Aod*)

Mafic intrusive rocks of uncertain but probable late Archaean age are present in the northern part of SHERLOCK. Massive, medium- to coarse-grained dolerite (*Aod*) forms prominent outcrops at Peawah Hill in the northeastern part of SHERLOCK and on Depuch Island. Linear aeromagnetic lineaments trend northeast and northwest and are also presumed to reflect mafic dykes. Intrusion of the dykes post-dates the Pilbara Supergroup and may be related to volcanism of the Mount Bruce Supergroup.

Cainozoic deposits

Silcrete and opaline silica (*Czro*) form low-lying outcrops in the central-eastern portion of SHERLOCK along the strike of prominent fault-bounded quartzite ridges. Recrystallization and silicification of quartzite is the most likely explanation for the development of this unit on SHERLOCK.

Calcrete of residual origin (*Czrk*) is extensively developed over rocks of the Mallina Formation on the far eastern edge of SHERLOCK and over a variety of rock types close to major shears. Calcrete also forms in old drainage channels, where it is assumed to be alluvial (*Czak*). Laterite (*Czrf*) is locally developed on the eastern side of SHERLOCK.

A yellow to red sand and silt unit has been deposited as fine outwash in diluvial fans (*Qwb*). It has been locally reworked by wind action but generally stabilized by extensive grass and shrub cover. The unit covers much of the plain south of the Whim Creek Belt.

Colluvium (*Qc*) comprises gravel and sand as sheetwash and talus, locally derived from elevated outcrops.

Present-day drainage channels contain alluvial clay, silt, sand, and gravel (*Qaa*).

Alluvial sand, silt, and clay are mostly developed on floodplains over the Caines Well Granitoid Complex and may or may not include gilgai and pebbly sands (*Qab* and *Qao* respectively). Gilgai is a clay-rich silt or sand deposit characterized by the development of numerous cracks and sinkholes. The clay expands and contracts according to water content and in dry conditions produces an irregular 'crabhole' surface.

Eolian sand (*Qs*) forms rare unstable dunes in the southern and eastern parts of SHERLOCK. The dunes do not appear to favour any particular orientation, but many are located on the windward side of large outcrops.

Rare lacustrine deposits (*Qac*) on the eastern most side of SHERLOCK consist of clay, silt, and evaporite in shallow depressions.

Lime-cemented dune sand and beach conglomerate including shell fragments (*Qpmb*) outcrop discontinuously at or near the coast.

Partially vegetated calcareous clay, silt, and sand (*Qhms*) form supratidal flat deposits on the landward fringe of the intertidal zone (tidal flats) and elevated relicts within that zone.

Tidal-flat deposits, with or without mangrove swamp (*Qhmm* and *Qhmu* respectively), also comprise clay, silt, and sand but tend to be less sandy than supratidal mudflat deposits (*Qhms*).

Structure

Regional structure

Most structural studies of the Pilbara granite–greenstone terrane are of the eastern Pilbara region and may not be entirely relevant to the western Pilbara. The formation of batholithic-scale domal granitoid complexes is central to the structural evolution of the eastern Pilbara. The greenstones that constitute the Pilbara Supergroup occupy synclinal positions between the domes. The greenstones are dominated by a subvertical schistosity that passes continuously between adjacent greenstone belts, commonly paralleling both the granite–greenstone contacts and the schistosity in the outer margins on the domes themselves (Hickman, 1983). The domes appear to be diapiric structures, and according to Hickman (1983) it was the gravitational sinking of the Pilbara Supergroup between active diapirs that produced the major upright folds of the greenstones. Bickle et al. (1985) preferred a model of horizontal tectonics whereby greenstones are thrust over sialic crust and deformed, with the sialic crust subsequently reactivated, forming diapirs.

Hickman (1975) identified four episodes of deformation in the Marble Bar – Nullagine region, which have subsequently been recognized elsewhere in the granite–greenstone terrane (Hickman, 1983):

- The first deformation event (D_1) broadly groups all structures deformed by D_2 and includes migmatization and interfolding of greenstone and granite. This phase correlates with D_1 and D_2 of Bickle et al. (1985), who recognized possible thrusting and major recumbent folding.

- The second deformation event (D_2) is the main deformation related to diapirism. It resulted in the major upright to locally overturned folding of the greenstones. Diapirism was episodic over a wide period of time (Hickman, 1984) and resulted in several generations of structures. A major phase of diapirism occurred after deposition of the De Grey Group and is broadly equated by Hickman (1983) to the 'Mosquito Creek Orogeny' of Noldart and Wyatt (1962). Emplacement and/or doming of the Caines Well Granitoid Complex on SHERLOCK relates to this event.

- The third deformation event (D_3) includes conjugate folding and faulting associated with regional east–west compression and strike-slip faulting. Late-stage deformation of the Whim Creek Belt was a result of D_3, but the northeast-striking cleavage is earlier (late D_2). Barley (1987) recognized two phases of folding within the belt. The first phase relates to movement along the Kents Bore and Loudens Faults and is characterized by upright open folds about southwest- and northeast-plunging axes. Associated with this folding is the development of steeply southeast dipping slaty cleavage in fine-grained and more competent rocks. The second phase of folding recognized by Barley (1987) involved the refolding of earlier structures by east-trending folds and development of a weak axial-planar cleavage.

- The fourth deformation event (D_4) involved tight to open folding about subhorizontal axial planes, but its localized distribution makes relationships with D_3 unclear. No D_4 structures are identified on SHERLOCK.

Post–Pilbara Supergroup deformation is reflected in the development of major open folds and faulting of the Mount Bruce Supergroup. In the vicinity of SHERLOCK, major northeasterly trending faults are a response to southeasterly directed extension during deposition of the Fortescue Group (Blake, 1984).

Structural history of SHERLOCK

The most conspicuous structure on SHERLOCK is the domal feature that exposes the Caines Well Granitoid Complex. Granite-boulder conglomerates at the base of the Whim Creek Group, and exposures of an unconformity at AMG 785886 and AMG 885940, reveal that components of the granitoid complex underlie the Whim Creek Group (see **Geochronology**). In the western part of SHERLOCK there is also an angular unconformity between the Whim Creek Group and underlying metabasalt (*Aba*). The metabasalt shows a steeply inclined foliation that trends about 160°, compared to a shallow-dipping foliation in the immediately overlying Warambie Basalt.

The rocks of the Whim Creek Group flank the Caines Well Granitoid Complex to the southeast and northeast and typically young and dip away from the complex at angles less than 30°. Reversals in dip reflect both topographic controls on deposition and open folding about the axial surfaces of southwesterly trending folds. Within the Whim Creek Belt, fold axes are impossible to trace over distances of more than a few kilometres due to later faulting. A subvertical axial-planar cleavage is developed within sedimentary rocks, and a penetrative schistosity is developed within basalt and felsic volcanic rocks. The axes of parasitic and minor folds typically plunge at less than 45° towards the northeast (~075°) and southwest (~240°).

The Whim Creek Group and the Louden Volcanics are folded around the northeastern margin of the Caines Well Granitoid Complex, immediately south of the prominent northeast truncation formed by the Sholl Shear Zone. Way-up directions determined from pillow basalt in the Louden Volcanics indicate the presence of a large-scale, northeast-plunging and upright-facing anticline. Although primary movement along the Sholl Shear Zone is sinistral (Barley, 1987), simple drag along this fault cannot account for this large-scale fold since the expected anticlinal axis would trend easterly rather than northeasterly. The fold thus represents a major northeasterly plunging anticline related to the main phase of folding recognized within the Whim Creek Belt.

The main phase of folding recognized within the Whim Creek Belt is also recognized in the Mallina Formation, except that in the latter the northeasterly trending axes of upright and locally overturned folds can be traced for many kilometres. No earlier structures were confidently recognized within the Mallina Formation on SHERLOCK. However, at least two earlier phases of deformation affect the Mallina Formation on MOUNT WOHLER (Smithies, in prep.), including the widespread development of large, north-trending upright to overturned folds. The Croydon Anticline, the nose of which lies in the southeastern part of SHERLOCK, is one of these folds. On SHERLOCK, gneiss within the Caines Well Granitoid Complex also shows the development of tight folds with northerly trending fold axes, which pre-date the main northeasterly trending folds and may relate to the same deformation event that produced the Croydon Anticline. Ultramafic xenoliths within the gneiss also define what is possibly a broad north-trending fold structure.

Deformation after the main phase of folding on SHERLOCK consists of kink bands, which are particularly common in the Mallina Formation. Conjugate kink folds are occasionally preserved and indicate a maximum compressive stress in a northeasterly direction.

The Whim Creek Belt is extensively faulted along steeply dipping northeasterly, east-northeasterly, and northwesterly trending planes (Fig. 6). Block faulting is well developed in the Opaline Well area. Two major fault structures on SHERLOCK are the east-northeasterly trending Sholl Shear Zone and the fault system marked by quartzite outcrop (*Asq*) in the southeastern part of SHERLOCK. The quartzite is flanked on both sides by, and overlies, a zone of intense shearing referred to here as the Mallina Shear Zone. While the quartzite itself is tightly folded about upright northeast-trending fold axes, it is not extensively sheared and may have been deposited after the main movement along the shear zone. Deformation fabrics associated with both the Mallina and Sholl Shear Zones define steep (~75°), southerly dipping shear planes. Early movement along the Sholl Shear Zone was predominantly sinistral (Barley, 1987), although only evidence for later dextral movement is preserved on SHERLOCK. Minor faulting with dextral strike-slip movement that parallels the Sholl and Mallina Shear Zones also occurred within the Whim Creek Belt (e.g. immediately west of Coolwater Well).

The Loudens Fault is the most prominent of the northeast-trending faults and links the Sholl and Mallina Shear Zones on the eastern side of SHERLOCK. Where the Loudens Fault cuts the Mallina Shear Zone, it imposes a sinistral displacement of about 1 km on that shear (Fig. 6). The fault is steep to vertically dipping. Similarly orientated faults (such as the Copper Bore Fault) are found in the southwestern part of SHERLOCK. The preservation of part of the Mount Bruce Supergroup on the eastern side of the Loudens Fault indicates a late east-side-down displacement.

The Kents Bore Fault is a poorly defined fault system that swings from east-trending in the southwest to northeast-trending in the northeast. Most shear planes dip very steeply to the southeast. The southwestern portion of the fault system is defined to some extent by the contact between the Whim Creek Belt and the Caines Well Granitoid Complex. To the north of Whim Creek, the fault is difficult to trace, although it appears that faulting along the southern side of Mount Negri and further to the northeast is the continuation of the Kents Bore Fault system. Within this area, extensive north-easterly trending shearing has imposed a schistosity on all rocks (including those of the Fortescue Group), and the earlier northeast-trending (~075°) axial-planar schistosity has been locally overprinted.

