Department of
Industry and Resources

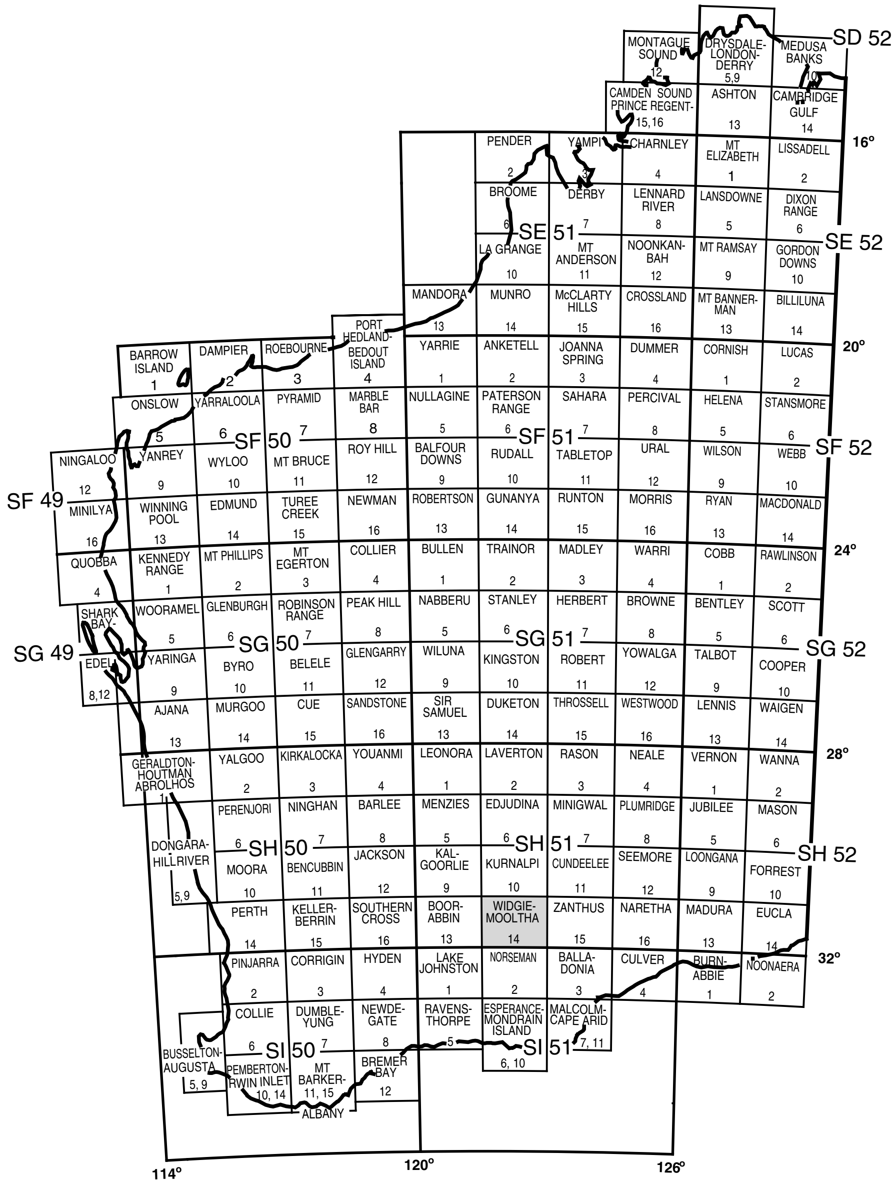
EXPLANATORY NOTES

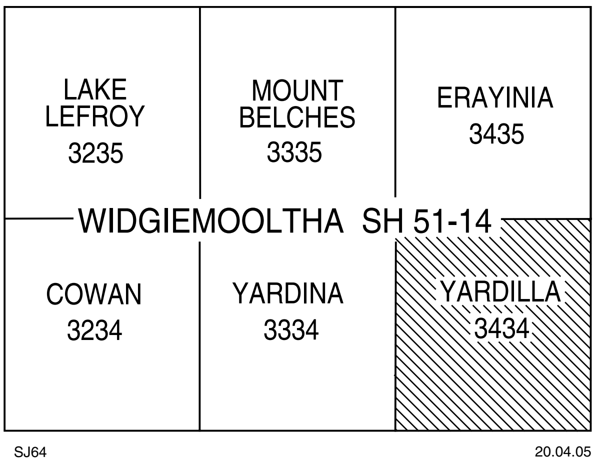
GEOLOGY OF THE YARDILLA 1:100 000 SHEET

by S. A. Jones

1:100 000 GEOLOGICAL SERIES

Geological Survey of Western Australia


SD 52
MONTAGUE SOUND 12
DRYSDALE-LONDON-DERRY 5,9
MEDUSA BANKS 10
CAMDEN SOUND PRINCE REGENT- 15,16
ASHTON 13
CAMBRIDGE GULF 14
16°
PENDER 2
YAMPI 3
CHARNLEY 4
MT ELIZABETH 1
LISSADELL 2
BROOME 6
DERBY 7
LENNARD RIVER 8
LANSDOWNE 5
DIXON RANGE 6
SE 51
SE 52
LA GRANGE 10
MT ANDERSON 11
NOONKAN-BAH 12
MT RAMSAY 9
GORDON DOWNS 10
MANDORA 13
MUNRO 14
McCLARTY HILLS 15
CROSSLAND 16
MT BANNER-MAN 13
BILLILUNA 14
20°
BARROW ISLAND 1
DAMPIER 2
ROEBOURNE 3
PORT HEDLAND-BEDOUT ISLAND 4
YARRIE 1
ANKETELL 2
JOANNA SPRING 3
DUMMER 4
CORNISH 1
LUCAS 2
ONSLOW 5
YARRALOOLA 6
PYRAMID 7
MARBLE BAR 8
NULLAGINE 5
PATERSON RANGE 6
SAHARA 7
PERCIVAL 8
HELENA 5
STANSMORE 6
SF 50
SF 51
SF 52
NINGALOO 12
YANREY 9
WYLOO 10
MT BRUCE 11
ROY HILL 12
BALFOUR DOWNS 9
RUDALL 10
TABLETOP 11
URAL 12
WILSON 9
WEBB 10
SF 49
MINILYA 16
WINNING POOL 13
EDMUND 14
TUREE CREEK 15
NEWMAN 16
ROBERTSON 13
GUNANYA 14
RUNTON 15
MORRIS 16
RYAN 13
MACDONALD 14
24°
QUOBBA 4
KENNEDY RANGE 1
MT PHILLIPS 2
MT EGERTON 3
COLLIER 4
BULLEN 1
TRAINOR 2
MADLEY 3
WARRI 4
COBB 1
RAWLINSON 2
SHARK BAY-EDEL 8,12
WOORAMEL 5
GLENBURGH 6
ROBINSON RANGE 7
PEAK HILL 8
NABBERU 5
STANLEY 6
HERBERT 7
BROWNE 8
BENTLEY 5
SCOTT 6
SG 49
SG 50
SG 51
SG 52
YARINGA 9
BYRO 10
BELELE 11
GLENGARRY 12
WILUNA 9
KINGSTON 10
ROBERT 11
YOWALGA 12
TALBOT 9
COOPER 10
AJANA 13
MURGOO 14
CUE 15
SANDSTONE 16
SIR SAMUEL 13
DUKETON 14
THROSSELL 15
WESTWOOD 16
LENNIS 13
WAIGEN 14
28°
GERALDTON-HOUTMAN ABROLHOS 1
YALGOO 2
KIRKALOCKA 3
YOUANMI 4
LEONORA 1
LAVERTON 2
RASON 3
NEALE 4
VERNON 1
WANNA 2
PERENJORI 6
NINGHAN 7
BARLEE 8
MENZIES 5
EDJUDINA 6
MINIGWAL 7
PLUMRIDGE 8
JUBILEE 5
MASON 6
SH 50
SH 51
SH 52
DONGARA-HILL RIVER 5,9
MOORA 10
BENCUBBIN 11
JACKSON 12
KAL-GOORLIE 9
KURNALPI 10
CUNDEELEE 11
SEEMORE 12
LOONGANA 9
FORREST 10
PERTH 14
KELLER-BERRIN 15
SOUTHERN CROSS 16
BOOR-ABBIN 13
WIDGIE-MOOLTHA 14
ZANTHUS 15
NARETHA 16
MADURA 13
EUCLA 14
32°
PINJARRA 2
CORRIGIN 3
HYDEN 4
LAKE JOHNSTON 1
NORSEMAN 2
BALLA-DONIA 3
CULVER 4
BURN-ABBIE 1
NOONAERA 2
COLLIE 6
DUMBLE-YUNG 7
NEWDE-GATE 8
RAVENS-THORPE 5
ESPERANCE-MONDRAIN ISLAND 6, 10
MALCOLM-CAPE ARID 7, 11
SI 50
SI 51
BUSSELTON-AUGUSTA 5, 9
PEMBERTON-IRWIN INLET 10, 14
MT BARKER-ALBANY 11, 15
BREMER BAY 12
114°
120°
126°


