Department of
Industry and Resources

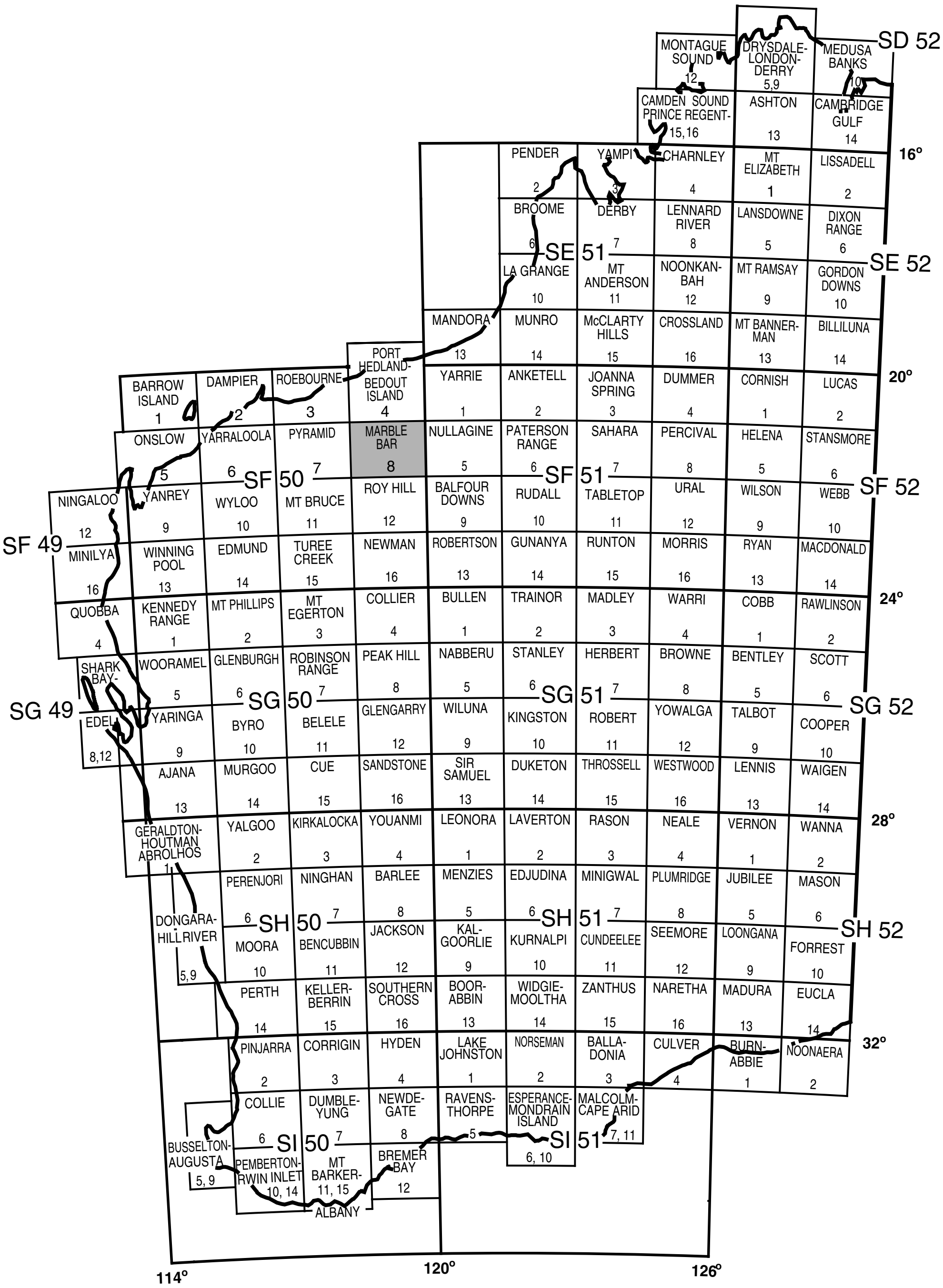
EXPLANATORY NOTES

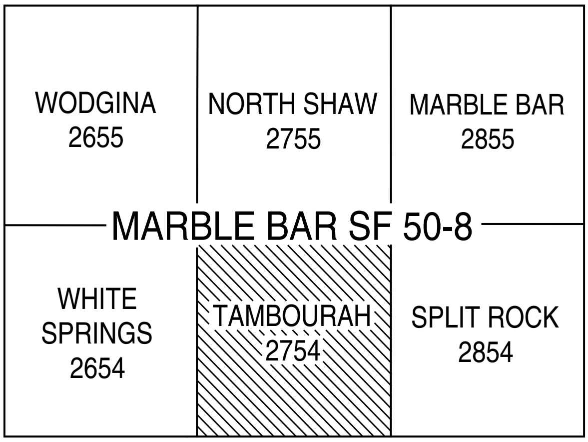
# GEOLOGY OF THE TAMBOURAH 1:100 000 SHEET

by M. J. Van Kranendonk

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

# GEOLOGY OF THE TAMBOURAH 1:100 000 SHEET

by
M. J. Van Kranendonk

Perth 2003

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**Cover photograph:**
View looking west of the Shaw River between the Hillside Track and White Quartz Hill. Low outcrops are of the Shaw Granitoid Complex

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# Geology of the Tambourah 1:100 000 sheet

by

M. J. Van Kranendonk

## Abstract

The TAMBOURAH 1:100 000 sheet lies in the southern-central part of the well-exposed East Pilbara Granite–Greenstone Terrane of the Pilbara Craton. Apart from sparse Cainozoic cover, the sheet area is entirely underlain by Archaean rocks, including metavolcanic and metasedimentary rocks of the Pilbara Supergroup, outliers of the basal parts of the Fortescue Group, and a variety of granitoid rocks that outcrop in parts of three domical complexes and as minor intrusions.

The Pilbara Supergroup on TAMBOURAH is subdivided into four groups. The lowermost part of the stratigraphy includes the dominantly volcanic Warrawoona Group (c. 3430 Ma) and the unconformably overlying, c. 3240 Ma, Sulphur Springs Group. Amphibolite-facies, shelf-type supracrustal rocks of the Golden Cockatoo Formation form infolded remnants in the Yule Granitoid Complex across what may be an unconformity with c. 3430 Ma orthogneiss. The age of this formation is unknown, but it is interpreted as a basal part of the Sulphur Springs Group. Disconformably overlying the Warrawoona and Sulphur Springs Groups are low-grade metasedimentary and metavolcanic rocks of the undated Gorge Creek Group. Lying unconformably on all of these older rocks are coarse clastic metasedimentary rocks of the c. 2940 Ma De Grey Group (Lalla Rookh Sandstone).

The Yule, Shaw, and Tambina Granitoid Complexes are multi-component structural domes that have intrusive and sheared intrusive contacts with surrounding greenstones. The oldest phases are tonalite–trondhjemite–granodiorite (TTG) in composition, whereas younger components are monzogranites. Dated phases of the granitoid complexes range in age from c. 3485 to 2850 Ma.

The Pilbara Supergroup is unconformably overlain by undated coarse clastic sedimentary rocks at the base of the Fortescue Group in two small, fault-bounded sub-basins within the Emerald Mine Greenstone Complex. Outcrops of the Fortescue Group (Tumbiana Formation) are also present along the southern edge of the map sheet, where they lie unconformably on granitoid rocks.

Metamorphic grade in the greenstones decreases away from granitoid complexes, from middle and lower amphibolite facies, through widespread lower greenschist facies, to prehnite–pumpellyite facies. Relicts of low- to medium-pressure granulite-facies (two pyroxenes, no garnet) assemblages are rarely preserved in amphibolite enclaves in the Shaw Granitoid Complex. Metamorphism accompanied intrusion of granitoid rocks into the Yule Granitoid Complex at c. 3240 Ma and c. 2940 Ma.

Three periods of deformation were recognized in the granite–greenstone basement. $D_1$ took place during accumulation of the Warrawoona Group and synvolcanic intrusion of TTG sills, between c. 3469 and 3430 Ma, and is manifest as a gneissic layering in early granitoid phases. $D_2$ structures are present in the Western Shaw greenstone belt and include foliations and lineations defined by amphibolite- to greenschist-facies metamorphic minerals, and folds. These structures formed at c. 3240 Ma during granitoid intrusion and doming of the Yule Granitoid Complex. $D_3$ structures are prominently developed in the Lalla Rookh – Western Shaw Structural Corridor, a 30 km wide, north–south-striking, fault-bounded zone of tightly folded, faulted, and sheared rocks resulting from northwest–southeast oriented compression at c. 2940 Ma. Intrusion of the post-tectonic Cooglegong and Spear Hill Monzogranites took place at c. 2850 Ma. $D_4$ faults accompanied deposition of the Fortescue Group and opening of the Hamersley Basin. These rocks were later affected by low amplitude folding and renewed faulting ($D_5$).

TAMBOURAH had extensive small-scale mining operations, particularly for epigenetic gold, at the Tambourah (177 kg gold produced) and Western Shaw (46 kg gold produced) mining centres around the turn of the last century. Alluvial gold was mined from Western Shaw until 1997. Alluvial tin and tantalum were mined in the 1960s from albite pegmatite swarms around the margins of the Cooglegong and Spear Hill Monzogranites. Chrysotile asbestos was mined from serpentinized peridotites of the Daltons Suite, whose contacts have been explored for nickel–copper sulfides and platinum group elements. Beryllium oxide and gemstone-quality emeralds were also mined within, and marginal to, the Shaw Granitoid Complex in the 1960s and 1970s. There are currently no operating mines on TAMBOURAH.

**KEYWORDS:** Pilbara Craton, greenstone, granitoid, Pilbara Supergroup, structural evolution, metamorphism, gold, tin, emerald.

# Introduction

## Location, access, and land use

The TAMBOURAH* 1:100 000 sheet (SF 50-8, 2754) is bound by latitudes 21°30'S and 22°00'S and longitudes 119°00'E and 119°30'E (Fig. 1) and lies within the central southern part of the MARBLE BAR 1:250 000 sheet, 60 km southwest of Marble Bar in the East Pilbara Mineral Field. The sheet area can be accessed by a triangle of three unsealed roads including the BHP Iron Ore road to the west, the Woodstock – Hillside – Marble Bar track, which traverses the map area from west to east, and a track from Hillside Station to Bamboo Springs in the southeast (Fig. 2). Much of the map area is only accessible by 4WD vehicle on unmaintained tracks or by driving across country, while rugged terrain in the southwest can only be visited by walking or by helicopter. Some of the tracks are at least 20 years old, abandoned, and quickly deteriorating due to erosion. Potable water is present in many permanent and temporary water holes, particularly on the Shaw River.

The only extant settlement on TAMBOURAH is Hillside Station, a thriving cattle enterprise. Woodstock Station lies 7 km to the west of TAMBOURAH on the Woodstock – Hillside – Marble Bar track, and also runs cattle onto the sheet area. The Redmont Camp of the BHP Iron Ore railway lies in the southwest of the sheet (Fig. 2).

Historically, TAMBOURAH was the site of several once quite large mining centres, including the Eley, Coondina, and Cooglegong tin camps, the Western Shaw gold town, which had its own ore railway and telegraph station, and a smaller mining settlement at Soanesville in the northwest. Part of the Yandeyarra Aboriginal Reserve is in the southwestern corner of the sheet and land vested directly in Aboriginal corporations occupies the western part of the sheet area (Fig. 2). Ancient Aboriginal petroglyphs are common on granitoid tors throughout the area.

## Climate, vegetation, and physiography

The climate of TAMBOURAH is arid with an average annual rainfall of 316 mm. Summer rainfall between December and April may be heavy due to thunderstorms or decaying tropical cyclones; winter rains are commonly lighter. Summers are very hot, with mean maximum temperatures in the high 30s to low 40s (°C), and the winters are mild, with mean minimum July temperatures of around 10°C.

TAMBOURAH lies within the Fortescue Botanical District and is broadly divisible into three regimes (Beard, 1975). The main channel and associated floodplains of the Shaw, Western Shaw, and Yule rivers, and the larger creeks are lined with riverain Sclerophyll woodlands of River Gum (*Eucalyptus camaldulensis*). The most widespread regime consists of shrub steppe of soft spinifex (*Triodia pungens*) with scattered *Acacia*, *Grevillia*, and *Hakea* species. This regime occurs mainly on the large granitoid complexes (low granite hills; see Fig. 2). The third regime is a tree steppe of Snappy Gum (*Eucalyptus brevifolia*) with spinifex, and scattered *Acacia, Grevillia, and Hakea* species. This regime is restricted to hills and ranges that are underlain predominantly by metamorphosed volcanic and sedimentary rocks.

The topography on TAMBOURAH reflects the bedrock geology; greenstones outcrop as strike-controlled ridges, whereas granitoid rocks are typically weathered flat, with a subdued undulating topography occasionally broken by tors and laterite mesas. This topography forms the ‘Range’ and ‘Low granite hills’ divisions shown on Figure 2. Outcrop is extremely good, except in the central parts of the Shaw Granitoid Complex where rocks are partly covered by alluvium and colluvium. The highest measured elevation of 541 m is along the southern edge of the map sheet, where the Fortescue Group unconformably overlies granitoid rocks. The most rugged topography is along a north–south striking range that reaches a maximum height of 506 m in the south-central and northern parts of the sheet. In the northern part, two steep-sided plateaus are underlain by ferruginized banded iron-formation (BIF) and derived ferruginous duricrust. This surface represents a relict weathering peneplain of the Hamersley Surface (Campana et al., 1964). Cutting across the Shaw Granitoid Complex is the Black Range (Fig. 2), a prominent ridge, continuous for 57 km, which rises steeply up to 130 m above the surrounding plain.

TAMBOURAH is transected by numerous creeks that flow into the Shaw and Yule Rivers, the former reaching a maximum width of 1.5 km on either side of the Black Range at Hillside Station (Fig. 2). Drainage flows dominantly northwards to the Indian Ocean, but the creeks are dry for most of the year except during the wet summer months.

## Map reliability

TAMBOURAH is the result of detailed mapping using 1:25 000-scale colour aerial photographs. The bulk of the area was mapped by foot traverses spaced at 2–5 km intervals. Mapping in the area of low granite hills in the southwest of the sheet was completed by helicopter, with stops approximately every 5 km.

Mapping of TAMBOURAH for the Geological Survey of Western Australia (GSWA) commenced in 1998 and continued through 1999, with approximately 25% of the sheet area mapped by Mark Pawley, a PhD student at the University of Newcastle. Map coverage was also, in part, achieved while the author was an Australian Research Council Post-Doctoral Fellow at the University of Newcastle between 1995 and 1996, under the supervision of Dr W. J. Collins. During this period, Sipa Resources Pty Ltd provided 1:25 000 colour aerial photographs. In 1995, CRA Ltd provided field support, but in 1996 mapping was supported by the Australian Geological Survey Organisation (AGSO, now Geoscience Australia). Field mapping with AGSO and GSWA was complemented by the use of processed Landsat TM imagery (Glikson, 1998) and processed 400 m line-spaced

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

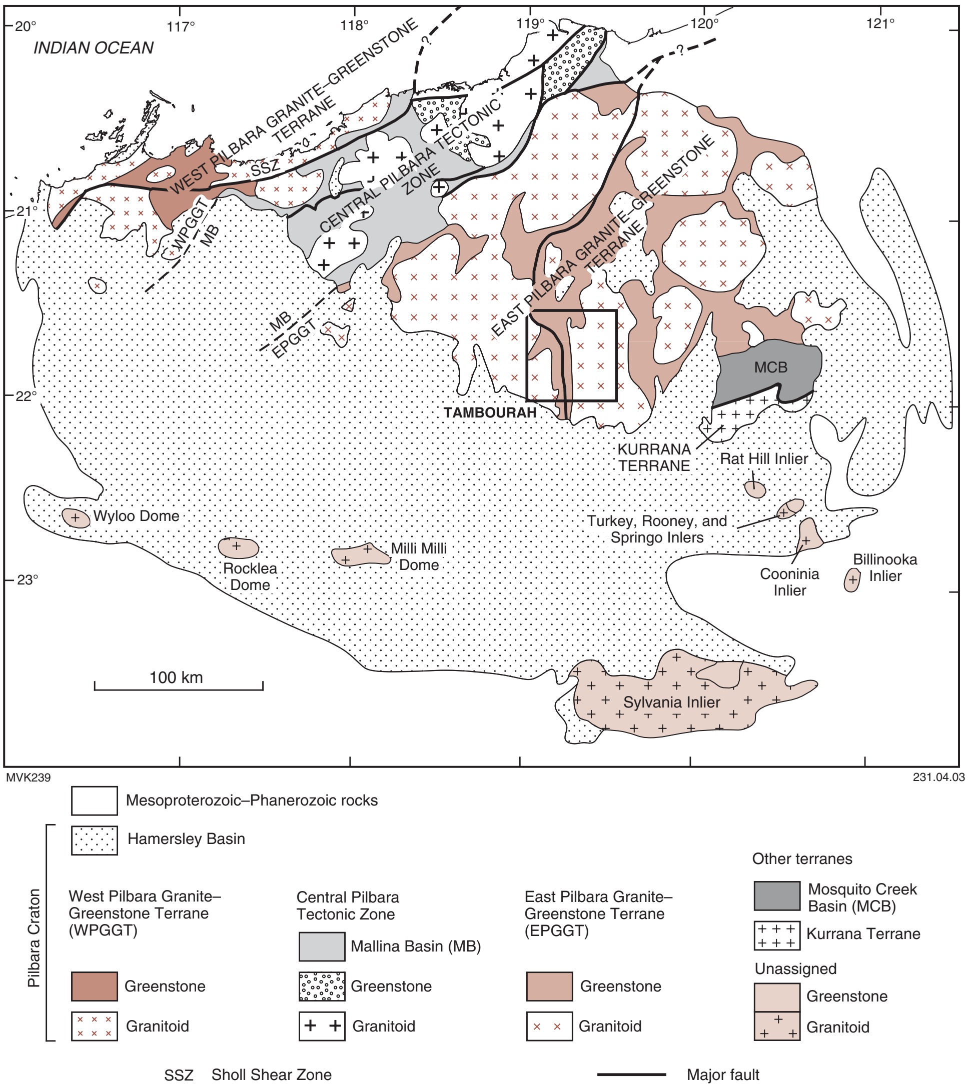



**Figure 1. Location of TAMBOURAH in the northern part of the Pilbara Craton**

airborne magnetic and radiometric data (Mackey and Richardson, 1997a,b).

## Regional geological setting and previous investigations

TAMBOURAH lies within the northern part of the Pilbara Craton, an ovoid area of stable continental crust that consists of two main tectonic elements; exposed windows of Palaeoarchaean to Neoarchaean granite–greenstone basement, and unconformably overlying, Neoarchaean to Paleoproterozoic volcanic and sedimentary rocks of the Mount Bruce Supergroup deposited in the Hamersley Basin (Trendall, 1990). TAMBOURAH is situated within the southern part of the largest window of granite–greenstone basement in the Pilbara Craton.

Hickman and Lipple (1978) described the geology of TAMBOURAH in reference to the MARBLE BAR 1:250 000 sheet. Hickman (1983) discussed the early history of geological investigations in the Pilbara Craton and provided a comprehensive overview of the geology of the region. Hickman (1983, 1990) referred to the supracrustal rocks across the northern Pilbara Craton as the Pilbara Supergroup and defined several formations and groups. More recent work has shown that the northern part of the Pilbara Craton is divisible into several lithotectonic elements with distinct lithostratigraphy and geochronological histories (Hickman, 1999; Van Kranendonk et al., 2002).

## Greenstones

The greenstone succession of the East Pilbara Granite–Greenstone Terrane is defined as the Pilbara Supergroup (Hickman, 1983) and is divided into five unconformity- or intrusion-bound groups deposited over about 575 m.y. (Table 1; Horwitz, 1990; Buick et al., 1995; Van Kranendonk and Morant, 1998; Van Kranendonk et al., 2002). At the base of the succession are the dominantly volcanic rocks of the c. 3515 Ma Coonterunah Group, which has been divided into three formations

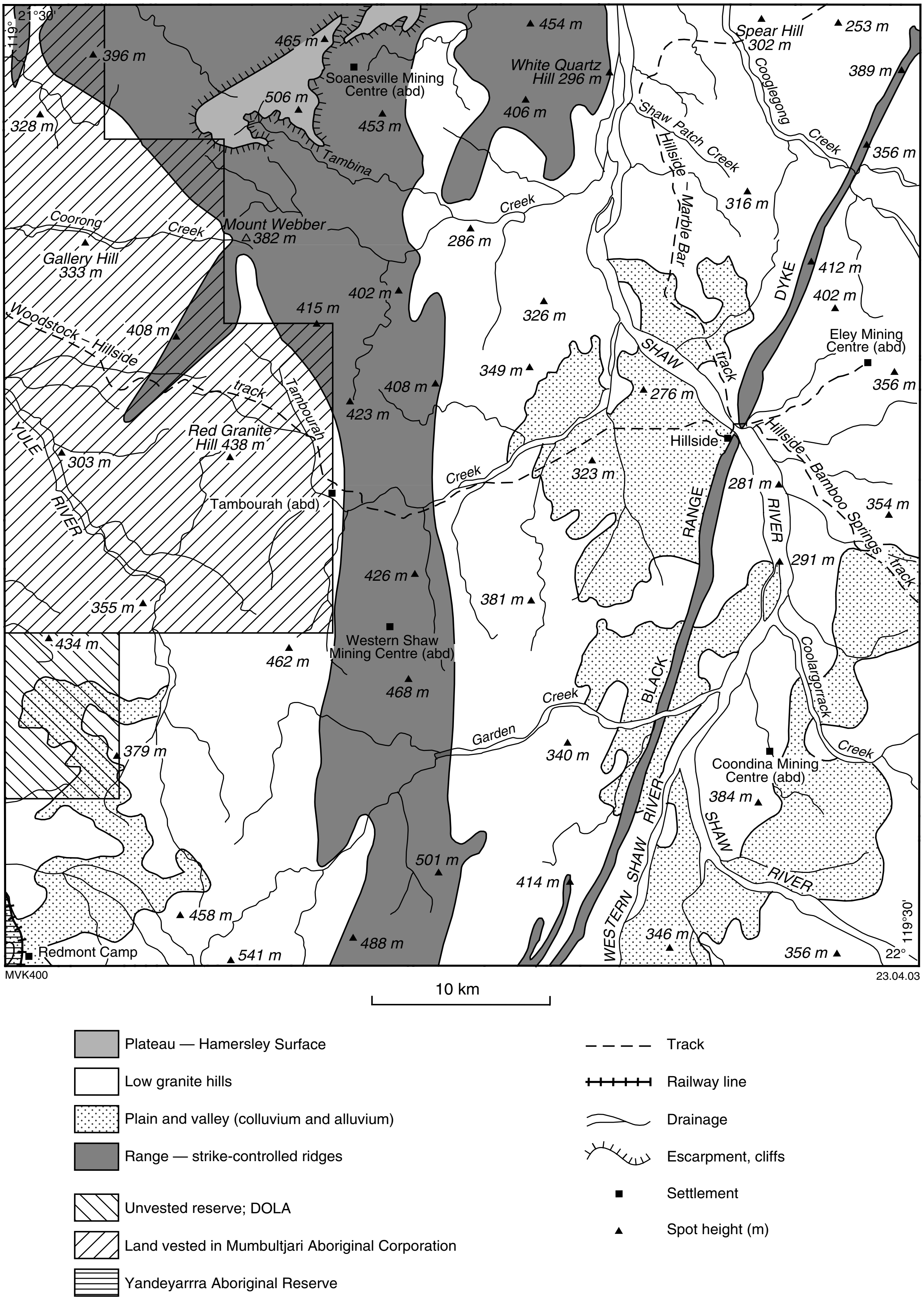



**Figure 2. Physiography of TAMBOURAH and location of Aboriginal lands**

**Table 1. Stratigraphy of the Pilbara Supergroup**

| *Group* | *Subgroup* | *Formation* | *Age (Ma)* | *Reference* |
|---|---|---|---|---|
| **De Grey** | | Lalla Rookh Sandstone | | |
| | | Cattle Well | ≤ c. 3048 | Williams (1999) |
| | | Pyramid Hill | | |
| | | Honeyeater/Cooneina Basalt | | |
| **Gorge Creek** | | Paddy Market | | |
| | Soanesville | Corboy | | |
| | | Pincunah Hill | | |
| | | Kangaroo Caves | c. 3238–3235 | Brauhart (1999) |
| | | Kunagunarrina | | |
| **Sulphur Springs** | | Leilira | | |
| | | Golden Cockatoo | | |
| | | Budjan Creek | c. 3308 | Bagas and Van Kranendonk (in prep.) |
| | | Charteris Basalt | | |
| | Kelly | Wyman | c. 3325–3319 | McNaughton et al. (1993); Nelson (2002) |
| | | Euro Basalt | | |
| | | Strelley Pool Chert | | |
| | Salgash | Panorama | c. 3458–3426 | Thorpe et al. (1992a); Nelson (2001, 2002) |
| | | Apex | | |
| **Warrawoona** | | Towers | | |
| | | Duffer | c. 3474–3463 | McNaughton et al. (1993); Thorpe et al. (1992a); Nelson (2001, 2002) |
| | | Ada | | |
| | Talga Talga | McPhee | | |
| | | North Star Basalt | c. 3490 | Van Koolwijk et al. (2001) |
| | | Dresser | c. 3490 | Thorpe et al. (1992b) |
| | | Double Bar | | |
| **Coonterunah** | | Coucal | c. 3515 | Buick et al. (1995) |
| | | Table Top | | |

(Van Kranendonk and Morant, 1998). The overlying Warrawoona Group was deposited from c. 3490 to 3319 Ma and lies on the Coonterunah Group, locally across a high-angle unconformity (Buick et al., 1995; Van Kranendonk, 2000) or across conformable contacts. These lower groups are composed of repeated (ultra)mafic through felsic volcanic cycles, typically capped by chert. Felsic volcanic horizons include: the 3515 Ma Coucal Formation of the Coonterunah Group (Buick et al., 1995; Van Kranendonk, 2000); the 3474–3463 Ma Duffer Formation at the top of the Talga Talga Subgroup of the Warrawoona Group (Hickman, 1990; age data from Thorpe et al., 1992a; McNaughton et al., 1993); the 3458–3426 Ma Panorama Formation at the top of the Salgash Subgroup of the Warrawoona Group (Thorpe et al., 1992a; Nelson, 2001, 2002); the 3325–3319 Ma Wyman Formation at the top of the Kelly Subgroup of the Warrawoona Group (McNaughton et al., 1993; Barley and Pickard, 1999; Nelson, 2002). Episodes of felsic volcanism in the Warrawoona Group were coeval with granitoid magmatism and deformation across the East Pilbara Granite–Greenstone Terrane (e.g. Hickman, 1983; Williams and Collins, 1990; Barley and Pickard, 1999; Van Kranendonk et al., 2002).

The presence of very old crustal relicts (c. 3600 Ma) is implied by the occurrence of inherited zircons in granitoid rocks and by a c. 3578 Ma age from a xenolith of gabbroic anorthosite in the Shaw Granitoid Complex (McNaughton et al., 1988; Van Kranendonk et al., 2002). These data imply that the Warrawoona Group was deposited on a sialic basement and does not represent oceanic crust, as also suggested by Green et al. (2000) based on evidence of geochemical contamination of basaltic rocks of the Coonterunah and Warrawoona Groups.

Map and geochronological studies of the Soanesville greenstone belt in the late 1980s to 1990s by Sipa Resources showed that the mafic to felsic volcanic sequence around the Strelley Granite was significantly younger than the Warrawoona Group with which it had previously been correlated (Vearncombe et al., 1995; Morant, 1998; Brauhart, 1999). These rocks have been formally recognized as the Sulphur Springs Group, with three component formations (Van Kranendonk and Morant, 1998; Van Kranendonk et al., 2002). Sensitive high-resolution ion microprobe (SHRIMP) U–Pb dating of zircons from the Strelley Granite and the related felsic volcanic rocks of the Sulphur Springs Group has shown that the group was deposited between c. 3255 and 3235 Ma (Buick et al., 2002). Van Kranendonk and Collins (1998) and Van Kranendonk (1999, 2000) recognized the Sulphur Springs Group in the Pincunah and East Strelley greenstone belts. Van Kranendonk (1999, 2000) showed that the Leilira Formation at the base of the group was unconformable on the Warrawoona Group in at least two places. There have been several detailed studies of the volcanogenic-hosted massive sulfide mineralization associated with the intrusion of the Strelley Granite (Vearncombe et al., 1995, 1998; Morant, 1998; Brauhart et al., 1998; Vearncombe and Kerrich, 1999; Brauhart, 1999).

The Sulphur Springs Group is disconformably overlain by the undated Gorge Creek Group (Van Kranendonk, 2000), which is in turn unconformably overlain by the coarse clastic De Grey Group (Hickman, 1983; Wilhelmij and Dunlop, 1984). The De Grey Group was largely deposited at c. 2940 Ma in response to sinistral transpression across the craton (Van Kranendonk and Collins, 1998).

The successive supracrustal sequences in the East Pilbara Granite–Greenstone Terrane were deposited unconformably on older rocks and consistently dip and young away from the domical granitoid complexes (Hickman, 1984; Van Kranendonk et al., 2002). Bedding dips shallow gradually with decreasing age of the sequences and with increasing distance away from the margins of the granitoid complexes, suggesting that supracrustal sequences have wedge shapes that thicken away from the granitoid domes. These features were explained by Hickman (1975, 1984) as the result of progressive granitoid diapirism, a conclusion supported by more recent studies (Collins, 1989; Collins et al., 1998; Collins and Van Kranendonk, 1999; Van Kranendonk et al., 2001a,b, 2002). The preservation of synclinorial remnants of 2775–2715 Ma rocks of the Fortescue Group over synclines of the older greenstones between domical granitoid complexes indicates that doming continued until at least c. 2715 Ma (Hickman, 1984; Van Kranendonk, 2000, 2003; Van Kranendonk et al., 2001b, 2002). Van Kranendonk and Collins (1998) presented a deformation model for NORTH SHAW and TAMBOURAH, whereby volcanism and related granitoid doming at c. 3240 Ma (also Van Kranendonk, 1997) was succeeded by sinistral transpression at c. 2940 Ma (regional $D_3$ deformation) within the Lalla Rookh – Western Shaw Structural Corridor.

Krapez (1993) presented a sequence-stratigraphic model for the north Pilbara Craton based on observed changes in stratigraphy across a set of craton-wide sinistral strike-slip faults first identified by Krapez and Barley (1987). Remapping has established that the model was based on incorrect correlations of stratigraphic sequences, which were undated at that time, and that the strike-slip faults are late structures that did not control the original extent of greenstone sequences (Van Kranendonk and Collins, 1998; Van Kranendonk et al., 2001b, 2002).

## Granitoid complexes

Granitoid complexes in the East Pilbara Granite–Greenstone Terrane range from 25 to 110 km in diameter, with centres spaced an average of 60 km apart (Fig. 1; defined as 'batholiths' by Hickman, 1983). Older plutonic components of these complexes fall into three distinct age groups similar to those of felsic volcanic rocks in adjacent greenstone belts. These include an older suite of c. 3499–3430 Ma tonalite–trondhjemite–granodiorite (TTG) plutons and gneisses (Pidgeon, 1978; Bickle et al., 1983; Williams et al., 1983; McNaughton et al., 1988, 1993; Williams and Collins, 1990; Buick et al., 1995), and younger suites of homogeneous, foliated granitoid plutons that vary in age from 3310 ± 10 Ma in the eastern part of the terrane (Pidgeon, 1984; Williams and Collins, 1990; Bickle et al., 1993; Nelson, 1997; Barley and Pickard, 1999) to c. 3240 Ma in the western and northern parts of the terrane (Nelson, 1999, 2000; Van Kranendonk, 2000).

Bettenay et al. (1981) outlined the component features of the Shaw Granitoid Complex and its protracted, complex tectonothermal history, identifying several phases of granitoid rocks and four phases of deformation. Hickman (1983) identified and named most of the component intrusive phases within the granitoid complexes, and identified the abnormally sodic composition of the early suite. He cited earlier work and presented new data, indicating that the early sodic magmas could not have been produced through melting of sedimentary rocks. Bickle et al. (1983) described a little-deformed, c. 3500 Ma calc-alkaline TTG suite in the northern part of the Shaw Granitoid Complex (North Shaw Suite), which they interpreted as a transitional upper-crustal level equivalent to high-grade Archaean gneiss belts elsewhere. Bickle et al. (1993) studied these rocks in more detail and compared them favourably to modern calc-alkaline igneous suites developed in subduction settings, derived from melts in equilibrium with garnet in the lower crust. The age and geochemistry of the North Shaw Suite was used to suggest that it represents the intrusive equivalents of the felsic volcanic rocks of the Duffer Formation (Bickle et al., 1993).

Bickle et al. (1983) dated the North Shaw Suite at 3499 ± 22 Ma (whole rock Pb–Pb isochron), an age apparently confirmed by a U–Pb SHRIMP zircon age of 3493 ± 4 Ma from an unspecified locality (McNaughton et al., 1988). A 3578 ± 4 Ma age for a xenolith of gabbroic anorthosite (McNaughton et al., 1988) from the 3431 ± 4 Ma South Daltons Pluton of the Shaw Granitoid Complex (McNaughton et al., 1993) on TAMBOURAH, and 3524 ± 6 and 3509 ± 15 Ma xenocrystic zircons from the eastern margin of the Shaw Granitoid Complex (Zegers, 1996) suggest the presence of older crust in the terrane (see Van Kranendonk et al., 2002). A c. 3724 Ma xenocrystic zircon in the Panorama Formation on NORTH SHAW provides evidence of yet older crust (Thorpe et al., 1992a).

Bickle et al. (1989) found that late-tectonic (mainly monzogranite) suites in the Shaw Granitoid Complex were c. 2960 Ma and that the post-tectonic Cooglegong Adamellite was 2847 ± 34 Ma (both are whole rock Pb–Pb isochrons), with Sm–Nd model ages of 3200–3600 Ma. Hickman (1983 and citations of earlier work therein) and Bickle et al. (1983) showed that late- to post-tectonic granitoid rocks were derived by partial melting of pre-existing sialic crust.

