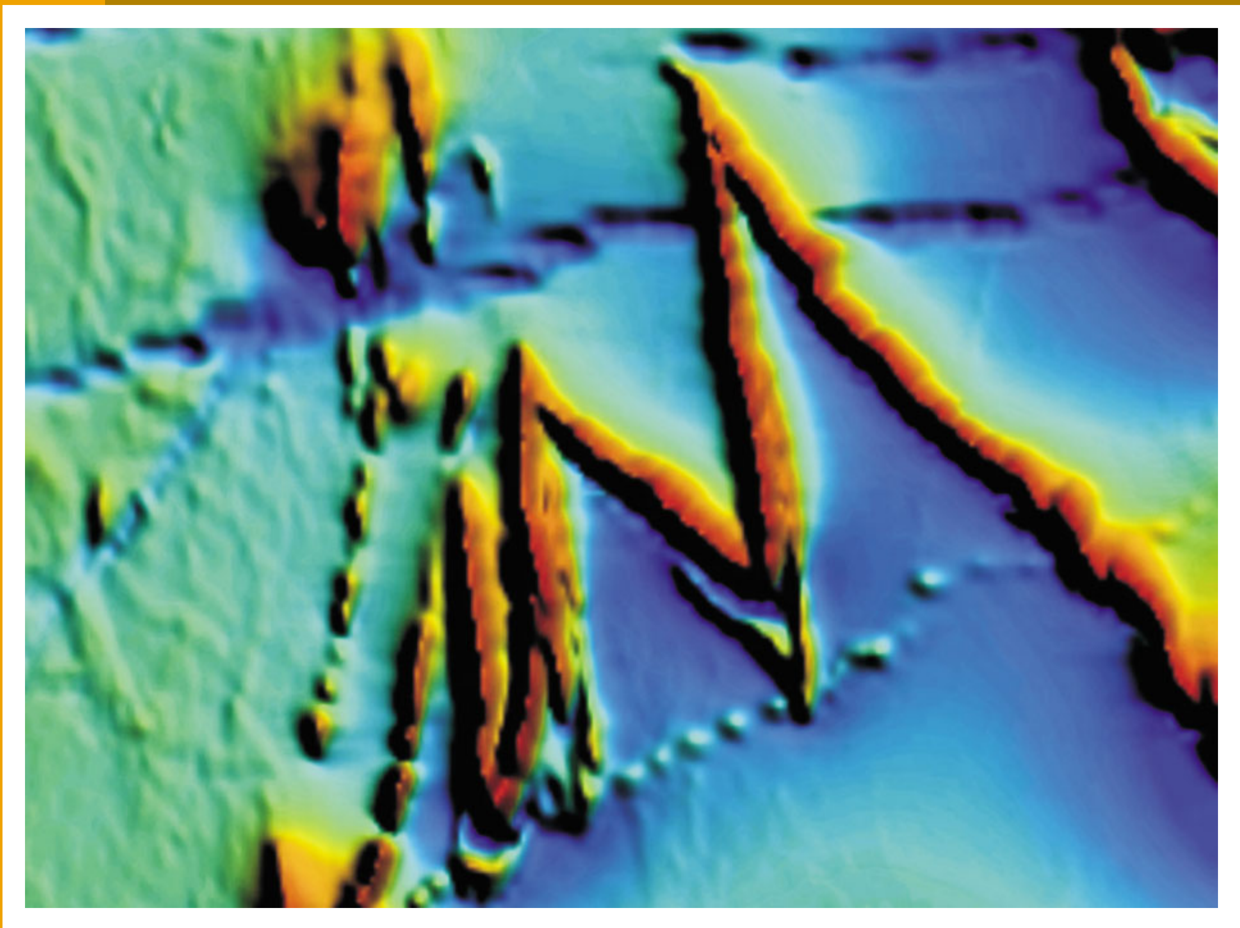
EXPLANATORY NOTES

GOVERNMENT OF WESTERN AUSTRALIA

# GEOLOGY OF THE MOUNT BELCHES 1:100 000 SHEET

by M. G. M. Painter and P. B. Groenewald

1:100 000 GEOLOGICAL SERIES



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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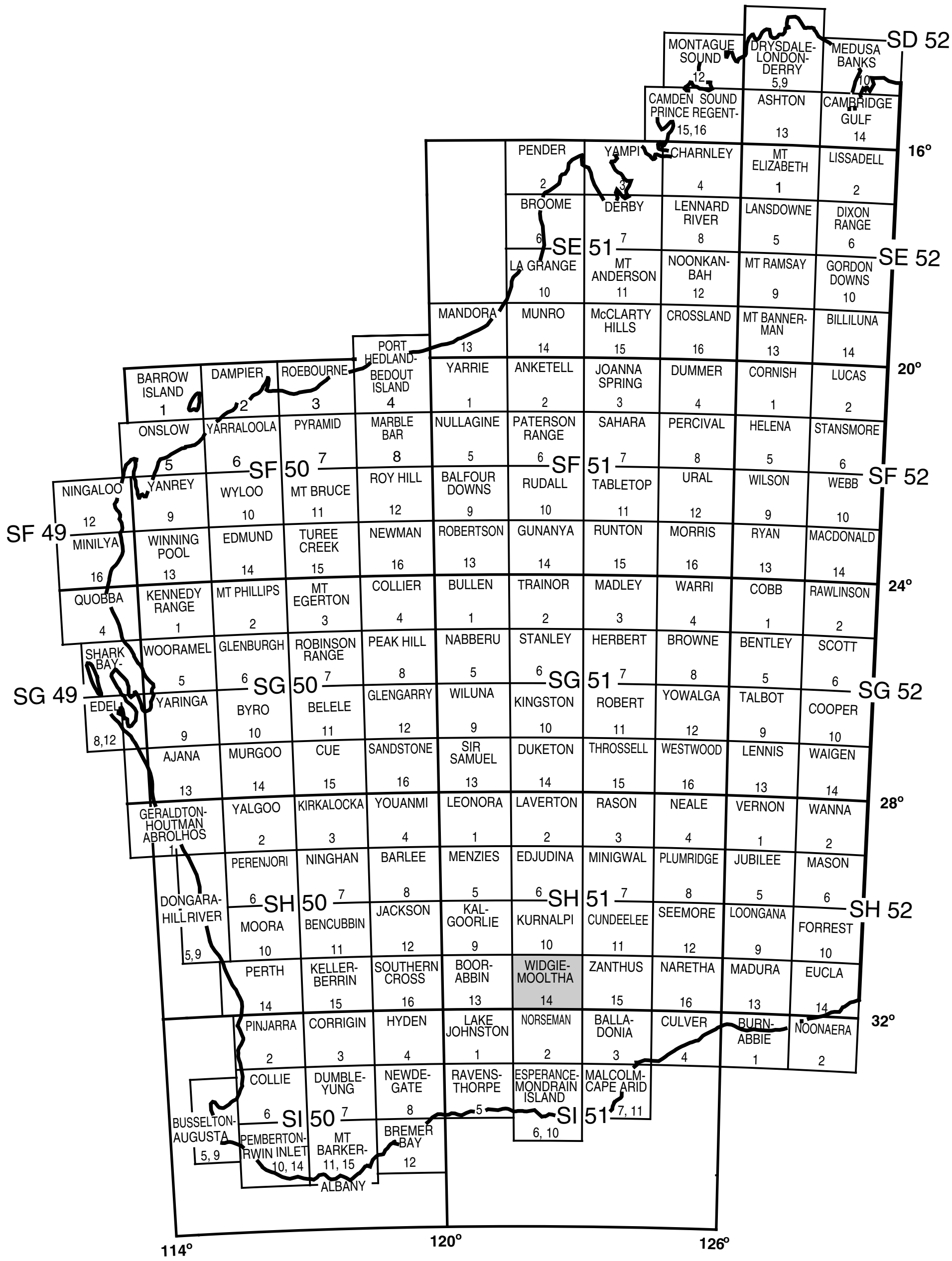

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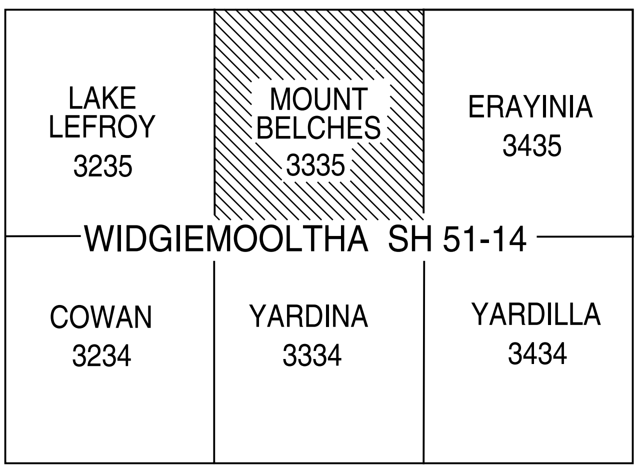

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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by
M. G. M. Painter and P. B. Groenewald

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**Cover photograph:**
**Aeromagnetic image of the Santa Claus Member in the region around the Randalls and Karnilbinia mining centres (courtesy Fugro Airborne Surveys Pty Ltd).**

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# Geology of the Mount Belches 1:100 000 sheet

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# Abstract

The MOUNT BELCHES 1:100 000 sheet, southeastern Eastern Goldfields, is dominated by Archaean rocks of the Yilgarn Craton, including metasedimentary rocks (wacke, mudstone, iron formation) of the Mount Belches Formation, with less abundant metamorphosed mafic to ultramafic volcanic and intrusive rocks, felsic volcanic and volcaniclastic rocks, and granitoids. These are locally overlain by Eocene sedimentary rocks.

MOUNT BELCHES is divided into four tectonostratigraphic units: the Gindalbie, Parker, and Mulgabbie greenstone domains, and the Randall Dome, where the Mount Belches Formation trends around and youngs away from a central granitoid. Major regional faults separate each of these domains. Thrust stacking and recumbent folding represent $D_1$ in the greenstone domains. In the Randall Dome, vertical granitoid propagation and contact metamorphism ($M_1$) caused bedding-parallel foliation development whose relationship to $D_1$ elsewhere is unclear. Strong east–west compression ($D_2$) is manifest as regional upright to overturned folds, crenulation of $S_1$, and development of the north-northwest-trending $S_2$. Peak upper greenschist- to amphibolite-grade regional metamorphism ($M_2$) probably post-dated $D_2$. Sinistral and reverse movements along major faults accommodated transpression during $D_3$ and $D_4$, resulting in uplift of the Randall Dome relative to the greenstone domains.

Gold mineralization at Randalls and Karnilbinia comprises complex vein sets with associated auriferous alteration. These developed in the rheologically competent Santa Claus Member iron formation at or adjacent to overturned anticlinal hinges. Similar alteration styles are exposed at structurally favourable sites throughout the Randall Dome.

Eocene block tilting and marine incursions resulted in deposition of the fluviodeltaic to estuarine Eundynie Group. The sequence accumulated in pre-Jurassic palaeodrainage channels that subsequently filled with playa sediments.

**KEYWORDS:** Archaean, Eastern Goldfields, Yilgarn Craton, greenstone, granite, metamorphic rocks, sedimentary rocks, banded iron formation, Mount Belches Formation, Santa Claus Member, Randall Dome, gold, Eundynie Group

# Introduction

The MOUNT BELCHES* 1:100 000 map sheet (SG 51-14, 3335), bounded by latitudes 31°00'S and 31°30'S, and longitudes 122°00'E and 122°30'E, is located in the north-central part of the WIDGIEMOOLTHA 1:250 000 sheet. This part of the southeastern Eastern Goldfields lies between Kalgoorlie–Boulder and Kambalda to the west-northwest, the Great Victoria Desert to the northeast, and the Fraser Range and Nullarbor Plain to the east and southeast. It occupies parts of the Coolgardie District of the Coolgardie Mineral Field, the Bulong District of the East Coolgardie Mineral Field, and the Kurnalpi District of the North East Coolgardie Mineral Field. The sheet takes its name from Mount Belches (335 m above Australian Height Datum — AHD), a rounded hill on the northern shore of Lake Randell.

## Access

There are no towns on MOUNT BELCHES. The nearest townships are Kalgoorlie–Boulder (65 km west-northwest), Kambalda (30 km west), Widgiemooltha (40 km west), and Coonana (70 km east). Although the pastoral leases of Mount Monger, Cowarna Downs, and Madoonia Downs stations cover much of MOUNT BELCHES, only Cowarna Downs Homestead (Fig. 1) is located on this sheet (MGA 388695†); the Madoonia Downs Homestead

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

† Localities are specified by the Map Grid of Australia (MGA) standard six-figure reference system whereby the first group of three figures (eastings) and the second group (northings) together uniquely define position, on this sheet, to within 100 m. Locations mentioned in the text are listed in Appendix 1.


**Figure 1. Main cultural and physiographic features on Mount Belches**

site (MGA 382242) has been abandoned in favour of the site at Binyarinyinna Rock on YARDINA to the south. Most of Lake Randell and the land up to 6 km south are classified as vacant Crown land.

Despite its proximity to Kalgoorlie–Boulder, there are no major roads in the area. Direct access from Kalgoorlie–Boulder to the northwest and centre north of the map sheet is by the Mount Monger Road past Mount Monger Station where it served as the now defunct Randalls haul road. Alternative routes from Widgiemooltha (along the unsealed Binneringie Road) or from Mount Monger Station (along the poorly maintained, unsealed Mount Monger South Road) provide access to the south of the map sheet, as do station tracks on the east side of Lake Randell. Also, the Trans Australia Railway and Trans Access Road run east–west, less than 10 km north of the northern edge of MOUNT BELCHES. Several station tracks provide access to MOUNT BELCHES from the Trans Access Road. Station and exploration tracks provide access to most parts of the map sheet, but the area of vacant Crown land and local areas of dense scrub have poor access.

## Climate, physiography, and vegetation

MOUNT BELCHES has a semi-arid climate. The nearest weather stations at Kalgoorlie–Boulder, Norseman, and Rawlinna record annual rainfall averages of 264 mm, 284 mm, and 192 mm respectively; evaporation rates exceed 2370 mm per annum*. Rainfall is most consistent in the winter months but downpours from thunderstorms and decayed tropical cyclones provide sporadic rainfall during summer. Summer temperature maxima are often in excess of 35°C and commonly exceed 40°C. In the winter months, minima below 2°C are common, with occasional frosts.

Large playa systems dominate the physiography of MOUNT BELCHES (Fig. 1). The largest of these is Lake Randell, which occupies the north-central part of the area and extends westerly across the sheet onto LAKE LEFROY to the west. A series of smaller lakes extends south from Lake Randell along the eastern side of the sheet and culminates at the northern shores of Dog Lake south of the abandoned Madoonia Downs Homestead site. The terrain is irregular north of Lake Randell, with the Seabrook Hills, Mount Belches, Trig Hills, Low Trap Hills, and Roe Hills interspersed with broad colluvial and sheetwash plains. South of Lake Randell, deep weathering and colluvial cover obscure much of the geology and have resulted in low undulating hills punctuated by chains of lateritic breakaways. Relief over the map sheet area is low (<150 m). A breakaway at Hawke Hill (425 m AHD) northwest of Karnilbinia mine is the highest point on MOUNT BELCHES; the lowest (276 m AHD) is in the southeastern playa lakes.

Botanically, MOUNT BELCHES falls entirely within the South Western Interzone of Beard (1990) and covers one of the more complex regions within this zone (Beard, 1975). Most of the map sheet comprises woodlands of salmon gum (*Eucalyptus salmonophloia*) variably intermingled with goldfields blackbutt (*E. lesouefii*) and giant mallee (*E. oleosa*), and with merrit (*E. flocktoniae*) in the south. An understory of tall shrubs dominated by broombush (*Eremophila scoparia*) is interspersed with patchy occurrences of bluebush (*Maireana sedifolia*), greybush (*Cratystylis concephala*), and saltbush (*Atriplex vesicaria*), with a ground layer of sparse grasses and ephemeral herbs. Wattle, mulga (*Acacia* spp.), and broombush are concentrated on soils over granite and metasomatically altered metasedimentary rocks, whereas blackbutt prefers soils developed from mafic rocks. North of Lake Randell, the plains largely comprise steppe of sparse salmon gum with an understory of bluebush and grasses. Small ridges in this area are dominated by black oak (*Casuarina pauper*). Samphire (*Halosarcia* spp.), saltbush, bluebush, and greybush predominate in and surrounding the playas (Beard, 1975, 1990). The Randells Forest Reserve occupies the northern part of the sheet, between Hawke Hill and Red Peak Gully.

## Previous investigations

Early mapping by Clarke (1925) covered the region from the Mount Monger area to St Ives on LAKE LEFROY. The greenstones of northwestern MOUNT BELCHES were mapped and the location but not the geology of the Randalls and Karnilibinia leases noted. Granite in the southwestern corner of MOUNT BELCHES was also mapped. Clarke (1925) described the geology of the region and, in particular, the geology of the leases in the Mount Monger area.

The geology of the MOUNT BELCHES sheet has been recorded on two editions of WIDGIEMOOLTHA (1:250 000). The first edition (Sofoulis et al., 1965) and accompanying explanatory notes (Sofoulis, 1966) were used as a basis for nickel exploration, particularly around Kambalda. For MOUNT BELCHES, these publications recorded the chevron folding in the metasedimentary rocks north of Lake Randell and inferred anticlines over the granitoids intruding the metasedimentary rocks. The second edition of the WIDGIEMOOLTHA (1:250 000) geological map (Griffin and Hickman, 1988) and the accompanying notes (Griffin, 1989) were produced in response to major mining activity at Kambalda (nickel) and St Ives (gold), and the subsequent increase in geological knowledge in and around these mining areas. This remapping clarified the geology of the area covered by MOUNT BELCHES. Regional studies (Swager, 1995a; Swager et al., 1995; Krapez et al., 1997) have included portions of MOUNT BELCHES in broad tectonic models for the Eastern Goldfields.

Dunbar (1966) and Dunbar and McCall (1971) recorded in detail the sedimentology of the 'Mount Belches Beds', determining a flysch-type turbiditic depositional environment. Williams (1971, 1972) and Williams and Hallberg (1973) mapped and analysed layered sills in the northwestern corner of MOUNT BELCHES. As part of an effort by the Geological Survey of Western Australia (GSWA) to investigate controls on gold mineralization and potential for base metal mineralization

* Climate data from Commonwealth Bureau of Meteorology website, December 2, 1999.

in the Eastern Goldfields, Hickman (1986) recorded the geology of the greenstones of the Mount Monger area at 1:50 000 scale. The eastern part of this study covers the mafic and ultramafic rocks of the northwestern corner of MOUNT BELCHES. Detailed geology of the Randalls gold deposits and a mechanism of formation is described in Newton et al. (1998).

Open-file reports, maps, and data for mining and exploration tenements submitted to the Department of Minerals and Energy (DME) are available on the Western Australian Mineral Exploration database (WAMEX) system at the DME library in Perth and at the GSWA Kalgoorlie Regional Office.

## Current work

Mapping of MOUNT BELCHES is part of the ongoing 1:100 000 mapping program of the Yilgarn Craton by the GSWA. MOUNT BELCHES is part of one of the largest areas of greenstone in the Eastern Goldfields yet to be mapped at 1:100 000 scale. Data from MOUNT BELCHES will be incorporated into a forthcoming version of GSWA's seamless geological geographic information system (GIS; Groenewald et al., 2000), which currently holds data for twenty 1:100 000 map sheets from the southern Eastern Goldfields.

Mapping of MOUNT BELCHES was carried out between April and November 1998, apart from the Roe Hills where mapping was completed in mid-1999. MOUNT BELCHES was mapped using 1:50 000-scale black and white aerial photographs taken over WIDGIEMOOLTHA (1:250 000) in February 1997*. Aeromagnetic data with a line-spacing of 200 m captured by Fugro Airborne Surveys (formerly World Geoscience Corporation) was used for geological interpretation. Landsat Thematic Mapper (TM) false-colour imagery (using ratios of bands 2, 3, 4, 5, and 7) enhanced the interpretation of regolith unit distributions.

## Nomenclature

All Archaean rocks on MOUNT BELCHES have been exposed to varying grades of metamorphism. Where primary textures are preserved and the precursor rock can be identified, the prefix 'meta-' is omitted for ease of description. Metamorphic terminology is only used for metamorphic rocks whose protolith is unrecognizable.

# Regional geological setting

MOUNT BELCHES is in the southeastern Eastern Goldfields Province of the Yilgarn Craton. The Eastern Goldfields comprises a series of attenuated greenstone belts intruded by, and interstitial to, similarly elongate granitoid plutons and complexes (Fig. 2). Anastomosing regional scale faults, mostly of sinistral strike-slip shear, dissect the province, but broad-scale stratigraphic correlations persist across these faults (Passchier, 1994; Swager, 1997). The regional stratigraphy comprises a lower basaltic unit, overlain by komatiite, followed by an upper basalt unit (with komatiitic affinities), and then a sequence of felsic volcanic and volcaniclastic rocks (Swager, 1995a, 1997; Swager et al., 1995). Clastic sedimentary rocks unconformably overlie this sequence. The komatiite is interpreted as a regional marker that extends across the Eastern Goldfields, but other units vary laterally, and localized felsic volcanic rocks occur at numerous intervals throughout the sequence. The stratigraphic sequence was deposited between 2710 and 2675 Ma, with the komatiite eruption event at around 2705 Ma (Nelson, 1997). The geological history of the rocks on MOUNT BELCHES is summarized in Table 1.

Four major compressional episodes interspersed with extension have been recognized (Swager et al., 1995; Nelson, 1997; Swager, 1997). $D_1$ thrust stacking followed by intense upright $D_2$ folding mark the two major folding events (2675–2657 Ma; Nelson, 1997). These were followed by $D_3$ sinistral movement on north-northwest-trending regional strike-slip faults and $D_4$ oblique movement on the same structures between 2660 and 2620 Ma (Swager et al., 1995; Nelson, 1997; Swager, 1997). Regional metamorphic grade of the greenstones is broadly related to the distribution of the granitoids (Binns et al., 1976). Peak grades of upper greenschist to lower amphibolite facies were reached subsequent to $D_2$ deformation and the bulk of granitoid emplacement at approximately 2660–2640 Ma (Nelson, 1997; Swager, 1997).

Myers (1990), Swager (1995a, 1997), and Swager et al. (1995) subdivided the Eastern Goldfields into tectonostratigraphic blocks bounded by major faults, or 'terranes'. According to this scheme, MOUNT BELCHES lies at the junction of the Kalgoorlie, Gindalbie, and Kurnalpi Terranes. Groenewald et al. (2000) recognized the validity of a regional subdivision of the Eastern Goldfields on lithostratigraphic grounds, but argued that there is inadequate distinction to allow conventional use of the term 'terrane'; these authors have thus used a subdivision into Kalgoorlie (formerly the Kalgoorlie and Gindalbie Terranes) and Edjudina–Laverton greenstones. These are subdivided into domains that are the approximate equivalents of the 'terranes' or, within the former Kalgoorlie terrane, each of its domains. Of the Kalgoorlie greenstones, the Parker and Gindalbie domains are represented on the western side of MOUNT BELCHES (Fig. 3). Of the Edjudina–Laverton greenstones, only the Mulgabbie domain is exposed (Fig. 3). The Mount Belches Formation (formerly Mount Belches Beds; Griffin, 1989) was considered a stratigraphically late sequence that was part of a belt of post-$D_1$ sedimentary rocks contiguous with and laterally equivalent to conglomerates at Penny Dam on KANOWNA (Ahmat, 1995; Swager, 1995a).