LAKE LEFROY 3235
MOUNT BELCHES 3335
ERAYINIA 3435
WIDGIEMOOLTHA SH 51-14
COWAN 3234
YARDINA 3334
YARDILLA 3434

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGY OF THE YARDILLA 1:100 000 SHEET

by
S. A. Jones

Perth 2005

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Cover photograph:
Recumbent F_1 fold in chert, northeast YARDILLA (MGA 491500E 6504070N)

Contents

Figures

Tables

Geology of the Yardilla 1:100 000 sheet

by

S. A. Jones

Abstract

The YARDILLA 1:100 000 sheet is in the southeastern part of the Eastern Goldfields area, on the margin of the Yilgarn Craton, and includes part of the Albany–Fraser Orogen. Most of the map area comprises Archaean metasedimentary, metavolcanic, and intrusive rocks. Proterozoic granulite- to amphibolite-facies gneisses form the Fraser Range in the southeast corner, and the Proterozoic Woodline Formation overlies the Archaean rocks in an east-northeasterly trending belt in the northwest. Flat-lying Cainozoic Eundynie Group sedimentary rocks overlie the Archaean basement in the northern half.

Structural trends on YARDILLA differ markedly from the regional structural grain of the Eastern Goldfields Granite–Greenstone Terrane, and reflect the effects of the Mesoproterozoic Albany–Fraser Orogen. Five deformation events are recognized in the Archaean rocks:

- D_1 recumbent folding;
- open to tight upright folding from east-northeast–west-southwest crustal shortening during the D_2 event, accompanied by peak M_2 metamorphic conditions at lower–middle greenschist to amphibolite facies;
- regional-scale D_3–D_4 faults (recognized only on aeromagnetic images);
- D_5 Albany–Fraser related deformation. This event is subdivided into D_{5a} open northeast-plunging folds and warps; D_{5b} clockwise rotation of D_1 to D_{5a} structures, from the regional north-northwest trend to a dominantly northeast trend; development of a late overprinting steep northeast-oriented cleavage during D_{5c}; and late crosscutting D_{5d} brittle structures.

An increase in metamorphic grade in the Archaean rocks is initially seen as an increase in mica grain size and the degree of schistocity, followed by the appearance of garnet close to the craton margin. This garnet isograd is near-parallel to the Yilgarn Craton – Albany–Fraser Orogen contact.

Three deformation stages (D_{F1} to D_{F3}) were also recognized in the Proterozoic rocks of the Fraser Range, reflecting the complex history of the Albany–Fraser Orogen. These stages include the well-developed, northeast-striking, steeply dipping D_{F1} gneissic banding, with a shallow to moderate northeast-plunging lineation and dextral shear-sense indicators, steep D_{F2} shear bands with steep fine lineations, and subvertical northwest-striking strike-slip faults.

The only commodity produced on YARDILLA is dimension stone from the Fraser Range gneisses. The area has been explored for gold, base metals, uranium, diamond, and lignite.

KEYWORDS: Yardilla, Yilgarn Craton, regional geology, deformation, Albany–Fraser Orogen, structural geology, dimension stone.

Introduction

The YARDILLA* 1:100 000-scale map sheet (SG 51-14, 3434; Jones and Ross, 2005) is in the southeastern part of the WIDGIEMOOLTHA 1:250 000-scale map sheet, bound by longitudes 122°30' and 123°00'E, and latitudes 31°30' and 32°00'S (Fig. 1). The northern part of YARDILLA lies in the Kurnalpi District of the North East Coolgardie Mineral Field and the southern part is in the Dundas Mineral Field. YARDILLA is about 100 km south-southeast of Kalgoorlie–Boulder, with the Great Victoria Desert to the east and the Nullarbor Plain to the southeast. The Fraser Range cuts across the southeastern corner of YARDILLA, and the map is named after Yardilla Bore on Fraser Range Station (Fig. 2).

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

Access

The southern margin of YARDILLA (Fig. 1) is 8–10 km north of the Eyre Highway, about 100 km east of Norseman and