## Deformation and metamorphism

Van Kranendonk (2000), Blewett (2000, 2002), and Van Kranendonk et al. (2002) have summarized previous investigations regarding the deformational history of the East Pilbara Granite–Greenstone Terrane. There are two opposing views regarding the tectonic evolution of this terrane. Several authors proposed that deformation was primarily the result of granitoid diapirism during episodic partial convective overturn of the upper crust (Hickman, 1983, 1984; Collins, 1989; Collins et al., 1998; Collins and Van Kranendonk, 1999; Van Kranendonk et al., 2001a,b, 2002). Van Kranendonk and Collins (1998) showed that episodes of diapirism occurred prior to, during, and after craton-wide sinistral transpression at 2940 Ma. An alternative view is that doming of granitoid complexes occurred after c. 3200 Ma and was preceded by one or more episodes of crustal thickening resulting from Alpine-style thrusting (Bickle et al., 1980, 1985; Bettenay et al., 1981; Boulter et al., 1987; van Haaften and White, 1998; Blewett, 2002). However, Van Kranendonk et al. (2001a,b) presented evidence that countered the models of van Haaften and White (1998, 2001). Van Kranendonk et al. (2002) presented a critique of the evidence on which the other horizontal tectonic models were based and pointed out that diapirism and late transpression could account for the local development of horizontal structures.

Wijbrans and McDougall (1987) obtained two principal ages of metamorphism from greenstones of the Western Shaw greenstone belt on TAMBOURAH from a study of Ar–Ar dating. These include an amphibolite-facies event at c. 3240 Ma and an overprinting greenschist-facies event at c. 2950 Ma. Van Kranendonk and Collins (1998) ascribed these events to $D_2$ regional doming and $D_3$ sinistral transpressional deformation respectively, based on structural field mapping. Zegers et al. (1998) confirmed a c. 2945 ± 5 Ma age for related $D_3$ sinistral shear deformation in the Mulgandinnah Shear Zone along the western margin of the Shaw Granitoid Complex. Zegers et al. (1999) obtained numerous $^{40}$Ar–$^{39}$Ar results on hornblende from in and around the Shaw Granitoid Complex.

## Mount Bruce Supergroup

The Mount Bruce Supergroup is a Neoarchaean to Palaeoproterozoic cover sequence that lies unconformably on the northern Pilbara granite–greenstones and is composed of three groups (Trendall, 1990; Thorne and Trendall, 2001). Hickman (1983) and Thorne and Trendall (2001) summarized the stratigraphy of the lowermost Fortescue Group, whose age is constrained by U–Pb zircon dates of 2768 ± 16 Ma (Pidgeon, 1984) and c. 2765 Ma (maximum 2775 ± 10 Ma; Arndt et al., 1991). Higher levels of the group have returned dates of 2715 ± 6 and c. 2687 Ma (Arndt et al., 1991), and 2717 ± 2 Ma (Nelson, 1997). A date from the Black Range dyke on TAMBOURAH, a large doleritic feeder dyke to the Mount Roe Basalt at the base of the Group, is c. 2772 Ma (Wingate, 1999).

Blake and Barley (1992) proposed a sequence stratigraphic model for the Mount Bruce Supergroup, renaming it the Mount Bruce Megasequence Set and identifying component sequences, supersequences, and megasequences. Blake (1993) presented a detailed stratigraphic sequence analysis, speculating that the lower parts of the succession represent a record of a protracted, two-phase, late Archaean continental break-up. In this model, the Nullagine Sequence is interpreted to have formed during west-northwesterly to east-southeasterly directed crustal extension, and the subsequent Mount Jope Supersequence records south-southwesterly to north-northeasterly directed rifting of the southern margin of the Pilbara Craton. Thorne and Trendall (2001) described the tectonic setting of the Fortescue Group in terms of a single protracted rifting event.

# Archaean rocks

The simplified bedrock geology of TAMBOURAH is shown on Figure 3, and the main structural features of the map are shown on Figure 4. A summary of the geological history of the map area is presented in Table 2 and in Figure 5, and all geochronological data for the sheet area is summarized in Table 3. The map area is dominantly underlain by variably deformed and metamorphosed late to early Archaean metavolcanic and metasedimentary rocks that form little-deformed monoclinal successions in arcuate greenstone belts, and more strongly deformed and dismembered rocks in the Emerald Mine Greenstone Complex (Van Kranendonk, 1998). Coeval suites of granitoid rocks form broad (30–60 km-diameter), domical granitoid complexes. Unconformably overlying these older rocks in the central-northern and far southern margins of the sheet area are outliers of little-deformed and weakly meta-morphosed sedimentary rocks of the Fortescue Group (Fig. 3).

Relatively well preserved tracts of metavolcanic and metasedimentary rocks with mostly coherent stratigraphy are present in the Western Shaw and Soanesville greenstone belts. These belts are bounded by faults or by intrusive and/or sheared intrusive contacts with granitoid complexes. The Emerald Mine Greenstone Complex is underlain by schistose rocks of the Warrawoona and Gorge Creek Groups, and by intrusive peridotites. The Keep It Dark Synclinorium of the Lalla Rookh Sandstone is present along the faulted boundary between the Soanesville greenstone belt and the Emerald Mine Greenstone Complex in the north-central part of TAMBOURAH.

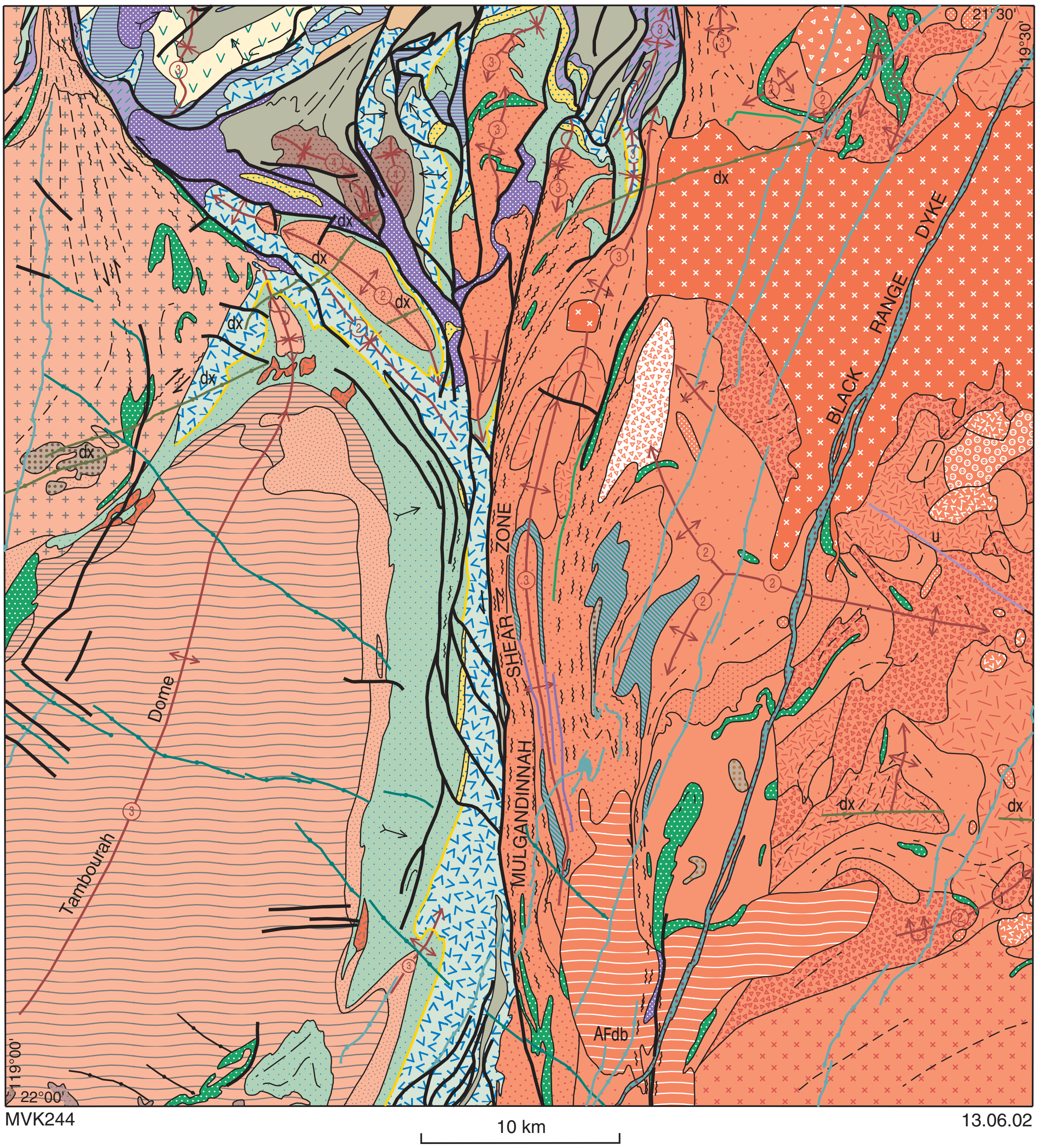
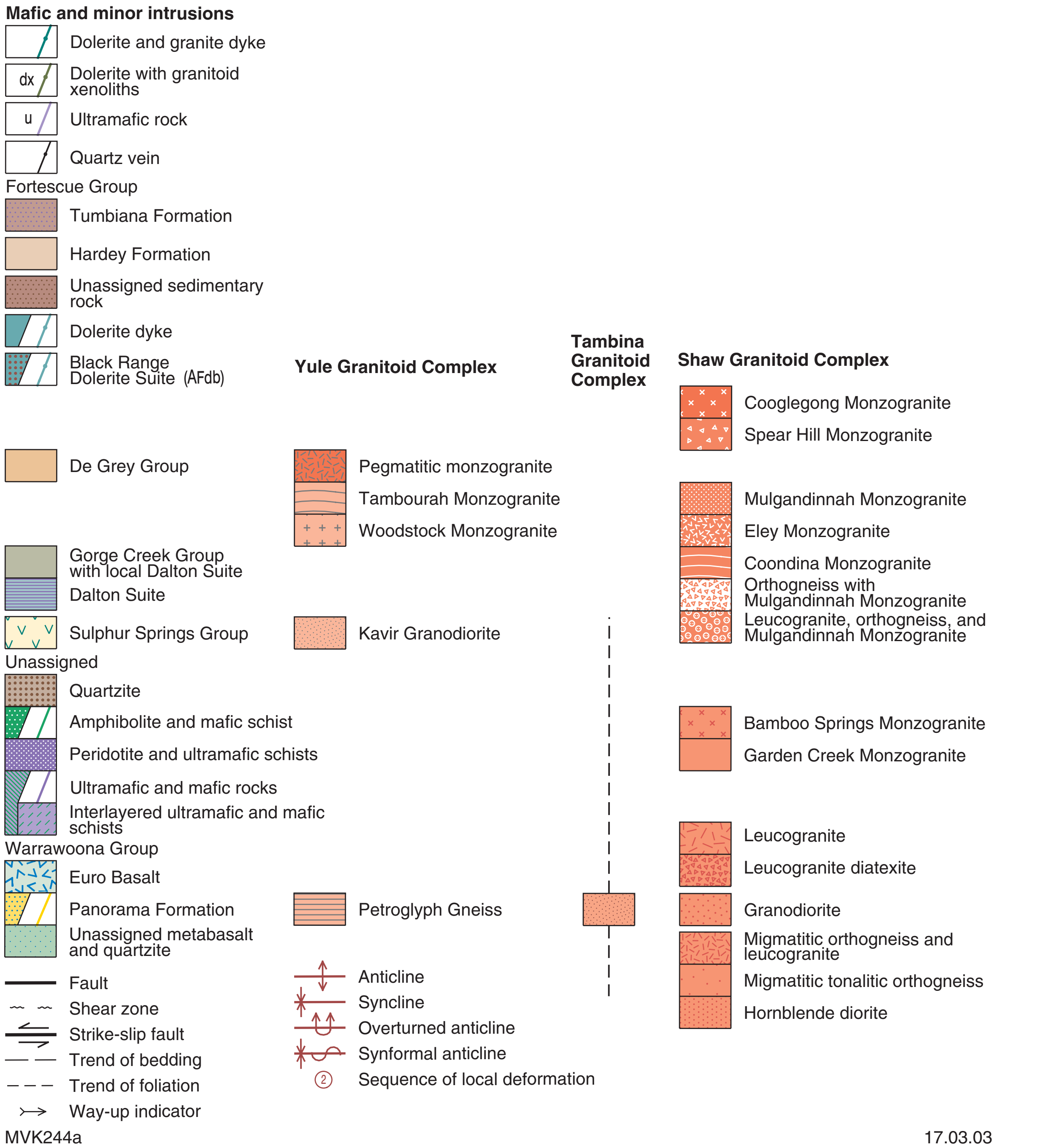



**Figure 3. Simplified bedrock geology of TAMBOURAH**

Granitoid rocks are exposed in parts of the Shaw, Yule, and Tambina Granitoid Complexes — domical areas that are composed of several distinct, mappable plutonic or gneissic units that have either intrusive or sheared intrusive contacts (or both) with greenstones. Structural and gravity data combine to suggest that the domical granitoid complexes link up at depth beneath intervening greenstones and thus represent structural domes of a continuous, mid-crustal granitoid layer beneath upper crustal greenstones (Wellman, 2000).

The main structural map elements on TAMBOURAH (Fig. 4) include parts of two domes and the southern half of the Lalla Rookh – Western Shaw Structural Corridor (LWSC; previously the Central Pilbara Structural Corridor of Van Kranendonk and Collins, 1998). These large-scale structures in turn contain, or are bounded by, secondary structural elements such as folds, brittle faults, ductile mylonite zones, and brittle–ductile deformation zones.

The Tambourah and Shaw Domes are composed of a core of granitoid rocks and an outer rind of greenstones that are distributed in belts or complexes (Fig. 4). The Shaw Dome includes the Shaw Granitoid Complex and the Emerald Mine Greenstone Complex. The western




margin of the Shaw Dome is the Mulgandinnah Shear Zone and the South Daltons Fault. For the Tambourah Dome, greenstones face away from the Tambourah Granite out to the faulted margin against the Shaw and Yule Granitoid Complexes. In the north, however, the Mount Webber Syncline and Tambina Anticline subtly complicate matters, but are included within the larger dome since there is no fault to separate components in this area.

The north-striking Lalla Rookh – Western Shaw Structural Corridor transects the central part of the map area (Fig. 4). It affects rocks of the Soanesville greenstone belt, the Emerald Mine Greenstone Complex, the Keep It Dark Synclinorium, and the margins of the Shaw and Yule Granitoid Complexes. The LWSC is characterized by north-northeast to northeast-plunging folds that are bounded by the sinistral Mulgandinnah and Pulcunnah Shear Zones in the Shaw and Yule Granitoid Complexes, respectively. The boundaries of the LWSC are locally discrete faults, but elsewhere are gradational contacts along the limits of penetrative regional $D_3$ strain.

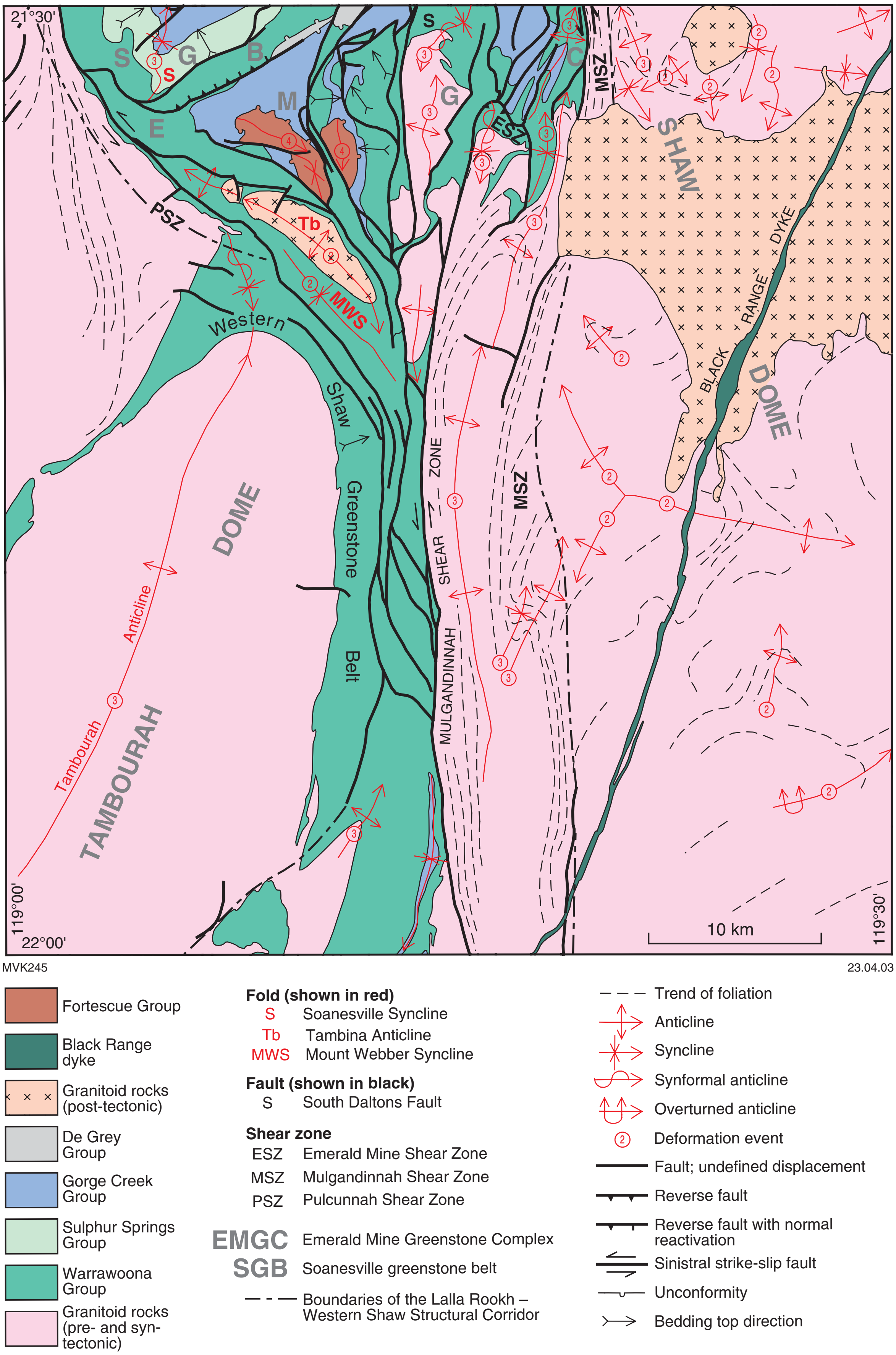



**Figure 4. Lithotectonic and structural elements of TAMBOURAH. Note the western and eastern strands of the Mulgandinnah Shear Zone**

**Table 2. Summary of the geological evolution of Tambourah**

| *Age (Ma)* | *Geological event* |
|---|---|
| 3600–3469 | Formation of ancient sialic crust and early basaltic volcanism of the Coonterunah and lower Warrawoona Groups (not exposed, excised by younger intrusions, as xenoliths in younger rocks, and/or recycled) |
| 3469–3462 | Intrusion of tonalitic plutons in Shaw Granitoid Complex and eruption of the Duffer Formation, Warrawoona Group (not exposed) |
| 3462–3433 | $D_1$: Migmatization of orthogneiss and folding of gneissic layering; basaltic volcanism and subordinate felsic magmatism of the Warrawoona Group (partly exposed as undivided Warrawoona Group, and as xenoliths and xenocrysts in younger rocks) |
| 3433–3425 | Intrusion of tonalitic to granitic plutons, and doming; eruption of the Panorama Formation, Warrawoona Group |
| 3419–3400 | Partial melting and generation of granitic leucosome veins; epigenetic Au mineralization |
| 3400–3325 | Deposition of the Euro Basalt, Warrawoona Group |
| 3325–3300 | Intrusion of the Bamboo Springs Monzogranite, Shaw Granitoid Complex; accompanied by voluminous granitoid plutonism, doming of granitoid complexes, shear deformation and amphibolite-facies metamorphism to the east of Tambourah |
| 3255–3235 | Deposition of the Sulphur Springs Group; VHMS massive sulfides (not on Tambourah) |
| c. 3240 | $D_2$: onset of doming of the Tambourah Dome and Tambina Granitoid Complex; amphibolite-facies metamorphism and foliation development; granite plutonism; epigenetic Au |
| 3235 – c. 3000 | Deposition of the Gorge Creek Group and intrusion of the Dalton Suite with Cu, Ni, Zn, Pb, and PGE mineralization |
| 2955–2919 | $D_3$: WNW–ESE compression; formation of the Lalla Rookh – Western Shaw Structural Corridor; sinistral strike-slip movement on the Mulgandinnah and Pincunah Shear Zones; diatexis and granitoid plutonism; doming of the Tambourah Dome; greenschist-facies metamorphism; deposition of the Lalla Rookh Sandstone with alluvial Au; emeralds, chrysotile asbestos, epigenetic Au |
| c. 2880–2850 | Intrusion of Cooglegong and Spear Hill Monzogranites; Sn–Ta–Li–Brl mineralization |
| 2772–2750 | Deposition of basal conglomerate and sandstone of the Fortescue Group in fault-bound basins; deposition of the Mount Roe Basalt and Hardey Formations (mostly not on Tambourah); intrusion of dolerite dykes; alluvial Au in basal conglomerates |
| c. 2750 | $D_4$: upright, open folding and faulting of basal conglomerates, Fortescue Group |
| c. 2719 | Deposition of the Tumbiana Formation, Fortescue Group |
| c. 755–? | Intrusion of east-northeasterly trending dolerite dykes of the Mundine Well Suite, synchronous with, or followed by, intrusion of east-southeasterly trending dolerite dykes of the Round Hummock Suite during $D_5$ faulting and intrusion of quartz veins |
| 545–65 | Palaeozoic and Mesozoic erosion; formation of Hamersley peneplain surfaces |
| 55–present | Uplift and dissection of plateau surfaces; deposition of Cainozoic units |

# Warrawoona Group

## Unassigned units stratigraphically beneath the Panorama Formation (*AW(ut)*, *AW(ubs)*, *AW(bus)*, *AW(bh)*, *AW(bm)*, *AW(bvc)*, *AW(bms)*, *AW(bvs)*, *AW(bvz)*, *AW(ba)*, *AW(bag)*, *AW(c)*, *AW(ch)*, *AW(sq)*, *AW(f)*)

Unassigned units of the Warrawoona Group are predominantly basaltic rocks that outcrop in the western half of the Western Shaw greenstone belt. These rocks lie stratigraphically beneath the Panorama Formation, which is one of the few uniquely recognizable units in the map area and across the entire east Pilbara (Van Kranendonk et al., 2002). The contact of these rocks with the Panorama Formation is conformable, but as there are a variety of formations below the Panorama Formation with predominantly basaltic components, it is impossible to confidently ascribe them to particular formations.

Schistose, highly strained ultramafic rocks with tremolite–serpentine–chlorite and locally talc–carbonate mineralogy (*AW(ut)*) are interpreted to be metamorphosed komatiites. Where these rocks are volumetrically dominant, but interlayered with chlorite schists (metabasalts) at a scale too small to be mapped separately as a result of intense flattening, the rocks are collectively ascribed to the unit *AW(ubs)*. Where the reverse proportions are true, the rocks are mapped as *AW(bus)* and typically also contain strongly transposed and recrystallized beds of blue-grey chert or white quartzite, or both.

Basaltic rocks metamorphosed under greenschist-facies conditions and affected by relatively low strain are broadly subdivided on the basis of composition into tholeiites (*AW(bh)*) and high-Mg basalts (*AW(bm)*). The former are typically dark brown weathered rocks composed of chlorite–epidote–plagioclase – opaque

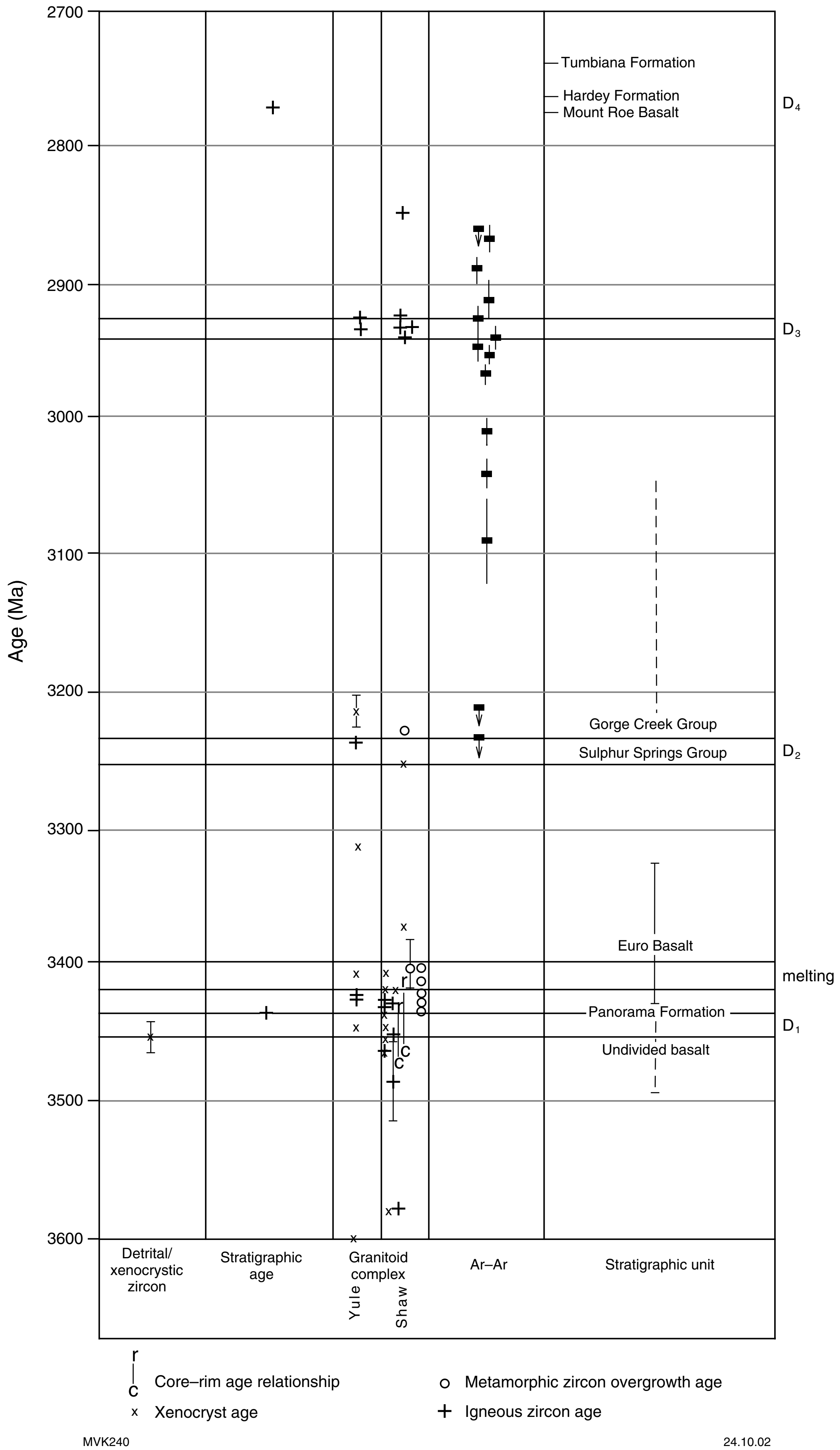



**Figure 5. Geological evolution of Tambourah, summarizing radiometric data in Table 3**

**Table 3. Summary of geochronological data from TAMBOURAH**

| *Sample number* | *MGA coordinate Easting* | *Northing* | *Rock description* | *Age (Ma)* | *Method* | *Reference* |
|---|---|---|---|---|---|---|
| 142879 | 749050 | 7618400 | Spear Hill Monzogranite(*AgSsh*); Shaw Granitoid Complex | 2851 ± 2 | SHRIMP U–Pb zircon | Nelson (1998) |
| 142883 | 746900 | 7620350 | Syn-$D_3$ monzogranite sheet; Shaw Granitoid Complex | 2919 ± 2 (P)<br>3417 ± 2 (X) | SHRIMP U–Pb zircon | Nelson (1998) |
| 142884 | 721400 | 7604400 | Folded, schlieric monzogranite in the saddle reef of folded greenstones around the nose of the Tambourah Dome (*AgYwo*); Yule Granitoid Complex | 2933 ± 3 (P)<br>3215 ± 9 (X)<br>3312 ± 3 (X)<br>3404 ± 4 (X)<br>3443 ± 4 (X)<br>3600 ± 3 (X) | SHRIMP U–Pb zircon | Nelson (1998) |
| 142885 | 716800 | 7602920 | Faintly schlieric, K-feldspar porphyritic monzogranite (*AgYwor*); Yule Granitoid Complex | 2927 ± 3 (P) | SHRIMP U–Pb zircon | Nelson (1998) |
| 142965 | 741400 | 7598950 | Monzogranite dyke derived from melting of tonalite (*AgSmuxn*); Shaw Granitoid Complex | 2929 ± 4 (P)<br>3405 ± 5 (X) | SHRIMP U–Pb zircon | Nelson (2000) |
| 142966 | 741400 | 7598950 | Migmatitic orthogneiss (*AgSg*); Shaw Granitoid Complex | 3430 ± 4 (P)<br>3228 ± 8 (S*) | SHRIMP U–Pb zircon | Nelson (2000) |
| 142967 | 741400 | 7598950 | Schlieric monzogranite derived by melting of orthogneiss (*AgSmuxn*); Shaw Granitoid Complex | 2929 ± 5 (P)<br>3413 ± 7 (X)<br>3580 ± 5 (X) | SHRIMP U–Pb zircon | Nelson (2000) |
| 142968 | 731620 | 7592500 | Foliated biotite tonalite (*AgSg*); Shaw Granitoid Complex | 3425 ± 4 (P)<br>3445 ± 4 (X) | SHRIMP U–Pb zircon | Nelson (2000) |
| 142972 | 729870 | 7582000 | Felsic volcaniclastic of the Panorama Formation (*AWps*); Western Shaw greenstone belt | 3433 ± 6 (P)<br>3451 ± 10 (X) | SHRIMP U–Pb zircon | Nelson (2001) |
| 168923 | 742600 | 7585000 | Hornblende quartz diorite (*AgSd*); Shaw Granitoid Complex | 3462 ± 3 | SHRIMP U–Pb zircon | Nelson (2001) |
| 169019 | 707340 | 7569120 | Biotite–hornblende quartz diorite (*AgYtan*); Tambourah Dome, Yule Granitoid Complex | 3428 ± 6 | SHRIMP U–Pb zircon | Nelson (2002) |
| B25 | 748700 | 7596300 | Black Range Dyke (*AFdb*) | 2772 ± 2 (P) | U–Pb SHRIMP baddeleyite | Wingate (1999) |
| F1 | 741000 | 7586280 | Amphibolite raft (*Aba*); Shaw Granitoid Complex | 3430 ± 6 (S*) | SHRIMP U–Pb zircon | Froude et al. (1983) |
| F2 | 718250 | 7602100 | Immature quartz arenite (*AWpsq*); Western Shaw greenstone belt | 3400 ± 20 | SHRIMP U–Pb zircon | Froude et al. (1983) |
| M95-28a | 721750 | 7602100 | Porphyritic quartz diorite orthogneiss (*AgYpt*) from the nose of the Tambourah Dome; Yule Granitoid Complex | c. 3420 | SHRIMP U–Pb zircon | Van Kranendonk, unpublished data |
| M95-31 | 721400 | 7604400 | Homogeneous, K-feldspar porphyritic monzogranite (*AgYwo*) in the saddle reef of folded greenstones around the nose of the Tambourah Dome; Yule Granitoid Complex | c. 2930 | SHRIMP U–Pb zircon | Van Kranendonk, unpublished data |

**Table 3.** (continued)

| *Sample number* | *MGA coordinate Easting* | *Northing* | *Rock description* | *Age (Ma)* | *Method* | *Reference* |
|---|---|---|---|---|---|---|
| M95-71b, 71c | 739220 | 7609780 | Amphibolite xenolith (71b) cut by leucosome veins (71c) in homogeneous granodiorite (*AgSg*); Shaw Granitoid Complex | c. 3452 (X)<br>3428 (S)<br>3417 (S)<br>3410 (S)<br>3399 ± 5 (Sr)<br>3337 (Sr)<br>3298 (Sr)<br>3236 (Sr) | SHRIMP U–Pb zircon | Van Kranendonk, unpublished data |
| M95-78 | 736400 | 7608750 | Homogeneous granodiorite (*AgSg*); Shaw Granitoid Complex | c. 3430 (P)<br>c. 3413 (S) | SHRIMP U–Pb zircon | Van Kranendonk, unpublished data |
| M96-556a | 721750 | 7602100 | Sheet of homogeneous grey granite (*AgYka*) cutting porphyritic orthogneiss (M95-28a) in the nose of the Tambourah Dome; Yule Granitoid Complex | c. 3240 (P) | SHRIMP U–Pb zircon | Van Kranendonk, unpublished data |
| T94/31 | 742190 | 7616180 | Synkinematic pegmatite in Mulgandinnah Shear Zone; Shaw Granitoid Complex | 2934 ± 2 (P)<br>3251 ± 3 (Xc)<br>3416 ± 4 (Xc)<br>3369 ± 3 (Xr)<br>3434 ± 5 (Xc) | SHRIMP U–Pb zircon | Zegers (1996) |
| T94/221 | 748050 | 7582720 | Biotite granodiorite gneiss (*AgSn*); Shaw Granitoid Complex | 3451 ± 1 (P)<br>3427 ± 5 (S)<br>3433 ± 7 (Xr)<br>3466 ± 5 (Xc)<br>3416 ± 7 (Xr)<br>3469 ±15 (Xc) | SHRIMP U–Pb zircon | Zegers (1996) |
| T94/222 | 746820 | 7582580 | Weakly foliated quartz diorite (*AgSd*); Shaw Granitoid Complex | 3463 ± 2 (P)<br>3419 ± 8 (S)<br>2887 ± 11 | SHRIMP U–Pb zircon<br><br>$^{40}$A – $^{39}$Ar | Zegers (1996) |
| UWA-98053 | 732220 | 7618150 | South Daltons Pluton (*AgSg*); Shaw Granitoid Complex | 3431 ± 4 (P) | SHRIMP U–Pb zircon | McNaughton et al. (1993) |
| N/A | 732220 | 7618150 | Gabbroic anorthosite enclave in South Daltons Pluton; Shaw Granitoid Complex | 3578 ± 4 (P) | SHRIMP U–Pb zircon | McNaughton et al. (1988) |
| WILL | 731620 | 7592500 | Tonalitic gneiss (*AgSg*); Shaw Granitoid Complex | 3485 ± 30 | SHRIMP U–Pb zircon | Williams et al. (1983) |
| T94/9 | 731500 | 7615650 | Blue-green hornblende from a mylonitic part of the South Daltons Pluton (*AgSg*); Shaw Granitoid Complex | 3006 ± 11 | $^{40}$Ar – $^{39}$Ar | Zegers (1996) |
| T94/13 | 731750 | 7613300 | Foliated amphibolite enclave in the South Daltons Pluton (*Aba*); Shaw Granitoid Complex | 3038 ± 11 | $^{40}$Ar – $^{39}$Ar | Zegers (1996) |