The Yilgarn Craton has been stable throughout the Proterozoic and Phanerozoic. The mafic Widgiemooltha dyke swarm of mostly east-northeast-trending gabbroic dykes intruded the region at about 2420 Ma (Nemchin and Pidgeon, 1998). Mesoproterozoic continental collision thrust granitic and gabbroic rocks of the Fraser Complex over the southern margin of the Yilgarn Craton at

* Aerial photographs are available from the Western Australian Department of Land Administration (DOLA).

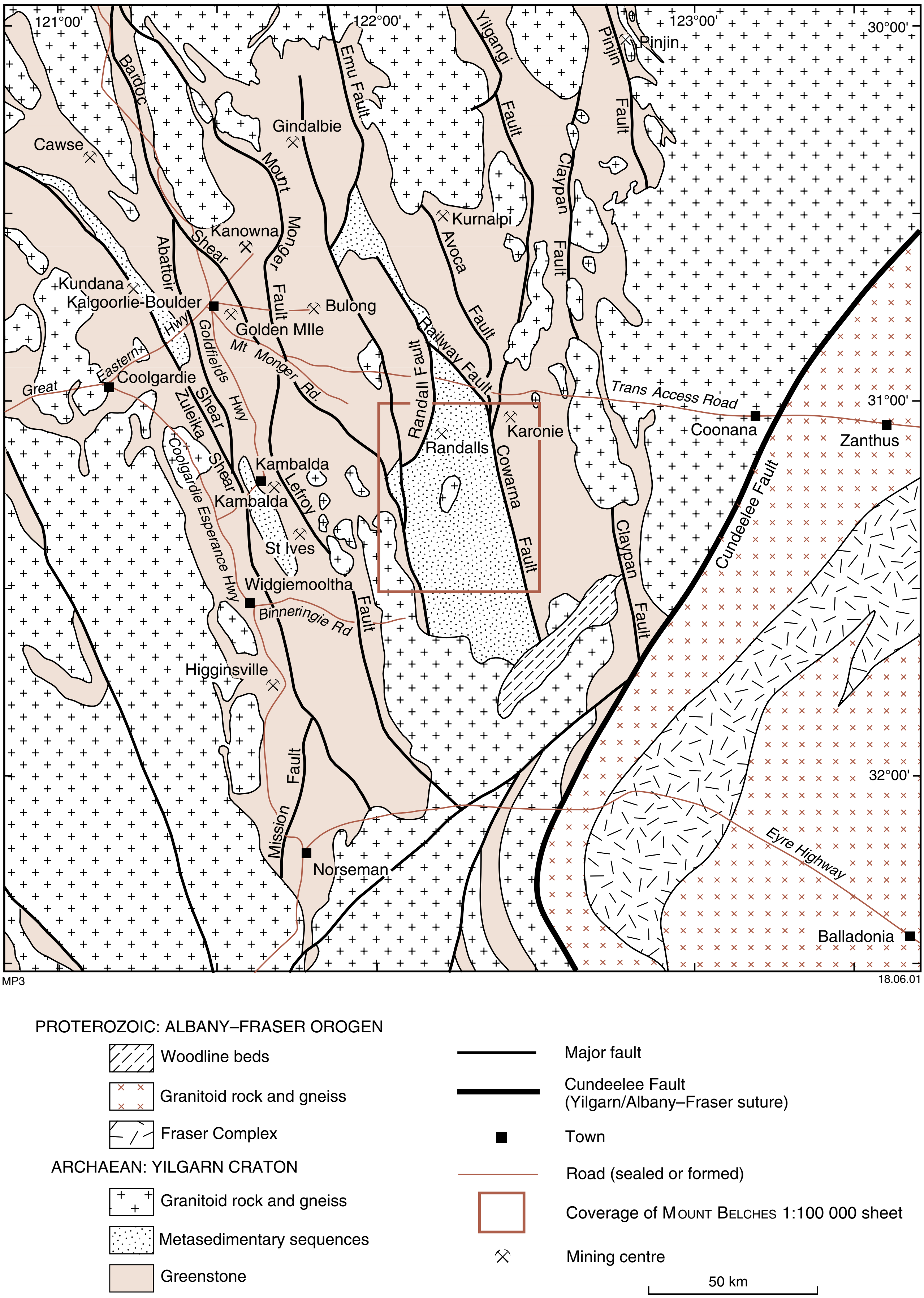


**Figure 2. Regional geological setting of MOUNT BELCHES**

**Table 1. Summary of the geological history of MOUNT BELCHES**

| *Age (Ma)* | *Randall Dome* | *Gindalbie, Mulgabbie, and Parker domains* |
|---|---|---|
| c. 2705[(a)] | | Deposition of komatiitic basalt synchronous with intrusion of layered mafic to ultramafic sills |
| c. 2675[(a)] | Deposition of Mount Belches Formation ?$D_1$: Intrusion of pre-$D_2$ granitoid into Mount Belches Formation, hornfelsing ($M_1$), development of layer-parallel foliation | Deposition of felsic volcanic and volcaniclastic rocks $D_1$ — thrust stacking and recumbent folding |
| 2675–2660[(b)] | *$D_2$ — upright east–west compression* | |
| | Development of chevron folds | Development of the Bulong Anticline and Miller Dam Syncline |
| | *$M_2$ — peak regional metamorphism* | |
| | Mid-amphibolite facies | Lower greenschist to lower amphibolite facies |
| 2660–2640[(b)] | *$D_3$ — transpression, net sinistral shear on regional faults* | |
| | Reorientation of $F_2$ axes during relative uplift of the Randall Dome | Warping of $F_2$ axes, drag folds adjacent to major faults |
| 2650–2630[(b)] | *$D_4$ — oblique faulting* | |
| | Brittle vein structures at Randalls and Karnilbinia, synchronous with gold mineralization | Minor faults crosscutting regional faults |
| | *Gold mineralization* | |
| c. 2420[(c)] | Intrusion of the Widgiemooltha dyke swarm, associated hornfelsing ($M_3$) | |
| c. 1210[(d)] | Intrusion of the Fraser dyke swarm | |
| <200[(e)] | Uplift, erosion, development of palaeodrainage, ?laterite development | |
| 50–38[(e)] | Block tilting, deposition of the Eundynie Group in palaeodrainage channels, ?laterite development | |
| 38–present | Uplift, erosion, laterite development | |

**NOTES:** (a) Nelson (1995)
(b) Swager (1997) and references therein
(c) Nemchin and Pidgeon (1998)
(d) Wingate et al. (2000)
(e) Clarke (1994)

about 1300 Ma (Myers, 1985; Condie and Myers, 1999). This allowed deposition and deformation of the Woodline beds (Griffin, 1989) southeast of MOUNT BELCHES (Fig. 2), and intrusion of the Fraser dyke swarm of northeast- to north-northeast-trending mafic dykes within 100 km of the suture at around 1210 Ma (Wingate et al., 2000).

Pre-Jurassic palaeodrainage channels were flooded in the Palaeocene by marine transgressions that deposited the largely fluviodeltaic and estuarine Eundynie Group (Clarke, 1994). Deep weathering in a humid climate combined with cratonic stability has contributed to the development of extensive laterite profiles. Semi-arid conditions throughout most of the Neogene and Quaternary enhanced development of playa lakes and their associated dune systems in the lowlands defined by the palaeodrainage channels (Griffin, 1989; Clarke, 1994).

# Precambrian geology

Most outcrops on MOUNT BELCHES are Archaean. Several distinct, fault-bounded rock packages define tectono-stratigraphic domains on MOUNT BELCHES (Fig. 3). A central northerly trending belt up to 30 km in width comprises sedimentary rocks of the Mount Belches Formation and is defined here as the Randall Dome (see **Structure and metamorphism**). Mafic to ultramafic igneous rocks predominate in the northwest (Bulong Anticline of the Gindalbie domain) and northeast (Mulgabbie domain). Sequences comprising mafic igneous rocks, sedimentary rocks, and minor felsic volcanogenic rocks are poorly exposed in the central west (Parker domain), central east, and southeast (Mulgabbie domain). Unlike most regions of the Eastern Goldfields, granitoids constitute only a small proportion of the map sheet, mostly in the southwestern corner. Several

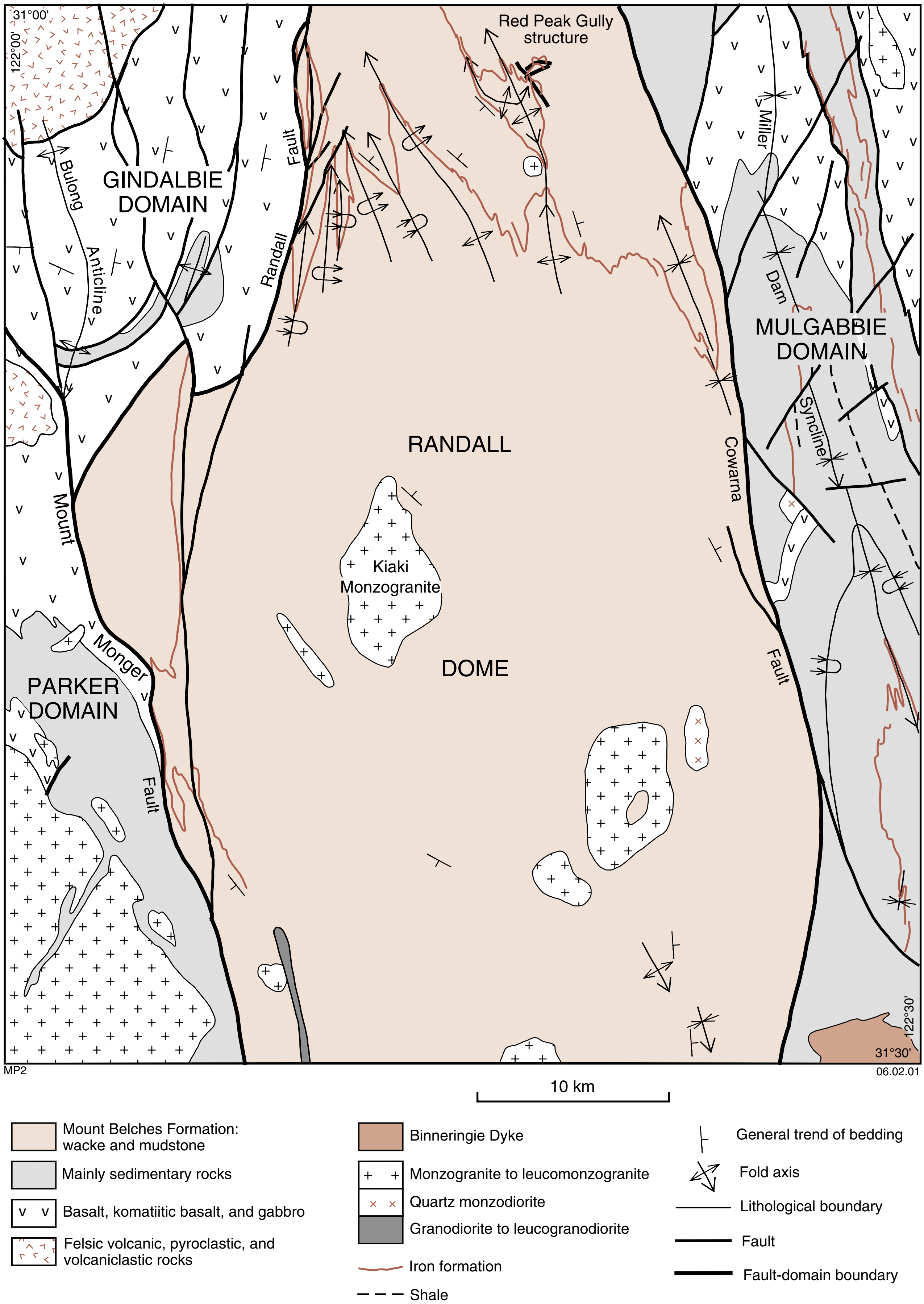


**Figure 3. Interpreted Precambrian geology of Mount Belches, including major faults and tectonostratigraphic domains**

granitoids are associated with hornfelsing and possibly metasomatism of the Mount Belches Formation, and the presence of a large granitoid intrusion beneath the Randall Dome is inferred. Proterozoic rocks are represented by volumetrically minor, unmetamorphosed mafic dykes. Most Precambrian rocks on MOUNT BELCHES are deeply weathered and mantled by regolith.

# Stratigraphy and correlations

The three greenstone domains on MOUNT BELCHES (Gindalbie, Parker, and Mulgabbie domains) and the newly defined Randall Dome contain discrete packages of rock that are bound by regional scale fault systems. Broad-scale stratigraphic correlations have been drawn through each of these domains and they share similar structural and metamorphic histories (Nelson, 1997; Swager, 1997).

## Greenstone sequences

In the Bulong Anticline of the Gindalbie domain, Hickman (1986) described the stratigraphic succession as a 'felsic unit' overlain by a 'mafic unit'. Sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon age dating on KANOWNA and KURNALPI (Nelson, 1995) allowed recognition that younger felsic volcanic and volcaniclastic rocks (2672 ± 12 Ma) are overlain by older basalts and layered intrusions (2705 ± 4 Ma). Swager (1995a) inferred a thrust fault at this contact, consistent with the strong foliation and the broad $F_2$ folding of this foliation on the contact between the felsic rocks and the mafic rocks in the Bulong Anticline. Although faulting was not inferred at the time, Hickman (1986) considered the contact between the felsic and mafic rocks to be important in the localization of gold mineralization in the Bulong Anticline on MOUNT BELCHES and LAKE LEFROY.

In the Mulgabbie domain, the stratigraphy is poorly constrained because younging indicators and contacts are very rare. Basalts with rare gabbroic and ultramafic subunits are interpreted to be overlain by a sequence of predominantly sedimentary rocks. In the southeast, younging indicators reveal that the sedimentary package is overturned, contrasting with normal indicators in the central east and suggesting nappe folding of the sequence prior to east–west compression. The contact between the volcanic- and sedimentary-dominated sequences is not exposed.

Mafic, ultramafic, felsic, and sedimentary rocks of the Parker domain are very poorly exposed. No stratigraphy could be determined on MOUNT BELCHES.

## Mount Belches Formation, Randall Dome

The relationship between the Mount Belches Formation (Appendix 2) and adjacent greenstone sequences is obscured by a basal intrusive contact and by the faulted limits to its upper and lateral extent. The presence of felsic volcaniclastic (Griffin, 1989), granitic (Dunbar, 1966), and mafic clasts in pebble lags and mass-flow units indicates that the Mount Belches Formation is stratigraphically above at least some of the mafic and felsic units and granitoids of the southern Eastern Goldfields.

A distinct stratigraphy for the entire Mount Belches Formation cannot be established using present data, largely due to poor exposure. North of Lake Randell, the lowermost unit of a local stratigraphy (Fig. 4) is dominated by wackes with subordinate graded wacke–mudstone units. This is overlain by the Santa Claus Member (Appendix 2), in which graded wacke–mudstone and mudstone units are interbanded with up to three units of cherty banded iron-formation (BIF). Immediately above and below the cherty BIF units, graded wacke–mudstone units are magnetitic, and it is these units that give the Santa Claus Member its highly magnetic signature. Above the Santa Claus Member, non-magnetic wackes give way to graded wacke–mudstones, then mudstones, over a stratigraphic thickness of up to 150 m. Above this, exposure deteriorates and continuity is uncertain. The thickest continuous sequence, located on the western limb of the main anticline through Randalls mining centre, is about 2500 m in true thickness, which represents a minimum thickness for the Mount Belches Formation (assuming no structural duplication in the wackes below the Santa Claus Member). Dunbar and McCall (1971) suggested a total stratigraphic thickness of about 3600 m.

Correlation of this stratigraphy south of Lake Randell is difficult because no distinct marker unit such as the Santa Claus Member can be recognized. Several BIF and chert horizons, however, may be laterally equivalent to this unit. If the BIF south of Lake Randell on the western side of Randall Dome is a fragment of the Santa Claus Member, then the enclosing sedimentary rocks are more pelitic than their lateral equivalents north of the lake. Here, mudstones are overlain by graded wacke–mudstones before the sequence is truncated by the Mount Monger Fault. On the eastern side of Randall Dome, a similar succession adjacent to the Cowarna Fault comprises graded wacke–mudstones that give way to an approximately 300 m-thick unit of mudstones that contains isolated chert units, again a possible Santa Claus Member correlative. At this locality, mudstones are also overlain by graded wacke–mudstones that are truncated by the Cowarna Fault. Graded wacke–mudstones characterized by metamorphic staurolite south of the abandoned Madoonia Downs Homestead site (MGA 393207) represent iron-rich turbidites. These may be a lateral equivalent to the Santa Claus Member in an area of higher sediment load and diluted iron content, but the staurolitic zone is localized, and no mudstone horizon encloses it.

Whereas Ahmat (1995) and Swager et al. (1995) suggested that the Penny Dam conglomerate (on KANOWNA and GINDALBIE) and the Mount Belches Formation are laterally equivalent units, the findings of this study indicate that such a relationship is unlikely. The Mount Belches Formation contains evidence of pre-$D_2$ deformation, which is absent from the Penny Dam conglomerate (Swager, 1995a; see **Structure and metamorphism**). Secondly, the Penny Dam conglomerate grades south-

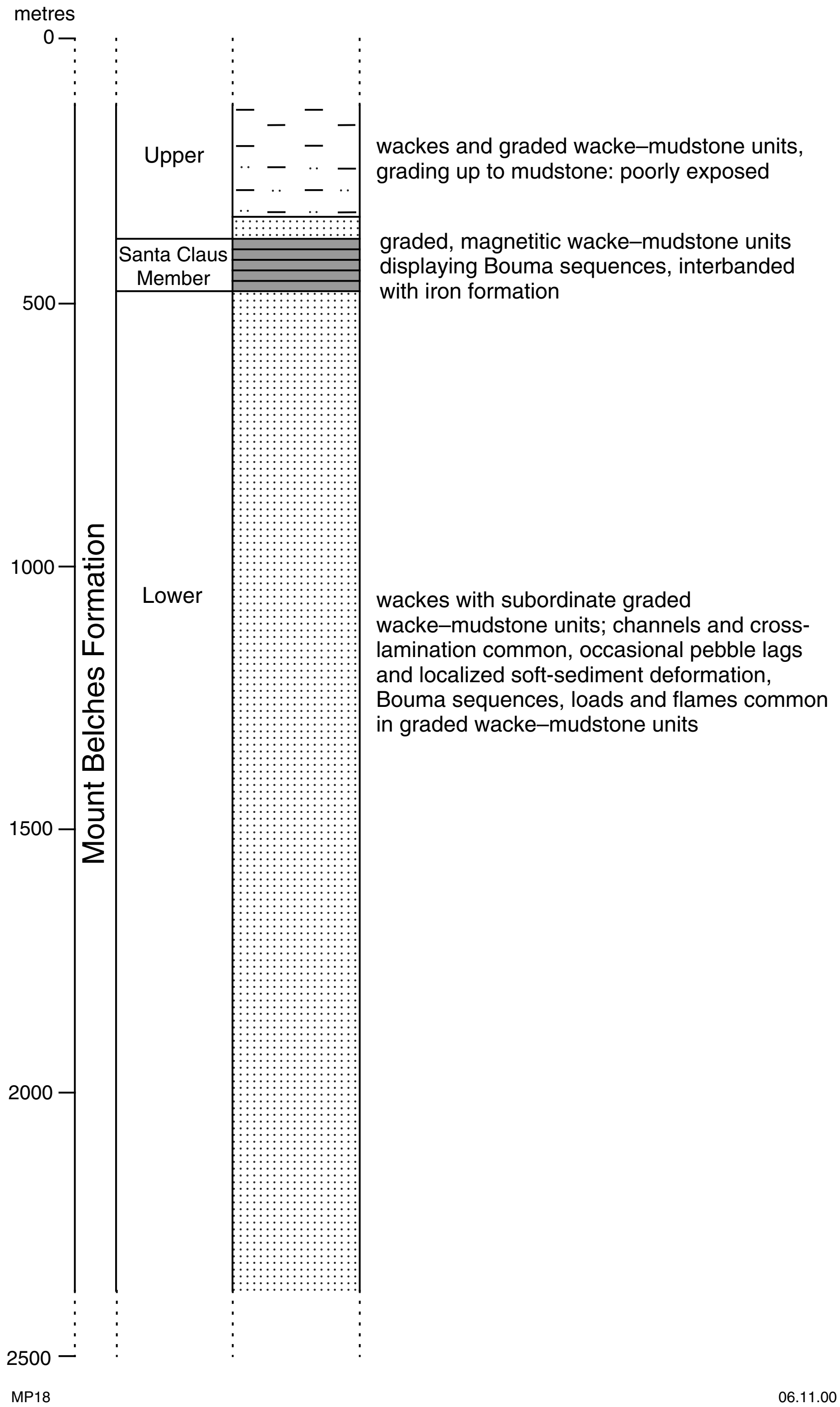


**Figure 4. Stratigraphy of the Mount Belches Formation north of Lake Randell**

wards and laterally into quartz-rich sandstones at Gundockerta Hill on KURNALPI. Although complex facies relationships could account for such a relationship, a direct lateral transition from conglomerate through relatively clean quartz sandstone and into the flysch-facies wackes of the Mount Belches Formation is unlikely. Unfortunately, exposure is absent for about 20 km between Gundockerta Hill and the northernmost exposures of the Mount Belches Formation (Swager, 1993, 1994), and aeromagnetic signatures are suppressed. Thirdly, palaeocurrent indicators suggest a northerly provenance on the western limbs and a southerly provenance on the eastern limbs of steeply plunging anticlines — unfolding of the sequence shows that palaeocurrents were sourced from the east. Given these structural and sedimentological discrepancies, a petrogenetic relationship between the Mount Belches Formation and the Penny Dam conglomerate is unlikely. The Mount Belches Formation is therefore either faulted out south of Gundockerta Hill or the Penny Dam conglomerate and associated sandstones unconformably overlie the Mount Belches Formation.

The lack of a relationship between the Mount Belches Formation and the Penny Dam conglomerate, by corollary, counters a relationship with the other late sedimentary sequences (Merougil beds, Kurrawang Formation, Yilgangi conglomerate), whether inferred as a dismembered flysch/molasse basin (Dunbar, 1966; Krapez et al., 1997), or as individual basins behind the hinges of roll-over anticlines (Swager, 1997). Other features peculiar to the Mount Belches Formation that are not recorded in these other sedimentary sequences, and which cannot be used as correlative evidence but are interesting to note, include amphibolite facies metamorphism (see below), the presence of iron formation, gold mineralization, a broad extent (up to an order of magnitude greater than these other sedimentary sequences), absence of conglomerate, and abundance of turbiditic rocks. It can be speculated that the Mount Belches Formation represents a lateral, clastic-dominated equivalent of the upper strata of the felsic volcanic and volcaniclastic Black Flag Formation (also commonly of turbiditic affinity; Swager et al., 1995) near Kalgoorlie. Alternatively, the formation may represent an otherwise absent sequence unconformably overlying the felsic volcaniclastic rocks. Pre- to syn-$D_1$ basin development for the Mount Belches Formation would explain both the presence of pre-$D_2$ structures and of rare mafic, felsic, and granitic clasts.

