EXPLANATORY NOTES

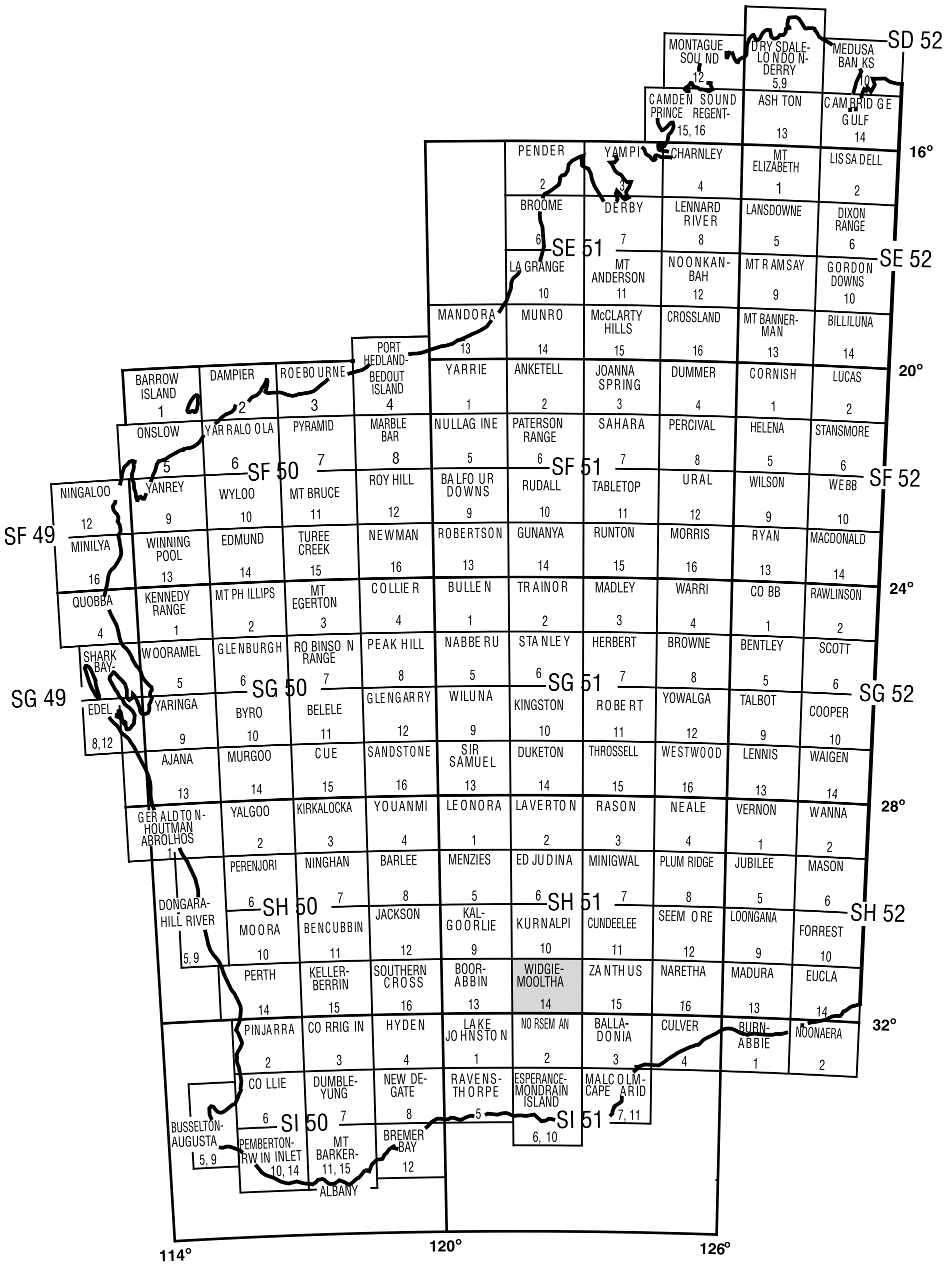
Department of Industry and Resources

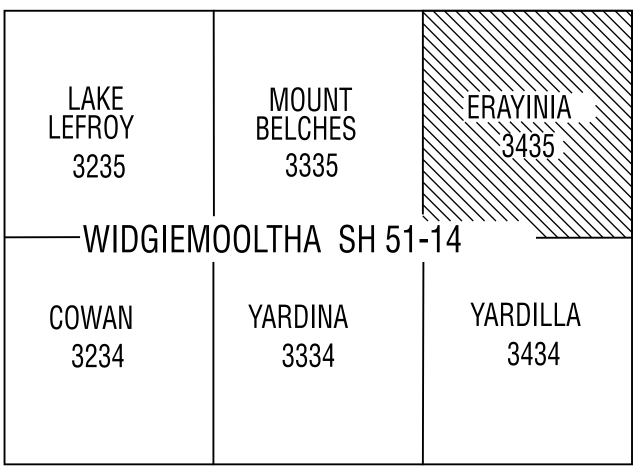
GEOLOGY OF THE ERAYINIA 1:100 000 SHEET

by SA Jones

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia





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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY
OF THE ERAYINIA
1:100 000 SHEET

by
S. A. Jones

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Cover photograph:
Deeply weathered sandstone of the Cenozoic Eundynie Group, central ERAYINIA

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Geology of the Erayinia 1:100 000 sheet

by

S. A. Jones

Abstract

The ERAYINIA 1:100 000 sheet area is about 50 km northwest of the southeastern margin of the Yilgarn Craton, in the Kurnalpi Terrane of the Eastern Goldfields Superterrane. A large part of the map area comprises Archean metasedimentary, mafic volcanic and intrusive rocks, and large granitic intrusions belonging to the Erayinia Granitic Suite. The Proterozoic Woodline Formation overlies the Archean rocks on southwestern ERAYINIA and flat-lying Cenozoic Eundynie Group sedimentary rocks overlie the Archean basement on the southern half of the map sheet area.

Deformation and metamorphism of Archean rocks on ERAYINIA includes D_1 recumbent folds and a bedding-parallel foliation (S_1). Open to tight upright folding resulting from east-northeast – west-southwest crustal shortening during the D_2 event was accompanied by peak M_2 metamorphic conditions ranging from lower greenschist to amphibolite facies. Tightening of these folds and the development of oblique north-northwest-oriented shear zones occurred during continued east–west compression at a late stage of D_2 to D_3. Dextral and sinistral faulting occurred during a possible D_4 event. The dominant structures on ERAYINIA include the north-northwest-oriented Roe Hills Fault, which separates the c. 2667 Ma Mount Belches Formation in the west from older Kurnalpi Terrane rocks to the east. The north–south-oriented Karonie Shear zone hosts a number of significant gold deposits on northern ERAYINIA.

Northeast-oriented upright folds and a variably developed axial-planar cleavage in the Proterozoic Woodline Formation are the result of northwest–southeast compression during the D_5 event. This event marks deformation related to the onset of the Albany–Fraser Orogeny along the southeastern margin of the Yilgarn Craton and is associated with a lower greenschist facies metamorphic overprint (M_5).

On northern and central ERAYINIA there are several gold prospects south of the Karonie gold mine, which is a shear-zone hosted gold deposit in amphibolite facies rocks. There are nickel prospects in a north-northwest-oriented belt of mafic–ultramafic rocks on the eastern side of the Roe Hills Fault zone. Small base metal prospects are located on the eastern side of the map sheet.

KEYWORDS: Archean, granite, greenstone, Eastern Goldfields Superterrane, Kurnalpi Terrane, gold.

Introduction

The ERAYINIA* 1:100 000 map sheet (SH 51-14, 3435), occupies the northeastern corner of the WIDGIEMOOLTHA 1:250 000 map sheet, and is bounded by latitudes 31°00'S and 31°30'S and longitudes 122°30'E and 123°00'E. The map sheet lies in the Kurnalpi District of the North East Coolgardie Mineral Field, about 100 km east of Kalgoorlie (Fig. 1), with the Great Victoria Desert to the east and the Nullarbor Plain to the southeast.

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

Access

ERAYINIA is about 100 km east-southeast of Kalgoorlie–Boulder and covers two pastoral leases, Cowarna Downs on northwestern ERAYINIA, and Madoonia Downs on central western ERAYINIA (Fig. 2). The homesteads of these stations are on the adjacent map sheet area, MOUNT BELCHES.

Access to ERAYINIA from Kalgoorlie–Boulder is via the Trans Access Road that runs parallel to the east–west Trans Australian Railway. Numerous fence-line tracks off the Trans Access Road connect to a network of variably maintained exploration tracks extending across ERAYINIA. There is also a well-maintained track from the Trans

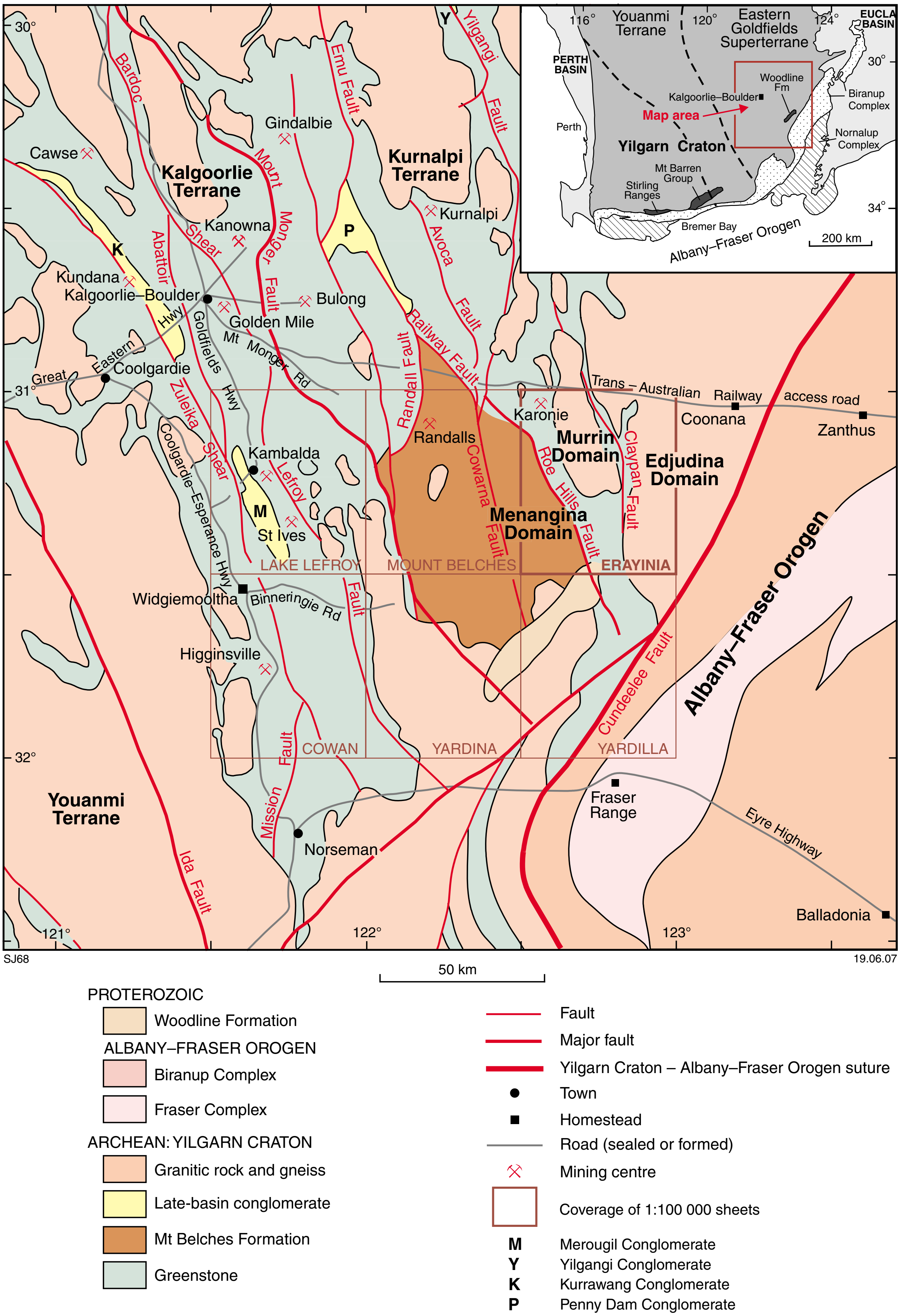


Figure 1. Location and regional geological setting of Erayinia

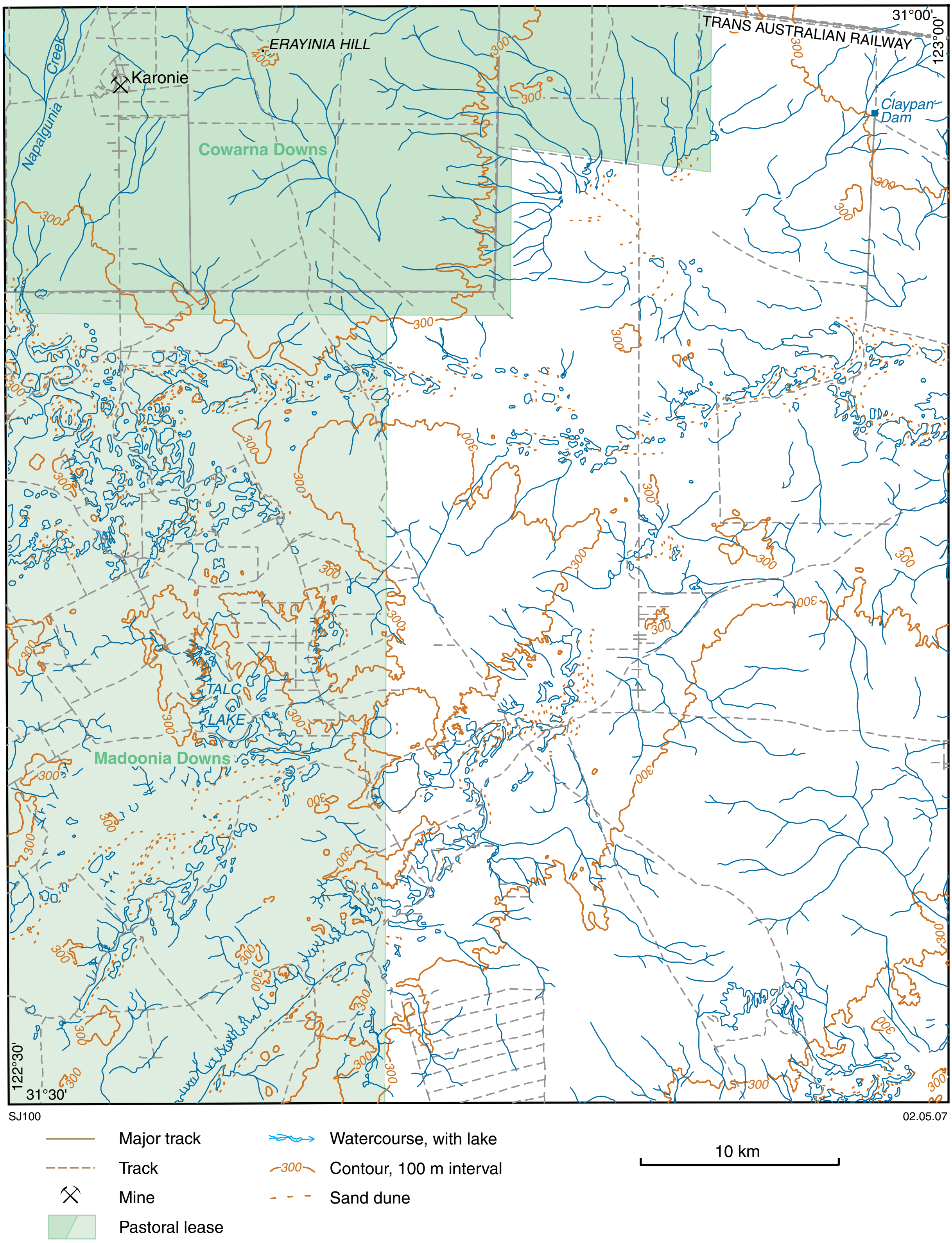


Figure 2. Main cultural and physiographic features on Erayinia

Access Road to the Karonie gold mine, which gives access to good exploration tracks.

Climate, physiography, and vegetation

The climate of ERAYINIA is semi-arid. Average annual rainfalls recorded at the closest weather stations, Norseman and Rawlinna, are 287 and 195 mm, respectively. The highest rainfall is typically during the winter months with sporadic rainfall in summer from isolated thunderstorms and dissipated tropical cyclones. Temperatures in the summer months commonly exceed 35°C and winter minimum temperatures commonly drop below 5°C with minor frosts*.

Streams are typically ephemeral, although some swamps and gnamma holes retain water through all but the driest months. Some creeks form sizeable drainage patterns across ERAYINIA. They include the southwest-draining Napalgunia Creek on the northwestern corner of the map sheet; the west to east drainage pattern across the centre of ERAYINIA, informally named Lake Rivers; and a series of large northeast-trending playa lakes on the southwestern part of ERAYINIA (Fig. 2). The lakes generally have low but steep scarps and rocky outcrops on the western shore, whereas the eastern margins are dominated by sand dunes and abundant small ephemeral lakes. The best outcrops of Archean rocks are around the lakes on the central and western parts of the map sheet.

ERAYINIA has large areas of irregular terrain consisting of isolated low ridges and broad sheetwash plains. A deep weathering profile and thick colluvium cover much of the bedrock. Although bedrock exposure is poor, bedrock structural trends visible on aerial photos and satellite imagery suggest that the regolith cover is relatively thin in places. Relief is typically low across the sheet area, with the highest point (419 m above Australian Height Datum; AHD) at Erayinia Hill. A large rock-covered ridge on the southern part of ERAYINIA is formed by the Proterozoic Woodline Formation.

ERAYINIA lies in the Eremaean Botanical Province of Diels (1906), and occupies part of the southwest Botanical Province and the southwest interzone of the Eremaean Province of Beard (1975, 1985, 1990). The broad low ridges and sheetwash plains that dominate ERAYINIA are covered mainly by mixed eucalypt woodland including *Eucalyptus salmonophloia*, black butt (*E. lesouefii*, *E. dundasii*), and patches containing both giant mallee (*E. oleosa*) and merrit (*E. flocktoniae*). The eucalypts are intermingled with tall shrubs dominated by broombush (*Eremophila scoparia*), greybush (*Cratystylis concephala*), bluebush (*Maireana sedifolia*), and saltbush (*Atriplex vesicaria*), with a patchy ground layer of grasses and ephemeral herbs (Beard 1975, 1990). Large open areas are interspersed with the thick mixed bushland and consist of widely spaced salmon gums and gimlet, with an understory of bluebush and grasses. Wattle, mulga (*Acacia* spp.), and broombush are common on granite-derived soils, especially on the western side of the map sheet area. In localized zones amongst the bouldery granite outcrops on northern and central ERAYINIA, there are minor occurrences of *Eucalyptus woodwardii* (lemon-flowered gum), *Eucalyptus kruseana* (bookleaf mallee), and red flowering bottlebrush species. On mafic-derived soils, black-butt eucalypt species are common. The vegetation around the playa lake systems is dominated by samphire (*Halosarcia* spp.), saltbush, bluebush, and greybush (Beard 1975, 1990). Large patches of spinifex are common on granite and felsic volcanic rock outcrops across the map sheet. The soils are highly calcareous on the southern part of ERAYINIA, but become slightly less calcareous to the north and west (Northcote et al., 1968). Sandy soil is present on many outcrops, especially around granite outcrops on northeastern and central ERAYINIA.

* Climate data from Commonwealth Bureau of Meteorology website, 2007

Previous investigations

Sofoulis (1966) recorded the geology of the ERAYINIA sheet in the first edition of WIDGIEMOOLTHA (1:250 000). The geology of ERAYINIA was revised by Griffin (1989) in the second edition of WIDGIEMOOLTHA (1:250 000). Broad tectonic models of the Eastern Goldfields have included parts of ERAYINIA (e.g. Swager 1995, 1997; Krapez et al., 1997). The Erayinia Granitoid Complex (Griffin, 1989) is now known as the Erayinia Granitic Suite (Riganti and Groenewald, 2004). Proterozoic rocks of the Woodline Formation have been dated by Turek (1966) and Hall and Jones (2005).

Open-file reports, maps, and data from mining and exploration tenements submitted to the Department of Industry and Resources (DoIR) are available from the WA Mineral Exploration database (WAMEX) at the DoIR library in Perth and at the GSWA Kalgoorlie regional office. WAMEX reports are becoming progressively available online at the DoIR website (www.doir.wa.gov.au).

Current work

Mapping on ERAYINIA was carried out to complete 1:100 000 scale coverage of the eastern margins of the Yilgarn Craton. Data from ERAYINIA has been added to the East Yilgarn 1:100 000 Geological Information Series (Geological Survey of Western Australia, 2007), a seamless geological geographic information system covering most of the Eastern Goldfields.

Fieldwork for ERAYINIA was carried out in October 2002 and from April to November 2003. Mapping was based on 1:25 000 aerial colour photographs taken in January 2002. Aeromagnetic data with a line spacing of 200 m flown by Fugro Airborne Surveys in 2001 was used for geological interpretation. Landsat Thematic Mapper false-colour imagery (using ratios of bands 2, 3, 4, 5, and 7) assisted the interpretation of regolith unit distribution.

Nomenclature

Although Archean rocks on ERAYINIA have been affected by different grades of metamorphism, for ease of description the prefix 'meta' has not been used where primary textures are well-enough preserved to allow identification of a protolith. Metamorphic terminology has been applied to rocks for which protoliths cannot be identified.

Regional geology

ERAYINIA is close to the southeastern margin of the Eastern Goldfields Superterrane (Cassidy et al., 2006), which is characterized by a pronounced north-northwest structural fabric defined by a network of anastomosing major faults and linear to arcuate greenstone belts separated by large elongate granitic bodies (Fig. 1). The geological history of the area is shown in Table 1. The Eastern Goldfields Superterrane has been subdivided into a number of terranes, based on differing lithostratigraphic packages that are separated by major faults, although there is currently no consensus on the precise locations of terrane boundaries (e.g. Myers, 1990, 1995, 1997; Swager, 1995, 1997; Swager et al., 1997; Groenewald, et al., 2002; Barley et al., 2002; Cassidy et al., 2006). Following the nomenclature of Cassidy et al. (2006), ERAYINIA lies within the Bulong, Murrin, and Edjudina Domains of the Kurnalpi Terrane. The Roe Hills Fault separates the Bulong and Murrin Domains on ERAYINIA, while the Claypan Fault forms the boundary between the Murrin and Edjudina Domains (Swager, 1995; Myers, 1997; Cassidy et al., 2006). It has been suggested that the Kurnalpi Terrane can be separated from the Kalgoorlie Terrane based on lithostratigraphy and sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon ages (Swager, 1995; Brown et al., 2001). These studies highlighted the presence of banded iron-formation (BIF) and smaller volumes of komatiite in the Kurnalpi Terrane than in the Kalgoorlie Terrane. SHRIMP U–Pb zircon data (Nelson, 1997; Swager et al., 1997) suggests that andesitic–dacitic volcanism in the Kurnalpi Terrane occurred at 2720–2705 Ma, slightly earlier than in the Kalgoorlie Terrane. However, Nelson (1995) dated a felsic volcanic unit that lies between two komatiite flows in the western part of the Menangina Domain at 2706 ± 3 Ma, and a volcaniclastic unit overlying this succession at 2673 ± 7 Ma, demonstrating contemporaneity with similar units in the Kalgoorlie Terrane. Because the stratigraphy of the Kurnalpi Terrane remains poorly understood, further work is necessary to characterize the differences between these terranes.

The Bulong Domain is bounded by the Mount Monger, Randall, Emu, Avoca, and Roe Hills Faults and consists of a thick siliciclastic turbiditic sequence (Fig. 1). To the east, the Menangina Domain (formerly the Jubilee and Steeple Hill Domains of Swager, 1997) lies between the Emu and Yilgangi Faults and consists of mafic–felsic volcanic and volcaniclastic rocks (Fig. 1). To the west of the Avoca Fault there is a west-dipping, west-younging sequence of basalt and several thin and discontinuous komatiite layers dominated by olivine cumulate with minor amounts of gabbro and spinifex-textured basalt. Regional lateral facies changes from basalt-dominated to felsic volcaniclastic–dominated sequences are interpreted as original depositional features representing local coeval felsic volcanic centres (Swager, 1995). East of the Avoca Fault there is a folded sequence of basalt–dolerite and thin, discontinuous komatiite (Steeple Hill Syncline), overlain by a highly variable sequence of felsic and mafic volcanic and volcaniclastic rocks and minor amounts of fine-grained metasedimentary rock. To the north, this sequence dips and youngs to the east and contains several basaltic to felsic volcanic and volcaniclastic sequences with marked lateral facies variation between mafic- and felsic-dominated components. The upper sequence is divided by a major shear zone into an upper unit with an age of 2684 ± 3 Ma (Nelson, 1995), and a lower felsic fragmental unit with an age of 2708 ± 7 Ma (Nelson, 1997). In the eastern part of the Menangina Domain, thin komatiite units (possible structural repetitions) are truncated against the Yilgangi Fault. Swager (1995) also noted regional low-angle faults separating mafic and felsic successions and suggested that D_1 thrusting resulted in some local stacking of the greenstones.

The Murrin Domain is bounded to the west by the Yilgangi and Roe Hills Faults and the Claypan Fault to the east (Fig. 1). The stratigraphy can be broadly summarized as a west-dipping, westward younging sequence of mafic to felsic volcanic and volcaniclastic rocks and interlayered metasedimentary rocks including mudstone, chert, siltstone, sandstone, and minor amounts of conglomerate. Substantial calc-alkaline (andesitic) volcanic and volcaniclastic rocks are present throughout this domain. Low-angle faults, folding, and marked lateral facies variations are common. Large-scale bedding-parallel D_1 thrust faults may have repeated and/or juxtaposed various volcano-sedimentary sequences.

The Edjudina Domain, bounded by the Claypan and Pinjin Faults (Fig. 1), is characterized by tholeiitic basalt, calc-alkaline andesitic volcanic complexes, and minor amounts of komatiite (Swager, 1995). These are overlain by a laterally extensive belt of epiclastic rocks that are interleaved with distinct regional marker horizons of banded iron-formation, chert, and slate, and have been intruded by dolerite sills (Swager, 1997). An age of 2708 ± 6 Ma has been obtained for a fragmental dacite in a felsic sequence associated with calc-alkaline rocks in the southeast of the Edjudina Domain (Nelson, 1995). The eastern part of the Edjudina Domain contains middle to upper amphibolite-facies greenstones bounded to the east by a granite–gneiss complex. The amphibolite-facies greenstones are thought to represent a lower crustal level of the Edjudina Domain, and consist of an eastern association of basalt and banded iron-formation and a western andesite–dacite sequence. Minor amounts of komatiite are found throughout the sequence. Within the intermediate volcanic sequence, a fragmental dacite has been dated at 2713 ± 14 Ma (Nelson, 1995).