**Table 3.** (continued)

| *Sample number* | *MGA coordinate Easting* | *Northing* | *Rock description* | *Age (Ma)* | *Method* | *Reference* |
|---|---|---|---|---|---|---|
| T94/17 | 735900 | 7575720 | Granodiorite with mylonitic foliation (*AgSg*); Shaw Granitoid Complex | 2887 ± 11 | $^{40}Ar – ^{39}Ar$ | Zegers (1996) |
| T94/23 | 743150E | 7584250 | Muscovite from metapelite enclave (*Ahpf*); Shaw Granitoid Complex | 2949 ± 14 | $^{40}Ar – ^{39}Ar$ | Zegers (1996) |
| T94/32 | 742150 | 7616150 | Hornblende from an amphibolite boudin in the Mulgandinnah Shear Zone; Shaw Granitoid Complex (*Aba*) | 2944 ± 9 | $^{40}Ar – ^{39}Ar$ | Zegers (1996) |
| T94/215 | 732700 | 7594300 | Hornblende from folded amphibolite in the Mulgandinnah Shear Zone (*Aba*); Shaw Granitoid Complex | 2909 ± 12 | $^{40}Ar – ^{39}Ar$ | Zegers (1996) |
| T94/220 | 746810 | 7582550 | Hornblende from quartz diorite (*AgSd*); Shaw Granitoid Complex | 2924 ± 11 | $^{40}Ar – ^{39}Ar$ | Zegers (1996) |
| 81-657 | 721780 | 7602400 | Olive-green hornblende from amphibolite-facies metabasalt (*AW(bh)*) in the nose of the Tambourah Dome; Western Shaw greenstone belt | 2865 ± 9 | $^{40}Ar – ^{39}Ar$ | Wijbrans and McDougall (1987) |
| 81-658 | 741000 | 7586280 | Olive-green hornblende from amphibolite (*Aba*); Shaw Granitoid Complex | >2840 | $^{40}Ar – ^{39}Ar$ | Wijbrans and McDougall (1987) |
| 82-314 | 717650 | 7603600 | Blue-green hornblende from amphibolite-facies metabasalt (*AW(bh)*); Western Shaw greenstone belt | >3209 | $^{40}Ar – ^{39}Ar$ | Wijbrans and McDougall (1987) |
| 82-315 | 718780 | 7603300 | Muscovite in quartz arenite of the Panorama Formation (*AWpsq*); Western Shaw greenstone belt | 2941 ± 7 | $^{40}Ar – ^{39}Ar$ | Wijbrans and McDougall (1987) |
| 82-350 | 726780 | 7592900 | Olive-green hornblende (*AW(bh)*); Western Shaw greenstone belt | 2965 ± 8 | $^{40}Ar – ^{39}Ar$ | Wijbrans and McDougall (1987) |
| 82-356 | 728900 | 7591600 | Blue-green hornblende from amphibolite-facies metabasalt (*AW(bh)*); Western Shaw greenstone belt | >3234 | $^{40}Ar – ^{39}Ar$ | Wijbrans and McDougall (1987) |
| N/A | 725490 | 7592880 | Microadamellite from Tambourah Dome (*AgYka*); Yule Granitoid Complex | 3087 ± 34 | Rb–Sr whole rock | Cooper et al. (1982) |

**NOTES:**
(D) detrital zircon age
(P) primary igneous age
(S) secondary plateau or metamorphic zircon age; r = rim
(X) xenocrystic zircon; c = core, r = rim
* interpretation by the current author

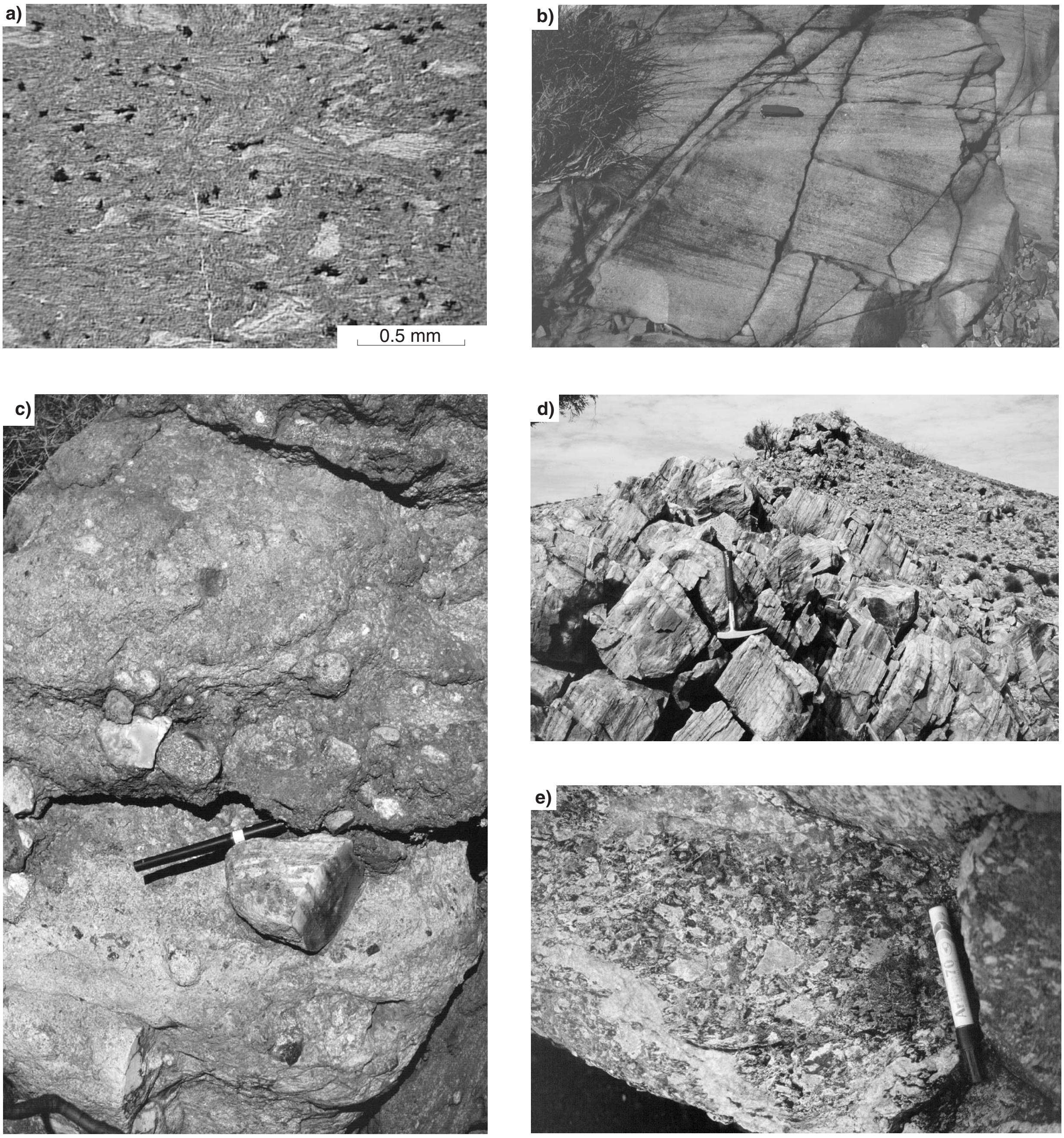



**Figure 6. Thin section and outcrop views of the Warrawoona Group: a) Thin section, in plane polarized light, of silicified high-Mg basalt (*AWebz*), showing relict patches of fine-grained pyroxene spinifex texture; b) cross-bedded felsic volcaniclastic sandstone (pen knife is 9 cm long; MGA 729789E 7582005); c) polymictic volcaniclastic conglomerate (pen is 13 cm long; MGA 729889E 7586555N); d) view south of bedded white quartzite from the southern part of the Western Shaw greenstone belt (hammer is 38 cm long; MGA 727289E 7569405N); e) agglomerate texture of felsic volcanic rock (*AWpa*) incorporated as an inclusion within the far southwestern margin of the Shaw Granitoid Complex: marker pen is 14 cm long (MGA 731639E 7568355N)**

minerals (–quartz), whereas the latter rocks typically weather to an orange-brown and are composed of bladed actinolite in fine-grained chlorite(–talc). Carbonate-altered metabasalts (*AW(bvc)*) originated as high-Mg basalts, but now contain less than 40% carbonate in addition to chlorite(–talc–actinolite). Highly strained equivalents of these rocks have been mapped separately (*AW(bms)*). Highly strained chloritic schists derived from tholeiitic parents (*AW(bvs)*) are composed of foliated chlorite with intergrowths of epidote–actinolite–plagiocalse–quartz – opaque minerals. Metabasalts beneath some chert beds are locally highly silicified, and these rocks are essentially composed of quartz with opaque minerals (*AW(bvz)*). In thin section, some of these rocks retain relict pyroxene-spinifex textures, indicating derivation from a high-Mg protolith (Fig. 6a). These textures and the presence of abundant opaque minerals distinguish these rocks from felsic volcanic rocks.

Metabasalts adjacent to the Tambourah Dome are amphibolites (*AW(ba)*), having been affected by contact metamorphism during granite emplacement at c. 3240 Ma (cf. Wijbrans and McDougall, 1987). These characteristically dark brown weathered rocks contain fine- to medium-grained intergrowths of hornblende and plagioclase, with smaller amounts of epidote, titanite, and quartz. Volcanic textures such as pillows, varioles, and hyaloclastite breccias are extensively preserved despite a penetrative foliation and lineation defined by the elongate, platy growth of hornblende. Amphibolites that lie immediately adjacent to granitoid rocks, and those preserved as enclaves within them, have been locally injected by up to 50% by volume of granite veins, and these have been mapped separately (*AW(bag)*).

Blue-grey and white layered cherts (*AW(c)*) are similar to counterparts in the Euro Basalt (*AWec*), displaying a millimetre- to centimetre-scale layering defined principally by colour changes. Much of the white chert was introduced as layer-parallel sheets into the blue-grey chert host. Several metre-thick beds of white, recrystallized quartzite (*AW(sq)*) are interlayered with basalt throughout the lower part of the Warrawoona Group immediately adjacent to the Tambourah Granite. These rocks are well bedded at a centimetre to decimetre scale and are mostly plane bedded. Some bedded cherts are fed by swarms of massive to brecciated blue-black to grey chert veins (*AW(ch)*; MGA 728796E 7584339N).

Thin units of nondescript quartz–sericite schist (*AW(f)*) are present in strongly deformed mafic rocks and tectonic megabreccia of the unassigned Warrawoona Group east of the South Daltons Pluton in the Emerald Mine Greenstone Complex (MGA 734300E 7613400N).

## Panorama Formation (*Awpp*, *Awps*, *Awpr*, *Awpsc*, *Awpa*, *Awpch*, *Awpsq*)

The Panorama Formation on TAMBOURAH is mainly composed of felsic volcaniclastic rocks, subordinate felsic lavas and chert, and beds of quartzite. The formation is recognized throughout most of the Western Shaw greenstone belt, around the Tambina Granitoid Complex, and as a faulted and folded unit around the granitoid lobes of the Emerald Mine Greenstone Complex. A suite of strongly foliated quartz-eye porphyry to aphanitic felsic sills (*AWpp*) is located in metabasalt (*AW(bh)*) adjacent to the Tambourah Dome.

The best preserved section through the Panorama Formation on TAMBOURAH (MGA 729839E between 7581155N and 7587155N) is within the geographical middle of the Western Shaw greenstone belt. At this locality, the formation is east facing and slightly overturned. It has a minimum thickness of 250 m and is predominantly composed of volcaniclastic rocks that coarsen upwards (*AWps*). At the base of the formation are quartz-porphyritic felsic schists that were probably originally either rhyolitic lavas (*AWpr*) or subvolcanic sills (*AWpp*). These rocks are overlain by 2–5 m of grey layered chert composed of 1–2 mm clastic material interpreted to be felsic volcanic ash. Above this is a recessive-weathering unit of grey-red sericitic schist (?shale or rhyolite). Forming the main ridge to the east are graded and cross-stratified volcaniclastic sandstones (*AWps*), the bulk of which contain (≤1 cm), subangular clasts of blue-grey chert, thin, pale-grey clasts of very fine grained felsic ash, and rare clasts of white porcelanite. A sample of this rock has been dated at 3433 ± 6 Ma (Nelson, 2000). Along strike are well-sorted volcaniclastic sandstones with well-developed cross-stratification (Fig. 6b). These rocks grade up into volcaniclastic conglomerates (*AWpsc*) that contain very well rounded, flattened, lineated clasts up to 4 cm across of black chert, bedded black and white cherty mudstone, felsic agglomerate, porcelanite, and quartz pebbles (Fig. 6c). At the stratigraphic top is a thin unit of fine-grained cherty tuff and coarse felsic agglomerate (*AWpa*) with quartz-filled gas cavities. Coarse felsic agglomerate with angular fragments of white, fine-grained rhyolite in a green matrix of epidote–sericite–chlorite form inclusions in the far southwestern part of the Shaw Granitoid Complex. Several swarms of blue-black, massive to brecciated, chert veins (*AWpch*) feed bedded chert near the top of the Panorama Formation (e.g. MGA 730250E 7594750N).

Along strike to the south of the main felsic volcaniclastic unit in the Western Shaw greenstone belt, and around the Tambina Granitoid Complex, a high ridge of white quartzite (*AWpsq*), up to 20 m thick, is interpreted as the Panorama Formation. The quartzite is plane bedded at a centimetre to decimetre scale (Fig. 6d), although graded bedding and cross-stratification were locally observed. Around the granitoid lobes of the northwest Shaw area, the Panorama Formation is composed of strongly deformed, thoroughly recrystallized quartz–sericite schist, which may locally contain abundant chloritoid porphyroblasts (with or without chlorite) and one or more of kyanite, andalusite, and sillimanite (Morant, 1984).

Two inclusions (MGA 731640E 7568300N) of felsic volcanic rocks (*AWpa*) in the far southwestern part of the Shaw Granitoid Complex preserve agglomeratic (Fig. 6e) and flow-banded igneous textures, but have been recrystallized to a largely granoblastic assemblage of diopside–epidote–quartz–plagioclase–titanite.

## Euro Basalt (*Aweba*, *Awebm*, *Awebc*, *Awebk*, *Aweubs*, *Aweb*, *Awebh*, *Awed*, *Awebhx*, *AWebs*, *Awebz*, *Awesq*, *Awec*, *Awecg*, *Aweci*, *Awech*)

The Euro Basalt lies conformably above the Panorama Formation and is principally composed of interbedded tholeiitic and high-Mg metabasalt, and metadolerite, with thin beds of metamorphosed chert and quartzite. The maximum thickness of this formation is about 2.25 km in the Western Shaw greenstone belt. These rocks have been metamorphosed predominantly to greenschist facies, although some rocks adjacent to the Shaw Granitoid Complex in the south and along the northwestern limb of the Tambourah Dome have been metamorphosed to amphibolite facies. Basalts metamorphosed to amphibolite facies (*AWeba*) are typically medium grained intergrowths of hornblende–epidote–plagioclase–titanite(–actinolite –quartz).

Metamorphosed high-Mg basalts (*AWebm*) are present at the base of the formation in the southern part of the Western Shaw greenstone belt, conformably on quartzite of the Panorama Formation. These rocks mostly weather to a pale orange-brown and may be massive or pillowed. In thin section they may display relict pyroxene-spinifex texture with scattered augite phenocrysts up to 1 mm long. The rocks are characteristically recrystallized to a fine-grained intergrowth of chlorite, serpentine, tremolite–actinolite, and carbonate. Local alteration includes carbonate, epidote, and titanite, whereas chlorite is present in fractures. Extensively carbonate-altered rocks have been mapped separately (*AWebc*) and are most extensively developed adjacent to the western margin of the Shaw Granitoid Complex. A thin unit of metamorphosed and recrystallized (carbonate–talc–chlorite) basaltic komatiite (*AWebk*) is present between the Tambina Granitoid Complex and the Tambourah Dome, where it outlines a large-scale 'S'-asymmetric fold. A unit of metakomatiite (*AWebk*; MGA 726839E 7566155N) in the far southern part of the Western Shaw greenstone belt is composed of chlorite–serpentine–tremolite–talc–magnetite (?–chromite), but coarse pyroxene- and olivine-spinifex texture is preserved. Highly transposed ultramafic and mafic schists, or those interlayered at a scale too small to show on the map, dominated by peridotites, are denoted by *AWeubs*.

Massive basaltic rocks were mapped as *AWeb*. Dark brown weathering, pillowed to massive tholeiitic basalts (*AWebh*) and related syn-volcanic dolerite intrusions (*AWed*) are the dominant components of the formation, and may represent the Miralga Creek Member identified on NORTH SHAW by Van Kranendonk (2000). Tholeiitic metabasalts are composed of fine-grained intergrowths of chlorite(–epidote) and plagioclase(–quartz), with trace amounts of opaque minerals. A 500 m-thick sill of medium-grained dolerite (*AWed*) in the south-central part of the Western Shaw greenstone belt (MGA 730539E 7583565) consists of porphyroblasts of actinolite in a matrix of plagioclase, epidote, chlorite, and titanite, the latter pseudomorphing ilmenite. A unit of fine- to medium-grained dolerite, and local gabbro (*AWed*) in the Emerald Mine Greenstone Complex (MGA 729439E 7606555N) contains a relict texture defined by igneous pyroxenes and amphiboles. However, these minerals have been replaced by metamorphic actinolite and chlorite, and the plagioclase is saussuritized.

A thin unit of tholeiitic volcanic rocks with heterogeneous igneous textures (*AWebhx*) is present adjacent to the western margin of the Shaw Granitoid Complex in the southern part of the Western Shaw greenstone belt (MGA 731139E 7568504N). These rocks, metamorphosed to amphibolite facies and intruded by granitoid rocks, include planar-bedded tuffs with centimetre-scale bedding, some agglomerates, and irregularly layered rocks that are tentatively interpreted as pahoehoe flows. These are the only known examples of possibly subaerial mafic volcanic rocks in the Warrawoona Group.

Thoroughly recrystallized and strongly sheared chloritic schists (*AWebs*) are composed of aligned chlorite together with intergrowths of epidote–actinolite–plagioclase–quartz – opaque minerals and are probably derived from metabasalts. Very highly strained and carbonate-altered (*AWebs*) high-Mg metabasalts adjacent to the western margin of the Shaw Granitoid Complex in the southern half of the map area contain carbonate and chlorite(–tremolite). Silicified metabasalt (*AWebz*) is present in the south-central part of the Western Shaw greenstone belt beneath a thin chert bed that is overlain by talc–carbonate rock. The zone of silicification has a ragged western (lower) margin, and relict volcanic textures such as amygdales, varioles, and pillows are widely preserved. In thin section, some of these rocks can be seen to retain relict pyroxene-spinifex texture, indicating derivation from a high-Mg protolith.

Interbedded with the volcanic rocks of the formation are a number of thin sedimentary units, mostly representing interflow hiatuses in volcanism. A unit of white, planar-bedded quartzite (*AWesq*), similar to that stratigraphically below and mapped as the Panorama Formation (*AWpsq*), is present in the lower parts of the formation in the southern portion of the Western Shaw greenstone belt. This unit tapers out along strike to the north. At stratigraphically higher levels in the formation are two main types of cherty interflow sedimentary rocks; the more common characterized by blue-grey and white layered chert (*AWec*), and the more distinctive type represented by bright-green, massive to weakly layered chert (*AWecg*). Whereas the former commonly contains clastic detritus and thus represents a tuffaceous horizon, the latter is most commonly a silicified flowtop, although a tuffaceous component can also be locally identified. Basaltic flows are locally separated by cherty BIF (*AWeci*) in which bedding at 5 mm scale is defined by alternating layers of red, blue, black, and grey material. A thin vein of blue-grey, massive hydrothermal chert (*AWech*) feeds bedded chert (MGA 730517E 7573987N).

## Golden Cockatoo Formation (*Ajx*)

The Golden Cockatoo Formation outcrops in a highly tectonized sliver along the northeastern margin of the Yule Granitoid Complex (MGA 711639E 7616455N), at the faulted contact with the Soanesville greenstone belt. These rocks include a mixture of amphibolite, muscovite-bearing metapelite, and white- to beige-weathering quartzite (*Ajx*). Original bedding is not preserved and these rocks are tightly folded and strongly foliated.

## Sulphur Springs Group

Since the revision of stratigraphy for the publication of the NORTH SHAW sheet (Van Kranendonk and Morant, 1998; Van Kranendonk, 1999, 2000), results of mapping on TAMBOURAH and geochemical data show that basaltic rocks and cherts underlying the Leilira Formation of the Sulphur Springs Group on NORTH SHAW, which were previously classified as the Six Mile Creek Formation of the Sulphur Springs Group, are similar to the Euro Basalt. Thus, the Six Mile Creek Formation is no longer recognized, and the base of the Sulphur Springs Group is therefore re-defined herein as the unconformity at the base of the Leilira Formation (Van Kranendonk, 1999, 2000).

## Leilira Formation (*ASls*, *ASlc*)

The Leilira Formation outcrops only in the northern part of the map area, within the Soanesville greenstone belt. The formation is predominantly composed of interbedded fine- to medium-grained lithic arenite and wacke (*ASls*). The rocks are typically sandstones, but locally vary to coarse pebbly sandstone with chert fragments, and thinly bedded siltstones. Bedding is well developed at centimetre to metre scale. In finer grained rocks, bedding is defined by variations in the amount of opaque minerals and metamorphic chlorite, indicating an origin as an intermediate to mafic tuff. Wackes contain subangular to subrounded clasts of quartz and plagioclase in a fine-grained quartzofeldspathic matrix. The formation is locally capped by centimetre-layered, grey, white, and blue-black chert (*ASlc*), representing silicified, fine-grained clastic sediment; possibly volcaniclastic ash.

A thin unit of quartz sandstone and metapelite (*AWesq*) outcrops in the southern part of the Western Shaw greenstone belt (MGA 731220E 7568600N). At this locality the rocks have been metamorphosed to upper greenschist facies, and the metapelite contains garnet, biotite, and muscovite in addition to quartz and tourmaline and trace amounts of opaque minerals. Tourmaline is present as small crystals throughout the matrix of the rock, and is abundant within, or on the margins of, thin, isoclinally folded quartz veins at outcrop scale.

## Kunagunarrina Formation (*ASkuk*, *ASkbm*, *ASkb*, *ASkbt*, *ASkcw*)

The Kunagunarrina Formation is composed dominantly of komatiitic, high-Mg, and tholeiitic metabasalt, metamorphosed to greenschist facies. The formation reaches a maximum thickness of 1750 m where it outcrops in the northern part of the sheet area, on the southern limb of the Soanesville Syncline. Pyroxene-spinifex texture was observed in basaltic komatiite (*ASkuk*) near the base of the formation (MGA 715939N 7616655N). Elsewhere, some of the rocks weather to a light-orange colour and have been interpreted as high-Mg basalt, and pillows were locally observed in this unit (*ASkbm*). Most of the formation, however, is composed of massive tholeiitic basalt (*ASkb*), in which pillows have not been observed. In the middle of the formation is a 50 m-thick unit of carbonate-altered mafic tuff and sandstone (*ASkbt*). This dark-brown rock is composed of centimetre-size mafic lapilli in a fine-grained, intermediate to mafic matrix now composed of chlorite, carbonate, and quartz (Fig. 7a). Millimetre- to centimetre-size chert and quartz clasts are scattered throughout the unit. In places, chert granule lag layers are present, with graded bedding and cross-bedding indicating that the unit is right way up, facing north. Near the base of the formation is a unit of centimetre-layered grey, black, and white chert (*ASkcw*), representing silicified fine-grained sediment.

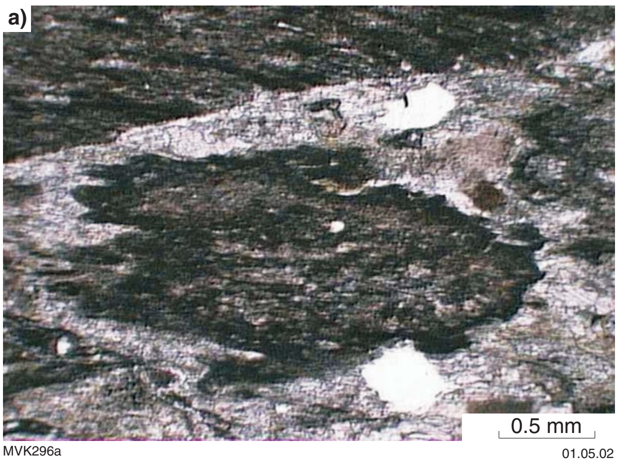




**Figure 7. Thin section views, in plane polarized light, of the Sulphur Springs Group: a) mafic tuff from the Kunagunarinna Formation (*ASkbt*), showing a ragged lapilli in a fine-grained matrix with anhedral quartz crystals (white areas); b) felsic tuff from the top of the Kangaroo Caves Formation (*AScbi*). Note the rounded to subangular quartz crystal fragments and devitrified glass shards, set in a fine-grained matrix of quartz and sericite that has been affected by hot, ductile flow folding**

### Kangaroo Caves Formation (*AScbi*, *AScc*)

Conformably above the Kunagunarrina Formation is up to 200 m of andesitic to rhyolitic volcanic rocks of the Kangaroo Caves Formation (*AScbi*). These rocks vary from grey-green to pale yellow and have massive to fragmental textures. One sample of felsic tuff, now a quartz–sericite schist, contains rare quartz crystal fragments and common glass shards, lapilli, and zoned vesicles that have been affected by ductile flow folding (Fig. 7b). Overlying this unit is up to 20 m of centimetre-layered grey-blue and white layered chert (*AScc*). This unit is composed of fine-grained volcaniclastic (including andesitic shard-rich sandstone) and epiclastic (including black mudstone, sandstone, and breccia) detritus intruded by discordant veins and concordant sills of white chert and black kerogenous chert.

## Gorge Creek Group

Well-preserved sedimentary rocks of the Gorge Creek Group conformably overlie the Sulphur Springs Group in the northwestern part of TAMBOURAH (MGA 718000E 7619400N). More strongly deformed and tightly folded remnants of the group lie in sheared contact with the Euro Basalt throughout the Emerald Mine Greenstone Complex and in the southern part of the Western Shaw greenstone belt. Only the lower three formations of the group (Pincunah Hill, Corboy, and Paddy Market Formations), known as the Soanesville Subgroup, are present on TAMBOURAH.

### Pincunah Hill Formation (*AGii*, *AGih*, *AGift*, *AGifc*, *AGif*, *AGihc*)

The lowest units of the Pincunah Hill Formation in the Emerald Mine Greenstone Complex include red and black, thinly bedded BIF (*AGii*), which includes subordinate black and white layered chert, or red-weathering black and grey shales (*AGih*). It is possible that in some areas, rocks mapped as BIF represent ferruginized, silicified shales affected by post-Cretaceous weathering. Shales locally pass gradationally up into 50 m of felsic schist and felsic volcaniclastic tuff (*AGift*; MGA 726610E 7615950N), which is overlain by up to 300 m of very fine grained, homogeneous quartz–sericite schist, intruded by blue-black chert veins. These rocks pass up into centimetre-layered, grey and white cherts that contain a clastic component and are interpreted to be silicified felsic ash (*AGifc*). This unit also locally contains clastic sedimentary rocks (?reworked tuffs), some of which were derived from tuffaceous rocks that display centimetre- to decimetre-scale bedding. A unit of powdery, white-weathering felsic volcanic rock (*AGif*), with associated jasperlitic chert and grey bedded chert (silicified felsic ash), outcrops in the Emerald Mine Greenstone Complex (MGA 726739E 7616156N).

Fine-grained, red-weathering shale (*AGih*) is interbedded with, and passes up and laterally into, sandstone of the Corboy Formation (*AGcs*) in the Soanesville greenstone belt. In the Emerald Mine Greenstone Complex, Pincunah Hill Formation shales outcrop together with other rocks of the Gorge Creek Group on the top of a high plateau, which represents a pre-Quaternary Cainozoic weathering peneplain. Here, the shales have been extensively silicified to grey, white, and black layered chert (*AGihc*; Fig. 8a), but the shale precursor can be viewed at the base of steep, deep gullies. Similar rocks are present in the southern part of the Western Shaw greenstone belt. Stratigraphically above the shales are up to 275 m of red and black BIF and chert (*AGii*).

Banded iron-formation in the southern part of the Western Shaw greenstone belt is composed of millimetre- to centimetre-thick layers of red-brown and white material. This is overlain by thin units of light-grey siltstone, quartz sandstone, and red and grey shales that pass up into more homogeneous, interbedded grey shales and siltstones.

### Corboy Formation (*AGcs*, *AGct*, *AGcq*, *AGcw*)

The Corboy Formation outcrops in the Soanesville greenstone belt and Emerald Mine Greenstone Complex. Rocks in the former consist of up to 1000 m of siltstone grading up into sandstone with metre-scale bedding (*AGcs*), whereas rocks in the latter grade upwards from chert-pebble conglomerate and sandstone (*AGct*), through quartzite with local cross-bedding (*AGcq*), to silty shale, wacke, and lithic arenite (*AGcw*). A similar stratigraphy is present at the base of the formation, where it unconformably overlies cherty shales in the tightly folded sliver of the Gorge Creek Group described by Boulter et al. (1987; MGA 729139E 7620856N and 730389E 7619906N). The unconformity is marked by a basal angular breccia, 10 cm of ferruginous sandstone, and chert-pebble conglomerate (Fig. 8b). Clasts in the conglomerates vary from well-rounded cobbles to subangular pebbles, and are matrix supported.

### Paddy Market Formation (*AGph*, *AGpi*)

Rocks of the Paddy Market Formation conformably overlie the Corboy Formation in the large flat-topped plateau in the Emerald Mine Greenstone Complex (MGA 722440E 7616950N). The formation consists of ferruginized and silicified grey shales (*AGph*) and BIF (*AGpi*). The shales are invariably silicified to a grey, white, and black layered chert on top of the plateau, whereas the BIF is composed of millimetre-bedded, red, white, and black material and subordinate ferruginous shale.

## Dalton Suite (*AaDLx*, *AaDLo*, *AaDLpd*, *AaDLp*, *AaDLlx*)

A number of layered ultramafic and mafic sills lie within the Gorge Creek and Sulphur Springs Groups, and in the Euro Basalt, particularly in the Soanesville

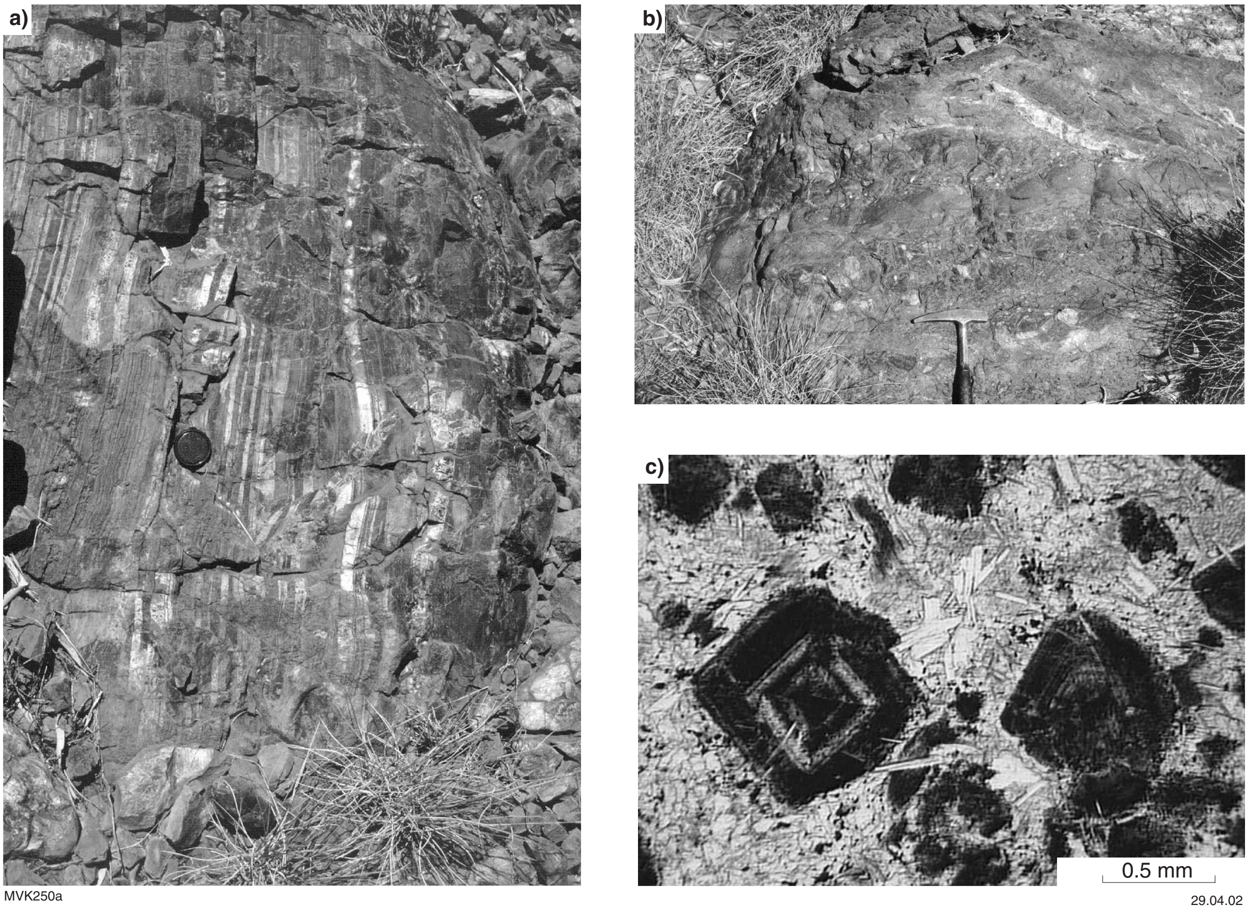



**Figure 8. Outcrop and thin section views of the Gorge Creek Group and Dalton Suite: a) Characteristic grey and white layered chert derived through silicification of shale, from the Pincunnah Hill Formation of the Gorge Creek Group (*Agih*; lenscap is 5 cm in diameter; MGA 729440E 7620950N); b) view south of overturned unconformity between silicified shales of the Pincunah Hill Formation (*Agih*; top of photograph) and coarse clastic rocks of the Corboy Formation (*Agcs*; hammer head is 20 cm long; MGA 729440E 7620950N); c) thin section, in plane polarized light, of metapyroxenite (*Aux*) in which euhedral, zoned, twinned augite crystals have been recrystallized to a very fine grained assemblage of metamorphic minerals and fine dustings of opaque minerals**

greenstone belt and the Tambina and Emerald Mine Greenstone Complexes. Individual sills are up to 300–400 m thick, and may be differentiated into a lower pyroxene leucogabbro (*AaDLlx*; including olivine websterite to harzburgite) and an upper gabbronorite (*AaDLo*). In the Soanesville greenstone belt, sills are differentiated upwards from dunite (≤250 m; *AaDLpd*) through peridotite (*AaDLp*) and pyroxenite (*AaDLx*) to gabbronorite (*AaDLo*).