Block faulting is a prominent feature of the Opaline Well area and the southeastern portion of the Whim Creek Belt. The earliest faults that can be recognized trend east-northeasterly, parallel to the Sholl Shear Zone, although the predominant fault directions are north-easterly (parallel to the Loudens Fault) and northwesterly. Two kilometres east of Opaline Well, the Mallina Shear Zone is displaced dextrally about 5 km, along a northwest-trending fault plane. Many of the northwest-trending faults, however, are truncated by northeast-trending faults that show more than one period of movement. The northeast-trending fault set includes faults that were active prior to the northwest-trending faults, after deposition of the Mount Negri Volcanics but before (e.g. faults about 3 km to the southwest of Mons Cupri) and after deposition of the lower Fortescue Group. Individual faults may thus have been reactivated many times.

Hickman (1983) noted that northeasterly and northwesterly trending faults are an extremely common feature of D_3, and it is possible that much of the faulting on SHERLOCK is related to this event. Faulting of the Fortescue Group is consistent with either north–south compression or northwest–southeast extension and is therefore distinct from D_3. The orientation of fold axes related to the main phase of folding suggests maximum compression from the southeast, which may account for at least some of the movement along the northeast-trending faults, including the Loudens Fault and the various faults that constitute the Kents Bore Fault system.

Barley (1987), however, suggested that the Whim Creek Group accumulated between two northeast-trending faults — hence, movement of the Kents Bore and Loudens Faults pre-dates deposition of the Whim Creek Group. While this possibility cannot be discounted, there is little physical evidence to support it.

The age of movements along the Sholl and Mallina Shear Zones is unclear. Movement of the Sholl Shear Zone post-dates development of the c. 3100 Ma Sholl Belt (Horwitz and Pidgeon, 1993) southwest of SHERLOCK, where the main and early sense of displacement was sinistral (Hickman, A. H., 1996, pers. comm.). Later movement in that area was dextral and displaced rocks related to the c. 2920 Ma Munni Munni Complex (Arndt et al., 1991) by about 30 km (Hickman, A. H., 1996, pers. comm.). On SHERLOCK, movement along the shear was dextral and truncated greenstones in the vicinity of Symond Well. Aeromagnetic data suggest that green-stones underlie tidal flats north of the Sholl Shear Zone around Peawah Hill, and isolated outcrops of felsic volcanic and volcaniclastic rocks support this proposition. Greenstones at Symond Well and around Peawah Hill are separated by about 35 km of dextral movement along the

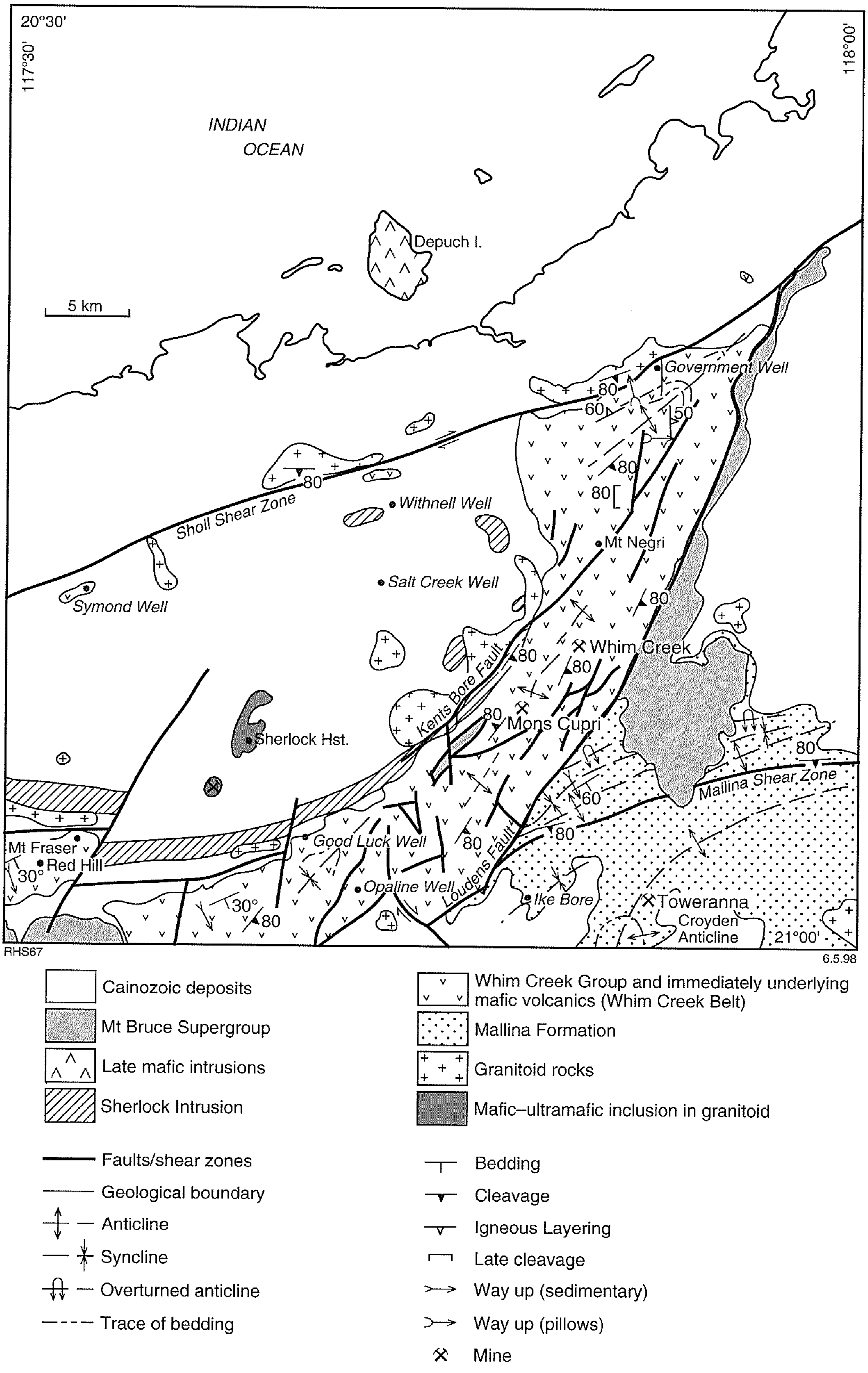


Figure 6. Structural geology of Sherlock

Sholl Shear Zone, which is consistent with the displacement estimated from the Sholl Belt. Consequently, it appears likely that part of the Whim Creek Group and overlying mafic rocks were originally north of the Sholl Shear Zone.

Metamorphism

According to Oversby (1976), peak regional metamorphism occurred throughout the Pilbara Craton at about 2950 Ma. Neither the Bookingarra Granite (*AgRg*) of the Caines Well Granitoid Complex nor the Whim Creek Group was affected by this event. Metamorphism of these rocks is of lower greenschist facies and is characterized by the development of chlorite, epidote, and actinolite in mafic rocks and epidote, chlorite, and sericite in felsic to intermediate rocks. This low-grade metamorphism is also heterogeneously distributed; for example, some parts of the Louden Volcanics show almost complete recrystallization to chlorite and actinolite, while fresh forsteritic olivine is preserved in others. Recrystallization may have been facilitated along zones of deformation. No evidence was found on SHERLOCK to support the contention by Fitton et al. (1975) that the regional metamorphic grade within the Mallina Formation increases southward.

The Peawah Granodiorite, and a late leucogranite stock 2 km southeast of Opaline Well, induced contact metamorphism of rocks of the Mallina Formation. The resulting spotted hornfels associated with the Peawah Granodiorite consists of a biotite–almandine assemblage, while that of the leucogranite consists of a sillimanite–biotite–cordierite assemblage. The latter assemblage reflects low to moderate pressures, and temperatures greater than 550°C (Spear and Cheney, 1989).

Amphibolite, which unconformably underlies the Whim Creek Group in the westernmost part of SHERLOCK, includes a metamorphic assemblage of hornblende–plagioclase(–epidote) indicative of recrystallization at epidote–amphibolite to amphibolite facies. Ultramafic xenoliths in gneiss of the Caines Well Granitoid Complex (*AgRn*) contain an assemblage of hornblende–plagioclase–clinopyroxene, suggesting slightly higher grades of recrystallization at upper amphibolite facies. Ultramafic xenoliths contain an assemblage of cummingtonite–orthopyroxene–olivine. This assemblage reflects conditions close to the amphibolite–granulite transition. The development of gneissic segregations and migmatization within the gneiss of the Caines Well Granitoid Complex (*AgRn*) suggests that the ultramafic xenoliths and the protolith to the gneiss could have been metamorphosed together.

Geochemistry

Mafic volcanic rocks

Glikson et al. (1986b) reported on the geochemical compositions of basalts throughout the Pilbara Craton. Included in these data (Glikson et al., 1986a) are 61 analyses of basaltic rocks from SHERLOCK, which have been supplemented by analyses of 10 samples collected during the present study. Few analyses are available from the Warambie Basalt, but Glikson et al. (1986b) and Barley (1987) agreed on the typically tholeiitic characteristic of this unit.

The main disagreement regarding mafic rocks of the SHERLOCK area lies with the recognition (Hickman, 1977), or otherwise (Fitton et al., 1975; Barley, 1987), of two distinct volcanic subdivisions within the sequence that immediately overlies the Whim Creek Group. Field evidence supports the recognition of the two distinct sequences referred to by Hickman (1977) as the Louden and Mount Negri Volcanics. However, Barley (1987) indicated that the geochemistry permits no distinction between the two and used the data of Glikson et al. (1986a) to support his contention. Glikson et al. (1986a) presented compositional variation diagrams showing the Louden Volcanics and two groups of 'Negri Volcanics' — one of spinifex-textured high-Mg basalts and the other referred to as tholeiites. The geochemistry of the Louden Volcanics and the high-Mg basalts from the 'Negri Volcanics' is virtually identical, but Glikson et al. (1986b, table 2) pointed out that the 'tholeiites' are compositionally distinct from both, having higher TiO_2, Zr, and Y concentrations and higher Ce/Yb values.