The Eastern Goldfields Superterrane was affected by four major compressional events, with various authors also arguing for extensional deformation both preceding the earliest compression and at various times during the compressive cycle (Table 1; Archibald et al., 1978; Archibald, 1987; Hammond and Nisbet, 1992; Williams, 1993; Passchier, 1994; Swager et al., 1997; Nelson, 1997; Swager 1997; Weinberg et al., 2003; Blewett et al., 2004). Typically, the earliest deformation event (D_e) has been interpreted as an extensional event, the nature of which is not well constrained (Hammond and Nisbet,

Table 1. Summary of the geological history of the southeastern Eastern Goldfields Superterrane

Age (Ma)	*Features*	*Timing constraints*
	D_e — extension	
c. 2705	Low-angle shear on granite–greenstone contacts[a] Deposition of komatiite–basalt synchronous with intrusion of layered mafic to ultramafic sills	Felsic tuff interbedded with komatiites c. 2705 Ma[b]
>?2666	Deposition of Black Flag Group; Mount Belches Formation[c]; intrusion of pre-D_2 granite into Mount Belches Formation[e]	Youngest depositional age of Black Flag Group and Mount Belches Formation[d]
	D_1 — N–S compression (?diachronous)	
2683 – <?2672	N–S-directed thrusting and local recumbent folding[e,f,k]; M_1 associated with development of layer-parallel foliation	Felsic volcanic rocks 2681 ± 5 Ma, 2675 ± 3 Ma[o] maximum age; 2674 ± 6 Ma post-D_1 felsic porphyry dyke[r] between Kalgoorlie and Democrat
	Post-D_1 and pre-D_2 extension	
<2672 – >2655	Follows D_1 with roll-over anticlines and E–W extension leading to clastic infill of local synclinal basins[h]	Post-D_1 and pre-D_2 felsic porphyry 2674 ± 6 Ma[r]; pre-dates Kurrawang and Merougil Conglomerates; Voluminous granitic intrusions at 2675–2657 Ma[o]
	D_2 (Wangkathaa Orogeny[z]) — E–W compression (?diachronous)	
c.2675 – 2655	E–W shortening with upright folds and shallow NNW-plunging fold axes[e,g,i]; folding and doming of granite bodies driven by granite-buoyancy regional stresses[t]; M_2 peak metamorphic conditions during D_2–(?D_3) lower-middle greenschist facies to amphibolite facies	Maximum: 2675 ± 2 Ma[j] post-D_1 monzogranite; minimum 2660 ± 3 Ma[o] post-D_2 monzogranite; Kambalda Anticline; syn- or late-deposition of the Kurrawang Sequence at 2655 Ma[d]
	D_3 — transpression	
c. 2663 – 2645[h,o]	Tightening of F_2 folds[l,m]; conjugate shearing wanes at 2630 Ma; contemporaneous with and outlasting D_2	Minimum: 2658 ± 13 Ma (Brady Well Monzogranite); Boulder–Lefroy Fault[m,e], Butchers Flat Fault[e]
	D_e post-orogenic collapse	
c. 2640	Post-metamorphic orogenic collapse[s]	Late-tectonic granite c. 2640 Ma; Ida Fault
	D_4 — transpression	
< ?2640	W to WNW oblique sinistral faults[g]; NE to ENE oblique dextral–reverse faults[g,k]; Low-Ca granitic intrusion throughout D_2–D_4[t]	2638 ± 26 Ma[p]; 2651 ± 5 Ma[q] post-tectonic alkaline granites; Paddington area, Mount Charlotte, Black Flag Fault
	Dyke intrusion	
c.2420	Intrusion of Widgiemooltha dyke swarm	c. 2420[u] Binneringie Dyke, Lake Cowan
	Deposition of Woodline Formation	
<1620	Deposition of Woodline Formation; NW to SE paleo-flow direction	>1737 Ma Quartz arenite, ERAYINIA
	D_5 — Albany–Fraser-related deformation	
c. 1345 – 1260	Deformation of Archean rocks (and Woodline Formation) related to dextral transpression probably during late Stage I phase[v] of the Albany–Fraser Orogeny; M_3 lower greenschist- to amphibolite-facies metamorphism of Archean and Proterozoic rocks (Woodline Formation) during the Albany–Fraser Orogeny	YARDILLA and southern ERAYINIA
	Dyke intrusion	
c. 1210	Intrusion of Fraser dyke swarm Peak thermal metamorphism post-dates main collisional event[x] (early ?Stage II)	c. 1210 Ma[w] dolerite dyke, Kambalda 1205 ± 10 Ma[x] random mineral growth overprinting compressive fabrics; Mount Barren Group[x]
	Marine transgressions	
50 – 38	Deposition of Eundynie Group, and Cowan and Lefroy paleodrainage channels; laterite formation (?)	50–38 Ma[y]; southeastern Eastern Goldfields
<38	Uplift, erosion, laterite development	38 Ma–present; southeastern Eastern Goldfields

NOTES:
(a) Passchier (1994)
(b) Hammond and Nisbet (1992)
(c) Painter and Groenewald (2001)
(d) Krapez et al. (2000)
(e) Swager and Griffin (1990)
(f) Gresham and Loftus-Hills (1981)
(g) Witt (1994)
(h) Swager (1997)
(i) Hunter (1993)
(j) Swager and Nelson (1997)
(k) Archibald et al. (1981)
(l) Swager et al. (1995)
(m) Swager (1989)
(n) Chen et al. (2001)
(o) Nelson (1997)
(p) Hill et al. (1992)
(q) Nelson (1995)
(r) Kent and McDougall (1995)
(s) Goleby et al. (1993)
(t) Weinberg et al. (2003)
(u) Nemchin and Pidgeon (1998)
(v) Clark et al. (2000)
(w) Wingate et al. (2000)
(x) Dawson et al. (2003)
(y) Clarke (1994)
(z) Blewett et al. 2004

1992; Passchier, 1994). This event was followed by D_1 compression, which involved thrusting and recumbent folding, and was followed by east-northeast to west-southwest crustal shortening during D_2, producing major upright F_2 folds (2675–2657 Ma; Nelson, 1997). Subsequent D_3 sinistral movement and associated folding on north-northwesterly trending regional strike-slip faults was then followed by D_4 overprinting with oblique reverse movement on the same structures between 2660 and 2620 Ma (Swager et al., 1997; Nelson, 1997; Swager, 1997).

Regional metamorphism in the Eastern Goldfields Superterrane ranges from low- to intermediate-pressure facies and may correlate with the distribution of granitic bodies (Witt, 1991; Ridley, 1993; Swager 1997; Mikucki and Roberts, 2003). Metamorphic grades in greenstones are typically higher (amphibolite facies) along the margins of surrounding granites, whereas lower grade zones (greenschist facies) are found in the central parts of greenstone belts. Peak metamorphic conditions were typically reached during D_2 deformation, probably contemporaneous with the bulk of granitic emplacement at approximately 2660–2640 Ma (Witt, 1991; Nelson, 1997; Swager et al., 1997).

Much of the Yilgarn Craton has been stable since the Archean with only minor deformation recorded during the Proterozoic and Phanerozoic. At about 2420 Ma, east-northeasterly trending mafic dykes of the Widgiemooltha dyke swarm intruded the region (Nemchin and Pidgeon, 1998). The maximum depositional age of the Proterozoic Woodline Formation was previously considered to be 1620 ± 100 Ma based on Rb–Sr data (Turek, 1966), but recent SHRIMP U–Pb dating suggests a maximum depositional age of c. 1730 Ma (Hall and Jones, 2005). Deformation of this sequence and the Archean rocks along the southeastern margin of the Yilgarn Craton is attributed to the Albany–Fraser Orogeny, which resulted from the continental collision of the Yilgarn and East Antarctic cratons between 1345 and 1140 Ma (Myers, 1990, 1995; Nelson et al., 1995; Clark et al., 2000). At c. 1210 Ma, the northeasterly to north-northeasterly trending Fraser dyke swarm intruded an area within 100 km of the southeastern margin of the Yilgarn Craton (Wingate et al., 2000).

Large paleodrainage channels formed during pre-Jurassic glaciation events and were inundated during the Paleocene by marine transgressions, resulting in widespread deposition of the largely fluviodeltaic to estuarine Eundynie Group (Clarke, 1994; Clarke et al., 2003). Subsequent development of extensive laterite profiles resulted from prolonged deep weathering. 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 paleodrainage channels (Griffin 1989; Clarke, 1994; Clarke et al., 2003).

Archean geology

Archean rocks on ERAYINIA are predominantly deeply weathered, poorly exposed, and covered by regolith. The best outcrops of Archean rocks are in northwestern and central ERAYINIA on the western edges of small playa lakes; they include granitic, metavolcanic, and metasedimentary rocks (Fig. 3). Metasedimentary rocks of the Mount Belches Formation form a northwest-trending sequence along the western edge of ERAYINIA. To the east of this formation there is a narrow northwest-trending belt of mafic–ultramafic rocks. The central part of ERAYINIA is dominated by a mixed volcano-sedimentary sequence of mafic and felsic volcanic rocks interlayered with sedimentary rocks that include conglomerate, sandstone, mudstone, and chert. The Archean volcano-sedimentary sequence is intruded by variably deformed granitic rocks of the Erayinia Granitic Suite in the central part of the sheet area; a small belt of greenstone separates this granite suite from a series of large granitic bodies on the eastern edge of ERAYINIA.

Poor exposure and deep weathering of most of the Archean outcrops on ERAYINIA limit the correlation of units and identification of a coherent stratigraphy. However, aeromagnetic imagery can be used to correlate greenstone units with those on adjacent map sheets (MOUNT BELCHES, Painter and Groenewald, 2000; ROE, Smithies, 1994; YARDILLA, Jones and Ross, 2005; and YARDINA, Hall et al., 2006). Within the Murrin and Edjudina Domains of the Kurnalpi Terrane (Fig. 1), broad-scale stratigraphic correlations are possible and similar structural histories are observed.

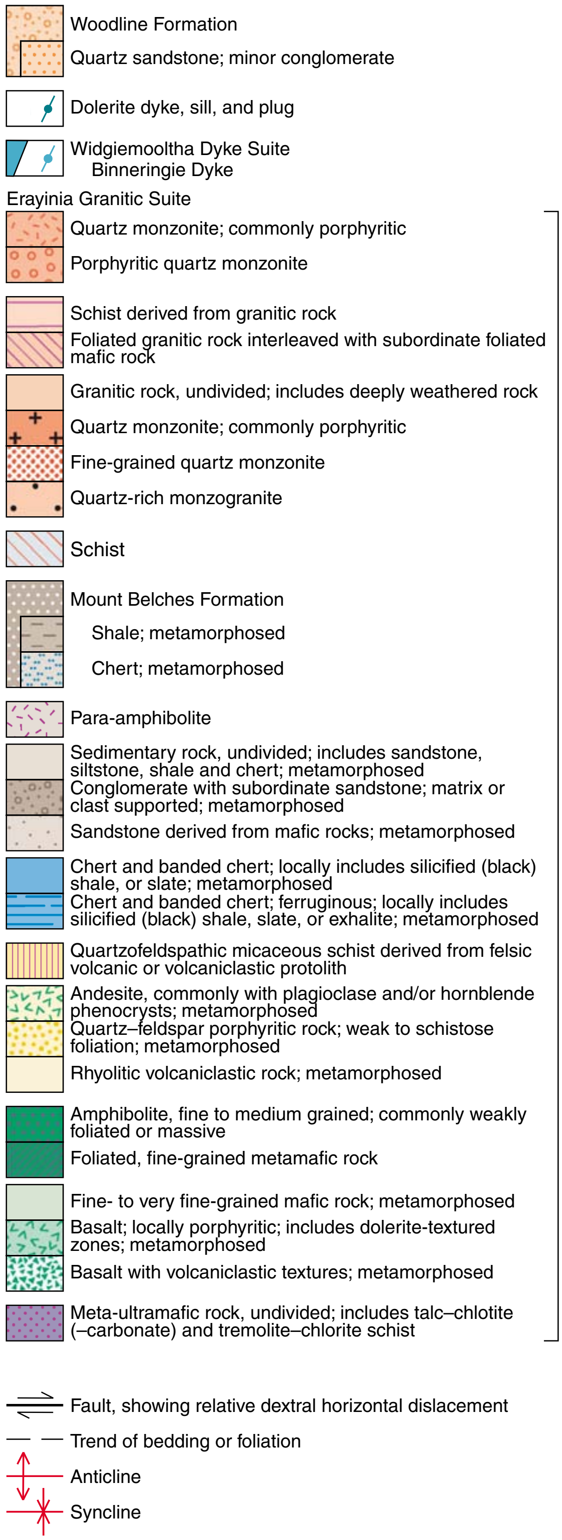
The Mount Belches Formation, which extends along the western edge of ERAYINIA on the eastern limb of the Miller Dam Anticline, is a thick turbiditic sequence with a maximum depositional age of 2666 ± 5 Ma (Krapez et al., 2000). The formation forms a dome above a series of granitic bodies within a large fault-bounded block forming the Bulong Domain (Painter and Groenewald, 2001). Krapez et al. (2000) interpreted the Mount Belches Formation to be a lateral facies equivalent of the Penny Dam Conglomerate to the north, with a facies transition from coarse, proximal polymictic conglomerates to a distal turbiditic sequence. The Penny Dam Conglomerate represents a sedimentary basin, unconformably overlying the older, multiply deformed Archean rocks. Alternatively, Painter and Groenewald (2001) suggested that the Mount Belches Formation may correlate with the upper part of the Black Flag Group in the Kalgoorlie Terrane, because of the similarity of detrital zircon ages and multiple deformation events in the two units. However, no D_1 structures have been recorded in the Penny Dam Conglomerate. In addition, paleoflow measurements in Mount Belches Formation sandstone indicate a flow direction from the east, rather than from the north (Painter and Groenewald, 2001). Therefore, the Mount Belches Formation most likely correlates to the upper part of the Black Flag Group rather than the Penny Dam Conglomerate.

The Mount Belches Formation may extend to the southwestern corner of ERAYINIA, where there is a series of northeast-trending ridges composed of quartz sandstone, siltstone, and chert breccia. These sedimentary rocks may represent a lateral facies change from less quartz-rich sandstone and wacke further north.

The Roe Hills Fault zone separates the Mount Belches Formation on southwestern ERAYINIA from older rocks of the Murrin Domain to the east (Figs 1 and 3). The central and southern part of ERAYINIA is a generally westward younging, mixed volcano-sedimentary sequence of mafic and felsic volcanic rocks interlayered with sedimentary rocks including sandstone, mudstone, chert, and conglomerate. A relatively narrow mafic–ultramafic sequence extends along the eastern side of the Roe Hills Fault zone.

A sandstone unit in the Karonie mine (GSWA 1779916, MGA 458085E 6566870N, Wingate and Bodorkos, 2007a) on northern ERAYINIA has a mean SHRIMP U–Pb age of 2703 ± 5 Ma, implying that the sandstone was derived from a single source. A rhyolitic volcaniclastic unit on central ERAYINIA (GSWA, 177919, MGA 483550E 6542740N, Wingate and Bodorkos, 2007b) has an igneous crystallization age of 2680 ± 5 Ma. This unit is overlain by a thick sedimentary sequence of sandstone, conglomerate, and siltstone and shows a lateral facies change whereby the proportion of volcanic to sedimentary rocks decreases markedly to the south. Only minor exposures of basalt and felsic volcanic rocks are present along the southern margin of ERAYINIA. A syncline just to the east of the mafic–ultramafic sequence along the Roe Hills Fault may be equivalent to the Steeple Hill syncline to the north on KURNALPI (Swager, 1995).

The Claypan Fault separates the Murrin Domain from the Edjudina Domain (Swager, 1995) and is interpreted to extend south through the greenstone sequence between the large granitic bodies on northeastern ERAYINIA (Figs 1 and 3). On the eastern side of this fault, in the Edjudina Domain, the greenstone sequence consists of interlayered mafic and felsic schists, and ferruginous chert bands that define tight folds observed on aeromagnetic images. Further to the east, along the eastern margin of ERAYINIA, thin komatiite units and basalt are interlayered with metasedimentary rocks. There is a significant increase in metamorphic grade in the Edjudina Domain from greenschist to amphibolite facies adjacent to large, strongly foliated granitic bodies. This increase in grade might represent uplift from deeper crustal levels, or a contact aureole from the adjacent granites.



Mixed granitic and mafic rocks (*Axmgs-mbs*)

A mixed unit of strongly foliated fine-grained metabasalt interlayered at metre scale with foliated granite (*Axmgs-mbs*) outcrops within large granite outcrops on southeastern ERAYINIA (MGA 495500E 6522500N).

Ultramafic rocks (*Amu, Amusr, Amust*)

Ultramafic rocks, including undifferentiated ultramafic rocks (*Amu*), tremolite(–chlorite–talc–carbonate) schist (*Amusr*), and talc–chlorite(–carbonate) schist (*Amust*), are found predominantly in a northwest-trending belt extending south from the Roe Hills along the western margin of ERAYINIA. These ultramafic units are well exposed in a series of costeans on the western side of the lakes throughout this area. Although these rocks are predominantly strongly foliated and deeply weathered, cumulate textures are still locally visible. In this area, the ultramafic units are closely associated with gabbro and basalt and may form part of a compositionally layered sill or flow, as reported on MOUNT BELCHES (Painter and Groenewald, 2001).

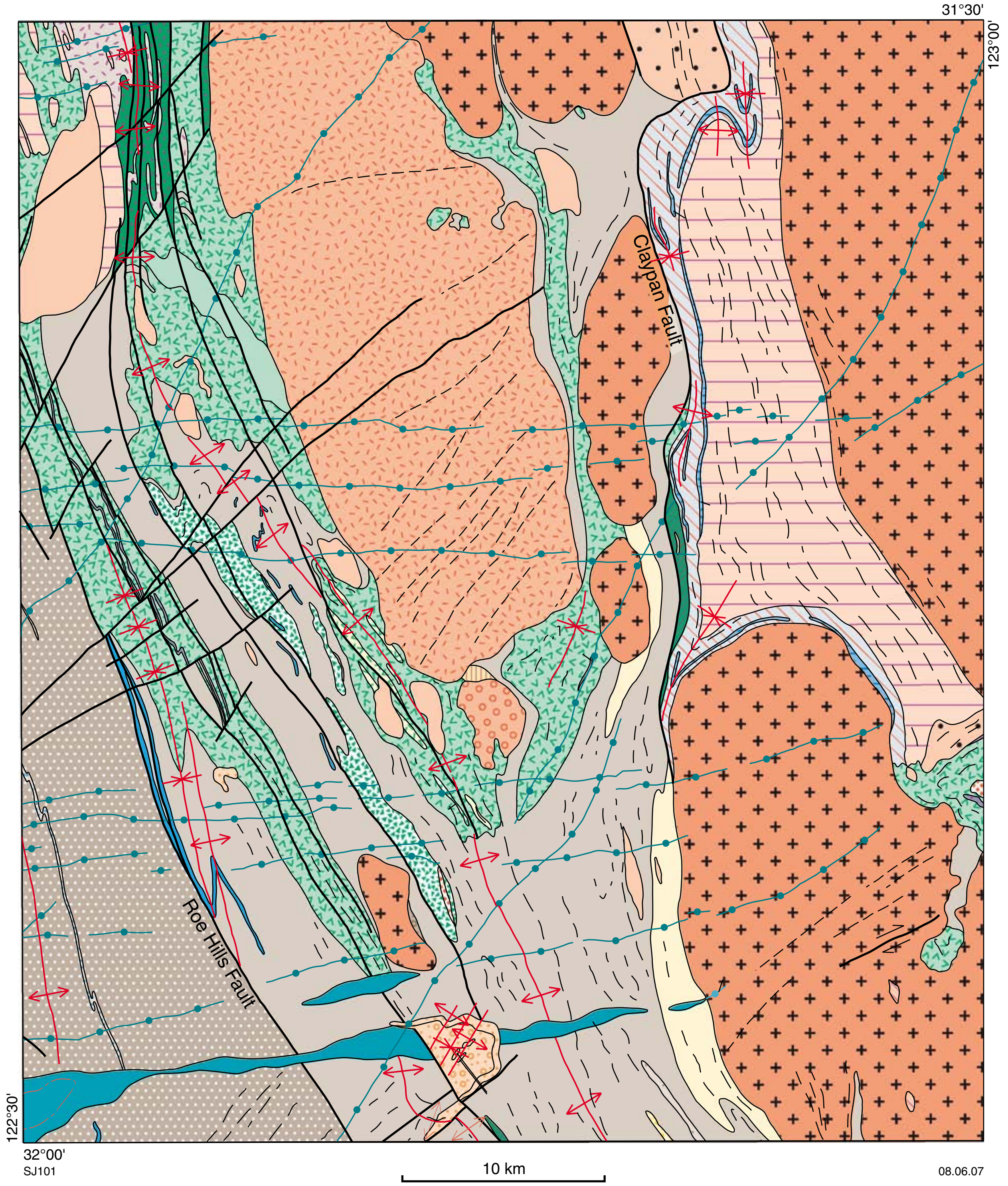


Figure 3. Interpreted bedrock geology on Erayinia

Tremolite(–chlorite–talc–carbonate) schist (*Amusr*) and tremolite-altered pyroxenite are closely interlayered along the lake shore northwest of Talc Lake (MGA 457450E 6543650N). Pyroxenite is also present in RAB drillholes to the south of the lake (MGA 459440E 6541000N) and in thin section has a cumulate texture of tightly packed coarse euhedral to subhedral pyroxene grains with minor amounts of interstitial amphibole and plagioclase. In this sample, fine acicular tremolite overgrows the pyroxene grains. Talc–chlorite (–carbonate) schist (*Amust*), possibly after peridotite, is also found in this area, closely associated with the tremolite(–chlorite–talc–carbonate) schist (*Amusr*). Talc generally dominates these rocks and there are scattered coarse carbonate blebs throughout. Just north of Talc Lake (MGA 461940E 6533610N) the talc–carbonate

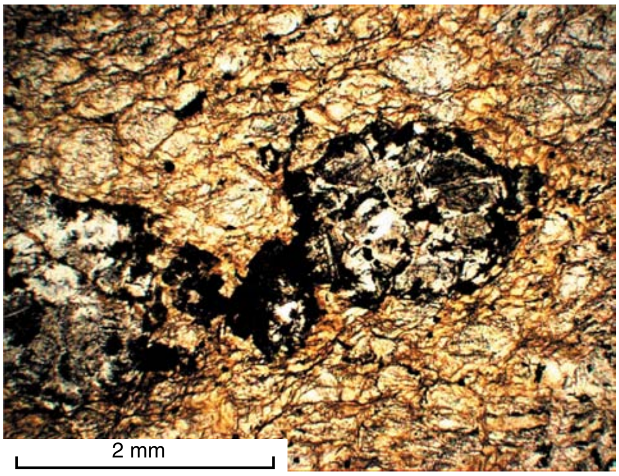


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Figure 4. Coarse carbonate patches and talc after an olivine cumulate rock (*Amu*): northwestern Erayinia (MGA 461945E 6533610N; GSWA 165565; 2.5× magnification, plane-polarized light)

rock has a coarse ?olivine cumulate texture. In thin section, relict round grains (2–3 mm) are tightly packed and completely replaced by talc and carbonate, with the relict cumulate grains still visible within the coarse carbonate blebs (Fig. 4). Similar textures were observed in drillhole samples to the north of Talc Lake (MGA 459250E 6541460N).

Talc–chlorite(–carbonate) schist (*Amust*) also outcrops on central Erayinia (MGA 480340E 6537970N). At this locality the deeply weathered ultramafic unit overlies (or perhaps intrudes) a westward younging, steeply east-dipping sequence of mudstone and chert, and a flow-top breccia unit above the underlying basalt.

Ultramafic rocks are also present near the eastern edge of Erayinia associated with basalt in a small zone surrounded by granite (MGA 499700E 6531800N). The deeply weathered ultramafic rocks are predominantly talc–chlorite(–carbonate) schist (*Amust*), possibly derived from peridotite. In thin section, talc dominates and there are chlorite and serpentine patches containing abundant opaques (mostly magnetite). A strong foliation is defined by an alignment of talc, chlorite, and serpentine.

Metamorphosed fine-grained mafic rocks (*Amba, Ambs, Ab, Abb, Abbg, Abbo, Abbp, Abbv, Abbx*)

Fine-grained mafic rocks form about 25% of the exposed Archean rocks on Erayinia. Undivided fine-grained mafic rocks (*Ab*), basalt (*Abb*), and mafic schist derived from basalt (*Ambs*), are metamorphosed at low- to mid-greenschist facies and are common throughout Erayinia. Amphibolite derived from basalt (*Amba*) is most common on northwestern Erayinia adjacent to, and within, granitic bodies. These mafic units are predominantly massive, fine grained, and lack textures such as amygdales and flow-top breccias. The metamorphosed basalt typically has a fine interlocking, felted texture of chlorite, albite, amphibole, and minor amounts of quartz, plagioclase, and opaques.

Amygdaloidal basalt (*Abbg*) is common on western, central, and southern Erayinia, and forms a marker horizon at the eastern edge of the ultramafic sequence north of Talc Lake (MGA 456200E 6546900N). On central Erayinia, amygdaloidal basalt (Fig. 5) is associated with basalt that has volcaniclastic textures (*Abbv*) and basaltic breccia (*Abbx*) (e.g. MGA 473100E 6526500N; Fig. 6). Amygdales are up to 1 cm wide and are commonly infilled with calcite, clays, and chlorite. The volcaniclastic basalt units commonly contain angular clasts of amygdaloidal basalt in clast- and matrix-supported horizons interlayered with massive and vesicular basalt.

Porphyritic basalt (*Abbp*) forms a large outcrop on northern Erayinia within a larger body of basalt (MGA 472200E 6567000N). It also forms a small rubbly outcrop near the western margin of the Erayinia Granitic Suite (MGA 463300E 6556400N). The porphyritic basalt typically contains abundant euhedral to subhedral feldspar phenocrysts, up to 2.5 cm, randomly oriented in a fine dark groundmass. Pillow basalt (*Abbo*) is observed at the edge of a lake on western Erayinia (MGA 459170E 6550240N) where distinct pillows indicate a westward younging sequence (Fig. 7). Small outcrops of pyroxene-spinifex-textured basalt are common within the ultramafic sequence near the western edge of Erayinia, on the western side of Talc Lake and the lakes to the northwest. The pyroxene-spinifex-textured basalt contains abundant randomly oriented fine pyroxene needles that form the spinifex textures typical of MgO-rich basalt that is associated with komatiite.

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Figure 5. Dark carbonate-filled spherical amygdales in deeply weathered amygdaloidal basalt (*Abbg*): central Erayinia (MGA 473080E 6527215N)

Metamorphosed medium- to coarse-grained mafic rocks (*Aod, Aog*)

Dolerite (*Aod*) is a medium-grained mafic rock metamorphosed at mid- to upper-greenschist facies. It is found on northwestern ERAYINIA near the Karonie mine and along the western edge of ERAYINIA. The unit is typically massive and weakly foliated with ophitic to subophitic textures preserved. Dolerite is commonly associated with finer grained mafic rocks and may represent the coarser grained zones of differentiated mafic flows.