# Archaean rock types

## Metamorphosed ultramafic rocks (*Au, Auk, Aup, Aus, Aux*)

Most ultramafic rocks on MOUNT BELCHES outcrop in the Bulong Anticline, with minor exposures in the Trig Hills and Roe Hills in the northeast. Undivided ultramafic rocks (*Au*) are typically deeply weathered, so their protoliths cannot be determined with certainty. These are locally associated with 'silica caprock' in which a relict cumulate texture fabric is recognizable in some areas.

Komatiite (*Auk*) is not exposed on MOUNT Belches, but has been identified from percussion drillchips south of Lake Randell (MGA 098376). The rock comprises fine-grained serpentinite with distinctive, bladed, olivine-spinifex texture.

Peridotite (*Aup*) in the Roe Hills (MGA 512577) and locally in the Bulong Anticline is altered and weathered to an assemblage largely consisting of talc, carbonate, and serpentine, but cumulate textures are commonly preserved. Cumulate phases were largely olivine with lesser amounts of orthopyroxene and clinopyroxene. The association of cumulate-textured metaperidotite with coarse-grained pyroxene spinifex-textured komatiitic basalt in the Roe Hills suggests a ponded lava-flow origin similar to the komatiites, peridotites, and dunites near Bulong on KANOWNA (Ahmat, 1995). Igneous compositional variations within this peridotite provides evidence for west to east igneous fractionation and thus way-up to the east.

Pyroxenite (*Aux*) is recognized in the Trig Hills (MGA 429681), and locally in the Bulong Anticline as basal units to gabbros or komatiitic basalt flows (Williams, 1972; Hickman, 1986). Pyroxene has been replaced by metamorphic amphibole (tremolite, actinolite, or hornblende), and minor talc and chlorite. Pyroxenes locally display cumulate textures. Plagioclase, kaolinized by weathering, is subordinate and interstitial to the pyroxenes.

Serpentinite (*Aus*) in the Trig Hills (MGA 428670) is massive, fine grained, and dark coloured in outcrop. Petrological examination reveals an assemblage of serpentine, carbonate, talc, ?tremolite, and magnetite with relict cumulate textures of olivine and pyroxene, indicating a peridotite protolith. In the Bulong Anticline, Williams and Hallberg (1973) found most serpentine to be antigorite, and argued that this was generated through the metamorphism of lizardite formed by hydrothermal alteration following deposition or intrusion of ultramafic rocks. Serpentinite is susceptible to strain focusing and, where foliated, is deeply weathered and poorly exposed.

Where associated with gabbro, ultramafic units (*Au*, *Aux*, *Aup*, *Aus*) may form part of a compositionally layered sill or flow. Such units have been coded separately where recognized on MOUNT BELCHES, such as those of the Seabrook Sill (*AaSEx, AaSEp*; see below). These have similar textures to the ultramafic rocks described above, but are described below in the context of the related rock units.

## Metamorphosed fine-grained mafic rocks (*Ab, Aba, Abf, Abm, Abv, Abve*)

Mafic extrusive rocks metamorphosed at upper greenschist to lower amphibolite facies constitute the bulk of the greenstones of the Bulong Anticline in the northwest of MOUNT BELCHES and the Roe, Low Trap, and Trig hills in the northeast. Undivided massive mafic rock (*Ab*) is fine to medium grained and moderately weathered. Foliated variants of these (*Abf*) are common in the Low Trap and Roe hills. Textures indicative of an extrusive nature, such as amygdales and flow-top breccias, are rare but widespread in these lithologies. The major foliation recorded is that of the northerly trending $S_2$ fabric, and the intersection of this foliation with primary layering commonly defines a moderately southward-plunging, pencilled outcrop style (Fig. 5). At the northwest limit of the Roe Hills, strongly foliated, very fine grained mafic rock, which superficially resembles argillaceous meta-sedimentary rock, contains millimetre-scale quartz–carbonate segregations that are most likely amygdales. Mineralogically, metabasites typically comprise a very fine grained felted mass of chlorite, with hornblende and plagioclase and less common quartz.

Basalt (*Abv*) is fine grained and commonly has features indicative of an extrusive origin, such as elongate amygdales, pillows, and interlayered sedimentary rocks. Metamorphosed basalts typically comprise an assemblage of very fine grained chlorite, amphibole (commonly hornblende or actinolite), or both with subordinate

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**Figure 5. Pencilled outcrop style in foliated mafic rock (*Abf*), Low Trap Hills (MGA 440688), probably representing bedding-foliation intersection. This lineation is interpreted to parallel the plunge of the Miller Dam Syncline**

plagioclase and quartz. At only one locality on an island in the west of Lake Randell are such basalts significantly epidotized (*Abve*; MGA 053513). The epidotization varies from veined and patchy to massive, and occurs where the basalts are intruded by a hypabyssal rock of dacitic composition (see **Metamorphosed felsic volcanic and volcaniclastic rocks**).

Komatiitic or high-Mg basalt (*Abm*) is distinguished by common pyroxene spinifex texture and less common variolitic texture. Pillows occur locally. Komatiitic basalt constitutes the bulk of the Bulong Anticline in the northwest of MOUNT BELCHES and is interbanded with basalt (*Abv*) at a small outcrop in the central west (MGA 067423). Throughout the Roe Hills, komatiitic basalt is present as thin layers within foliated mafic rock (e.g. MGA 512600) and as a larger, possibly ponded, flow unit north-northeast of Powder Dam (MGA 495695). In the Trig Hills west of Eastern Dam, komatiitic basalt is associated with a massive serpentinite (MGA 426672). Pyroxenes are pseudomorphed by acicular amphibole (commonly tremolite), whereas the groundmass typically comprises a felted mass of chlorite.

Amphibolite (*Aba*) represents the medium- to high-grade metamorphism of fine-grained mafic rocks. The protolith cannot be determined with certainty, but a gradation into basalt is locally evident, such as at Round Hill (MGA 461423). A chlorite–hornblende–plagioclase(–quartz) assemblage is common. Hornblende and less commonly actinolite are replaced by chlorite and plagioclase.

Thin interleaved units of basalt with subordinate dolerite (*Abf*) and gabbro (*Aog*) probably represent thick lava flows in which differentiation occurred. About 7 km east of Cowarna Downs Homestead, several strike ridges correspond to foliated gabbroic bands. Foliated basalt is exposed in the valleys between the ridges. Cumulate textures are preserved locally in the coarser fractions, but the original mineralogy has largely been destroyed by metamorphism. Orientation of the subunits suggests younging to the west.

A series of differentiated mafic to ultramafic volcanic rocks are exposed in a ?$D_1$ fold structure in the Bulong Anticline (MGA 152590), southeast of Peters Dam. They grade from pyroxenite (*Aux*), through gabbro and microgabbro (*Aog*), to massive then variolitic high-Mg basalt (*Abm*) at the top. Much of the basalt has a grainy appearance that probably represents original fine-grained phenocrysts in the flow. The uppermost portions of each flow contain varioles that increase in abundance from sparse several metres below the uppermost contact, to abundant at the contact. The presence of varioles suggests either an extrusive or shallow intrusive origin, but the completeness and lack of truncation of the gradation in variole content in two vertically adjacent units is more compatible with lavas than sills. This sequence defines a younging direction to the northeast. Similar layering is exposed in sheared komatiitic basalt (*Abm*) on a peninsula into Lake Randell (MGA 168518), where relict pillows are discernible and indicate younging to the south. The flows are of the order of metres thick, rendering the differentiation too fine to depict at 1:100 000 scale.

## Layered mafic to ultramafic intrusions

### Seabrook Sill (AaSEo, AaSEx, AaSEp)

Williams (1971, 1972) and Williams and Hallberg (1973) described in detail the geology of the layered intrusions of the Eastern Goldfields, including those of the Seabrook Hills. The Seabrook Sill (MGA 124670) intrudes komatiitic basalt (*Abm*), and is considered a high-level, ultramafic to mafic, layered intrusion that contains a well-developed differentiation sequence from harzburgite, through orthopyroxenite, norite, norite–gabbro and gabbro, to rare anorthosite and granophyre (Williams, 1972). Primary mineral assemblages have been almost entirely destroyed by serpentinization, metamorphism, or both, but original textures are preserved. Ultramafic rocks now largely comprise an assemblage of serpentine, tremolite, talc, chlorite, and actinolite. Mafic rocks consist of an assemblage of tremolite, chlorite, saussuritized plagioclase, and titanite (Williams, 1971, 1972; Williams and Hallberg, 1973). On MOUNT BELCHES, three units have been distinguished: peridotite, pyroxenite, and gabbro.

Gabbro (*AaSEo*) forms the uppermost layer recognized in the Seabrook Sill. Relict euhedral pyroxenes occur locally in these units. Overall, plagioclase content increases upwards through the gabbroic unit. Williams (1972) recognized a poorly exposed granophyric top to the Seabrook Sill, but this was not located in the current mapping. Pyroxenite (*AaSEx*) lies between peridotite and gabbro in the Seabrook Sill. Cumulate texture is common. Pyroxenite typically comprises cumulus orthopyroxene with intercumulus plagioclase, with a higher plagioclase content in more noritic horizons. Peridotite (*AaSEp*), commonly altered to a talc–carbonate assemblage, forms the basal unit of the differentiation sequence in the Seabrook Sill. There are cumulate textures, similar to those in other peridotites (*Aup*), throughout. Several peridotite units intruding komatiitic basalt stratigraphically below the main part of Seabrook Sill (e.g. 2 km east of Hard To Find Dam; MGA 110668) contain weak differentiation trends and are considered by Williams (1972) to be lenses of the Seabrook Sill, although repetition of a single peridotite unit by faulting is another possibility.

Williams and Hallberg (1973) suggested, on the basis of bulk geochemical similarities (Table 2), that the Seabrook Sill is comagmatic with the komatiitic basalts of the Bulong Anticline that it intrudes.

**Table 2. Geochemical comparison of the Seabrook Sill and host komatiitic basalts**

| | *Seabrook Sill bulk* | *Komatiitic (high-Mg) basalts, Seabrook Hills* 1 | 2 | 3 |
|---|---|---|---|---|
| | **Weight percent (%)** | | | |
| $SiO_2$ | 50.9 | 49.4 | 49.1 | 51.2 |
| $TiO_2$ | 0.34 | 0.48 | 0.46 | 0.52 |
| $Al_2O_3$ | 12.4 | 11.2 | 10.0 | 10.2 |
| FeO(total) | 9.3 | 9.9 | 9.6 | 10.0 |
| MnO | 0.16 | 0.16 | 0.22 | 0.17 |
| MgO | 16.7 | 14.1 | 17.0 | 17.3 |
| CaO | 8.3 | 7.9 | 11.8 | 8.6 |
| $Na_2O$ | 1.2 | 2.68 | 0.72 | 1.43 |
| $K_2O$ | 0.14 | 0.12 | 0.11 | 0.08 |
| $P_2O_5$ | 0.06 | 0.06 | 0.05 | 0.09 |
| Total | 99.50 | 96.00 | 99.06 | 99.59 |

**SOURCE:** Williams and Hallberg (1973)

### Oak Hill Sill (AaOHo)

The Oak Hill Sill is located in the core of the Bulong Anticline. It takes its name from the prominent exposure at Oak Hill. Relict cumulate textures are developed in gabbro (*AaOHo*). An ultramafic basal unit was not recognized.

The Oak Hill Sill has previously been referred to as the 'Mount Monger East Sill' (Swager and Griffin, 1990). The inference from their interpretation is that this sill is a faulted fragment of the Mount Monger Sill. Hickman (1986) inferred a possible link with the Seabrook Sill. Current mapping shows that the sill is truncated by faults at both ends, and it seems unlikely from aeromagnetic data that it is the continuation of the Mount Monger Sill.

### Mount Monger Sill (AaMMo)

The Mount Monger Sill is well-exposed on LAKE LEFROY to the west, with only its easternmost extremity exposed on MOUNT BELCHES (MGA 614050). Gabbro in this sill (*AaMMo*) locally displays relict cumulus plagioclase and amphibole after pyroxene. On LAKE LEFROY to the west, pyroxene spinifex texture is present in gabbro near the top of the lower lens of the Mount Monger Sill at Mount Monger (as depicted in Williams and Hallberg, 1973).

Near Mount Monger, the Mount Monger Sill displays a full compositional gradation from a lower peridotite unit, through a pyroxenite unit and into gabbro (Williams and Hallberg, 1973). On MOUNT BELCHES, only the gabbroic portion of this series is exposed. Swager and Griffin (1990) referred to this sill as the 'Mount Monger West Sill' on the presumption that it represented only a portion of a larger, faulted sill. Data collected during this mapping suggest that this is not likely (see above), so the original name is applied.

## Metamorphosed mafic intrusive rocks (*Aog*)

Gabbro (*Aog*) is a medium-grained mafic rock type with relict igneous texture. Ophitic and subophitic textures are commonly preserved and cumulate textures are locally present. Original pyroxene is replaced by metamorphic amphibole (commonly hornblende) or chlorite, depending on the grade of metamorphism. Plagioclase is commonly saussuritized. In the Bulong Anticline, most gabbro units are oriented parallel or subparallel to layering. This, combined with locally recognizable igneous fractionation, indicates that the gabbros are either sills or parts of differentiated mafic flows. Larger sills from this area have been named and are described above. Gabbro adjacent to ultramafic or basaltic units may represent compositional layering within the sills or flows. Gabbro units in the Low Trap Hills (MGA 420622) are attenuated, which may reflect structural disruption (?boudinage).

## Metamorphosed felsic volcanic and volcaniclastic rocks (*Af, Afdp, Afi, Afs*)

Metamorphosed felsic volcanic and volcaniclastic rocks are uncommon and poorly exposed on MOUNT BELCHES. Undivided felsic rocks of volcanogenic origin (*Af*) are deeply weathered on MOUNT BELCHES and are only poorly exposed in the middle of the western side of the sheet (MGA 102350). The deeply weathered schist subcrop contains quartz eyes that may represent phenocrysts. Similar lithologies are present on LAKE LEFROY (Griffin and Hickman, 1988) to the northwest of this exposure.

Porphyritic dacite (*Afdp*) is exposed on an island in Lake Randell on the western margin of MOUNT BELCHES (MGA 052512). Phenocrysts include zoned and pericline-twinned albite (partially sericitized) and hornblende, with less common actinolite (probably after pyroxene) and titanite. Uncommon, poorly developed granophyric textures are also present. The groundmass comprises very fine grained quartz and feldspar (?albite and ?orthoclase) that probably represent devitrified glass. Epidote occurs as veins and partial replacements of mafic minerals. An intrusive contact with adjacent epidotized basalt is exposed, and epidotized basaltic xenoliths are locally common. Banding defined by albite phenocryst concentrations is present. Consideration of field and petrological characteristics suggests that the porphyritic dacite is hypabyssal.

Undivided intermediate rocks of volcanogenic origin (*Afi*) are located in the northwest corner of MOUNT BELCHES (MGA 055690). Their composition varies from andesitic to dacitic, and the rocks are schistose and deeply weathered.

Sheared felsic rocks of volcanogenic origin (*Afs*) outcrop in the core of the Bulong Anticline in the northwest corner of MOUNT BELCHES. Graded bedding is present, suggesting that the units are either pyroclastic or epiclastic rocks. Williams (1972) recorded rhyolite units west of the Seabrook Hills, but Hickman (1986) noted that these are subordinate in abundance to the volcaniclastic rocks. Most exposures are moderately to strongly schistose, particularly near the contact with the overlying mafic and ultramafic rocks.

## Metasedimentary rocks (*As, Asbi, Ash, Asq, Ac, Aci*)

Metasedimentary rocks are deeply weathered and are the most abundant lithologies on MOUNT BELCHES. Those rocks exposed in the Randall Dome are distinct, and have been grouped as the Mount Belches Formation, which is described separately below. Other metasedimentary rocks, which constitute subordinate proportions of the domains outside the Randall Dome, are described here.

Undivided sedimentary rocks (*As*) are typically lateritized and include metamorphosed mudstone to siltstone to fine-grained sandstone. Graded bedding is locally preserved. Local quartz–mica schist is included in this classification because it contains relict sedimentary structures (bedding, grading).

Shale (*Ash*) is exposed at numerous localities (e.g. MGA 495465) and is typically carbonaceous. Bedding and interbeds of coarser lithologies are locally preserved and a slatey cleavage is locally developed. In the Bulong Anticline, supergene silicification of shales blurs the distinction between shale and chert (*Ac*; see below). Hickman (1986) regarded many of these units as quiescent, graphitic and sulfidic interflow sediments. Exposure of many shale units in this area, however, is poor and it is difficult to confirm a truly sedimentary origin for some units. Given their superficial similarity to carbonaceous phyllonite (*Aly*; see below), some of these ‘shales’ could be tectonic in origin.

Quartz-rich sedimentary rocks (*Asq*) are exposed in the southeastern corner of MOUNT BELCHES. The rocks are deeply weathered but bedding and grading is recognized in fresher exposures. Bedding is of thin to medium thicknesses (5 to 100 mm) and comprises basal fine sandstone that grades up to a quartz-rich, dark-coloured siltstone, indicating that at these localities these sedimentary rocks are overturned (Fig. 6). This lithology is similar to the sheared, reworked volcaniclastic rocks (*Afs*) in the northwest, but interbands of felsic volcanic rocks are absent and quartz clasts, which lack characteristic features such as embayments, are probably not of volcanogenic origin.

Intermediate to mafic schist (*Asbi*) has been included in the metasedimentary rocks because rare examples of bedding and interlayering with more felsic sedimentary units are present. Intermediate to mafic schist is very poorly exposed in the southwest quadrant of MOUNT BELCHES, and comprises foliated quartz–chlorite siltstone, chlorite and quartz–chlorite schist, and less common interbands of quartz–muscovite schist. Sporadic exposures of the intermediate to mafic schists are present between porphyritic dykes in southwestern MOUNT BELCHES (*Agpsi*; see **Granitoid rocks**). Precursor lithologies may have been intermediate volcaniclastic rocks or their reworked equivalents. Some of these rocks could also represent sheared variants of metasomatically altered rocks of the Mount Belches Formation (*Asba*).

Chert (*Ac*) is common in the Bulong Anticline but is rare elsewhere on MOUNT BELCHES. One unit consists of thin white bands of chert finely interbedded with mudstone. These chert units probably represent quiescent chemical sedimentation, but Hickman (1986) recognized that most chert units in the Bulong Anticline represent supergene silicification of graphitic and sulfidic shales. Chert units vary from white to grey, may be massive or banded, and contain variable proportions of iron oxides. Only when iron-oxides predominate is the unit classified as BIF (*Aci*). The Santa Claus Member (*Asbn*; see below) of the Mount Belches Formation forms the most prominent iron formation on MOUNT BELCHES, and minor BIF units within the Randall Dome south of Lake Randell


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**Figure 6. Overturned, thinly bedded, quartz-rich metasedimentary rocks (*Asq*; looking north), northeast of Dog Lake (MGA 500235). Inverted beds grade from fine sandstone (light grey) to mudstone (dark grey); younging is toward the bottom-right of the picture**

are probably its lateral extension. Elsewhere, BIF is restricted to minor units in metabasalt sequences in the Trig Hills (MGA 435682) and Bulong Anticline (MGA 141575), and to the southeast corner of MOUNT BELCHES where it is interbanded with quartz-rich sedimentary rocks (MGA 516245). Banded iron-formation comprises predominantly magnetite and chert with subordinate hematite, jasper, and ferruginous shale. Banding is commonly obscured by supergene iron oxides that coat the surface of an outcrop, giving it a dark, massive appearance.

### *Mount Belches Formation (Asb, Asbm, Asbn, Asbw, Asbwm, Asba, Asbh)*

The Mount Belches Formation, a distinct package of metamorphosed, multiply deformed wackes and mudstones, is the most extensive unit on MOUNT BELCHES. Fresh exposures are common in the low hills between the north shore of Lake Randell and the Randalls (MGA 250650) and Karnilbinia (MGA 225625) mining centres. Platforms on the northern and western shores of many lakes provide excellent exposures, in which sedimentary structures and features are preserved in fine detail. In the northern parts of many lakes, aerial photography has been used to trace bedding and folding geometries where a thin veneer of lacustrine mud mantles fresh to weathered platforms of the Mount Belches Formation ($L_l$/*Asb*).

Undivided Mount Belches Formation (*Asb*) is typically poorly exposed and deeply weathered. It comprises varying proportions of metamorphosed wacke and mudstone, with rare BIF and pebbly sandstone beds. Metasomatized variants are locally preserved, and deeply weathered phyllitic (to schistose) variants are common in the low hills south of Lake Randell. Tabular kaolinitic clots after mica (biotite) or andalusite commonly distinguish the foliated metasedimentary rocks in deeply weathered exposures, with local hollows after garnet. Sedimentary and tectonic structures are only visible in detail at breakaways and lake shores, although the regional subvertical $S_2$ foliation is widespread.

Mudstones (*Asbm*) are locally dispersed in the Mount Belches Formation, but are only evident as mappable units in the southwest and central east of MOUNT BELCHES. These rocks are fine to medium grained, depending upon the degree of metamorphism. Metamorphosed mudstones are typically biotitic, quartzofeldspathic schists, but chlorite, muscovite, andalusite, sillimanite, staurolite, and garnet locally constitute significant proportions, particularly in the mudstones in the central east of MOUNT BELCHES. Platy minerals locally define bedding-parallel foliation. Grading and parallel lamination are the most common sedimentary structures; cross lamination is present locally. Rare chert is associated with the mudstones. The mudstones are considered indicative of distal or low-energy deposition of fine-grained sediment. Turbidity, traction, and contour currents are probable depositional mechanisms.

The Santa Claus Member iron formation (*Asbn*) is unusual in that it contains only subordinate proportions of cherty BIF; most of the unit is of graded beds in which the pelitic portion is magnetitic (Fig. 7). Bed morphologies are consistent with deposition from a waning current. Whether the iron content is the result of clastic deposition of pelitic iron-rich material or post-depositional induration is not clear. Lithologies present include banded magnetite–quartz rock, magnetitic graded wacke–mudstone units, non-magnetitic graded wacke–mudstone units, and amphibolitic rocks derived by metasomatism (see *Asba* below). Magnetite–quartz rocks are finely laminated, defined by alternating abundances of magnetite and quartz, and contain accessory grunerite, chlorite, and apatite (Dunbar, 1966). Other units are similar to the clastic metasedimentary rocks described above but contain common magnetite, grunerite, and cummingtonite, and accessory epidote and tourmaline (Dunbar, 1966; Newton et al., 1998). The Santa Claus Member is a clear marker horizon that defines distinctive chevron folds north of Lake Randell. Aeromagnetic data reveal that the unit extends beneath Lake Randell to the east and south, and forms complex interference fold patterns in the Red Peak Gully area. To the west, the iron formation is smeared along the Randall Fault and outcrops as a complexly deformed unit at Bare Hill (MGA 203640). Iron formation (*Aci*) further south in the Randall Dome (MGA 139406, 139393, and 164260) is interpreted to be the lateral continuation of the Santa Claus Member, but outcrop is poor and this cannot be confirmed. Here, the unit is thinner than north of Lake Randell and is composed of cherty BIF; no graded iron-formation beds are exposed at these localities.