When sample localities from Glikson et al. (1986a) were compared with lithological boundaries mapped during the present study, all samples classified chemically as high-Mg basalt but previously ascribed to the 'Negri Volcanics' were found to lie in areas mapped as Louden Volcanics. It is important to note that geochemical sampling (Glikson et al., 1986a; and this study) covered all igneous lithologies within both the Louden Volcanics (including the pillow basalt) and the Mount Negri Volcanics. Compositional distinctions between the two volcanic sequences are best seen in terms of SiO_2, TiO_2, FeO^*/MgO (FeO^* is total iron recalculated as FeO), Zr, and V; a plot of TiO_2 versus FeO^*/MgO (Fig. 7), in particular, also discounts the possibility that the Louden and Mount Negri Volcanics relate to a single fractionation series. Hence, there are clear geochemical grounds for separating the Louden Volcanics from the Mount Negri Volcanics.

All igneous rocks of the Louden and Mount Negri Volcanics do, nevertheless, share some compositional characteristics that distinguish them from other basaltic rocks within the Pilbara Supergroup: they are siliceous and contain high concentrations of Ti, Zr, Nb, P, Y, and rare-earth elements. Barley (1986) suggested that the high-Mg basalts (Louden Volcanics, but grouped then within the 'Negri Volcanics') owed such characteristics to contamination of high-Mg magmas by sialic crust, and Sun et al. (1989) subsequently quantified the process whereby siliceous high-Mg basalts are produced from a komatiite parent by assimilation of about 14% felsic crust followed by significant crystal fractionation.

Felsic volcanic rocks

Glikson et al. (1986a) reported 29 chemical analyses of felsic volcanic rocks from the Whim Creek Group. In

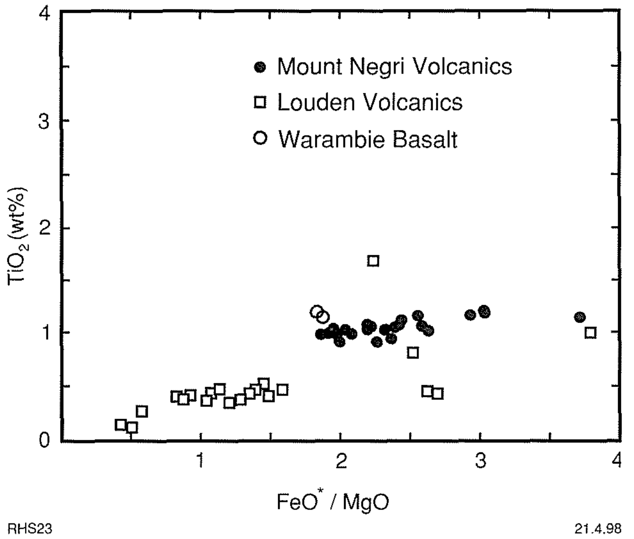


Figure 7. Compositional variation diagram comparing the Louden and Mount Negri Volcanics and the Warambie Basalt. Modified from Smithies (1996)

terms of rock types recognized in the present study, 24 of these analyses show that rocks are from the Mount Brown Rhyolite Member of the Mons Cupri Volcanics (*ACfr*), while the remaining five analyses show that rocks are from tuffaceous units within the Cistern Formation (*ACct*). All analyses are of metaluminous calc-alkaline volcanic rocks. Tuffs from the Cistern Formation fall into the compositional range between andesite and dacite, while the Mount Brown Rhyolite Member rocks span the range from dacite (a few samples only) to rhyolite (Fig. 8). The K_2O/Na_2O value varies considerably between 0.2 and 1.9; however, most of the rocks are potassium rich.

Geochronology

Table 1 documents the geochronological data for rocks from SHERLOCK. The minimum age of the rocks on the Whim Creek Belt is constrained by the maximum age of the Mount Bruce Supergroup (i.e. c. 2770 Ma — Arndt et al., 1991). In a stratigraphic sense, constraints on the maximum age of the belt depend on interpreted relationships between that belt and the rocks of the De Grey Group (Mallina Formation). According to Hickman (1990), the available evidence indicates that the De Grey Group pre-dates the Whim Creek Group. Fitton et al. (1975) and Horwitz (1979, 1990), however, preferred to correlate the units of the De Grey Group with the Whim Creek Group. Unfortunately, contacts between the two groups are invariably tectonic, and comparisons between the structural histories of the two groups identify no unequivocal temporal relationships. Hence, as the youngest detrital zircons extracted from rocks of the Mallina Formation are 2997 ± 20 Ma (Nelson, 1997), the Whim Creek Group, based on the interpretation of Hickman (1990), would be c. 2997 Ma or younger.

The oldest date obtained from the Whim Creek Belt is a U–Pb zircon (SHRIMP) age of 3009 ± 4 Ma from vitric tuff of the Cistern Formation (Nelson, in prep.). Although this date is within the uncertainty range of the maximum age for the Mallina Formation (2997 ± 20 Ma), it appears likely that the Whim Creek Group is older than, or the same age as, the Mallina Formation.

The lithologically inhomogeneous character of the Caines Well Granitoid Complex is exemplified by recent U–Pb zircon (SHRIMP) dating, which gives the age of the Bookingarra Granite (*AgRg*) and the gneiss (*AgRn*) as 2925 ± 4 Ma and 3093 ± 4 Ma respectively (Nelson, 1997). Thus, if the Whim Creek Group is c. 2997 Ma and younger, then at least one phase of the Caines Well Granitoid Complex post-dates deposition of the group. However, no intrusive contacts were seen between the Caines Well Granitoid Complex and the Whim Creek Group during the course of this study.

Although the gneiss from the granitoid complex is inhomogeneous, the material dated is significantly older than the porphyritic phase of the gneiss north of the Sholl Shear Zone, which has been dated at 3014 ± 3 Ma (Nelson, 1997).

Lead model ages on galena date mineralization within the Cistern Formation at Mons Cupri and the Mons Cupri Volcanics at Salt Creek at c. 2950 Ma (Richards and Blockley, 1984; Richards, 1983). This is also the age of intrusion of the Peawah Granodiorite (2948 ± 5 Ma) in the southeastern part of SHERLOCK.

The tourmaline-bearing leucogranite (*Agl*) that intrudes the Mallina Formation to the south of Opaline Well has been dated at 2765 ± 5 Ma (Nelson, 1997). This

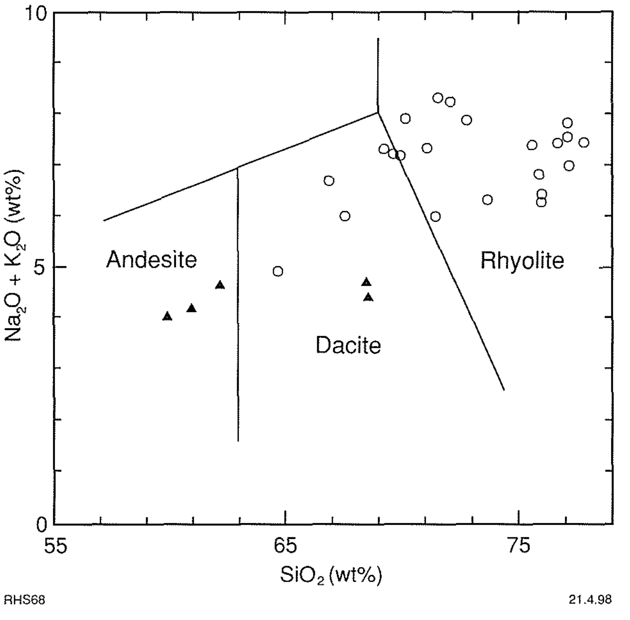


Figure 8. Plot of Na_2O+K_2O versus SiO_2 (Le Maitre, 1989) for the felsic volcanic rocks of the Whim Creek Group. O = Mount Braun Rhyolite Member; ▲ = tuff from the Cistern Formation

Table 1. Geochronological data for SHERLOCK

Age (Ma)	*Method*	*Lithology/material*	*Rock code*	*Location*	
				Longitude	*Latitude*
(e) c.2950	Pb (galena) model age	mineralization at Mons Cupri	*ACc*	Mons Cupri deposit	
(f) 2950 ± 10	Pb (galena) model age	Salt Creek deposit	*?ACfl?ACc*	Salt Creek deposit	
(a) 2990 ± 7	SHRIMP (zircon)	Mons Cupri	*ACf*	Red Hill area	
(d) 3009 ± 4	SHRIMP(zircon)	felsic volcanic rock	*ACct*	Red Hill area	
(c) 2925 ± 4	SHRIMP (zircon)	Caines Well Granitoid Complex	*AgRg*	117°46'57"E	20°50'51"S
(c) 3093 ± 4	SHRIMP (zircon)	Caines Well Granitoid Complex	*AgRn*	117°35'55"E	20°52'07"S
(c) 3014 ± 3	SHRIMP (zircon)	gneiss (north of Sholl Shear Zone)	*Ang*	117°41'44"E	20°44'46"S
(c) <2997 ± 20	SHRIMP (zircon)	Mallina Formation (grit)	*ADm*	117°50'35"E	20°57'12"S
(c) 2948 ± 5	SHRIMP (zircon)	Peawah Granodiorite	*Agpe*	117°59'29"E	20°59'19"S
(b) 2830 ± 30	Sm–Nd whole rock/mineral	'Millindinna Complex'	–	–	–
(b) 2960 ± 20	Pb–Pb whole rock	'Millindinna Complex'	–	–	–
(c) 2765 ± 5	SHRIMP (zircon)	late granite (Opaline Well)	*Agl*	117°43'16"E	20°59'13"S

REFERENCES: (a) Barley et al., 1994; (b) Korsch and Gulson, 1986; (c) Nelson, 1997; (d) Nelson, in prep.; (e) Richards, 1983; (f) Richards and Blockley, 1984

leucogranite is a peraluminous crustal melt related to enhanced crustal heat flow during the magmatism that produced the Fortescue Group. Because such melts are characteristically hydrous, they commonly crystallize close to their source, which, in this case, is likely to be the Mallina Formation itself. The localization of the leucogranite in proximity to the Loudens Fault provides further evidence that the fault was a major active structure at, or about, the time the Fortescue Group was deposited.