Gabbro (*Aog*) is most common near the western edge of ERAYINIA and is interlayered with metabasalt and amphibolite. The gabbro commonly contains very coarse amphibole crystals (up to 5 cm) randomly oriented and intergrown with variable amounts of plagioclase (e.g. MGA 456200E 6545930N). At this locality there is a sharp contact between the gabbro and fine-grained basalt to the west. Deeply weathered gabbro also outcrops on eastern ERAYINIA (MGA 484560E 6544460N) where it has a coarse cumulate texture and is interlayered with finer grained mafic rocks and chlorite schist.

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Figure 7. Basalt pillows (*Abbo*) indicate upright bedding, younging to top right: central Erayinia (MGA 459170E 6550240N)

Metamorphosed felsic volcanic rocks (*Amfs, Amfak, Af, Afa, Afd, Afrp, Afrvt*)

Felsic volcanic rocks (*Af*) and strongly foliated felsic volcanic rocks (*Amfs*) are predominantly metamorphosed at lower greenschist facies and have a typical mineral assemblage of quartz–feldspar–muscovite(–chlorite).

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Figure 6. Basaltic breccia (*Abbx*), predominantly containing chlorite-altered angular basaltic clasts and minor dacitic clasts, randomly oriented in a fine- to medium-grained chlorite-rich matrix: central Erayinia (MGA 463630E 6541795N)

These felsic units are most common on central ERAYINIA and along the southeastern margin of the map sheet. These rocks are typically deeply weathered and are identified in the field by small round quartz eyes and subhedral to anhedral feldspar crystals in a fine- to medium-grained groundmass. In thin section they are characterized by a fine-grained quartzofeldspathic matrix and randomly oriented feldspar and subordinate quartz phenocrysts. The feldspar phenocrysts are moderately to strongly sericitized and quartz grains are commonly embayed. A few fine epidote and accessory apatite grains are scattered throughout the fine matrix.

Porphyritic felsic volcanic rocks outcrop in several locations on ERAYINIA. Porphyritic rhyolite (*Afrp*) forms a large rubbly outcrop on northwestern ERAYINIA about 5 km south of the Karonie gold mine. This unit also outcrops near the southeastern margin of the map sheet, forming a small ridge (MGA 474200E 6522700N). In thin section, this porphyritic unit has an unusual texture of coarse euhedral plagioclase scattered in a finer groundmass of tightly packed randomly oriented plagioclase laths (Fig. 8). Rhyolitic volcaniclastic rock (*Afrvt*) outcrops on central ERAYINIA (MGA 474500E 6532000N) and on the eastern part of the sheet (MGA 483500E 6543000N; Fig. 9). Andesite (*Afa*), andesitic volcaniclastic rock, rhyodacitic volcaniclastic rock, and carbonate-altered andesite (*Amfak*) are commonly observed in RAB chips from central ERAYINIA. Dacite (*Afd*) forms a large rubbly outcrop on central ERAYINIA (MGA 474800E 6531900N) and is associated with rhyolitic volcani-clastic rocks, basalt, and basalt-derived sandstone. The felsic volcanic rocks on central ERAYINIA form part of a mixed volcano-sedimentary sequence of interlayered basalt, felsic volcanic rocks, and sedimentary rocks.

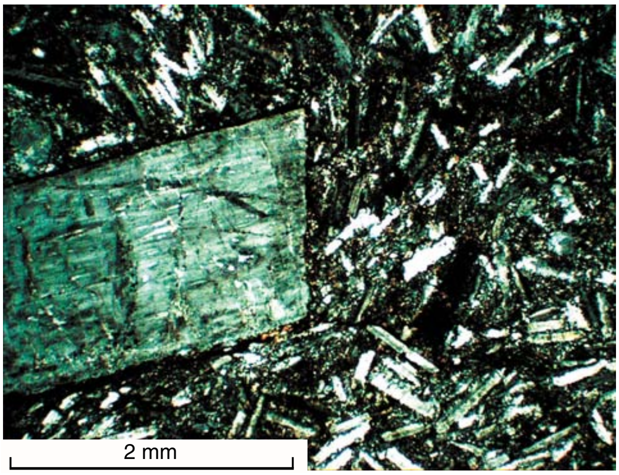

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Figure 8. Large plagioclase phenocrysts in a fine groundmass of randomly oriented plagioclase laths in a porphyritic felsic volcanic rock from southern Erayinia (MGA 474330E 6522630N; GSWA 165573; 2.5× magnification, cross-polarized light)

Metasedimentary rocks (*Amda, Amts, As, Ascp, Asgp, Ash, Asl, Ass, Ast, Astb, Astq, Acc, Acci, Accx*)

Most metamorphosed sedimentary rocks exposed on ERAYINIA are deeply weathered, but retain features indicating their sedimentary origin. Sedimentary units are best exposed along the southern edge of the map sheet and on central, eastern, and western ERAYINIA. Undivided metamorphosed sedimentary rocks (*As*) include metamorphosed mudstone, siltstone, and fine-grained sandstone. Strongly foliated and metamorphosed sedimentary rocks are mapped as metasandstone (*Amts*) and para-amphibolite (*Amda*). Para-amphibolite is observed predominantly on northwestern ERAYINIA and is associated with numerous granitic intrusions and the Karonie Shear zone.

Mudstone or shale (*Ash*) and siltstone (*Asl*) is commonly interlayered with the mafic–ultramafic sequence on the eastern side of the Roe Hills Fault zone (e.g. MGA 456000E 6546500N) and also form part of a thick sedimentary sequence on central ERAYINIA (e.g. MGA 463000E 6546000N). Fine-grained sedimentary rocks, including mudstone interlayered with sandstone (*Ass*), are also common along the southern margin of the map sheet, forming small rubbly outcrops on low ridges. Mudstone and siltstone is typically dark grey, variably carbonaceous, and is commonly interbedded with paler grey, fine-grained sandstone. In some locations, small spherical pyritic concretions are scattered throughout the mudstone and range in size from 1 to 5 mm. Some shale is silicified and is difficult to distinguish from chert (*Acc*). Sedimentary structures such as graded beds, flame structures, scours, and rip-up clasts are visible in fresher exposures along the lake edges. However, most exposures are deeply weathered and moderately to strongly foliated and, as bedding is not visible, classification is based on the presence of local grain-size variations between mudstone, siltstone, and fine-grained sandstone.

Medium- to fine-grained quartzofeldspathic sandstone (*Ast*) is common on central and eastern ERAYINIA (e.g. MGA 486000E 6546000N). Quartzofeldspathic sandstone (*Amts*) also outcrops on western and southern parts of the map sheet area (e.g. MGA 462000E 6536500N). This unit typically has a grain size ranging from 1 to 3 mm and is predominantly weakly foliated, but in places such as the area north of Talc Lake (MGA 464000E 6540000N) there is a strong tectonic fabric. Sandstone derived largely from basalt (*Astb*) outcrops on central and southern ERAYINIA, and is associated with basalt, intermediate volcanic rocks, and metasedimentary rocks. Although this sandstone is predominantly massive, metre-scale bedding is visible in places and, at a broader scale, the sandstone appears to be interlayered with basalt. In areas of deep weathering this unit is difficult to distinguish from the adjacent basalt, but in thin section the rock has fine angular detrital quartz grains with abundant chlorite, feldspar, and biotite forming a fine granular matrix. A weakly developed foliation is defined predominantly by aligned chlorite and muscovite, and appears to overprint an earlier planar fabric that may have been bedding. This early planar fabric is defined by slight variations in grainsize and phyllosilicate content.

Quartz-rich sandstone (*Astq*) is most common on southern ERAYINIA, where rubbly outcrops form a series of low sinuous ridges. The quartz-rich sandstone is typically massive to weakly bedded at a metre scale, with diffuse mm- to cm-scale bedding in places. In thin section the rock comprises a fine, granular quartz-dominated matrix, with angular irregular quartz grains that typically lack volcanogenic features such as embayments, suggesting that the quartz-rich sandstones have a non-volcanogenic origin.

Polymictic conglomerate (*Ascp*) and conglomerate interbedded with sandstone (*Asgp*) outcrop on central ERAYINIA (e.g. MGA 473900E 6531700N) and are also

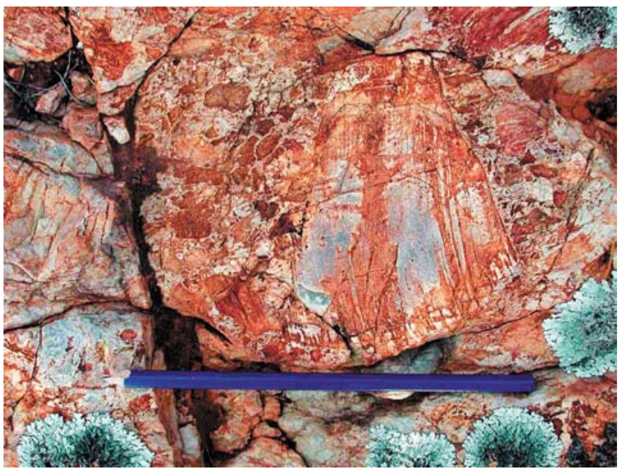

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Figure 9. Poorly sorted angular felsic clasts in a matrix-supported rhyolitic breccia (*Afrvt*), central Erayinia (MGA 474570E 6531570N)

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Figure 10. Polymictic conglomerate (*Asgp*): central Erayinia (MGA 471860E 6525840N)

observed in RAB chips in this area. The conglomerate is composed of clasts of basalt, granite, and metasedimentary rock (Fig. 10). Several clasts display iron staining after sulfides, with disseminated sulfides present in a few rounded siliceous clasts. The conglomerate units are predominantly matrix supported and moderately to strongly foliated. Polymictic conglomerate is also observed on southern Erayinia (e.g. MGA 471860E 6525840N).

Banded chert (*Acc*) is common on southern and central Erayinia (e.g. MGA 463140E 6546780N) and defines large D_2 folds that are visible on aerial photographs and aeromagnetic images. The chert typically forms small narrow ridges and varies from strongly laminated, white, pale, and dark grey chert, to black massive chert, and diffusely banded black, red, and white chert. The chert is commonly interbedded with mudstone or siltstone. It is difficult to determine the origin of the chert units in the absence of detailed petrographic studies, but they may represent diagenetic or supergene silicification of graphitic and sulfidic laminated mudstones and siltstones, rather than chemical sedimentary deposits during periods of tectonic quiescence. A large rubbly outcrop of iron-rich chert (*Acci*) is observed on eastern Erayinia (MGA 485000E 6546000N) and contains abundant iron oxides with hematite coatings that obscure original features. These units are similar in appearance to BIFs, such as those recorded on Mount Belches to the northwest (Painter and Groenewald, 2001). Chert breccia (*Accx*) is common on southern Erayinia and consists of angular chert fragments in a fine, siliceous iron-stained matrix. The chert breccia forms units up to 2 m wide that are commonly interbedded with finely laminated chert or mudstone. At MGA 477500E 6520650N, a minor amount of pyrite is disseminated throughout the matrix and in angular chert clasts.

Mount Belches Formation (*Abe-s*)

The Mount Belches Formation (*Abe-s*) is a thick sequence of metamorphosed turbiditic sandstone and mudstone that covers much of Mount Belches (Painter and Groenewald, 2000, 2001), northern Yardina (Hall et al., 2006), and the western edge of Erayinia (Fig. 1). Mount Belches Formation rocks are dominated by fine- to coarse-grained wacke interbedded with metamorphosed sandstone, siltstone, and mudstone, accompanied by minor amounts of metamorphosed chert, BIF, and conglomerate. On Erayinia, the dominant rock types of the Mount Belches Formation are metamorphosed wacke–sandstone sequences that commonly display graded bedding (Fig. 11), parallel and cross laminations, scours, Bouma cycles, and soft sediment deformation. Many beds have metamorphosed mudstone as the uppermost interval (now dominated by medium-grained metamorphic biotite). Petrographically, the metamorphosed wackes contain relict detrital quartz grains (up to 5 mm) interspersed with biotite clots and poikiloblastic plagioclase crystals, with subordinate amounts of hornblende, chlorite, muscovite, and carbonate, and accessory amounts of magnetite, zircon, titanite, and apatite. The metamorphosed mudstone layers have a similar mineral assemblage, except where the metamorphic grade is higher, where staurolite, andalusite, and garnet are present. The sequence is interpreted to represent deposition by mass-flow traction and turbidity currents in a submarine environment (Painter and Groenewald, 2001).

SHRIMP U–Pb zircon ages from detrital zircons of the Mount Belches Formation metamorphosed sandstone on Erayinia (GSWA 177917; MGA 452380E 6547130N; Bodorkos et al., 2006) indicate a maximum depositional age of c. 2667 Ma (Fig. 12).

Granitic rocks (*AER-gc, AER-gcap, AER-gcp, Amgs, Amgss, Ag, Agc, Agca, Agce, Agcg, Agcp, Agmq*)

Granitic rocks make up about half of the exposed rock on Erayinia, with many granitic rocks classified as undivided (*Ag*). Deeply weathered outcrops are commonly strongly kaolinized, with no distinguishable feldspar, amphibole,

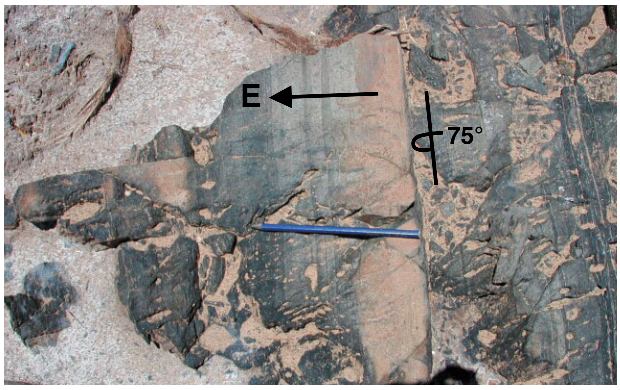

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Figure 11. Graded beds in Mount Belches Formation (*Abe-s*) indicate overturned bedding, western Erayinia (MGA 451450E 6548650N)

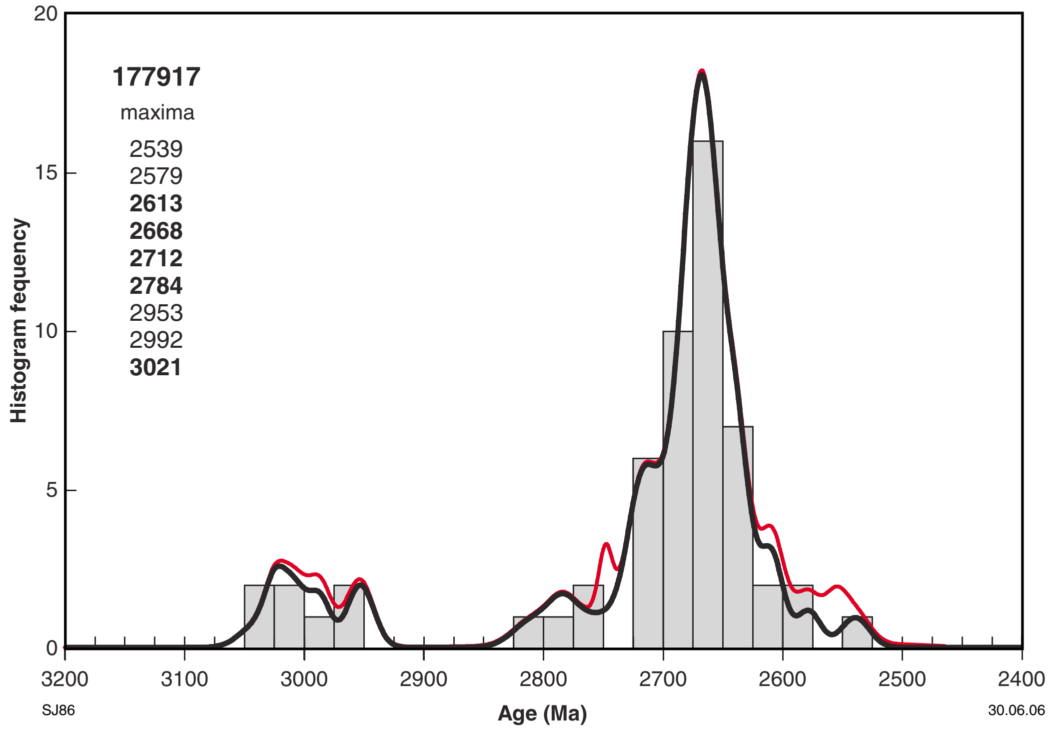

Figure 12. Probability density diagram for sample 177917: metamorphosed tuffaceous sandstone, Round Hill. Black curve, maxima values, and frequency histogram (bin width 25 Ma) include only data with discordance <10% and *f*204 <1% (54 analyses of 50 zircons). Red curve includes all data except discordant analyses (60 analyses of 54 zircons)

or mica to aid in their classification. Much of the granite terrain is dominated by granite-derived sand and soils interspersed with silcrete, calcrete, and scattered loose boulders of strongly weathered granite, which are mapped as relict material over granite (Rgp_g). Foliated granite (*Amgss*) and schistose granite (*Amgs*) are most common around the margins of the large Erayinia Granitic Suite in the northern part of the map sheet area, and in the northwest adjacent to metasedimentary rocks and metabasalt. Foliated and schistose granite is also common on southeastern and eastern Erayinia, where it defines shear zones within the granite.

Figure 13. Porphyritic quartz monzonite (*Agcp*): eastern Erayinia (MGA 492750E 6521225N)

The Erayinia Granitic Suite is predominantly quartz monzonite (*AER-gc*) with common porphyritic zones (*AER-gcp*). Porphyritic quartz monzonite contains abundant feldspar phenocrysts, typically 1 to 1.5 cm long (Fig. 13). Porphyritic fine-grained quartz monzonite (*AER-gcap*) containing abundant euhedral feldspar phenocrysts (typically 1 to 1.5 cm long) intrudes a thick basalt sequence on central Erayinia (MGA 475500E 6534000N) at the southern end of the Erayinia Granitic Suite.

Other granitic rocks on Erayinia are quartz monzonite (*Agc*) and equigranular quartz monzonite (*Agce*) with minor amounts of hornblende and/or biotite. Porphyrytic quartz monzonite (*Agcp*) contains abundant feldspar phenocrysts, typically 0.5 to 1 cm across, and megacrystic quartz monzonite (*Agcg*) has large zoned feldspar megacrysts up to 3 cm across. These units are most common on northern and central Erayinia. Massive fine-grained quartz monzonite (*Agca*) outcrops on southern Erayinia as a large dyke intruding a volcano-sedimentary sequence (MGA 473600E 6526500N). The unit has a fine sugary texture of interlocking quartz, feldspar, and minor amounts of biotite. Foliated mafic xenoliths are common in granite close to contacts with basalt (e.g. MGA 461300E 6570300N). Quartz-rich monzogranite (*Agmq*) is most common on eastern Erayinia.

The quartz monzonites on Erayinia typically contain about 20% quartz and belong to the Erayinia Clan of

Cassidy and Champion (2002). This clan is unique to the eastern parts of the Kurnalpi and Widgiemooltha 1:250 000 map sheets and has a SHRIMP U–Pb zircon age of c. 2660–2655 Ma (Cassidy and Champion, 2002; Fletcher and McNaughton, 2002). The geochemistry of these granites is described by Johnson (1991), Champion and Sheraton (1997), and Smithies and Champion (1999).

Low- to medium-grade metamorphic rocks (*Ams, Amsbg, Amscm*)

Metamorphic rocks with an unknown protolith are predominantly in highly strained areas on eastern Erayinia adjacent to several large granitic bodies. Schist (*Ams*), chlorite schist, chlorite–muscovite schist (*Amscm*), biotite–garnet schist (*Amsbg*), and muscovite schist are closely interlayered at the Calliope Prospect (approximately MGA 484400E 6539000N); the biotite–garnet schist (*Amsbg*) is immediately adjacent to strongly foliated granitic rock. These metamorphic units are also found in drillholes to the south (MGA 484400E 6535000N).

Chlorite schist and chlorite–muscovite schist (*Amscm*) have well-developed schistocity defined by aligned medium-grained chlorite, muscovite, and minor amounts of quartz. The abundance of chlorite suggests that the schist might have been derived from a mafic precursor. Muscovite schist is a strongly foliated rock with a fabric defined by aligned muscovite and recrystallized quartz. The biotite–garnet schist (*Amsbg*) contains abundant biotite with subordinate muscovite and garnets (up to 2 mm) scattered throughout. The strong foliation is defined by aligned biotite and generally wraps around the garnets.

Veins and dykes (*g, zq*)

Small fine- to medium-grained granitic dykes (*g*) ranging from 1 to 5 m in width are common throughout Erayinia. They are typically steeply dipping with a north-northeast trend and are weakly to strongly foliated with minimal contact metamorphism at the dyke margins.

Quartz veins (z*q*) are common throughout Erayinia and are typically composed of massive white quartz. Minor laminated and crystalline quartz veins are also observed. The veins rarely contain carbonate and display a range of morphologies, including foliation- and bedding-parallel tension-gash arrays, and conjugate sets. A wide apron of quartz colluvium (*Cq*) typically surrounds the quartz veins.

Deformation and metamorphism

Four Archean deformation events (D_1 to D_4) and three metamorphic events (M_1 to M_3) are recognized on Erayinia.

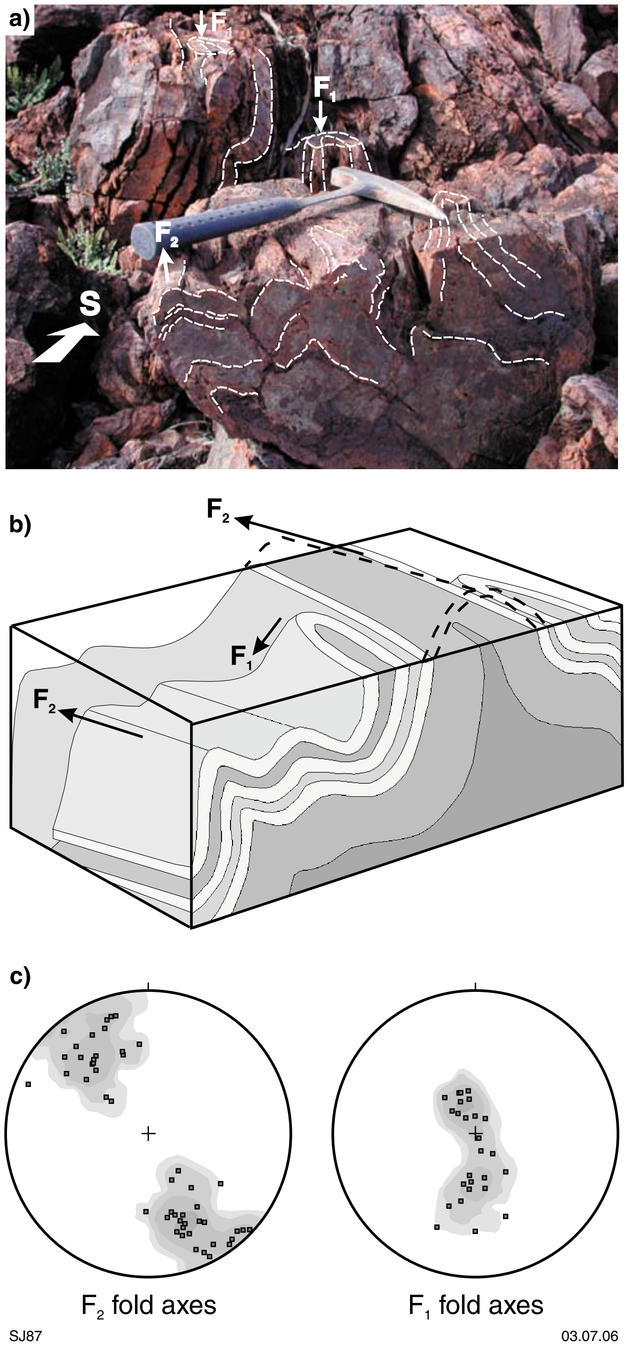

Figure 14. a) F_1 and F_2 fold hinges in banded chert, central Erayinia (MGA 468960E 6536860N); b) diagram illustrating the refolded fold pattern in a); c) stereoplots of F_1 and F_2 folds on central Erayinia

D_1 event

The earliest deformation event (D_1) on Erayinia is characterized by a penetrative S_1 foliation that is near parallel to bedding and is commonly overprinted by a second foliation (S_2). In banded cherts on central Erayinia, tight to isoclinal F_1 folds are refolded by north-northwesterly trending upright F_2 folds (e.g. MGA 468960E 6536859N; Fig. 14). Stereoplots illustrate the marked difference in the orientations of F_1 and F_2 fold axes (Fig. 14c). The D_1 structures on ERAYINIA formed during north–south compression, possibly during the regional D_1 event (2700 to 2675 Ma; Kent and McDougall, 1995; Nelson, 1997).

D_2 event

The D_2 event produced open to tight upright folds with a moderately to well-developed penetrative foliation (S_2) during strong east–west compression (Fig. 15). A north-northwesterly oriented penetrative S_2 foliation related to tight F_2 folding is the dominant fabric throughout ERAYINIA, and is typically within 10 to 20° of the S_1 fabrics. F_2 fold hinges form prominent features observed on aerial photographs and aeromagnetic images, particularly on central ERAYINIA, and are predominantly defined by chert bands (e.g. MGA 464430E 6546210N). Stereoplots of D_2 fabric elements (Fig. 16) illustrate the consistent north-northwest orientation of the S_2 fabric and show that it is axial planar to upright to moderately north-northwesterly plunging folds. Although there is a large spread in the bedding measurements, they provide a beta axis that lies on the average S_2 foliation plane.

On eastern and southeastern ERAYINIA, the S_2 foliation shifts from a north-northwesterly to an approximately north–south orientation (Fig. 16), as do the poles to bedding, indicating north–south-oriented F_2 folding. This change in trend from west to east is interpreted to reflect a splay in structures around the large granite bodies on central ERAYINIA. A large northeast-trending synform on eastern ERAYINIA (Fig. 3, approximately MGA 484000E 6535000N) is defined by an iron-rich banded chert and may represent an early F_1 fold, or a rotated F_2 fold.

The dominant north-northwesterly oriented S_2 fabric is also observed throughout the Erayinia Granitic Suite on central and northern ERAYINIA. In the central part of the complex (e.g. MGA 467670E 6555540N) the S_2 fabric overprints an earlier shallow-dipping foliation that lies

Figure 15. Moderately northwest-plunging open F_2 folds: central Erayinia (MGA 463730E 6546035N)

parallel to aligned mafic enclaves and compositional banding and may represent a flow foliation (Fig. 17).