Wackes (*Asbw*) are the most common mappable lithology of the Mount Belches Formation to the north of Lake Randell (Fig. 4). The metamorphosed wackes are fine to coarse sand in grain size and commonly show graded bedding. Other common sedimentary structures and features include parallel and cross lamination, scours, grading, Bouma sequences, and horizons of soft-sedimentary deformation. Less common sedimentary structures and features include trough cross-bedding, climbing ripples, channels (Fig. 8), reverse grading, pebble lags, intraclasts, and mass-flow plough structures. Many beds have mudstone as an uppermost interval (now composed of medium-grained, neomorphic biotite), although the ratio of mudstone to wacke is typically less than 1:10. Petrographically, large (up to 5 mm) quartz grains are interspersed with biotite clots and commonly poikiloblastic plagioclase, with less common hornblende, chlorite, muscovite, and carbonate, and accessory magnetite, zircon, titanite, and apatite. The wacke was deposited by mass-flow, traction, and turbidity currents in a submarine environment.

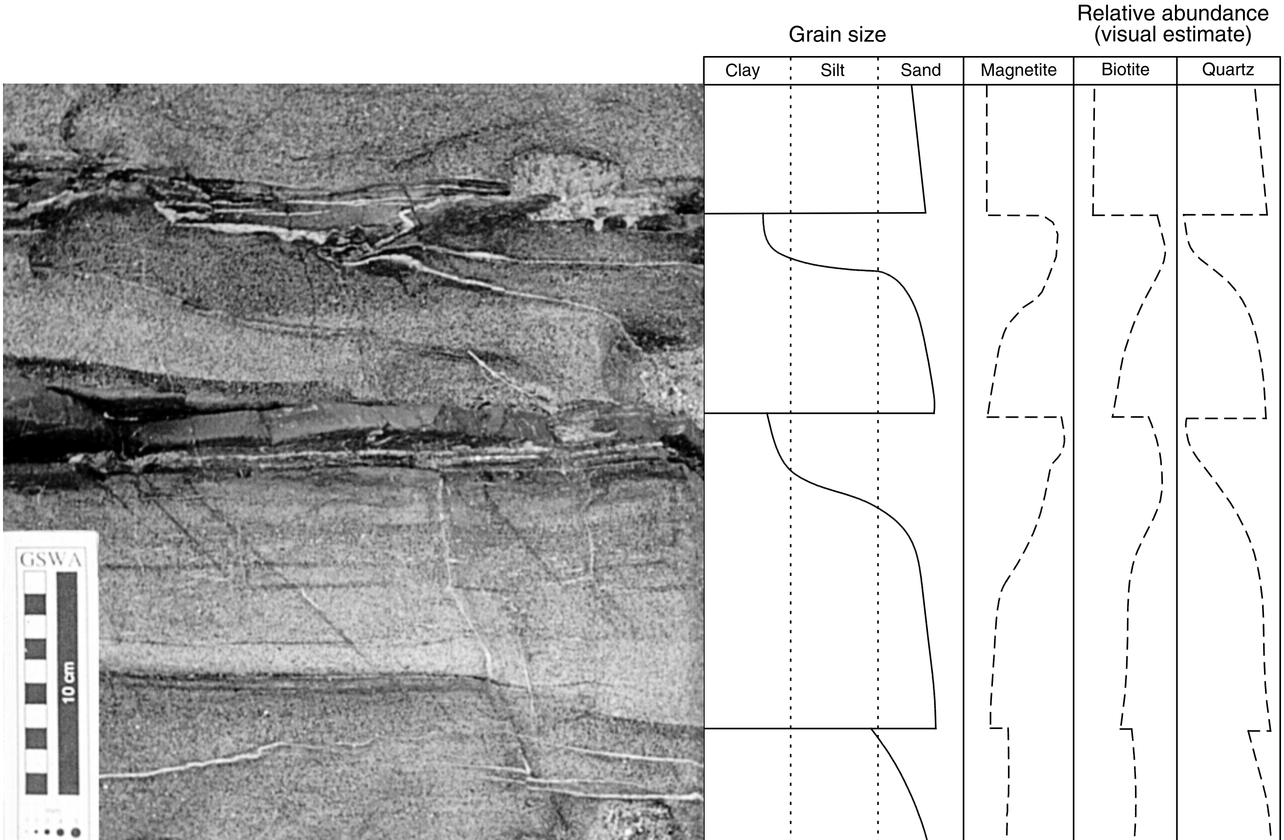


**Figure 7. Graded magnetitic beds, Santa Claus Member, Mount Belches Formation (*Asbn*; Santa Claus Member type locality; MGA 304590). Graphs to the right indicate approximate proportions of major minerals over the thickness of each bed, as estimated from field observations. Magnetite is concentrated in the pelitic portion (dark) of each bed**

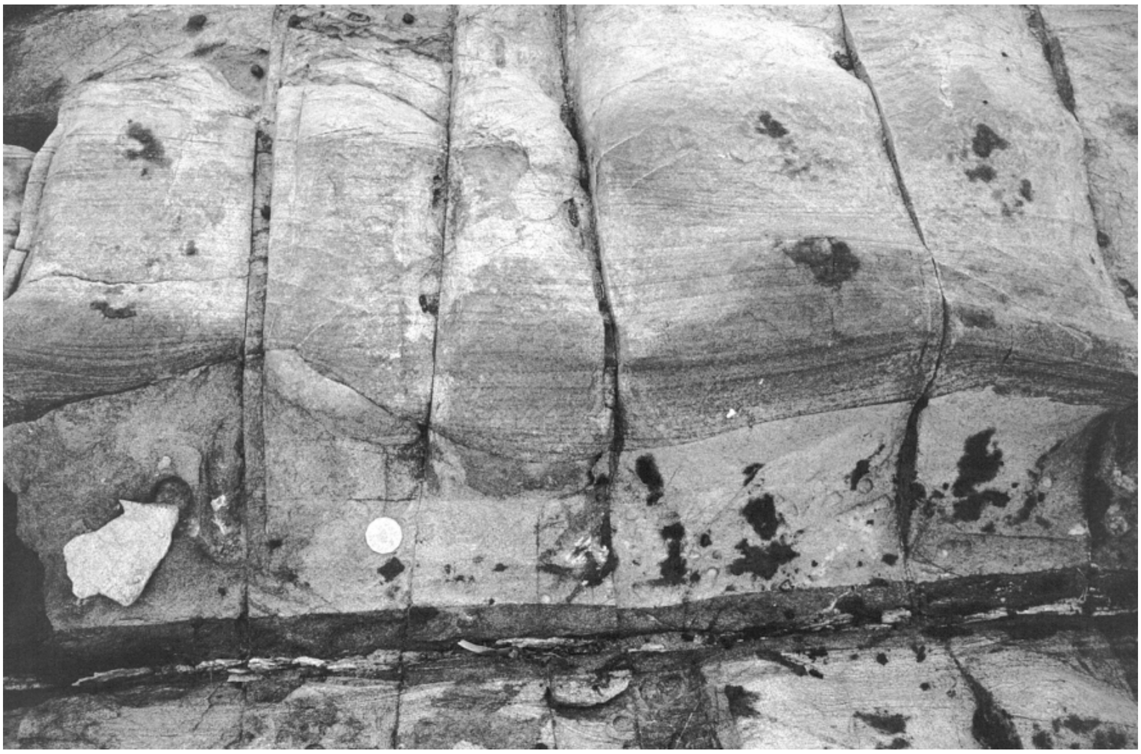
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**Figure 8. Channels in the wacke facies, Mount Belches Formation (*Asbw*; MGA 273575). Coin is 3 cm in diameter**

Graded wacke–mudstone units (*Asbwm*) are exposed locally north of Lake Randell (Fig. 4), but are only evident as mappable entities in the southwest, central east, and southeast of MOUNT BELCHES. Bouma sequences are very common; a complete sequence is commonly preserved, with the base represented by coarse to fine sand-sized, metamorphosed wacke, and the top represented by typically coarser grained metamorphic biotite. Sedimentary structures are abundant, the most common being grading, parallel and cross lamination (Fig. 9), scours, loads, and flames. Starved ripples and climbing ripples are present locally. Soft-sediment deformation and massive, poorly sorted beds with mudstone intraclasts (now biotitic) interrupt the sequence. Rare blind synsedimentary faults with slippage of less than 10 cm are present. Petrographically, the basal wacke portion of the bed is similar to those described above, but the mudstone portion of the bed contains coarse (up to 1.5 mm) blades or clots of neoblastic biotite interspersed with finer grained quartz, plagioclase, chlorite, muscovite, and magnetite, with staurolite, andalusite, and garnet at several localities. The occurrence of the coarse neomorphic biotite (and locally staurolite) commonly gives outcrop the false appearance of reverse grading. The graded wacke–mudstone precursors were deposited by turbidity currents on a submarine slope, with subordinate mass-flow and traction current deposition.

Metasomatized variants of the Mount Belches Formation (*Asba*) have a distinct appearance in outcrop, largely due to the development of a medium- to coarse-grained quartz–Ca-amphibole(–grunerite) assemblage and the lath, rosette or stellate habit of the amphiboles. At Randalls and Karnilbinia mining centres, the iron formation hosts an alteration assemblage of magnetite, cummingtonite–grunerite, hornblende, actinolite, biotite, chlorite, carbonate, and iron sulfides (Newton et al., 1998). Wackes above and below the Santa Claus Member host an alteration assemblage of magnetite, quartz, chlorite, and grunerite, with biotite porphyroblasts and minor Ca-amphiboles and carbonates. These alteration zones are distinguished by amphiboles with a lath or rosette habit and by the interstitial granuloblastic quartz (Newton et al., 1998). Elsewhere on MOUNT BELCHES, such alteration is exposed at a variety of scales. At Dog Lake (MGA 411163), minor alteration zones up to 10 mm either side of veinlets axial planar to $F_2$ folds are present. Immediately adjacent to the Cowarna Fault southwest of Round Hill, large alteration zones not obviously associated with quartz veining are locally garnetiferous (MGA 443390). Alteration zones west of the Cowarna Fault (e.g. MGA 368420) are poorly exposed, but appear to be spatially extensive. Of lesser abundance is alteration with a quartz–carbonate(–chlorite–magnetite) assemblage, which is evident as diffuse patches south and southwest of Karnilbinia mining centre.

Hornfelsed variants of the Mount Belches Formation (*Asbh*) form mappable units adjacent to granite in the centre of MOUNT BELCHES (MGA 257441) and the Binneringie Dyke (MGA 406169). On a smaller scale, hornfelsed metasedimentary rocks define haloes up to 10 m wide adjacent to well-exposed Proterozoic dykes. The nature of the hornfels is a function of the protolith.

Adjacent to the granite, granitoid sills have intruded wackes and mudstones of the Mount Belches Formation (Fig. 10). Contact metamorphism has resulted in a layered gneiss with a quartz–labradorite–hornblende(–clinopyroxene–biotite) assemblage (Fig. 10). These rocks are interpreted as a roof pendant above the granitoid at the centre of the Randall Dome. At other localities, sillimanite is in mudstones adjacent to the Proterozoic dykes.

## Granitoid rocks (*Ag, Agdq, Agg, Agm, Agmq, Agp, Agpsi, Agy*)

Granitoid rocks constitute only a small proportion of MOUNT BELCHES. Most granitoids are classified as undivided (*Ag*) because deep weathering precludes unambiguous classification. Such exposures are typically so strongly kaolinized that there is no distinguishable feldspar, amphibole or mica — only quartz remains as a primary constituent. Further degradation of such exposures results in granitic soils interspersed with silcrete and minor exposures of weathered granitoid, which is mapped as relict material after regolith deflation over a granitoid ($Rgp_g$).

Quartz monzodiorite (*Agdq*) outcrops at two localities in the central eastern area of MOUNT BELCHES (MGA 455437 and 410320). These rock types comprise an assemblage of oligoclase–quartz–amphibole with chlorite, epidote, sericite, clay minerals, and iron oxides as alteration or weathering minerals. Textures vary from seriate to porphyritic, with oligoclase and amphibole as phenocrysts. All feldspars are either altered or weathered, with common sericite and clay minerals giving a cloudy texture. Where fresh, oligoclase contains polysynthetic and pericline twinning and possible antiperthite is also present. Amphiboles (possibly pargasite and hornblende sensu stricto) are altered to chlorite and epidote, or to clay minerals and iron oxides where weathered. Crystal shapes and cleavages, however, are recognizable. Metamorphism of the intrusion is suggested by granoblastic textures in quartz and low-grade replacement of the amphiboles, but tectonic foliation is absent. The southern outcrop was previously mapped as syenite (Griffin and Hickman, 1988) and was labelled the ‘Madoonia syenite’ by Swager (1995a), but geochemical (Table 3; Smithies and Champion, 1999) and petrological evidence indicates a quartz monzodioritic composition, with variation to leucogranodiorite. Smithies and Champion (1999) considered felsic alkaline igneous rocks such as these to be the last felsic magmatic event to have affected the Eastern Goldfields, between 2650 and 2630 Ma. Given the chemical differences and the possibility of metamorphism, the validity of the grouping of these rocks with the syenites as part of the late felsic alkaline igneous event (Smithies and Champion, 1999) may be equivocal.

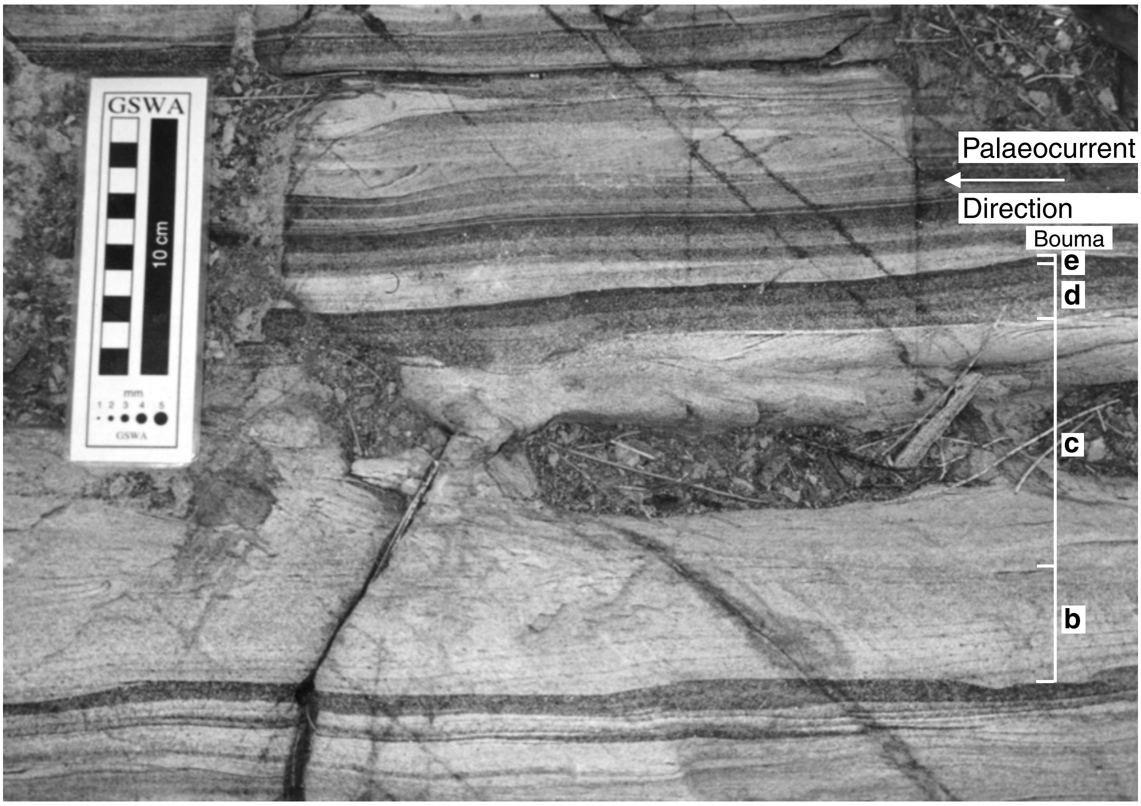


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**Figure 9. Bouma sequences in the graded wacke–mudstone facies, Mount Belches Formation (*Asbwm*; MGA 272575). The central bed shows an incomplete Bouma sequence (b–e labelled, c division partly obscured by recent sediment). Climbing ripples indicate palaeocurrent directions from the north (right of picture) on this western limb of an anticline**


**Figure 10. Layered biotite- to pyroxene-hornfels (*Asbh*; dark) between massive to porphyritic metagranitoid sills (light), south of Lake Randell (MGA 259439), dipping 40° towards 011° (bottom-right of picture)**

Numerous north-northwest-trending dykes of granodioritic to leucogranodioritic (*Agg*) composition, which are locally associated with elevated aeromagnetic responses, are exposed in the southern half of MOUNT BELCHES. Such dykes have a seriate texture and are commonly associated with plugs and dykes of pegmatite (*p*) and weathered granitoid (*Ag*).

Monzogranite to leucomonzogranite (*Agm*) forms the bulk of the granitoid terrain in the southwest of MOUNT BELCHES. The area probably comprises a suite of intrusions whose margins are indistinct due to poor exposure. Late-stage porphyritic dykes are common. In the large intrusions, textures vary from equigranular to seriate (most common) and rarely to porphyritic. Compositions are variable within the range of monzogranite to granodiorite. Granitoid assemblages are quartz–oligoclase–orthoclase (–albite–microcline–biotite–hornblende). Hornblende-bearing varieties have the highest content of microcline and, conversely, biotite-bearing, hornblende-barren varieties contain rare or no microcline. Accessory minerals include zircon, magnetite, ?monazite, titanite, and muscovite. Mafic mineral content does not exceed 10%. Metamorphic minerals include muscovite–sericite and chlorite. Localized textures, such as recrystallized quartz, quartz inclusions in recrystallized phenocryst rims, and chlorite that partially replaced biotite or hornblende, may reflect some metamorphism. A small exposure of quartz-rich monzogranite (*Agmq*) is located in the central west area of MOUNT BELCHES (MGA 086375). Quartz contents approach the 60% limit on the monzogranite field defined by the International Union of Geological Sciences (IUGS; Le Maitre et al., 1989). This unit probably represents a residual phase of the monzogranite 1 km southwest of this exposure.

Porphyritic granitoids (*Agp*) are present as dykes or plugs throughout MOUNT BELCHES. Compositionally, these porphyritic granitoids are quartz-rich varieties of leucomonzogranite to leucogranodiorite. In the Roe Hills, the foliated mafic rocks (*Abf*) are interleaved with numerous porphyritic dykes, ranging from 1 to 15 m in width. Although apparently less deformed than the mafic rocks, the porphyritic dykes are locally sheared and folded, indicating a pre-$D_2$ origin. In the southwestern corner of MOUNT BELCHES, porphyritic dykes (*Agp*) are consistently interlayered with quartz–chlorite schist (*Asbi*). Exposure is typically poor to non-existent, but remote sensing reveals a distinctive banding appearance caused by variations in vegetation concentrations over the rock types. These areas have been given a separate code *(Agpsi)* because most exposures are of porphyritic felsic dykes only (which constitute no more than 40% of the unit) — the schistose interbands are only rarely exposed.

Porphyritic syenogranitic to leucosyenogranitic dykes (*Agy*) are located east of the quartz monzodiorites. Orthoclase, quartz, and minor plagioclase and microcline phenocrysts are hosted by a groundmass of quartz, K-feldspar, and biotite. Metamorphic minerals include chlorite (after biotite), muscovite, epidote, and sericite

**Table 3. Representative analyses of quartz monzodiorites north of the abandoned Madoonia Downs Homestead site**

| | *Quartz monzodiorite, Madoonia Downs* 1 | 2 |
|---|---|---|
| | **Weight percent (%)** | |
| $SiO_2$ | 65.08 | 67.51 |
| $TiO_2$ | 0.36 | 0.28 |
| $Al_2O_3$ | 15.49 | 15.18 |
| $Fe_2O_3$ | 1.51 | 1.22 |
| FeO | 2.03 | 1.51 |
| MnO | 0.07 | 0.02 |
| MgO | 2.63 | 1.89 |
| CaO | 2.49 | 2.53 |
| $Na_2O$ | 7.77 | 8.31 |
| $K_2O$ | 0.61 | 0.33 |
| $P_2O_5$ | 0.18 | 0.14 |
| LOI | 1.03 | 0.69 |
| Total | 99.25 | 99.61 |
| | **Parts per million** | |
| Sc | 8.8 | 7.3 |
| V | 59 | 42 |
| Cr | 161 | 119 |
| Ni | 43 | 42 |
| Cu | 5 | 3 |
| Pb | 12 | 9 |
| Zn | 62 | 52 |
| Ga | 21 | 22 |
| Rb | 30.6 | 8.8 |
| Sr | 1 167 | 1 142 |
| Y | 8.4 | 13.5 |
| Zr | 126 | 103 |
| Nb | 2.8 | 3.4 |
| Ba | 2 642 | 2 203 |
| La | 40 | 29 |
| Ce | 69 | 49 |
| Nd | 20 | 16 |
| Th | 6 | 6 |
| U | bd | bd |

NOTE: bd below detection levels

SOURCE: Smithies and Champion (1999)

along K-feldspar cleavage planes. In outcrop, foliation is defined by biotite alignment.

### *Kiaki Monzogranite (Agkk)*

The Kiaki Monzogranite (*Agkk*) is a leucomonzogranite in the centre of the Randall Dome (MGA 240415). Due to the lack of geographical names in the area, it takes its name from the nearest man-made feature, which is on the north shore of Lake Randell — Kiaki Soak. The granitoid is deeply weathered but where fresh comprises oligoclase–quartz–microcline–biotite–muscovite–hornblende with accessory titanite, epidote, and ?pyrite. Anhedral amphibole, which is probably after pyroxene, appears to be partly replaced by epidote and mica, although this could represent uralitization of original pyroxene. Two generations of oligoclase are apparent: a primary generation that contains sericitic inclusions, exhibits warped or disrupted twin lamellae and irregular extinction, and a secondary generation that is clean and contains quartz inclusions. Similarly, there are at least two generations of quartz (quartz with undulose extinction and granuloblastic quartz) and microcline (microcline with warped twins and irregular extinction, and poikilotopic microcline). These secondary generations may reflect regional metamorphism of the granitoid, but the regional north- to north-northwest-trending $S_2$ foliation is absent. Flat-lying to shallow-dipping sedimentary rocks of the Mount Belches Formation are intruded and metamorphosed by the Kiaki Monzogranite. Numerous sills of leucomonzogranite and quartz-rich leucomonzogranite vary in texture from seriate to porphyritic, and are interleaved with compositionally layered pyroxene hornfels of intermediate composition (*Asbh*; see **Mount Belches Formation**), possibly a roof pendant in the carapace of an extensive monzogranite.