Stratigraphy

Correlation between mafic rock types

Mafic volcanism is an important feature of the stratigraphic interval above the Mons Cupri Volcanics; field relationships suggest that the Opaline Well Intrusion and rocks of the Sherlock Intrusion also post-date the Mons Cupri Volcanics but pre-date the Mount Bruce Supergroup. Consequently, it is inviting to speculate about relationships between these rock types within possible constraints established by field, petrographic, and geochemical relationships. Possible constraints include the facts that:

- the Cistern Formation (redefined to include some units previously assigned to the Mons Cupri Volcanics) is a narrow stratigraphic interval of felsic tuffs and tuffaceous sediments but contains layers of basalt (*AaOb*) — in other words, it is a bimodal volcanic sequence;
- vesicular basalt and acicular (clinopyroxene)-textured basalt (*AaOb*) within the Cistern Formation are probably flows and apparently connect, via dykes, to sills belonging to the Opaline Well Intrusion;
- while the acicular (clinopyroxene)-textured basalt (*AaOb*) is a distinctive lithology, similar rocks also lie within the basal portion of the Rushall Slate (the Comstock Member — *ACrc*) and within the Louden Volcanics (e.g. *Aey*);
- the Opaline Well Intrusion and rocks of the Sherlock Intrusion are petrographically distinct — the former being typically more mafic and the latter being typically quartz rich;
- rocks of the Opaline Well Intrusion do not show intrusive contacts with rocks that are stratigraphically higher than the top of the Cistern Formation, although basalt flows possibly relating to that intrusion lie within the basal portion of the Rushall Slate (i.e. the Comstock Andesite Member);
- the Louden Volcanics and the Mount Negri volcanics are distinct, both in outcrop and in geochemistry;
- finer grained rocks within the Opaline Well Intrusion cover the same petrographic range as the Louden Volcanics.

Consequently, it may be speculated that the Comstock Member and the basalts within the Cistern Formation relate to the same mafic volcanic event, which occurred during, and outlasted, the waning stages of felsic volcanism. The Opaline Well Intrusion may represent feeders for this mafic volcanism. The lack of intrusive contacts between rocks of the Opaline Well Intrusion and the Rushall Slate, and the restriction of basaltic units to the lower portions of the shale, may also indicate that mafic magmatism did not outlast deposition of the shale.

It is also possible that the Opaline Well Intrusion represents feeders for the Louden Volcanics, and this would place the bulk of the Rushall Slate stratigraphically above the Louden Volcanics or possibly as correlatives of the clastic unit at the top of the volcanics. The true nature of the contact between the Louden Volcanics and the Rushall Slate is, however, unclear (see **Unconformities**). Alternatively, it is possible that the Opaline Well Intrusion comprises phases of distinctly different age; some relate to basaltic magmatism within the Cistern Formation, while the majority are feeders to the later Louden Volcanics.

Unconformities

The Warambie Basalt – amphibolite unconformity

In the western part of SHERLOCK there is an angular unconformity between the Whim Creek Group and underlying metabasalt (*Aba*). The metabasalt has a steeply inclined foliation that trends at about 160°, compared to a shallow-dipping foliation in the immediately overlying Warambie Basalt, which trends at about 075°.

The basal granite – greenstone unconformity

Unconformities between the basal granite and Archaean greenstone sequences are rare (Barley, 1987; Dawes et al.; 1995). The one between the Whim Creek Group and the gneissic phase of the Caines Well Granitoid Complex is locally well exposed and has been described in detail by Barley (1987). It is best exposed in the vicinity of Red Hill, where granite-bearing boulder conglomerates with a felsic, mafic, or mixed matrix are found. The unconformity is also exposed to the east (AMG 785886 and AMG 885940) within the Whim Creek Belt itself.

The Louden Volcanics – Whim Creek Group ?unconformity

There is no conclusive evidence for a regional or significant unconformity between the Whim Creek Group and the Louden Volcanics. Where contacts are not faulted (e.g. near Red Hill) they appear conformable. It is possible that deposition of the volcanic rocks and the Rushall Slate was partly contemporaneous and that the lower contact with the volcanic rocks is conformable. The implication of this would be that the Louden Volcanics represents a formation within the Whim Creek Group, but field relationships required to clarify this are not available.

The Mount Negri Volcanics – Louden Volcanics unconformity

Contacts between the Louden Volcanics and the Mount Negri Volcanics are mostly faulted, but some are locally unconformable. A distinct compositional gap also separates the two volcanic units. Conglomerate (*Aep* and in *Aes*) is found at, or near, the top of the Louden Volcanics, where it is associated with pillowed basalts and may mark the transition to an erosional hiatus that separates the Louden and Mount Negri Volcanics.

The Whim Creek Group – Mallina Formation unconformity

Outcrops on SHERLOCK provide no direct means of assessing the relationship between the Whim Creek Group and the Mallina Formation. The existence of this unconformity has been suggested by Hickman (1977, 1983, 1990) and accepted by Barley (1987) but was rejected by Horwitz (1979, 1990), who suggested that the Mallina Formation and the upper Whim Creek Group are correlatives. While the available geochronology is consistent with either hypothesis, the latter is preferred.

Evolution and original extent of the Whim Creek Group

Barley (1987) suggested that the Whim Creek Group accumulated within an elongate, fault-bounded structural 'pull-apart' basin, in an ensialic setting. Progressive accumulation was controlled by continued movement along the bounding Kents Bore and Loudens Faults but did not extend beyond those faults. Barley (1987) suggested that mafic volcanism (Warambie Basalt) began in the southern part of the belt and was followed by eruptions of voluminous felsic lavas and pyroclastic material (Mons Cupri Volcanics). The sequence was reworked in fanglomerate deposits along the northern margin (Kents Bore Fault) of the basin. Renewed faulting was accompanied by explosive volcanism, subsidence, and deposition of tuffaceous sediments, including the turbidites of the Rushall Slate. Further faulting was accompanied by eruption of the 'Negri' (Louden and Mount Negri) Volcanics, which were preferentially deposited over pre-existing second-order basins. The basin subsequently experienced upright folding during closure.

The Whim Creek Group sits on granite–greenstone basement and there is strong geochemical evidence for contamination of the constituent mafic magmas by sialic basement. This study has shown, however, that the Kents Bore and Loudens Faults do not mark the original outcrop extent of the Whim Creek Group, and there is no evidence that those faults had a dominating effect on deposition within the group.

The Whim Creek Group and the Louden and Mount Negri Volcanics are folded around the northeastern margin of the Caines Well Granitoid Complex immediately south of the Sholl Shear Zone (see **Structure**). Simple sinistral drag along this fault cannot account for the large-scale fold, since the expected anticlinal axis would trend easterly rather than northeasterly. The fold is interpreted to be a major northeast-plunging anticline related to the main phase of folding recognized within the Whim Creek Belt. The present geometry of the Whim Creek Belt thus suggests that the belt represents the remnants of a domal structure centred on the Caines Well Granitoid Complex, and that the belt originally extended around the northern margin of the Caines Well Granitoid Complex or, more likely, originally overlay the entire area of the granite dome. This is consistent with the presence of the Whim Creek Group southwest of Balla Balla and possibly also at Symond Well (Miller and Smith, 1975). Furthermore, there is evidence that the Whim Creek Group originally extended northward beyond the Sholl Shear Zone (see **Structure**).

Structural evidence (see **Structure**) indicates that much of the movement along many of the major faults post-dates the development of the Whim Creek Group. North of Whim Creek, traces of the Kents Bore Fault intersect the Whim Creek Group itself — clearly indicating that it is not a bounding fault. Early faulting clearly influenced deposition of the Cistern Formation and Rushall Slate, but these formations are not marginal to either the Kents Bore or Loudens Fault and, therefore, it is not clear whether these faults had any major control on deposition.

Economic geology

There are four historical mining centres on SHERLOCK. Two of these — at Mons Cupri and Whim Creek — extracted copper ores, while gold was mined at Toweranna, and asbestos (chrysotile) was mined near Green Hill Bore.

The Whim Creek deposit was discovered in 1888 and was worked until the mid-1920s. A total of 79 263 t of copper ore was mined, containing about 11 500 t of copper, from stratabound copper–zinc mineralization near the base of the Rushall Slate. The slate defines an open, northeast-plunging syncline, and the main ore horizon is mainly confined between two northeast-striking faults separated by about 500 m. The main ore horizon has a maximum thickness of 14 m and contains the primary ore minerals pyrite and/or pyrrhotite, chalcopyrite, sphalerite, and minor amounts of galena (Reynolds et al., 1975). Total reported reserves include 132 448 t of oxide ore at 4.8% copper and an additional 294 834 t of sulfide ore at 2.5% copper (Reynolds et al., 1975).

The Mons Cupri mine is about 4 km southwest of Whim Creek and attained limited production until its closure in 1917. Known reserves are up to 15 Mt of ore at 1% copper, including 1 Mt of ore at 2.5% lead, 3.6% zinc, and 62 ppm silver (Miller and Gair, 1975). The mineralization forms disseminated stockworks, veins, and massive lenses of chalcopyrite, pyrite, galena, and sphalerite, contained primarily within a chalcedony–chlorite–siderite pipe. According to Miller and Gair (1975), the host rock comprises rhyolite fragmental rocks of the Mons Cupri Volcanics. Investigation of the deposit during the present study showed the host rock to comprise abundant boulder conglomerate, medium- to coarse-grained clastic and volcaniclastic rocks, and lesser amounts of felsic pyroclastic rocks. Finer grained clastic rocks including well-laminated shales (the supposed bedded silica caprock of Miller and Gair — 1975) and the Comstock Andesite Member are at the top of the succession and overlie the mineralization. Thus, the mineralized stratigraphic interval is the redefined Cistern Formation.

Gossans have developed within the Whim Creek Group at Salt Creek (near Balla Balla) and have been explored for their base-metal potential. Drilling identified 650 000 t of ore with grades of up to 1.18% copper, 3.53% lead, 9.1% zinc, and 43 g/t silver (Butler, R., 1997, pers. comm.). This massive sulfide mineralization is within fine- to medium-grained tuffaceous siltstone and is overlain by basalt, suggesting a correlation of the host sequence with the Cistern Formation.

Geophysical exploration has identified the presence of a layered mafic body south of Balla Balla, and this has been investigated in terms of its potential for vanadium and titanium mineralization. The intrusion ranges from serpentinite and pyroxenite at the base, to anorthosite, then norite and gabbro, and granophyre at the top. The mineralized zone is a stratiform and strata-bound seam of titaniferous magnetite with a strike length of over 15 km. About 150 Mt of ore at 0.5% vanadium oxide and 16% titanium oxide has been estimated.

The Toweranna mining centre is about 15 km south-southeast of Whim Creek and has yielded 4052 t of ore from which a total of 161.8 kg of gold was extracted. Gold mineralization is in pyrite-rich quartz veins within, and marginal to, a coarse-grained feldspar porphyry (*Apto*) that intrudes the Mallina Formation. The porphyry intrudes the sheared axial region of the northeasterly plunging Croydon Anticline. According to Hickman (1983), a similar porphyry intrudes the axis of the anticline 13 km to the south, suggesting that both emplacement of the porphyry and the mineralization are structurally controlled.