D_{3-4} events

Transpression during D_3 and D_4 resulted in reverse and sinistral lateral movement on regional north-northwesterly trending faults (Nelson, 1997; Swager, 1997). On Erayinia Hill (MGA 465430E 6568260N), the S_2 foliation is overprinted by small northwest-trending shear bands in metre-wide zones that display an apparent sinistral offset (Fig. 18). However, several large north-northwesterly oriented structures on ERAYINIA show dextral displacements (see **Roe Hills Fault zone**).

Numerous fault sets were measured on ERAYINIA and display a wide variety of fault geometries and kinematics. There are clearly multiple faulting events, with some faults offsetting mafic dykes of the c. 2420 Ma Widgiemooltha dyke swarm (Nemchin and Pidgeon, 1998), and younger faults offsetting mafic dykes of the c. 1210 Ma Fraser dyke swarm (Wingate et al., 2000). These faults may represent far-field effects of the Albany–Fraser Orogeny (see **Albany–Fraser Orogeny**).

Roe Hills Fault zone

The Roe Hills Fault zone on western ERAYINIA defines the boundary between the c. 2667 Ma Mount Belches Formation of the Bulong Domain and an older mafic–ultramafic sequence of the Murrin Domain. The fault zone consists of a series of closely spaced, steeply dipping north-northwesterly oriented faults extending south-southeast from the Roe Hills. A number of thin ultramafic units on the eastern side of the fault zone are truncated by these structures. To the north, on KURNALPI, a similar relationship is seen where ultramafic units are truncated by the Yilgangi and Cowarna Faults (Swager, 1995).

The eastern limit of the Mount Belches Formation was originally interpreted as the Cowarna Fault on MOUNT BELCHES (Painter and Groenewald, 2001), but recent mapping (Jones, 2005) and a c. 2667 Ma age from detrital zircons near the western edge of ERAYINIA (GSWA 177917; MGA 452380E 6547130N; Bodorkos et al., 2006) indicate that the Mount Belches Formation extends eastward to the Roe Hills Fault zone on ERAYINIA.

Two northwest-oriented faults of the Roe Hills Fault zone are exposed along the western margin of ERAYINIA (site 1, MGA 451400E 6548000N; site 2, MGA 453740E 6551080N; Fig. 19). At site 1, a steep north-northwesterly oriented fault juxtaposes basalt with metasedimentary rocks of the Mount Belches Formation and good indicators of dextral shear are found in the highly deformed rocks of the fault zone (Fig. 20). A weakly developed stretching lineation plunges gently to moderately to the northwest and, together with shear-band boudins, indicates an oblique dextral sense of displacement. Isoclinal folding of quartz veins and intrafolial folds, both of which have hinges parallel to the north-northwesterly oriented foliation, are common within the fault zone (Fig. 20b). Kinematic indicators are not as clear at site 2, where a shear zone

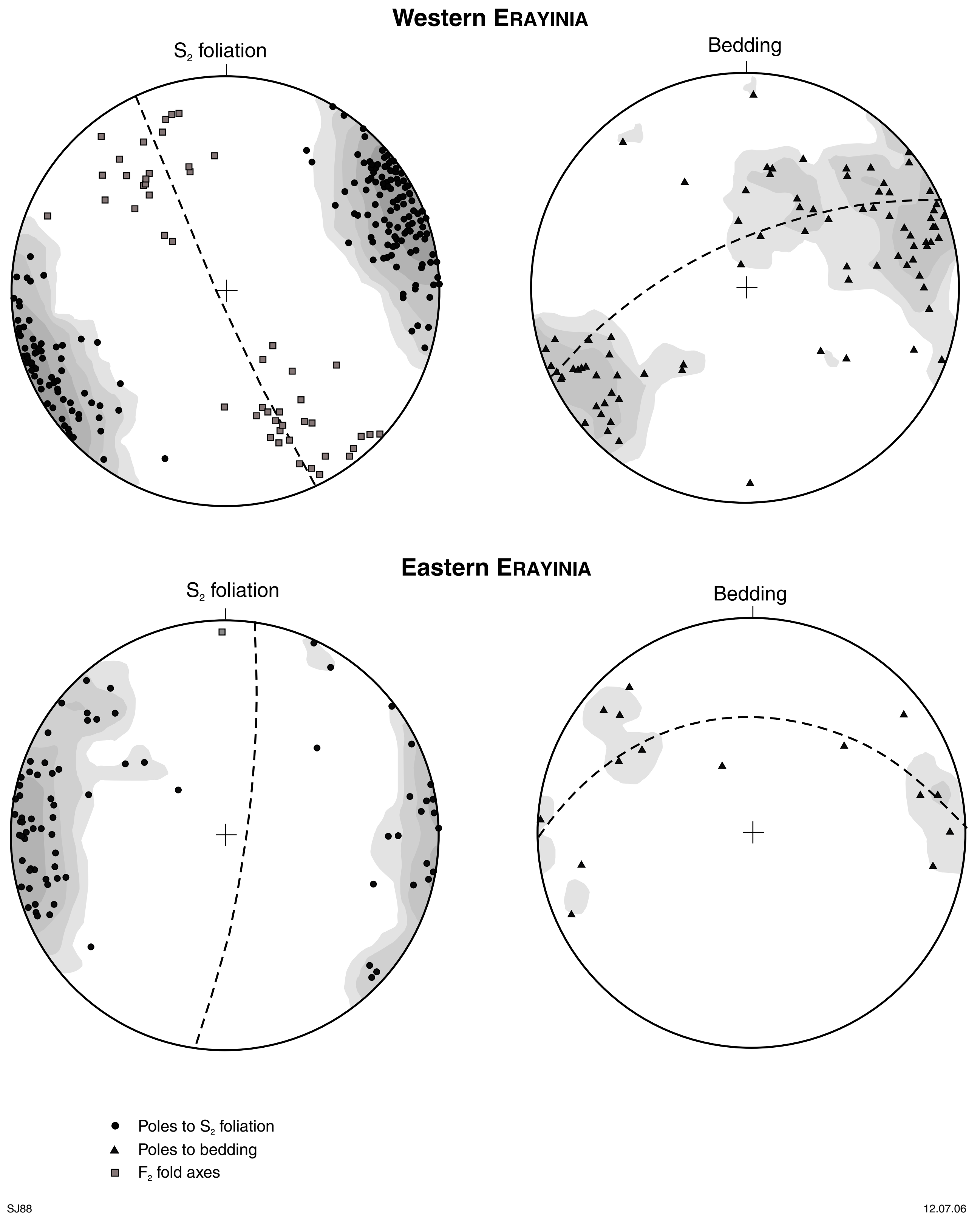

Figure 16. Stereoplots of poles to bedding and S_2 foliation for the western and eastern areas of ERAYINIA

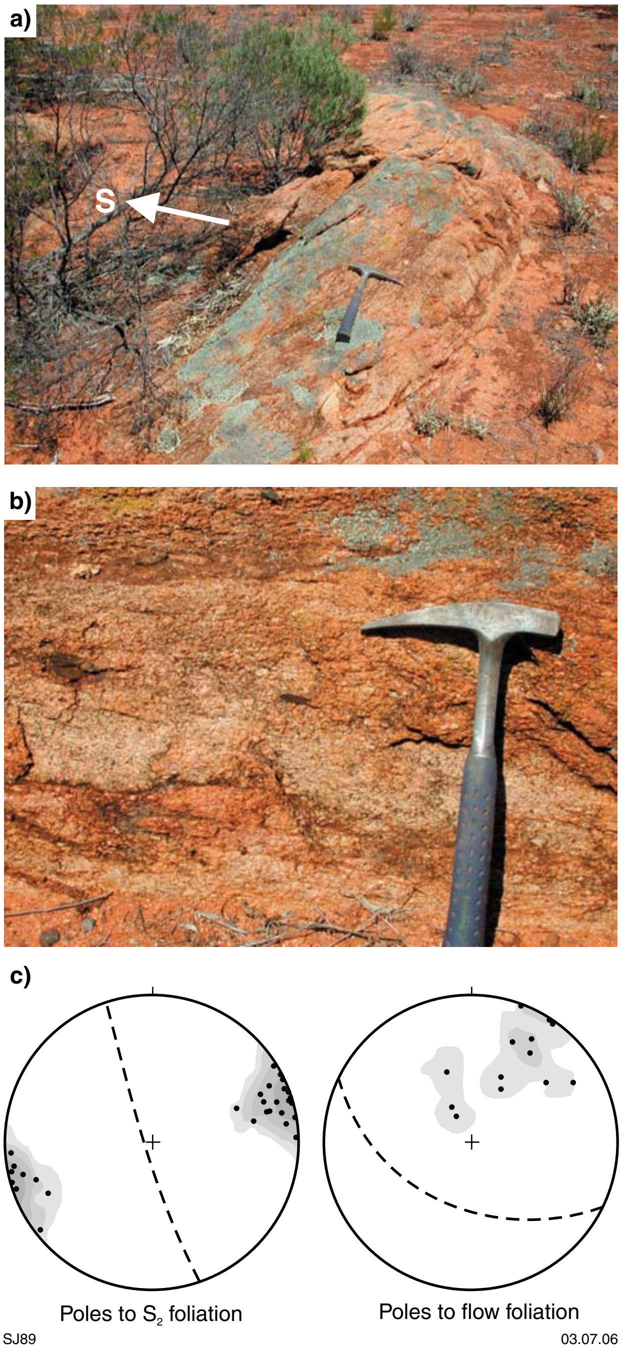

Figure 17. a) Moderately southeast-dipping flow foliation in the Erayinia Granitic Suite, northern Erayinia, MGA 467670E 6555540N; b) close-up of the foliation, which is parallel to compositional banding in the granite; c) stereoplots illustrate the marked difference between the orientations of the early flow foliation and the tectonic fabric (S_2)

is exposed as a narrow zone of strongly quartz-veined chlorite schist within lower grade, relatively undeformed basalt (Fig. 19b). A weakly developed northwest-plunging stretching lineation is developed along the fault. The similarity of the fault geometry and orientation of the stretching lineations at this site to those observed at site 1 suggests that this fault may also have a dextral sense of displacement.

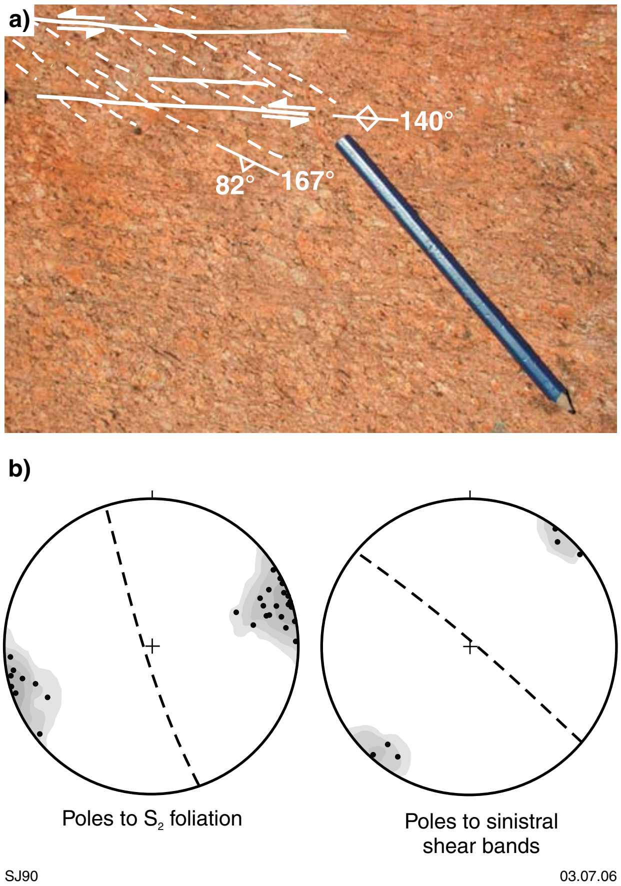

Figure 18. a) Shear bands with an apparent sinistral offset overprint the S_2 fabric in granite, northern Erayinia, MGA 465430E 6568260N; b) Stereoplots illustrate the two fabrics

The structures at sites 1 and 2 are interpreted to have formed at a late stage of D_2, or during D_3 transpression, and accompanied the tightening of the regional northwest-trending F_2 fold structures in this area (Painter and Groenewald, 2001). If the ultramafic units east of the Roe Hills Fault zone on ERAYINIA are equivalent to those truncated by the Cowarna and Yilgangi Faults on KURNALPI, the offset of these ultramafic units may represent right-lateral steps during dextral transpression on the large northwest-oriented structures.

Along the western margin of ERAYINIA, a series of northeast-oriented faults offset the north-northwesterly oriented structures and bedding trends with a consistent sinistral sense of displacement (Fig. 3). These faults are visible on aeromagnetic images and in the field, and the observed fault drag indicates sinistral displacement. These structures consistently cut across the late D_2–D_3 northwest-oriented faults and may have formed during D_4.

Karonie Shear zone

A broad north-oriented shear zone, over 100 m wide, extends through the Karonie mine and is parallel to the regional foliation and bedding trends (Fig. 3). The shear zone hosts significant gold mineralization and on

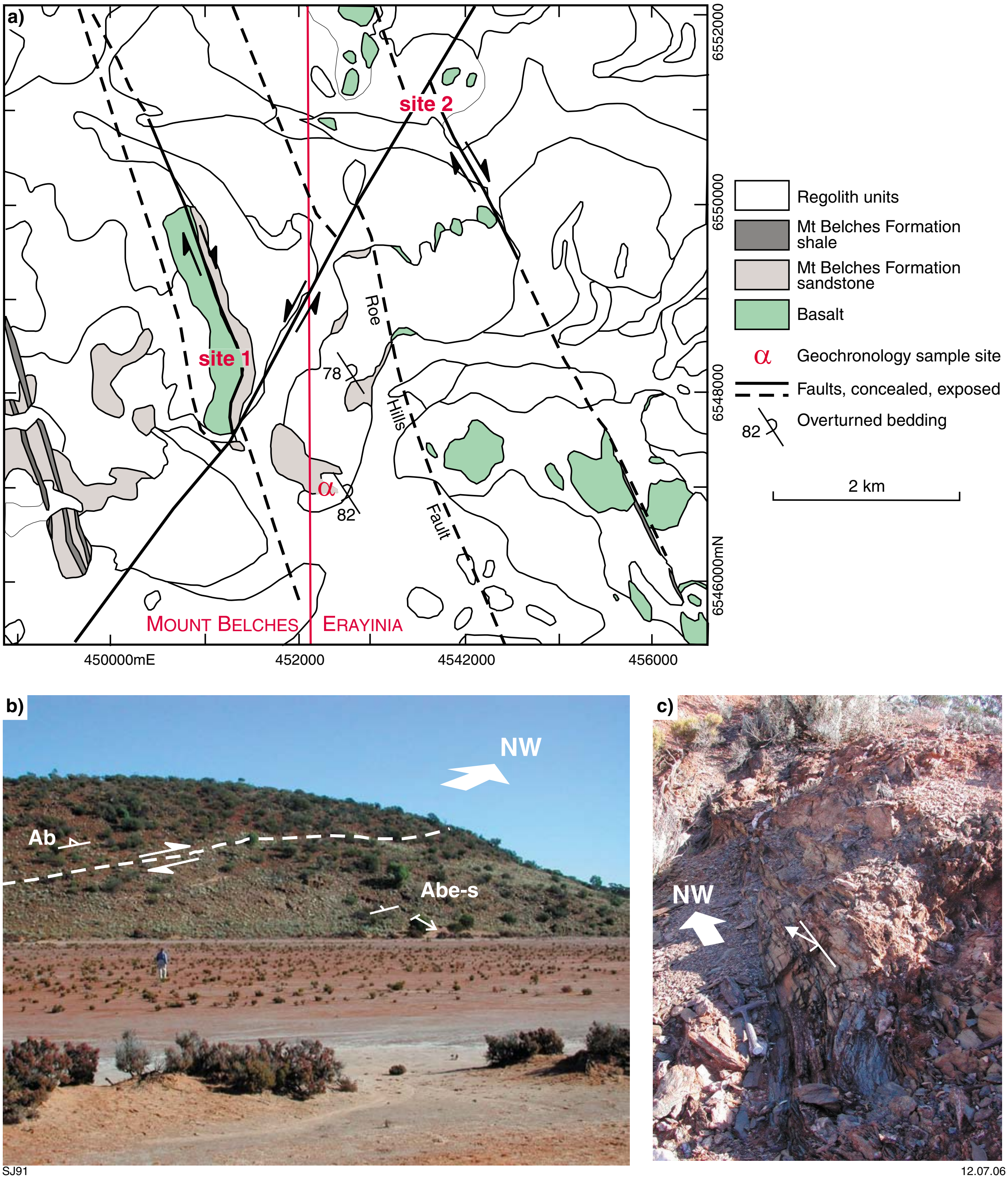

Figure 19. a) Map of the Roe Hills Fault zone at the boundary between Erayinia and Mount Belches, showing the locality of the geochronology sample site in the Mount Belches Formation sandstone. b) At site 1, a steep northwest-oriented fault juxtaposes basalt with Mount Belches Formation sandstone (MGA 451400E 6548000N). c) A second northwest-oriented fault with shallow northwest-plunging lineations extends through basalt at site 2 (MGA 453740E 6551080N)

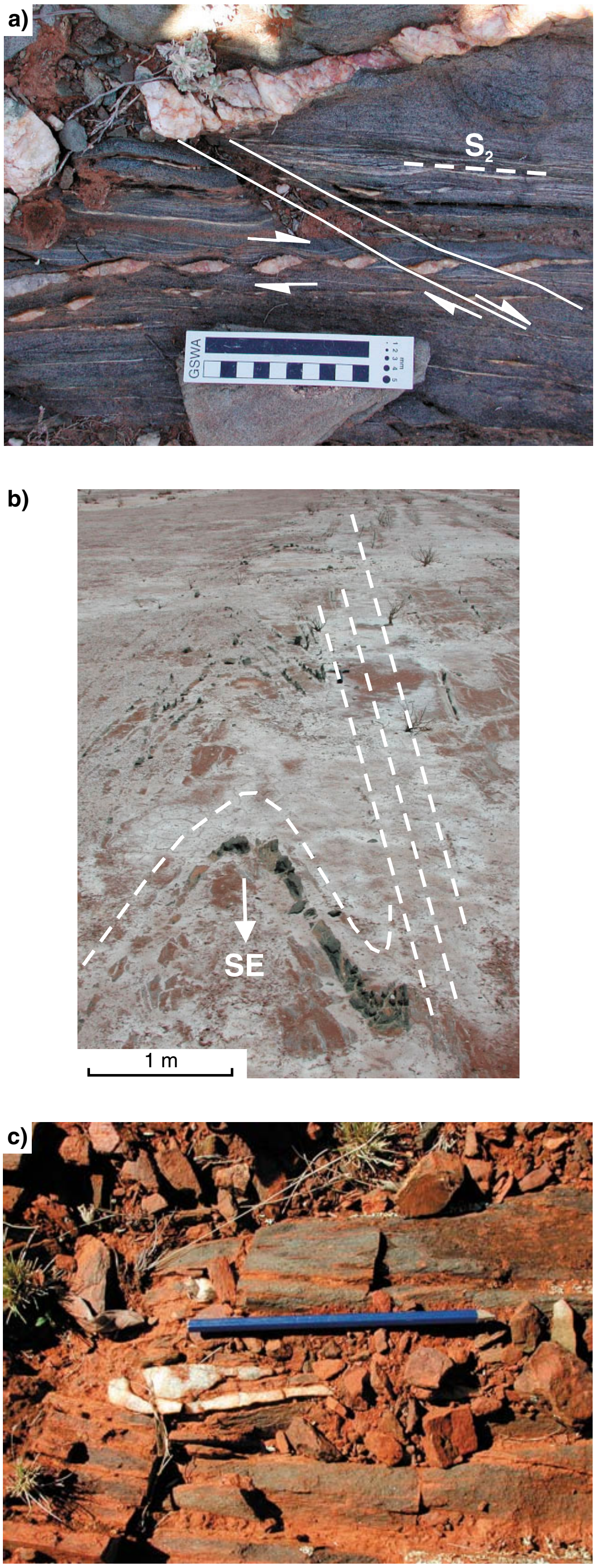

Figure 20. **Textures within the Roe Hills Fault zone: a) dextral offset of shear band boudins (MGA 451350E 6548770N); b) folds in Mount Belches Formation sandstone, west of the fault at site 1 (shown on Fig. 19), which plunge moderately to the southeast (MGA 451470E 6548695N); c) isoclinally folded quartz vein within the fault zone (MGA 451640 6548420N)**

aeromagnetic images appears to extend south through gold prospects such as French Kiss, Nautilus, and French Kiss South (see **Karonie gold deposits**). The shear zone is in medium- to coarse-grained amphibolite and minor para-amphibolite with abundant calc-silicate alteration. Tight isoclinal and intrafolial folds are common throughout the shear zone. Possible dextral displacement is suggested by asymmetric folding, and the Main Zone orebodies at Karonie may be in pressure shadows along the major ductile structure. The shear zone is offset by a set of northeast-oriented sinistral faults. The fault geometry and kinematics of the Karonie Shear zone and later structures appear to be similar to those of the Roe Hills Fault zone.

Miller Dam Anticline

The Miller Dam Anticline is a large fold in the Mount Belches Formation near the western edge of ERAYINIA (Fig. 21). This structure was originally interpreted as a syncline (Miller Dam Syncline; Painter and Groenewald, 2001), but reliable younging indicators, including graded beds, sharp scoured bases, and flame structures along the eastern limb of the fold on ERAYINIA, indicate that it is a an anticline plunging moderately north. This fold has similar geometry to the north-plunging anticlines outlined by the Santa Claus Member on MOUNT BELCHES. In the northern part of the fold, close to the hinge zone, bedding becomes slightly overturned and dips to the west. The Roe Hills Fault zone most likely formed along the eastern margin of this large fold late during D_3.

Claypan Fault

The Claypan Fault is interpreted to extend along the western edge of the granite bodies on eastern ERAYINIA, separating the Murrin Domain from the Edjudina Domain (Fig. 3). Although no structure is observed on the ground, there is a marked increase in metamorphic grade across the fault, with relatively undeformed greenschist-facies felsic volcaniclastic rocks and basalt to the west, and muscovite schist, chlorite–muscovite schist, and biotite–garnet schist to the east of the structure. This increase in metamorphic grade might represent a contact aureole against the large granite bodies to the east, or may be the result of uplift and exposure of rocks from deeper crustal levels. The granite on the eastern side of the fault is strongly foliated and shows a weakly developed stretching lineation plunging gently to the north. Within this area, ferruginous chert bands are common and define tight to isoclinal folds observed on aeromagnetic images.

Metamorphism

Metamorphic grades on ERAYINIA are predominantly lower to middle greenschist facies, with amphibolite-facies rocks in areas adjacent to large granite bodies and within broad shear zones. The metamorphic grades reflect the interaction of two metamorphic events (M_1 and M_2) on ERAYINIA.

The M_1 event in the Archean rocks on ERAYINIA is characterized by lower greenschist-facies mineral assemblages of muscovite, quartz, chlorite, and feldspar in

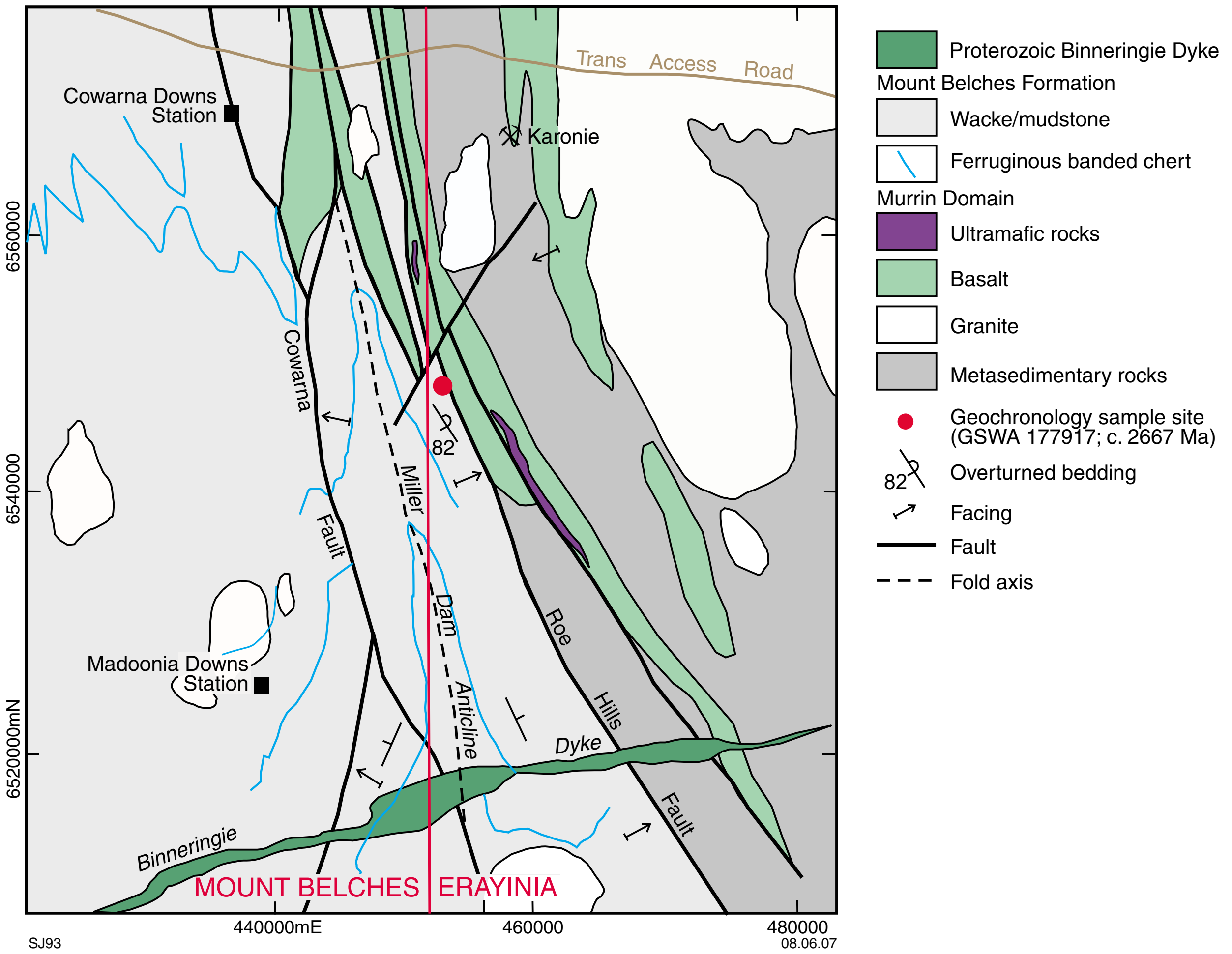

Figure 21. Map illustrating the Miller Dam Anticline extending from Erayinia onto Mount Belches

metasedimentary rocks, and chlorite and feldspar in metabasalts. These minerals define the bedding-parallel penetrative S_1 foliation. The precise timing of M_1 during D_1 is uncertain, with various authors giving ages that range from 2700 to 2675 Ma in the Kalgoorlie region (Kent and McDougall, 1995; Nelson, 1997; Swager, 1997).