Olivine-cumulate textures are preserved in basal parts of the sills, with variable amounts and proportions of intercumulate clinopyroxene and orthopyroxene. Olivine is extensively altered to serpentine and magnetite in these rocks, whereas pyroxenes are typically fresh. In the upper, more mafic parts of the sills, alteration is much more extensive, with saussuritization of plagioclase, bastite alteration of orthopyroxene, and growth of zoisite, fine-grained chlorite, and actinolitic amphibole. Asbestos veins in sheared metadunite were mined from the Soanesville mining centre (MGA 727039E 7617606N and 726989E 7618456N).

# Unassigned rocks

## Ultramafic rocks (*Aub*, *Aubs*, *Auc*, *Aucx*, *Aup*, *Aus*, *Aux*)

A variety of ultramafic rocks throughout Tambourah cannot be confidently correlated with an established intrusive suite or formation, and may locally represent younger intrusions. Such unassigned ultramafic rocks, described below in alphabetical order, are present in the Tambina and Emerald Mine Greenstone Complexes, within the Western Shaw greenstone belt, and in the Shaw Granitoid Complex.

Several long, thin rafts of greenstone in the Shaw Granitoid Complex are composed of interlayered amphibolite, medium-grained metaperidotite, metachert, and metaquartzite (*Aub*). These rocks have been transposed during $D_3$ deformation and contain penetrative foliations and lineations. Other transposed rock successions are dominated by ultramafic compositions over chloritic schists; the two components are interbedded at a scale of decametres (*Aubs*) and probably represent the sheared remnants of interbedded tholeiitic and high-Mg basalts.

A distinctive unit (*Auc*) of dark-brown-weathering, characteristically speckled rock is interbedded with metabasalts throughout the Western Shaw greenstone belt and in the Tambina and Emerald Mine Greenstone Complexes. This rock is composed of talc, and carbonate or chlorite (or both), and represents a metamorphosed ultramafic rock, probably komatiite. Carbonate porphyroblasts are commonly magnesite, although dolomite may also be present. Individual units vary from massive, medium-grained rocks (e.g. MGA 728439E 7568155N) to very highly strained schists (e.g. MGA 728889E 7588155N) in which white, massive quartz veins are locally present with fine to coarse, euhedral pyrite ('devil's dice'). These rocks are host to gold mineralization at several places along strike in the Western Shaw mining centre (e.g. MGA 728539E 7584955N and 728139E 7583455N). A unit of strongly schistose to massive talc–chlorite–carbonate megabreccia (*Aucx*; MGA 733539E 7611705N) separates the South Daltons Pluton from folded granitoid lobes to the east. Within this unit are large blocks (≤1 km) of amphibolite, metamorphosed high-Mg basalt, chert, and granite.

Fine- to medium-grained, green metaperidotite that weathers rusty brown to dark brown, is common through the greenstones of the map area, particularly in the Emerald Mine Greenstone Complex. The largest area of peridotite (*Aup*) and derived ultramafic schists (*Aus*) is along the southwestern margin of the Emerald Mine Greenstone Complex (around MGA 723139E 7610655N). Metaperidotites typically contain serpentine–chlorite–magnetite, although there are locally serpentine–magnetite(–chlorite–talc) schists as well. Although the age and association of these rocks is uncertain, it is likely that they are related to the stratigraphically overlying differentiated ultramafic to mafic sills of the Dalton Suite. In the Emerald Mine Greenstone Complex, weakly deformed, fine-grained, massive peridotite (*Aup*) contains widespread relics of cumulus-olivine texture, although the olivine is altered to serpentine, chlorite, and opaque minerals. This dark-blue to greenish-black rock weathers to tan brown and forms low outcrops. A weak foliation, manifest primarily as a fracture cleavage, is locally developed.

A single outcrop of pyroxenite (*Aux*) in the Shaw Granitoid Complex (MGA 755039E 7592055N) may be part of a dyke. The rock is massive, equigranular, and medium grained, weathering to dark brown to black. In thin section it consists of up to 50% by volume of completely altered (dusted magnetite and tremolite) euhedral augite crystals, up to 2 mm in size, in a groundmass of tremolite, Mg-chlorite, and plagioclase (Fig. 8c).

## Mafic rocks (*Aba*, *Abag*, *Ab*, *Abs*)

Strongly deformed or structurally isolated mafic rocks (or both), which cannot be placed with certainty into any stratigraphic unit, are present in several places across TAMBOURAH, particularly as rafts within the Shaw and Yule Granitoid Complexes.

Xenoliths and rafts of medium- to coarse-grained amphibolite (*Aba*) are widespread throughout the Shaw Granitoid Complex. These rocks are equigranular and typically display penetrative foliations and, commonly, lineations. Local basaltic textures are preserved, such as pillow rinds and ocelli (MGA 741200E 7580800N), but in general the rocks are featureless. Granitoid veins have extensively invaded amphibolite rafts in several places throughout the complex (*Abag*), as well as along the southwest end of the greenstone septum between the Tambourah Dome and the Yule Granitoid Complex (MGA 707350E 7590900N). A sliver of mafic schist (*Ab*) further north in the Yule Granitoid Complex (MGA 708250E 7620000N) contains local amphibolite, but also extensive chloritic schist, and is interbedded with quartzite and ultramafic schist. Highly strained chloritic schists (*Abs*) have also been identified and were probably derived from tholeiitic basalts or metagabbros, or both.

## Metasedimentary rocks (*Asq*, *Asqi*, *Ahpf, Ac*)

Thin units (typically <100 m) of transposed, but still obviously bedded, quartzite (*Asq*) are present in the Shaw Granitoid Complex, where they are commonly associated with amphibolite and may be continuous along strike for up to 10 km (e.g. MGA 736639E 7590155N). These fine- to medium-grained, amphibolite-facies rocks have been thoroughly recrystallized to granoblastic textures.

Scattered outcrops of mostly shallowly dipping quartzite (*Asq*) outcrop about halfway down the western edge of the map sheet within the Yule Granitoid Complex (MGA 710639E 7598655N). Bedding at decimetre scale is widely preserved and is subparallel to penetrative foliations defined by aligned micas. As described in **Structural geology**, it is most likely that the quartzites were deposited unconformably on a basement of orthogneiss that had already been deformed. The stratigraphic affiliation of these rocks is unknown; they may either belong to the Golden Cockatoo Formation, the De Grey Group (Smithies, 2002), or to an unknown affiliation.

A distinctive unit of ferruginous quartzite (*Asqi*) is present in two adjacent areas within the Shaw Granitoid Complex (MGA 743639E 7581855N and 741439E 7577805N). In close proximity to these rocks are amphibolite-facies metapelitic schists (*Ahpn*; MGA 743389E 7584355N). These rocks are quartzofeldspathic muscovite schists and gneiss, locally with deep-red almandine garnet. Some samples contain sillimanite and coarse, highly poikolitic porphyroblasts of a previous mineral species (?cordierite) now altered entirely to muscovite, and others contain sillimanite, biotite, and garnet. These rocks are folded and may represent part of the Golden Cockatoo Formation.

Units of fine-grained, layered chert (*Ac*) that are parallel to bedding in metabasalts or amphibolite characteristically consist of alternating layers of grey-blue and white chert. Some other cherts in the Western Shaw greenstone belt are discordant to bedding and do not contain layering. These are beige to blue-grey and commonly have a faint breccia texture or an irregular weathering surface, or both.

# De Grey Group

## Lalla Rookh Sandstone (*ADlc*)

The Lalla Rookh Sandstone outcrops in two small areas along the southern end of the Keep It Dark Synclinorium within the Emerald Mine Greenstone Complex (MGA 724639E 7619356N and 727239E 7620456N). The two outcrop areas are separated by a fault, but the other contacts of the formation are unconformities. The rocks consist of matrix-supported pebble to boulder conglomerate and interbedded pebbly to coarse-grained feldspathic sandstone (*ADlc*). Principal clast types include layered black and white or black and grey chert derived from the Gorge Creek Group, and white quartz. Bedding is typically at 1 m scale, defined by alternating conglomerate and sandstone.

The western outcrop area is elongate to the northeast and contains rocks that are gently deformed into an open syncline. It was deposited over, and during normal reactivation of, a significant reverse fault that separates the Soanesville greenstone belt from the Emerald Mine Greenstone Complex (see **Structural geology**). The southeastern contact is interpreted to be an onlap against the high plateau of the Gorge Creek Group. Rocks of the eastern area were deposited unconformably over several ridges of chert. This relationship is best seen at the northern tip of the second chert ridge, where bedding in the chert at 355°/60°E is truncated by conglomerate with bedding at 290°/16°N (MGA 727139E 7620356N).

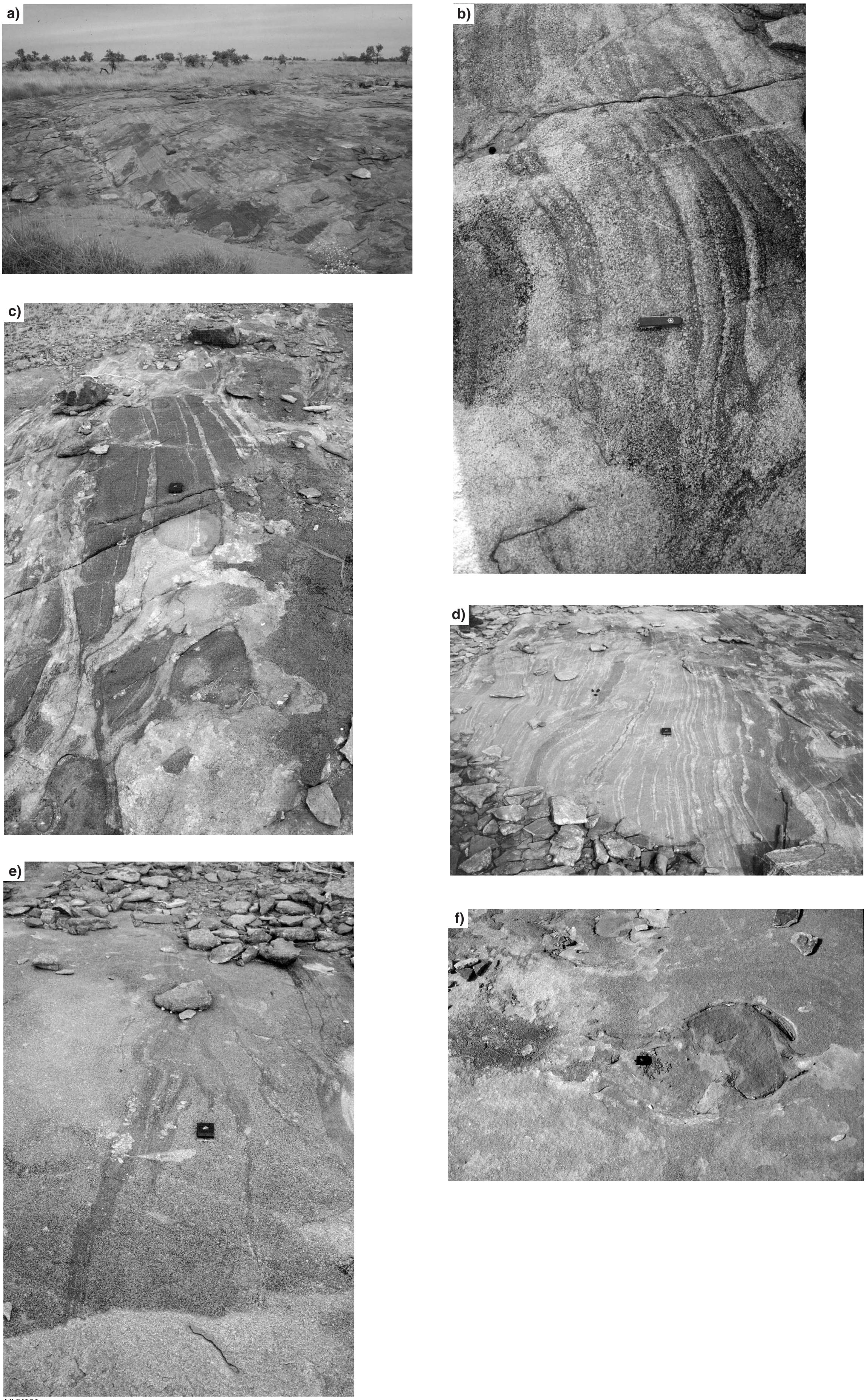
# Granitoid complexes

## Yule Granitoid Complex (*AgYpt*, *AgYpti*, *AgYka*, *AgYwo*, *AgYwoi*, *AgYwox*, *AgYwor*, *AgYta*, *AgYtan*, *AgYpe*)

The Yule Granitoid Complex on TAMBOURAH is composed of two structural domains: a part of the main complex in the west, and the Tambourah Dome in the east. The two domains are separated by a strongly deformed, synformal roof pendant of greenstones that becomes progressively more digested by granite to the southwest and onto WHITE SPRINGS (Hickman, 1983).

The oldest rocks are heterogeneous TTG orthogneisses (*AgYpt*, *AgYpti*), preserved as remnants in younger granites along the outer margin of the Tambourah Dome and as scattered inclusions within the main complex. These rocks are typically blue-grey biotite TTGs, with sheeted leucogranite veins, but there is also a more mesocratic biotite–hornblende-bearing phase that is quartz diorite to quartz monzodiorite in composition and plagioclase porphyritic. A sample of this unit was dated from the nose of the Tambourah Dome, and yielded an igneous emplacement age of c. 3420 Ma (unpublished U–Pb SHRIMP data on zircons). The gneisses were invaded by sheets of medium- to coarse-grained leucogranite during a period of migmatization that occurred prior to the intrusion of homogeneous, foliated, grey biotite granodiorite and monzogranite of the c. 3240 Ma Kavir Granodiorite (*AgYka*; unpublished U–Pb SHRIMP data on zircons; Fig. 9a). In areas within the Tambourah Dome where gneisses and Kavir granitoid rocks are extensively sheeted together, they have been mapped as a distinct unit (*AgYpti*).

The main part of the Yule Granitoid Complex on TAMBOURAH consists of K-feldspar-porphyritic to megacrystic biotite monzogranite of the 2933 ± 3 Ma Woodstock Monzogranite (*AgYwo*; Hickman, 1983; date from Nelson, 1998). This unit is typically well foliated and becomes mylonitized within the Pulcunnah Shear Zone at the northeastern margin of the complex, and only just extends into the northwestern margin of the Tambourah Dome. In lower strain areas, it is occasionally possible to identify igneous flow foliations defined by aligned K-feldspar megacrysts. This texture has been overprinted by a tectonic foliation defined by elongate quartz or biotite, or both. Where the Woodstock Monzogranite forms an intrusive sheeted network in orthogneiss and contains many rafts, xenoliths, and inclusions of the older rocks, it has been mapped separately (*AgYwoi*). An area of granite containing extensive inclusions of amphibolite was mapped separately (*AgYwox*; MGA 714000E 7599000N). Extending south and west from one such area of extensively preserved orthogneiss is an extensive subtype of the Woodstock Monzogranite that is characterized by compositional layering defined by alternating, 3–15 cm-thick layers of leucocratic and melanocratic monzogranite (*AgYwor*; Fig. 9a). The boundaries of the layers are gradational and the layering may extend in a planar fashion for tens of metres. All layers contain an igneous texture and mostly contain tabular K-feldspar phenocrysts. Locally, the layering is deflected or disrupted, or both, by the effects of igneous flow (Fig. 9b). At one particularly good exposure (MGA 715750E 7602750N), the Woodstock Monzogranite has intruded homogeneous grey granitoid rocks as a net of veins and dykes that has a preferred emplacement orientation along a pre-existing foliation in the host rock (Fig. 9c). Sheeted vein intrusion and in situ melt generation of veins has resulted in a gneiss (Fig. 9d). Where the volume of sheeted granite intrusion is greater than 80%, the host is only recognizable as wispy schlieren, having been almost completely digested by the invading granite (Fig. 9e). Trains of host blocks are locally present in the Woodstock Monzogranite. At the previous locality, the blocks display evidence for strong dextral igneous flow (Fig. 9f) as a result of emplacement during regional shearing at c. 2930 Ma (Van Kranendonk and Collins, 1998; Zegers et al., 1998; Pawley and Collins, 2002). The transition in textures observed in this outcrop is thought to represent the different stages of granite emplacement: from sparse dykes emplaced into a host, to sheeted dykes and digestion of the host by the invading granite, to the coalescence of magma and emplacement of a homogeneous granite (Fig. 10).

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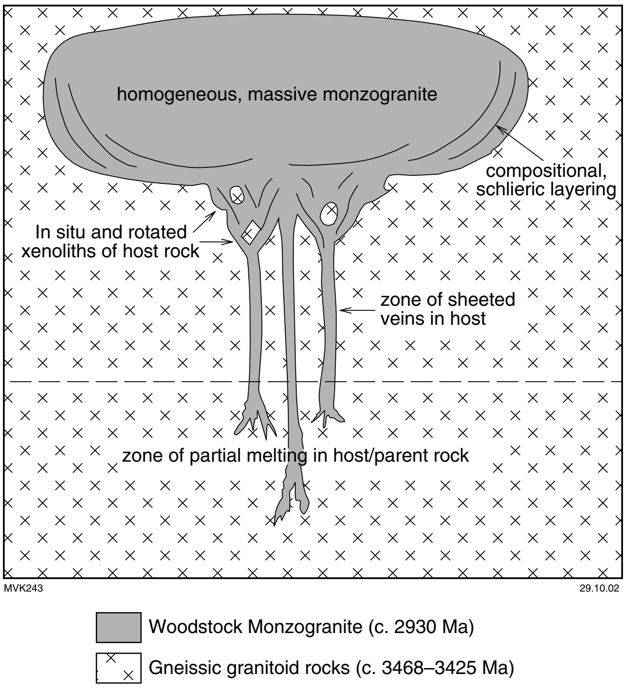


**Figure 10. Diagrammatic sketch of the features associated with emplacement of the Woodstock Monzogranite**

Forming the core of the Tambourah Dome is a heterogeneous unit (*AgYta*) comprising 50–80% very coarse, but patchy, pegmatitic monzogranite and coarse-grained syenogranite of unknown age. This is present within homogeneous, weakly foliated, grey granitoid rocks — probably the Kavir Granodiorite (*AgYka*) — and locally coarse-grained to pegmatitic biotite leucogranite. The pegmatitic phase does not form sharp-walled dykes, but is present as irregular patches within the host rocks and appears to have crystallized in situ from locally derived fluids or melts, or both. Very large (commonly 30–40 cm) K-feldspar crystals with graphic intergrowths of quartz characterize the pegmatite, and patches of small garnets were locally observed. In the southwestern part of the sheet area, coarse-grained to pegmatitic leucogranite forms a sheeted intrusive complex in the host granodiorite (*AgYtan*).

Coarse-grained to pegmatitic monzogranite (*AgYpe*) is common along the margins of, and within, the southern edge of the greenstone septum that separates the Tambourah Dome from the main part of the Yule Granitoid Complex. This rock type mostly forms elongate sheets, and is typically strongly foliated, having been emplaced during $D_3$ deformation, probably as a marginal phase of the Woodstock Monzogranite (see **Structure**).

## Tambina Granitoid Complex (*AgTn*, *AgTp*, *AgT*)

The Tambina Granitoid Complex forms a doubly plunging anticline in the central-northern part of the sheet area. The main units of the complex are distributed in an annular pattern around the fold, but none have been dated.

In the core of the dome is a grey, gneissic, biotite tonalite (*AgTn*) that has a similar appearance to gneisses in adjacent complexes dated at c. 3450 Ma. Sheets and veins of medium- to coarse-grained leucogranite characterize this unit. A more homogeneous unit of well foliated, fine- to medium-grained, grey biotite granitoid (*AgT*) surrounds the gneissic core and occupies the small lobe to the northwest. This unit probably represents the same precursor as in the gneiss, but it may alternatively represent a younger unit. A K-feldspar porphyritic monzogranite (*AgTp*) is present around the southeastern nose of the dome.

## Shaw Granitoid Complex

The Shaw Granitoid Complex occupies the core of the Shaw Dome in the eastern half of the map sheet. Granitoid rocks of the complex typically have strongly sheared intrusive contacts with greenstones of the Western Shaw greenstone belt and Emerald Mine Greenstone Complex. However, a well-preserved intrusive contact with low-strain amphibolite-facies greenstones is present in the far south (MGA 731500E 7567000N). The complex may be divided into several texturally and compositionally distinct units as deduced from crosscutting intrusive relationships and the results of SHRIMP U–Pb zircon geochronology. Overall, the eastern half of the complex on TAMBOURAH consists of gneissic migmatites and diatexites derived from partial melting of c. 3460 Ma TTG protoliths at c. 3410 Ma. The western margin of the complex is occupied by foliated, mostly homogeneous granodioritic to granitic rocks that range in age from c. 3435 to 3425 Ma. In the southern part of the complex are several discrete intrusive phases intruded at c. ?3300–2930 Ma, the later components being emplaced during regional $D_3$ deformation. The post-tectonic c. 2850 Ma Cooglegong

**Figure 9. (Opposite page) Outcrop features of the Woodstock Monzogranite (*AgYwo*; MGA 715750E 7602750N): a) straight compositional ('schlieric') layering in K-feldspar porphyritic monzogranite; b) texturally 'graded' compositional ('schlieric') layering in igneous monzogranite, which is folded and truncated by compositional, and texturally identical, isotropic monzogranite in the lower part of the photograph; c) a network of monzogranite veins in a homogeneous, but strongly foliated grey granitoid host; note that most of the veins intrude parallel to the foliation in the host, giving the rock a 'gneissic' appearance; d) an injection migmatite of Woodstock Monzogranite veins in homogeneous grey granitoid rock. The volume of vein injection has caused the host to undergo partial melting, as indicated by the palaeosome margins to the vein just left of the compass, which is 13 cm long; e) coarse-grained monzogranite with relict schlieren derived from incomplete digestion of the relict host; note the growth of K-feldspar phenocrysts/porphyroblasts in the schlieren. Compass is 13 cm long; f) an asymetrically rotated xenolith of the host in isotropic Woodstock Monzogranite, indicating dextral igneous flow**

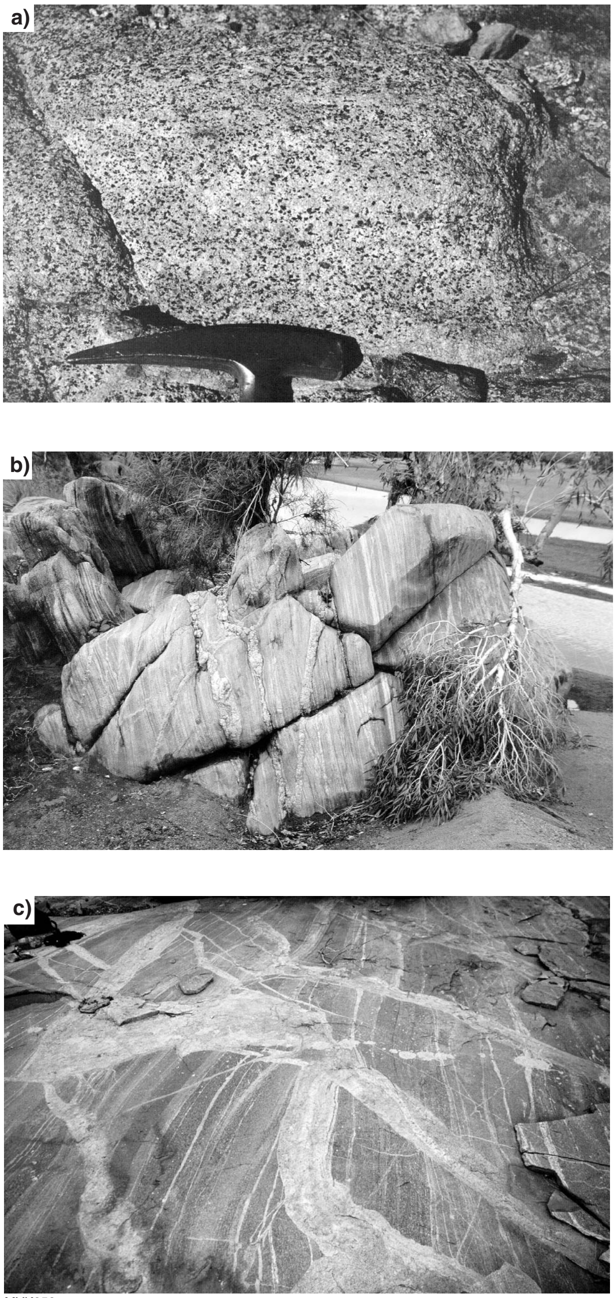

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**Figure 11. Outcrop features of homogeneous grey granodiorite of the Shaw Granitoid Complex: a) typical exposure of mesocratic quartz diorite to monzodiorite with hornblende clots (*AgSd*) of the Shaw Granitoid Complex (hammer head is 20 cm long; MGA 741140E 7585450N); b) grey, migmatitic tonalitic orthogneiss (*AgSn*; MGA 742640E 7616150N); c) low-strain enclave of grey tonalitic rocks, showing the multiple sheeted nature of the protolith and a random, fracture-fill pattern of younger granitic dykes (MGA 739340E 7609900N); d) synplutonic mafic dykes in homogeneous grey granodiorite (*AgSg*; MGA 742440E 7602350N)**

and Spear Hill Monzogranites occupy much of the northern part of the complex. Interspersed with all but the youngest components are amphibolite xenoliths and rafts of greenstones.

### Older gneissic rocks (AgSd, AgSn, AgSnp, AgSg, AgSnh, AgSnl, AgSlxn, AgSl, AgSgp, AgSgl, AgSgx, AgSnld, AgSnli)

The oldest recognized component of the Shaw Granitoid Complex on TAMBOURAH is a mesocratic, hornblende–quartz diorite to monzodiorite (*AgSd*) with a distinctive spotty texture (Fig. 11a). This medium- to coarse-grained unit has a colour index of 10–25% defined by minor amounts of green biotite, but mostly by 2–5 mm-long hornblende crystals that contain intergrown titanite and some 1–2 mm-long zircon crystals. The leucocratic material is composed mostly of plagioclase, with 10–20% quartz and up to 10–15% microcline, with trace amounts of apatite. The unit forms a large raft in the central-western part of the complex where it has been intruded by the Garden Creek Monzogranite (*AgSgc*; MGA 741139E 7585155N), and forms smaller inclusions in tonalite gneiss throughout much of the central-southern map area (Fig. 3). The diorite displays a weak gneissic layering defined by 1–3 cm-wide leucocratic layers that may represent leucosome veins derived from partial melting. This unit is similar in appearance to the North Shaw Tonalite in low strain areas where it does not contain a gneissic layering (Van Kranendonk, 2000). Zegers (1996) obtained a SHRIMP U–Pb zircon age of 3463 ± 2 Ma from a sample of this unit (sample T94/222; Table 3) located approximately 1 km west of the Shaw River, about 1.5 km north of Garden Creek (MGA 746820E 7582580N). This sample also returned an $^{40}Ar–^{39}Ar$ date on hornblende of 2878 ± 12 Ma, interpreted to represent the age of metamorphic cooling of the rock (Zegers, 1996; Zegers et al., 1999).

Medium-grained, grey granitoid rocks with TTG compositions intruded the hornblende–quartz diorite. Typically, these rocks are gneissic (*AgSn*), with up to 30% of centimetre- to metre-wide veins of leucogranite that were either injected into the rock or derived from the host through in situ partial melting (Fig. 11b). In low strain areas, TTGs can be seen originally emplaced as a sheeted sill complex in which individual components had slight variations in mafic mineral content and texture (Fig. 11c). The scale of sheeting varies from 30 cm to several metres, although large areas may be entirely homogeneous. Typically the rocks contain less than 8% biotite. Grey granitoid rocks with porphyritic feldspar were locally mapped as a separate unit (*AgSnp*). A few broad outcrop platforms contain thin mafic dykes that are interpreted as synplutonic with intrusion of the granitoid rocks (Fig. 11d). The granitoid gneisses contain numerous xenoliths of amphibolite gneiss that outline regional folds. Some amphibolites contain relict orthopyroxene and clinopyroxene, indicating that granulite-facies temperatures were reached prior to extensive amphibolite-facies retrogression, but pressure conditions during metamorphism were low, as no evidence of relict garnet has been observed in these rocks.

Zegers (1996) dated a sample (T94/221; 748050E 7582720N) of grey granitoid gneiss from the south-central part of the sheet area by the U–Pb SHRIMP method on zircon. The results were interpreted to yield a mean age of 3451 ± 1 Ma, but this rock contains zircons with older cores (3469 ± 15 and 3466 ± 5 Ma) and younger rims (3433 ± 7 and 3416 ± 7 Ma; Table 3). The ages of the zircon cores are similar to the age of the Coolyia Creek Tonalite of the North Shaw Suite (Nelson, 1999; Van Kranendonk, 2000) and of grey gneisses from the eastern margin of the complex (Zegers, 1996), and the two rim ages correspond to the time of intrusion of the homogeneous granitoids along the western margin of the complex (*AgSg*) and a period of partial melting respectively (see below).

Gneissic rocks in the central part of the granitoid complex were extensively melted to form a distinctive texture of scattered hornblende porphyroblasts in rocks with diffuse and indistinct, often wispy, relict gneissic layering and large, typically round, single crystals of K-feldspar (*AgSnh*; Fig. 12a,b). As described for similar rocks on NORTH SHAW (Van Kranendonk, 2000), this texture forms as a result of breakdown of biotite in the igneous precursor during partial melting.

Where the orthogneiss contains 30–50% of leucogranite, it was mapped as *AgSnl*, indicating it is still recognizably an orthogneiss. Where leucogranite derived from melting is more than 50%, the rock was mapped as a leucogranite diatexite (*AgSlxn*). In these rocks, gneissic layering is only preserved as wispy biotitic schlieren. Medium-grained homogeneous and schlieric leucogranite is interlayered with patches, lenses, or layers of K-feldspar rich granite (Fig. 12c). The mafic mineral content is mostly less than 1–2% by volume and small xenoliths of amphibolite and hornblende–quartz diorite are common. Large areas of leucogranite diatexite are present in the northeastern and southeastern parts of the map area (MGA 751000E 7615000N and 752000E 7586000N respectively). Leucogranite (*AgSl*) is the dominant lithology in the northeastern corner of the sheet area and in the southeast (MGA 756500E 7619000N and 756389E 7577155N respectively), where it is relatively homogeneous with only faint traces of relict gneissosity. Van Kranendonk (2000) showed that the generation of leucogranite on adjacent NORTH SHAW and MARBLE BAR spanned a protracted period from c. 3445 to 3410 Ma (dates from Nelson, 1998, unpublished data).

Homogeneous, equigranular, medium-grained leucocratic granodiorite (*AgSg*) crosscuts migmatitic orthogneiss in the folded granitoid lobes in the northwestern part of the complex (Fig. 13a), and further south along the western side of the complex. Some of the homogeneous, leucocratic rocks contain feldspar-porphyritic textures (*AgSgp*). In many places, the homogeneous grey granitoid rocks are intruded by sheets of medium- to coarse-grained, foliated leucogranite, and where this is widely developed the rocks have been mapped as a separate unit (*AgSgl*; Fig. 13b).

Mesocratic to melanocratic granitoid rocks (*AgSgx*) with up to 35% hornblende are present adjacent to amphibolite rafts in the South Daltons Pluton, and are interpreted as granitoid magmas contaminated by assimilated mafic material. Conversely, the large enclave of amphibolite in the South Daltons Pluton (MGA 733139E 7616155N) and a thin rind of mafic rocks around the northern margin of the central granitoid lobe in the northwest Shaw area (MGA 735389E 7613755N; Fig. 14a) have been affected by metasomatic alteration during and after granite emplacement (Fig. 14b,c). Previously, Bickle et al. (1980, 1985) interpreted these rocks as calc-silicates and used them as marker beds to outline isoclinal folds. However, detailed mapping shows that the ‘calc-silicates’ are a mixture of metre-thick granitoid sills and amphibolite (Fig. 14a) that have been altered by metasomatic fluids associated with granitoid intrusion. Amphibolites become progressively more leucocratic towards the granitoid contact and display a change in mineralogy from hornblende–plagioclase – opaque minerals to rocks with tremolite, actinolite, epidote, titanite, and saussuritized plagioclase. In contrast, granitoid sills become more mafic away from the granitoid contact, probably due to assimilation of amphibolite or possibly as a result of metasomatic exchange of components with amphibolite. The least-altered granitoid sills adjacent to the granitoid contact contain fresh plagioclase, quartz, actinolite, tremolite, and opaque minerals and are well foliated (Fig. 14d). Further away, feldspars are saussuritized by fluids introduced by thin greisen veins (Fig. 14e), whereas the most distal sheets have been completely recrystallized to a granoblastic assemblage of epidote, actinolite, and titanite (Fig. 14f).