Nickel and copper mineralization have been recorded near Symond Well (Sherlock Bay deposit) in the northwestern part of SHERLOCK, but outcrop is extremely poor and most geological observations are made from drillcore (Miller and Smith, 1975). The mineralization is within a quartz–amphibole–magnetite–sulfide schist that forms part of a steeply north dipping sequence of mafic, intermediate, and felsic volcanic rocks and gabbro. A thin sequence of rhyolite forms the footwall to the ore horizon, separating it from ultramafic bodies that lie adjacent to the Caines Well Granitoid Complex. Ore minerals include pyrite, pyrrhotite, pentlandite, and chalcopyrite, with grades of up to 1.4% nickel and 0.5% copper.

References

ARNDT, N. T., NELSON, D. R., COMPSTON, W., TRENDALL, A. F., and THORNE, A. M., 1991, The age of the Fortescue Group, Hamersley Basin, Western Australia, from ion microprobe zircon U–Pb results: Australian Journal of Earth Sciences, v. 38, p. 261–281.

BARLEY, M. E., 1986, Incompatible element enrichment in Archaean basalts — a consequence of contamination by older sialic crust rather than mantle heterogeneity: Geology, v. 14, p. 947–950.

BARLEY, M. E., 1987, The Archaean Whim Creek Belt, an ensialic fault-bounded basin in the Pilbara Block, Australia: Precambrian Research, v. 37, p. 199–215.

BARLEY, M. E., 1997, The Pilbara Craton, *in* Greenstone belts *edited by* M. J. de WIT and L. ASHWALL: Oxford, Clarendon Press, 809p.

BARLEY, M. E., McNAUGHTON, N. J., WILLIAMS, I. S., and COMPSTON, W., 1994, Age of Archaean volcanism and sulphide mineralization in the Whim Creek Belt, west Pilbara: Australian Journal of Earth Sciences, v. 41, p. 175–177.

BICKLE, M. J., BETTENAY, L. F., BARLEY, M. E., GROVES, D. I., CHAPMAN, H. J., CAMPBELL, I., and de LAETER, J. R., 1983, A 3500 Ma plutonic and volcanic calc-alkaline province in the Archaean East Pilbara Block: Contributions to Mineralogy and Petrology, v. 84, p. 25–35.

BICKLE, M. J., BETTENAY, L. F., CHAPMAN, H. J., GROVES, D. I., McNAUGHTON, N. J., CAMPBELL, I., and de LAETER, J. R., 1989, The age and origin of the younger granitic plutons of the Shaw Batholith in the Archaean Pilbara Block, Western Australia: Contributions to Mineralogy and Petrology, v. 101, p. 361–376.

BICKLE, M. J., MORANT, P., BETTENAY, L. F., BOULTER, C. A., BLAKE, T. S., and GROVES, D. I., 1985, Archaean tectonics of the Shaw Batholith, Pilbara Block, Western Australia — structural and metamorphic tests of the batholith concept, *in* Evolution of Archaean supracrustal sequences *edited by* L. A. AYRES, P. C. THURSTON, K. D. CARD, and W. WEBER: Geological Association of Canada, Special Paper, v. 28, p. 325–341.

BLAKE, T. S., 1984, The lower Fortescue Group of the northern Pilbara Craton — stratigraphy and palaeogeography, *in* Archaean and Proterozoic basins of the Pilbara — evolution and mineralization potential *edited by* J. R. MUHLING, D. I. GROVES, and T. S. BLAKE: University of Western Australia, Geology Department and University Extension, Publication No. 9, p. 123–143.

CAMPANA, B., HUGHES, F. E., BURNS, W. G., WHITCHER, I. G., and MUCENIEKAS, E., 1964, Discovery of the Hamersley iron deposits: Australasian Institute of Mining and Metallurgy, Proceedings, no. 210, p. 1–30.

COLLINS, W. J., 1989, Polydiapirism of the Mount Edgar Batholith, Pilbara Block, Western Australia: Precambrian Research, v. 43, p. 41–62.

DAVID, T. W. E., 1932, Explanatory notes to accompany a new geological map of the Commonwealth of Australia, based on the maps already published by the geological surveys of the various states: Sydney, Commonwealth Council for Scientific and Industrial Research, 177p.

DAWES, P. R., SMITHIES, R. H., CENTOFANTI, J., and PODMORE, D. C., 1995, Sunrise Hill unconformity — a newly discovered regional hiatus between Archaean granites and greenstones in the northeastern Pilbara Craton: Australian Journal of Earth Sciences, v. 42, p. 635–639.

FINUCANE, K. J., and SULLIVAN, C. J., 1939, The Whim Well and Mons Cupri copper mines, Pilbara Goldfields: Aerial Geology and Geophysical Survey North Australia, Western Australia Report, no. 55.

FITTON, M. J., HORWITZ, R. C., and SYLVESTER, G. C., 1975, Stratigraphy of the early Precambrian in the West Pilbara, Western Australia: Australia CSIRO, Mineral Research Laboratories, Division of Mineralogy, Report FP11, 41p.

GLIKSON, A. Y., DAVY, R., and HICKMAN, A. H., 1986a, Geochemical data files of Archaean volcanic rocks, Pilbara Block, Western Australia: Australia BMR, Record 1986/14, 12p.

GLIKSON, A. Y., PRIDE, C., JAHN, B., DAVY, R., and HICKMAN, A. H., 1986b, RE and HFS (Ti, Zr, Nb, P, Y) element evolution of Archaean mafic–ultramafic volcanic suites, Pilbara Block, Western Australia: Australia BMR, Record 1986/6, 85p.

HICKMAN, A. H., 1975, Precambrian structural geology of part of the Pilbara region: Western Australia Geological Survey, Annual Report 1974, p. 68–73.

HICKMAN, A. H., 1977, Stratigraphic relations of rocks within the Whim Creek Belt: Western Australia Geological Survey, Annual Report 1976, p. 53–56.

HICKMAN, A. H., 1981, Crustal evolution of the Pilbara Block, Western Australia: Geological Society of Australia, Special Publication, no. 7, p. 57–69.

HICKMAN, A. H., 1983, Geology of the Pilbara Block and its environs: Western Australia Geological Survey, Bulletin 127, 268p.

HICKMAN, A. H., 1984, Archaean diapirism in the Pilbara Block, Western Australia, *in* Precambrian Tectonics Illustrated *edited by* A. KRÖNER and R. GREILING: Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung, p. 113–127.

HICKMAN, A. H., 1990, Granite–greenstone terrain, *in* Third International Archaean Symposium Excursion Guidebook No. 5 — Pilbara and Hamersley Basin *edited by* S. E. HO, J. E. GLOVER, J. S. MYERS, and J. R. MUHLING: University of Western Australia, Geology Department and University Extension, Publication No. 21, p. 2–13.

HICKMAN, A. H., 1997, A revision of the stratigraphy of Archaean greenstones in the Roebourne–Whundo area, west Pilbara: Western Australia Geological Survey, Annual Review, 1996–97, p. 76–81.

HICKMAN, A. H., and LIPPLE, S. L., 1975, Explanatory notes on the Marble Bar 1:250 000 Geological Sheet, W.A.: Western Australia Geological Survey, Record 1974/20, 90p.

HORWITZ, R. C., 1979, The Whim Creek Group, a discussion: Royal Society of Western Australia, Journal, v. 61, p. 67–72.

HORWITZ, R. C., 1990, Palaeogeographic and tectonic evolution of the Pilbara Craton, northwestern Australia: Precambrian Research, v. 48, p. 327–340.

HORWITZ, R. C., and GUJ, P., 1987, Re-accreditation of the Whim Creek Group: Australia CSIRO, Division of Mineral and Geochemical Research, Review 1985, p. 6–7.

HORWITZ, R. C., and PIDGEON, R. T., 1993, 3.1 Ga tuff from the Sholl Belt in the West Pilbara — further evidence for diachronous volcanism in the Pilbara Craton of Western Australia: Precambrian Research, v. 60, p. 175–183.

KORSCH, M. J., and GULSON, B. L., 1986, Nd and Pb isotopic studies of an Archaean layered mafic–ultramafic complex, Western Australia, and implications for mantle heterogeneity: Geochimica et Cosmochimica Acta, v. 50, p. 1–10.

KRAPEZ, B., 1984, Sedimentation in a small, fault-bounded basin — the Lalla Rookh Sandstone, east Pilbara Block, *in* Archaean and Proterozoic basins of the Pilbara, Western Australia — evolution and mineralization potential: University of Western Australia, Geology Department and University Extension, Publication No. 9, p. 89–110.

KRAPEZ, B., 1993, Sequence stratigraphy of the Archaean supracrustal belts of the Pilbara Block, Western Australia: Precambrian Research, v. 60, p. 1–45.

KRAPEZ, B., and BARLEY, M. E., 1987, Archaean strike-slip faulting and related ensialic basins — evidence from the Pilbara Block, Australia: Geological Magazine, v. 124(6), p. 555–567.

LE MAITRE, R. W., 1989, A classification of igneous rocks and glossary of terms: Oxford, Blackwell Scientific Publications, 193p.

MARSTON, R. J., 1979, Copper mineralization in Western Australia: Western Australia Geological Survey, Mineral Resources Bulletin 13, 208p.

MILLER, L. J., and GAIR, H. S., 1975, Mons Cupri copper–lead–zinc–silver deposit, *in* Economic Geology of Australia and Papua New Guinea — 1. Metals *edited by* C. L. KNIGHT: Australasian Institute of Mining and Metallurgy, Monograph 5, p. 195–202.

MILLER, L. J., and SMITH, M. E., 1975, Sherlock Bay nickel–copper, *in* Economic Geology of Australia and Papua New Guinea — 1. Metals *edited by* C. L. KNIGHT: Australasian Institute of Mining and Metallurgy, Monograph 5, p. 168–174.

NELSON, D. R., 1997, Compilation of SHRIMP U–Pb zircon geochronology data, 1996: Western Australia Geological Survey, Record 1997/2, 189p.

NELSON, D. R., in prep., Compilation of SHRIMP U–Pb zircon geochronology data, 1997: Western Australia Geological Survey, Record.

NOLDART, A. J., and WYATT, J. D., 1962, The geology of portion of the Pilbara Goldfield covering the Marble Bar and Nullagine 4 mile map sheets: Western Australia Geological Survey, Bulletin 115, 199p.

OVERSBY, V. M., 1976, Isotopic ages and geochemistry of Archaean acid igneous rocks from the Pilbara, Western Australia: Geochimica et Cosmochimica Acta, v. 40, p. 817–829.