## Low- to medium-grade metamorphic rocks (*Alf, Aly*)

Metamorphic rocks whose protoliths are uncertain are volumetrically minor on MOUNT BELCHES, and are located in or near fault zones. Felsic schist (*Alf*) is exposed on the east and west flanks of Bare Hill. It probably represents sheared sedimentary rocks of the Mount Belches Formation in the Randalls Shear or one of its splays. Carbonaceous phyllonite with cataclasite and mylonite (*Aly*) is exposed at several localities, but only at mappable scale in major fault zones in the central east of the sheet. Although visually similar to carbonaceous varieties of shale (*Ash*), it is distinguished by folded and brecciated fragments of the Mount Belches Formation. These rocks have a strong subvertical foliation superimposed upon them, along which there are conflicting movement indicators and varying degrees of movement at outcrop scale.

## Veins, dykes, and plugs (*q, p*)

Quartz veins (*q*) are common features on MOUNT BELCHES. They crosscut all Archaean rock types and have varying morphologies including bedding- and foliation-parallel, ladder sets, tension gash arrays, and conjugate sets. There are several generations of veining, with folded pre-$D_2$ veins overprinted by axial-planar syn-$D_2$ veins. In contrast, quartz dykes (*q*) are rare, and do not exceed a few metres in thickness or several hundred metres in length. These dykes are commonly surrounded by an apron of colluvial vein quartz pebbles and boulders (*Cq*). Most veins and dykes are of massive milky quartz. Laminated milky quartz veins, crystalline quartz veins, and veins containing other minerals, such as carbonate, are rare.

Metasomatic alteration of the Mount Belches Formation (*Asba*) is commonly associated with quartz veining. Figure 11a illustrates the feathered termination of a laminated quartz vein with Ca-amphibole–quartz alteration immediately around the vein. The host rock is wacke (*Asbw*). This example shows that alteration is associated with only some vein sets. A small quartz vein that is crosscut and therefore precedes the laminated vein and alteration has locally retarded propagation of the alteration front (Fig. 11a). Cryptic veining is responsible

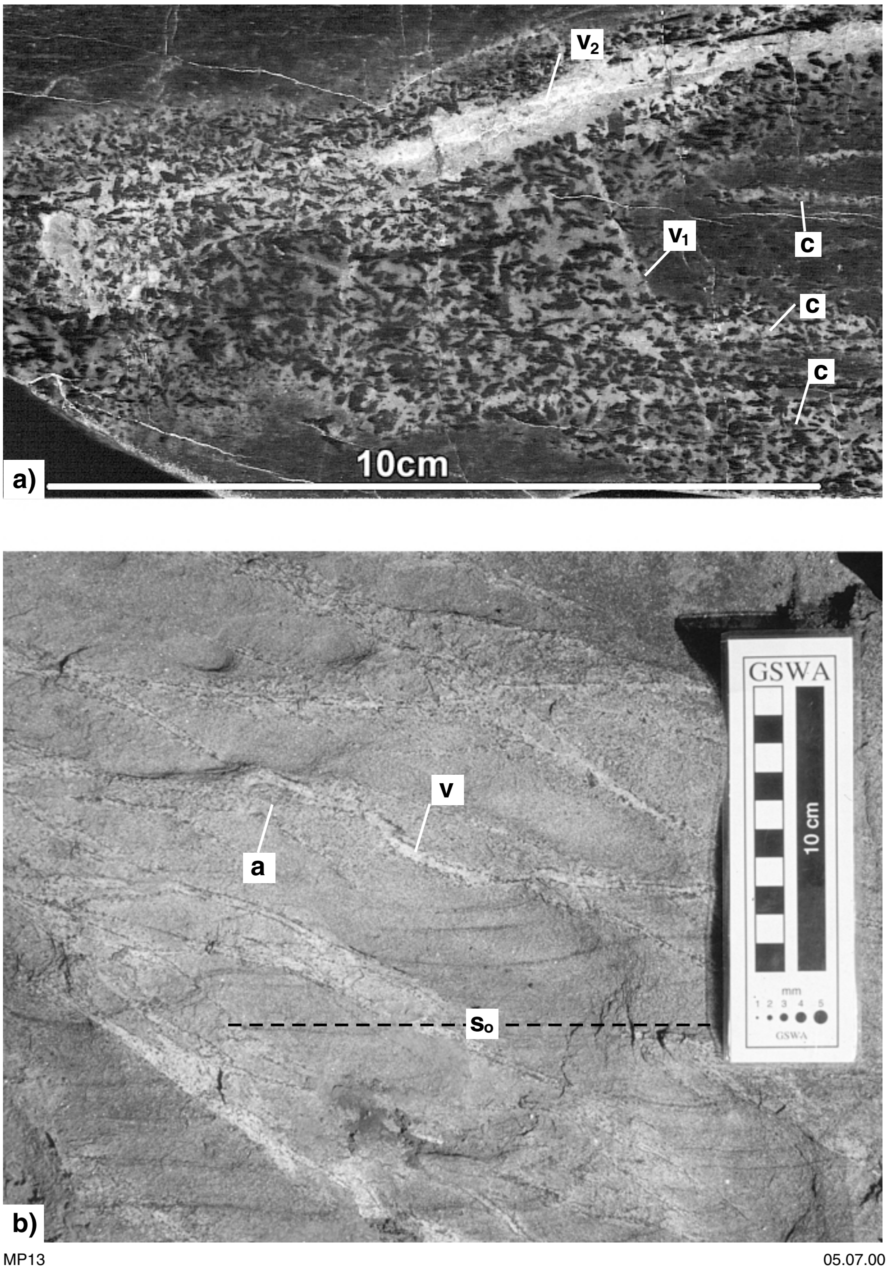


**Figure 11. Metasomatic Ca-amphibole–quartz alteration associated with quartz veining in metasedimentary rocks of the Mount Belches Formation (*Asba*), Randall Dome: a) an early generation vein ($V_1$) has retarded propagation of an alteration front around a later laminated quartz(–carbonate) vein ($V_2$), and small alteration zones parallel to bedding encapsulate cryptic veining (c; GSWA 153475; MGA 438394); b) a fine network of quartz veins (v) crosscut bedding ($S_0$) and display amphibolitic alteration haloes (a; MGA 278575)**

for small alteration zones parallel to the sedimentary lamination (Fig. 11a). Vein arrays result in a massive zone of alteration (Fig. 11b). Metasomatic alteration is not always obviously associated with veining (see **Mount Belches Formation**). Whether cryptic veining or a large fluid flux with appropriately wider alteration zones is responsible is not clear.

Several vein sets occur in the Santa Claus Member (*Asbn*) of the Mount Belches Formation (Newton et al., 1998). Rheological differences between the iron formation and the enclosing wackes have resulted in preferential development of quartz veins, commonly as arrays or ladder sets with a shallow southwest dip, within the iron formation. Gold is associated with alteration around these shallow-dipping veins. The concentration of these veins, and therefore gold concentration, is controlled by proximity to north-northeasterly trending faults and associated veins. Bedding-parallel veins are common immediately above and below the BIF.

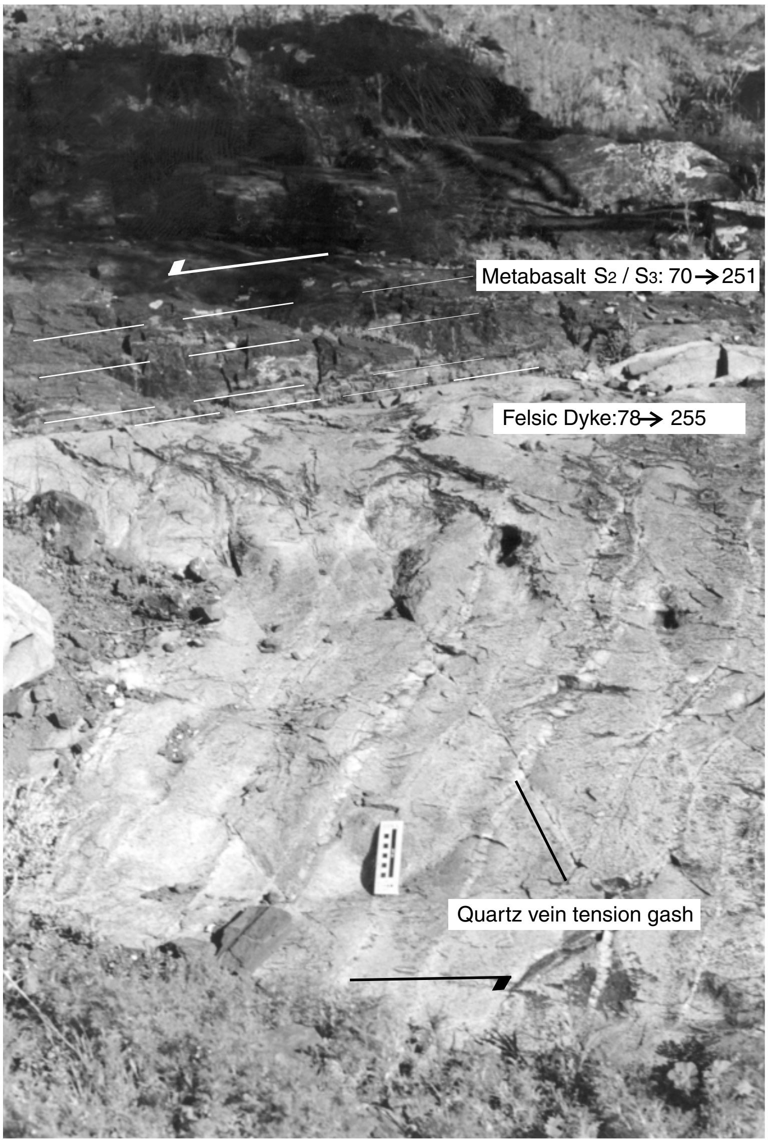


**Figure 12. Tension gash array of quartz veins, exposed in a felsic porphyritic dyke intruding metabasalt, near the hinge zone of an $F_3$ drag fold (MGA 514483), indicating sinistral movement on the $S_2$–$S_3$ foliation. This is consistent with the sense of movement inferred on the drag fold from aeromagnetic data**

Quartz veins forming a tension gash array are exposed in a felsic porphyritic dyke crosscutting basalt 9 km northeast of Round Hill (MGA 514483; Fig. 12). The dyke crosscuts the regional $S_2$ foliation at a shallow angle. Aeromagnetic data reveal that this locality is on the eastern limb of an $F_3$ drag fold immediately adjacent to a north-northwesterly trending fault. The tension gash array is probably a response to rheological differences between the porphyritic dyke and the basalt during lateral sinistral movement along the fault and, locally, on $S_2$(–$S_3$) during $D_3$.

Pegmatite dykes and plugs (*p*) are probably of Archaean age and are common south of Lake Randell. Occurrences are clustered and are commonly associated regionally with other granitoids, suggesting that these features represent poorly exposed stockworks in the carapace zone of the granitoid at depth. Thin (centimetre-sized) contact metamorphic haloes are present where the pegmatite intrudes metasedimentary rock, and intense quartz veining is localized around some pegmatite dykes and plugs. Pegmatite has been exploited historically for tantalite at minor workings 3 km north of 8 Mile Dam (MGA 167218).

## Structure and metamorphism

At least four deformation events and three metamorphic events are recognized on MOUNT BELCHES. Bedding-parallel $S_1$ foliations occur in the Bulong Anticline, where refolded $F_1$ folds are implied by the anticline to the southeast of Peters Dam (Peters Dam Anticline). In the Mulgabbie domain, a large-scale, $D_1$ recumbent fold is implied by inverted sedimentary rocks in the southeast of MOUNT BELCHES. In the Randall Dome, pre-$D_2$ deformation is manifested as a bedding-parallel foliation in the Mount Belches Formation and as refolded folds in the Santa Claus Member on the northern boundary with KURNALPI (here termed the Red Peak Gully structure). The relationship of pre-$D_2$ deformation in the Randall Dome with $D_1$ elsewhere in the Eastern Goldfields is unclear because different deformation mechanisms are invoked: granitoid intrusion and ?doming in the Randall Dome (see **Tectonic development of the Randall Dome**) and thrusting elsewhere (Swager, 1997).

Strong east–west compression during the second deformation event ($D_2$) is manifest as prominent chevron folds defined by the Santa Claus Member of the Mount Belches Formation, and also such features as the Bulong Anticline, Miller Dam Syncline, and the widespread north- to north-northwest-trending $S_2$ foliation. In the Randall Dome, numerous north-plunging $F_2$ folds are exposed north of Lake Randell, whereas south of the abandoned Madoonia Downs Homestead site, $F_2$ folds plunge exclusively southward. These, combined with the outward younging of the Mount Belches Formation, define the Randall Dome.

Transpression during $D_3$ and $D_4$ resulted in largely reverse vertical and sinistral lateral movement on regional faults. One prominent $F_3$–$F_4$ fold is exposed in basalt northeast of Round Hill in the Mulgabbie domain. Although it is commonly difficult to distinguish between these events on MOUNT BELCHES, $D_3$ and $D_4$ are evident as tightening and realignment of $F_2$ fold axes in the Mount Belches Formation, subhorizontal quartz veins with auriferous alteration at Randalls and Karnilbinia, as ladder sets of veins, as minor fault offsets of $D_2$ structures, and as warping of the $S_2$ foliation.

Comparison of the structural features of the various domains on MOUNT BELCHES reveals consistency with published regional definitions of structural deformation events (Swager and Griffin, 1990; Swager, 1997), although the pre-$D_2$ deformation in the Randall Dome is anomalous. Textures on MOUNT BELCHES (see **Metamorphism** below) are consistent with the interpretation that peak regional metamorphism ($M_2$) coincided with or immediately followed $D_2$ (Binns et al., 1976; Ridley et al., 1997). Evidence for the deformations is different in each of the tectonostratigraphic domains.

## Gindalbie domain

The Gindalbie domain (Fig. 3), located to the north and west of the Randall Fault in the northwestern corner of MOUNT BELCHES, is dominated by the $F_2$ Bulong Anticline. In this structure, Swager (1995a) inferred $D_1$ thrusting on the contact between the felsic volcanic and volcaniclastic rocks and the overlying but older mafic volcanic and sub-volcanic rocks (see **Stratigraphy and correlations**). Field evidence is consistent with such an interpretation. The strong foliation in the vicinity of the contact swings from northerly trending near the northern edge of MOUNT BELCHES (MGA 114687), through to east-northeasterly in exposures approaching the axis of the Bulong Anticline (MGA 089641), suggesting $F_2$ folding of a pre-existing $S_1$ fabric.

The hinge of the south-plunging $F_2$ Bulong Anticline passes through the folded gabbro unit at Oak Hill southwest of Peters Dam, but its trend is lost southward beneath Lake Randell and northward beneath Emu Flat. The mafic and ultramafic rocks do not preserve a distinct $S_2$ foliation, although a preferential north–south alignment of constituent grains is present locally.

Southeast of Peters Dam, a tight fold is evident in differentiated mafic to ultramafic lava flows (see above). Remapping of this structure has shown younging indicators trending northward, and bedding trends dipping outwards, away from the hinge of the structure. In contrast to previous interpretations (Hickman, 1986; Griffin, 1989; Swager, 1995a), this structure is interpreted as a steeply northward-plunging anticline. Here termed the Peters Dam Anticline, the structure is closed to isoclinal, with poorly exposed sedimentary rocks in the core overlain by the layered flows of komatiitic basalt. An $F_1$ origin for the Peters Dam Anticline is preferred because aeromagnetic data reveal broad $D_2$ folding of marker units in the Peters Dam sequence by the Bulong Anticline. A faulted contact with the rocks to the east and west, possibly related to $D_1$, is inferred (Fig. 3).

## Mulgabbie domain

The Mulgabbie domain is located to the east of the Cowarna Fault and is divided into two subdomains: the western subdomain forming the Trig and Low Trap hills, Round Hill, and other outcrops south of Lake Randell, and the eastern subdomain forming the Roe Hills and the valley separating them from the Trig and Low Trap hills in the very northeastern corner of MOUNT BELCHES.

Sparse structural and younging data combined with aeromagnetic imagery allow definition of a shallowly south-plunging $F_2$ syncline, here termed the Miller Dam Syncline (Fig. 3), as the dominant feature of the western subdomain. The syncline takes its name from Miller Dam (MGA 456636), which is located near the interpreted trace of the fold axis. Numerous bedding–foliation intersection lineations, that are most likely parallel to the $F_2$ axial hinge, plunge southward at an angle of 30° to 50° throughout the Trig, Low Trap, and Roe hills. A syncline is indicated by volcanic (MGA 455698) and sedimentary (MGA 432616 and 503477) younging indicators, in conjunction with the geometry of gabbro units in the very north of the Trig Hills (MGA 435697 to MGA 453694) and the faulted, arcuate shape of the basalt–sedimentary rock contact south of the Low Trap Hills (as indicated by outcrop and aeromagnetic data — Fig. 3). The syncline appears to be overturned to the east as indicated by the moderately to steeply east-dipping $S_2$ foliation and the west-dipping orientation of mafic to ultramafic rocks on the western side of the structure. Sedimentary rocks in the southeast of MOUNT BELCHES (MGA 502237) dip moderately westwards but face downward, suggesting an $F_1$ hinge between this locality and the next metasedimentary rock exposure 22 km northwards, which faces upward. Banded iron-formation defines a strong aeromagnetic marker that traces an inverted $F_2$ syncline (Fig. 3) beneath Palaeozoic cover. Such broad scale overturning of sedimentary rocks suggests large-scale $F_1$ recumbent folding of the sequence in the Mulgabbie domain. Basalt of low metamorphic grade at Round Hill is interpreted from aeromagnetic data to be faulted out, and the relationship of these basalts to the rest of the syncline is unclear.

A faulted boundary is interpreted between the western and eastern subdomains, as indicated by strongly foliated rocks on the eastern side of the Trig and Low Trap hills and aeromagnetic contrasts. Banded iron-formation on MOUNT BELCHES (MGA 685463) and KURNALPI to the north defines a strong aeromagnetic marker that extends south-southeast to ERAYINIA under cover. Igneous grading in the Roe Hills further to the east indicates younging to the east.

## Parker domain and southwestern granitoid complex

The Parker domain is located south and west of the Mount Monger Fault (Fig. 3). The granitoid complex in the southwestern corner of MOUNT BELCHES comprises largely monzogranite and leucomonzogranite (*Agm*), with porphyritic felsic dykes (*Agp*), pegmatite (*p*), and sheared metasedimentary rock intruded by sheeted porphyritic felsic dykes (*Agpsi*). Due to poor exposure, trends defined by these lithologies may only be observed with remote sensing. These trends wrap around the bulk of the granitoids, which are largely massive and do not contain the $S_2$ regional foliation. In particular, about 3 km northwest of 8 Mile Dam, one pod of granitoid and associated regolith approximately 2.5 km long (MGA 130220) has a lozenge shape defined by the anastomosing of the metasedimentary rock and dyke complex (*Agpsi*) around it. Although there are no sense of shear indicators in outcrop, the geometries suggested by remote sensing are consistent with regional sinistral shear.

Elsewhere in the Parker domain, basalt (*Abv*) and komatiitic basalt (*Abm*) are sporadically exposed near the central western edge of MOUNT BELCHES. Porphyritic dacite to rhyodacite is present on the eastern edge of a large circular aeromagnetic anomaly on the boundary with LAKE LEFROY.

## Randall Dome

The Randall Dome is a newly recognized feature that incorporates the sedimentary rocks of the Mount Belches Formation and the granitoids that intrude it. It is bound by the Cowarna, Randall, and Mount Monger Faults (Fig. 3). Present mapping has shown that four generations of regional-scale deformation have affected these rocks. The dome probably developed by granitoid doming, followed by stronger east–west regional compression, and subsequent, largely sinistral, strike-slip movement along regional faults.

Evidence for a pre-$D_2$ deformation is sporadically preserved in the Randall Dome. Local irregularities and facing reversals within the Mount Belches Formation probably represent pre-$D_2$ folding. A local pre-$D_2$, weak bedding-parallel foliation is defined by the alignment of constituent quartz, feldspar, and mica grains. Immediately south of Lake Randell, layer-parallel foliation is strong in hornfelsed, shallow-dipping sedimentary rocks intruded by granitic sills adjacent to the Kiaki Monzogranite. Here, the early foliation is defined by preferential alignment of biotite, amphibole, and clinopyroxene (Fig. 13a), and is folded by open $F_2$ folds. In breakaways in the Madoonia Hills, an early flat to shallow-dipping foliation (Fig. 13b) is widespread, and this foliation is locally folded by open $F_2$ folds and crenulated by the subvertical $S_2$ foliation (e.g. MGA 272237).

The $F_2$ chevron folds defined by the Santa Claus Member are the most obvious expression of $D_2$ on MOUNT BELCHES. Aeromagnetic data reveal that the chevron style of folding is restricted to the exposed folds; under cover along strike to the southeast, a more plastic style of folding dominates (Fig. 3). The $S_2$ foliation is common though not ubiquitous throughout the Randall Dome. Where present, $S_2$ is axial planar to $F_2$, trends north to north-northwest, and is defined by mica alignment in the graded wacke–mudstones and mudstones of the Mount Belches Formation. In the Randalls mining centre, minor north-northwesterly quartz-filled faults are considered $D_2$ compensation structures reactivated by subsequent deformations (Newton et al., 1998).

The poorly exposed Red Peak Gully structure in the north of MOUNT BELCHES takes its name from Red Peak Gully, an ephemeral stream that passes through the middle of the structure. Iron formation of the Santa Claus Member has been folded, refolded, and faulted to define a distorted triangular shape (Fig. 3) that is only apparent on aeromagnetic imagery. It represents a regional-scale interference pattern where a pre-$D_2$ fold is interpreted to have trended west-northwesterly, but has been folded by north-northwesterly trending $F_2$ folds (see **Tectonic development of the Randall Dome**). Bedding orientations are only measurable in sedimentary rocks above and below the Santa Claus Member (whose sedimentary features are obscured by supergene iron oxides). Moderate dips to the southwest were measured on the southwestern flank of the structure, and moderate dips to the north on the northern flank and to the east on the eastern flank are inferred from aeromagnetic data. The northwestern tip of the structure lies on KURNALPI to the north, where isoclinal closure of the pre-$D_2$ fold is exposed in the iron formation. Also at this locality are meso-scale $F_1$–$F_2$ interference patterns in the iron formation.