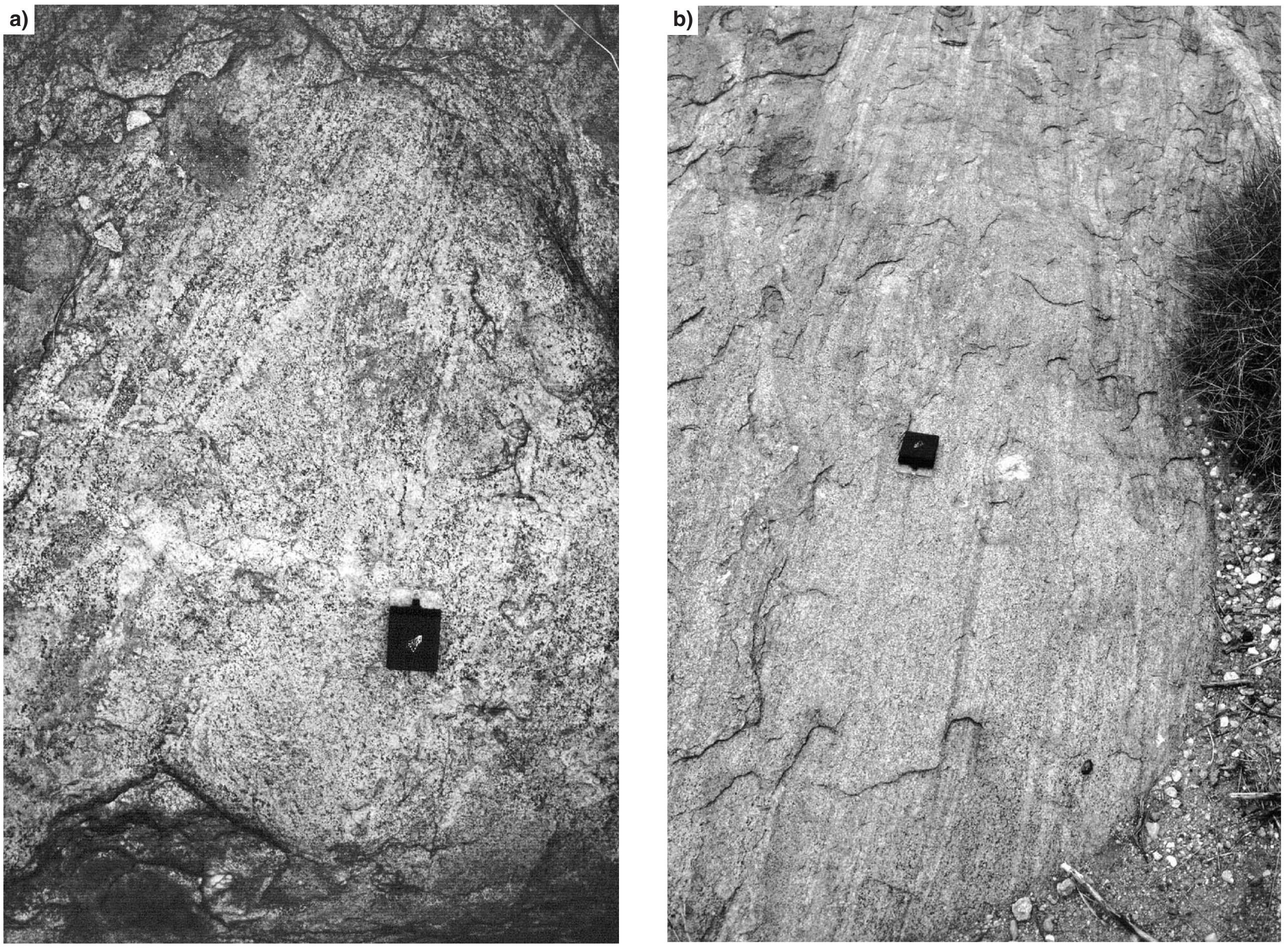




**Figure 12. Features relating to in situ melting of orthogneiss in the Shaw Granitoid Complex:**
**a) migmatitic tonalite gneiss that has been partly recrystallized during in situ melting to form a spotty hornblende-textured rock in which the migmatitic layering has become somewhat indistinct (*AgSnh*; compass is 13 cm long; MGA 741390E 7598450N);**
**b) a more extensively melted example of tonalitic orthogneiss with large K-feldspar porphyroblasts in which the original migmatitic layering is preserved only as wispy schlieren (*AgSl*; compass is 13 cm long; MGA 741390E 7598450N);**
**c) leucogranite diatexite (*AgSlxn*) with fragmented pods of amphibolite, almost completely melted orthogneiss with coarse spotty hornblende and irregular veins of pure leucogranite (hammer is 38 cm long; MGA 756890E 7619160N)**

The younger suite of grey granitoid rocks (*AgSg*) is mostly foliated, but becomes mylonitized in the Mulgandinnah Shear Zone and is locally intruded by leucogranite sheets, but nowhere is it migmatitic. Several samples of this unit have been dated (GSWA 142966 and 142968, UWA-98053, M95-78) and fall in the range 3435 to 3425 Ma, including the c. 3431 ± 4 Ma South Daltons Pluton (Table 3). This suite is therefore correlative with the eruption of the Panorama Formation, and was emplaced as a sill relatively high in the stratigraphy of the Warrawoona Group relative to the c. 3468 Ma TTG suite, as shown schematically in Figure 15.

Mixtures of some of the above rock types are present in several areas throughout the complex. Large platforms in the east-central and southeastern parts of the complex with numerous inclusions and larger rafts of hornblende–quartz diorite (*AgSd*) in tonalitic orthogneiss (*AgSn*) with abundant leucogranite (*AgSl*) were mapped as *AgSnld*. Mixtures of tonalitic orthogneiss (*AgSn*) and sheets of leucogranite (*AgSl*) that have been intruded by weakly foliated dykes and sheets of fine- to medium-grained, homogeneous biotite monzogranite (*AgSmu*) were mapped as *AgSnli* (e.g. MGA 740139E 7597155N).

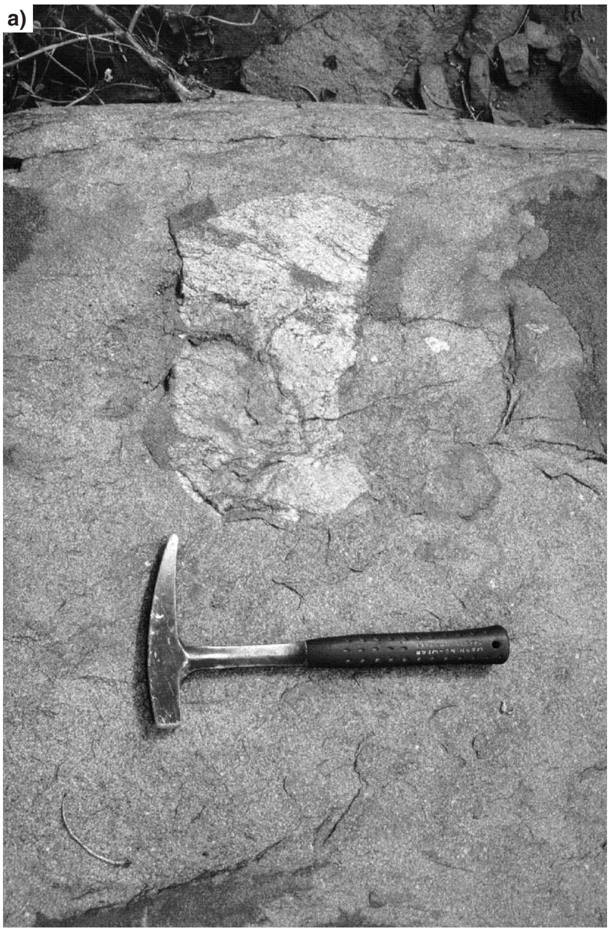




**Figure 13. Outcrops views of granitoid intrusions in the Shaw Granitoid Complex: a) Homogeneous grey granodiorite (*AgSg*) with an included xenolith of migmatitic orthogneiss (*AgSn*) from the folded granitoid lobes in the northwestern part of the Shaw Granitoid Complex (MGA 735440E 7613450N; hammer is 38 cm long); b) homogeneous grey granodiorite with sheeted leucogranite dykes (*AgSgl*; MGA 744640E 7617850N; hammer is 38 cm long)**

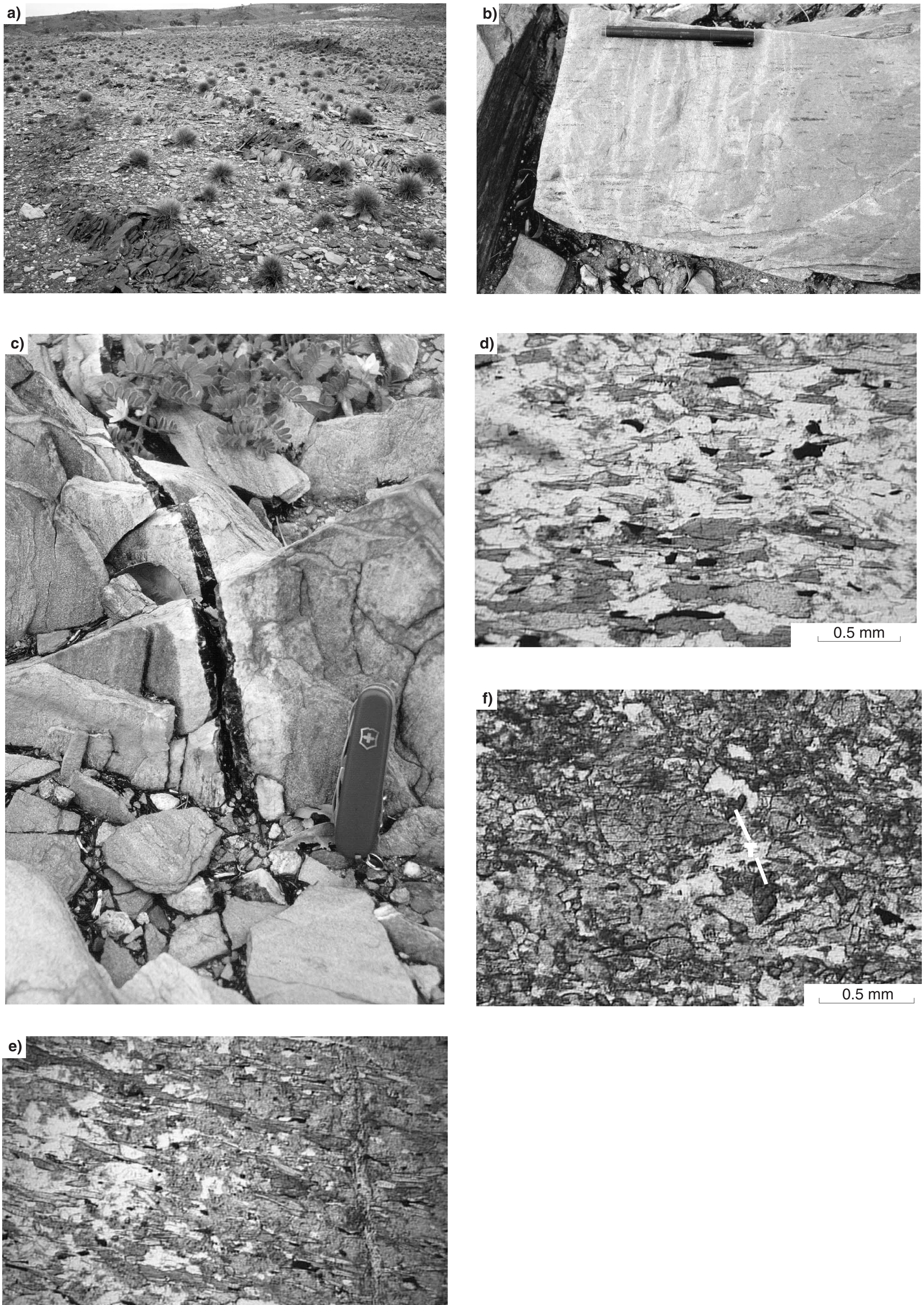
### *Foliated granitoid rocks (AgSbs, AgSgc, AgScn, AgSel, AgSmu, AgSgcu, AgSmp, AgSnmu, AgSilmu, AgSmuxn)*

In the southern part of the complex are several strongly foliated, but non-migmatitic, plutons. These include the Bamboo Springs Monzogranite (*AgSbs*), Garden Creek Monzogranite (*AgSgc*), Coondina Monzogranite (*AgScn*), Eley Monzogranite (*AgSel*), and several textural varieties of the Mulgandinnah Monzogranite (*AgSmu*). None of these phases on Tambourah have been dated by U–Pb zircon methods, but several are thought to be c. 3000–2930 Ma, based on Pb–Pb whole rock dating by Bickle et al. (1989) and by compositional correlation with the dated Mulgandinnah Monzogranite (*AgSmu*) on North Shaw (Nelson, 1998; Van Kranendonk, 2000).

The Bamboo Springs Monzogranite (*AgSbs*; Hickman, 1983) is a well-foliated, coarse-grained, biotite monzogranite with elongate, rectangular K-feldspar phenocrysts up to 2 cm long. In places it has a schlieric texture defined by layers of more melanocratic monzogranite, and it may also be transected by swarms of pegmatitic granite dykes. Foliations are defined typically by aligned K-feldspar phenocrysts and elongate quartz, and these are parallel to schlieren. Contacts with adjacent units are not exposed, but small dykes and sheets of the Mulgandinnah Monzogranite (*AgSmu*) cut the pluton. This unit is lithologically similar to the c. 3315 Ma Corunna Downs Granitoid Complex (Barley and Pickard, 1999), and may be the same age.

The Garden Creek Monzogranite (Bettenay et al., 1981) is a medium-grained, leucocratic, biotite monzogranite that has been affected by a very strong tectonic foliation. The granite has intrusive contacts with amphibolite (*Aba*), ferruginous sandstone (*Asqi*), and hornblende–quartz diorite (*AgSd*), but is cut by the Coondina Monzogranite (*AgScn*) in the southern and western parts of the map sheet. In the southern and eastern parts of Tambourah, where the pluton is coarser grained and less strongly deformed, it contains muscovite, locally with small patches of garnet and tourmaline (*AgSgcu*). A sample collected for U–Pb SHRIMP dating failed to provide usable results. Sheets of strongly foliated K-feldspar-megacrystic monzogranite (*AgSmp*) are present in the Mulgandinnah Shear Zone. These rocks have sharp contacts with adjacent TTG, but in contrast to them, are not migmatitic and display evidence of only the late high-strain shear zone fabric.

The Coondina Monzogranite (*AgScn*; Hickman, 1983) has intruded mafic and ultramafic rocks (*Aba*, *Aup*), orthogneiss (*AgSn*, *AgSnp*), homogeneous grey granitoid rocks (*AgSg*), as well as the Garden Creek Monzogranite, but has been intruded by small plutons of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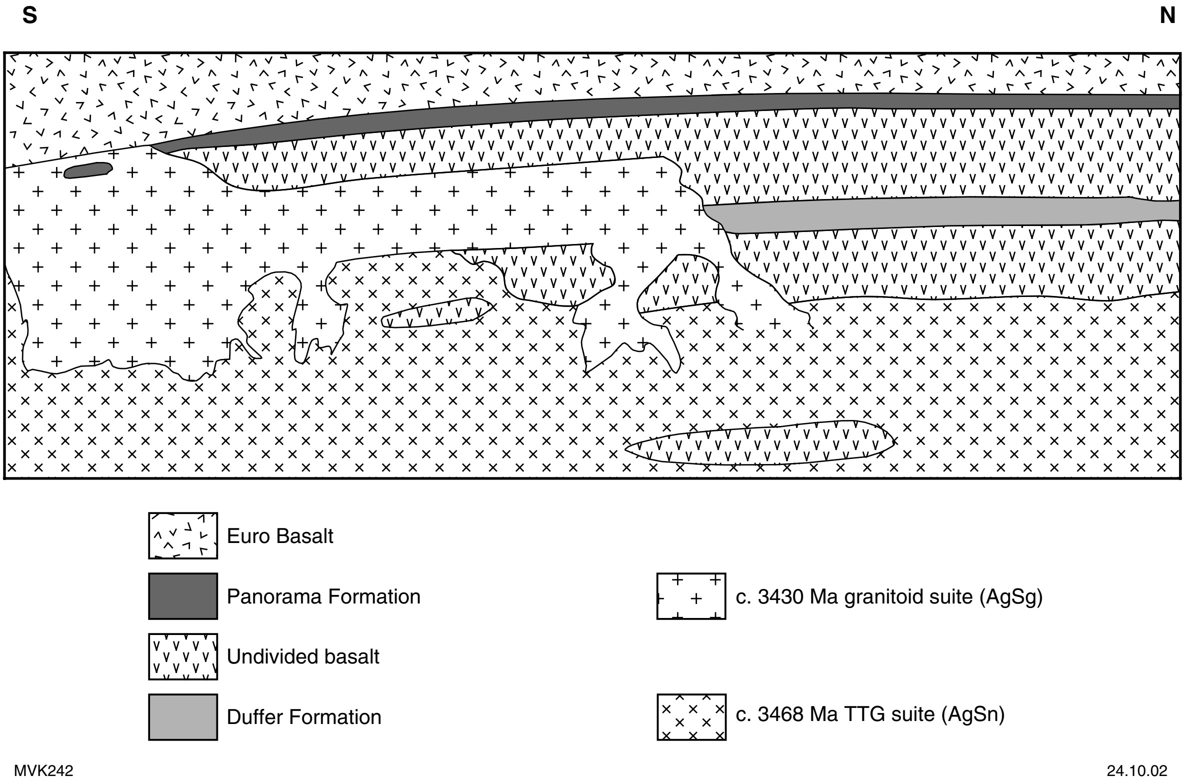



**Figure 15. Schematic cross section showing how successively younger suites of granitoid rocks in the Shaw Granitoid Complex excise progressively higher parts of the greenstone succession from north to south**

the Mulgandinnah Monzogranite (*AgSmu*). The Coondina Monzogranite is a medium-grained, typically K-feldspar-porphyritic biotite monzogranite that has a penetrative foliation defined by aligned K-feldspar phenocrysts and biotite, and by elongate quartz. K-feldspars are up to 1 cm long and mostly elongate, although they may be rectangular or rounded. In the southeastern part of TAMBOURAH (MGA 738839E 7568355N) the monzogranite has intruded orthogneiss, but was infolded with it during $D_3$ sinistral shear deformation, suggesting that it was synkinematic with this phase of deformation and thus is c. 2936 Ma.

The Eley Monzogranite (*AgSel*; Hickman, 1983) is a weakly to moderately foliated, K-feldspar-porphyritic (typically cubic, 1 cm across) biotite monzogranite. Other than the K-feldspar phenocrysts, it is lithologically similar to the Mulgandinnah Monzogranite. This unit is best exposed in the east-central part of the map sheet (MGA 757139E 7600155N and 754839E 7594855N), but it continues south along the eastern side of the sheet area. The monzogranite has intruded orthogneiss and diatexite (*AgSn*, *AgSnl*, *AgSlxn*), but is intruded by pegmatitic granite dykes of the Cooglegong Monzogranite (*AgScgpe*).

Two mixtures of granitoid rocks involving these younger granitoid rocks were identified. One type (*AgSnmu*) consists of orthogneiss (*AgSn*) that has been intruded by numerous sheets of foliated, fine- to medium-grained, grey granite and K-feldspar-porphyritic monzogranite (*AgSmu*). The second type (*AgSilmu*) consists of schlieric leucogranite (*AgSl*) and remobilized orthogneiss (*AgSn*) that has been intruded by sheets of K-feldspar-megacrystic monzogranite (?*AgSel* or *AgSmu*, or both).

**Figure 14. (Opposite page) Outcrop and thin section features of the alteration halo around the northern rim of the central, folded granitoid lobe in the northwest Shaw Granitoid Complex (MGA 735440E 7613755N): a) view east-southeast of highly strained, sheeted granitoid contact with thin, discontinuous peels of amphibolite (hammer is 38 cm long); b) post-tectonic alteration veins cutting foliated granitoid (pen is 14 cm long); c) view onto foliation surfaces of strongly foliated and downdip lineated granitoid cut by post-tectonic tourmaline vein that has a bleached alteration halo (pen knife is 9 cm long); d) thin section, in plane polarized light, of a granitoid sheet proximal to the main body of the folded granitoid lobe, showing aligned, acicular actinolite (dark) and tremolite (light), and opaque minerals in a matrix of fresh plagioclase and quartz; e) thin section, in plane polarized light, of a granitoid sheet — slightly more distal from the main body and past some amphibolite rafts — that has the same mineralogy as in e), but has been altered by a post-tectonic vein cutting across the foliation on the right, causing alteration of adjacent matrix feldspars; f) thin section, in plane polarized light, of a distal granitoid sheet with coarse epidote–actinolite–titanite (T) mineralogy formed as a result of interaction with, and partial assimilation of, entrained peels of amphibolite; this rock had been interpreted as a calc-silicate by Bickle et al. (1980, 1985)**

A series of small plutons and related dykes of the 2928 ± 2 Ma (Nelson, 1998; sample 142882) Mulgandinnah Monzogranite (*AgSmu*) intruded gneisses, leucogranite, and all of the younger plutonic phases of the Shaw Granitoid Complex across the map area, except for the younger Cooglegong and Spear Hill Monzogranites. The fine- to medium-grained monzogranite is blue-grey and weathers to a dark chocolate-brown thin rind on rounded boulders that form tors above the surrounding flat granitoid terrain. The unit is typically weakly to penetratively foliated, with foliations defined by elongate quartz and aligned biotite in outcrop, and by the formation of subgrains of quartz and a fracture cleavage through feldspars in thin section. Plagioclase forms 40% of the rock and is oligoclase in composition, and typically has heavily saussuritized cores. Microcline forms 25% of the rock and there is also local myrmekite. Accessory minerals include titanite, apatite, magnetite, and allanite, the latter two minerals forming conspicuous dark spots in the rock that are mantled by white feldspar. Zircon is abundant as very fine grains, and there is secondary growth of epidote, sericite, carbonate, and chlorite after biotite. A subtype of the Mulgandinnah Monzogranite found only in one locality (MGA 751739E 7591955N), consists of K-feldspar-porphyritic monzogranite that does have the characteristic brown-weathering rind on boulders in tors.

A diatexite composed of c. 2930 Ma granitic components and orthogneiss (*AgSmuxn*) is exposed in spectacular platforms in the bed of Tambourah Creek in the northwestern part of the Shaw Granitoid Complex (MGA 741339E 7598955N). The bulk of the unit is composed of comagmatic mesocratic and leucocratic monzogranite phases that display mutually crosscutting relationships (Fig. 16a). In some cases, leucocratic monzogranite is mantled by a biotitic palaeosome rind in the mesocratic phase, suggesting that the former are partial melts of the latter (Fig. 16b). Elsewhere, leucocratic granite sheets represent remobilized orthogneissic diatexite, formed during intrusion of the younger components. These may have very complex structures that formed through remobilization of melted orthogneiss during intrusion (Fig. 16c). Locally, dykes of leucogranite melt were observed to aggregate from partial melts of orthogneiss. Orthogneiss and melt phases were dated separately by Nelson (2000), who found that the precursor gneiss was 3430 ± 4 Ma (GSWA 142966) and the leucocratic dyke was 2929 ± 4 Ma (GSWA 142965), the same age as a K-feldspar-porphyritic component of another part of the diatexite (GSWA 142967).

### Post-tectonic granitoid rocks (AgSsh, AgScgpt, AgScgla, AgScge, AgScgp, AgScgpe, AgScgc, AgSr)

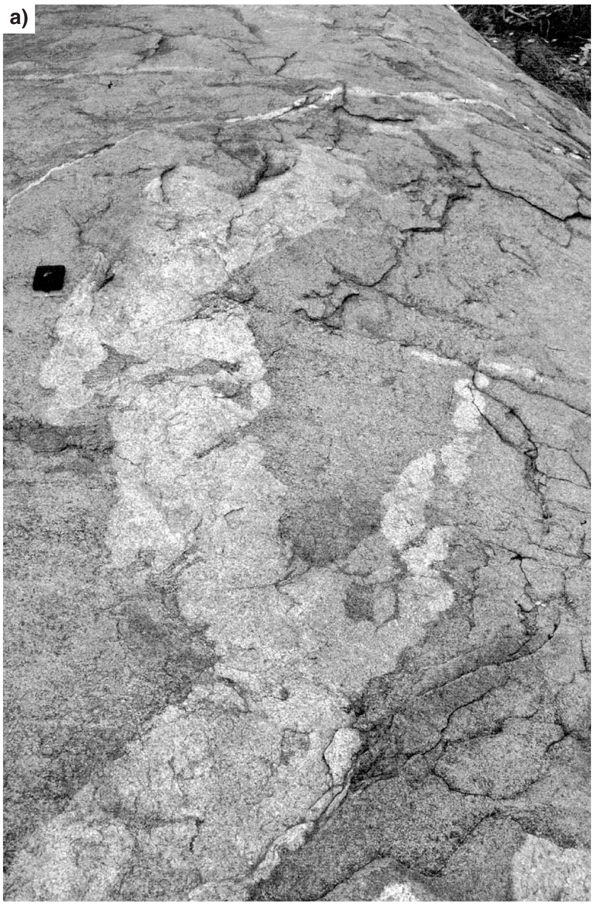
Intrusive into all of the previously described units are the undeformed, typically coarse grained Spear Hill and Cooglegong Monzogranites (Hickman, 1983). The Spear Hill Monzogranite (*AgSsh*) is a smaller pluton comprising only K-feldspar-porphyritic biotite monzogranite with steeply dipping contacts, whereas the Cooglegong Monzogranite comprises several mappable units and represents a large, thick sill with a subhorizontal basal contact against older units (Fig. 17a; MGA 747139E 7598755N). Crosscutting relations were observed for some units of the Cooglegong Monzogranite, whereas others grade into one another. Nelson (1998) obtained a date of 2851 ± 2 Ma on the Spear Hill Monzogranite. This date is interpreted to also apply to the Cooglegong Monzogranite, as suggested by field relations, the distinct metallogeny of the granites, and the Pb–Pb whole-rock data of Bickle et al. (1989).

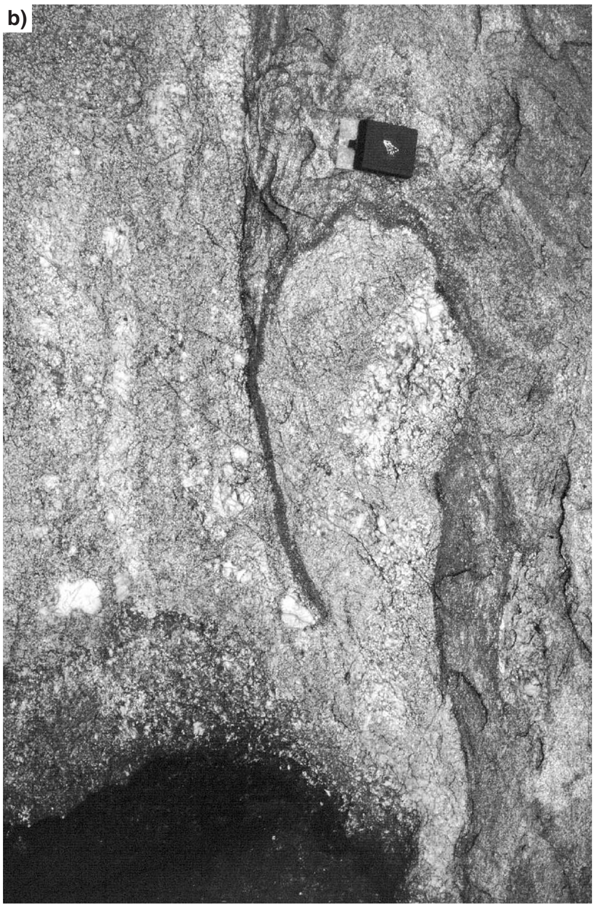
The Cooglegong Monzogranite forms a broad, east–west-striking sill with a funnel-shaped, more steeply dipping southern promontory. Near the southern end of this promontory, on an island in the Shaw River (MGA 749339E 7595355N), is the oldest phase — a dark blue-grey biotite–hornblende–titanite monzogranite with aligned K-feldspar megacrysts and felsic ocelli (*AgScgpt*). This rock is characterized by a strong vertical flow lineation defined by aligned K-feldspar megacrysts and elliptical, 3 × 1 cm felsic haloes around euhedral, poikolitic titanite crystals (Fig. 17b). Biotite and hornblende comprise 15–20% of the rock, whereas the felsic clots constitute 20–25% of the rock, and K-feldspar megacrysts 5%. The rest of the rock is composed of a coarse-grained, seriate-textured matrix of quartz, microcline, and plagioclase. In thin section the rock contains 1–2% primary magnetite and yellow-brown pleochroic biotite and blue-green pleochroic hornblende in a medium-grained groundmass of quartz–plagioclase–microcline–perthite with traces of apatite and zircon. Alteration of this primary igneous assemblage includes saussuritized cores of plagioclase grains, and chlorite, epidote, and titanite replacement of biotite. The elliptical felsic clots cored by titanite are probably the same as Hibbard's (1995) felsic ocelli and are consistent with growth during precipitation of specific minerals consequent on magma replenishment, mixing, or other changes in pressure–temperature conditions, whereby the deuteric style of alteration represents a late-stage magmatic effect. This unit is interpreted to be a feeder pipe to at least part of the sill complex.

Cutting the feeder pipe is a medium-grained, leucocratic biotite monzogranite that is massive and equigranular (*AgScgla*). This phase forms a discontinuous dyke to the south, and forms the main part of the southern promontory to the north, but it is also locally preserved over large areas in the main body (at MGA 755739E 7607655N and 745839E 7611555N).

An outer margin of coarse-grained equigranular biotite monzogranite (*AgScge*), and an inner phase of K-feldspar-porphyritic to megacrystic biotite monzogranite (*AgScgp*) comprise the main part of the Cooglegong Monzogranite. Contacts between these two units are gradational and they form components of igneous layering in which layers of finer grained biotite leucogranite are also present. Contacts with older rocks are mostly shallow. In the underlying unit of orthogneiss, dykes and flat sheets of megacrystic Cooglegong Monzogranite display strong igneous flow alignment of K-feldspar phenocrysts (Fig. 17c; MGA 747438E 7596255N).