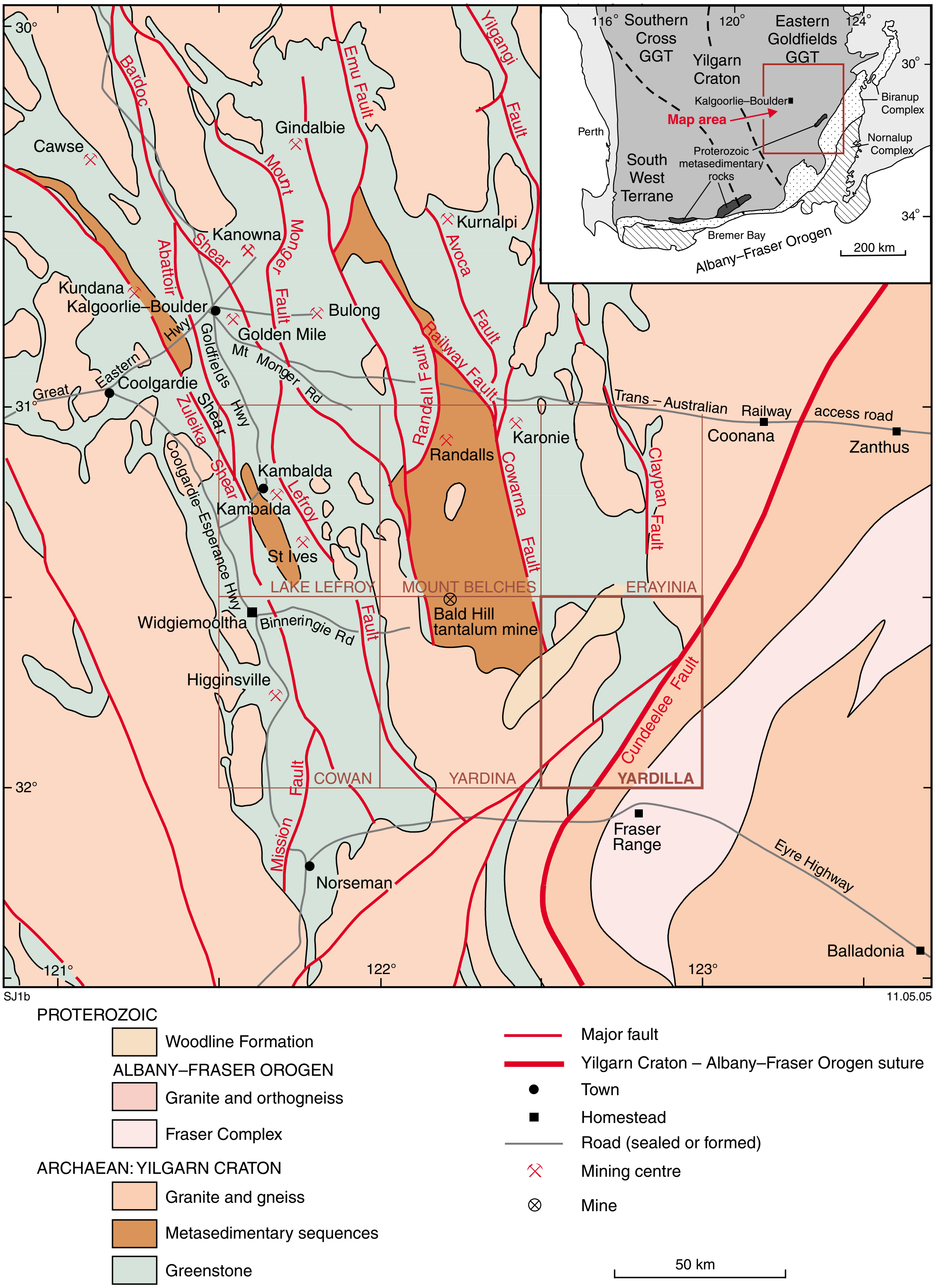

Figure 1. Regional geological setting of YARDILLA

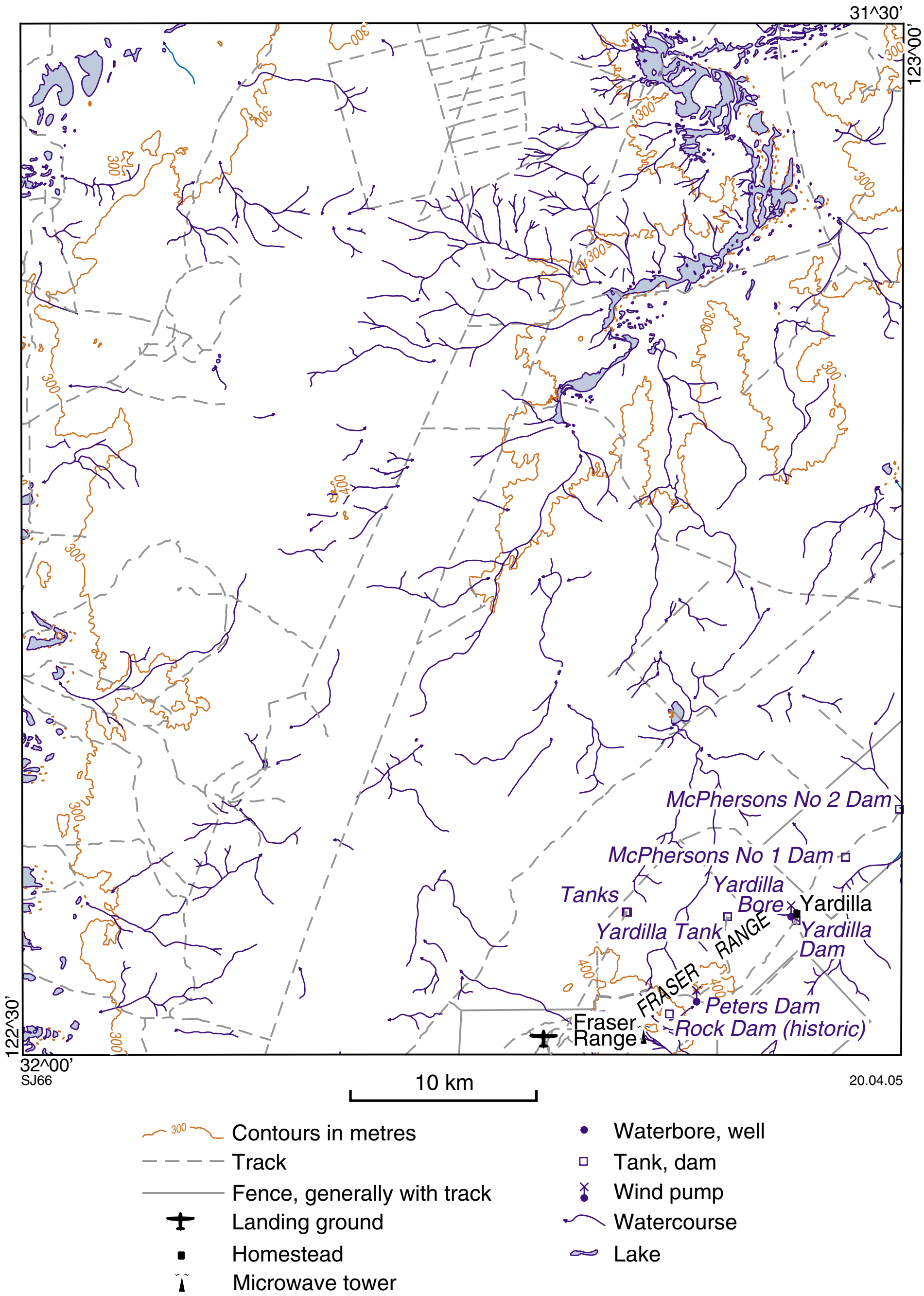

Figure 2. Main cultural and physiographic features on YARDILLA

Widgiemooltha, and 100 km west of Balladonia. Fraser Range Station is the sole pastoral lease on YARDILLA, but the homestead is just south of the map sheet. The majority of land on YARDILLA is classified as vacant Crown Land.

Access to YARDILLA is limited because the area is covered by very dense scrub with only a few exploration tracks, and some station tracks in the southeast corner (Fig. 2). The main access to the sheet is via a central northeasterly track off the Eyre Highway. This track can also be reached from the Trans Access Road (Fig. 1), about 50 km north of YARDILLA, which runs parallel to the east–west Trans Australia Railway and provides alternate access from Kalgoorlie. YARDILLA can also be reached from Widgiemooltha via a series of minor tracks, south of the Bald Hill tantalum mine.