Sinistral movement along the bounding Randall and Cowarna Faults is representative of $D_3$–$D_4$. West and southwest of the Randalls mining centre, the $F_2$ axial planes have been reoriented from north-northwesterly trending through northerly to north-northeasterly trending against the Randall Fault, indicating increased flattening strain with proximity to the fault (Swager, 1995a). This is most probably due to oblique movement on the Randall Fault during $D_3$–$D_4$ (see **Tectonic development of the Randall Dome**). Newton et al. (1998) attributed

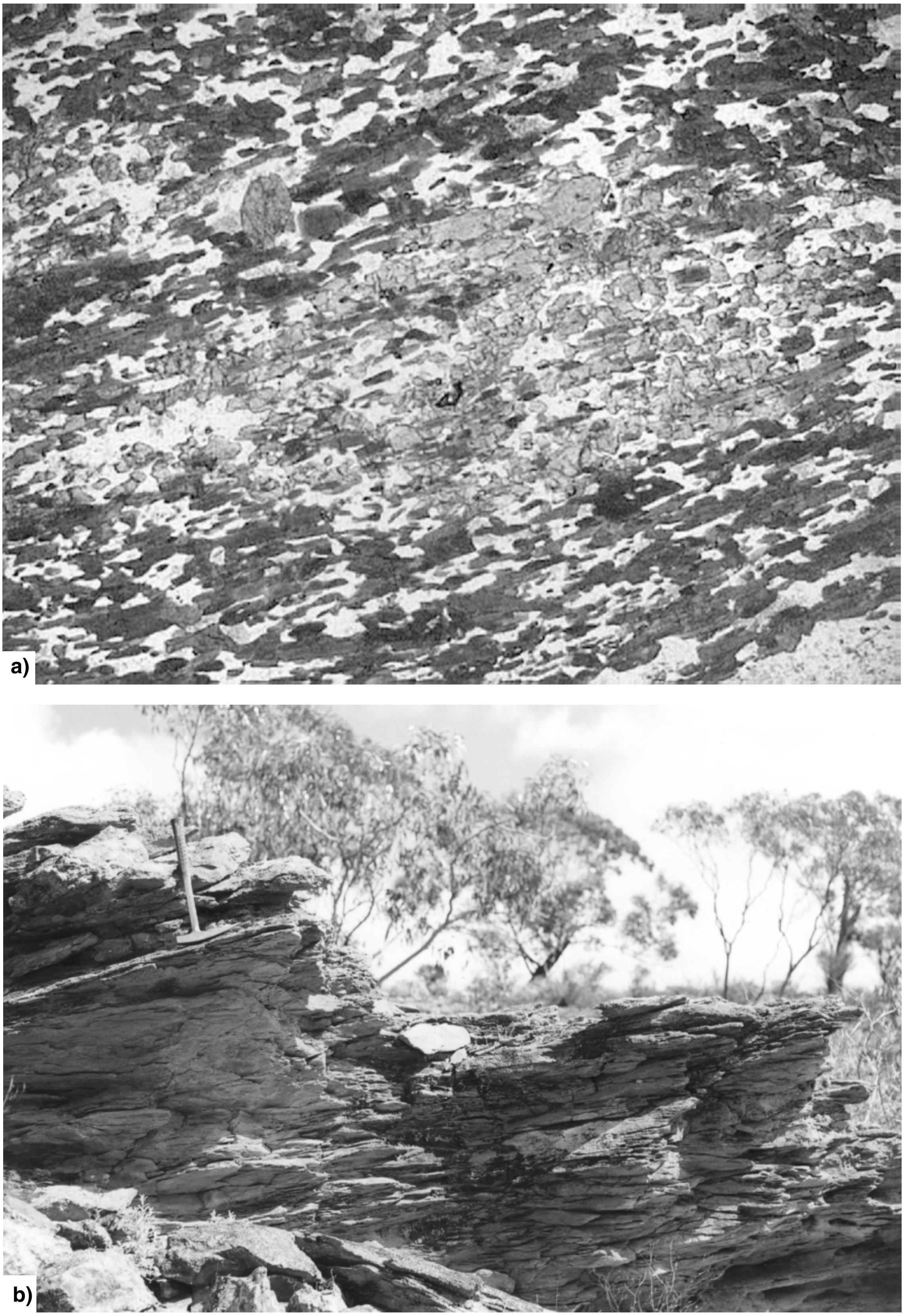

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**Figure 13. Manifestations of the pre-$D_2$ foliation in the Randall Dome: a) Pre-$D_2$ foliation in hornfelsed Mount Belches Formation (*Asbh*) defined by layer-parallel alignment of partially retrogressed clinopyroxene (mid grey, centre), hornblende (dark grey), and minor biotite in the carapace zone of the central granitoid of the Randall Dome (field of view 4 mm across, crossed polars, GSWA 153453; MGA 259439); b) Flat-lying pre-$D_2$ foliation in breakaways of metasedimentary rocks of the Mount Belches Formation (*Asb*), Randall Dome (MGA 280250)**

several features of the Randalls gold deposits, including north- to northeast-trending faults and quartz veins associated with gold mineralization, to late, post-$D_2$ deformation. A prominent fold 9 km northeast of Round Hill is immediately adjacent to a regional north-northwest-trending fault and is probably a drag fold developed during $D_3$ sinistral shear, resulting in the development of tension gash arrays (see **Veins, dykes, and plugs** above). Broad-scale warps of the northerly trending axis of the Randall Dome are classified as $F_3$–$F_4$, formed during a period interpreted as one of regional sinistral transpression (Chen et al., 2001).

## Major faults

Three regional-scale faults dissect the geology of MOUNT BELCHES: the Randall Fault, the Mount Monger Fault, and the Cowarna Fault (Fig. 3). The faults are typically obscured by laterite, alluvium, colluvium or playa-lake systems, but intense foliation of the Randall Fault or an adjacent splay is poorly exposed on the flanks of Bare Hill, and the phyllonite of the Cowarna Fault is exposed southwest of Round Hill. The Mount Monger Fault is not exposed on MOUNT BELCHES but rotary air-blast (RAB) drillchips east of Old Dry Lake show phyllonite at depth, separating mafic to ultramafic rocks to the west from the Mount Belches Formation to the east. An inference from the regional study of Swager (1995a, 1995b) is that the Cowarna Fault may be contiguous with the Yilgangi Fault on EDJUDINA and therefore part of the Keith–Kilkenny Fault Zone.

The Randall Fault marks the juxtaposition of the Mount Belches Formation against the metabasalts and metasedimentary rocks of the Bulong Anticline. It is obscured by regolith except at Bare Hill, where a tight, reoriented $F_2$ syncline in the Santa Claus Member of the Mount Belches Formation is exposed within the fault zone. Quartzofeldspathic schist on the lower flanks of the hill does not preserve reliable movement indicators, but features of the iron formation provide some insight into the fault movement. Chevron folds in the iron formation plunge 25–55° northward, similar to the larger $F_2$ folds defined by the Santa Claus Member. These folds are consistently overturned, with axial planes dipping eastward at around 60°. Such an angle is consistent with dips of volcanic and sedimentary units in the Bulong Anticline to the west. Low-angle truncation of magnetic markers (?basalt flows or gabbro sills) of the Bulong Anticline contrasts with the highly disrupted nature of the Mount Belches Formation, and suggests that the Randall Fault is subparallel to layering in the Bulong Anticline, and therefore dips moderately eastward. Vertically, the overturned fold axes and the progressive inclination of regional fold axes towards the fault are consistent with east-over-west reverse movement, which is also consistent with the contrasting metamorphic grades of the Bulong Anticline and the Randall Dome (see **Metamorphism**).

Southwest of Round Hill, the Cowarna Fault and associated splays are well exposed, with plan views and vertical sections visible in outcrops adjacent to some playa lakes. Here, the Cowarna Fault is a reverse fault that dips steeply west, as indicated by brittle (Fig. 14) and plastic movement indicators. West-over-east reverse vertical movement on the Cowarna Fault is consistent with the juxtaposition of amphibolite facies, garnet-bearing metasedimentary rocks of the Mount Belches Formation with greenschist facies chloritic metabasalts southwest of Round Hill. Lateral movement indicators are less clear, and although commonly ambiguous, sinistral indicators predominate.

The continuity of these faults is inferred through interpretation of aeromagnetic data. Magnetic markers reveal drag folds and truncation of units, allowing interpretation of fault positions and characteristics. Flattening of fold structures and attenuation of units along the Mount Monger and Cowarna Faults is consistent with net sinistral lateral movement. The asymmetric geometry of the major overturned anticline through the Randalls mining centre necessitates interpretation of faulting near to the fold axis. No major zone of faulting was recognized in field exposures because the hinge zone is topographically recessive, but there are minor faults near the hinge on the northern shore of Lake Randell, and a fault of this orientation was recorded by Newton et al. (1998) in the Randalls mining centre.

## Metamorphism

The regional study of Binns et al. (1976) extended only to the northern and westernmost portion of MOUNT BELCHES, but indicated mid-greenschist to greenschist–amphibolite transition facies (low grade of Binns et al., 1976) metamorphism in the north of the Randall Dome and the Gindalbie domain, and mid- to high-amphibolite facies (high grade of Binns et al., 1976) metamorphism for the Mulgabbie domain. Although not a major component of this study, fieldwork has shown that metamorphic grades vary significantly over MOUNT BELCHES. In the Bulong Anticline, medium-grade metamorphism appears to diminish to low-grade metamorphism away from the core of the fold. Similarly, high-grade contact metamorphism at the core of the Randall Dome appears to grade radially to medium-grade regional metamorphism (low amphibolite facies). In contrast to Binns et al. (1976), mafic to ultramafic rocks of the Mulgabbie domain appear to be of low to medium grade, consistent with the local preservation of primary microtextures. Limited outcrop in the Parker domain in the west and southwest also indicates low to medium grades.

The metamorphic grade distributions are the result of the interaction of three metamorphic events on MOUNT BELCHES, not including hydrothermal alteration (serpentinization) of mafic to ultramafic rocks immediately after deposition ($M_0$). Contact metamorphism ($M_1$) of the Mount Belches Formation preceded post-$D_2$ regional metamorphism ($M_2$). Hornfels ($M_3$) haloes Proterozoic gabbroic dykes.

Hornfelsed ($M_1$) Mount Belches Formation is exposed adjacent to the Kiaki Monzogranite. Shallowly dipping metawacke and metamudstone units, which are interbanded with granitic sills, are metamorphosed to a clinopyroxene-bearing hornfels (see **Mount Belches Formation**). $S_1$ is defined by strong preferential alignment

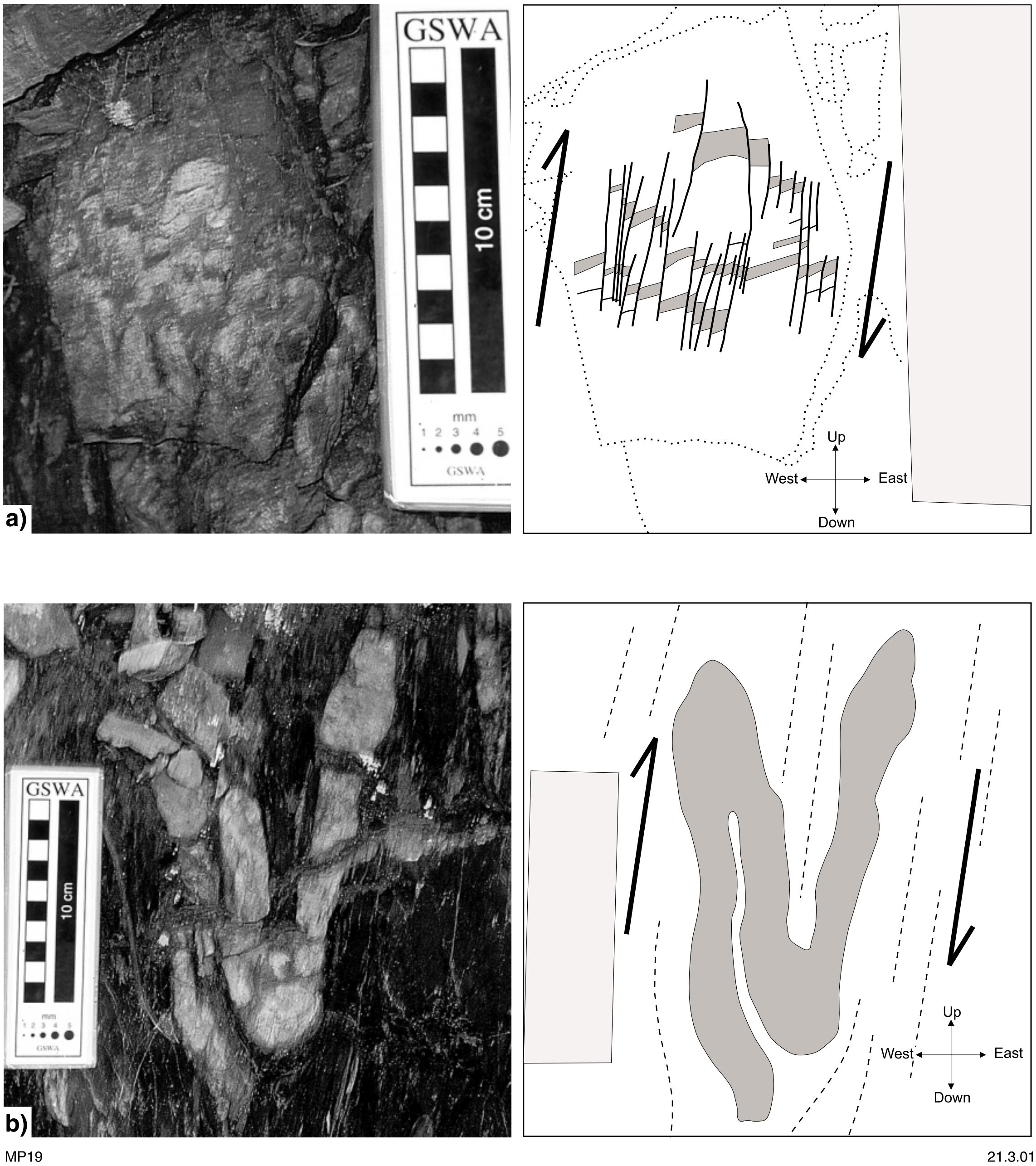


**Figure 14. Reverse (west over east — thick arrows) movement indicators of the Cowarna Fault (MGA 446397), vertical sections, looking north: a) Photograph and sketch of minor brittle disruption of a fragment of metasedimentary rock within the fault zone. The minor faults (dark lines) are parallel to the dominant foliation ($S_3$–$S_4$) in the fault zone. The dotted line in the diagram is for reference only; b) Photograph and sketch of a dismembered z-fold of metasandstone within phyllonite (*Aly*) with the $S_3$–$S_4$ foliation (dashed line) anastomosing around it, indicative of plastic reverse movement**

of biotite, amphibole or clinopyroxene (depending on grade) parallel to bedding.

Regional metamorphism ($M_2$) is of mid-greenschist to amphibolite facies throughout Mount Belches but grades vary regionally. In the Randall Dome, local assemblages in metawacke and metamudstone of quartz–feldspar–biotite–garnet(–?almandine) and quartz–feldspar–biotite–staurolite(–?cordierite) are indicative of low- to mid-amphibolite grade, which is consistent with local andalusite development in metamudstone. Also, the lack of preservation of $S_2$ in biotitic metamudstone units from numerous localities suggests that the metamorphic peak post-dated $D_2$. In the Gindalbie and Mulgabbie domains, mafic rocks commonly contain either a felted mass of chlorite, or chlorite after hornblende, and true amphibolites are limited, indicating greenschist and (lower) amphibolite grade metamorphism. Ultramafic rocks preserve cumulate microtextures and contain abundant antigorite (Williams and Hallberg, 1973), which, according to Binns et al. (1976), is also consistent with mid-greenschist to lower amphibolite grade metamorphism. In the Bulong Anticline, higher proportions of metamorphic amphibole closer to the core of the structure may reflect a decreasing metamorphic gradient away from the core. Equivocal textures in some granitoids, including the Kiaki Monzogranite, may indicate $M_2$ metamorphism (see **Granitoid rocks**).

Contact metamorphic effects are present in the Mount Belches Formation adjacent to several Proterozoic mafic dykes ($M_3$). Sillimanite is developed within 10 m of thin (5 m wide) dykes west of Round Hill (MGA 411452).

## Tectonic development of the Randall Dome

Several features are consistent with the interpretation that granitoid doming is responsible for $D_1$ in the Randall Dome. Younging directions, apart from minor exceptions, are consistently away from the centre of the dome. Beds in contact with the Kiaki Monzogranite have shallow to moderate dips (0–40º), have undergone high-grade contact metamorphism ($M_1$), and are intimately interbanded with sills of granitoid material of similar composition to the main granitoid. This suggests progressive emplacement of the Kiaki Monzogranite by a mechanism of sill intrusion followed by incorporation or flaking of the sedimentary rocks. The layer-parallel, flat lying $S_1$ in the metasedimentary rocks interstitial to the sills and in lateritic breakaways elsewhere is consistent with a horizontal flattening strain induced above an upward-propagating granitoid (Mareschal and West, 1980). The lack of a flat-lying fault contact between the apex of the granite and the metasedimentary rocks precludes thrusting and duplexing up and over the granitoid as a mechanism for the formation of $S_1$ in the Randall Dome.

The fold interference pattern of the Red Peak Gully structure on the northern flank of the Randall Dome is consistent with the development of a west-northwesterly trending, open $F_1$ fold subparallel to the margin of the granitoid (Fig. 15). Such a fold could form by thrusting or slumping of a thick sequence of sedimentary rock during the vertical propagation of the Kiaki Monzogranite. The expected continuity between the marker horizon of the Santa Claus Member and the Red Peak Gully structure from such a model is not observed due to truncation at depth of the Santa Claus Member (inferred from aeromagnetic data). The nature of the discontinuity is unclear; a detachment similar to that revealed by the Australian Geological Survey Organisation (AGSO) seismic line northwest of MOUNT BELCHES (Goleby et al., 1993; Swager et al., 1997) is one possibility, intrusion by the upward-propagating granitoid is another.

Deformation related to granitoid doming has been documented elsewhere in the Eastern Goldfields. Witt and Davy (1997) described structures associated with dome-related pre-$D_2$ and post-$D_2$ granitoids throughout the southwestern Eastern Goldfields. Subhorizontal to shallowly plunging lineations and intense ductile deformation at the contact with greenstone are common features. There are several reasons that these features are not observed in the Randall Dome: the carapace zone

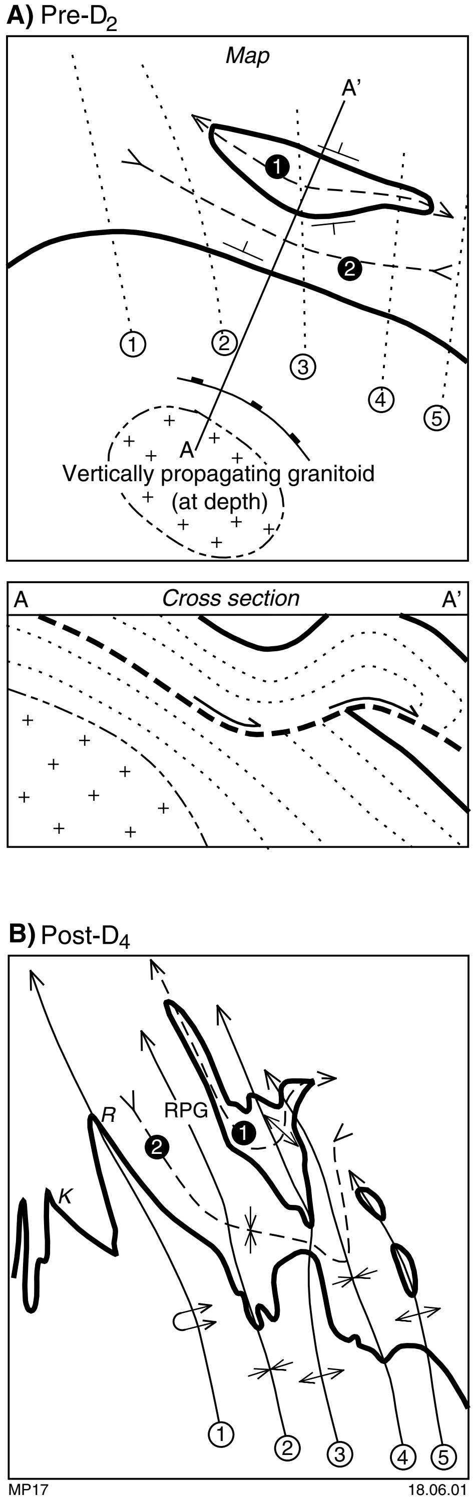


**Figure 15. Model for the development of the Red Peak Gully structure, northern Randall Dome. Thick black line represents the Santa Claus Member iron formation: a) $F_1$ folds (black circle, white numeral) develop by slumping of the sedimentary pile (cross section) during vertical granitoid propagation (future axes of $F_2$ folds are projected); b) Present distribution of the Santa Claus Member with interpreted $F_1$ (black circle, white numeral) and $F_2$ fold axes (white circle, black numeral). Abbreviations used: RPG — Red Peak Gully structure, R — Randalls mining centre, K — Karnilbinia mining centre**

(rather than a deeper section of the granitoid) is exposed, the contact is preserved in one locality only, and exposure of the granitoid is poor so lineations are difficult to define.

The tightening and reorientation of $F_2$ folds adjacent to the Randall Fault is probably a result of space problems incurred during syn- to post-$D_2$ sinistral and reverse movement on the Randall Fault (see **Major faults** above). Assuming the Randall Fault is subparallel to layering in the Bulong Anticline, syn- to post-$D_2$ impingement of the Randall Dome onto the east-dipping Randall Fault would result in realignment, tightening, and overturning of $F_2$ fold axes in the Randall Dome as observed. Such a process effectively represents ramping of the Mount Belches Formation up the Randall Fault during $D_2$–$D_3$. Similar, but less severe, reorientation of $F_2$ axes is apparent from aeromagnetic data on the eastern side of the Randall Dome, where the steeply west-dipping Cowarna Fault impinges upon folds in the Mount Belches Formation.

The contrasting lack of strong $F_2$ folds in the shallowly dipping metasedimentary rocks in the centre of the Randall Dome is indicative of the effects of granitoid buttressing of the regional stress regime. The Randall Dome is at its broadest (east–west) where the Kiaki Monzogranite is exposed; aeromagnetic data indicate that the granitoid may, at depth, be as broad as 20 km at these latitudes. Consistent with such an interpretation is the subvertical but outward younging of the Mount Belches Formation away from the Kiaki Monzogranite and adjacent to the bounding faults. That the Kiaki Monzogranite may have been metamorphosed but lacks the $S_2$ foliation is also consistent with deflection of the regional stress regime around the central pluton.

The timing of pre-$D_2$ structures in the Randall Dome relative to $D_1$ thrusting in the Bulong Anticline (Swager, 1995a) and at St Ives 50 km to the east (Swager and Griffin, 1990) is not clear. Krapez et al. (1997) suggested that accumulation of the flysch facies sediments in the Eastern Goldfields, including the Mount Belches Formation, occurred in a foreland sag developed during initial deformation of the region. Such a model would require deposition of the Mount Belches Formation synchronous with thrust development elsewhere, and development of doming (and hence pre-$D_2$ structures in the Randall Dome) after regional thrusting ($D_1$), but before regional east–west compression ($D_2$). The inclusion of felsic and mafic clasts within the Mount Belches Formation is consistent with such a model, but growth faulting or block tilting prior to $D_1$ could also have derived these. An alternative explanation is that vertical granitoid propagation on a broader scale is responsible for $D_1$ thrusting elsewhere, but it is only in the Randall Dome that the relationships are preserved.