The southeastern part of the Cooglegong Monzogranite is underlain by coarse-grained biotite monzogranite with common pegmatitic patches (*AgScgc*). The pegmatitic

a)


b)


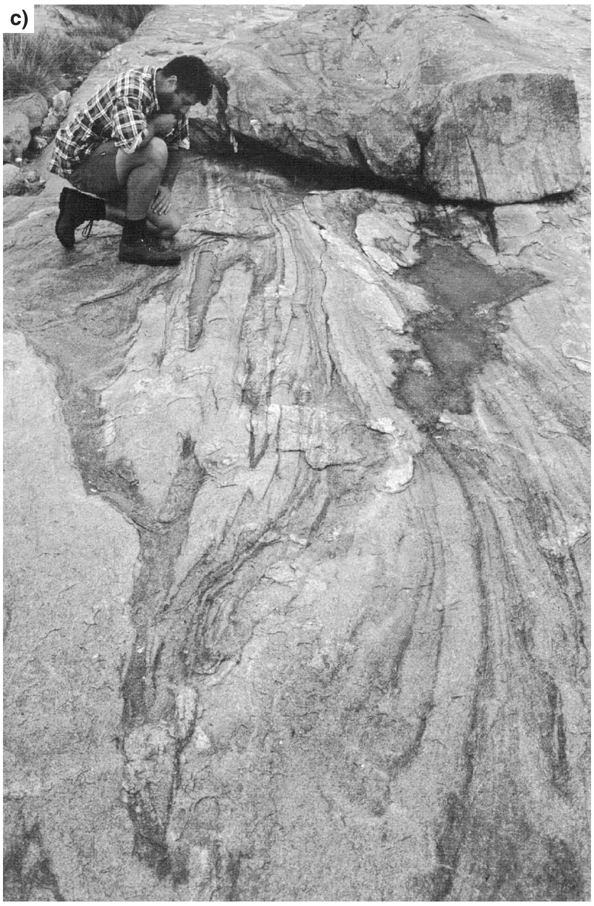
c)


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**Figure 16. Features of the diatexite formed during the generation and emplacement of the Mulgandinnah Monzogranite (*AgSmuxn*; MGA 741340E 7598950N) at c. 2927 Ma (Nelson, 2000):**
**a) mutually crosscutting relationships between comagmatic leucocratic monzogranite (white) and grey biotite monzogranite (compass is 13 cm long);**
**b) a vein of coarse, irregular-textured leucogranite diatexite derived from melted and remobilized orthogneiss that is intruding comagmatic, grey biotite monzogranite; note the biotitic rind around the leucocratic phase (lenscap is 5 cm in diameter);**
**c) highly irregular, very ductile flow folds in comagmatic leucocratic monzogranite and grey biotite monzogranite; note the biotitic reaction rinds around parts of the leucocratic phase**

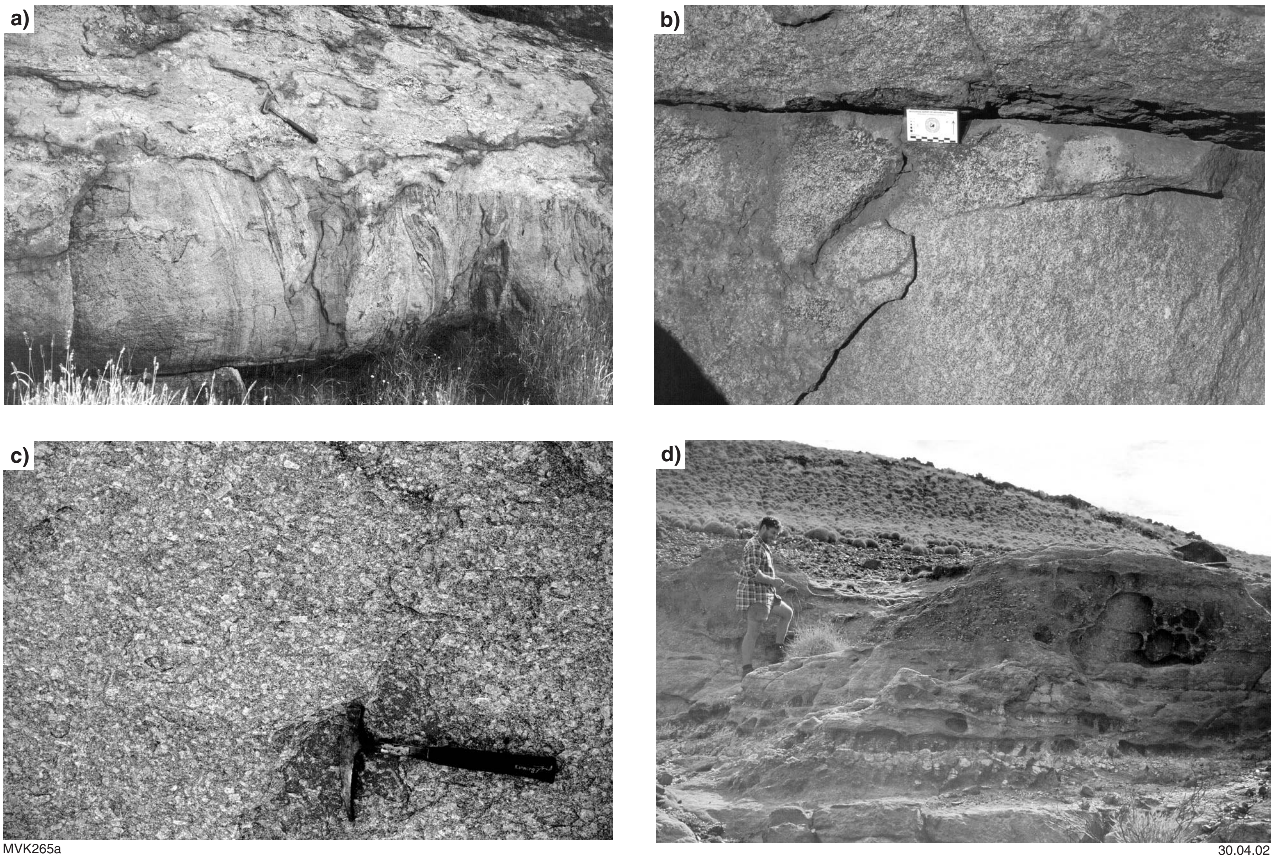


**Figure 17. Features of the Cooglegong Monzogranite in the Shaw Granitoid Complex: a) flat, basal contact against subvertical orthogneiss (*AgSn*; MGA 746940E 7598750N; hammer is 38 cm long); b) vertical igneous flow alignment of felsic clots cored by titanite in the feeder dyke (*AgScgx*; MGA 749140E 7595450N); c) horizontal igneous flow alignment of euhedral, elongate K-feldspar phenocrysts (*AgScgp*; 748940E 7594950N; hammer is 38 cm long); d) textural zonation of feldspar crystals in a subhorizontal pegmatite sheet (*AgScgpe*; MGA 739840E 7589700N) marginal to the main body of the granite**

patches are typically irregular in shape and variable in size, but have characteristically very large (up to 40 cm) K-feldspar crystals with graphic quartz intergrowth. In some places, large K-feldspar crystals with graphic intergrowth textures are present as scattered single crystals throughout coarse-grained monzogranite, giving the rock the appearance of a patchwork quilt. Locally, pegmatitic granite with graphic intergrowth textures covers up to 20 $km^2$ (*AgScgpe*; MGA 755039E 7602755N).

Pegmatite dykes (*AgScgpe*) form locally dense swarms around the margins of the Cooglegong Monzogranite, and were sites of alluvial tin mining. Areas of particularly dense swarms are around the Eley mining centre in the southeast (MGA 755739E 7600555N), the Five Mile Creek mining centre in the southwest (MGA 748639E 7602855N), and the Cooglegong Mining Centre in the north (MGA 750139E 7615455N and 754339E 7616855N). In the south and southwest, dykes are shallow dipping to flat, and display textural layering parallel to their contacts between coarse-grained granite and pegmatite (Fig. 17d; MGA 739840E 7589700N).

The youngest felsic unit in the Shaw Granitoid Complex is an undeformed, east-southeast-striking rhyolite dyke (*AgSr*) located in the northeast part of the sheet area (MGA 754339E 7616755N). This dyke forms part of a more extensive swarm to the north on NORTH SHAW (Van Kranendonk, 1999) that is oriented parallel to the contact of the complex with the adjacent greenstones of the Coongan Belt. The pale-brown-weathering, blue-black dyke is highly siliceous and forms a narrow ridge a few metres higher than surrounding granitoid platforms. The age of this dyke is unknown, but it must be older than the c. 2772 Ma Black Range dolerite dyke of the Fortescue Group.

## Vein quartz and gossan (*Aq, go*)

Massive white quartz veins (*Aq*) are present within faults that cut granitoid rocks and greenstones. The most prominent of these defines the western boundary of the Mulgandinnah Shear Zone along the western margin of the Shaw Granitoid Complex, and is intimately associated with $D_3$ structures. Other quartz veins may be the same age or slightly younger, but quartz veins are not present in the Fortescue Group, suggesting that most formed prior to c. 2770 Ma.

Two dykes of dark red-brown weathering, massive gossan (*go*) are present in the Western Shaw greenstone belt north of the Woodstock–Hillside – Marble Bar track (MGA 730899E 7594955N). Broken samples are porous and white in colour, commonly consisting of a fine, reticulated network of silica veinlets, interstitial porosity, and dark-purple centimetre-wide veins of hematite(–magnetite). The porosity is interpreted to result from weathering of sulfide minerals.

# Fortescue Group

Rocks of the Fortescue Group are present along the southern edge of the map sheet in the west, and in two sub-basins of coarse clastic rocks within the Emerald Mine Greenstone Complex. In addition to these supracrustal rocks, northeast-striking dolerite dykes of the Black Range dolerite suite cut principally across the granitoid complexes, but also cut greenstones in the southern and northwestern parts of the Western Shaw greenstone belt.

## Unassigned clastic rocks (*AF(s)*, *AF(sc)*, *AF(st)*)

Two unconformity- and fault-bounded sub-basins of coarse clastic rocks of the basal Fortescue Group are present within the middle of the Emerald Mine Greenstone Complex. These small sub-basins are isolated from other outcrops of the Fortescue Group and it is therefore uncertain whether they were deposited prior to the basal Mount Roe Basalt, as suggested by Blake (1984), or if they represent outliers of the younger Hardey Formation. The coarse clastic rocks fill topographic depressions, in part across growth faults, as originally suggested by Blake (1984, 1993).

The rocks in the sub-basins include boulder to pebble conglomerate (*AF(sc)*) and granular, coarse quartzose sandstones (*AF(st)*) of feldspathic litharenite and sublitharenite composition (Folk et al., 1970; Chan, 1998). Locally very coarse (≤50 cm) and angular clast-bearing conglomerates (e.g. MGA 724439E 7610855N) along some margins of the sub-basins represent scree slope deposits. Coarse conglomerates were deposited on proximal alluvial fans, whereas pebbly sandstones and granular coarse sandstones were deposited as more-distal alluvial fans and braided stream deposits (Chan, 1998). Clasts in the conglomerates include thinly bedded grey and white silicified shales and quartzose sandstone of the unconformably underlying Gorge Creek Group, and less commonly chloritic and/or fuchsitic schists and massive black chert derived from greenstone protoliths. In at least one place (MGA 720839E 7613405N), white quartz, golden-cream felsites, and massive black chert are present, a triad suggestive of derivation from a felsic volcanic unit. Chan (1998) described thinly bedded (1–2 m) basaltic rocks within both sub-basins and textural features suggestive of flows. However, at least one of the units, which is too small to show at 1:100 000 scale, is discordant to the bedding and thus must represent a thin dyke or sill.

The western sub-basin is highly elongate in a west-southwest – east-northeast direction and forms a canoe-shaped syncline bounded by faults along the northeastern, southern, and eastern margins (Fig. 18) and by an unconformity with the Gorge Creek Group along the western margin. A maximum thickness of the basin fill is estimated at 2550–3000 m, measured along the long axis of the sub-basin. The eastern sub-basin has an unconformable contact on older rocks in the north and south, but is bounded by faults on the east and west. It has a maximum stratigraphic thickness of approximately 1000 m.

Blake (1984) determined an easterly palaeocurrent direction for the rocks of the sub-basins, whereas Chan (1998) determined a trimodal flow direction for the western basin, to the northeast, southwest, and east-southeast. In the eastern sub-basin, Chan (1998) determined a unimodal flow direction to the west-northwest. Combined, these data suggest that the two sub-basins were originally connected and filled by detritus

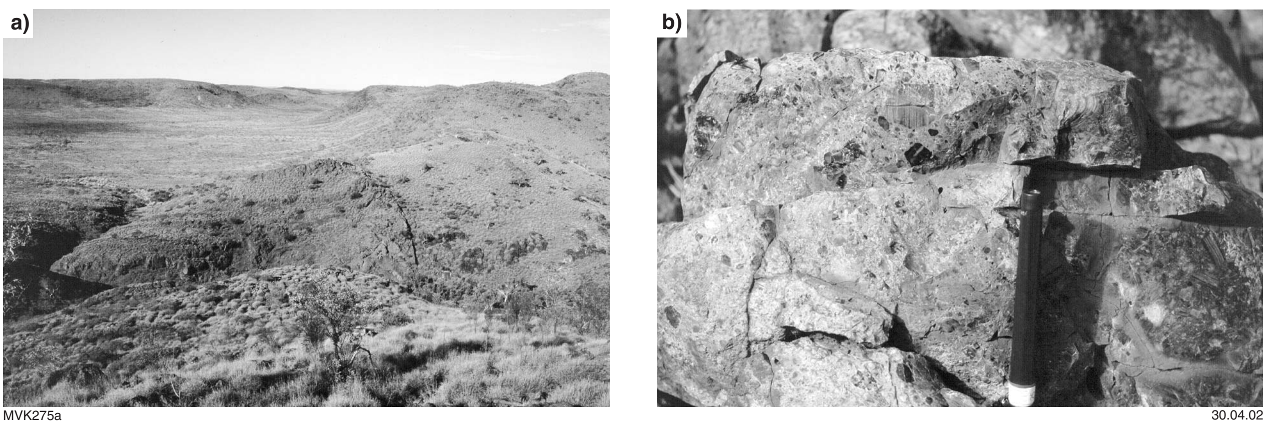


**Figure 18. a) View southeast of the southern faulted contact of the western sub-basin of coarse clastic rocks of the Fortescue Group (*AF(sc)*) against older greenstones; note the mostly flat orientation of bedding and the slight upturn of beds adjacent to the fault (MGA 722140E 7612950N); b) silicified fault breccia from the same locality as (a); portion of pen is about 10 cm long**

from a ring of surrounding highlands. Chan (1998) presented a depositional model of marginal coarse alluvial fans and central braided streams.

At the far southern edge of the sheet area, the Fortescue Group lies unconformably on granitoid rocks of the Tambourah Dome. The basal rocks of the group consist of coarse, angular arkose and cobble conglomerate (*AF(s)*) with metre-thick beds and rounded clasts up to 12 cm across near the base. The pink-grey arkose is composed primarily of proximal detritus derived from the underlying granitic rocks, principally fragments of plagioclase crystals. This succession fines upwards and is overlain conformably by rocks of the Tumbiana Formation (*AFt*).

## Dolerite dykes (*AF(d)*, *AFdb*)

The Black Range dolerite dyke (*AFdb*) has a maximum width of 500 m and is mostly a single intrusion, but just north of Hillside Station the dyke is composed of three parallel intrusions separated by granitoid enclaves, across 1 km in width. The rock varies from a medium-grained dolerite to a coarse-grained, ophitic leucodiorite. Intrusion of the dyke caused melting of adjacent granitoid host rocks within 3 m of the contact, and produced a low-grade metamorphic aureole for up to 70 m away from its margins. The Black Range dyke has been dated from the map area at 2772 ± 2 Ma (Wingate, 1999), similar in age to the basal Mount Roe Basalt of the Fortescue Group (Arndt et al., 1991).

Parallel to the Black Range dyke are several texturally similar, weakly (deuterically) altered dolerite dykes that cut across the whole map area (*AF(d)*). Whereas many are likely to be the same age as the Black Range dyke, Van Kranendonk (1999, 2000) pointed out that one of them intruded the Kylena Basalt on NORTH SHAW and was therefore probably younger. A younger age for such dykes is supported by age data obtained from Wingate (1999) farther south in the Sylvania Inlier of the Pilbara Craton. Dated at c. 2747 Ma, this age corresponds to the eruption of the Kylena Formation (Thorne and Trendall, 2001).

## Hardey Formation (*AFhs*)

The southern edge of a small unit of pebble conglomerate and sandstone of the Hardey Formation (*AFhs*) outcrops along the northern edge of the sheet area (MGA 726600E 7621050N). These rocks contain dominantly white quartz-pebble clasts in a highly siliceous matrix of coarse sand, and weather to a light-orange colour.

## Tumbiana Formation (*AFt*)

A 3–4 m-thick unit of green-brown shale and pisolitic tuff (*AFt*) overlies basal arkosic grits and conglomerates of the Fortescue Group along the southern edge of the sheet area. The pisolitic tuff comprises packed ovoid pisoids, 2–7 mm in diameter, that dispay concentric internal structures (Fig. 19). They are composed of devitrified mafic ash and thus represent accretionary lapilli.

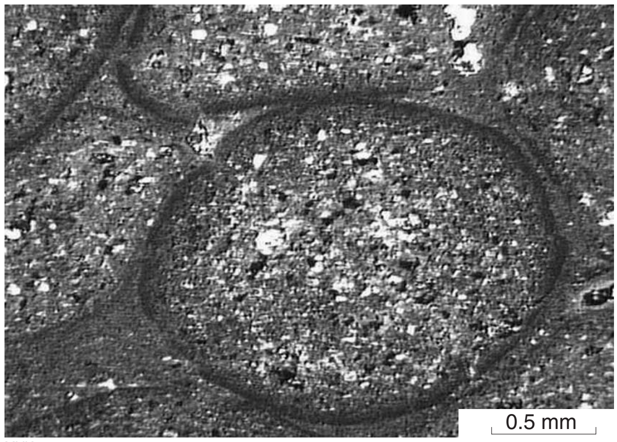


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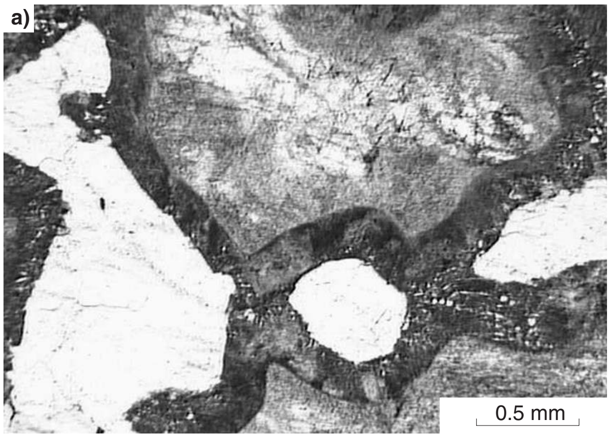
**Figure 19. Thin section, in plane polarized light, of pisolites with concentric structures in an intermediate pisolitic lapilli tuff of the Tumbiana Formation (*AFt*)**

# Archaean or Proterozoic dykes (*d*, *dx*, *u*, *q*)

Two swarms of dolerite dykes that post-date the Fortescue Group cut the sheet area. One dyke that trends east-northeast across the northern part of the sheet area cuts dolerite dykes of the Black Range dolerite suite (*AFdb*; MGA 747000E 7613750N) and belongs to the Mundine Well Suite (*dx*; Hickman and Lipple, 1978). Tyler (1990) stated that this suite extends across the Pilbara Craton and was younger than the Bangemall Group and thus probably younger than Mesoproterozoic in age. A date of 755 ± 3 Ma was obtained for two dykes of the swarm from the Bangemall Basin, but granitic dykes of the swarm from the northern Pilbara Craton returned only xenocrystic zircons (Wingate and Giddings, 2000).

The dyke of the Mundine Well Suite on TAMBOURAH is distinctive where it cuts granitoid complexes because it is flanked on one or both sides by a ridge, up to 5 m high and 5 m wide, of undeformed, dark-pink-weathering granite (MGA 742640E 7612600N). In places, this granite is the only material present in the fractures (MGA 709040E 7597650N) and can be distinguished from surrounding granitoid rocks because it contains coarse-grained, amoeba-shaped quartz, up to 4 cm across. In some places along the strike length of the east-northeast-striking dyke, the dolerite contains numerous granitoid xenoliths that have a distinctive, coarse-grained, blobby texture defined by spherical to ovoid patches of grey quartz surrounded by pink feldspar.

In thin section, the granitoid rocks are composed of linked, elliptical to elongate aggregates of quartz, 1–10 mm large, in a red matrix of feldspar. The quartz may be isolated within feldspar, but more commonly forms an interconnected lacework, or 'chain of pearls' (Fig. 20a). The quartz is composed of coarse, unstrained crystals with sutured common boundaries and sharp curved boundaries with adjacent myrmekite or feldspar. A dark-pink rind of myrmekite, typically 0.5 mm wide, surrounds the quartz



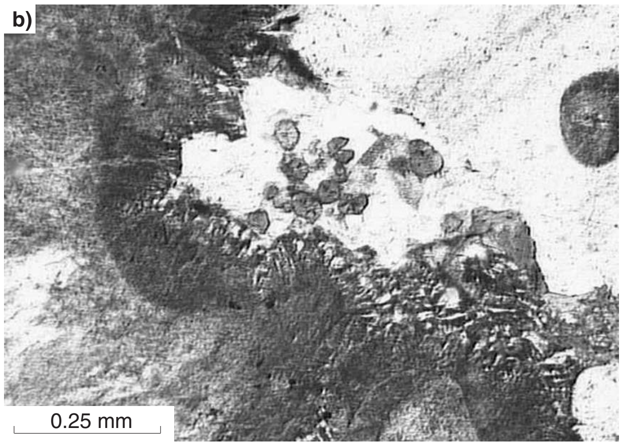





**Figure 20. Thin section textures of melted granite adjacent to post-Fortescue Group dolerite dykes (*dx*; MGA 709040E 7597650N): a) plane polarized light view of beads of polycrystalline quartz (white) separated from partly altered K-feldspar by a rind of very fine myrmekite; b) detail, in plane polarised light, of myrmekite rim, showing the growth of vermicular albite into quartz (in the top right), away from the coarser-grained, more calcic feldspar in the bottom left. Small balls of green biotite with a radiating crystal texture occupy the outer part of the quartz; c) thin section, in cross polarized light, of a relict plagioclase crystal that has largely been replaced by a fine-grained mosaic of quartz and feldspar**

(Fig. 20a,b). Feldspars comprise relict cores of coarse-grained plagioclase and K-feldspar rimmed by fine-grained, recrystallized feldspar and myrmekite (Fig. 20c). Green biotite is present locally in quartz along boundaries with myrmekite, and in one location, as radial clots in unstrained feldspar and quartz (Fig. 20b). This distinctive quartz texture is interpreted to reflect the effects of in situ partial melting, whereby heat from intrusion of dolerite caused quartz to become mobile and partially react with adjacent feldspars to form myrmekite. Where melting of the country rock was more extensive, complete dykes of remobilized granite were emplaced along the fractures. The local absence of dolerite from these fractures may reflect complete passage of the magma and subsequent closure of the fracture. The fact that some dykes contain a hydrous mafic mineral assemblage suggests that melting of the host was facilitated by excess water during intrusion of wet magmas.

The east-northeast-trending dyke, as well as dykes of the Black Range dolerite suite are cut by a swarm of thin, east-southeast-trending dolerite dykes across the western and southern part of the sheet area (*d*; Round Hummock Suite of Hickman and Lipple, 1978). This crosscutting relationship may be observed in the Shaw Granitoid Complex at the southern edge of the sheet area (MGA 736339E 7565755N).

The dykes of this younger swarm (*d*) are typically fine grained, dark green to black weathering, with a fine ophitic texture of plagioclase laths and interstitial augite. Some contain a hydrous mafic mineral assemblage of actinolite and epidote intergrown with plagioclase. In these dykes, relicts of pyroxenes have been completely altered to fine-grained green chlorite, sericite, and ?feldspar, probably as a result of intense deuteric alteration. One dyke in the central-eastern part of the sheet area (MGA 752500E 7594400N) is very fine grained and ultramafic–mafic in composition (*u*). These were emplaced in fractures that are filled along strike by quartz (*q*), and quartz veins commonly fill parallel fractures to some of the dykes.

# Cainozoic geology

Ferruginous duricrust (*Czrf*) includes massive, pisolitic and nodular laterite, and locally, consolidated ferruginous alluvium. These deposits form a dissected laterite plateau on top of many hills on TAMBOURAH over a variety of rock types, particularly on ferruginous shale and BIF of the Gorge Creek Group in the Emerald Mine Greenstone Complex. In these areas the laterite forms pisolitic to nodular hematite, maghemite, and goethite–limonite crusts up to several metres thick. Clay alteration of underlying rocks may reach several tens of metres depth.

Large areas of granitoid rocks are covered by quartz and feldspathic sand, gravel, and silt derived from in situ decomposition of the granitoid rocks (*Czrg*). These variably consolidated deposits comprise mixed eluvium and colluvium that have not been transported any great distance, but are being eroded by the present drainage. Broad flat areas of unconsolidated quartzofeldspathic eluvial sand with quartz and rock fragments that are unaffected by the modern drainage, are interpreted as Quaternary in age (*Qrg*). Similar deposits on low-gradient sheetwash plains and outwash fans are interpreted as Quaternary colluvium (*Qcg*).

Massive, nodular, and cavernous white calcrete (*Czrk*) covers small areas of granitoid and ultramafic rocks on TAMBOURAH. It is derived from in situ alteration and destruction of the bedrock and may be variably silicified. On granitoid rocks the parent calcrete is largely concealed beneath a veneer of colluvium that contains cobbles of broken, angular, and highly irregular-shaped calcrete and fragments of feldspar crystals and white quartz from pegmatite veins.

In the middle of the Tambourah Dome (MGA 714489E 7580955N) are two hills capped by about 2–3 m of mottled grey and white, vuggy chert, or 'silcrete' (*Czrz*), which overlies 10–20 m of calcrete (*Czrk*). A bright, white colluvial apron of transported, and eroded calcrete detritus (*Qck*) surrounds the silcrete caps.

Variably consolidated colluvium is present across the map area on a variety of slope gradients. Undivided colluvium (*Czc*) comprises sand, silt, and gravel on outwash fans, scree slopes, and talus aprons, and is dissected by recent streams and drainage gullies. A specific variety of variably consolidated and dissected colluvium is composed of quartz–feldspar gravel, sand, silt, and clay derived proximally from, and deposited on, granitoid rocks (*Czcg*). Ferruginous silt, sand, and gravel (*Czcf*), which is variably consolidated and dissected, represent eroded laterite. Locally, they consist of cemented goethite–limonite pisolites and nodules weathered out of laterite.

Dissected, and locally eroded alluvium (*Czaa*) is present along the Shaw River and some other larger creeks, but is most widely developed between the Western Shaw River and Haunted Hole Creek in the south. Here, as on the southern edge of the Tambourah Dome, the detritus is coarse-grained conglomerate and gravel with clasts primarily of the Fortescue Group. These deposits form flat areas that are either actively being eroded along their margins by present streams and/or replaced, and locally covered, by Quaternary overbank deposits (*Qao*).

Unconsolidated colluvial sand, silt, and gravel (*Qc*) are present on outwash fans, and on scree and talus slopes in small pockets across the rugged greenstone terrain of TAMBOURAH. These surficial deposits reflect the processes of proximal mass wasting due to uplift and erosion. Sheetwash deposits (*Qw*) are composed of silt, sand, and pebbles that were deposited on distal fans with no defined drainage, on low-gradient plains distant from the rugged greenstone hills. Sheetwash sand and quartz-pebble deposits derived from granitoid rocks (*Qwg*) directly overlie areas of granitoid rock.

In the larger streams and in the Shaw River are unconsolidated deposits of sand, coarse sand, and gravel (*Qaa*). These deposits are typically well sorted, although they may be variable across and along the main drainage channels, with broad sandy areas, gravel and pebble bars, and broad pebbly washes. The active stream channels are typically bounded by lines of snappy gums, beyond which are marginal overbank deposits consisting of alluvial sand, silt, and minor gravel (*Qao*), which have been partly stabilized by buffle grass and sparse undergrowth. These deposits commonly form on flat floodplains adjacent to main drainage channels at bends in the streams, or on low islands within the streams. Smaller creeks contain unconsolidated silt, sand, coarse sand, and gravel (*Qa*) within narrow channels and dendritic arrays of low-angle gullies marked by a greater density of shrubs.

Overbank deposits have been subdivided in places along the Shaw River and its tributaries, as they display a mappable variation in clast size. Closest to the present streams are unconsolidated conglomerates with cobbles, pebbles, and sand (*Qaog*) deposited on gravel bars and adjacent overbank plains. In contrast, the most distal overbank deposits and some alluvial floodplains consist of white clay (*Qaoc*), with intervening areas occupied primarily by sand and silt (*Qao*). Similar claypans located away from streams represent small lake deposits (*Ql*).

# Structural geology

The structural geology of TAMBOURAH includes five generations of structures, based on crosscutting relationships between structures and magmatic phases in granitoid domes, unconformities between volcano-sedimentary groups that contain different sets of structures, and overprinting structures in some outcrops. The principal triad of pre-Fortescue Group structures is well developed around the nose of the Tambourah Dome, where the later two generations of structures have been constrained by dating of granitoid rocks. The structural hierarchy outlined herein applies only to the sheet area and differs from the scheme presented by Blewett (2000) for the whole of the northern Pilbara Craton.

## $D_1$: c. 3470–3435 Ma

The products of $D_1$ deformation were observed in the Shaw, Yule, and Tambina Granitoid Complexes. These include a migmatitic layering and tight to isoclinal folds of leucosome veins in migmatitic orthogneisses (*AgSn*, *AgSd*, *AgTn*, *AgYpt*, *AgYpti*), schlieric leucogranite (*AgSnl*, *AgSnh*) and diatexite (*AgSlxn*). Whereas the host rocks affected by these structures are c. 3470–3451 Ma, a minimum age for the formation of $D_1$ structures and melt veins is provided by rocks that do not contain these structures, dated at between 3435–3425 Ma in the Shaw Granitoid Complex (*AgSg*; MGA 735439E 7613455N; e.g. Fig. 11a). This phase of deformation was followed by granitoid plutonism at c. 3435–3425 Ma, and then by the generation of a low volume of partial melts from 3419 to 3399 Ma, although no structures associated with this melting have been recognized.

## $D_2$: c. 3240 Ma

Several different types of structures are broadly grouped together under $D_2$. The ages of these structures have not been directly dated, but geochronology of granitoid rocks and metamorphic minerals, combined with evidence from regional considerations, suggests that they formed at some time between c. 3430 and 3240 Ma.

A set of close to tight, north-trending folds are present east of the Spear Hill Monzogranite in the northern part of the Shaw Granitoid Complex (approximately MGA 753000E 7618000N). These folds are interpreted as $D_2$ in age because they affect rocks and structures older than 3400 Ma, and are transected by $S_3$ foliations. The hinges of these southerly trending $D_2$ folds are parallel to southeast-plunging hornblende elongation lineations. Another $D_2$ fold is the horseshoe-shaped, domical fold outlined by a raft of amphibolite and quartzite that wraps around the southern margin of the Spear Hill Monzogranite (approximately MGA 745400E 7616000N). The tight, west-plunging syncline along the southern limb of the horseshoe-shaped fold probably also belongs to this set. This fold, together with several nearby folds, all plunge towards one another and define a triple-point sink. Several other folds in the Shaw Granitoid Complex may be of $D_2$ age, including the fold defined by folded hornblende elongation lineations in a large amphibolite enclave in the south-central part of the sheet area (MGA 741139E 7581155N).

Rocks of the Western Shaw greenstone belt contain folds and penetrative foliations and lineations defined by amphibolite-facies mineral assemblages and deformed varioles (Fig. 21a) that can be related to $D_2$ amplification of the Tambourah Dome at c. 3240 Ma, granite intrusion, and amphibolite-facies metamorphism (Van Kranendonk and Collins, 1998). The trend and plunge of $D_2$ linear fabric elements in the western limb of the Tambourah Anticline point towards the centre of the limb from all sides, indicative of a zone of sinking such as is characteristically found around granitoid diapirs (cf. Dixon and Summers, 1983; Collins et al., 1998). The age of $D_2$ deformation in this area is inferred from $^{40}Ar$–$^{39}Ar$ ages of c. 3240 Ma from hornblende from the Western Shaw greenstone belt (Wijbrans and McDougall, 1987), and a similar SHRIMP U–Pb zircon date from granitoid sheets (*AgYka*; Fig. 21b) in the nose of the Tambourah Dome (unpublished U–Pb SHRIMP data).

Prominent $D_2$ structures include the northwest–southeast trending, doubly plunging Tambina Anticline and Mount Webber Syncline in the northern part of the Western Shaw greenstone belt. The Tambina Anticline is outlined by the concentric distribution of granitoid phases in the core of the Tambina Granitoid Complex and by dips of foliations and bedding in flanking greenstones. Greenstones are strongly transposed around the Tambina Granitoid Complex, with highly stretched mineral elongation lineations ($L_2$) on foliations ($S_2$) developed parallel to transposed and locally boudinaged bedding (Fig. 21c). The axial trace of the Mount Webber Syncline is located in homogeneous amphibolite-facies metabasalt, and can be recognized by three distinctive cherts present in reverse order on either limb of the fold. The position of the fold axis was determined by the maximum prolate shape fabric (L>>S) defined by deformed plagioclase aggregates, varioles, and rods of amphibolite (Fig. 21d). Northeast–southwest-trending $D_3$ folds of the Tambourah Dome overprint the $F_2$ axes of the Tambina Anticline, as described in the following section.

Another large-scale $D_2$ fold is present in the southern part of the Western Shaw greenstone belt (MGA 727139E 7578155N). This steeply north-plunging anticline is outlined by folded bedding and has a hinge parallel to amphibolite-facies mineral elongation lineations. The eastern limb is cut off by a fault. Along strike to the north, a $D_2$ fold of greenstones verges to the east on a sub-horizontal hinge that is parallel to $L_2$ mineral elongation lineations. The fold may have formed when greenstones were shed off the rising Tambourah Dome, in a manner analogous to the origin of recumbent folds flanking the Mount Edgar Granitoid Complex described by Collins (1989). On the western limb of the Tambourah Dome (MGA 718739E 7605655N), a rootless isoclinal fold of a 20 m-thick, grey-weathering quartzite is also interpreted to be a $D_2$ structure.

$D_2$ folds are also developed in an outlier of metaquartzite (*Asq*) in the Yule Granitoid Complex (MGA 709139E 7597155N). Bedding in the quartzite is parallel to gneissic layering in underlying orthogneiss, indicating that $D_1$ deformation of the orthogneiss occurred before quartzite deposition. The quartzites were then folded about axes parallel to strong south-southwesterly plunging mineral elongation lineations ($D_2$) and then cut by veins and dykes of homogeneous granitoid derived from the c. 2933 Ma Woodstock Monzogranite, which were emplaced during $D_3$ deformation (see below).

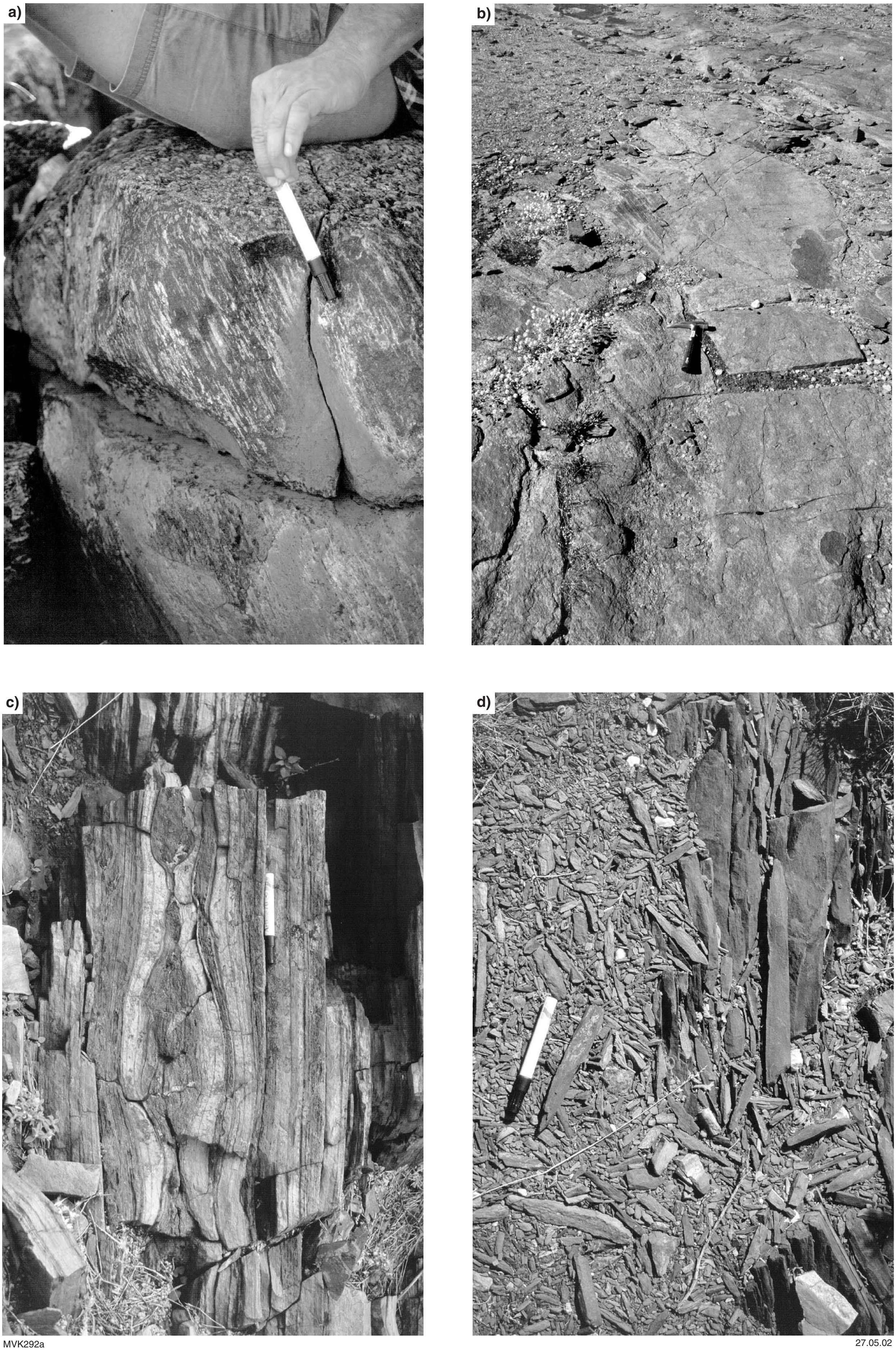
## $D_3$: c. 2940 Ma

Structures related to $D_3$ transpression at c. 2940 Ma affect all rocks of the map area. They are most strongly developed within the 10–33 km-wide, north-striking Lalla Rookh – Western Shaw Structural Corridor (LWSC) that transects the central part of TAMBOURAH (Fig. 4; Van Kranendonk, 1998; renamed from the Central Pilbara Structural Corridor of Van Kranendonk and Collins, 1998). The LWSC is characterized by kilometre-wide zones of sinistral shear in marginal granitoid rocks (Pulcunnah and Mulgandinnah Shear Zones), discrete faults in greenstones, and by north- to north-northeast-plunging folds. The boundaries of the LWSC shown on Figure 4 are gradational, and demarcate the limits of penetrative fabrics. Spaced foliations and folds extend across into the adjacent rocks, as described below.