Climate, physiography, and vegetation

The climate of YARDILLA is semi-arid, with the closest weather stations at Norseman and Rawlinna recording annual rainfall averages of 289 and 198 mm respectively. The highest rainfall is typically during the winter months, with sporadic rainfall in summer from isolated thunderstorms and decayed tropical cyclones. Streams are typically ephemeral, although some swamps and gnamma holes retain water through all but the driest months. Temperatures in the summer months commonly exceed 35° to 40°C, and during winter, minimum temperatures commonly drop below 5°C with occasional frosts (climate data from the Commonwealth Bureau of Meteorology website <http://www.bom.gov.au>).

YARDILLA is dominated by large areas of irregular terrain consisting of isolated low ridges and broad sheetwash plains. Deep weathering and thick colluvial cover, particularly in the south, obscures much of the bedrock. Although bedrock exposure is poor, bedrock structural trends are visible on aerial photos and satellite imagery, suggesting that the regolith cover is relatively thin in places. In the central part, drainage is typically to the northeast into a playa lake system that dominates the northeastern corner of YARDILLA. The terrain west of this lake system is typically more irregular, with scarps, broad ridges, and greater bedrock exposure. In contrast, the southeastern corner is dominated by broad elongate ridges of Proterozoic gneisses forming the Fraser Range. The Proterozoic Woodline Formation also forms large isolated rock-covered ridges on northwestern YARDILLA. Relief is typically low across the map sheet area, with the highest point (527 m above Australian Height Datum; AHD) in the Fraser Range and the lowest point (266 m above AHD) in the playa lake system in the northeast.

YARDILLA 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 YARDILLA are mainly covered by mixed eucalypt woodland including *Eucalyptus salmonophloia*, blackbutt (*E. lesouefii, E. dundasii*), patches of 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 understorey of bluebush and grasses. Wattle, mulga (*Acacia* spp.), and broombush are common on granite-derived soils, particularly in the west, whereas blackbutt species prefer soils derived from mafic rocks. Vegetation in and around the playa lake system is dominated by samphire (*Halosarcia* spp.), saltbush, bluebush, and greybush (Beard, 1975, 1990). Large patches of spinifex are common on granite, felsic volcanic rocks, and gneissic outcrops in the Fraser Range. The soils are highly calcareous in the southern part of YARDILLA, becoming slightly less calcareous to the north and west (Northcote et al., 1968). Many outcrops are covered with sandy soil, particularly around granite and Fraser Range gneisses.

Previous investigations

Sofoulis et al. (1965) recorded the geology of YARDILLA in the first edition 1:250 000-scale map of WIDGIEMOOLTHA and in the accompanying Explanatory Notes (Sofoulis, 1966). The geology of YARDILLA was revised by Griffin and Hickman (1988) in the second edition 1:250 000-scale map of WIDGIEMOOLTHA and the accompanying Explanatory Notes (Griffin, 1989). Broad tectonic models of the Eastern Goldfields area have included parts of YARDILLA (e.g. Swager, 1995, 1997; Krapez et al., 1997). YARDILLA was included in a regolith geochemistry study of the Fraser Range region (Morris et al., 2000), and in a gravity survey by Shevchenko (2000).

Proterozoic rocks of the Fraser Range and Woodline Formation have been included in many regional studies of the Albany–Fraser Orogen (e.g. Myers, 1990; Duebendorfer, 2002; Nelson et al., 1995; Clark et al., 1999, 2000). Tyrwhitt and Orridge (1975) examined the mineral prospectivity of the Fraser Range.

Open-file reports, maps, and data for mining and exploration tenements submitted to the Department of Industry and Resources (DoIR) are held in the Western Australian mineral exploration (WAMEX) system at the DoIR library in Perth and at the Geological Survey of Western Australia's (GSWA's) Kalgoorlie regional office. WAMEX reports are also progressively becoming available online on the DoIR website (<http://www.doir.wa.gov.au>).

Current work

Mapping on YARDILLA was carried out as part of a new mapping initiative of GSWA to complete the mapping of the eastern margins of the Yilgarn Craton. These areas contain abundant greenstones, but are poorly understood and therefore underexplored. Data from YARDILLA will be added to the East Yilgarn 1:100 000 Geological Information Series — a seamless compilation of 57 map sheets at 1:100 000 scale (Groenewald et al., 2000; Groenewald and Riganti, 2004).

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

Nomenclature

Although Archaean rocks on YARDILLA have been affected by variable grades of metamorphism, where primary textures are adequately preserved to allow identification of a protolith, the prefix 'meta' is not used for ease of description. Metamorphic terminology is applied to rocks in which primary mineralogy cannot be identified.

Regional geology

YARDILLA lies on the southeastern margin of the Eastern Goldfields Granite–Greenstone Terrane, at the contact with the Proterozoic Albany–Fraser Orogen (Tyler and

Hocking, 2001, 2002). The Eastern Goldfields Granite–Greenstone Terrane 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 Eastern Goldfields Granite–Greenstone Terrane has been subdivided into a number of terranes, based on differing lithostratigraphic packages, that are separated by major tectonic features, although there is no consensus on precise terrane boundary locations (e.g. Myers, 1990, 1997; Swager, 1995, 1997; Swager et al., 1997; Groenewald et al., 2002).

YARDILLA lies in the Kurnalpi terrane of Myers (1997), which is between the Emu–Randall and Claypan Faults (Fig. 1). Swager (1995), and Brown et al. (2001) suggested that the Kurnalpi terrane, and other terranes east of the Keith–Kilkenny Fault (e.g. the Edjudina, Linden, and Laverton terranes) can be separated from the Kalgoorlie terrane using lithostratigraphy and sensitive high-resolution ion microprobe (SHRIMP) U–Pb zircon ages. These studies highlighted the presence of banded iron-formation (BIF) and the small volumes of komatiite in the Kurnalpi terrane compared to the Kalgoorlie terrane. SHRIMP U–Pb zircon data (Nelson, 1997; Swager et al., 1997) suggest that the andesitic–dacitic volcanism in the Kurnalpi terrane occurred at 2720–2705 Ma, slightly earlier than in the Kalgoorlie terrane. However, Nelson (1995) and Groenewald et al. (2002) dated a felsic volcanic unit that lies between two komatiite layers at 2706 ± 3 Ma, and a volcaniclastic unit overlying this succession at 2673 ± 7 Ma, demonstrating contemporaneity with similar units in the Kalgoorlie terrane. The stratigraphy of the Kurnalpi area remains poorly understood and further work is necessary to constrain the characteristics of the terranes.

The regional stratigraphy of the Kurnalpi terrane can be broadly divided into a basal basaltic unit with upper marker units of komatiite, overlain by a highly variable sequence of mafic and felsic volcanic and volcaniclastic rocks. In places, the basal basaltic unit grades laterally into felsic epiclastic-dominated packages, which Swager (1995) interpreted as an original depositional feature. The upper sequence of mafic and felsic volcanic rocks is separated by a major shear zone into a lower felsic fragmental unit with an age of 2708 ± 7 Ma (Nelson, 1997) and an upper package of rocks with an age of 2684 ± 3 Ma (Nelson, 1995).