In summary, the Randall Dome represents the interference of vertical granitoid propagation with regional east–west compression. Pre-$D_2$ structures may have formed purely by doming of the Kiaki Monzogranite. Alternatively, intrusion of the Kiaki Monzogranite during $D_1$ thrusting along a detachment into ramp anticlines would have enhanced such folds by magma inflation. Relative metamorphic grades, fold vergences, bedding orientations, fault orientations, and available sense of shear indicators suggest that the Randall Dome was uplifted during regional deformation (?$D_2$–$D_3$) between and relative to the Mulgabbie domain to the east and the Gindalbie and Parker domains to the west (see cross section on map).

# Proterozoic mafic dykes (*Ƥdy, Ƥdyb*)

Proterozoic mafic dykes (*Ƥdy*) are exposed at several localities on MOUNT BELCHES. Examination of aeromagnetic data shows that dykes are far more common than indicated by exposure, and that a number of dyke sets are apparent. Weathered dykes are typically overlain by rich red soil with calcareous nodules. Where fresh, intruded rocks have a hornfelsed halo (see **Metamorphism**). The dykes are fine to medium grained and are of a gabbroic to noritic composition, comprising subhedral calcic plagioclase (labradorite) with subordinate clinopyroxene (augite), magnetite, granophyric texture, and rare K-feldspar. No primary olivine crystals are evident in dykes on MOUNT BELCHES, but these have been reported elsewhere in the Yilgarn Craton (Hallberg, 1987).

Two suites of dykes have been distinguished: the c. 2420 Ma Widgiemooltha dyke swarm and the c. 1210 Ma Fraser dyke swarm. These can be distinguished empirically by their orientations when using aeromagnetic data, but have not been segregated on MOUNT BELCHES due to the lack of fresh outcrop.

## Widgiemooltha dyke swarm

Dykes of the Widgiemooltha dyke swarm trend between 060° and 080° and correspond to linear aeromagnetic anomalies. Magnetically negative, east-northeast-trending dykes are crosscut by similarly oriented, magnetically positive dykes.

The Binneringie Dyke (*Ƥdyb*) is a large discontinuous dyke trending approximately 070° that is considered to be part of the Widgiemooltha dyke swarm. It is exposed in the southeastern corner of MOUNT BELCHES (Fig. 3) and forms prominent ridges on YARDINA and COWAN to the south and southwest (Griffin, 1989) where it forms a topographic divide between Lakes Cowan and Lefroy. The discontinuous Binneringie Dyke almost transects the Yilgarn Craton, from near Narrogin (southeast of Perth) in the west almost to the Fraser Complex in the east. Nemchin and Pidgeon (1998) dated baddeleyite from granophyre near the western extremity, deriving a SHRIMP U–Pb age of 2418 ± 3 Ma and Pb–Pb age of 2420 ± 7 Ma. Myers et al. (1997) suggested that dyke emplacement in the Yilgarn Craton coincided with continental disintegration. Nemchin and Pidgeon (1998) suggested that the Widgiemooltha igneous event may be related to 2450 Ma dyke emplacement and associated volcanism (not in the Yilgarn Craton) in Archaean cratons worldwide, which was part of the disintegration of an Archaean–Proterozoic supercontinent.

## Fraser dyke swarm

Only one example of the Fraser dyke swarm* is exposed on MOUNT BELCHES, 5.5 km north of Sampsons Dam (MGA 186224), but it is deeply weathered. Many dykes of the Fraser dyke swarm are recognized on MOUNT BELCHES using aeromagnetic data, typically trending 020–045° but varying locally in orientation. Baddeleyite from granophyre in one of these dykes in the Victory Gold Mine at Kambalda was dated, yielding a SHRIMP $^{207}Pb/^{206}Pb$ age of 1212 ± 10 Ma (Wingate et al., 2000). These authors suggested that the dykes were emplaced subparallel to and approximately synchronous with the Albany–Fraser Orogen in a zone of flexure formed by crustal loading during orogenesis (Wingate et al., 2000).

# Cainozoic geology

Sedimentation in Mesozoic palaeodrainage channels and deep weathering profiles characterize the Cainozoic geology of MOUNT BELCHES. Changes in climate and extensive marine transgressions have affected the southern coast of Western Australia and the southern part of the Yilgarn Craton. Much of the complexity is a result of mild block tilting subsequent to Australia's separation from Antarctica in the Cretaceous. These deposits have been ascribed to the Eundynie Group and assorted regolith types.

## Eundynie Group (*CzE, CzEh, CzEl*)

Eocene rocks of the Eundynie Group of the southern Eastern Goldfields vary from fluvial, to deltaic, to estuarine, to marine in character, and are associated with the palaeodrainage channels of the region. The Lefroy Palaeoriver flowed west to east through the lowlands now occupied by Lake Lefroy on LAKE LEFROY and Lake Randell on MOUNT BELCHES and their associated dune systems (Griffin, 1989; Hocking and Cockbain, 1990; Clarke, 1994). The series of lakes and dunes on the eastern side of the map, from Lake Randell to Dog Lake in the south and to ERAYINIA to the east, covers the Jurassic confluence of the Lefroy and Cowan Palaeorivers (Hocking and Cockbain, 1990; Clarke, 1994). Rocks of the Eundynie Group are commonly located immediately adjacent to these systems, but in the south of MOUNT BELCHES are also spatially associated with modern drainage channels.

Undivided Eundynie Group sedimentary rocks (*CzE*) are commonly deeply weathered or poorly exposed, and comprise sandstone, conglomerate, gravel, siltstone, mudstone, shale, and rare limestone and spongolite (rock containing a high proportion of sponge spicules). Silcrete obscures most features of undivided Eundynie Group, but it is likely that most are of the Hampton Sandstone. The Hampton Sandstone (*CzEh*) is the most widespread unit of the Eundynie Group on MOUNT BELCHES. Outcrops are concentrated in the south and east, and extend as far northward as Round Hill and Miller Dam. Well-sorted tabular sandstone beds are exposed east of Dog Lake (MGA 498152) but bedding in the sandstone is typically obscure and sorting poor. Cross-bedding and channels are preserved in rare vertical sections (Fig. 16). Conglomerate lags containing rounded to angular vein quartz clasts are common and gravel interbeds, siltstone interbeds, and spongolite are present locally. Silcrete commonly caps sandstone exposures and obliterates primary textures, as at the outcrops south of Miller Dam (MGA 448616). Massive to fossiliferous limestone (*CzEl*) is exposed on the southern margin of the Lake Randell playa system (MGA 095434 and 106434). Fossils include various bivalves, brachiopods, gastropods, and possibly bryozoans. Detrital quartz grains are also present.

Clarke (1994) discussed the stratigraphy of the Eundynie Group in detail (Fig. 17). The Hampton Sandstone is of Middle to Late Eocene age. An upper unit of the sandstone transgresses laterally into the Princess Royal Spongolite in the Lefroy palaeodrainage channel (Clarke, 1994), and probably also in the Cowan palaeodrainage channel (Fig. 17). A lower unit is the lateral equivalent of the upper part of the Pidinga Formation in the Lefroy palaeodrainage channel, a sequence of locally lignitic siltstone and claystone interpreted as floodplain to delta deposits, and the Werrilup Formation in the Cowan palaeodrainage channel, a similar sequence representing tidal, deltaic, and lacustrine depositional environments. Regionally, the Eundynie Group is correlated with the Plantagenet Group of the Bremer Basin and the Wilson Bluff Limestone, Hampton Sandstone, and Pindinga Formation of the Eucla Basin (Clarke, 1994).

The characteristics and fauna of the limestone south of Lake Randell are similar to the Norseman Limestone (c.f. Clarke, 1994) to the south in the Cowan palaeodrainage channel, but its stratigraphic position is uncertain due to discontinuous outcrop. Marine limestone, representative of a marine transgression, has not previously been reported from the Lefroy palaeodrainage channel.

Clarke (1994) determined in detail the environment of deposition of the Eundynie Group. According to Clarke (1994), rifting from Antarctica and subsequent relative uplift of the Yilgarn Craton along the Jarrahwood Axis (which trends through the Madoonia Hills towards Round Hill) formed the southward-sloping Ravensthorpe Ramp. This resulted in the reversal of the Cowan Palaeoriver southward towards Esperance, changing the confluence of the Lefroy and Cowan Palaeorivers into a divide.

Fluviodeltaic sedimentation in the Cowan and Lefroy palaeodrainage channels was followed by deposition of the deltaic Hampton Sandstone and estuarine Princess Royal Spongolite during the Tortachilla and Aldinga marine transgressions (Clarke, 1994). Exposure of the Hampton Sandstone east of Round Hill and south of the abandoned Madoonia Downs Homestead site indicates that this unit is not restricted to the Lefroy palaeodrainage channel but is also common in the upper reaches of the Cowan palaeodrainage channel. It seems that the mid- to late-Eocene divide inferred by Clarke (1994) was not well established and that deltaic sedimentation extended over

* The Fraser dyke swarm is a new term assigned to the northeasterly trending dykes in the area after the 1:100 000 map was published.

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**Figure 16. Channel at the base of the Hampton Sandstone, Eundynie Group (MGA 415337). White saprock in the lower third of the photograph is kaolinized metasedimentary rocks of the Mount Belches Formation (*Asb*)**

the former confluence of the palaeorivers during the heights of the marine transgressions. Laterally equivalent Princess Royal Spongolite was developed in estuaries in the flooded Cowan palaeodrainage channels distal to the delta sediments.

The limestone south of Lake Randell represents a marine transgression into the Lefroy palaeodrainage channel. Considering the faunal similarities to the Norseman Limestone and the abundance of Hampton Sandstone in the vicinity, it is likely that this marks the highest point of one of the mid- to late-Eocene marine transgressions (the Tortachilla transgression if it is a Norseman Limestone equivalent).

Tabular beds of the Hampton Sandstone in the Cowan palaeodrainage channel have dips of up to 8° with random orientations, indicating mild, post-Eocene, crustal warping.

# Regolith

Regolith development on Mount Belches has been a prolonged process. Climate change, from wet and humid in the Palaeogene to the semi-arid conditions of the Neogene and today, combined with relative tectonic stability, has resulted in the development of complex deep weathering profiles and expansive playa complexes (Anand, 1997).

## Relict units (*Rl, Rf, $Rgp_g$, Rz*)

Prolonged deep weathering of the Eastern Goldfields has resulted in extensive development of relict regimes. The characteristics of the lateritic profiles vary according to the composition of the parental lithologies.

Laterite development is extensive on Mount Belches, occurring over numerous rock types (*Rl*). Some of the thickest laterites develop on mafic and ultramafic rocks, particularly adjacent to faults where the parent rocks are more foliated or fractured. Such laterites obscure the Randall Fault and the rocks of the Bulong Anticline to the west. Similar profiles are developed over the sedimentary rocks of the Mount Belches Formation. Breakaways locally provide a section through a lateritic profile where saprock (which exhibits relict textures of the parent rock) grades upward into a mottled zone that is variably kaolinitic and ferruginous, to be capped by a ferruginous duricrust. Siliceous horizons, which are variably ferruginous, occur sporadically throughout the lateritic profile. Lateritic profiles are best exposed at The Dog Gap (MGA 173691) and in the central east of the sheet 7 km southwest of Round Hill (MGA 485477), whereas prospect pits in the southernmost Roe Hills reveal nodular ferruginous duricrust overlying serpentinites.

Ferruginous duricrust (*Rf*) represents only the caprock of the lateritic profile that predominates at several

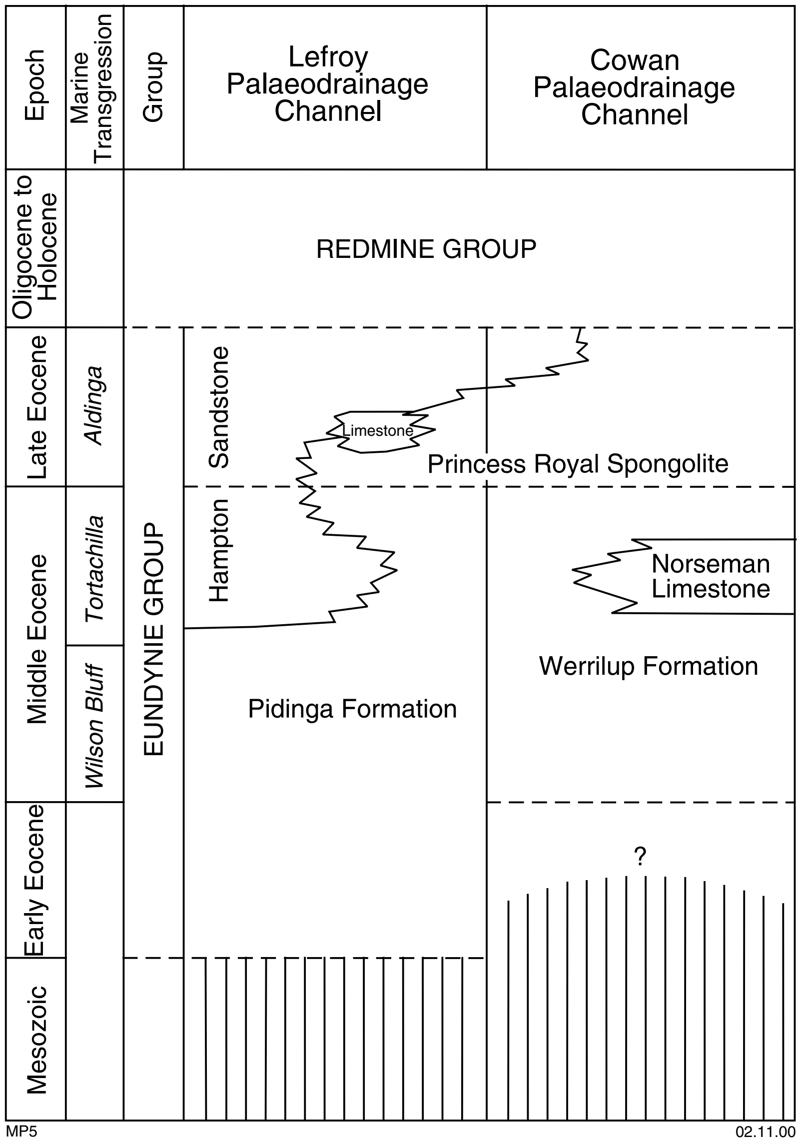


**Figure 17. Stratigraphy of the Eocene Eundynie Group in the Cowan and Lefroy palaeodrainage channels on Mount Belches after Clarke (1994). It is likely that most outcrops on this map sheet belong to the Hampton Sandstone**

localities, including the north shore of Lake Randell (MGA 190536). Ferruginous duricrust comprises massive hematitic ironstone that is variably siliceous and goethitic. Exposure is typically as low hills or breakaways.

Residual material over granitoids (*Rgp*$_g$) is largely represented by soil of granitic composition (containing clay, quartz sand, and saprolite fragments), silcrete, and poorly exposed kaolinized granitoid. Such deposits probably represent deflation over deeply weathered granitoids, and are most common in the southwest corner of Mount Belches.

Silcrete (*Rz*) is present within the lateritic profile over ultramafic, mafic, granitic, and sedimentary rocks on Mount Belches, and commonly occurs as low hills and breakaways. The most extensive exposures cap the sedimentary rocks of the Eocene Eundynie Group (e.g. MGA 370190). Less extensive units overlie granitoids where primary textures are locally preserved. Silcrete comprises chert to jasper (depending on iron content) that may be interstitial to relict rock components or may be massive.

## Colluvium, sheetwash, and sandplain units (*C, Cf, Cgp*$_g$*, Ck, Cq, W, Wf, S*)

Colluvium and sheetwash are distinguished from each other on Mount Belches by their slope of deposition. Colluvium (*C*) is deposited on either sloping or irregular ground, whereas sheetwash (*W*) is deposited on broad gently sloping plains or flats adjacent to Quaternary drainage (*A*). Undivided sheetwash and colluvium comprises variably ferruginous clay, silt, and sand with less common iron-oxide granules, calcrete and silcrete nodules, and lithic float. Ferruginous sheetwash (*Wf*) and colluvium (*Cf*) each contain common to abundant ferruginous granules, nodules or peloids. The ferruginous clasts typically have a polished surface. Many of these deposits represent reworking of the ferruginous duricrust of laterites, commonly as lags of iron-rich material after winnowing of lighter grains by fluvial or sheetwash processes.

Quartzofeldspathic colluvium and wash ($Cgp_g$) comprises quartz- and feldspar-rich silt and sand. Most of the components are sourced from adjacent granitoid. Rare outcrops and aeromagnetic data indicate that this material largely overlies granitoids. Some quartzofeldspathic colluvium contains distinctive, common calcrete nodules (*Ck*). Colluvium adjacent to prominent exposures of the Proterozoic gabbroic dykes also contains common calcrete nodules (*Ck*).

Prominent quartz blows are surrounded by an apron of detrital vein quartz debris (*Cq*). Similar deposits are at the base of some breakaways over the Mount Belches Formation where ferruginous duricrust is not developed, because vein quartz is the only centimetre-sized, weathering-resistant component of the rocks.

Sandplain deposits (*S*) are of limited extent on MOUNT BELCHES. They consist of sheets of yellow quartz sand that are worked into locally prominent dunes. Minor silt and clay are also present. Isolated sand dunes without surrounding sandplains are included in this category.

### Lacustrine units ($L_l$, $L_d1$, $L_d2$, $L_m$, *Lk*)

The playa lake systems on MOUNT BELCHES occupy the Jurassic confluence of the Lefroy and Cowan Palaeorivers (Hocking and Cockbain, 1990; Clarke, 1994) and consist of playas ($L_l$), active dunes ($L_d1$), stabilized dunes ($L_d2$), and areas of mixed deposits ($L_m$). The playas, of which Lake Randell is the largest on MOUNT BELCHES, are broad flat expanses of clay, mud, and sand that contain localized concentrations of carbonate, gypsum, and halite. Active dunes are typically free of vegetation or vegetated only by samphire and saltbush. Active dunes are largely composed of yellow sand with variable amounts of detrital or endogenic gypsum (kopi). Stabilized dunes are vegetated by eucalypts, are of similar composition to the active dunes, and are locally eroded. Mixed deposits comprise interspersed playa, evaporite, dune, and alluvial deposits on broad flats adjacent to larger playas that are grouped because they cannot otherwise be represented at 1:100 000 scale. Calcrete (*Lk*) is located as mappable units within the dunes of the playa lake complexes. Calcrete comprises banded to massive to nodular carbonates (calcite) with subordinate silica, quartz, and iron oxides.

### Alluvium units (*A1*, *A2qz*)

Alluvial deposits have not been subdivided on MOUNT BELCHES. Quaternary alluvium (*A1*) consists of clay, silt, sand, and gravel. It occupies active ephemeral stream channels, adjacent flats, and deltas where streams flow onto the playa flat.

Older alluvial deposits (*A2qz*) are exposed as small breakaways located adjacent to playa lakes 4–5 km east-southeast of the abandoned Madoonia Downs Homestead site (MGA 430228). These rocks comprise medium to coarse, detrital quartz grains cemented by ferruginous chalcedony and rarely iron oxides, and relict bedding and grading are locally preserved. These deposits represent indurated Cainozoic fluvial to lacustrine sediments. These units might be part of the Eundynie Group or overlying Redmine Group (c.f. Clarke, 1994), but this cannot be determined from observed outcrops.

# Economic geology

## Gold

The Randalls and Karnilbinia mining centres represent the two major occurrences of gold mineralization in the Mount Belches Formation. These are classified as orogenic gold deposits according to the scheme of Groves et al. (1998). Mining in the region commenced in the early 1900s (Clarke, 1925) and has occurred sporadically since that time. In the mid-1990s, the Mount Monger Gold Project mined at both the Randalls mining centre, where the Santa Claus and Craze deposits were exploited in one open cut (referred to as Santa-Craze in Newton et al., 1998), and at the Karnilbinia mining centre, where the Rumbles deposit was exploited. A small pit south of Karnilbinia exploited the Cock-Eyed Bob deposit. Up to March 1997, combined figures of 3 222 700 t of ore at 3.2 g/t yielded 10 300 kg of gold (Newton et al., 1998). The mines are presently under care and maintenance.

Economic gold mineralization at Randalls and Karnilbinia mining centre is intimately associated with the iron formation of the Santa Claus Member. Deposits and prospects are preferentially located in the overturned anticlinal hinge zones and immediately adjacent limbs. Within the Randalls deposits, gold is in the alteration zones adjacent to quartz veins rather than within the veins themselves. Shallow-dipping, post-$D_2$ quartz veins within the rheologically competent Santa Claus Member are clustered about synchronous north-northwest-trending faults with minor displacements. Gold concentrations are therefore highest adjacent to these faults because vein concentration is intense. Auriferous alteration zones typically comprise an assemblage of magnetite, cummingtonite–grunerite, hornblende, actinolite, biotite, chlorite, carbonate, and iron sulfides. Wackes immediately above and below the iron formation are also altered. These alteration zones comprise an assemblage of magnetite, quartz, chlorite, and grunerite, with biotite porphyroblasts, minor Ca-amphiboles and carbonates, and are distinguished by the lath or rosette habit of the amphiboles and the interstitial granoblastic quartz (Newton et al., 1998).

Metasomatically altered sedimentary rocks in the Randall Dome are associated with mesoscale to cryptic quartz veining, but some are related to fluids expelled from shallow granitoids and others to the Cowarna Fault Zone. Although no free gold has been observed in these rocks, similar alteration assemblages in sedimentary rocks adjacent to the Randalls and Karnilbinia deposits (Newton et al., 1998) suggest a common formational mechanism (Painter, 1999). They are characterized by lath- or stellate-habit Ca-amphibole in a mass of granuloblastic quartz, but are also locally associated with lesser amounts of biotite, almandine, and carbonate (see **Mount Belches Formation** above). These alteration assemblages are considered part of a continuum commonly associated with gold mineralization that represents metasomatism under varied pressure–temperature conditions. Carbonate-rich alteration represents upper greenschist facies alteration whereas the amphibolitic alteration represents lower amphibolite facies alteration (where calcium is preferentially partitioned into amphibole rather than carbonate; Witt, 1991; Groves et al., 1995; McCuaig and Kerrich, 1998).

In the Bulong Anticline, the Hickmans Find (MGA 079633) and Duchess of York (MGA 095630) prospects are located at the faulted contact of the felsic volcanic unit with the overlying, but younger mafic volcanic and intrusive rocks. Hickmans Find was discovered during project mapping of the Mount Monger area in the early 1980s by the GSWA (referred to as 'Chert Ridge' in Hickman, 1986). Inferred resources were 61.2 kg of gold at 1.8 g/t at Hickmans Find and 303.6 kg at 2.3 g/t at Duchess of York (Hickman, 1986).