A regional mid-greenschist to amphibolite-facies metamorphic event (M_2) partially overprints the earlier metamorphism with a similar mineral assemblage of quartz–muscovite–chlorite–feldspar–biotite–amphibole in metasedimentary rocks, and chlorite–feldspar–biotite–amphibole in metabasalts. Metamorphic mineral assemblages in metabasalts on Erayinia are dominated by chlorite and feldspar. Peak M_2 metamorphic conditions were most likely coeval with deformation during the D_2 event, as there is commonly a weak alignment of muscovite, quartz, chlorite, and amphibole parallel to the S_2 crenulation cleavage. This regional low- to medium-grade event is common throughout the Eastern Goldfields Superterrane and evidence for it is broadly correlated with the distribution of granitic rocks (Witt, 1991; Ridley, 1993; Swager 1997; Mikucki and Roberts, 2003). Deformation during the D_2 event was most likely contemporaneous with emplacement of most of the granites at 2665–2640 Ma (Witt, 1991; Nelson, 1997; Swager et al., 1997).

A third metamorphic event (M_3) has been reported on Mount Belches, to the west of Erayinia, with contact metamorphism of Archean metasedimentary rocks adjacent to Proterozoic mafic dykes (Painter and Groenewald, 2001). However, no contact metamorphism was observed on Erayinia as the Proterozoic mafic dykes mapped in the field are small, generally less than 1 m wide, and all intrude basalt or granite.

Proterozoic geology

Paleoproterozoic Widgiemooltha dyke swarm and unassigned dykes (Ꝑod, *ꝐWIbi-o*)

Numerous unassigned dykes (Ꝑod) are visible on aeromagnetic images and the east–west-oriented dykes are generally interpreted to be part of the c. 2420 Ma Widgiemooltha dyke swarm (Sofoulis, 1966; Nemchin and Pidgeon, 1998). The Binneringie Dyke is the largest dyke in the Widgiemooltha dyke swarm, and is over 320 km in length with a maximum width of 3.2 km near Lake Cowan. The Binneringie Dyke extends onto southern Erayinia, but is only exposed in a series of small outcrops, so the extent of the dyke is determined mainly by aeromagnetic interpretation. Small outcrops of the Binneringie Dyke (MGA 485500E 6521800N) consist of mesocratic dolerite and gabbro (*ⱣWIbi-o*), which has a coarse equigranular texture of interlocking pyroxene and plagioclase. Small, east–west-trending mafic dykes of the Widgiemooltha dyke swarm also intrude basalts along the western edge of ERAYINIA (MGA 456520E 6545370N) and granites on eastern ERAYINIA (MGA 486810E 6550920N).

The dykes are relatively narrow within granitic rocks and widen within supracrustal sequences. They are typically vertical to subvertical with sharp contacts and narrow chilled margins (Hallberg, 1987). At a regional scale, the contacts are relatively straight, but in detail they are irregular with local embayments and small apophyses extending into the adjacent country rocks. There is only minor contact metamorphism, up to a metre in width, next to the largest dykes such as the Binneringie and Jimberlana Dykes (McCall and Peers, 1971). Flow layering parallel to the dyke margins is most common in the smaller dykes of the Widgiemooltha dyke swarm (Hallberg, 1987). Vertical magmatic layering, both cryptic and rhythmic, has been reported from marginal zones in the Binneringie Dyke (McCall and Peers, 1971), but true phase layering with cumulate textures has only been reported from the Jimberlana Dyke (Campbell et al., 1970).

The most precise age for the Widgiemooltha dyke swarm is from the Binneringie Dyke, where Nemchin and Pidgeon (1998) obtained an age of 2418 ± 3 Ma, based on the concordia intercept of three conventional baddeleyite U–Pb ages. This is within the error of (and is more precise than) the SHRIMP U–Pb baddeleyite age of 2420 ± 7 Ma (Nemchin and Pidgeon, 1998). The age is also within the error of the combined Celebration Dyke and Jimberlana Dyke Rb–Sr age of 2420 ± 30 Ma (Turek, 1966) and the Sm–Nd isochron age of 2411 ± 52 Ma for the Jimberlana Dyke (Fletcher et al., 1987).

Woodline Formation (*Ᵽwo-s, Ᵽwo-sh, Ᵽwo-stq, Ᵽwo-sx*)

The Woodline Formation (formerly known as the Woodline Beds; Griffin, 1989) outcrops as a series of low ridges on southwestern ERAYINIA (Fig. 1). The formation forms a northeast-trending belt over 50 km in length, extending southwest through YARDILLA and YARDINA. The unit is about 250 m thick (Fig. 22), based on mapping and drillhole data (Asarco Ltd, 1971; WMC Resources Ltd, 1991), and is predominantly a quartz-rich sandstone (*Ᵽwo-stq*), with interlayered siltstone (*Ᵽwo-sh*) and undifferentiated Woodline Formation (*Ᵽwo-s*). There is a small outcrop of breccia (*Ᵽwo-sx*) on southern ERAYINIA (MGA 470950E 6520800N). Although the base of the Woodline Formation is poorly exposed, there is an angular unconformity separating it from the underlying Archean rocks near a small playa lake just south of Talc Lake (MGA 463120E 6533250N; Fig. 23). At this location, subhorizontal quartz-rich sandstones overlie steeply dipping northwest-striking Archean metasedimentary rocks. A similar relationship between Proterozoic and Archean rocks was reported on YARDINA by Griffin (1989).

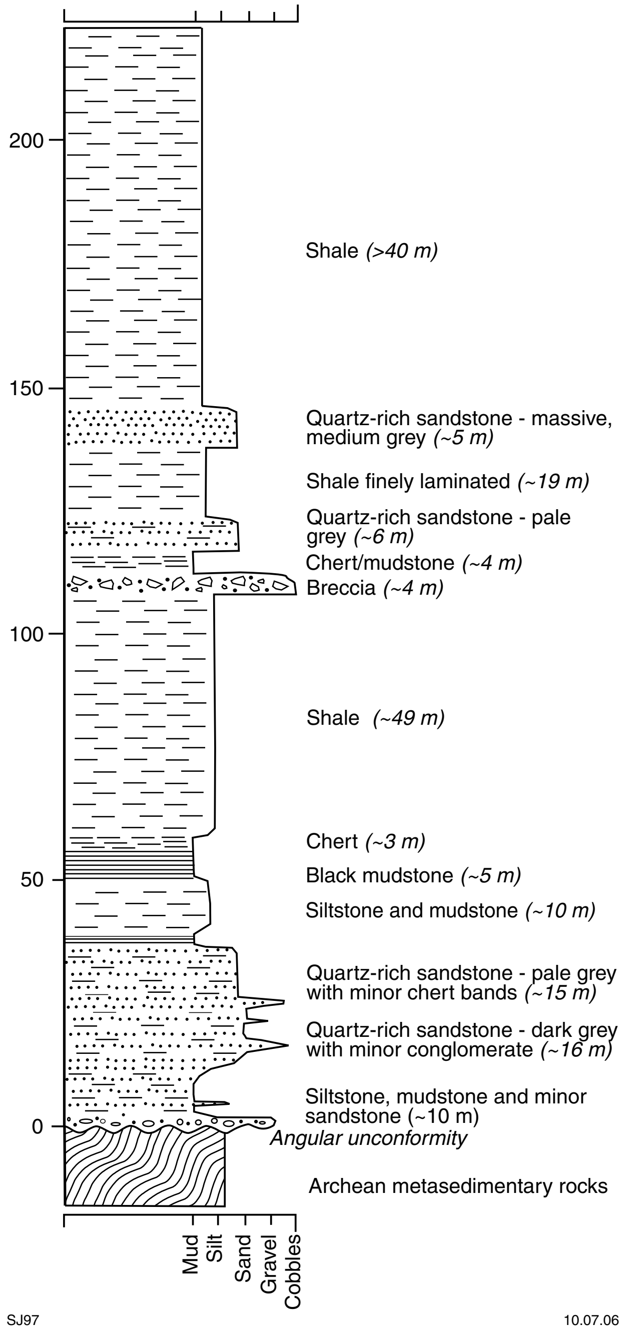

Figure 22. Graphic log illustrating the general stratigraphy of the Woodline Formation from drillhole data (Asarco Ltd, 1971)

Woodline Formation rocks are only weakly deformed and outcrops are typically relatively fresh. Sedimentary structures such as tabular bedding, trough cross-bedding, rip-up clasts, ripples, sole marks, scours, and graded beds are well preserved (Fig. 24). Graded bedding, scoured bases, and truncated cross-bedding indicate beds are the right way up. In a few locations, matrix- to clast-supported breccias and conglomerates with clast sizes ranging from 1 to 20 cm are interbedded with finer grained, well-sorted quartz-rich sandstone, and minor amounts of chert and mudstone.

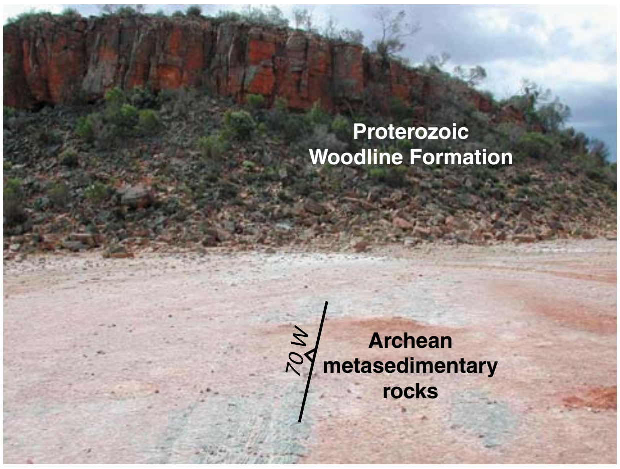

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Figure 23. Subhorizontal quartz sandstone of the Woodline Formation unconformably overlying steeply dipping northwest-oriented Archean metasedimentary rocks exposed in the lake pavement, central Erayinia (MGA 463120E 6533250N)

The well-sorted, well-rounded, and quartz-rich sandstone units of the Woodline Formation indicate distal deposition. The conglomerates, cross-bedded sandstones, ripples, and sole marks indicate a relatively high-energy, possibly fluvial, depositional environment such as a braided stream system. Trough cross-beds and ripples in Woodline Formation rocks indicate a predominantly north to south flow direction (Hall and Jones, 2005).

A maximum depositional age of c. 1737 Ma for the Woodline Formation is provided by U–Pb SHRIMP dating of detrital zircons (Hall and Jones, 2005) and is almost within the error of a Rb–Sr isochron age of 1620 ± 100 Ma (Turek, 1966) determined for these rocks. It is also consistent with a diagenetic xenotime age of c. 1697 Ma determined for the Mount Barren Group (Dawson et al., 2002), which is about 300 km to the southwest and may be a lateral equivalent of the Woodline Formation.

The Woodline Formation was previously thought to be an allochthonous unit that was thrust onto the Yilgarn Craton during the Albany–Fraser Orogeny (Myers, 1990). However, most of the activity during the Albany–Fraser orogen was between 1345 and 1100 Ma, and deposition of the Woodline Formation predates this activity by 300–500 Ma. The lack of a basal thrust in the Woodline Formation, the weak deformation, and the unconformable basal contact indicate that the sedimentary rocks do not represent an allochthonous thrust sheet.

Fraser dyke swarm (*Pod*)

The northeast-trending Fraser dyke swarm intrudes the southeastern Yilgarn Craton, parallel to the Albany–Fraser Orogen, and extends onto ERAYINIA (Fig. 3). These dykes are predominantly composed of undeformed dolerite (Wingate et al., 2000). They are mostly interpreted from aeromagnetic data but are found locally in outcrop (Fig. 25).

Wingate et al. (2000) obtained an age of 1212 ± 10 Ma for a northeast-trending dyke from an opencut mine at Kambalda, 100 km to the west of the sheet area. This is similar to the average age (c. 1210 Ma; Evans, 1999) of the east–west trending Gnowangerup dyke swarm in the western part of the Albany–Fraser Orogen. Wingate et al. (2000) suggested that the Fraser dyke swarm was emplaced during the 1345–1140 Ma Albany–Fraser Orogeny, subparallel to the boundary between the orogen and the Yilgarn Craton in a zone of flexure formed by crustal loading during orogenesis, or by crustal relaxation and extension caused by the cessation of northwest-directed convergence.

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Figure 24. Symmetric ripples in quartz sandstone, Woodline Formation, central Erayinia (MGA 463090E 6533260N)

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Figure 25. A mafic dyke that trends 050° may belong to the Fraser Dyke swarm, northwestern Erayinia (MGA 456515E 6545370N). A number of northeast-oriented faults offset the dyke with apparent sinistral displacement of about 1–2 m

Albany–Fraser Orogeny

D_5 event

The D_5 event and associated metamorphic overprint (M_4) affected both the Archean Yilgarn Craton rocks and the Proterozoic Woodline Formation and marks the onset of deformation during the Albany–Fraser Orogeny along the southeastern margin of the Yilgarn Craton (Jones, 2005, 2006; Jones and Hall, 2004). Deformation associated with this event is more pronounced on YARDILLA, which straddles the contact between the Albany–Fraser Orogen and the Yilgarn Craton, but early D_5 structures are observed on southern ERAYINIA, and are characterized by shallow to moderately southwest-plunging open folds and warps and a variably developed axial-planar cleavage. These folds are best exposed in the Proterozoic Woodline Formation on southwestern ERAYINIA, where a large gently southwest-plunging syncline has been mapped in quartz-rich sandstones (Fig. 26). The axial-planar cleavage is a fine anastomosing pressure-solution fabric that crosses the bedding at a high angle (Fig. 27). In thin section, the pressure-solution fabric crosses syntaxial overgrowths on quartz grains, and therefore clearly post-dates diagenesis (Fig. 28). The effects of this folding can also be seen in the underlying Archean rocks in this area. A series of northeast- and northwest-trending Archean quartzite ridges define a large F_2 fold to the west of the syncline in the Proterozoic Woodline Formation (Fig. 26). The northwest-trending quartzite ridges in the central part of the map (Fig. 26) have a sinuous appearance with open northeast-trending folds, suggesting localized refolding of the northwest-oriented F_2 structure during northwest–southeast compression associated with F_5. In this area, F_2 fold axes and bedding in the Archean rocks have been rotated and steepened during this later folding event, in contrast to the more typical orientations observed farther north (Fig. 29). The development of northeast-trending folds in the Proterozoic Woodline Formation and the refolding of Archean rocks during northwest–southeast shortening is consistent with the onset of deformation during the Albany–Fraser Orogeny (D_5) previously mapped on YARDILLA (Jones and Ross, 2005; Jones, 2003, 2006).

A number of faults observed on ERAYINIA may be attributed to the Albany–Fraser Orogeny. For example, northeast-oriented dextral shears are observed within a large granite body on southeastern ERAYINIA (MGA 496360E 6525290N). Further north, near the western edge of ERAYINIA (MGA 456520E 6545370N), northeast-trending mafic dykes that are most likely part of the Fraser dyke swarm (c. 1210 Ma, Wingate et al., 2000) are offset by north-northeasterly oriented faults with a dextral displacement. On southern ERAYINIA, numerous faults offset the folded Woodline Formation (Fig. 26). A northeast-oriented fracture set also overprints earlier fabrics in granites on northern and eastern ERAYINIA (Fig. 30).

M_5 event

The Proterozoic Woodline Formation is metamorphosed to lower greenschist facies (M_5), as indicated by fine muscovite within the matrix of some quartz-rich sandstones, and a weakly to moderately developed foliation defined by aligned muscovite in the siltstones. The lower greenschist facies overprint is not observed in the surrounding middle to upper greenschist facies Archean rocks. The M_5 event was most likely a result of deformation during the Albany–Fraser Orogeny (Jones, 2006).

Phanerozoic geology

Gunbarrel Basin

Permian sedimentary rocks (*Psdp*)

Rare diamictites on ERAYINIA may represent Permian glacial deposits of the Gunbarrel Basin. A thin polymictic diamictite (*Psdp*) outcrops near the southern margin of ERAYINIA (MGA 469980E 6519200N). It is a poorly sorted, matrix-supported rock containing cobbles and pebbles of schist, garnet-amphibolite, granitic gneiss, sandstone, siltstone, and basalt. It is unconsolidated, undeformed, and unmetamorphosed. The very poor sorting and the presence of garnet-amphibolite and granitic gneiss clasts (most likely from the Albany–Fraser Orogen) distinguish it from the overlying Cenozoic Eundynie Group. Similar poorly sorted deposits are found on map sheets to the east (e.g. CUNDEELEE), and have been ascribed to the glacial Permian Paterson Formation of the Gunbarrel Basin (e.g. Bunting and van de Graaff, 1972).

Bremer Basin

Cenozoic Eundynie Group (*EeEU-s*, *EeEU-stc*)

The Cenozoic geology on ERAYINIA is characterized by widespread deposits of deltaic to marine sedimentary rocks in paleodrainage channels, and by deep weathering profiles and lateritization. The deposition of deltaic to marine sedimentary rocks was the result of extensive marine transgressions during the Eocene, which affected the southern part of Western Australia, including southeastern parts of the Yilgarn Craton. These sedimentary rocks form the Eundynie Group.

The Eocene Eundynie Group comprises fluviodeltaic and estuarine to marine sediments, and is observed throughout the southern Eastern Goldfields, predominantly within large dendritic paleodrainage channels (such as the Cowan and Lefroy paleodrainages) that formed at the margins of the Eucla Basin. On ERAYINIA, the paleodrainage patterns are similar to the present-day drainage systems. For example, on southwestern and central ERAYINIA the thickest deposits of Eundynie Group are associated with a series of large playa lakes that flow to the northeast and converge with an east-northeasterly trending drainage system. The drainage system on ERAYINIA is described in the Explanatory Notes for the WIDGIEMOOLTHA 1:250 000 hydrogeological sheet

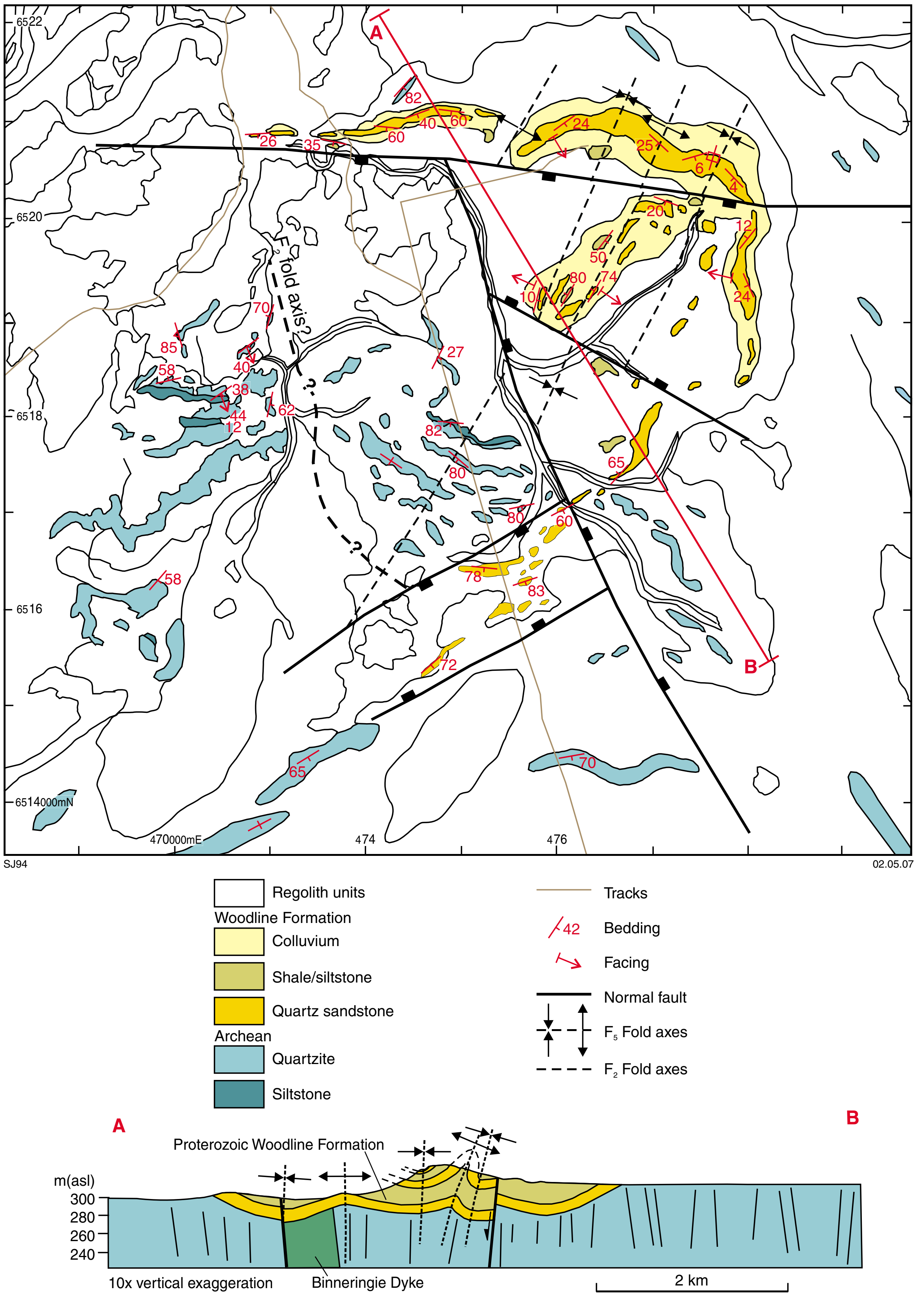

Figure 26. **Map and cross section of a syncline in the Proterozoic Woodline Formation, southern Erayinia. Numerous faults disrupt the sequence and juxtapose Proterozoic rocks with Archean quartzites and siltstone on the western side of the map. Northeast-oriented folds indicate northwest–southeast shortening, which is consistent with the D_5 event in the underlying Archean rocks and marks the onset of deformation during the Albany–Fraser Orogeny in the Yilgarn Craton**

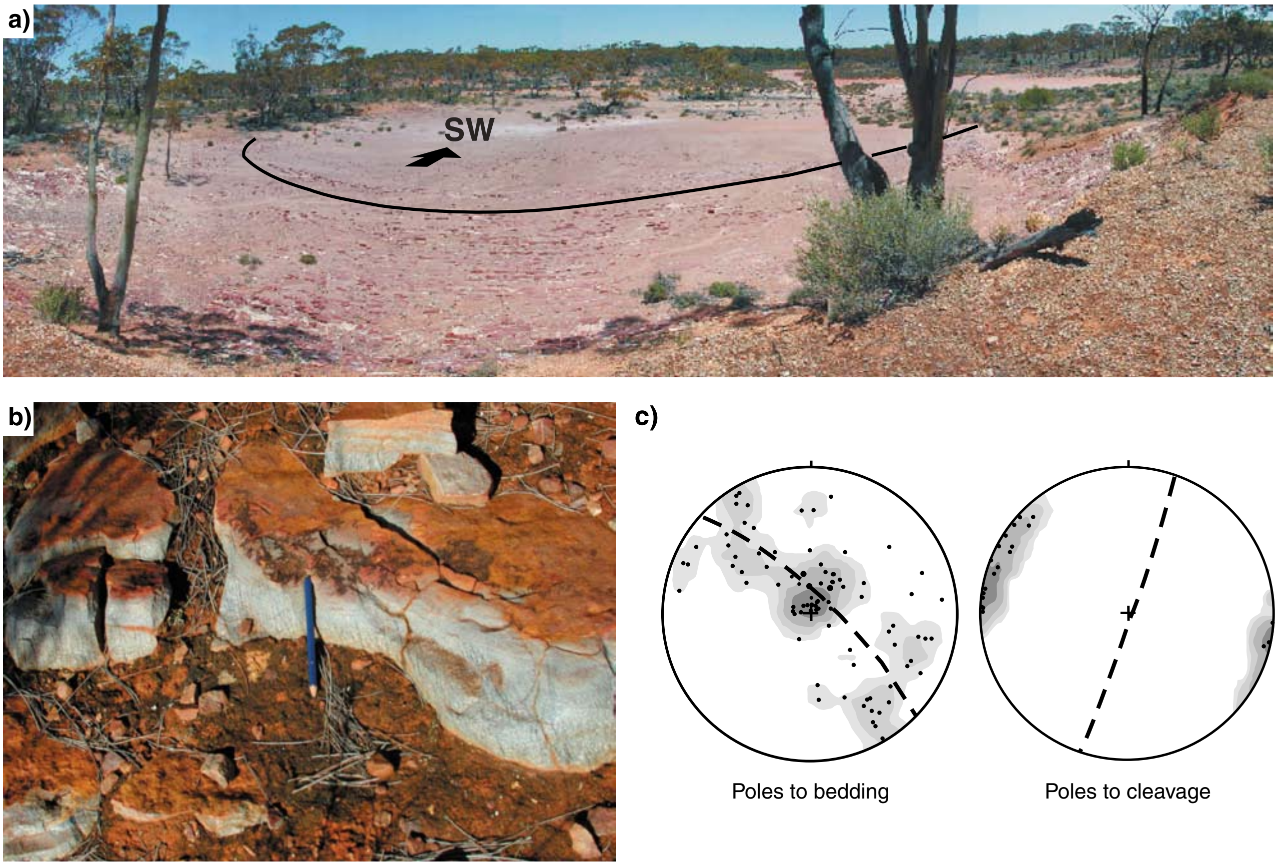

Figure 27. a) Southwest-plunging D_5 fold on the northern limb of the large syncline in the Proterozoic Woodline Formation, southern Erayinia. A well-developed axial-planar cleavage is developed in the siltstone (MGA 471730E 6520780N). b) Pressure-solution cleavage in quartz sandstone crosscuts the bedding at a high angle, southern Erayinia (MGA 475100E 6520760N). c) Stereoplots of poles to S_0 and poles to cleavage illustrate the dominantly open nature of the F_5 folding and the northeast-oriented axial-planar cleavage

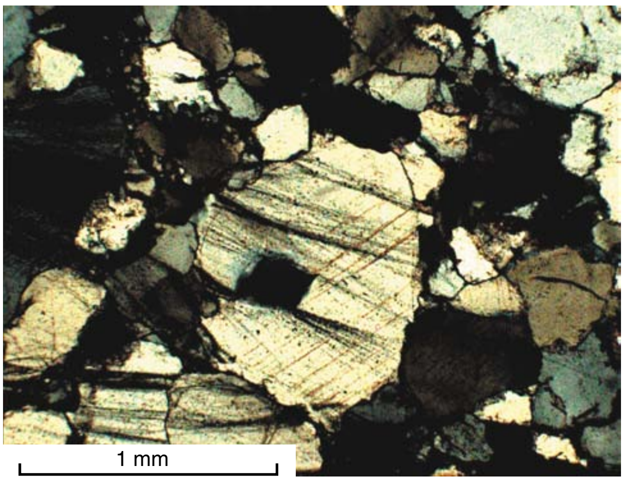

Figure 28. Pressure-solution fabric (S_5) crosscuts a syntaxial overgrowth on quartz grains in the Woodline Formation, indicating that this fabric formed post diagenesis, southern Erayinia (MGA 474955E 6520870N, GSWA 165572; cross-polarized light; 6.3× magnification)

(Kern, 1996). Although the Cowan system now flows south to the Bremer Basin, it is thought to have originally flowed to the northeast, based on the acute angle of its convergence with the Lefroy system (Hocking and Cockbain, 1990; Clarke, 1994). Reversal of the Cowan channel as a result of uplift along the Jarrahwood Axis between the Cowan and Lefroy paleodrainage channels occurred during post-Eocene warping of the area. Dips of up to 8° are recorded on some of the large tabular-bedded sandstone units of the Eundynie Group on eastern Erayinia and similar dips are observed on the Mount Belches sheet (Painter and Groenewald, 2001).