The Eastern Goldfields Granite–Greenstone Terrane was affected by four major compressional events, separated by periods of extension (Archibald et al., 1978; Archibald, 1987; Swager et al., 1997; Nelson, 1997; Swager, 1995, 1997; Williams, 1993; Table 1). Typically, the earliest deformation event (D_1) involved thrusting and recumbent folding, followed by extended east-northeast–west-southwest crustal shortening during D_2, producing major regional-scale upright F_2 folds (2675–2655 Ma; Nelson, 1997). Recent studies (Davis and Maidens, 2003; Weinberg et al., 2003) suggest that the D_2 event was diachronous, with episodic compression–extension switching attributed to the Wangkathaa Orogeny (Blewett et al., 2004).

The D_2 event was followed by D_3 sinistral movement and associated folding on north-northwesterly trending regional strike-slip faults. Weinberg et al. (2003) suggested that D_3 conjugate shearing waned at about 2630 Ma, contemporaneous with and outlasting D_2. Continued east–west shortening during D_4 resulted in northeast to east-northeast oblique dextral faults and northwest to west-northwest oblique sinistral faults. A minimum age for D_4 is derived from late- to post-tectonic low-calcium granites, with ages ranging from 2650 to 2630 Ma (Smithies and Champion, 1999).

Regional metamorphic grades in the Eastern Goldfields Granite–Greenstone Terrane range from low- to intermediate-pressure facies, and may partly reflect the distribution of granitic bodies (Witt, 1991; Ridley, 1993; Swager, 1997; Mikucki and Roberts, 2003). Metamorphic grades are typically higher (amphibolite facies) adjacent to the surrounding granite, whereas lower grade zones (greenschist facies) are observed in the central parts of the greenstone belts. Peak metamorphic conditions were typically reached during D_2 deformation, probably contemporaneous with the bulk of granitic emplacement at 2660 to 2640 Ma (Witt, 1991; Nelson, 1997; Swager, et al., 1997).

Much of the Yilgarn Craton has been stable since the Archaean with only minor deformation recorded during the Proterozoic and Phanerozoic. At about 2420 Ma, east-northeasterly trending mafic dykes of the Widgiemooltha Dyke Suite intruded the region (‘Widgiemooltha dyke swarm’ of Nemchin and Pidgeon, 1998). Deposition of the Proterozoic Woodline Formation is thought to have occurred at 1620 ± 100 Ma (Turek, 1966) and deformation of this sequence is attributed to the Albany–Fraser Orogen, which records the continent–continent collision of the Yilgarn Craton margin and east Antarctica between 1300 and 1100 Ma (Myers, 1990, 1995a). Myers (1990) and Tyler and Hocking (2001) divided this orogen into the Northern Foreland and the Biranup and Nornalup Complexes, based on rock types (Myers, 1990). During the collision, high-grade quartzofeldspathic gneisses and layered mafic intrusions of the Fraser Complex (part of the Biranup Complex) were thrust over the southern margin of the Yilgarn Craton. At about 1210 Ma, the northeasterly to north-northeasterly trending Fraser dyke swarm intruded an area within 100 km of the contact between the Yilgarn Craton and Albany–Fraser Orogen (Wingate et al., 2000).

Large palaeodrainage channels formed during pre-Jurassic glaciation events and were flooded 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 the development of playa lakes and their associated dune systems in the lowlands defined by the palaeodrainage channels (Griffin, 1989; Clarke, 1994; Clarke et al., 2003).

Table 1. Geological history of the southeastern Eastern Goldfields Granite–Greenstone Terrane

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	Subsequent deposition of Black Flag Group; Mount Belches Formation[c]; intrusion of pre-D_2 granite into Mount Belches Formation[d]	Youngest deposition age of Black Flag Group and Mount Belches Formation[e]
	D_1 N–S compression (?diachronous)	
2683 – <?2672	N–S-directed thrusting and local recumbent folding [d,f,g] M_1 associated with development of layer-parallel foliation	Felsic volcanic rocks 2681 ± 5 Ma, 2675 ± 3 Ma[h] maximum age; 2674 ± 6 Ma post-D_1 felsic porphyry dyke[i] 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[j]	Post-D_1 and pre-D_2 felsic porphyry 2674 ± 6 Ma[i] Pre-dates Kurrawang and Merougil Conglomerates Voluminous granitic intrusions at 2675–2657 Ma[h]
	D_2 (Wangkathaa Orogeny[k]) E–W compression (?diachronous)	
c. 2675 to 2655	E–W shortening with upright folds and shallow NNW-plunging fold axes[d,l,m]; folding and doming of granite bodies driven by granite buoyancy regional stresses[n] M_2 peak metamorphic conditions during D_2(–?D_3) lower–middle greenschist to amphibolite facies	Maximum: 2675 ± 2 Ma[o] post-D_1 monzogranite Minimum 2660 ± 3 Ma[h] post-D_2 monzogranite Kambalda Anticline: syn- or late-deposition of the Kurrawang Sequence at 2655 Ma[d]
	D_3 transpression	
c. 2663 – 2645[j,h]	Tightening of F_2 folds[p,q]; conjugate shearing wanes at 2630 Ma Contemporaneous with and outlasting D_2	Minimum: 2658 ± 13 Ma (Brady Well Monzogranite) Boulder–Lefroy Fault[q,d], Butchers Flat Fault[d]
	D_e post-orogenic collapse	
c. 2640	Post-metamorphic orogenic collapse[r]	Late-tectonic granite c. 2640 Ma; Ida Fault
	D_4 transpression	
<?2640	W to WNW oblique sinistral faults[l,s]; NE to ENE oblique dextral–reverse faults[l,g]; low-Ca granitoid intrusion thoughout D_2–D_4[n]	2638 ± 26 Ma[t]; 2651 ± 5 Ma[u] post-tectonic alkaline granites; Paddington area, Mount Charlotte, Black Flag Fault
	Dyke intrusion	
c. 2640	Intrusion of Widgiemooltha Dyke Suite	c. 2420[v] Widgiemooltha Dyke, Lake Cowan
	Deposition of Woodline Formation	
<1620	Deposition of Woodline Formation; NW to SE palaeoflow direction	1620 ± 100 Ma[w]; quartz arenite NW Yardilla
	D_5 Albany–Fraser Orogeny-related deformation	
c. 1345–1260	Deformation of Archaean rocks (and Woodline Formation) related to dextral transpression probably during late Stage I phase[x] of the Albany–Fraser Orogeny M_3 lower greenschist- to amphibolite-facies metamorphism of Archaean and Proterozoic rocks (Woodline Formation) during the Albany–Fraser Orogeny; peak thermal metamorphism post-dates main collisional event (Stage I)[y]	Southeast Yardilla 1205 ± 10 Ma[z] random mineral growth overprinting compressive fabrics; Mount Barren Group
	Dyke intrusion	
c. 1210	Intrusion of Fraser dyke swarm	c. 1210 Ma[y] dolerite dyke, Kambalda
	Marine transgressions	
50–38	Deposition of Eundynie Group, and Cowan and Lefroy palaeodrainage channels; (?)laterite formation	50–38 Ma[za]; 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) Swager and Griffin (1990)
(e) Krapez et al. (2000)
(f) Gresham and Loftus-Hills (1981)
(g) Archibald et al. (1981)
(h) Nelson (1997)
(i) Kent and McDougall (1995)
(j) Swager (1997)
(k) Blewett et al. (2004)
(l) Witt (1994)
(m) Hunter (1993)
(n) Weinberg et al. (2003)
(o) Swager and Nelson (1997)
(p) Swager et al. (1995)
(q) Swager (1989)
(r) Goleby et al. (1993)
(s) Chen et al. (2001)
(t) Hill et al. (1992)
(u) Nelson (1995)
(v) Nemchin and Pidgeon (1998)
(w) Turek (1966)
(x) Clark et al. (2000)
(y) Wingate et al. (2000)
(z) Dawson et al. (2003)
(za) Clarke (1994)

Yilgarn Craton

The majority of outcrops on YARDILLA are Archaean and include granitic, metavolcanic, and metasedimentary rocks (Fig. 3). Variably deformed granitic rocks make up about one-third of the map area, predominantly on the western side of the sheet. The surrounding area is dominated by Archaean metasedimentary rocks, with minor metamorphosed mafic and felsic volcanic and volcaniclastic rocks. The Archaean rocks are predominantly deeply weathered, with a thick cover of regolith that results in very poor exposure over much of YARDILLA. The best outcrops of Archaean rocks are on the western edges of the playa lake system in the northeast.