PIDGEON, R. T., 1978, 3450 m.y. old volcanics in the Archaean layered greenstone succession of the Pilbara Block, Western Australia: Earth and Planetary Science Letters, v. 37, p. 421–428.

REYNOLDS, D. G., BROOK, W. A., MARSHALL, A. E., and ALLCHURCH, P. D., 1975, Volcanogenic copper–zinc deposits in the Pilbara and Yilgarn Archaean Blocks, *in* Economic Geology of Australia and Papua New Guinea — 1. Metals *edited by* C. L. KNIGHT: Australasian Institute of Mining and Metallurgy, Monograph 5, p. 185–195.

RICHARDS, J. R., 1983, Lead isotopes as indicators of old stable craton in Western Australia: Geochemical Journal, v. 17, p. 247–255.

RICHARDS, J. R., and BLOCKLEY, J. G., 1984, The base of the Fortescue Group, Western Australia — further galena lead isotope evidence on its age: Australian Journal of Earth Sciences, v. 31, p. 257–268.

RYAN, G. R., and KRIEWALDT, M., 1964, Facies changes in the Archaean of the West Pilbara Goldfield: Western Australia Geological Survey, Annual Report 1963, p. 28–30.

RYAN, G. R., KRIEWALDT, M., and BOCK, W., 1965, Roebourne, W.A. Sheet SF/50–3 International Index: Australia BMR, 1:250 000 Geological Series.

SMITHIES, R. H., 1996, Refinement of the stratigraphy of the Whim Creek Belt, Pilbara granite–greenstone terrain — new field evidence from the Sherlock 1:100 000 sheet: Western Australia Geological Survey, Annual Review 1995–96, p. 118–123.

SMITHIES, R. H., in prep., Geology of the Mount Wohler 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes.

SPEAR, F. S., and CHENEY, J. T., 1989, A petrogenetic grid for pelitic schists in the system $SiO_2 - Al_2O_3 - FeO - MgO - K_2O - H_2O$: Contributions to Mineralogy and Petrology, v. 101, p. 149–164.

SUN, S-S., NESBITT, R. W., and McCULLOCH, M. T., 1989, Geochemistry and petrogenesis of Archaean and early Proterozoic siliceous high-magnesian basalts, *in* Boninites *edited by* A. J. CRAWFORD: Sydney, Unwin Hyman, p. 148–173.

THORNE, A. M., 1990, Geology of the Pilbara Craton, *in* Third International Archaean Symposium Excursion Guidebook No. 5 — Pilbara and Hamersley Basin *edited by* S. E. HO, J. E. GLOVER, J. S. MYERS, and J. R. MUHLING: University of Western Australia, Geology Department and University Extension, Publication No. 21, p. 13–36.

THORPE, R. I., HICKMAN, A. H., DAVIS, D. W., MORTENSEN, J. K., and TRENDALL, A. F., 1992, U–Pb zircon geochronology of Archaean felsic units in the Marble Bar region, Pilbara Craton, Western Australia: Precambrian Research, v. 56, p. 169–189.

WILLIAMS, I. S., and COLLINS, W. J., 1990, Granite–greenstone terranes in the Pilbara Block, Australia, as coeval volcano-plutonic complexes; evidence from U–Pb zircon dating of the Mount Edgar batholith: Earth and Planetary Science Letters, v. 97, p. 41–53.

WOODWARD, H. P., 1911, The geology and ore deposits of the West Pilbara Goldfield: Western Australia Geological Survey, Bulletin 41, 142p.

Appendix

Definition of stratigraphic names from the SHERLOCK 1:100 000 sheet

Cistern Formation

(redefined)

Derivation of name: Miller and Gair (1975).

Distribution: Outcrops locally between Red Hill (20°57'50"E, 117°31'40"S) and Whim Creek (20°50'30"E, 117°50'00"S).

Type area: 2 km north-northwest of Opaline Well (20°58'45"S, 117°42'40"E).

Lithology: Felsic tuff and reworked tuff, conglomerate, poorly sorted sandstone, siltstone, and laminated shale of dominantly epiclastic origin. Forms a generally upward-fining sequence. It includes abundant vitric (both crystal and lithic) tuffs of andesitic composition and minor amounts of basalt commonly showing pyroxene spinifex textures.

Thickness: up to 300 m.

Relationships and boundary criteria: Forms part of the Whim Creek Group. Overlies the Mons Cupri Volcanics with local unconformities and is conformably overlain by the Rushall Slate.

Age: Felsic tuffs dated at 3009 ± 4 Ma (Nelson, in prep.).

Comments: The name was originally used by Miller and Gair (1975) in reference to a sandstone–tuff unit overlying tuffaceous and volcaniclastic beds at the top of the Mons Cupri Volcanics. The unit has been expanded to include those tuffaceous and volcaniclastic beds.

Comstock Member

(redefined — formerly Comstock Andesite Member)

Derivation of name: Miller and Gair (1975).

Distribution: A north-trending outcrop about 3 km long that passes through Mons Cupri (20°52'45"E, 117°48'20"S).

Type area: Between Mons Cupri and Comstock (20°52'55"E, 117°48'25"S).

Lithology: Basalt or high-Mg basalt, commonly heavily chloritized and ferruginized. The rocks are fine grained and many are vesicular. Most contain carbonate–chlorite pseudomorphs after pyroxene, which locally form a spinifex texture. The rock closely resembles basalt within the Cistern Formation and the Louden Volcanics.

Thickness: Less than 100 m.

Relationships and boundary criteria: Lies conformably within the lower part of the Rushall Slate of the Whim Creek Group.

Age: Between c. 3010 Ma (age of the Cistern Formation) and c. 2970 Ma (age of felsic volcanic rocks that overlie the Whim Creek Group on ROEBOURNE — Nelson, in prep.).

Synonymy: Comstock Andesite Member (Miller and Gair, 1975).

Sherlock Intrusion

Derivation of name: Sherlock Homestead (20°53'55"E, 117°38'40"S).

Distribution: Outcrops along the northern margin of the Whim Creek Belt between Tin Hut Bore (20°45'50"E, 117°46'40"S) and a point about 5 km northwest of Red Hill (20°57'50"E, 117°31'40"S).

Type area: Madabarena Pool (20°57'00"E, 117°36'35"S).

Lithology: The rock is medium- to coarse-grained gabbro and leucogabbro, ranging from massive to well foliated.

Thickness: Up to 800 m.

Relationships and boundary criteria: Intrudes between the Caines Well Granitoid Complex and the Whim Creek Belt. Possibly an intrusive equivalent to the Mount Negri Volcanics.

Age: Younger than c. 3010 Ma (age of the Whim Creek Group) but older than the c. 2770 Ma rocks of the Mount Bruce Supergroup.

Comments: One of numerous intrusive mafic rocks originally included in the regional 'Millindinna Complex' by Fitton et al. (1975).

Opaline Well Intrusion

Derivation of name: Opaline Well (20°58'45"S, 117°42'40"E).

Distribution: Outcrops locally between Red Hill (20°57'50"E, 117°31'40"S) and Tin Hut Bore (20°45'50"E, 117°46'40"S).

Type area: Opaline Well (20°58'45"S, 117°42'40"E) and 1 km west of Opaline Well.

Lithology: Gabbro, peridotitic gabbro and peridotite, and fine-grained gabbro. Outcrops locally show 1 to 10 m-scale igneous layering.

Thickness: Up to 800 m.

Relationships and boundary criteria: Intrudes the Whim Creek Group or lies at the contact between that group and rocks of the Sherlock Intrusion.

Age: Younger than c. 3010 Ma (age of the Whim Creek Group) but older than the c. 2770 Ma rocks of the Mount Bruce Supergroup. They pre-date emplacement of the Sherlock Intrusion and may be the intrusive equivalent of the Louden Volcanics.

Comments: One of numerous intrusive mafic rocks originally included in the regional 'Millindinna Complex' by Fitton et al. (1975).

Caines Well Granitoid Complex

Derivation of name: Caines Well (20°47'45"S, 117°48'30"E).

Distribution: West and north of the Whim Creek Belt (and North West Coastal Highway).

Type area: Intersection of the Sherlock River and the old North West Coastal Highway (20°52'10"S, 117°35'55"E).

Lithology: Monzogranitic gneiss containing biotite. Includes xenoliths of amphibolite facies ultramafic rocks. Also includes Bookingarra Granite (see below).

Relationships and boundary criteria: Forms part of the basement to the Whim Creek Group. It outcrops very poorly, exposed mainly in the bed of the Sherlock River or as xenoliths within the Bookingarra Granite.

Age: 3093 ± 4 Ma for gneiss to 2925 ± 4 Ma for Bookingarra Granite (Nelson, 1977).

Synonymy: Caines Well Granite.

Bookingarra Granite

Derivation of name: Bookingarra Creek (20°54'40"S, 117°44'10"E).

Distribution: West of the Whim Creek Belt, but east of Salt Creek Well (20°48'50"S, 117°43'30"E).

Type area: 2.5 km north-northeast of Kent Well (20°51'45"S, 117°46'35"E).

Lithology: Medium- to coarse-grained porphyritic rock ranging from hornblende- and biotite-bearing monzogranite to biotite-bearing syenogranite.

Relationships and boundary criteria: Forms the youngest recorded phase of the Caines Well Granitoid Complex.

Age: 2925 ± 4 Ma (Nelson, 1997).

Synonymy: Caines Well Granite.

References

FITTON, M. J., HORWITZ, R. C., and SYLVESTER, G. C., 1975, Stratigraphy of the early Precambrian in the West Pilbara, Western Australia: Australia CSIRO, Mineral Research Laboratories, Division of Mineralogy, Report FP11, 41p.