Outcrops of undivided Eundynie Group (*EeEU-s*) are most common on southwestern, central, and northeastern Erayinia, and are spatially associated with the modern drainage channels. Undivided Eundynie Group consists of a range of facies including poorly sorted fine- to medium-grained sandstone, interbedded siltstone and mudstone, conglomerate, iron-cemented gravel lenses, and spongolite. The outcrops are typically deeply weathered, with ubiquitous iron-staining and silicification obscuring many original sedimentary features. The sediments are only weakly to moderately consolidated

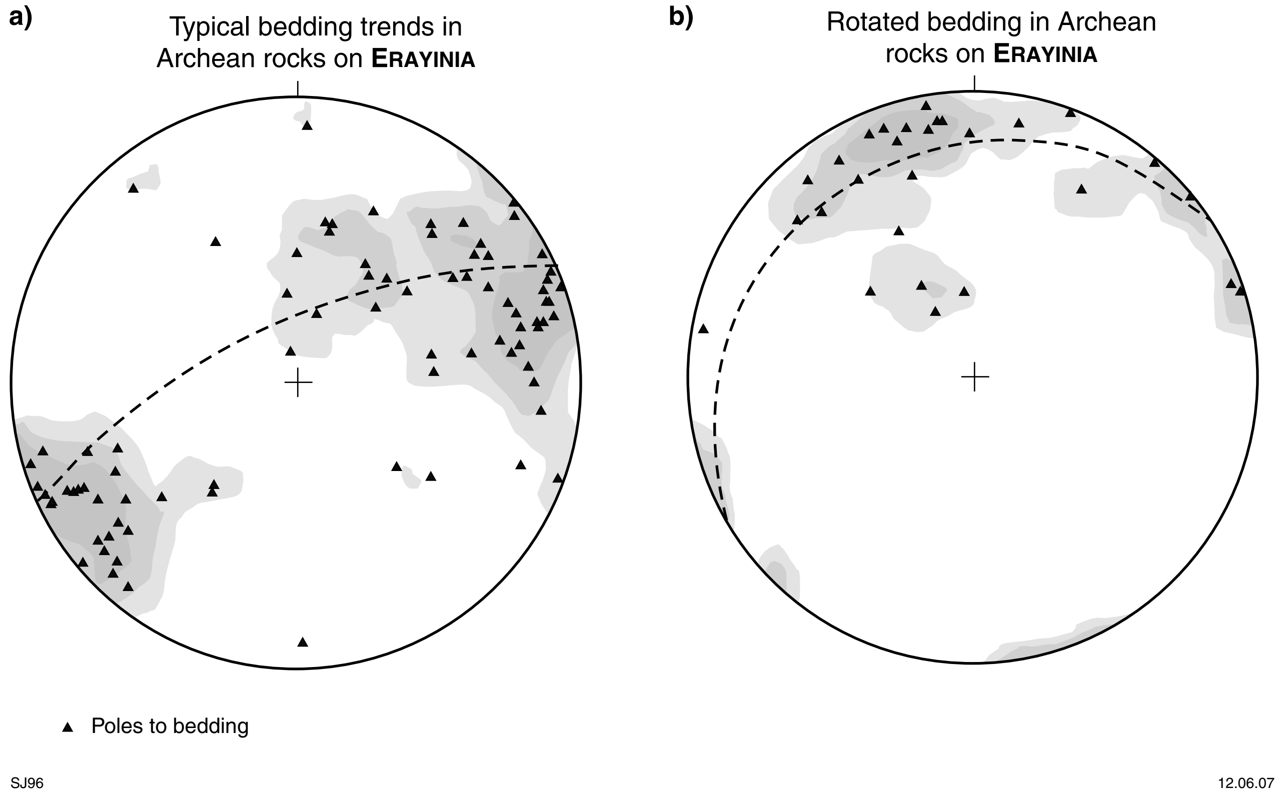

Figure 29. a) Poles to bedding define the typical trend of bedding and F_2 folds in Archean metasedimentary rocks on most of Erayinia. b) Bedding measurements from the Archean quartzite ridges on southwestern Erayinia (Fig. 26). Poles to bedding define an F_2 fold that has been rotated and steepened during the late folding event (D_5) that formed the large syncline in the overlying Proterozoic Woodline Formation

and silcrete or calcrete commonly forms a cap over the outcrops. Poorly sorted, variably spongolitic sandstone is the most common Eocene unit observed on ERAYINIA. It is typically massive to weakly bedded with flat-lying, metre-scale tabular beds. The flat-lying nature of the Eundynie Group and the presence of silcrete and calcrete caps results in the formation of scarps and 'mesa-type' outcrops (Fig. 31). This unit is thought to be more than 30 m thick. It forms scarps up to 30 m high beside the playa lakes on central ERAYINIA, and similar thicknesses have been recorded in RAB drillholes on central and eastern ERAYINIA.

Fossiliferous sandstone (*EeEU-stc*) most commonly contains sponge spicules and fine irregular burrows, predominantly 1–2 mm wide (?feeding traces). However, on central ERAYINIA, sponge spicules, bivalves, echinoderm plates, and bryozoans are found in small outcrops and RAB hole samples (e.g. MGA 477145E 6527940N and 483450E 6537820N).

The Cenozoic stratigraphy of the Eucla Basin presented by Clarke et al. (2003) is summarized in Figure 32. On ERAYINIA, most outcrops of undivided Eundynie Group are of spongolitic sandstone and associated sedimentary rocks that most likely correlate with the Late Eocene Pallinup

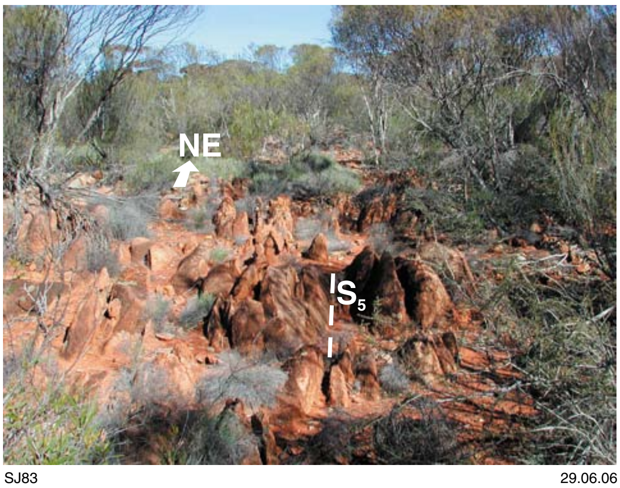

Figure 30. Steep northeast-oriented fracture cleavage in granite overprints an earlier north-northwest-oriented tectonic fabric, eastern Erayinia (MGA 463090E 6533260N). This late northeast-oriented fabric (?S_5) may represent deformation during the Albany–Fraser Orogeny and is similar to fracture patterns in granite on Yardilla, close to the southeastern margin of the Yilgarn Craton (Jones, 2005)

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Figure 31. Deeply weathered sandstone of the Cenozoic Eundynie Group, central Erayinia (MGA 473010E 6532620N)

Formation (Cowan paleovalley) or Princess Royal Member and Hampton Sandstone (Lefroy paleovalley; Clarke et al., 2003). In the Lefroy paleochannel, the Hampton Sandstone interfingers with the spongolitic Princess Royal Member; it was described by Clarke (1994) as a fine-grained to gravelly glauconitic sand, locally weakly cemented to sandstone. The unit contains marine fauna with the most common fossils being siliceous sponge spicules.

The Cenozoic sedimentary sequence reflects two marine transgressions during the Middle to Late Eocene (Clarke, 1994; Clarke et al., 2003). The first of these, the Tortachilla transgression, resulted in the deposition of fluviodeltaic to estuarine sediments (Werrillup Formation) on the lignitic sediments of the North Royal Formation. The second, the Tuketja transgression, was more extensive and the spongolitic Princess Royal Formation was deposited in an estuarine environment during the high stand. The interfingering Hampton Sandstone was deposited in a relatively high-energy environment, such as a near-shore beach, estuarine, or delta top environment (Jones, 1990; Clarke, 1994).

Regolith

The prolonged stability of the Yilgarn Craton and a marked climate change from wet, humid conditions in the Paleogene to the semi-arid conditions that have prevailed since the Neogene have resulted in deep weathering and the development of complex regolith profiles (Anand and Paine, 2002). On Erayinia, a significant proportion of the ground is covered by thick sheetwash or eolian deposits. The lack of significant relief and the dense vegetation cover on parts of Erayinia limited the effectiveness of satellite imagery and aerial photographs as aids for interpretation of regolith units.

Residual and relict units (*Rf*, Rgp_g, *Rk*, *Rz*, *Rzi*)

Residual lateritic profiles are preserved in a few locations on Erayinia and are best exposed in breakaways in the north. There, the deeply weathered bedrock grades upwards into kaolinitic saprolite and a mottled zone that is variably kaolinitic and ferruginous, typically capped by a variably siliceous and ferruginous duricrust. At most localities it is only this duricrust that can be seen.

Ferruginous duricrust (*Rf*) overlies a range of rock types, including Archean metasedimentary rocks, granite,

Epoch	Marine transgression	Group	Previous stratigraphy (Clarke, 1994)		Current stratigraphy (Clarke et al., 2003)	
			Cowan paleovalley	Lefroy paleovalley	Cowan paleovalley	Lefroy paleovalley
Oligocene to Holocene		Redmine Group				
Late Eocene	Tuketja	Eundynie Group	Princess Royal Spongolite	Princess Royal Spongolite and Hampton Sandstone	Pallinup Fm (Princess Royal Member)	Pallinup Fm (Princess Royal Member)
Mid–Upper Eocene			Upper Werrillup Fm	Pidinga Fm	Werrillup Fm	Werrillup Fm
	Tortachilla		Norseman Fm	Pidinga Fm	Norseman Fm	No unit recognized
Middle Eocene			Lower Werrillup Fm	Pidinga Fm	North Royal Fm	North Royal Fm

Figure 32. Stratigraphy of Cenozoic sedimentary rocks in the southern Eastern Goldfields region (after Clarke, 1994; Clarke et al., 2003)

and basalt; and Cenozoic sedimentary rocks. Ferruginous duricrust typically comprises hematite, with lesser amounts of goethite, and contains small siliceous lenses. It forms low ridges of massive to rubbly outcrops that are particularly common overlying basalt on northern ERAYINIA.

Residual material over granite (*Rgp*$_g$) is predominantly soil that is rich in clay and quartz sand, with minor amounts of silcrete, calcrete, and poorly exposed weathered granite boulders. These deposits are common overlying granite on central, northern, and eastern ERAYINIA.

Residual calcrete (*Rk*) is found in a few locations and is typically surrounded by colluvium, which includes abundant loose calcrete nodules and fragments (*Ck*). Silcrete (*Rz*) and ferruginous silcrete (*Rzi*) are most commonly formed over granitic rocks in the north and over Archean quartzites in the south. The silcrete typically forms rubbly outcrops on low hills and small breakaways and is predominantly milky white or cream to red brown, depending on the iron content.

Colluvium and sheetwash (*C*, *Cg*, *Ck*, *Cq*, *Ct*, *W*, *Wg*, *Wk*)

The distinction between colluvium and sheetwash on ERAYINIA has been based on the slope on which they lie. Colluvium (*C*) is present on gently sloping or undulating ground, whereas sheetwash (*W*) is deposited on subhorizontal ground or gently sloping plains adjacent to Quaternary alluvial channels. Undivided colluvium (*C*) and sheetwash (*W*) are predominantly composed of clay, silt, sand, calcrete and silcrete fragments, lithic clasts, and minor amounts of ferruginous granules and nodules.

Quartzofeldspathic colluvium (*Cg*) and sheetwash (*Wg*) deposits are observed above and adjacent to granitic rocks on central, northern, and eastern ERAYINIA. They are composed predominantly of clay, quartz sand, and lithic fragments of granitic composition. Calcrete-rich colluvium (*Ck*) and sheetwash (*Wk*) deposits contain significant proportions of calcrete nodules and fragments. The colluvial deposits commonly form low ridges, especially on eastern ERAYINIA. Quartz-rich colluvium (*Cq*) is composed of angular vein-quartz fragments and is common on the edges of playa lakes and around large quartz blows.

Lithic-rich colluvium (*Ct*) contains a high proportion of lithic clasts and lies on slopes immediately adjacent to outcrops of the Proterozoic Woodline Formation on southern ERAYINIA.

Lacustrine and sandplain units (L_d1, L_d2, L_m, L_p, *S*)

A series of playa lake systems on ERAYINIA forms tributaries of the Lefroy paleodrainage channel (Clarke, 1994) with several large playa lakes extending northeast from the southwestern corner of the map sheet area and converging with an east–west-trending playa lake system, informally named Lake Rivers. The drainage system includes playa lakes (L_p), active dunes (L_d1), stabilized dunes (L_d2), and areas of mixed lake deposits (L_m). The playa lake systems are made up of chains of small lakes separated by sand dunes, alluvial deposits, and small channels. Individual lakes form flat expanses of clay, mud, and sand with abundant gypsum, halite, and carbonate. Active dunes are variably composed of orange–yellow eolian sand and gypsum, and are typically non-vegetated or have only minor vegetation cover of predominantly samphire and saltbush. Stabilized dunes consist of eolian sand and clay and are vegetated predominantly by eucalypts, but also support casuarina and cypress in places. Mixed lacustrine deposits are on broad plains adjacent to playa lakes and consist of closely interspersed dunes, small lakes, and alluvial deposits.

Sandplain deposits (*S*) are predominantly composed of orange quartz sand. These deposits, which form an undulating terrain with scattered dunes, are most common on northeastern ERAYINIA.

Alluvial units (*A, Ap, Ak*)

Quaternary alluvium (*A*) on ERAYINIA includes ephemeral stream channel deposits, overbank deposits, and deltaic deposits. Alluvium consists of clay, silt, sand, and gravel of mixed composition. Non-vegetated to semi-vegetated clay- and silt-filled claypans (*Ap*) are relatively common along the drainage systems throughout ERAYINIA. Alluvial calcrete deposits (*Ak*) form rubbly outcrops with abundant blocks of calcrete and loose calcrete nodules within alluvial channels. These are most common on northern ERAYINIA.

Economic geology

Gold from the Karonie mine is the only metalliferous economic commodity that has been produced from within the boundaries of ERAYINIA. Surface and near-surface exploration has been carried out for many commodities, including gold, base metals, uranium, and diamonds. Various techniques have been employed, including rotary air blast (RAB), reverse circulation (RC), and diamond drilling, geological mapping, geophysical surveys, and rock chip and soil sampling. Open-file reports, maps, and other data submitted to the Department of Industry and Resources (DoIR) under the terms of mining and exploration tenements are available from the WA Mineral Exploration database (WAMEX) at the DoIR library in Perth, and at the GSWA Kalgoorlie regional office, or from the DOIR website (www.doir.wa.gov.au/GSWA).

Vein and hydrothermal mineralization — undivided

Precious metal — gold

There has been extensive gold exploration on ERAYINIA, focused mainly around the Karonie deposits (see **Karonie**

Main and Harry's Hill deposits) in a belt of mafic and sedimentary rocks extending south from the Karonie mine. There has also been some gold exploration in the Lake Rivers area on eastern ERAYINIA, and in the south as part of a larger exploration program mainly on YARDILLA.

Early exploration around the Karonie deposits and the French Kiss prospects (Fig. 33) was carried out mainly by Freeport Australian Minerals and later, in the 1980s and early 1990s, by Poseidon Exploration Ltd (Poseidon Exploration Ltd, 1992). There was intense exploration activity around the French Kiss prospects with various geochemical and drilling programs completed between 1985 and 1992, concentrating on an interpreted structurally complex area around the French Kiss lakes. RAB and follow-up RC drilling revealed many low-grade narrow intersections and substantial supergene enrichment in the weathered profile. In this area, the two best intersections were 8 m at 4.04 g/t Au from 36 m, and 20 m at 2.28 g/t Au from 36 m. Further exploration throughout this area has been undertaken by WMC Resources Ltd and Goldfields of Australia Ltd during the 1990s and 2000–01. The ground is currently held by Integra Ltd (formerly Relode Ltd) and recent exploration activity has included geological mapping and RC drilling south of the Karonie Main Zone pit and in the area around the French Kiss prospect. The Karonie deposits and prospects have been grouped and renamed the Aldiss Gold Project (Relode Ltd, 2003, 2004). Recent drilling at the Italia prospect, just north of French Kiss South, returned a high-grade intersection of 2 m at 8.60 g/t Au and lower grade intersections of 2 m at 4.5 g/t Au, 12 m at 1.6 g/t Au, and 4 m at 1.30 g/t Au (Relode Ltd, 2004). The Karonie group of deposits has a combined indicated resource of 6.16 Mt (contained metal 13 393 kg Au) (MINEDEX site no. S00389). The French Kiss South deposit has an indicated resource of 1.523 Mt at 2.0 g/t Au (3046 kg Au) (MINEDEX site no. S06414). The deposit is a supergene orebody hosted in regolith overlying mafic and felsic greenstones (Roberts et al., 2004).

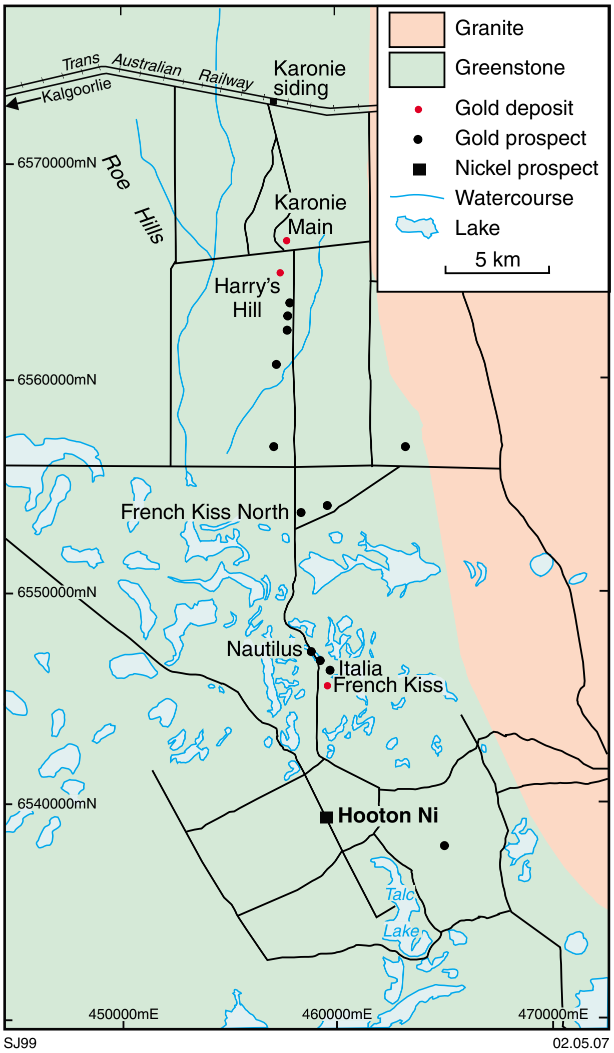

Figure 33. Locations of the main gold and nickel deposits and prospects on northwestern Erayinia

Extensive gold–nickel–PGE exploration by WMC Resources Ltd in joint venture with Gold Partners NL was undertaken from 1996–2002 on the band of ultramafic–mafic rocks extending from the Roe Hills to Talc Lake on central ERAYINIA (Fig. 33). A report by WMC Resources Ltd (2000, and references therein) lists previous work: by INSEL, Newmont, Jododex, and the Consolidated Goldfields – Mat-Kennecott JV from the late 1960s to 1970s; by Freeport, Glengarry Mining, Billiton Australia, and BHP Minerals Ltd in the 1980s; and by Metana Minerals NL and Gold Partners NL in the early 1990s. The WMC joint venture (1996–2002) followed up this work with RAB, RC, and diamond drilling, and reported the best gold intersection at Ginger Kiss prospect (about 1 km southwest of the French Kiss prospect) of 3 m at 2.15 g/t Au within deeply weathered micaceous clay above a porphyry unit (WMC Resources Ltd, 1996). This zone was thought to be an extension of the Au anomaly associated with the nearby French Kiss prospect to the east. WMC Resources Ltd (1999) also reported anomalous gold intersections from the Talc Lake area, with 18 m at 1.63 g/t Au from 138 m, and 2 m at 1.93 g/t Au from 2 m in the Central Lake area. RC drilling at the Sheehans Well prospect, northwestern ERAYINIA, recorded 5 m at 13.7 g/t Au from 50 m. However, follow-up drilling produced no significant results (WMC Resources Ltd, 1999, 2000, 2001).

A large exploration program in the Talc Lake area (also known as South Karonie) by a joint venture between BHP Minerals Pty Ltd, Broken Hill Propriety Co Ltd, Coopers Resources NL, and Enterprise Gold Mines NL, was undertaken in the late 1980s and early 1990s looking for orebodies like those in the Randalls mining centre to the west (Painter and Groenewald, 2001) in structurally complex banded iron-formations interpreted from aeromagnetic data. The program included airborne radiometric and magnetic surveys, soil sampling, ground magnetic surveys, rock chip sampling, auger drilling, and diamond, RC and RAB drilling, but failed to return any significant results. The most promising result was 3 m at 0.18 g/t Au in the Karonie South area, which is dominated by salt lakes which are deemed to make further exploration too expensive (Coopers Resources NL, 1990).

A number of other gold exploration programs on ERAYINIA failed to achieve any significant results. They include: an extensive RAB program on central ERAYINIA from 1984–90 by a BHP–Newmont – New Holland joint venture (BHP Gold Mines Ltd, 1991); the Madoonia Downs exploration project (1994–97) including soil sampling and RAB drilling by Kilkenny Gold NL on YARDILLA and the southern margin of ERAYINIA (Kilkenny Gold NL, 1997); and a smaller exploration program in 1997, the Leatherhead Project, investigating folded metasedimentary rocks in association with a syenite porphyry dyke (Pearson and Preston, 1997; Butler, 1998) east of the Madoonia Downs project.

Karonie Main and Harry's Hill deposits

The Karonie Main and Harry's Hill deposits are within a north-trending, steeply west-dipping shear zone about 3 km west of the Erayinia Granitic Suite. The area is predominantly composed of amphibolite and metasedimentary rocks and the shear zone is generally conformable with the main lithological trends (Poseidon Exploration Pty Ltd, 1992; De Luca, 1995). A recent review of the gold deposits at Karonie was provided by Roberts et al. (2004) and is summarized here.

Gold was produced from the Karonie area from a series of openpits and some underground workings with a total combined production, from the West and Main Zones (Fig. 33) and Harry's Hill openpit mines, of 4960.349 kg Au during the period from 1987 to 1992.

The gold deposits are predominantly hosted by medium- to coarse-grained (quartz-) amphibolite (possibly after a fractionated dolerite or ?para-amphibolite) and finer grained amphibolite (after ?metabasalt). De Luca (1995) suggested a tholeiitic precursor for the amphibolite, based on whole-rock geochemistry and high ilmenite content. Minor layers of quartz–biotite(–plagioclase–K-feldspar–almandine garnet) metasedimentary rock and rare black metashale also host some of the ore. The metasedimentary rocks are predominantly fine to medium grained with mm- to cm- scale banding and a granoblastic fabric throughout. However, sedimentary structures such as cross-bedding and flame structures are locally preserved. A metasedimentary unit is well exposed in the hinge zone of a shallow, north-plunging tight fold at the northern end of the Main Zone pit (Roberts et al., 2004).

The Main Zone orebody has a strike length of about 600 m and is about 40 m wide, consisting of several lenses that are generally conformable with the strike of the shear zone. The West Zone orebody is smaller, about 120 m in length and 4–12 m wide. The metamorphic grade in strongly sheared rocks of the Main and West Zone pits is estimated to be mid- to upper-amphibolite facies based on the presence of hornblende, calcic plagioclase, and minor amounts of cummingtonite and almandine garnet in mafic rocks. Either side of the shear zone, the grade decreases to greenschist-facies actinolite-bearing mafic rocks. De Luca (1995) recognized that strike-parallel faults bound the higher grade zone, indicating late post-metamorphic differential uplift.

The broad shear zone that hosts the deposits is wider than 100 m and is dominated by a well-developed foliation defined by mm- to m-scale mineral banding that has abundant tight to isoclinal folds and intrafolial folds. Larger scale folding is also well developed in calc-silicate assemblages on the eastern margin of the Main and West Zone pits, with mesoscopic folds with z-asymmetry suggesting either dextral displacement during simple shear or folding parasitic to a nearby anticline.

Strike-parallel brittle–ductile faults ('Marker Units' in local mine terminology) are superimposed on the ductile deformation and lithological banding within the shear zone. The faults consist of cataclasite and quartz–calcite veins and are well developed in the southern face of the Main Zone pit (Fig. 34). Sinistral displacement on these faults is indicated by offset of the quartz–biotite metasedimentary unit in the northern part of the pit, which is consistent with the orientation of quartz-vein tension gash arrays along the western side of the pit (Fig. 35) and the en echelon geometry of the ore lenses (De Luca, 1995; Roberts et al., 2004). Moderate to high temperatures during the brittle–ductile faulting is suggested by associated quartz–amphibole–biotite–carbonate(–pyrrhotite–pyroxene) veins (De Luca, 1995). Late gently north-dipping faults offset the shear zone and strike-parallel brittle–ductile faults.

Alteration types recognized in the shear zone include biotite-rich assemblages in mafic gneiss, calc-silicate assemblages, and later alteration related to discrete brittle–ductile faults. The alteration assemblages are in alternating bands throughout the shear zone, but local crosscutting relationships indicate that calc-silicate alteration post-dated formation of biotite-rich assemblages. Fabric relationships suggest that hydrothermal activity was coeval with ductile deformation in the shear zone, with metamorphic recrystallization and strain recovery outlasting ductile deformation (De Luca, 1995; Roberts et al., 2004).