The Archaean rocks are intruded by the Proterozoic Binneringie and Jimberlana Dykes, and truncated in the southeastern corner of YARDILLA by Proterozoic amphibolite- to granulite-facies gneisses of the Fraser Range. In the northwest of YARDILLA the Proterozoic Woodline Formation forms an east-northeasterly trending belt (Fig. 3) overlying the Archaean rocks, and predominantly consists of quartzites, quartz conglomerates and shale.

Archaean geology

Poor exposure and the deeply weathered nature of most Archaean outcrops on YARDILLA limit the correlation of units and the identification of a coherent stratigraphy. However, aeromagnetic imagery can be used to correlate greenstone units in the northern part of YARDILLA with those on adjacent map sheets (MOUNT BELCHES, ERAYINIA, and YARDINA; Fig. 1). Archaean metasedimentary rocks that dominate the northern part of YARDILLA are likely to represent a continuation of the units to the north.

Metamorphosed fine-grained mafic rocks (*Abb*, *Ambs*)

Fine-grained mafic rocks form only a minor component of exposed Archaean rocks on YARDILLA, and the basalt (*Abb*) and foliated fine-grained mafic volcanic rocks (*Ambs*) are metamorphosed at lower- to middle-greenschist facies. These mafic rocks are at several locations on YARDILLA, including the northern margin of the playa lake system and the central area of the map sheet. Foliated mafic rocks are common in localized zones within the nonfoliated basalt.

The mafic units are predominantly massive and fine grained, and lack textures such as amygdales and flow top breccias. In the northern area, basalt is interlayered with mafic-derived volcanogenic sandstone, mudstone, and chert. The basalt typically has a fine interlocking, felted texture of chlorite, albite, and amphibole with minor quartz, plagioclase, and opaque minerals.

The only evidence of komatiitic characteristics is in saprolitic material on central YARDILLA (MGA 476077E 6487028N), where relict pyroxene-spinifex textures indicate derivation from komatiitic basalt.

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

Dolerite (*Aod*), a medium-grained mafic rock metamorphosed at lower- to middle-greenschist facies, is only in a few scattered locations, typically in the central part of YARDILLA. The unit is typically massive and weakly foliated with ophitic to subophitic textures preserved. Dolerite is typically associated with finer grained mafic rocks and may represent the coarser grained zones of differentiated mafic flows.

Metamorphosed felsic volcanic rocks (*Af*, *Amfs*, *Afdp*)

Felsic volcanic rocks (*Af*), metamorphosed at lower- to middle-greenschist facies, form scattered outcrops in the north, north and east of the playa lake system, and the central part of YARDILLA. These rocks are typically deeply weathered and 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 with randomly oriented feldspar and minor quartz phenocrysts. The feldspar phenocrysts are moderately to strongly sericitized and quartz grains are commonly embayed. Minor fine epidote and accessory apatite grains are scattered throughout the fine matrix. Strongly foliated felsic volcanogenic rocks (*Amfs*) outcrop in the northern and central parts of YARDILLA, and are also recognized in the field by subhedral feldspar phenocrysts and quartz 'eyes' in a strongly foliated groundmass.

Porphyritic dacite (to rhyodacite; *Afdp*) outcrops in several locations, including the northern part of YARDILLA, north and southeast of the playa lake system, and the central part of YARDILLA. The porphyritic unit north of the playa lake is identified on aeromagnetic images as a distinct magnetic high about 500 m wide. The porphyritic volcanic rocks typically have a finer grained groundmass than the felsic volcanic rocks (*Af*) and larger euhedral feldspar phenocrysts. In thin section the porphyritic volcanic rocks typically have abundant randomly oriented euhedral feldspar phenocrysts (up to 5 mm) and minor quartz phenocrysts in a very fine grained to glassy quartzofeldspathic groundmass. The feldspar phenocrysts are euhedral, commonly zoned, and moderately to strongly sericitized. Accessory apatite, titanite, epidote, and opaque minerals are observed throughout.

Metasedimentary rocks (*As*, *Ash*, *Amls*, *Ass*, *Amhs*, *Amlsm*, *Ast*, *Amts*, *Astb*, *Amtq*, *Akl*, *Accb*)

The majority of metasedimentary rocks exposed on YARDILLA are deeply weathered, but retain features indicating a sedimentary origin. These units are the most abundant rock types on YARDILLA and are best exposed on the northern and western edges of the playa lake system in the northern part of YARDILLA.