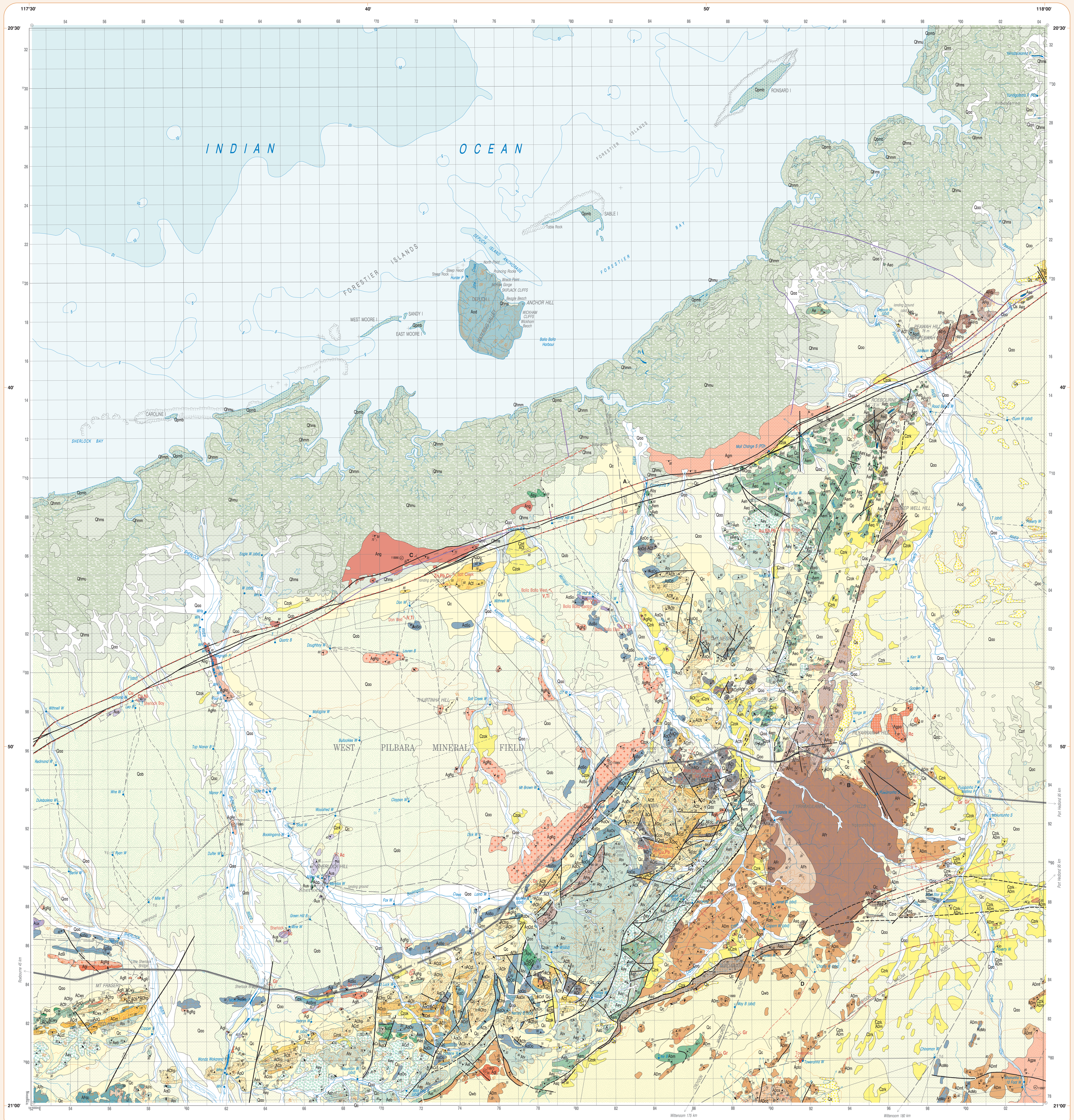
MILLER, L. J., and GAIR, H. S., 1975, Mons Cupri copper–lead–zinc deposit, *in* Economic Geology of Australia and Papua New Guinea — 1. Metals *edited by* C. L. KNIGHT: Australasian Institute of Mining and Metallurgy, Monograph 5, p. 195–202.

NELSON, D. R., 1997, Compilation of SHRIMP U–Pb zircon geochronology data, 1996: Western Australia Geological Survey, Record 1997/2, 189p.

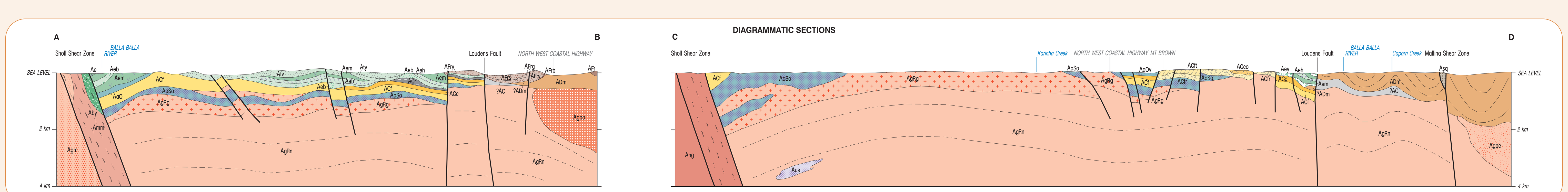
NELSON, D. R., in prep., Compilation of SHRIMP U–Pb zircon geochronology data, 1997: Western Australia Geological Survey, Record.

SHERLOCK

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA



DIAGRAMMATIC SECTIONS



Legend

CAINOZOIC — QUATERNARY

- Qhmm — Marine mud and silt; intertidal with mangroves
- Qhms — Shelly sand in coastal dunes and old beach deposits; contains *Anadara granosa*
- Qhmu — Silt and mud in supratidal to intertidal flats and lagoons
- Qpmb — Coastal limestone; lime-cemented shelly sand, dune sand, and beach conglomerate
- Qaa — Alluvium—sand and gravel in rivers and creeks; clay, silt, and sand in channels on floodplains
- Qac — Claypan deposits on floodplains
- Qao — Alluvial sand, silt, and clay in floodplains
- Qab — Alluvial sand, silt, and clay in floodplains, with gilgai surface in areas of expansive clay
- Qwb — Sheetwash sand, silt, and clay in distal outwash fans, with gilgai surface in areas of expansive clay
- Qc — Colluvium—sand, silt, and gravel in outwash fans and scree
- Qs — Eolian sand—red-yellow, wind blown sand; local ridges

- Czak — Calcrete—massive, nodular and cavernous limestone, variably silicified; alluvial origin
- Czrf — Ferricrete—includes ferruginous and pisolitic ironstone on lateritic surfaces
- Czrk — Calcrete—massive, nodular and cavernous limestone, variably silicified; residual origin
- Czro — Massive and nodular opaline silica; residual origin

- q — Quartz vein

HAMERSLEY BASIN — Mount Bruce Supergroup — Fortescue Group

- AFdc — **COOYA POOYA DOLERITE:** fine- to medium-grained dolerite
- AFh — **HARDEY FORMATION:** arkosic sandstone, pebbly sandstone, and tuffaceous grit
- AFr — **MOUNT ROE BASALT:** undifferentiated mafic volcanics, volcaniclastics, and tuffaceous sedimentary rocks
  - AFry — Vesicular basalt
  - AFrg — Glomeroporphyritic basalt
  - AFrb — Basaltic breccia
  - AFrc — Polymictic conglomerate; poorly sorted and matrix supported
  - AFrs — Well laminated shale, siltstone, and poorly sorted tuffaceous sandstone; well developed graded beds, ripple cross-bedding, and mudcracks

ARCHAEAN — PILBARA CRATON

- *c.* 2765 Ma — Agl — Leucogranite; medium-grained; biotite(-tourmaline)-bearing; unfoliated
- Aod — Dolerite and gabbro
- *c.* 2925 Ma — AgRg — **BOOKINGARRA GRANITE:** medium- to coarse-grained biotite monzogranite to syenogranite; locally strongly foliated; metamorphosed

Pilbara Supergroup

- Amm — Mylonite and mylonitic gneiss; in Sholl Shear Zone (Section only)
- AaMo — **Millindinna Intrusion:** gabbro; metamorphosed
- *c.* 2925 Ma — **Sherlock Intrusion**
  - AaSo — Gabbro; metamorphosed
  - AaSl — Leucogabbro; metamorphosed
  - AaSoy — Granophyric gabbro; metamorphosed
- AaO — **Opaline Well Intrusion:** fine- to coarse-grained mafic intrusive rock; minor extrusive mafic rock; metamorphosed
  - AaOb — Metabasalt, vesicular; local acicular pyroxene
  - AaOo — Metagabbro; acicular texture
  - AaOd — Metamorphosed dolerite or microgabbro; seriate to acicular textures
  - AaOv — Metamorphosed olivine gabbro; includes minor dunite, and pyroxenite; local metre-scale igneous banding from acicular-textured gabbro to olivine gabbro
- At — **MOUNT NEGRI VOLCANICS:** metamorphosed variolitic and vesicular basalt, undivided (Section only)
  - Atv — Variolitic basalt; metamorphosed
  - Aty — Vesicular basalt; metamorphosed
- Ae — **LOUDEN VOLCANICS:** undifferentiated metamorphosed basalt and high-Mg basalt; metamorphosed interbedded clastic units and chert
  - Aep — Polymictic conglomerate; poorly sorted and matrix supported; metamorphosed
  - Aeq — Quartzite; medium- to coarse-grained; black chert clasts; locally graded and trough cross-bedded; metamorphosed
  - Aes — Sandstone; fine- to medium-grained; poorly sorted; arkosic; includes shale beds and polymictic conglomerate; metamorphosed
  - Aec — Chert; banded red-grey; metamorphosed
  - Ael — Pillowed basalt; locally pyroxene spinifex textured; metamorphosed
  - Aey — Vesicular basalt; local abundant aphyric basalt and high-Mg basalt; metamorphosed
  - Aeb — Aphyric basalt; metamorphosed
  - Aed — Basalt, fine- to medium-grained; includes sills; metamorphosed
  - Aet — Serpentine-chlorite schist; sheared high-Mg basalt; metamorphosed
  - Aem — High-Mg basalt; pyroxene spinifex texure; local abundant komatiite, characterized by olivine spinifex texture; metamorphosed
  - Aeh — High-Mg basalt; acicular textures; minor komatiite, characterized by olivine spinifex texture; metamorphosed
  - Aeo — Peridotite; olivine cumulate texture; metamorphosed
- *c.* 2950 Ma
  - Agpe — **PEAWAH GRANODIORITE:** metamorphosed medium-grained tonalite to granodiorite; plagioclase phenocrysts; weakly foliated to massive
  - Apto — **TOWERANNA PORPHYRY:** metamorphosed porphyritic granodiorite; possibly equivalent to PEAWAH GRANODIORITE

De Grey Group (< 3000 Ma)

- ADm — **MALLINA FORMATION:** metamorphosed interbedded laminated shale, siltstone, and poorly sorted arkosic sandstone; minor layers of metachert and metamorphosed felsic tuff
  - ADmf — Shale, siltstone and sandstone, includes layers of feldspar(-hornblende) porphyry; metamorphosed
- **CONSTANTINE SANDSTONE**
  - ADcq — Quartzite; medium- to coarse-grained; minor fuchsitic metachert clasts; minor graded beds
  - ADcs — Interbedded poorly sorted sandstone and shale; minor graded beds; metamorphosed