### Lalla Rookh – Western Shaw Structural Corridor

#### *Mulgandinnah Shear Zone*

The most prominent feature of the LWSC is the approximately 4 km-wide sinistral Mulgandinnah Shear Zone along the western margin of the Shaw Granitoid Complex (Van Kranendonk and Collins, 1998; Zegers et al., 1998).

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The zone consists of two parallel, kilometre-wide strands of strongly deformed granitoid rocks that both show evidence of a westward increase in strain, as indicated by a change from amphibolite-facies gneiss (Fig. 22a), through porphyroclastic mylonite, to greenschist-facies ultramylonite. Both strands contain excellent and widely developed indicators of sinistral shear, including rotated feldspar porphyroclasts, S-asymmetrical folds, asymmetric boudin trains, and C–S–C' textures (Berthé et al., 1979; Fig. 22b,c). The strands are characterized by steeply west-dipping $S_3$ foliations and by mineral elongation lineations ($L_3$; Fig. 22d) whose generally shallow plunge (0–35°) varies along strike.

The western strand of the Mulgandinnah Shear Zone follows the contact of the Shaw Granitoid Complex from the southern part of the map into the folded granitoid lobes of the northwest Shaw area, wherein it dissipates (see below). A thick quartz vein occupies the western boundary of this strand in the southern part of the sheet area.

The eastern strand forms a zone approximately 1 km wide within the Shaw Granitoid Complex. To the south it merges with the western strand to form a high-strain zone 4–5 km wide. Further north it can be traced continuously to the contact of the post-tectonic Cooglegong Monzogranite. To the north of this, the strand follows the western margin of the complex, where it is intruded by voluminous synkinematic pegmatitic granite dykes (e.g. Fig. 22b) dated as 2934 ± 2 Ma (Zegers, 1996). The contact between granitoid rocks and greenstones in this area is marked by a brittle fault filled by massive white vein quartz, 1–5 m wide (e.g. White Quartz Hill at MGA 741439E 7616755N). The eastern strand grades eastwards into rocks unaffected by penetrative $D_3$ transposition, but which are nevertheless deformed into tight to open, northeast-trending $D_3$ folds with characteristic 'S'-asymmetry, and localized zones of high-strain mylonite.

A rootless isoclinal $D_3$ fold that is visible on Landsat images separates the two shear strands. The fold is outlined, from south to north, by a raft of amphibolite, a layer of leucogranite, and by $D_1$ foliations and gneissosity. The fold extends into the westernmost part of the folded granitoid lobes of the northwest Shaw area immediately west of the Cooglegong Monzogranite. This fold is one of several folds associated with shearing that formed in the northwest Shaw area, as described below.

### *Emerald Mine Greenstone Complex*

Five folded lobes of granitoid rocks and flanking greenstones are present in the northwest Shaw area of the Emerald Mine Complex between the western and eastern strands of the Mulgandinnah Shear Zone (Fig. 23; see also Bickle et al., 1985). The granitoid lobes are composed of at least two distinct phases. The largest fold, lobe 1, in the west is a doubly plunging anticline cored by the homogeneous 3431 ± 6 Ma South Daltons Pluton, which for the most part is medium grained and weakly strained (McNaughton et al., 1993). The southern parts of lobe 1 and lobe 2, most of lobe 4, and parts of lobe 3 are composed of little-deformed, high-level, weakly porphyritic granodiorite of the same suite. Weakly strained, magmatically sheeted tonalite and mesocratic quartz diorite of the 3499–3450 Ma North Shaw Suite underlies lobes 3 and 5. Highly strained gneissic equivalents of these rocks occupy part of lobes 4 and 5. The homogeneous granitoid suite intruded the gneisses, but were deformed by the folds in this area, indicating that the formation of gneissosity took place at between c. 3470 and 3430 Ma ($D_1$) and that folding must have been later than c. 3430 Ma. The folds also affect rocks of the Gorge Creek Group and are thus younger than c. 3235 Ma, contradicting a previous interpretation by Zegers et al. (1996), as discussed below.

Felsic schist of the Panorama Formation can be traced almost continuously around the granitoid lobes as a series of tectonically thinned and locally dismembered slivers. The formation strikes southeast and dips to the southwest around the northern parts of lobes 1 and 3. Facing directions from underlying and overlying pillow basalt in these areas indicate that the succession faces away from the granitoid rocks and is overturned (cf. Bickle et al., 1980). The hinges of folds through the axes of these lobes plunge to the south-southwest, parallel to chlorite lineations, and thus the folds represent synformal anticlines.

Lobe 1 is strongly foliated along its northern and southern contacts and lies in contact with amphibolite-facies pillow basalts that also form screens and inclusions within the lobe where they are extensively altered and metasomatized. North of lobe 1 granitoid rocks and flanking amphibolites is a unit of chloritic schist and breccia that contains dismembered and folded units characterized by strongly developed southwest-plunging lineations.

The sinistral mylonitic rocks of the western strand of the Mulgandinnah Shear Zone are continuous northward into the southern mylonitic roots of lobes 2–4 (Fig. 23). The eastern margin of lobe 2 is a 500 m-wide zone of sinistral porphyroclastic mylonite and straight gneiss. Sinistral mylonite fabrics in the northern part of the zone are tightly folded and cut by discrete sinistral shears as a result of progressive deformation (Fig. 24a). To the west, mylonitic fabrics follow the outline of the lobe. Along the

**Figure 21. (Opposite page) Outcrop views of structures around the Tambourah Dome: a) moderately northerly plunging lineated varioles ($L_2$) in amphibolite-facies metabasalt of the Western Shaw Greenstone Belt (MGA 726440E 7592000N); b) view to northwest of a sheet of homogeneous grey granodiorite of the Kavir Suite (*AgYka*) cutting migmatitic Petroglyph Orthogneiss (*AgYpt*) at a shallow angle in the nose of the Tambourah Dome (MGA 721740E 7602155N; marker pen is 14 cm long); c) strongly transposed and boudinaged bedding, parallel to $S_1$, in interlayered metaquartzite and amphibolite from the southeastern nose of the Tambina Anticline (MGA 728890E 7604900N; marker pen is 14 cm long); d) characteristic weathering pattern of lineated amphibolite marking the hinge of the Mount Webber Syncline (MGA 726040E 7603200N; marker pen is 14 cm long)**

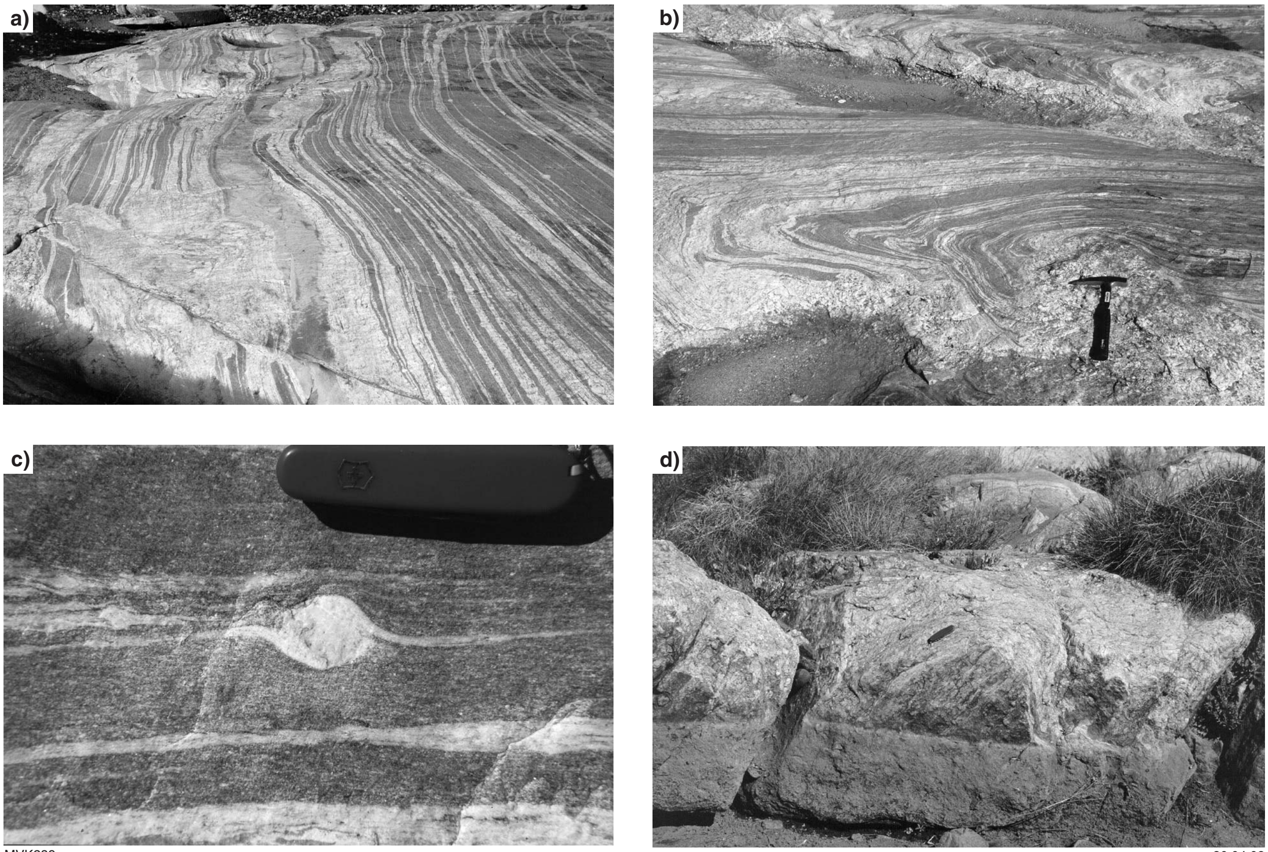


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**Figure 22. Outcrop features of the western strand of the Mulgandinnah Shear Zone in the Shaw Granitoid Complex: a) amphibolite-facies porphyroclastic straight gneiss; b) one half of an 'S'-asymmetric $D_3$ fold in porphyroclastic gneiss that is cored by synkinematic granite pegmatite. Pocket knife is 9 cm long; c) sinistral rotated feldspar in porphyroclastic mylonite; d) view west of characteristic south-plunging $L_3$ mineral aggregate lineations on the margin of a foliated synkinematic granite pegmatite. Pocket knife is 9 cm long**

northern contact, the foliation in black, weakly porphyroclastic, flinty ultramylonite derived from granitic protoliths (Fig. 24b) dips steeply to the north towards amphibolite-facies greenstones. Plunge directions of lineations within the mylonite and ultramylonite vary along strike from north-northwest in the northeast, to southwest along the western part of the contact where dextral kinematic indicators were observed (Fig. 23). North of lobe 2, lineated and foliated amphibolite-facies greenstones are disrupted and folded within a large-scale tectonic breccia (*Aucx*) characterized by south-southwesterly plunging lineations.

Lobe 3 is composed entirely of granoblastic, annealed tonalitic straight gneiss and mylonite. Mylonitic foliations follow the outline of the lobe and amphibolite-facies mineral elongation lineations plunge to the south and southwest. Kinematic indicators across the southern root of the lobe and along the western contact show sinistral displacement, whereas a Z-asymmetric fold of a perturbation along the eastern contact, together with Z folds and dextral shear bands in the adjacent greenstones, indicates a local component of dextral shear. Across the top of the lobe, kinematic indicators of reverse, south-side-up shear were observed.

Lobe 4 contains sinistral shear indicators along the southwestern contact and dextral indicators along the northwestern contact, with no evidence of overprinting relationships between the two. Along the northern contact, steeply plunging sheath folds were observed. In contrast, the southern part of the lobe is composed of weakly strained, homogeneous granodiorite–granite that contains folded $S_1$ foliations with a Z-asymmetry. Amphibolite-facies mineral elongation lineations plunge southwest along the western contact, but folds and lineations in the east plunge to the north.

Lobes 3 and 4 are separated from a tight synform of amphibolites to the east by the Emerald Mine Shear Zone, a biotite-rich schist zone intruded by white-feldspar pegmatite, which dips steeply to the west and contains steeply plunging mineral elongation lineations. Amphibolites to the east of the shear zone are folded about northwest-plunging hinges that are colinear with hornblende lineations.

Lobe 5 contains dextral porphyroclastic mylonite along the northeastern contact and within the lobe to the south (Figs 23, 24c). The dextral mylonites are folded around the top of the lobe (Fig. 24d) and cut by strands of sinistral

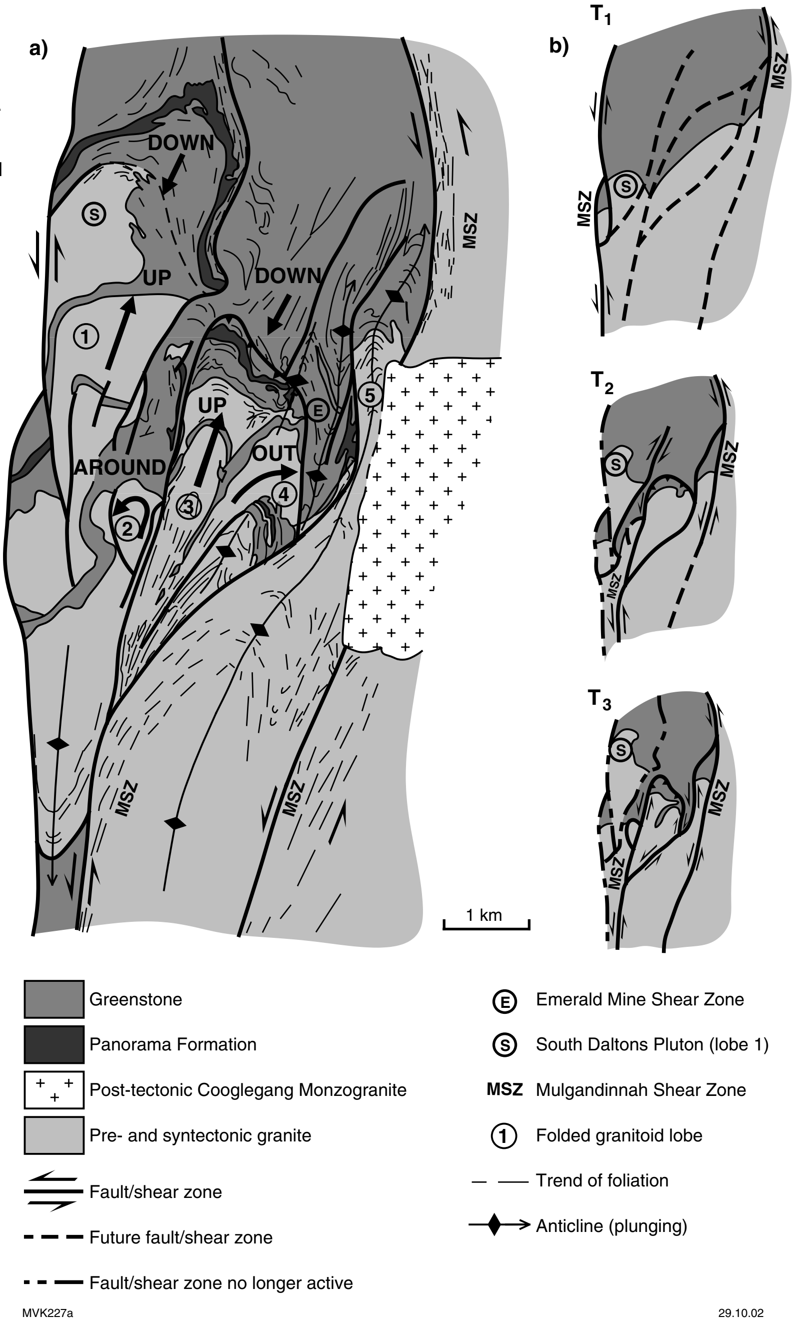
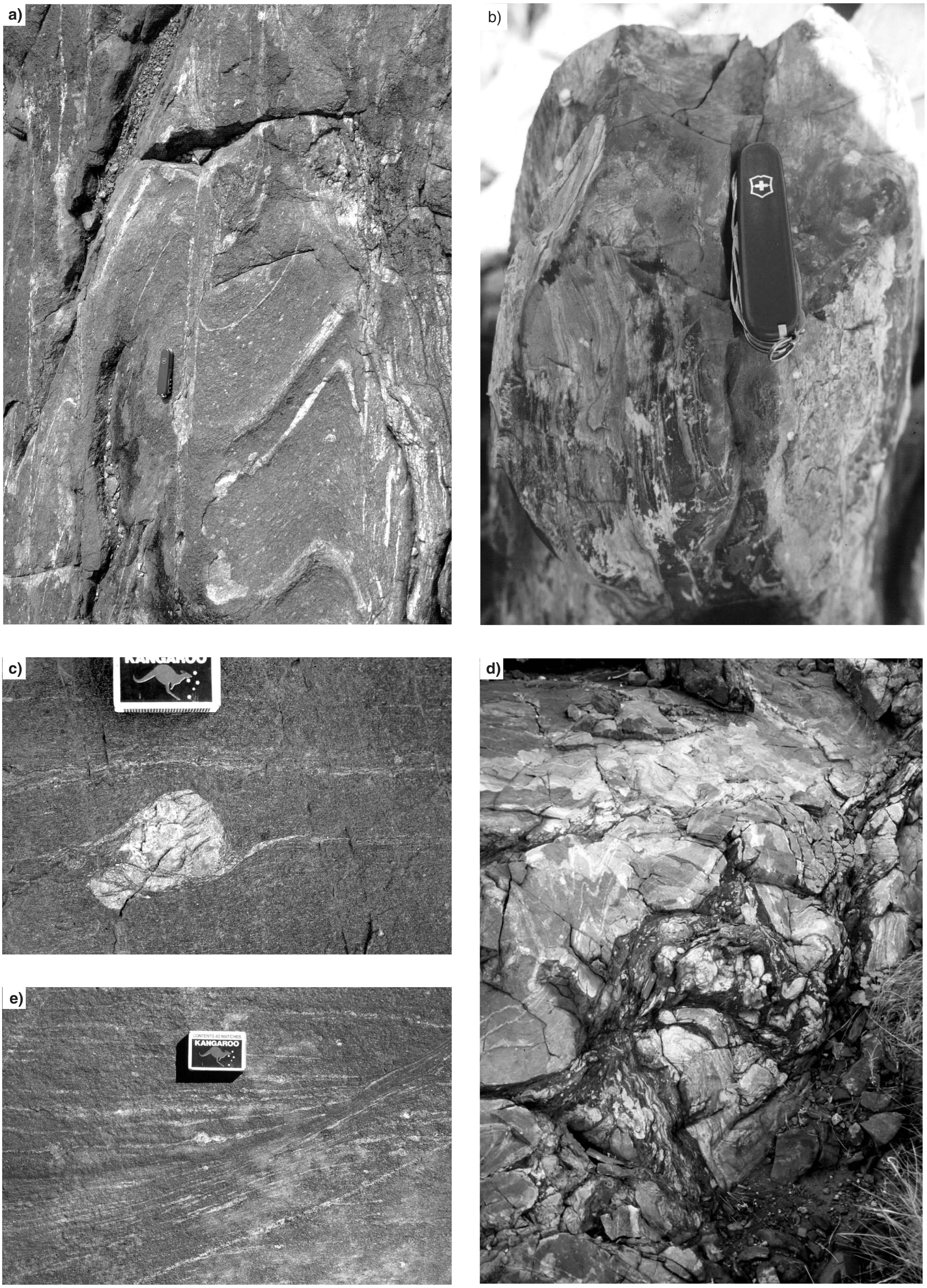



**Figure 23. Schematic evolution of the folded granitoid lobes in the northwest Shaw area: a) Schematic geological map of the folded granitoid lobes in the northwestern Shaw area showing the geometry of kinematic indicators; b) schematic evolution of the northwest Shaw area as a flower structure resulting from compression across stepped shear strands of the Mulgandinnah Shear Zone; frames $T_1$–$T_3$ are representative time slices during progressive $D_3$ deformation**

mylonite (Fig. 24e). Folds of the mylonitic foliations, like those of the amphibolites to the west, plunge to the northwest. The axial plane to the antiformal lobe 5 can be traced continuously south between the shear strands of the Mulgandinnah Shear Zone (Fig. 4).

The continuity of Mulgandinnah shear fabrics into the folded lobes of the northwest Shaw area, and the colinearity of fold hinges and greenschist-facies mineral elongation lineations between these areas have been used to suggest that structures in the northwest Shaw area formed at c. 2940 Ma during $D_3$ deformation (Van Kranendonk, 1997; Van Kranendonk et al., 2001b). This is supported by the fact that the folds affect rocks of the younger-than-3240 Ma Gorge Creek Group that elsewhere are affected only by $D_3$ deformation (Van Kranendonk,

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2000). This contradicts a previous interpretation that the folds formed prior to doming as a result of Alpine-style crustal thickening (Bickle et al., 1985; Zegers et al., 1996).

Instead, the folds of the northwest Shaw area are interpreted to have formed as a flower structure in a restraining bend between the stepped strands of the Mulgandinnah Shear Zone (Fig. 23b; Van Kranendonk, 1997; Van Kranendonk et al., 2001b). The crust in between the stepped strands experienced intense shortening as a result of the opposite sense of movement across the strands, resulting in crustal thickening and uplift (cf. Davis, 1984). Progressive displacement across the fault segments resulted in clockwise rotation of the short limb of the fold linking the shear strands relative to the maximum compressive stress direction, such that the sense of shear across it changed from sinistral to dextral through time (Fig. 24b). In this model, lobe 3 was squeezed out to the north and uplifted as a large sheath fold. Sinistral drag along the western boundary of lobe 3 caused sinistral shear of the eastern margin of lobe 2 and counter-clockwise rotation of its western part. Lobe 4 was pushed out to the east and folded across the Emerald Mine Shear Zone, which formed the eastern lateral ramp of penetrative deformation in this area. Northerly directed extrusion and uplift of granitoid lobes 1–4 caused overturning of the greenstones and exhumation of the deeper level metamorphic assemblages exposed in this area (Bickle et al., 1985).

Greenstones in the eastern part of the Emerald Mine Greenstone Complex are cut by numerous $D_3$ faults and deformed into tight $F_3$ folds. Some of these faults were re-activated during $D_4$ deformation, during deposition of the Fortescue Group. The complex is bound to the southwest by the sinistral $D_3$ Pulcunnah Shear Zone, to the north by a steeply dipping reverse fault, and to the east by north-striking sinistral fault strands along the western margin of the Shaw Granitoid Complex.

Within the complex, sinistral faults form a structural fan northwards from the southern tip of the South Daltons Pluton. $D_3$ folds vary from south and southwest plunging in the northeastern part of the complex, to northeast plunging in the western part of the complex. Similar to folds in the northwest Shaw area, a fold in the north-central part of the Emerald Mine Greenstone Complex is a south-plunging synformal anticline. The triangular area of Gorge Creek Group rocks in the central part of the complex is interpreted as the southern continuation of the more-linear exposures of the Gorge Creek Group to the east, which were offset by sinistral displacement to the northwest during $D_3$ deformation.

### Western boundary of the LWSC

The western boundary of the LWSC is marked by splayed strands of sinistral shear in the Yule Granitoid Complex, including a south-southwesterly striking strand in, and west of, a large greenstone enclave in the northwestern part of the sheet area, a central strand striking south from the northwestern corner of the map, and the Pulcunnah Shear Zone along the northeastern margin of the complex (Van Kranendonk, 1998, 2000). Finely spaced foliations and well-developed, shallow-plunging mineral elongation lineations characterize all zones in which sinistral displacement was identified by solid state fabrics such as S–C–C' textures and rotated K-feldspar phenocrysts (see Van Kranendonk, 2000).

The Pulcunnah Shear Zone is up to 1 km wide across the granite–greenstone contact, and is bound to the east by a fault within greenstones. The central shear strand dies out to the south, where strain is partly accommodated by brittle quartz-filled faults that are slightly offset to the east. Extending to the northeast from the southern tip of this zone is a broad zone of 060°-trending dextral shear, manifest as a strong igneous flow alignment of K-feldspars in isotropic monzogranite and rotational asymmetry of grey granitoid xenoliths (Pawley and Collins, 2002). The igneous flow fabrics in this high-strain zone indicate it formed during emplacement of the Woodstock Monzogranite at 2933 ± 3 Ma. The eastern end of this zone dies out along the intrusive contact between the Woodstock Monzogranite and the Western Shaw greenstone belt.

The triad of shears in this area bound a triangular zone filled by the low-strain, synkinematic Woodstock Monzogranite, which in this area contains numerous enclaves of amphibolite-facies metabasalt that are locally folded into open structures on southeast-plunging hinges, colinear with mineral elongation lineations. Structures in this area are interpreted to have developed during granite intrusion into a zone of extension within the overall northwest–southeast compressional regime of $D_3$ deformation (Van Kranendonk and Collins, 1998). The concentration of mafic enclaves within the shear strands suggests that the strands represent stages of shearing during the easterly migration of the granite–greenstone contact.

### Western Shaw greenstone belt

The Pulcunnah Shear Zone extends south into the Western Shaw greenstone belt as a set of linked, en echelon sinistral fault strands. These faults are characterized by either mylonitic chloritic or talc–carbonate schists, or both, that locally display C–S–C' textures indicative of sinistral displacement (Fig. 25). The highest strain zones are subparallel to bedding in the greenstones and characteristically contain quartz veins that have been mined for gold. The westernmost of these faults marks the western boundary of the LWSC.

In the far southern part of the Western Shaw greenstone belt is a northeast-plunging, S-asymmetric $D_3$ fold that is

**Figure 24. (Opposite page) Outcrop features of the folded granitoid lobes in the northwest Shaw area: a) folded sinistral porphyroclastic mylonite cut by discrete sinistral shears; northeastern margin of lobe 2; b) weakly porphyroblastic ultramylonite derived from granitoid rocks of lobe 2; c) K-feldspar porphyroclast in granite showing dextral rotational asymmetry; northern contact of lobe 5; d) folded dextral mylonite; northern margin of lobe 5; e) dextral porphyroclastic mylonite cut by sinistral shear zone; southern part of lobe 5**


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**Figure 25. Chlorite schist with C-S-C' fabrics indicative of sinistral shear; westernmost fault boundary of the LWSC in the Western Shaw Greenstone Belt (MGA 731240E 7591950N)**

centred on a lobe of the Tambourah Monzogranite. The western contact of the granite lobe crosscuts partly transposed, tightly folded bedding in the greenstones, whereas the eastern contact is parallel to bedding. The core of the granite lobe contains a single axial-planar foliation to the fold. Together, these features are used to infer that the granite lobe was emplaced into the nose of the fold during regional $D_3$ deformation.

Actinolite related to $D_3$ shearing has been dated from the Western Shaw greenstone belt at c. 2940 Ma and overprints amphibolite-facies mineral assemblages related to $D_2$ deformation at c. 3240 Ma (Wijbrans and McDougall, 1987).

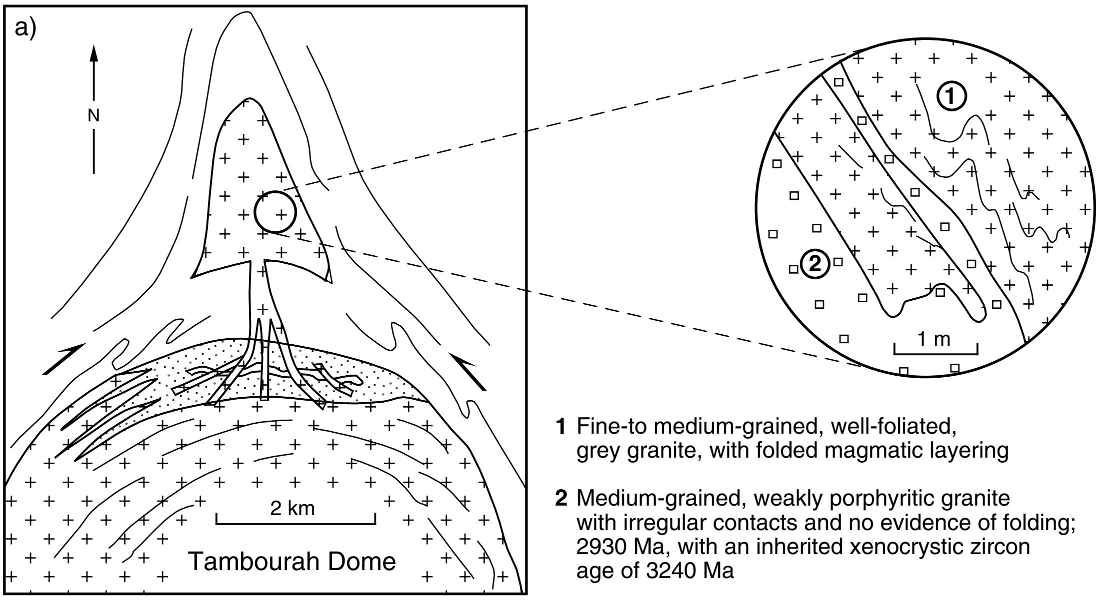
## Tambourah Anticline

The Tambourah Anticline is a large-scale, north-plunging anticline that folds rocks of the Western Shaw greenstone belt and $D_2$ structural fabric elements contained within it, including bedding-subparallel foliations and mineral elongation lineations defined by acicular hornblende and plagioclase aggregates in amphibolites. Bedding typically faces away from the granite except on the limbs of local $F_2$ and $F_3$ folds in the western limb of the Tambourah Anticline, where rocks are deformed into L-tectonites. The western and eastern margins of the Tambourah Anticline dip outward and define the overall antiformal geometry of the fold. However, the hinge of the fold at the granite–greenstone contact is overturned and plunges 80° to the south. Along the strike of the axial plane to the north, the plunge of the fold hinge becomes progressively more strongly overturned and is thus a synformal anticline plunging shallowly to the south.

Occupying the saddle reef position within folded greenstones in the hinge of the Tambourah Anticline is a triangular-shaped body of medium-grained to K-feldspar-porphyritic monzogranite (*AgYwo*; Fig. 26). This granite is composed of two texturally distinct phases: an early, medium-grained monzogranite with diffuse schlieren that outline open folds, and a later, isotropic K-feldspar-porphyritic phase that cuts the folds (Fig. 26a). The schlieric phase contains a weak quartz foliation parallel to the axial plane of the fold and was dated as 2933 ± 3 Ma (Nelson, 1998), the same age as the more massive phase (M. Van Kranendonk, unpublished U–Pb SHRIMP data). Swarms of undeformed medium-grained to pegmatitic granite dykes emanating from the central part of the Tambourah Dome along the axial plane of the main fold structure feed the saddle reef granite (e.g. Figs 26a, 27a). These features are used to suggest granite emplacement during the main episode of folding of the Tambourah Anticline (Fig. 26b). The weakly radiating swarm of pegmatitic granite dykes emanating from the northeastern margin of the Tambourah Dome are interpreted as a classic example of magma emplaced into a fanning array of axial-planar extensional fractures developed in the hinge of a buckle fold (cf. figs 21.26 and 21.28 of Ramsay and Huber, 1987). Along the trace of these veins to the northeast, northeast-trending $D_3$ folds overprint southeast-trending $D_2$ fabric elements in strongly transposed greenstones at the southeastern nose of the Tambina Anticline (Fig. 27b). Pegmatite veins were emplaced parallel to bedding on the eastern limb of the fold during sinistral shearing accompanying folding, as indicated by well-developed sinistral shear indicators (Fig. 27c). Undeformed pegmatite was emplaced into open folds in greenstones around the saddle reef granite, probably in response to sinistral shear rotation of the saddle reef granite, as shown schematically in Figure 26b.

# $D_4$ faulting and folding of the Fortescue Group

Structures developed in basal conglomerates of the Fortescue Group in the Emerald Mine Greenstone Complex include marginal normal faults and open east-southeasterly to southerly plunging synclines (Fig. 4). Chan (1998) showed that the faults marginal to the sub-basins were active as normal faults during deposition and then reactivated at some time later. The age of $D_4$ synclines trending along the basin axes is unknown.