The timing of gold mineralization at Karonie relative to the regional deformation and metamorphism is still uncertain. De Luca (1995) reported an association of gold with low-temperature minerals such as tellurides, epidote, and prehnite, and suggested that mineralization post-dated the high-temperature ductile deformation and metamorphism in the regional shear zone that hosts the deposits. The ore lenses are generally associated with pyroxene-bearing calc-silicate alteration, which suggests higher temperature mineralization, and that gold was probably remobilized to some extent during the later brittle–ductile faulting (Roberts et al., 2004).

Orthomagmatic mafic and ultramafic mineralization — layered mafic intrusions

Precious metal — platinum group elements

PGE exploration was carried out in the ultramafic–mafic rocks of the Talc Lake area and in the southern extension

Figure 34. South wall of the Main Zone pit, Karonie mine, northern ERAYINIA (MGA 458060E 6566420N)

of the Roe Hills on northwestern ERAYINIA as part of gold–nickel exploration programs by Freeport (1982–86), Glengarry Mining (1987–90), Metana Minerals NL (1990–91), Gold Partners NL in the early 1990s, and a joint venture of WMC Resources Ltd and Gold Partners NL from 1996 to 2002.

During the gold–nickel exploration program, WMC Resources Ltd routinely analysed samples for PGEs, and RC drilling at the Roe 1 prospect recorded up to 2 m at 120 ppb total PGEs from 52 m. This area is still considered to have potential for economic PGE mineralization (WMC Resources Ltd, 2000.

Base metal and steel industry metal — copper, nickel, lead, and zinc

Exploration for copper, lead, zinc, and nickel has been carried out on ERAYINIA. An extensive program that included costeans, geological mapping, ground and airborne magnetic surveys, soil sampling, and diamond drilling on central ERAYINIA (Talc Lake prospect, also known as Karonie South) by Newmont Pty Ltd from 1965 to 1970 found a number of thin gossans hosted by talc–magnesite altered ultramafic units along a strike length of 200 m (Newmont Pty Ltd, 1972). The best rock-chip assays from costeans returned 1.5% Ni and 0.35% Cu over an interval of 15 cm. In the early 1970s, Jododex Australia Pty Ltd continued exploration in the area, renaming it the Hooton prospect, and carried out soil sampling, magnetic surveys, and RC drilling. A best intersection of 3 m at 1.7% Ni and 0.28% Cu from 27.4 m depth was reported in a fine-grained chlorite schist with fine-grained pentlandite, violarite, and chalcopyrite (Jododex Australia Pty Ltd, 1978). However, a resampling program by Shell Ltd gave a best result of 3 m at 0.75% Ni and 0.05% Cu from around 24 m. No violarite was found; instead it was reported as more likely to be magnetite (WMC Resources Ltd, 2000).

Further nickel–gold–PGE exploration in ultramafic–mafic rocks of the Talc Lake area, and in the southern extension of the Roe Hills on northwestern ERAYINIA, was carried out by Freeport (1982–86), Glengarry Mining (1987–90), Metana Minerals NL (1990–91), Gold Partners NL in the early 1990s, and a joint venture of WMC Resources Ltd and Gold Partners NL from 1996 to 2002. This exploration program found a number of significant nickel sulfide intersections, including 1 m at 3.8% Ni from 155 m (including 0.5 m at 6.6% Ni) at Talc Lake, and 8.6 m at 0.45% Ni from 241.4 m at the Roe 2 prospect on northwestern ERAYINIA (WMC Resources Ltd, 1999). A report to the Australian Stock Exchange in 2005 indicated that Oroya Mining Ltd was then planning to commence exploration for nickel and gold in this area (Oroya Mining Ltd, 2005).

Nickel–gold exploration was also undertaken in the Lake Rivers area by a joint venture of Gutnick Resources NL, Mr M. G. Creasy, and WA Exploration Services Pty Ltd. They found a number of zones of elevated nickel (up to 76 ppm Ni) coinciding with elevated Cu values that were thought to be associated with ultramafic rock adjacent to the Cundeelee Fault (Creasy, 1998, 2001). As the area was flooded, the target was not tested completely and the exploration title was subsequently relinquished.

A joint venture between Gwalia Consolidated NL and Metana Minerals NL (now Gold Mines of Australia Ltd) carried out gold–copper–zinc exploration on the

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Figure 35. Steep north-northwest-oriented quartz veins associated with north-northeast-oriented faults on the southwestern wall of the Main Zone pit, Karonie mine, north Erayinia (MGA 458060E 6566420N). The orientation of the quartz veins is consistent with sinistral displacement on the associated faults

Urania–Calliope prospect on eastern ERAYINIA as a follow-up to previous exploration by Uranerz in the late 1970s and early 1980s. Airborne and ground magnetic surveys with follow-up RAB and RC drilling intersected a narrow band of massive pyrrhotite–pyrite and associated sphalerite (52–56 m) at 1.34% Zn at the Calliope prospect. At the Urania prospect, rock-chip sampling outlined anomalous zinc and copper zones (up to 392 ppm Zn and 177 ppm Cu), and two narrow anomalous gold zones corresponding to broad copper anomalies were identified from RAB drilling with a best result of 0.13% Cu (Metana Minerals NL, 1993, 1995).

Kimberlite and lamproite mineralization

Precious mineral — diamonds

Diamond exploration by CRA Exploration Pty Ltd on ERAYINIA has been focused on aeromagnetic and gravity anomalies along the margin of the Yilgarn Craton. Magnetic anomalies were tested by RC and aircore drilling but did not intersect any rocks with kimberlitic affinities (CRA Exploration Pty Ltd, 1994).

Stratabound sedimentary — clastic-hosted mineralization

Energy mineral — uranium

Uranium exploration was carried out by Uranerz Australia Pty Ltd during the late 1970s in the Lake Rivers area on eastern ERAYINIA. They were searching for placer-type uranium deposits in Cenozoic paleochannels, but a program including RC drilling and ground and airborne radioactivity surveys returned negative results (Uranerz Australia Pty Ltd, 1978).

Regolith — residual and supergene

Precious mineral — opal

A small opal occurrence within fractures in black shale adjacent to small porphyry bodies has been mined in an area adjacent to ERAYINIA on MOUNT BELCHES (Russgar Minerals NL, 1973). Exploration work has included costeans and geological mapping, but there has been no mining activity on the part of the tenement that is on ERAYINIA.

Hydrogeology

The hydrogeology of ERAYINIA is discussed in Explanatory Notes for the WIDGIEMOOLTHA 1:250 000 hydrogeological sheet (Kern, 1996). Most of the groundwater on ERAYINIA is saline to hypersaline with a limited amount of low-salinity groundwater in upland areas of granitic rocks. Fresh water for pastoralists is almost entirely derived from surface waters, a small amount of which comes from contour dams and rock walls. Most dams are located along drainages or on alluvial flats. Kern (1996) identified the Cenozoic sandstone, carbonate, and spongolite units in a large paleochannel as the most prospective aquifers on the WIDGIEMOOLTHA 1:250 000 sheet.

Acknowledgements

Thanks to Integra Ltd (formerly Relode Ltd) for access to the Karonie Gold deposits and for assistance with the GSWA open field trip on ERAYINIA.

References

ANAND, R. R., and PAINE, M., 2002, Regolith geology of the Yilgarn Craton, Western Australia: Implications for exploration: Australian Journal of Earth Sciences, v. 49, p. 3–162.

ARCHIBALD, N. J., 1987, Geology of the Norseman–Kambalda area, *in* Second Eastern Goldfields Geological Field Conference: Part A — Extended Abstracts: Geological Society of Australia (W.A. Division), p. 13–14.

ARCHIBALD, N. J., BETTENAY, L. G., BICKLE, M. J., and GROVES, D. I., 1981, Evolution of Archaean crust in the Eastern Goldfields Province of the Yilgarn Block: Geological Society of Australia, Special Publication, no. 7, p. 491–504.

ARCHIBALD, N. J., BETTENAY, L. G., BINNS, R. A., GROVES, D. I., and GUNTHORPE, R. J., 1978, The evolution of Archaean greenstone terrains Eastern Goldfields Province, Western Australia: Precambrian Research, v. 6, p. 103–131.

ASARCO LIMITED, 1971, Woodline Project, Final report: Western Australia Geological Survey Statutory mineral exploration report, A3146 (unpublished).

BARLEY, M. E., BROWN, S. J. A., KRAPEŽ, B., and CAS, R. A. F., 2002, Tectonostratigraphic analysis of the Eastern Yilgarn Craton: an improved geological framework for exploration in Archaean terranes: Amira International Limited, AMIRA Project no. P437A final report (unpublished).

BEARD, J. S., 1975, The vegetation of the Nullarbor area — Explanatory Notes to sheet 4, Vegetation Survey of Western Australia: University of Western Australia Press, 104p.

BEARD, J. S., 1985, The vegetation of Western Australia at the 1:3 000 000 scale: Western Australia Forests Department, Explanatory Notes: University of Western Australia Press, 32p.

BEARD, J. S., 1990, Plant life of Western Australia: Kenthurst, N.S.W.: Kangaroo Press, 319p.

BHP GOLD MINES LTD, 1991, Karonie Gold Exploration, Annual Report: Western Australia Geological Survey, Statutory mineral exploration report, A32847 (unpublished).

BLEWETT, R. S., CASSIDY, K. F., CHAMPION, D. C., HENSON, P. A., GOLEBY, B. S., JONES, L., and GROENEWALD, P. B., 2004, The Wangkathaa Orogeny: an example of episodic regional 'D_2' in the late-Archaean Eastern Goldfields Province, Western Australia: Precambrian Research, v. 130, p. 139–159.

BODORKOS, S., LOVE, G. J., NELSON, D. R., and WINGATE, M. T. D., 2006, 177917: metamorphosed tuffaceous sandstone, Round Hill; Geochronology dataset 624, *in* Compilation of geochronology data, June 2006 update: Western Australia Geological Survey.

BROWN, S. J. A., KRAPEZ, B., BERESFORD, S., CASSIDY, K. F., CHAMPION, D. C., BARLEY, M. E., and CAS, R. A. F., 2001, Archaean volcanic and sedimentary environments of the Eastern Goldfields Province, Western Australia — a field guide: Western Australia Geological Survey, Record 2001/13, 66p.

BUNTING, J. A., and van de GRAAFF, W. J. E., 1972, The Cundeelee 1:250 000 sheet: Western Australia Geological Survey, 1:250 000 Geological Series.

BUTLER, C.P., 1998, Leatherhead Project, Report: Western Australia Geological Survey, Statutory mineral exploration report, A52921 (unpublished).

CAMPBELL, I. H., McCALL, G. J. H., and TYRWHITT, D. S., 1970, The Jimberlana norite, Western Australia — a smaller analogue of the Great Dyke of Rhodesia: Geological Magazine, v. 107, p. 1–12.

CASSIDY, K. F., and CHAMPION, D. C., 2002, Granitoids of the southeastern Yilgarn Craton: Distribution, geochronology, geochemistry, petrogenesis and relationships to mineralization, *in* Characterization and metallogenic significance of Archaean granitoids of the Yilgarn Craton, Western Australia *edited by* A. WHITAKER, D. CHAMPION, K. CASSIDY, A. BUDD, I. FLETCHER, N. McNAUGHTON, and S. HAGEMANN: Perth Western Australia, MERIWA Project No. M281/AMIRA Project P482, Chapter 3 (unpublished).

CASSIDY, K. F., CHAMPION, D. C., KRAPEZ, B., BARLEY, M. E., BROWN, S. J. A., BLEWETT, R. S., GROENEWALD, P. B., and TYLER, I. M., 2006, A revised geological framework for the Yilgarn Craton, Western Australia: Western Australian Geological Survey, Record 2006/8, 8p.

CHAMPION, D. C., and SHERATON, J. W., 1997, Geochemistry and Sm–Nd isotope systematics of Archaean granitoids of the Eastern Goldfields Province, Yilgarn Craton, Australia: constraints on crustal growth: Precambrian Research, v. 83, p. 109–132.

CHEN, S. F., WITT, W. K., and LIU, S., 2001, Transpression and restraining jogs in the northeastern Yilgarn craton, Western Australia: Precambrian Research, v. 106, p. 309–328.

CLARK, D. J., HENSEN, B. J., and KINNY, P. D., 2000, Geochronological constraints for a two-stage history of the Albany–Fraser Orogen, Western Australia: Precambrian Research, v. 102, p. 155–183.

CLARKE, J. D. A., 1994, Evolution of the Lefroy and Cowan palaeodrainage channels, Western Australia: Australian Journal of Earth Sciences, v. 41, p. 55–68.

CLARKE, J. D. A., GAMMON, P. R., HOU, B., and GALLAGHER, S. J., 2003, Middle to Upper Eocene stratigraphic nomenclature and deposition in the Eucla Basin: Australian Journal of Earth Sciences, v. 50, p. 231–248.

COOPERS RESOURCES NL, 1990, South Karonie gold-base metal exploration, Final Report: Western Australia Geological Survey, Statutory mineral exploration report, A30021 (unpublished).

CRA EXPLORATION PTY LTD, 1994, Symons Diamond Exploration, Final Report: Western Australia Geological Survey, Statutory mineral exploration report, A43351 (unpublished).

CREASY, M. G., 1998, Lake Rivers Project, Report: Western Australia Geological Survey, Statutory mineral exploration report, A55802 (unpublished).

CREASY, M. G., 2001, Zanthus gold/nickel exploration, Surrender Report: Western Australia Geological Survey, Statutory mineral exploration report, A64042 (unpublished).

DAWSON, G. C., KRAPEZ, B., FLETCHER, I. R., MCNAUGHTON, N. J., and RASMUSSEN, B., 2002, Did late Palaeoproterozoic assembly of proto-Australia involve collision between the Pilbara, Yilgarn and Gawler Cratons? Geochronological evidence from the Mount Barren Group in the Albany–Fraser Orogen of Western Australia: Precambrian Research, v. 118, p. 195–220.

DAWSON, G. C., KRAPEZ, B., FLETCHER, I. R., MCNAUGHTON, N. J., and RASMUSSEN, B., 2003, 1.2 Ga thermal metamorphism in the Albany–Fraser Orogen of Western Australia: consequence of collision or regional heating by dyke swarms?: Journal of the Geological Society, London, v. 160, p. 29–37.

De LUCA, K. E., 1995, Gold mineralization in the Karonie greenstone belt, Eastern Goldfields, Western Australia: Western Australian School of Mines, MSc thesis (unpublished).

DIELS, L., 1906, Die Pflanzenwelt von West-Australien sudlich des Wendekreises: Vegetation der Erde 7, Leipzig, 326p.

EVANS, T., 1999, Extent and nature of the 1200 Ma Wheatbelt dyke swarm, southwestern Australia: University of Western Australia, BSc (Hons) thesis (unpublished).

FLETCHER, I. R., LIBBY, W.G., and ROSMAN. K. J. R., 1987, Sm–Nd dating of the 2411 Ma Jimberlana dyke, Yilgarn Block, Western Australia: Australian Journal of Earth Sciences, v. 34, p. 523–525.

FLETCHER, I. R., and McNAUGHTON, N. J., 2002, Granitoid geochronology: SHRIMP zircon and titanite data, *in* Characterization and metallogenic significance of Archaean granitoids of the Yilgarn Craton, Western Australia *edited by* A. WHITAKER, D. CHAMPION, K. CASSIDY, A. BUDD, I. FLETCHER, N. McNAUGHTON, and S. HAGEMANN: Perth, Western Australia, MERIWA Project No. M281/AMIRA Project P482, Report No. 222, Chapter 6 (unpublished).

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, 2007, East Yilgarn 1:100 000 Geological Information Series, June 2006 update: Western Australia Geological Survey.

GOLEBY, B. R., RATTENBURY, M. S., SWAGER, C. P., DRUMMOND, B. J., WILLIAMS, P. R., SHERATON, J. E., and HEINRICH, C. A., 1993, Archaean crustal structure from seismic reflection profiling, Eastern Goldfields, Western Australia: Australian Geological Survey Organisation, Record 1993/15, 54p.

GRESHAM, J. J., and LOFTUS-HILLS, G. D., 1981, The geology of the Kambalda nickel field, Western Australia: Economic Geology, v. 76, p. 1373–1416.

GRIFFIN, T. J., 1989, Widgiemooltha, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 43p.

GROENEWALD, P. B., MORRIS, P. A., and CHAMPION, D. C., 2002, Geology of the Eastern Goldfields and an overview of tectonic models, *in* The Northeastern Yilgarn Deep Seismic Reflection Survey: Geoscience Australia, Record 2003/28, p. 63–84.

HALL, C. E., and JONES, S. A., 2005, The Proterozoic Woodline Formation: New constraints from geochronology, sedimentology, and deformation studies, *in* GSWA 2005 extended abstracts: Promoting the prospectivity of Western Australia: Western Australia Geological Survey, Record 2005/5, p. 14–15.

HALL, C. E., JONES, S. A., and GOSCOMBE, B., 2006, Yardina, W.A. Sheet 3334: Western Australia Geological Survey, 1:100 000 Geological Series.

HALLBERG, J. A., 1987, Postcratonization mafic and ultramafic dykes of the Yilgarn Block, Australian Journal of Earth Sciences, v. 34, p. 135–149.

HAMMOND, R. L., and NISBET, B. W., 1992, Towards a structural and tectonic framework for the Norseman–Wiluna greenstone belt, Western Australia, *in* The Archaean: Terrains, processes and metallogeny *edited by* J. E. GLOVER and S. E. HO: University of Western Australia, Geology Department and University Extension, Publication no. 22, p. 39–50.

HILL, R. I., CHAPPELL, B. W., and CAMPBELL, I. H., 1992, Late Archaean granites of the southeastern Yilgarn Block, Western Australia: age, geochemistry, and origin: Royal Society of Edinburgh, Transactions, v. 83, p. 211–226.

HOCKING, R. M., and COCKBAIN, A. E., 1990, Regolith, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 590–602.

HUNTER, W. M., 1993, The geology of the granite–greenstone terrane of the Kalgoorlie and Yilmia 1:100 000 sheets, Western Australia: Western Australia Geological Survey, Report 35, 80p.

JODODEX AUSTRALIA PTY LTD, 1978, Hooton Ni–Cu Exploration Report: Western Australia Geological Survey, Statutory mineral exploration report, A4345 (unpublished).

JOHNSON, G. I., 1991, The petrology, geochemistry and geochronology of the felsic alkaline suite of the eastern Yilgarn Block, Western Australia: University of Adelaide, PhD thesis (unpublished).

JONES, B. G., 1990, Cretaceous and Tertiary sedimentation on the western margin of the Eucla Basin: Australian Journal of Earth Sciences, v. 37, p. 317–329.

JONES, S. A., 2003, Effects of the Mesoproterozoic Albany–Fraser Orogeny on the southeastern margin of the Yilgarn Craton: Western Australia Geological Survey, Annual Review 2002–03, p. 60–70.

JONES, S. A., 2005, Geology of the Yardilla 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 34p.

JONES, S. A., 2006, Mesoproterozoic Albany–Fraser Orogen-related deformation along the southeastern margin of the Yilgarn Craton: Australian Journal of Earth Sciences, v. 53, p. 213–234.

JONES, S. A., and HALL, C. E., 2004, Archaean and Proterozoic geology of the southeastern margin of the Yilgarn Craton — a field guide: Western Australia Geological Survey, Record 2004/18, 37p.

JONES, S. A., and ROSS, A., 2005, Yardilla, W.A. Sheet 3434: Western Australia Geological Survey, 1:100 000 Geological Series.

KENT, A. J. R., and McDOUGALL, I., 1995, ^{40}Ar–^{39}Ar and U–Pb age constraints on the timing of gold mineralization in the Kalgoorlie Gold Field, Western Australia: Economic Geology, v. 90, p. 845–859.

KERN, A. M., 1996, Widgiemooltha, W.A., Western Australia Geological Survey, 1:250 000 Hydrogeological Series Explanatory Notes, 16p.

KILKENNY GOLD NL, 1997, Madoonia Downs Project, Partial Surrender Report: Western Australia Geological Survey, Statutory mineral exploration report, A51681 (unpublished).

KRAPEZ, B., BROWN, S. J. A., and HAND, J., 1997, Stratigraphic signatures of depositional basins in Archaean volcanosedimentary successions of the Eastern Goldfields Province: Australian Geological Survey Organisation, Record 1997/41, p. 33–38.

KRAPEZ, B., BROWN, S. J. A., HAND, J., BARLEY, M. E., and CAS, R. A. F., 2000, Age constraints on recycled crustal and supracrustal sources of Archaean metasedimentary sequences, Eastern Goldfields Province, Western Australia: evidence from SHRIMP zircon dating: Tectonophysics, v. 322, p. 89–133.

McCALL G. J. H., and PEERS, R., 1971, Geology of the Binneringie Dyke, Western Australia: Sondruck Geologische Rundschau, v. 60, p. 1174–1263.

METANA MINERALS NL, 1993, Erayinia Joint Venture Progress Report: Western Australia Geological Survey, Statutory mineral exploration report, A38306 (unpublished).

METANA MINERALS NL, 1995, Erayinia Joint Venture Progress Report: Western Australia Geological Survey, Statutory mineral exploration report, A48295 (unpublished).

MIKUCKI, E. J., and ROBERTS, F. I., 2003, Metamorphic petrography of the Kalgoorlie region, Eastern Goldfields Granite–Greenstone Terrane: METPET database: Western Australia Geological Survey, Record 2003/12, 40p.

MYERS, J. S., 1990, Albany–Fraser Orogen, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 255–263.

MYERS, J. S., 1995, The generation and assembly of an Archaean supercontinent: evidence from the Yilgarn craton, Western Australia, *in* Early Precambrian Processes *edited by* M. P. COWARD and A. C. RIES: Geological Society of London, Special Publication no. 95, p. 143–154.

MYERS, J. S., 1997, Preface: Archaean geology of the Eastern Goldfields of Western Australia — regional overview: Precambrian Research, v. 83, p. 1–10.

NELSON, D. R., 1995, Compilation of SHRIMP U–Pb zircon dates, 1994: Western Australia Geological Survey, Record 1995/03, 244p.

NELSON, D. R., 1997, Evolution of the Archaean granite–greenstone terranes of the Eastern Goldfields, Western Australia: SHRIMP U–Pb zircon constraints: Precambrian Research, v. 83, p. 57–81.

NELSON, D. R., MYERS, J. S., and NUTMAN, A. P., 1995, Chronology and evolution of the middle Proterozoic Albany–Fraser Orogen, Western Australia: Australian Journal of Earth Sciences, v. 42, p. 481–495.

NEMCHIN, A. A., and PIDGEON, R. T., 1998, Precise conventional and SHRIMP baddeleyite U–Pb age for the Binneringie Dyke, near Narrogin, Western Australia: Australian Journal of Earth Sciences, v. 45, p. 673–675.

NEWMONT PTY LTD, 1972, Fraser Range base metals exploration, Final Report: Western Australia Geological Survey, Statutory mineral exploration report, A11952 (unpublished).

NORTHCOTE, K. H., ISBELL, R. F., WEBB, A. A., MURTHA, G. G., CHURCHWARD, M., and BETTENAY, E., 1968, Central Australia, *in* Atlas of Australian Soils: Australia CSIRO, 100p.

OROYA MINING LTD, 2005, Oroya to explore for nickel at Roe Hills: Report to Australian Stock Exchange, 27 January 2005, 10p.

PAINTER, M. G. M., and GROENEWALD, P. B., 2000, Mount Belches 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series.

PAINTER, M. G. M., and GROENEWALD, P. B., 2001, Geology of the Mount Belches 1:100 000 sheet: West Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 38p.

PASSCHIER, C. W., 1994, Structural geology across a proposed Archaean terrane boundary in the eastern Yilgarn Craton, Western Australia: Precambrian Research, v. 68, p. 43–64.

PEARSON, J., and PRESTON, V., 1997, Leatherhead Project, Annual Report: Western Australia Geological Survey, Statutory mineral exploration report, A52921 (unpublished).

POSEIDON EXPLORATION LTD, 1992, French Kiss Project, Annual Report: Western Australia Geological Survey, Statutory mineral exploration report, A37044 (unpublished).

RELODE LTD, 2003, Commences RAB drilling campaign at Karonie project: Report to Australian Stock Exchange, 29 October 2003, 2p.

RELODE LTD, 2004, Primary gold mineralisation defined at the Italia deposit: Report to Australian Stock Exchange, 20 February 2004, 6p.

RIDLEY, J. R., 1993, Implications of metamorphic patterns to tectonic models of the Eastern Goldfields, *in* Kalgoorlie 93 — An international conference on crustal evolution, metallogeny, and exploration of the Eastern Goldfields *compiled by* P. R. WILLIAMS and J. A. HALDANE: Australian Geological Survey Organisation, Record 1993/54, p. 95–100.

ROBERTS, F. I., WITT, W. K., and WESTAWAY, J., 2004, Gold mineralization in the Edjudina–Kanowna region, Eastern Goldfields, Western Australia: Western Australia Geological Survey, Report 90, 263p.

RUSSGAR MINERALS NL, 1973, Cowarna Opal Exploration, Progress Report: Western Australia Geological Survey, Statutory mineral exploration report, A3819 (unpublished).

SMITHIES, R. H., 1994, Geology of the Roe 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 15p.

SMITHIES, R. H., and CHAMPION, D. C., 1999, Late Archaean felsic alkaline igneous rocks in the eastern Goldfields, Yilgarn Craton, Western Australia: a result of lower crustal delamination?: Geological Society of London, v. 156, p. 561–576.

SOFOULIS, J., 1966, Widgiemooltha, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 25p.

SWAGER, C. P., 1989, Structure of the Kalgoorlie greenstones — regional deformation history and implications for the structural setting of the Golden Mile gold deposits: Western Australia Geological Survey, Report 25, Professional Papers, p. 59–84.

SWAGER, C. P., 1995, Geology of the greenstone terranes in the Kurnalpi–Edjudina region, southeastern Yilgarn Craton: Western Australia Geological Survey, Report 47, 31p.

SWAGER, C. P., 1997, Tectono-stratigraphy of late Archaean greenstone terranes in the southern Eastern Goldfields, Western Australia: Precambrian Research, v. 83, p. 11–42.

SWAGER, C. P., GOLEBY, B. R., DRUMMOND, B. J., RATTENBURY, M. S., and WILLIAMS, P. R., 1997, Crustal structure of granite–greenstone terranes in the Eastern Goldfields, Yilgarn Craton, as revealed by seismic reflection profiling: Precambrian Research, v. 83, p. 43–56.

SWAGER, C. P., and GRIFFIN, T. J., 1990, An early thrust duplex in the Kalgoorlie–Kambalda greenstone belt, Eastern Goldfields Province, Western Australia: Precambrian Research, v. 48, p. 63–73.

SWAGER, C. P., GRIFFIN, T. J., WITT, W. K., WYCHE, S., AHMAT, A. L., HUNTER, W. M., and McGOLDRICK, P. J., 1995, Geology of the Archaean Kalgoorlie Terrane — an explanatory note: Western Australia Geological Survey, Report 48, 26p.