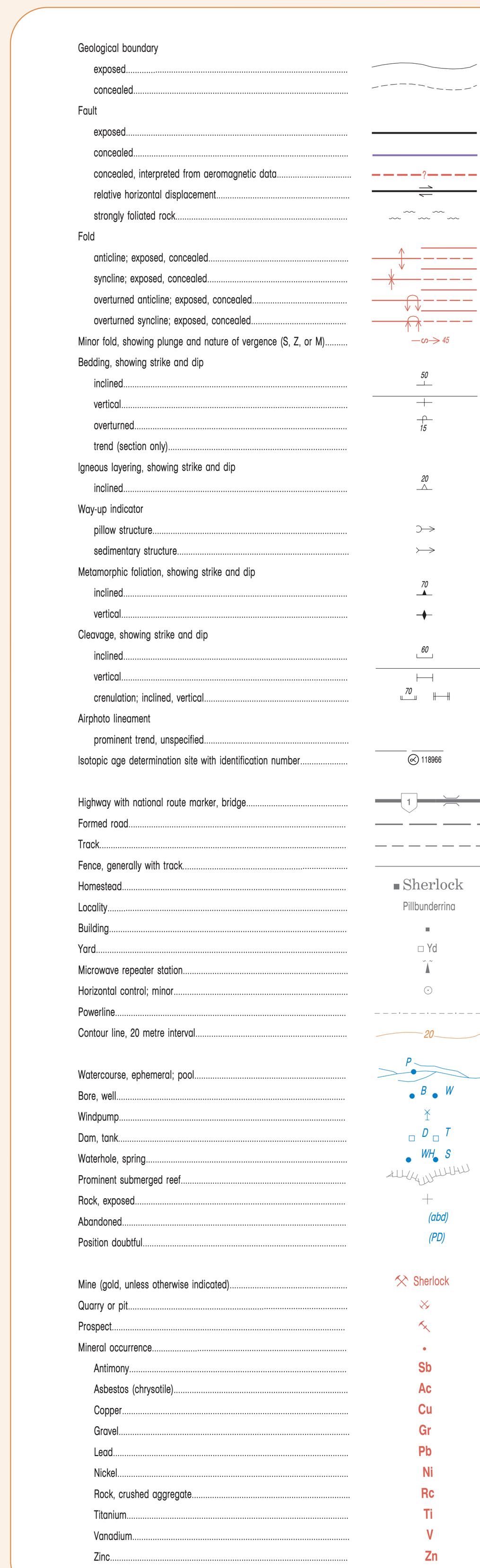
Pilbara Supergroup — Whim Creek Group (*c.* 3010 Ma)

- ACr — **RUSHALL SLATE:** metamorphosed well laminated shale and siltstone; minor sandstone; graded beds; maybe equivalent to lower part of **MALLINA FORMATION**
  - ACrc — **Comstock Member:** vesicular basalt; metamorphosed
- ACc — **CISTERN FORMATION:** metamorphosed tuffaceous felsic volcanic rock and fine- to coarse-grained felsic volcaniclastic rock, andesite to dacite; includes thin metabasaltic flows and sills
  - ACct — Andesite to dacite vitric tuff, locally rich in lithic and crystal fragments; metamorphosed
  - ACcf — Poorly sorted tuffaceous sandstone, siltstone and mudstone; felsic volcaniclastic and epiclastic origin; minor clastic rocks, including oligomictic conglomerate layers; graded beds; metamorphosed
  - ACco — Oligomictic conglomerate; felsic volcanic clasts; minor basaltic clasts; generally matrix supported; metamorphosed
- ACf — **MONS CUPRI VOLCANICS:** metamorphosed felsic volcanic and volcaniclastic rocks; rhyolite, dacite and minor andesite
  - ACft — Felsic volcanic and volcaniclastic rocks, tuffaceous; rhyolite, dacite and minor andesite; metamorphosed
  - ACfr — **Mount Brown Rhyolite Member:** porphyritic rhyolite and dacite; lavas and pyroclastics, minor tuff with feldspar and quartz phenocrysts; light-grey to white; locally flow banded; metamorphosed
  - ACfrp — Rhyolite to dacite porphyry, with quartz phenocrysts; dark grey; metamorphosed
- ACw — **WARAMBIE BASALT:** metamorphosed basalt and minor coarse-grained sedimentary rock; interfingers with basal portions of **MONS CUPRI VOLCANICS**
  - ACwx — Fragmental basalt, mafic breccia, and polymictic mafic conglomerate; locally abundant rhyolite boulders; metamorphosed
  - ACwy — Basalt, commonly vesicular; locally plagioclase-phyric to glomeroporphyritic; metamorphosed
- Asq — Quartzite; medium- to coarse-grained; subangular clasts and pebbles of metamorphosed black chert; locally graded beds and trough cross-beds
- Abm — High-Mg basalt; carbonate, chlorite, and sericite alteration; locally interbedded with shale and arkosic sandstone; minor tuffaceous volcaniclastic rocks; metamorphosed
- Aby — Basalt, commonly vesicular; metamorphosed

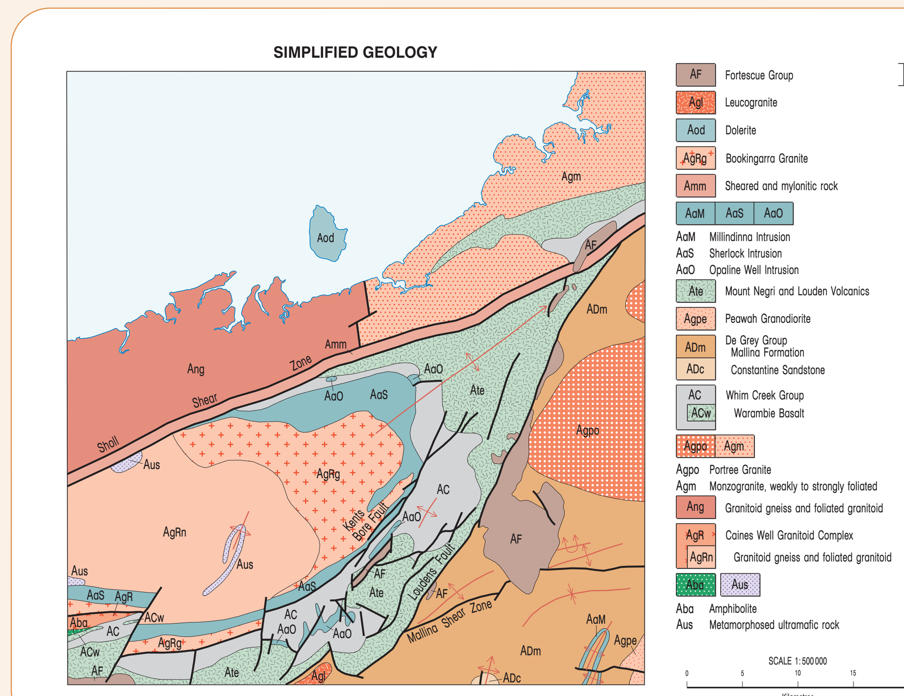
- Agpo — **PORTREE GRANITE:** medium- to coarse-grained biotite monzogranite; weakly foliated; metamorphosed
- Agm — Monzogranite; medium-grained; biotite-bearing; weakly to strongly foliated; metamorphosed
- *c.* 3015 Ma — Ang — Monzogranite, strongly foliated and locally gneissic; medium-grained; biotite-bearing; locally migmatitic and pegmatitic; metamorphosed to amphibolite facies
- *c.* 3095 Ma — AgR — **CAINES WELL GRANITOID COMPLEX:** granitoid gneiss and foliated granitoid rock; includes younger **BOOKINGARRA GRANITE** and xenoliths of metamorphosed mafic and ultramafic rocks
  - AgRn — Monzogranite, strongly foliated and locally gneissic; biotite-bearing; locally migmatitic; metamorphosed to amphibolite facies

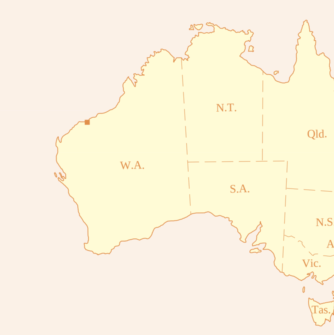
Pilbara Supergroup (> 3010 Ma)

- Aba — Amphibolite; medium-grained; strongly foliated
- Aus — Serpentinized ultramafic rock; retrogressed amphibolite-grade metamorphic rock
- Aux — Pyroxenite; locally ferruginized; weakly metamorphosed

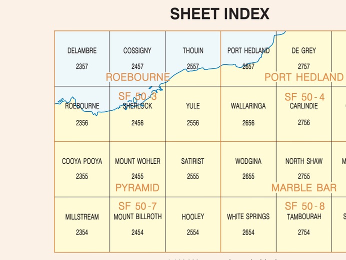


SIMPLIFIED GEOLOGY

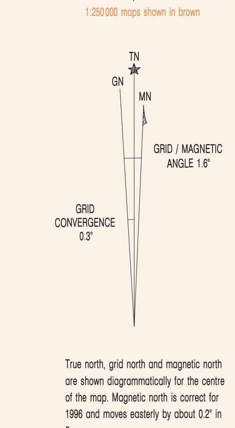




SHEET INDEX



1:100 000 maps shown in black



GOVERNMENT OF WESTERN AUSTRALIA
HON. NORMAN MOORE, M.L.C.
MINISTER FOR MINES

DEPARTMENT OF MINERALS AND ENERGY
L. C. RANFORD, DIRECTOR GENERAL

NGMA
PRODUCT OF THE NATIONAL GEOSCIENCE MAPPING ACCORD

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
DAVID BLIGHT, DIRECTOR

SCALE 1:100 000

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

TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM
BATHYMETRIC DATUM: LOWEST LOW SEA LEVEL

Grid lines indicate 1000 metre interval of the Map Grid Australia Zone 50

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

Geology by R.H. Smithies 1995

Edited by S. Willis, C. Strong, G. Loan and C. Brien

Cartography by C. Bartlett, B. Williams and P. Taylor

Topography from the Royal Australian Survey Corps with modifications from geological field survey

Bathymetric data supplied by the Department of Transport, and is not to be used for navigation purposes

Published by the Geological Survey of Western Australia. Copies available from the Mining Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, WA, 6004. Phone (09) 222 3459, Fax (09) 222 3444

This map is also available in digital form

Printed by Allwest Print, Western Australia

The recommended reference for this map is: SMITHIES, R.H., 1997, Sherlock, W.A. Sheet 2456: Western Australia Geological Survey, 1:100 000 Geological Series

SHERLOCK

SHEET 2456 FIRST EDITION 1997