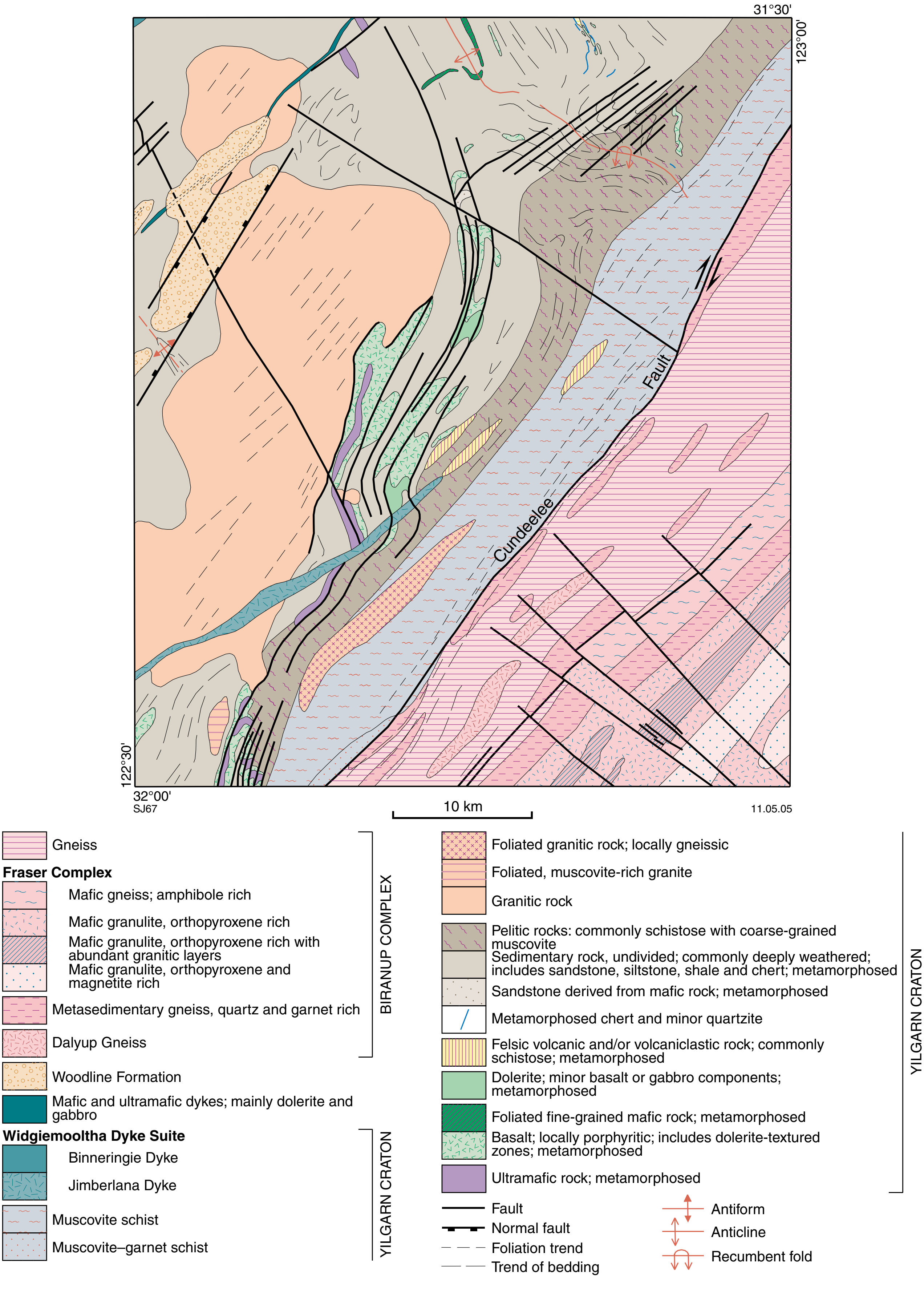

Figure 3. Interpreted Precambrian geology of Yardilla

Undivided metasedimentary rocks (*As*) include metamorphosed mudstone, siltstone, and fine-grained sandstone. Fine-grained quartz–mica schist is included in this classification because it retains relict sedimentary features such as bedding. These rocks are typically lateritized and commonly moderately to strongly foliated.

Mudstone or shale (*Ash*) and strongly foliated mudstone (*Amls*) are common in the northern part of YARDILLA and on the western sides of the playa lakes in the northeast. They are typically dark grey, carbonaceous, and interbedded with paler grey, fine-grained sandstone. In places, small (1–5 mm) spherical pyritic concretions are scattered throughout the mudstone. A weak to moderate foliation is present at most localities. Shale can be silicified and is difficult to distinguish from banded chert (*Accb*).

Siltstone and interbedded sandstone (*Ass*) are common on northern YARDILLA on the western side of the playa lake system. The unit is dominated by fine-grained dark-grey siltstone with paler millimetre- to centimetre-scale interbeds of fine- to medium-grained sandstone and dark-grey mudstone. Sedimentary structures, such as graded beds, flame structures, scour marks, and rip-up clasts are visible in fresher exposures on the lake edge (Fig. 4). However, most exposures are deeply weathered and moderately to strongly foliated (*Amhs*), and because bedding is not visible, classification is based on local grain-size variations from siltstone to fine-grained sandstone. On the western shores of the northeastern playa lakes, the siltstone–sandstone unit becomes more micaceous (predominantly muscovite; *Amlsm*) with a distinct coarsening of mica towards the southeast and a noticeable increase in the degree of schistocity. In the metasedimentary rocks in the southwest there is also an increase in mica grain size and abundance towards the Yilgarn Craton margin.

Medium- to fine-grained quartzofeldspathic sandstone (*Ast*) outcrops on northern and western YARDILLA and typically has a grain size ranging from 1 to 3 mm. The facies is predominantly weakly foliated, but contains a strong tectonic fabric in places, such as at the western edge of the playa lakes (*Amts*). A sandstone derived from basalt (*Astb*) outcrops on northern YARDILLA, north of the playa lake system. Although the sandstone is predominantly massive, metre-scale bedding is visible in places, and at a broader scale the sandstone appears to be interlayered with basalt. Deep weathering makes this unit difficult to distinguish from the adjacent basalt, but in thin section the rock has abundant fine angular quartz clasts with 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 grain size and phyllosilicate content.

Quartz-rich sedimentary rocks or quartzite (*Amtq*) outcrops on northwest YARDILLA and on the western side of the playa lake system. The quartzite is typically massive to weakly bedded at metre scale, with diffuse millimetre- to centimetre-scale bedding in places. In thin section the rock has a fine, granular, quartz-dominated matrix, with angular

a)

b)

Figure 4. a–b) Interbedded sandstone and laminated mudstone, northeastern YARDILLA (MGA 481345E 6495189N). Truncated cross beds, scoured bases and graded bedding in sandstone layers indicate younging directions

irregular quartz grains that typically lack volcanogenic features such as embayments suggesting that the quartzites have a nonvolcanogenic origin.

Interbedded limestone and chert (*Akl*) form a low ridge in the northern part of YARDILLA (MGA 480260E 6509160N). The limestone interbeds are typically pale grey–brown, fine grained, and range in thickness from 1 to 20 cm, with pale-grey chert interbeds ranging from 1 to 20 mm. The unit is strongly deformed, with dome-and-basin fold-interference patterns common. In thin section the limestone dominantly has a micritic texture with minor sparry zones and scattered angular fine (<1 mm) detrital quartz grains. Carbonate layers are interbedded with fine recrystallized polymosaic quartz laminae.

Chert (*Accb*) is relatively common in the northern part of YARDILLA, but rare in the south. It typically forms small narrow ridges and varies from strongly laminated, white, pale- and dark-grey, 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 accompanying tectonic quiescence. A few chert bands contain abundant iron oxides and commonly have hematite coatings that obscure original features. These units are similar in appearance to banded iron-formations, such as recorded on MOUNT BELCHES to the northwest (Painter and Groenewald, 2001). Many chert outcrops, particularly on the western side of the playa lake, are overlain by several metres of brecciated and randomly oriented angular chert clasts recemented in an iron-rich matrix. The breccia facies probably represent erosion and recementation during the Cainozoic.

Granitic rocks (*Ag*, *Amgsn*, *Amgsm*, *Agc*, *Agcm, Amgms*)

Granitic rocks make up about one-fifth of the exposed rocks on YARDILLA with most granitic rocks classified as undivided (*Ag*) due to the deep weathering. Outcrops are typically strongly kaolinized, with no distinguishable feldspar, amphibole or mica to aid in their classification. Much of the area in the granite terrain is dominated by granite-derived sand and soil interspersed with silcrete, calcrete, and scattered loose boulders of strongly weathered granite, which is mapped as relict material over granite (Rgp_g).