SWAGER, C. P., and NELSON, D. R., 1997, Extensional emplacement of a high-grade granite gneiss complex into low-grade granite greenstones, Eastern Goldfields, Western Australia: Precambrian Research, v. 83, p. 203–219.

TUREK, A., 1966, Rb–Sr isotopic studies in the Kalgoorlie–Norseman area, Western Australia: Australian National University, PhD thesis (unpublished).

TYLER, I. M., and HOCKING, R. M., 2002, A revision of the tectonic units of Western Australia: Western Australia Geological Survey, Annual Review 2000–01, p. 33–44.

URANERZ AUSTRALIA PTY LTD, 1978, Lake Rivers and Coonana uranium exploration, Report: Western Australia Geological Survey, Statutory mineral exploration report, A7874 (unpublished).

WEINBERG, R. F., MORESI, L., and van der BORGH, P., 2003, Timing of deformation in the Norseman–Wiluna Belt, Yilgarn Craton, Western Australia: Precambrian Research, v. 120, p. 219–239.

WILLIAMS, P. R., 1993, A new hypothesis for the evolution of the Eastern Goldfields Province, *in* Kalgoorlie 93 — An international conference on crustal evolution, metallogeny, and exploration of the Eastern Goldfields *compiled by* P. R. WILLIAMS and J. A. HALDANE: Australian Geological Survey Organisation, Record 1993/54, p. 77–83.

WINGATE, M. T. D., and BODORKOS, S., 2007a, 177916: metasiltstone, Karonie Mine; Geochronology dataset 665, *in* Compilation of geochronology data: Western Australia Geological Survey.

WINGATE, M. T. D., and BODORKOS, S., 2007b, 177919: felsic metavolcanic rock, Urania Prospect; Geochronology dataset 666, *in* Compilation of geochronology data: Western Australia Geological Survey.

WINGATE, M. T. D., CAMPBELL, I. H., and HARRIS, L. B., 2000, SHRIMP baddeleyite age for the Fraser Dyke Swarm, southeast Yilgarn Craton, Western Australia: Australian Journal of Earth Sciences, v. 47, p. 309–313.

WITT, W. K., 1991, Regional metamorphic controls on alteration assemblages associated with gold mineralization in the Eastern Goldfields Province Western Australia: Implications for the timing and origin of Archaean lode-gold deposits: Geology, v. 19, p. 982–985.

WITT, W. K., 1994, Geology of the Bardoc 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 50p.

WMC RESOURCES LTD, 1991, Woodline nickel/gold exploration, Annual Report: Western Australia Geological Survey, Statutory mineral exploration report, A35107 (unpublished).

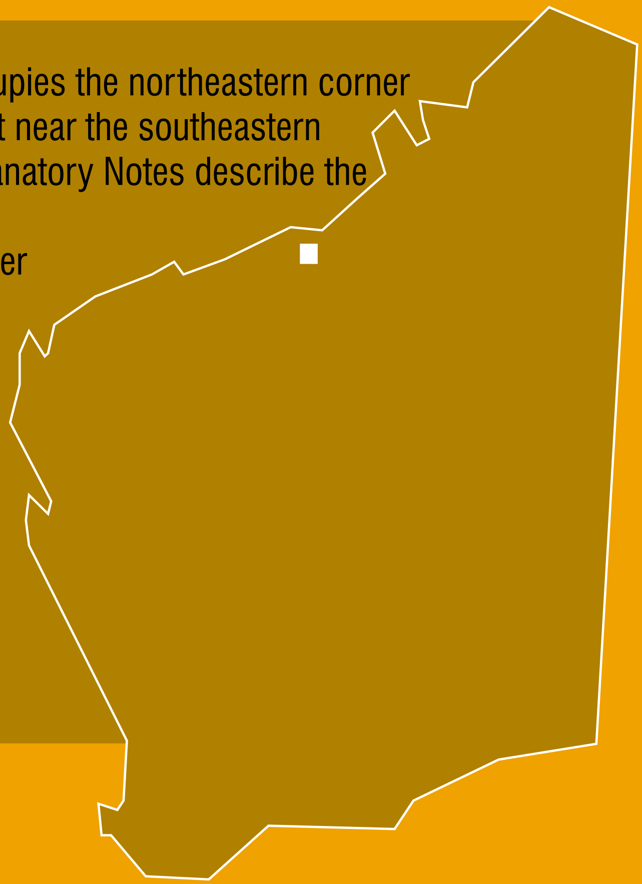
WMC RESOURCES LTD, 1996, Erayinia–Roe Hills gold–nickel–PGE exploration, Combined Annual Report: Western Australia Geological Survey, Statutory mineral exploration report, A46922 (unpublished).

WMC RESOURCES LTD, 1999, Erayinia–Roe Hills gold–nickel–PGE exploration, Combined Annual Report: Western Australia Geological Survey, Statutory mineral exploration report, A58094 (unpublished).

WMC RESOURCES LTD, 2000, Erayinia–Roe Hills gold–nickel–PGE exploration, Combined Annual Report: Western Australia Geological Survey, Statutory mineral exploration report, A60258 (unpublished).

WMC RESOURCES LTD, 2001, Erayinia–Roe Hills gold–nickel–PGE exploration, Combined Annual Technical Report: Western Australia Geological Survey, Statutory mineral exploration report, A62261 (unpublished).

The ERAYINIA 1:100 000 sheet area occupies the northeastern corner of the WIDGIEMOOLTHA 1:250 000 sheet near the southeastern margin of the Yilgarn Craton. These Explanatory Notes describe the Archean, Proterozoic, and Cenozoic rocks of the area, their relationship to other components of the Eastern Goldfields Superterrane, and the deformation and metamorphism that has affected them. The Karonie gold mine, which is a shear-zone hosted deposit in amphibolite facies rocks, is within the sheet area, which also includes several gold, nickel, and base metal prospects.



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JONES

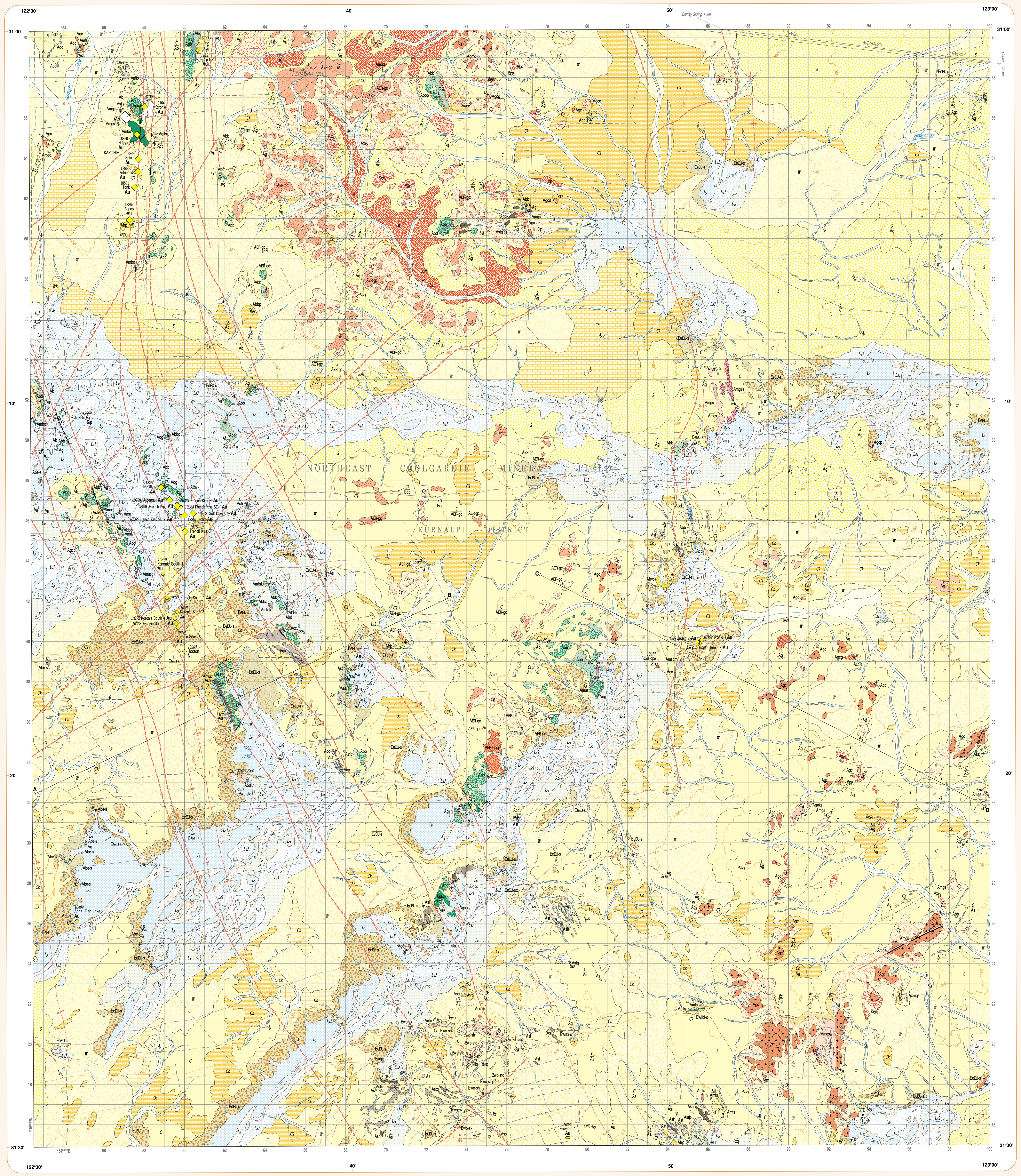
Geology of the Erayinia 1:100 000 sheet

EXPLANATORY NOTES

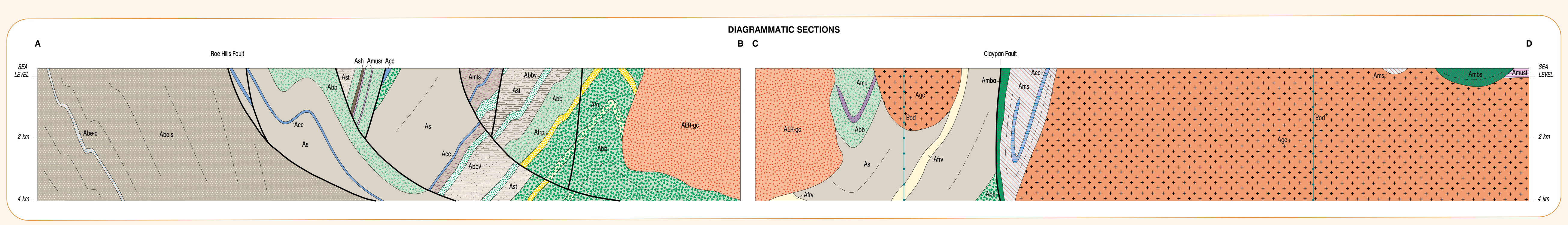
ERAYINIA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET 3435



DIAGRAMMATIC SECTIONS



CENOZOIC

Colluvial units

- *C* — Colluvium derived from different rock types; includes gravel, sand, and silt
- *Cg* — Quartzofeldspathic gravel, sand, and silt, commonly derived from granitic rock and associated weathering products
- *Ck* — Colluvium dominated by calcrete; includes loose nodules and irregular fragments
- *Cq* — Quartz-vein debris
- *Ct* — Lithic-rich colluvium
- *Cz* — Colluvium of silcrete; includes gravel, sand, and silt

Low-gradient slope units

- *W* — Clay, silt, and sand in extensive fans; local ferruginous gravel
- *Wg* — Clay, silt, and sand, commonly derived from granitic rock
- *Wk* — Clay, silt, and sand, with abundant calcrete nodules

Alluvial units

- *A* — Clay, silt, sand, and gravel in channels and on floodplains
- *Ap* — Clay and silt in claypans
- *Ak* — Calcrete and carbonate-cemented alluvium in fluvial channels

Lacustrine units

- *Ld1* — Dune and lake deposits; active systems within and adjacent to playa lakes; non-vegetated or poorly vegetated
- *Lm* — Mixed dune, evaporite, and alluvial deposits, typically adjacent to playa lakes
- *Lp* — Saline and gypsiferous evaporite deposits, clay, silt, and sand in playa lakes

Lacustrine unit

- *Ld2* — Stabilized dunes within and adjacent to playa lakes; typically vegetated

Sandplain unit

- *S* — Residual and eolian sand with minor silt and clay; low, vegetated dunes locally common

Residual or relict units

- *Rf* — Ferruginous duricrust, massive to rubbly; includes iron-cemented reworked products
- *Rgpg* — Quartzofeldspathic sand, gravel, and minor silcrete over granite; sparse granite outcrop; includes mottled and leached zones of weathering profile
- *Rk* — Calcrete
- *Rz* — Silcrete
- *Rzi* — Ferruginous silcrete

PALEOGENE — EOCENE — Eundynie Group (EUCLA BASIN)

- EeEU-s — **Eundynie Group:** undivided siliciclastic rocks, locally spongilitic, bituminous, calcareous, or bioclastic; generally poorly indurated; locally silicified and ferruginized
- EeEU-stc — Fossiliferous sandstone, massive to weakly bedded with abundant shell fragments

PALEOZOIC — PERMIAN (GUNBARREL BASIN)

- Psdp — Diamictite; polymict with boulders of garnet gneiss, granite, schist, and metasedimentary rocks

PALEOPROTEROZOIC

<1737 Ma [1,2]

WOODLINE FORMATION

- Ewo-sh — Shale
- Ewo-stq — Quartz sandstone; minor conglomerate
- Ewo-sx — Sedimentary breccia

c. 2420 Ma [3] — Widgiemooltha Dyke Suite

- EWIbi-o — **BINNERINGIE DYKE:** mainly dolerite and gabbro; includes cumulate and granophyric differentiates

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- g — Granitic dyke
- zq — Quartz vein or pod; massive, crystalline, or brecciated

ARCHEAN (YILGARN CRATON)

c. 2660 Ma [4] — Erayinia Granitic Suite

- AER-gc — Quartz monzonite; commonly porphyritic
- AER-gcap — Fine-grained porphyritic quartz monzonite
- AER-gcp — Porphyritic quartz monzonite

- Amgs — Schist derived from granitic rock
- Axmgs-mbs — Foliated metagranite interleaved with subordinate foliated, fine- to medium-grained metamafic rock; gneissic banding developed locally
- Amgss — Foliated metagranitic rock; includes local amphibolite lenses
- Ag — Granitic rock, undivided; includes deeply weathered rock
- Agc — Quartz monzonite; commonly porphyritic
- Agca — Fine-grained quartz monzonite
- Agce — Equigranular quartz monzonite; locally porphyritic
- Agcg — Megacrystic quartz monzonite
- Agcp — Porphyritic quartz monzonite
- Agmq — Quartz-rich monzogranite

- Ams — Schist; deeply weathered
- Amsbg — Biotite–garnet schist
- Amscm — Chlorite–muscovite schist

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c. 2666 Ma [5]

- Abe-s — **MOUNT BELCHES FORMATION:** undivided and commonly deeply weathered; varying proportions of wacke and mudstone, typically biotitic; rare banded iron-formation and pebbly sandstone beds; generally weakly metamorphosed but locally strongly hornfelsed
- Abe-c — Chert; metamorphosed (in section only)

- Amda — Para-amphibolite
- Amts — Schist derived from sandstone
- As — Sedimentary rock, undivided; includes sandstone, siltstone, shale, and chert; metamorphosed; commonly deeply weathered
- Ascp — Conglomerate; polymictic; metamorphosed
- Asgp — Conglomerate with subordinate sandstone; pebbles and boulders include granitic rock, chert, felsic porphyritic rock, and mafic rock; matrix or clast supported, metamorphosed
- Ash — Shale with subordinate chert; minor siltstone and sandstone; variably foliated; commonly silicified; metamorphosed; may include some slate and phyllite
- Asl — Siltstone; metamorphosed
- Ass — Sandstone to siltstone; local conglomerate; metamorphosed
- Ast — Sandstone, locally pebbly; subordinate conglomerate and siltstone; metamorphosed
- Astb — Sandstone derived from mafic rocks; metamorphosed
- Astq — Medium- to coarse-grained, quartz-rich sandstone; metamorphosed; common micaceous intervals; local quartzite
- Acc — Chert and banded chert; locally includes silicified (black) shale, slate, or exhalite; metamorphosed
- Acci — Chert and banded chert; ferruginous; locally includes silicified (black) shale, and slate; metamorphosed
- Accx — Chert breccia, commonly cemented with goethite; metamorphosed

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- Amfs — Quartzofeldspathic micaceous schist derived from felsic volcanic or volcaniclastic protolith
- Amfak — Meta-andesite; carbonate-altered
- Af — Felsic volcanic and volcaniclastic rocks; metamorphosed; commonly deeply weathered and kaolinized
- Afa — Andesite, commonly with plagioclase and/or hornblende phenocrysts; metamorphosed
- Afd — Dacite; commonly tuffaceous; locally brecciated; includes minor rhyolite, rhyodacite, and andesite; metamorphosed
- Afrp — Quartz–feldspar porphyritic rock; weak to schistose foliation; metamorphosed
- Afrv — Rhyolitic volcaniclastic rock; metamorphosed (in section only)
- Afrvt — **Bedded rhyolitic volcaniclastic rock with minor felsic volcanic rock; metamorphosed;** *c.* 2680 Ma from GSWA sample ID 177919 located approximately 6 km NW of Urania

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- Aod — Dolerite; minor basalt or gabbro components; metamorphosed
- Aog — Gabbro; minor pyroxenite or quartz gabbro components; metamorphosed

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- Amba — Amphibolite, fine to medium grained; commonly weakly foliated or massive
- Ambs — Foliated, fine-grained metamafic rock; locally hornfelsed or epidotized
- Ab — Fine to very fine grained mafic rock, undivided; metamorphosed; commonly deeply weathered
- Abb — Basalt; locally porphyritic; includes dolerite-textured zones; metamorphosed
- Abbg — Amygdaloidal basalt; metamorphosed
- Abbo — Pillow basalt; metamorphosed
- Abbp — Porphyritic to glomeroporphyritic basalt; fine to coarse plagioclase phenocrysts; local intense epidotization; metamorphosed
- Abbv — Basalt with volcaniclastic textures; metamorphosed
- Abbx — Basaltic fragmental rock; agglomerate, hyaloclastite peperite or breccia; metamorphosed

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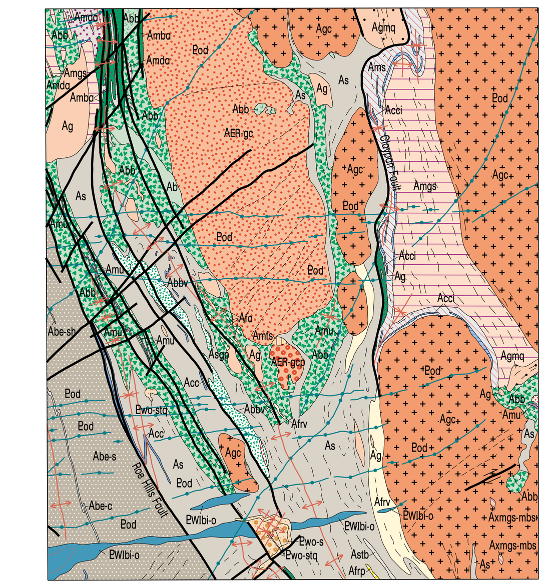
- Amu — Meta-ultramafic rock, undivided; includes talc–chlorite(–carbonate) and tremolite–chlorite schist
- Amusr — Tremolite(–chlorite–talc–carbonate) schist; locally serpentinized; komatiitic or pyroxenitic protolith
- Amust — Talc–chlorite(–carbonate) schist; minor tremolite–chlorite schist

INTERPRETED BEDROCK GEOLOGY



SCALE 1:500 000

0 5 10 15 20 Kilometres

- Ewo-s — Woodline Formation
- Ewo-stq — Quartz sandstone; minor conglomerate
- Eod — Dolerite dyke, sill, and plug
- EWIbi-o — Widgiemooltha Dyke Suite — Binneringie Dyke

Erayinia Granitic Suite

- AER-gc — Quartz monzonite; commonly porphyritic
- AER-gcp — Porphyritic quartz monzonite
- Amgs — Schist derived from granitic rock
- Axmgs-mbs — Foliated granitic rock interleaved with subordinate foliated mafic rock
- Ag — Granitic rock, undivided; includes deeply weathered rock
- Agc — Quartz monzonite; commonly porphyritic
- Agca — Fine-grained quartz monzonite
- Agmq — Quartz-rich monzogranite
- Ams — Schist
- Abe-s — Mount Belches Formation
- Abe-sh — Shale; metamorphosed
- Abe-c — Chert; metamorphosed
- Amda — Para-amphibolite
- As — Sedimentary rock, undivided; includes sandstone, siltstone, shale and chert; metamorphosed
- Asgp — Conglomerate with subordinate sandstone; matrix or clast supported; metamorphosed
- Astb — Sandstone derived from mafic rocks; metamorphosed
- Acc — Chert and banded chert; locally includes silicified (black) shale, or slate; metamorphosed
- Acci — Chert and banded chert; ferruginous; locally includes silicified (black) shale, slate, or exhalite; metamorphosed
- Amfs — Quartzofeldspathic micaceous schist derived from felsic volcanic or volcaniclastic protolith
- Afa — Andesite, commonly with plagioclase and/or hornblende phenocrysts; metamorphosed
- Afrp — Quartz–feldspar porphyritic rock; weak to schistose foliation; metamorphosed
- Afrv — Rhyolitic volcaniclastic rock; metamorphosed
- Amba — Amphibolite, fine to medium grained; commonly weakly foliated or massive
- Ambs — Foliated, fine-grained metamafic rock
- Ab — Fine to very fine grained mafic rock; metamorphosed
- Abb — Basalt; locally porphyritic; includes dolerite-textured zones; metamorphosed
- Abbv — Basalt with volcaniclastic textures; metamorphosed
- Amu — Meta-ultramafic rock, undivided; includes talc–chlorite(–carbonate) and tremolite–chlorite schist

YILGARN CRATON

For further details refer to main reference

Map symbols

Geological boundary
- exposed
- concealed
- concealed, interpreted from aeromagnetic data

Fault or shear
- exposed
- strike-slip, showing relative dextral horizontal displacement
- concealed
- concealed, interpreted from aeromagnetic data

Fold, showing axial trace
- anticline, exposed, concealed
- syncline, exposed, concealed

Small-scale fold axis, showing trend and plunge
- unspecified — 53

Trend of bedding or foliation

Bedding, showing strike and dip
- inclined — 37
- overturned — 68
- way-up not known, inclined — 87

Igneous layering, showing strike and dip
- inclined — 16

Way-up indicator
- pillow structure
- graded bedding

Metamorphic foliation, showing strike and dip
- inclined — 89
- strike and dip estimated from aerial photography
  - vertical

Cleavage, showing strike and dip
- inclined — 63

Lineation, unspecified, showing trend and plunge
- inclined — 80

Stretching lineation, showing trend and plunge
- inclined — 33

Bedding–cleavage intersection lineation, showng trend and plunge
- inclined — 56

Flow lineation, showing trend and plunge
- inclined — 7

Fracture, joint, or extension vein, showing strike and dip
- inclined — 89

Airphoto lineament
- unspecified
- fracture pattern in granitoid rock

Aeromagnetic lineament

Isotopic age determination site with identification number — 179098

Track
Fence, generally with track
Railway
Building
Breakaway
Sand dune
Contour line, 20 metre interval — 280

Watercourse
Dam — Dam

Mining centre — KARONIE
Mine, deposit, or prospect — Karonie
Opencut or quarry
Made ground or mining area
Tailings or stockpile

MINERAL OCCURRENCES

MINERALIZATION STYLES *

- Orthomagmatic mafic and ultramafic
- Vein and hydrothermal
- Stratabound volcanic and sedimentary
- Regolith hosted

MINERAL AND ROCK COMMODITY GROUPS

- Precious metal
- Steel industry metal
- Base metal
- Industrial mineral

MINERAL AND ROCK COMMODITIES

- Gold — **Au**
- Gypsum — **Gp**
- Nickel — **Ni**
- Zinc — **Zn**

OPERATING STATUS AND SITE IDENTIFICATION NUMBER

- Operating mine — e.g. 10164
- Mineral deposit — e.g. 18864
- Mineral occurrence or prospect — e.g. *10264*

Mineral occurrences and numbers are from the GSWA WAMIN database.
* Larger symbols represent mines or deposits also in the DoIR MINEDEX database.

Geology by S. A. Jones 2003

Geochronology by:

(1) A. Turek, 1966, Australian National University, PhD thesis (unpublished).

(2) C. E. Hall and S. A. Jones, 2005, Geological Survey of Western Australia, Record 2005/5, p. 14–15.

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

(4) I. R. Fletcher and N. J. McNaughton, 2002, MERIWA Report No. 222, p. 6.1–6.156.

(5) B. Krapez et al., 2000, Tectonophysics, v. 322, p. 89–133.

GSWA geochronology data are available online at http://www.doir.wa.gov.au/aboutus/geoview_launch.asp or on disk

Edited by A. Thomson, G. Loan, and B. Williams

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

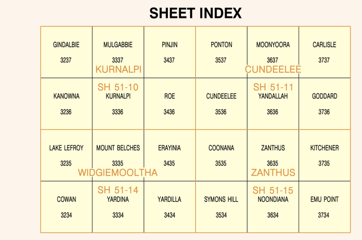
The recommended reference for this map is:
JONES, S. A., 2006, Erayinia, W.A. Sheet 3435: Western Australia Geological Survey, 1:100 000 Geological Series.

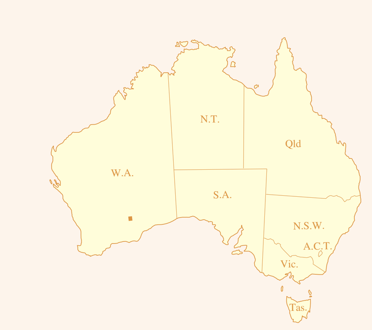
DATA DIRECTORY

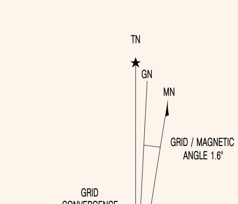
Theme	Data Source	Data Currency	Agency
Geology	GSWA	NOV 2005	Dept of Industry and Resources
Structural data	WAROX	NOV 2004	Dept of Industry and Resources
Mineral occurrences (non-confidential)	MINEDEX*	NOV 2005	Dept of Industry and Resources
	WAMIN	NOV 2005	Dept of Industry and Resources
Topography	DLI and GSWA field survey	2002	Dept of Land Information

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

SHEET INDEX







True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2006 and moves easterly by about 0.1° in 4 years.

Department of Industry and Resources

JOHN BOWLER, M.L.A.
MINISTER FOR RESOURCES

Geological Survey of Western Australia

TIM GRIFFIN
EXECUTIVE 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

ERAYINIA

SHEET 3435 FIRST EDITION 2006

Version 1.1 – December 2006