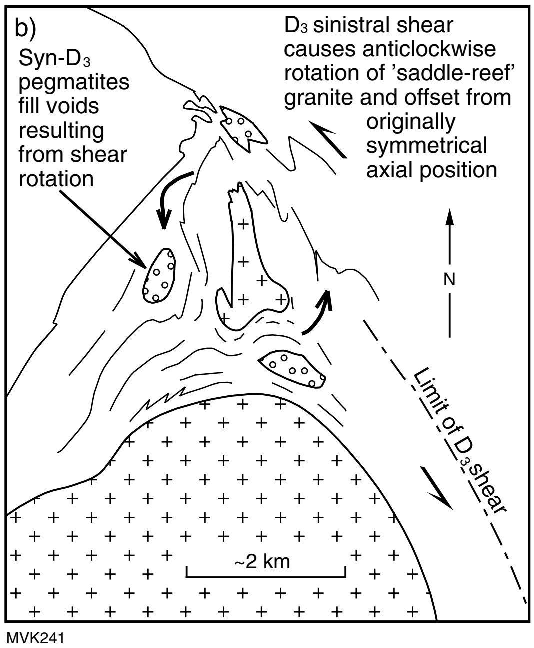




**Figure 26. Schematic diagram of $D_3$ structures around the nose of the Tambourah Dome: a) folding of greenstones around the nose of the Tambourah Dome and synkinematic intrusion of the saddle reef granite that was fed by granite dykes along the axial plane of the dome. Enlarged sketch shows relationships between two phases of the saddle reef granite, both of which have been dated, returning identical ages of c. 2933 Ma; b) schematic geological sketch showing the intrusion of small pegmatitic granitoid bodies into dilational gaps that formed as a result of rotation of the saddle reef granite due to a late component of sinistral shear along the Pulcunnah Shear Zone**

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## $D_5$ faulting

A late set of faults striking northwest–southeast to east–west cuts through the map sheet, parallel to the set of late dolerite dykes (*d*; Round Hummock Suite). These faults are most obvious where they offset the margins of granite–greenstone contacts, particularly along the eastern margin of the Yule Granitoid Complex (MGA 717500E 7604500N) and Tambourah Dome (MGA 726000E 7586950N), where they dominantly have a dextral sense of displacement.

Steeply dipping, east-striking faults filled by quartz veins that cut the Tambourah Dome just north of the southern margin of the sheet area (MGA 713000E 7566600N) are also interpreted to be late faults associated with this deformation.

# Metamorphism

Metamorphic grade varies throughout the map area, from high-temperature amphibolite- and rare granulite-facies assemblages within, and immediately adjacent to, granitoid complexes, to greenschist- and prehnite–pumpellyite-facies with increasing distance away from granitoid rocks (Fig. 28). This pattern is indicative of the contact-style metamorphism that typifies the whole of the east Pilbara (Hickman, 1983).

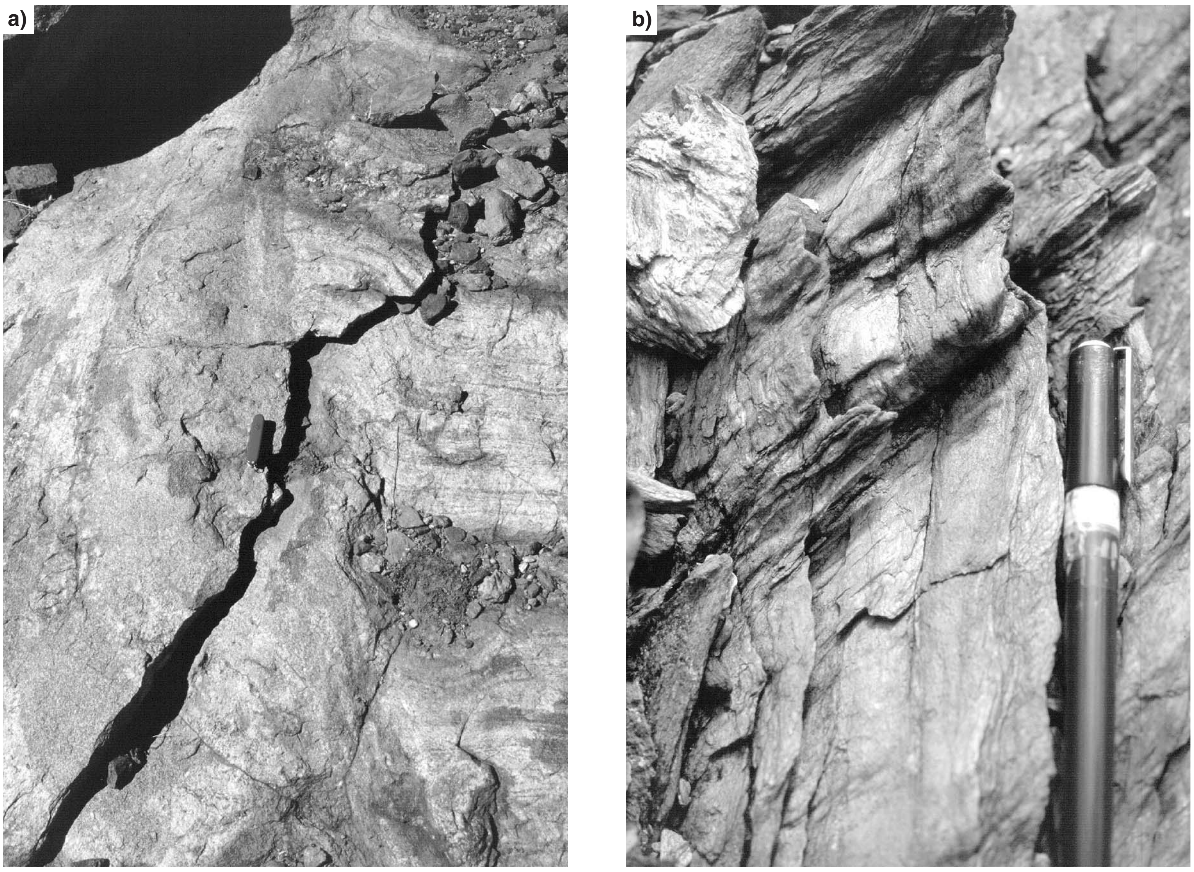



**Figure 27. Outcrop view of $D_3$ structures in the Lalla Rookh – Western Shaw Structural Corridor: a) View north of syn-$D_3$ granite sheet cutting interlayered orthogneiss and amphibolite along the axial plane of the Tambourah Dome at the granite–greenstone contact (MGA 721740E 7602155N); b) $D_3$ crenulation folds (above 13 cm long pen) of $S_2$ schistosity and $L_2$ lineations (parallel to length of pen) in chlorite schist from the southeastern hinge of the Tambina Anticline (MGA 728390E 7602900N); c) view onto horizontal surface of strongly foliated synkinematic pegmatite from the southeastern end of the Pulcunah Shear Zone (MGA 721790E 7602350N)**

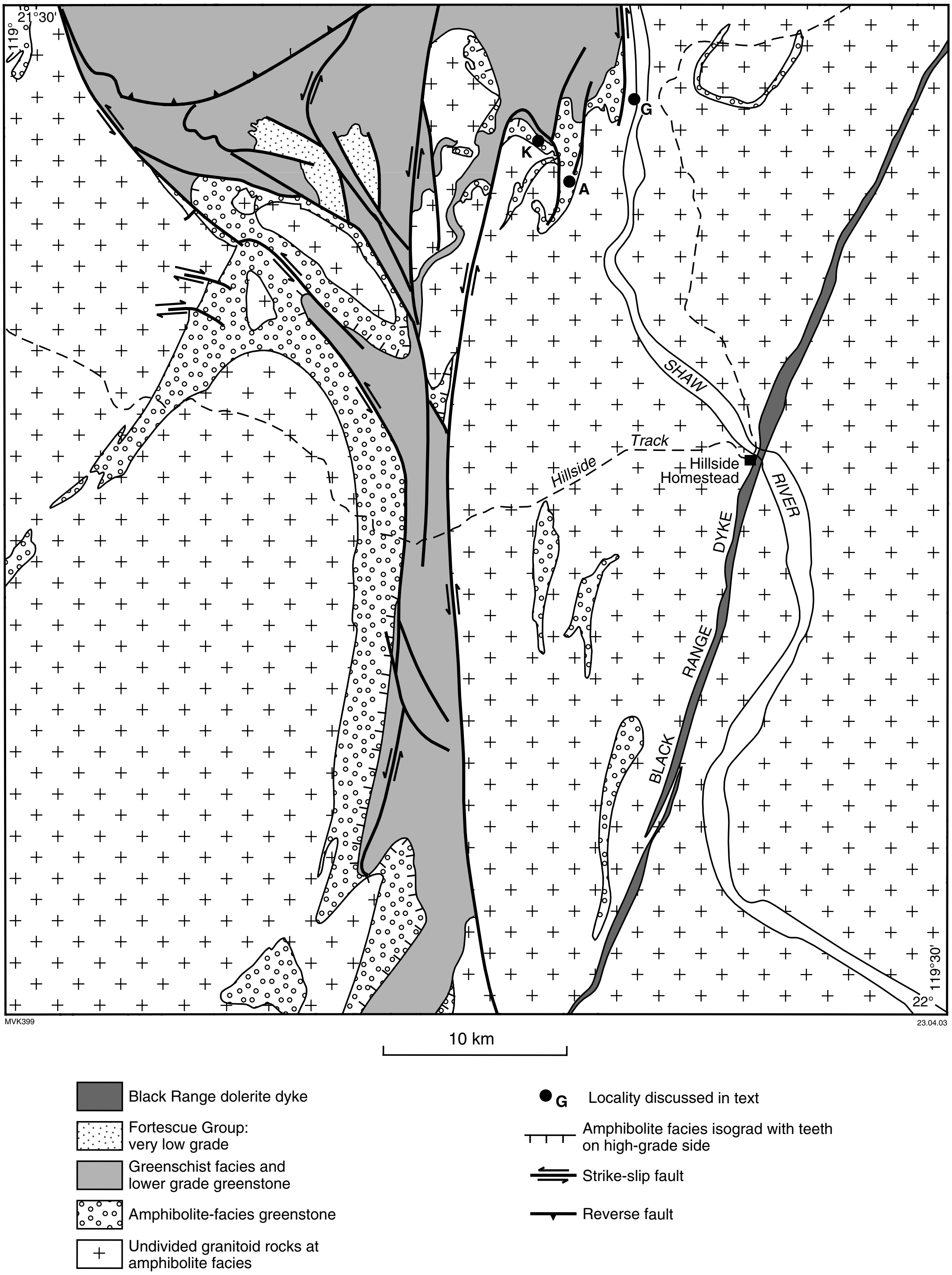


**Figure 28. Distribution of metamorphic facies on Tambourah**

Relict orthopyroxene was observed in an amphibolite enclave at one locality within the Shaw Granitoid Complex (G on Fig. 28). Otherwise, inclusions of supracrustal rocks in granitoid complexes contain ubiquitous amphibolite-facies assemblages, including hornblende–plagioclase–titanite assemblages in metamorphosed mafic rocks, and sillimanite–bioitite–muscovite–garnet in metapelites. Amphibolite-facies rocks also outcrop in the northwestern Shaw area, along the western half of the north-striking part of the Western Shaw greenstone belt adjacent to the Tambourah Dome, surrounding the Tambina Dome, and in the greenstone septum between the Yule Granitoid Complex and the Tambourah Dome (Fig. 28).

Amphibolite-facies assemblages in metamorphosed mafic rocks typically do not contain garnet and were thus developed under low to medium pressures. However, garnet and hornblende were observed at one locality in the northwestern Shaw area, in the tight syncline of greenstones between granitoid lobes 4 and 5 (A on Fig. 28). Greenschist-facies mafic rocks contain actinolite, chlorite, epidote, plagioclase, and opaque minerals.

Wijbrans and McDougall (1987) described metapelites from the greenstone roof pendant on the northwestern margin of the Tambourah Dome as containing biotite–garnet–staurolite–andalusite–sillimanite. Staurolite was described as being texturally early and sillimanite texturally late, indicating a prograde increase in temperature for this area.

Morant (1984) presented a detailed metamorphic study of aluminous schists (metapelites and felsic volcanic rocks) in and around the western part of the Shaw Granitoid Complex. Data from this study for the northwestern Shaw area was summarized in Bickle et al. (1985). These authors found a general increase in metamorphic temperature conditions towards the granitoid complex, based on petrographic observations of the distribution of, and overgrowth relationships between, the aluminosilicate polymorphs kyanite, andalusite and sillimanite. In general, greenschist-facies aluminous schists away from the granitoid complex contain kyanite (–chloritoid–staurolite). Closer to the granitoid complex, andalusite was observed overgrowing kyanite, with sillimanite overgrowing andalusite, whereas within the granitoid complex, sillimanite only was observed. All three aluminosilicate polymorphs were observed in one locality (K on Fig. 28), indicating pressures of about 3.7 – 5.6 kbars (Bickle et al., 1985).

The distribution and overgrowth relationships between the aluminosilicate polymorphs in the northwestern Shaw area was interpreted as part of a thrusting model proposed by Bickle et al. (1985). However, the thermal anomaly associated with the granitoid complex was '…not explained' and the absence of kyanite in the more deeply eroded rocks within the complex was '…perplexing…' (Bickle et al., 1985, p. 339). As an alternative, Collins and Van Kranendonk (1999) showed that the presence of kyanite along the margins of domal granitoid complexes in Archaean terrains was consistent with thermal models of diapirism presented by Mareschal and West (1980). They showed that the distribution of aluminosilicates observed by Morant (1984) and Bickle et al. (1985) were perfectly consistent with a model of diapirism as suggested by Hickman (1984), Collins (1989), and Van Kranendonk et al. (2002).

# Crustal evolution

Geochronological data for TAMBOURAH is presented in Table 3 and summarized in Figures 5 and 29. The most voluminous phase of felsic magmatism occurred between 3469 and 3451 Ma, with grey biotite tonalite and hornblende–quartz diorite protoliths in the Shaw Granitoid Complex. This phase of plutonism was coeval with the eruption of the Duffer Formation and voluminous basaltic volcanism preserved in other parts of the east Pilbara (Hickman, 1983; Van Kranendonk, 2000; Van Kranendonk et al., 2002).

A second, slightly younger group of plutonic rocks ranges in age from 3434 to 3425 Ma and was coeval with the upper part of the Panorama Formation dated at 3434–3426 Ma in the Western Shaw greenstone belt (GSWA 142972; Nelson, 2000) and elsewhere throughout the East Pilbara Granite–Greenstone Terrane (see Van Kranendonk et al., 2002). Granitoid rocks of this age are restricted to the western margin of the Shaw Granitoid Complex and include the 3431 ± 6 Ma South Daltons Pluton (UWA 98053; McNaughton et al., 1993), the other granitoid lobes of the northwest Shaw area (samples M95-71, M95-78; M. Van Kranendonk, unpublished data), sheared granitoid gneisses in the northern (T94/32; Zegers, 1996) and southern parts (GSWA 142968; Nelson, 2000) of the Mulgandinnah Shear Zone, and the protolith to 2929 Ma diatexite in the central-western part of the complex (*AgSnmu*; GSWA 142966; Nelson, 2000). Granitoid rocks of this age are also present around the margins of, and within, the Tambourah Dome (sample M95-28a; M. Van Kranendonk, unpublished data; GSWA 169019; Nelson, 2002).

A third pulse of granitic magmatism spans the range 3417 to 3394 Ma, but corresponds to the generation of small volumes of leucogranite melt rather than to widespread plutonism as in previous pulses. This pulse is identified from xenocrystic zircons in younger granitoid rocks (GSWA 142883 and sample T94/31), secondary zircons in older granitoid rocks (samples M95-78, T94/222, T94/221), and periods of zircon growth in an amphibolite inclusion and intrusive leucosome vein in the Shaw Granitoid Complex (samples M95-71b, M95-71c).

After a hiatus of about 70 m.y., zircon recrystallization and growth of zircon rims occurred at c. 3325 Ma (Zegers, 1996). This age correspond to a major felsic magmatic event further east, manifest as voluminous granitoid intrusion in the Corunna Downs and Mount Edgar Granitoid Complexes, and as eruption of the felsic volcanic Wyman Formation (Williams and Collins, 1990; Thorpe et al., 1992a; McNaughton et al., 1993; Barley and Pickard, 1999).

At c. 3250–3210 Ma there was another thermal event as evidenced by the age of granitoid plutons in the Yule

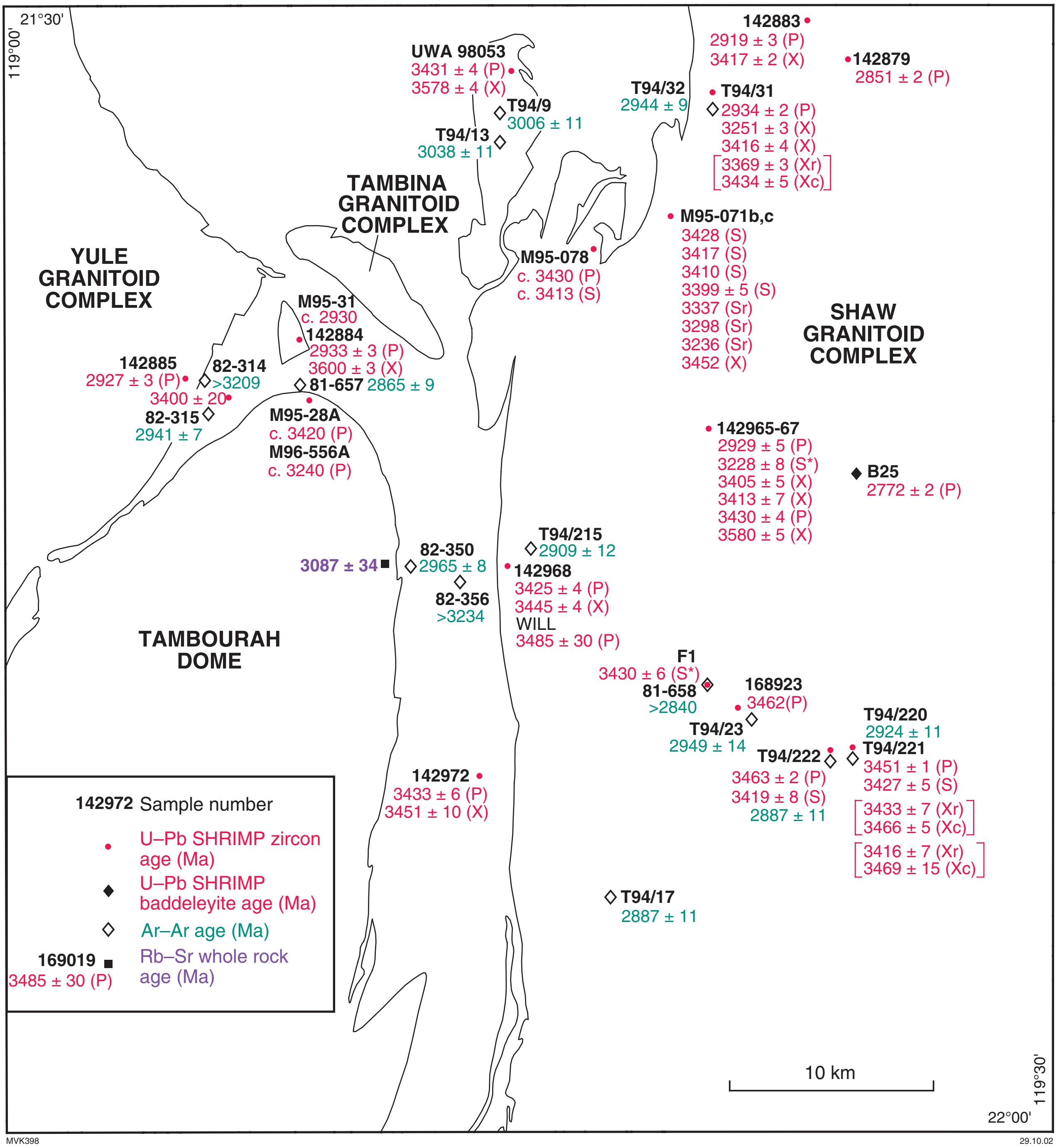


**Figure 29. Summary of geochronology on Tambourah. P = Primary igneous crystallization age; S = secondary plateau or metamorphic zircon age; Sr = Secondary age from metamorphic zircon overgrowth rim; S* = secondary zircon age, interpretation by author; X = Xenocrystic zircon; Xc = xenocrystic zircon, core; Xr = xenocrystic zircon, rim**

Granitoid Complex (unpublished SHRIMP zircon data), amphibolite-facies contact metamorphism in the Western Shaw greenstone belt (Wijbrans and McDougall, 1987), and zircon recrystallization in the Shaw Granitoid Complex (Zegers, 1996). This event correlates with the eruption of the Sulphur Springs Group in the northern part of the sheet area and on North Shaw (Buick et al., 2002; Van Kranendonk, 2000).

After an hiatus of almost 200 m.y., two Ar–Ar dates suggest the onset of renewed thermal activity between c. 3050 and 3005 Ma (Zegers et al., 1999). This event may relate to tectonism in the West Pilbara Granite–Greenstone Terrane (Smith et al., 1998; Van Kranendonk et al., 2002) or the eruption of the Honeyeater Basalt and Cattle Well Formation on Muccan in the East Pilbara Granite–Greenstone Terrane (Nelson, 1999; Williams, 1999), or both.

This was followed by the $D_3$ tectonothermal event at c. 2950–2919 Ma, as recorded by several emplacement ages of synkinematic granitoid rocks and Ar–Ar dates on hornblende (Fig. 5 and Table 3; Wijbrans and McDougall, 1987; Zegers, 1996; Nelson, 1998; Van Kranendonk and Collins, 1998; Zegers et al., 1998).

Emplacement of the post-tectonic Cooglegong and Spear Hill Monzogranites occurred in the Shaw Granitoid Complex at c. 2850 Ma (Nelson, 1998), and this was followed by flood basalt volcanism of the Fortescue Group during rifting at c. 2772 Ma (Arndt et al., 1991).

# Mineralization

TAMBOURAH is host to a number of small epigenetic gold and asbestos deposits in sheared greenstones, tin–tantalum–beryllium in post-tectonic granitoid rocks, and minor nickel–copper sulfide and platinum group element mineralization in differentiated ultramafic–mafic sills. Ferguson and Ruddock (2001) summarized the mineralization potential of the area.

## Beryllium

Two occurrences of beryllium oxide were documented in the Cooglegong Monzogranite on THE MARBLE BAR 1:250 000 sheet (Hickman and Lipple, 1978), but it was from an undetermined locality near the Cooglegong mining centre that 11 375.2 kg of BeO was mined from 96.18 t of ore earlier in the last century (Ferguson and Ruddock, 2001).

Gem-quality emeralds were mined at the Emerald Mine (MGA 737850E 7612450N) in the 1970s. Mining was undertaken in one or two deep shafts and in a 100 m-long trench within the Emerald Mine shear zone that wraps around granitoid lobes 3 and 4 of the northwest Shaw area (see Fig. 23). The shear zone contains coarse black biotite and white kaolinitized feldspars in addition to pale- to dark-green emerald crystals that were reportedly up to 30 cm or more in length. Some excellent emerald crystals may still be found there. The zone hosting the distinctive ore mineralogy is less than 1 m wide within strongly sheared chloritic schists characterized by steeply westerly dipping foliations and south-southwesterly plunging chlorite lineations. For a kilometre north of the mine, a 1–2 m-wide granite dyke that becomes 500 m thick in the nose of a tight anticline, intrudes the shear zone. The fluids from this granitic dyke may have supplied the elements required to crystallize the emeralds.

## Chrysotile asbestos

Asbestos was mined from serpentinized metaperidotites at the Fibre Queen (MGA 720450E 7607850N) and Olivine (MGA 719000E 7608500N) mines and at the Soanesville mining centre (MGA 727200E 7617550N). Hickman (1983) reported that 244.78 t of asbestos was mined from Soanesville to the end of 1977.

## Epigenetic gold

Epigenetic gold was mined near the turn of the 20th Century from the Tambourah (MGA 725400E 7593100N) and Western Shaw (MGA 728300E 7584500N) mining centres. Other prospects are present in foliated to sheared greenstones along the northeastern margin of the Tambourah Dome (MGA 725300E 7598000N), in the southwestern part of the Western Shaw greenstone belt (MGA 717600E 7603000N), and in the main part of the Western Shaw greenstone belt just north of the Woodstock – Hillside – Marble Bar track (MGA 729450E 7591700N).

At Tambourah, 163.2 kg of gold was mined from 0.3 – 0.6 m-wide quartz veins striking north–south in amphibolite, approximately 500 m east of the contact with the Tambourah Granite. The richest lead was approximately 1 km long, south of Tambourah Creek, about 300 m east of the stream running along the granite–greenstone contact. A total of 76.63 kg of gold was produced from the Tambourah mining centre (Ferguson and Ruddock, 2001).

The Western Shaw mining centre was composed of a number of long mine tunnels running just below the surface, following steeply dipping quartz veins oriented parallel to bedding in greenstones. The host lithology is a massive, medium-grained talc–carbonate(–chlorite) rock, similar to that which hosts the mineralization at Lynas Find, and which probably represents a metamorphosed komatiite. Gold mineralization is present in pyrite along the margins of the quartz veins that are boudinaged and weakly strained within very strongly schistose host rocks. The workings at Western Shaw merited a rail system for ore haulage, and a sizeable town was present at the turn of the 20th Century, complete with telegraph service. Until 1985, 46 kg of gold was processed through the Western Shaw mining centre; there has also been alluvial mining for 15 years until 1997 (Ferguson and Ruddock, 2001). Mining followed the course of a north–south palaeochannel just east of the main workings (from about MGA 7582000N to the Woodstock–Hillside – Marble Bar track). Gold was mined from coarse alluvial gravels to a depth of about 2 m, and was halted due to dispute over a land claim.

## Nickel–copper sulfides and platinum group elements

The Dalton Suite of layered mafic–ultramafic sills in the Soanesville area have been prospected for nickel–copper sulfide ore and platinum group elements. Of particular interest have been the contacts between the sills and host sedimentary rocks of the Gorge Creek Group along the southern limb of the Soanesville Syncline. No known production from this area has been recorded.

## Tin and tantalum

Alluvial tin and tantalum were discovered in 1890 (Simpson, 1948) and was extracted from the beds of creeks in and around the Cooglegong Monzogranite to depths of 1.5 – 2.5 m. Alluvial tin was mined from five principle centres, four of which are concentrated around the Cooglegong Monzogranite and referred to as the Shaw River tin field (Blockley, 1980). These include the Cooglegong, Eley, and Five Mile Creek mining centres, and the Canning Mine in the Tambourah Creek mining centre (MGA 738800E 7602800N). The Coondina mining centre was farther south on the eastern side of the Shaw River (MGA 748250E 7577400N). Lode tin was mined at only one locality, 1.8 km southeast of Spear Hill. Hickman (1983) reported that 6584.33 t of tin ore was produced up to 1977, worth a total of $7.1 million at that time. Mining continued through the 1970s, but has since been abandoned.

The bulk of tin mineralization is in the form of cassiterite. The origin of the mineralization is from albite pegmatites that have intruded host granitoid gneisses around the margins of the Cooglegong and Spear Hill Monzogranites, the latter intrusion dated as 2851 ± 2 Ma (Nelson, 1998). Approximately 75% of the total tin ore produced was extracted from the Cooglegong mining centre, with the largest operation focused over a 5.5 km stretch on Two Mile Creek, which was worked over a width of 20–60 m. Blockley (1980) discussed reserves and grades of tin mineralization in the Shaw River tin fields. Production from the Cooglegong mining centre comprised 466.32 t of low-grade tantalite with subordinate amounts also recorded from Eley, Hillside, and upper Five Mile Creek mining centres (Hickman, 1983). Kinny (2000) dated cassiterite from the Cooglegong Monzogranite at the Cooglegong and Hillside mining centres, and these returned ages of c. 2880 Ma, slightly older than the zircon age of the host Cooglegong Monzogranite (c. 2850 Ma).

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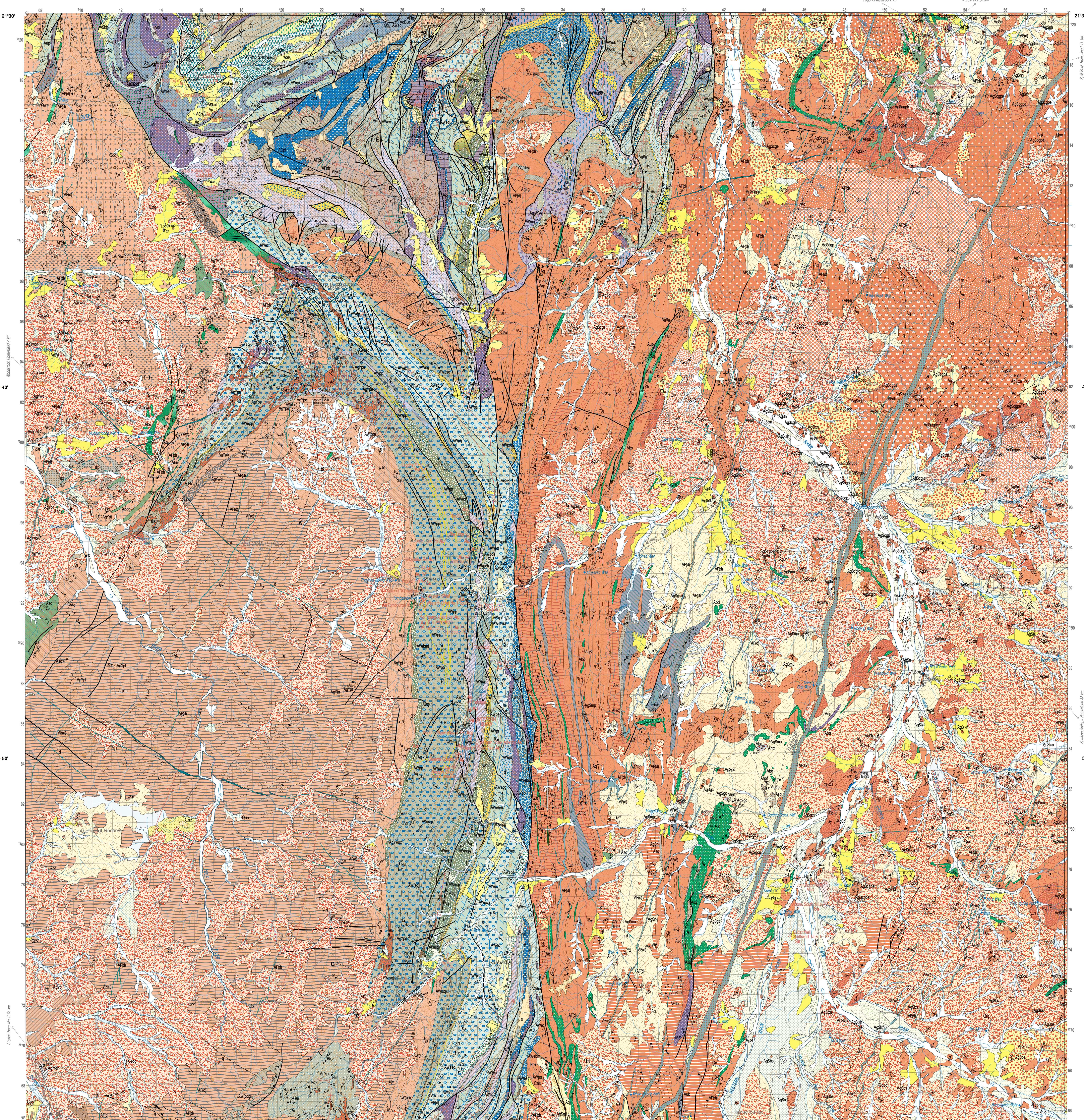

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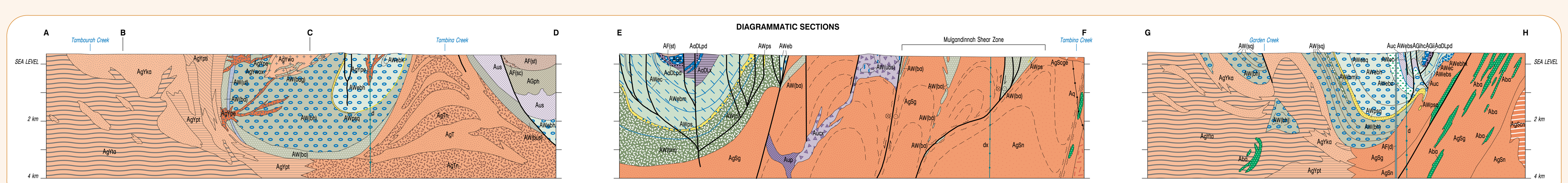

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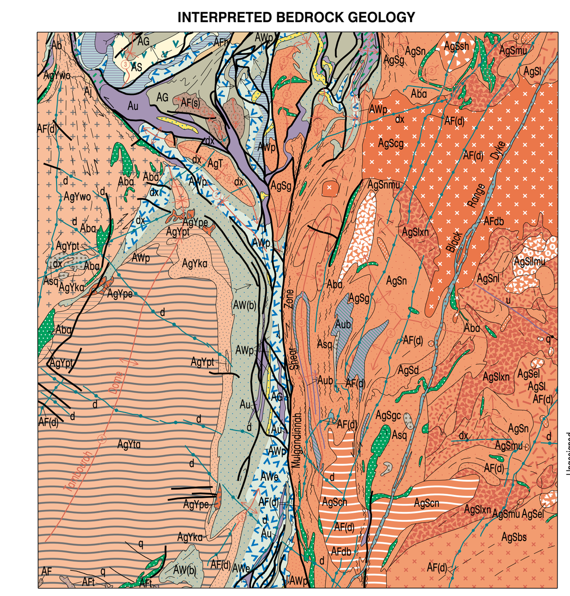

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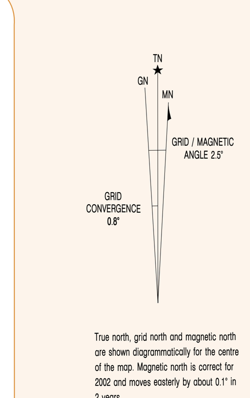


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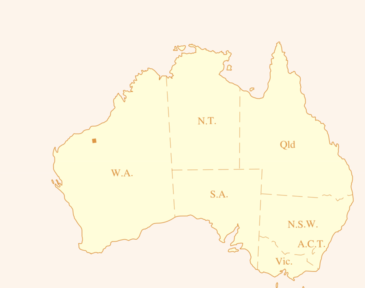


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