## Tantalum, tin, and lithium

Alluvial and colluvial cassiterite and tantalite have been mined at Bald Hill, 1–4 km south of MOUNT BELCHES. The minerals were derived from pegmatites that intrude and greisenize Mount Belches Formation rocks. Similar pegmatites on MOUNT BELCHES, which contain Li-bearing mica, have been exploited at the Mount Belches prospect (MGA 167218). No production figures are available.

## Opal

The Cowarna opal mine in the Roe Hills (13 km east of Cowarna Downs Homestead) contains mostly common opal (potch), jasper, and quartz, but rare precious opal, with green, blue, yellow, and 'ox-blood red' colour flashes was mined (Russgar Minerals NL, 1973). Precious opal, considered to be of higher quality than Coober Pedy opal, is present as stringers and less commonly as small pockets in deeply weathered shale and porphyry. Small-scale mining and exploration in the early 1970s yielded 15.6 kg of precious opal of variable quality from 1500 t of gangue.

## Nickel

No known nickel deposits are located on MOUNT BELCHES. Nickel exploration has periodically focused on the Bulong Anticline, particularly the Seabrook Sill, since the nickel boom of the 1970s. The layered intrusions of the Bulong Anticline are not considered likely hosts to primary nickel sulfide mineralization of economic value (Hickman, 1986). Any mineralization in this area is likely to be hosted by intrusive rocks rather than komatiites as at Kambalda (Marston, 1984). Other exploration in the Trig, Low Trap, and Roe hills has yielded minor nickel anomalies in sulfide-bearing mafic to ultramafic units.

## Talc

Talc was mined at the Lass O'Gowrie mine in the Bulong Anticline (1942–1957, 1411 t), 5 km east of MOUNT BELCHES on LAKE LEFROY (Hickman, 1986; Abeysinghe, 1996). Abundant talc replaces olivine in the peridotites of the Seabrook Sill, particularly those near the faulted contact with the underlying, but younger, felsic volcanic and volcaniclastic rocks. These are in a similar tectono-stratigraphic position to the deposits at Lass O'Gowrie.

# Hydrogeology

Kern (1996) described in detail the hydrogeology of WIDGIEMOOLTHA (1:250 000), which incorporates MOUNT BELCHES. No fresh groundwater was identified. Saline to hypersaline groundwater is contained in aquifers defined by the Eundynie Group in the palaeodrainage channels. Fractured-rock aquifers occupy most areas around outcrop but contain limited supplies. Water for pastoral purposes is entirely derived from surface waters. All dams on MOUNT BELCHES are thus located in modern drainage (*A1*).

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# Appendix 1

# Gazetteer of localities

| Locality | MGA coordinates Easting | Northing |
|---|---|---|
| 8 Mile Dam | 416950 | 6518800 |
| Bald Hill (YARDINIA) | 422300 | 6512900 |
| Bare Hill | 420450 | 6564050 |
| Cock-Eyed Bob deposit | 421500 | 6560000 |
| Cowarna Downs Homestead | 438800 | 6569500 |
| Cowarna opal mine | 449800 | 6568000 |
| Duchess of York prospect | 409500 | 6563300 |
| Eastern Dam | 445000 | 6566800 |
| Emu Flat | 408500 | 6569100 |
| Gundockerta Hill (KURNALPI) | 416600 | 6595800 |
| Hard To Find Dam | 409300 | 6567100 |
| Hawke Hill | 417600 | 6568900 |
| Hickmans Find prospect | 408000 | 6563400 |
| Karnilbinia mining centre | 423000 | 6562300 |
| Lass O'Gowrie mine (LAKE LEFROY) | 399200 | 6564900 |
| Low Trap Hills | 443000 | 6563500 |
| Madoonia Downs Homestead site (abandoned) | 438200 | 6524300 |
| Madoonia Hills | 421000 | 6523000 |
| Miller Dam | 445650 | 6563600 |
| Mount Belches | 427400 | 6558400 |
| Mount Belches prospect | 416600 | 6521800 |
| Mount Monger (LAKE LEFROY) | 403000 | 6561600 |
| Oak Hill | 410100 | 6559300 |
| Old Dry Lake | 405300 | 6538000 |
| Peters Dam | 413350 | 6560750 |
| Powder Dam | 449000 | 6567800 |
| Randalls gold deposit | 424800 | 6564200 |
| Randalls mining centre | 424600 | 6565500 |
| Roe Hills | 450000 | 6566000 |
| Round Hill | 446100 | 6542300 |
| Rumbles deposit | 422600 | 6562400 |
| Santa Claus–Craze deposit | 424600 | 6565300 |
| Sampsons Dam | 417500 | 6515400 |
| Seabrook Hills | 416000 | 6567000 |
| The Dog Gap | 416700 | 6569700 |
| Trig Hills | 445000 | 6569000 |

# Appendix 2

# Definition of new stratigraphic units

## Mount Belches Formation

*Derivation of name*: The unit has been previously referred to as the Belches Beds (Glikson, 1971), Mount Belches beds (Griffin and Hickman, 1988; Griffin, 1989), or the Mount Belches greywacke (Swager, 1995a). The unit takes its name from Mount Belches (MGA 274584) on the northern shore of Lake Randell.

*Lithology*: Variably interbedded wackes and mudstones comprise the Mount Belches Formation. Wacke and mudstone commonly occur together in graded beds, and sedimentary structures such as ripples, Bouma sequences, scours, loads, soft-sediment deformation, and channels, are locally preserved in fine detail. These rocks have been regionally metamorphosed to lower amphibolite grade, with local areas of contact metamorphism to pyroxene hornfels grade. Neomorphic biotite clots in the pelitic portions of beds commonly give the false impression of reverse grading. Staurolite, garnet, and andalusite are preserved locally. The sequence includes the Santa Claus Member iron formation, which contains magnetitic varieties of the above listed clastic lithologies, interbedded with cherty BIF units.

*Distribution*: The Mount Belches Formation occupies a meridional belt from southern KURNALPI in the north to the northeastern shore of Lake Cowan on YARDINA in the south, a distance of approximately 70 km. The sequence may extend under cover for a further 20 km to the south, but this is unclear. At no point does the breadth of the belt exceed 36 km, and it tapers significantly to less than 25 km breadth north of Lake Randell.

*Thickness*: The thickest continuous sequence of stratigraphy exposed on MOUNT BELCHES constrains the Mount Belches Formation to at least 2500 m thick. Dunbar and McCall (1971) estimated a total stratigraphic thickness of approximately 3600 m.

*Relationships with other units*: The relationship between the Mount Belches Formation and adjacent greenstone sequences is obscured by a basal intrusive contact and by the faulted limits to its upper and lateral extent. The presence of felsic volcaniclastic (Griffin, 1989), granitic (Dunbar, 1966), and mafic clasts in pebble lags and mass-flow units indicates that the provenance of the Mount Belches Formation includes mafic and felsic rocks typical of the southern Eastern Goldfields granite–greenstone province.

*Type area*: Good exposures of the Mount Belches Formation can be seen at several localities on the northern shores of Lake Randell, south of the Randalls mining centre. There is almost continuous exposure along the north shore of the lake for approximately 4 km (MGA 266569 to 307592), but the best localities are near the old boiler (MGA 272575), and the shore around a small island in Lake Randell (MGA 279574).

## Santa Claus Member

*Derivation of name*: The unit has previously been referred to as the Santa Claus Ironstone member (Griffin, 1989). The unit takes its name from the Santa Claus gold deposit where it is host to gold mineralization.

*Lithology*: The Santa Claus Member is an iron-rich package of sedimentary rock. Most of the unit comprises graded beds in which the pelitic portion is magnetitic. Two or three subordinate cherty BIF horizons are present. Lithologies present include banded magnetite–quartz rock, magnetitic graded wacke–mudstone units, non-magnetitic graded wacke–mudstone units, and amphibolitic (gruneritic and cummingtonitic) rocks derived by metasomatic alteration. Magnetite–quartz rocks are finely laminated, defined by alternating abundances of magnetite and quartz, and contain accessory grunerite, chlorite, and apatite (Dunbar, 1966).

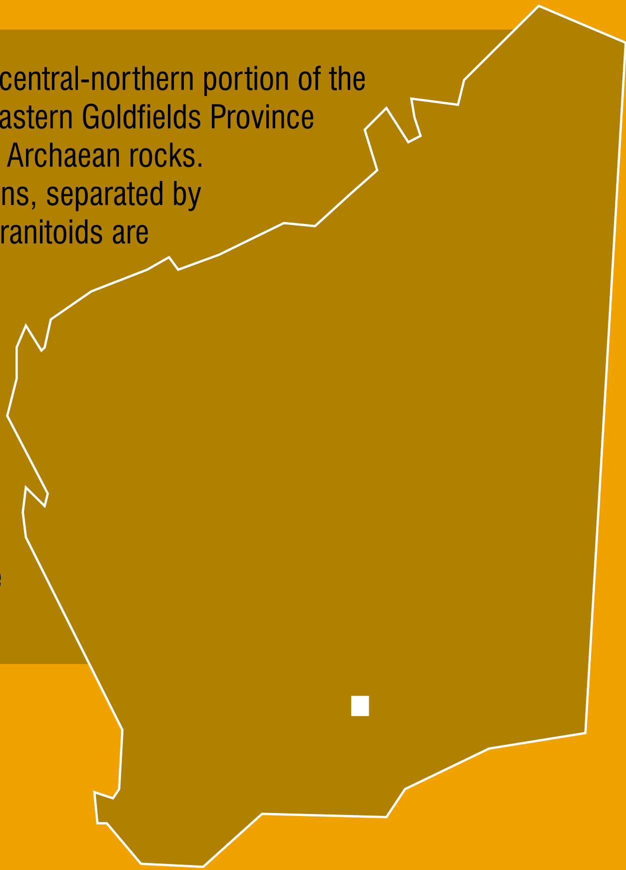
*Distribution*: The Santa Claus Member is restricted to the meridional trending belt occupied by the Mount Belches Formation. It is a clear marker horizon that defines distinctive chevron folds north of Lake Randell. Aeromagnetic data reveal that the unit extends beneath Lake Randell to the east and south, and forms complex interference fold patterns in the Red Peak Gully area. To the west, the iron formation is sheared along the Randall Fault and outcrops as a complexly deformed unit at Bare Hill (MGA 203640). Iron formation (*Aci*) further south in the Randall Dome (MGA 139406, 139393, and 164260) is interpreted to be the lateral continuation of the Santa Claus Member, but outcrop is poor and this cannot be confirmed.

*Thickness*: The thickness of the Santa Claus Member is variable along strike. To the north of Lake Randell, it is around 100–150 m thick. South of Lake Randell, the unit is as little as 10 m thick.

*Relationships with other units*: The Santa Claus Member forms part of the Mount Belches Formation. Its upper and lower contacts are diffuse. Moving up sequence, the base is marked by increasing proportions of magnetite in the pelitic portions of graded beds. Conversely, the top of the unit is marked by decreasing proportions of magnetite. Laterally to the west, the Randall Fault disrupts the unit. South of Lake Randell in the west, its continuation is considerably thinner, and it probably lenses out north of the Mount Belches tin, tantalum, and lithium mine site. To the west, the unit is faulted out against the Cowarna Fault, but, to the south of Lake Randell in the east, chert southwest of Round Hill and staurolitic pelites south of the abandoned Madoonia Downs Homestead site may be lateral equivalents.

*Type area*: The type area for the Santa Claus Member is on the northern shore of Lake Randell (MGA 304590), where the only natural, fresh exposure of the unit is preserved. At the time of writing, the unit may be observed in pits in the Randalls and Karnilbinia mining centres where metasomatic alteration is common.

The MOUNT BELCHES 1:100 000 map sheet covers the central-northern portion of the WIDGIEMOOLTHA 1:250 000 sheet in the southeastern Eastern Goldfields Province of the Yilgarn Craton. MOUNT BELCHES is dominated by Archaean rocks. Recent mapping has identified three greenstone domains, separated by regional-scale fault systems, and the Randall Dome. Granitoids are also present. Details are provided of the greenstone lithostratigraphy that comprises sedimentary rocks, with well-preserved primary structures and a notable magnetic marker unit, as well as mafic to ultramafic volcanic and intrusive rocks. The deformation and metamorphic history is documented together with an interpretation of complex early interference folding. The characteristics of overlying Cainozoic rocks are described. A summary of the economic geology of the area is also included.



**Further details of geological publications and maps produced by the Geological Survey of Western Australia can be obtained by contacting:**

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**100 Plain Street**
**East Perth WA 6004**
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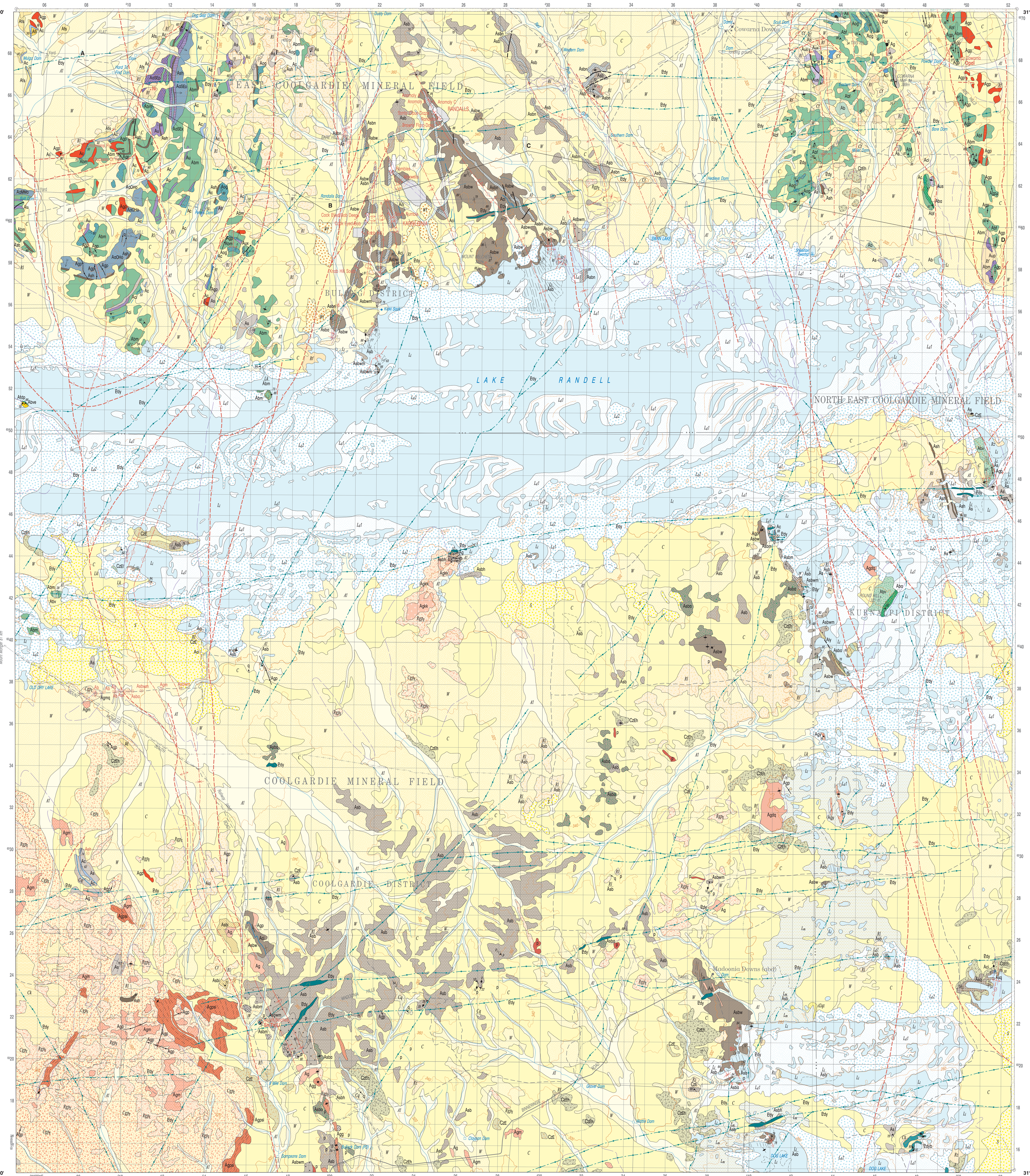
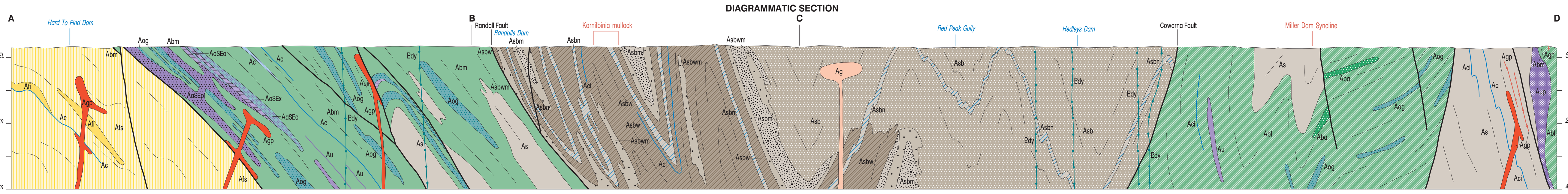
# MOUNT BELCHES

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA






## DIAGRAMMATIC SECTION




Colluvial units

Sheetwash units

Alluvial unit

Lacustrine units

Sandplain unit

Alluvial unit

Relict units

PHANEROZOIC

CAINOZOIC

PALAEOGENE

EOCENE

PROTEROZOIC

PALAEOPROTEROZOIC

ARCHAEAN

YILGARN CRATON

Geological boundary
- exposed
- concealed

Structural symbols are labelled according to the sequence of deformation events, where known
- local deformation events
  - $D_3$
  - $D_2$
  - $D_1$

Fault
- exposed
- concealed
- concealed, interpreted from aeromagnetic data

Strongly foliated rock

Fold, showing axial trace and generalized plunge direction
- anticline; exposed, concealed
- syncline; exposed, concealed
- overturned anticline; exposed, concealed
- overturned syncline; exposed, concealed
- antiformal syncline, exposed

Small-scale fold axial surface, showing strike and dip
- inclined

Small-scale fold axis, showing trend and plunge
- anticline
- Z-vergence
- S-vergence
- M-vergence

Bedding, showing strike and dip
- inclined
- inclined, way-up not known
- vertical
- overturned
- trend of bedding

Palaeocurrent, showing trend and sense of direction
- from asymmetrical ripple marks, sense known

Igneous layering, showing strike and dip
- inclined

Way-up indicator
- igneous layering
- pillow structure

Foliation, showing strike and dip
- inclined
- vertical
- trend of foliation

Cleavage, showing strike and dip
- inclined
- vertical

Stretching lineation, showing trend and plunge

Bedding–foliation intersection lineation, showing trend and plunge

Fracture or joint, showing strike and dip
- inclined
- vertical

Dyke or vein, showing dip
- inclined

Aeromagnetic lineament

Macrofossil locality

Formed road

Track

Railway, abandoned

Fence, generally with track

Homestead — Cowarna Downs

Building

Yard

Horizontal control, minor

Breakaway

Sand dunes

Contour line, height in metres

Watercourse

Soak

Swamp

Dam

Abandoned — (abd)

Position doubtful — (PD)

Mineral field boundary

Mining centre — RANDALLS

Mine (gold, unless otherwise indicated) — Rumbles

Mine, abandoned (for commodities other than gold)

Opencut

Prospect

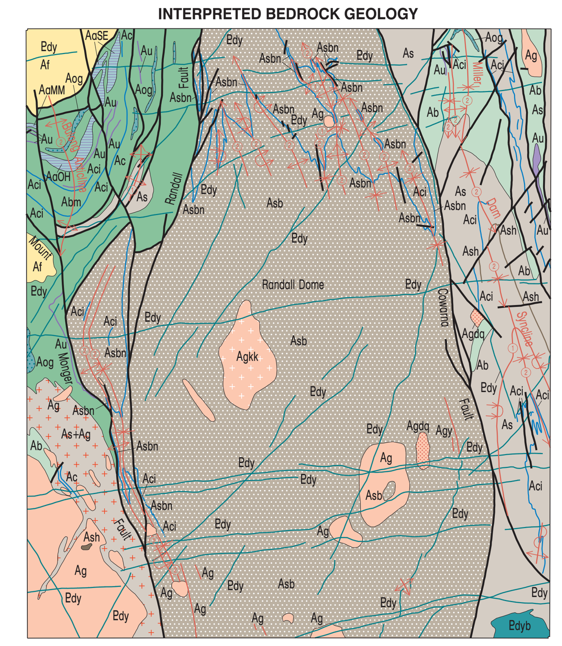
Opencut

Tailings or stockpile

Mineral exploration drillhole, showing subsurface data — Ash

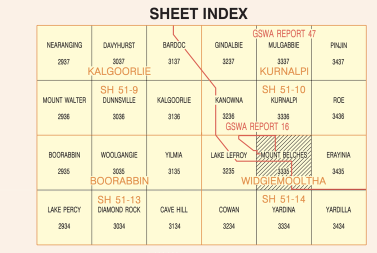
Mineral occurrence
- Lithium — Li
- Nickel — Ni
- Opal — Opal
- Staurolite — St
- Tin — Sn
- Tantalum — Ta

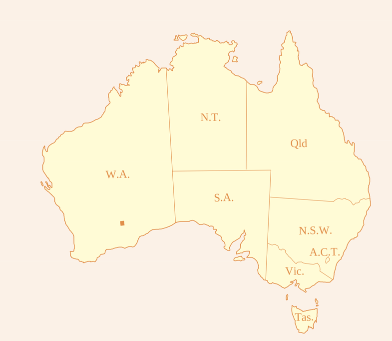
## INTERPRETED BEDROCK GEOLOGY



Dolerite dyke

## SHEET INDEX






Department of Industry and Resources

CLIVE BROWN, M.L.A.
MINISTER FOR STATE DEVELOPMENT

JIM LIMERICK
DIRECTOR GENERAL

Geological Survey of Western Australia

TIM GRIFFIN
DIRECTOR

SCALE 1:100 000

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

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

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

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

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

**Geology by M. G. M. Painter and P. B. Groenewald 1998–1999, and after GSWA maps and reports (see sheet index)**

Other references:
(1) A. A. Nemchin and R. T. Pidgeon, 1998, Australian Journal of Earth Sciences, v. 45, p. 673–675.

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

Cartography by G. Fletcher, A. Veale and P. Taylor

Topography from the Department of Land Administration Sheet SH 51-14, 3335, with modifications from geological field survey

Published by the Geological Survey of Western Australia. Copies available from the Information Centre, Department of Minerals and Energy, 100 Plain Street, East Perth, WA, 6004. Phone (08) 9222 3459, Fax (08) 9222 3444

This map is also available in digital form

Printed by the Sands Print Group, Western Australia

The recommended reference for this map is:
PAINTER, M. G. M., and GROENEWALD, P. B., 2000, Mount Belches, W.A. Sheet 3335: Western Australia Geological Survey, 1:100 000 Geological Series

TN

GRID CONVERGENCE 0.4°

True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2000 and moves easterly by about 0.1° in 2 years.

# MOUNT BELCHES

SHEET 3335 FIRST EDITION 2000