Strongly foliated granite (*Amgsn)* and strongly foliated muscovite-rich granite (*Amgsm*) in the southern and eastern parts of YARDILLA are within the high-strain suture zone. Where granite is less weathered it is predominantly coarse-grained equigranular quartz monzonite (*Agc*) or medium-grained quartz monzonite (*Agcm*) with minor hornblende(–biotite). Granites may contain large zoned feldspar megacrysts up to 3 cm across. Strongly foliated monzogranite (*Amgms*) outcrops in the southwest and commonly has coarse mica (predominantly muscovite) up to 6 mm across. The mica is strongly aligned and together with elongate strained quartz ribbons defines a tectonic fabric.

The quartz monzonites and monzogranites (*Agc*, *Agcm*, and *Amgms*) belong to the Erayinia 'clan' of Cassidy and Champion (2001). This 'clan' is unique to the eastern parts of KURNALPI (1:250 000) and WIDGIEMOOLTHA (1:250 000) and has a SHRIMP U–Pb zircon age of c. 2660–2645 Ma (Cassidy and Champion, 2001; Fletcher and McNaughton, 2002). The geochemistry of these granites has been described by Johnson (1991), Champion and Sheraton (1997), and Smithies and Champion (1999).

Low- to medium-grade metamorphic rocks (*Amscm*, *Amsm*, *Amsmg*, *Amsqm*)

Metamorphic rocks with an unknown protolith are predominantly observed in highly strained rocks in the southwestern, central, and northeastern parts of YARDILLA. These strongly deformed units are typically very deeply weathered, making identification of a protolith even more difficult.

Chlorite schist (*Amscm*) along the western edge of the playa lake system on northeastern YARDILLA has a well-developed schistosity dominated by strongly aligned medium-grained chlorite, muscovite, quartz, and clinozoisite, with minor magnetite giving the unit a slightly spotted appearance in the field. The abundance of chlorite suggests that the schist is derived from a mafic precursor. The most common unit in the zone marking the contact between the Yilgarn Craton and the Albany–Fraser Orogen is strongly foliated muscovite schist (*Amsm*) predominantly composed of fine- to medium-grained muscovite, and rare garnet (*Amsmg*). Quartz-rich muscovite schist (*Amsqm*) has a strong foliation defined by aligned muscovite and 1–3 mm-wide elongate quartz ribbons.

Veins and dykes (*g*, *gp*, *zq*)

Small fine-grained granitic dykes (*g*), ranging from 2 to 5 m in width, intrude basalt in the central part of YARDILLA. The dykes are typically steeply dipping with a north-northeast trend and are weakly to strongly foliated.

Small pegmatite and aplite dykes (*gp*) of unknown age intrude the Proterozoic gneisses of the Fraser Range. The pegmatite dykes contain quartz, feldspar, and muscovite, with minor tourmaline and titanite. They range from 1 to 100 cm in width and intrude along northwesterly fractures (e.g. MGA 484790E 6460720N) and parallel to the gneissic banding (e.g. MGA 498005E 6461625N). Larger pegmatite dykes (*gp*) are common on adjacent YARDINA, where they are associated with the granitic bodies and mined at Bald Hill for tantalum from tantalite.

Quartz veins (*zq*) are common on YARDILLA and 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. Multiple generations of veins are present, with abundant folded and rodded pre-D_2 quartz veins in metasedimentary rocks on the western edge of the playa lake system. These veins appear to be S_1- or bedding-parallel veins (or both) that are commonly folded by F_2 folds and overprinted by axial-planar syn-D_2 veins. Large parallel sets of massive white quartz veins, up to 3 m wide and several hundred metres in length, are common throughout the area. These veins are surrounded by a wide apron of white quartz-vein colluvium (*Cq*).

Archaean deformation and metamorphism

The deformation history of the YARDILLA area is complex because it covers the southeastern margin of the Yilgarn Craton and the contact with the Mesoproterozoic Albany–Fraser Orogen. Archaean structural trends on YARDILLA differ markedly from regional trends recognized elsewhere in the Eastern Goldfields Granite–Greenstone Terrane and reflect the effects of Mesoproterozoic collision between the Yilgarn Craton and east Antarctica during the Albany–Fraser Orogeny. The paucity of outcrop on YARDILLA combined with deep weathering made it difficult to obtain structural measurements for most of the area. However, excellent exposures on the western edges of the playa lakes in the northeast, particularly in the lake pavements, yielded valuable structural data and clear overprinting relationships.

Five deformation events (D_1 to D_5) are recognized in Archaean rocks on Yardilla and are summarized in Figure 5:

- D_1 recumbent folding;
- tight upright folding from east-northeast–west-southwest crustal shortening during the D_2 event;
- regional-scale D_3–D_4 faults (only recognized on aeromagnetic images);
- D_5 event related to deformation during the Albany–Fraser Orogeny.

At least four metamorphic events (M_1–M_4) have been recognized in the southeastern Eastern Goldfields Granite–Greenstone Terrane on Yardilla (Table 1). The M_4 event is related to the Albany–Fraser Orogeny and is described later.

The D_1 event

The D_1 event is recognized on Yardilla by the development of a fine penetrative foliation (S_1), commonly near-parallel to bedding, and rare tight to isoclinal recumbent F_1 folds and thrusts (Fig. 6). A subhorizontal stretching lineation is commonly developed on the S_1 surface, parallel to F_1 fold hinges, and is defined predominantly by recrystallized quartz. Common, early, bedding-parallel quartz veins are strongly deformed and rodded, with quartz rods parallel to L_1 and F_1 fold hinges. Early bedding-parallel quartz veins with distinct rodding are an unusual feature that appears to be a local phenomenon that has not been reported from adjacent areas in the Eastern Goldfields Granite–Greenstone Terrane. The veining is useful for identifying timing relationships during later folding events. Although the recumbent style of D_1 folding on Yardilla is the same as D_1 structures reported elsewhere in the Eastern Goldfields Granite–Greenstone Terrane, the timing of this event is still uncertain. Studies in the Kalgoorlie area suggest a range of ages for this event, from about 2700 to 2675 Ma (Kent and McDougall, 1995; Nelson, 1997). D_1 structures have also been reported in the Mount Belches Formation to the northwest (Painter and Groenewald, 2001). However, Krapez et al. (2000) dated zircons from the Mount Belches Formation on Mount Belches at 2665 Ma, suggesting that deposition may have post-dated the regional D_1 event. The D_1 structures measured on Yardilla may have been produced by a local event that pre-dated the regional D_2 event.

The D_2 event

Deformation during the D_2 event resulted in open to tight upright folds and variable development of a penetrative foliation (S_2) during strong east–west compression (Fig. 7). The F_2 fold hinges are prominent features on aeromagnetic images and refold earlier D_1 fabrics. A good example of this is on the lake shore on northeastern Yardilla (MGA 491500E 6504070N), where a recumbent D_1 fold in chert is refolded by an upright F_2 fold (Fig. 6c). The penetrative S_2 foliation is variably developed and is predominantly within 20°–30° of the S_1 fabric due to the dominantly tight to isoclinal nature of F_2 folds. The S_2 fabric forms a well-developed crenulation cleavage in hinge zones defined by aligned mica and is best developed in fine-grained pelitic units (Fig. 7b,c). Type-1 and Type-2 fold-interference patterns are developed locally between the F_1 and F_2 folds, with good dome-and-basin and dome–crescent–mushroom patterns. Dome-and-basin type patterns are best observed in Archaean carbonate rocks (Fig. 8). The style of F_2

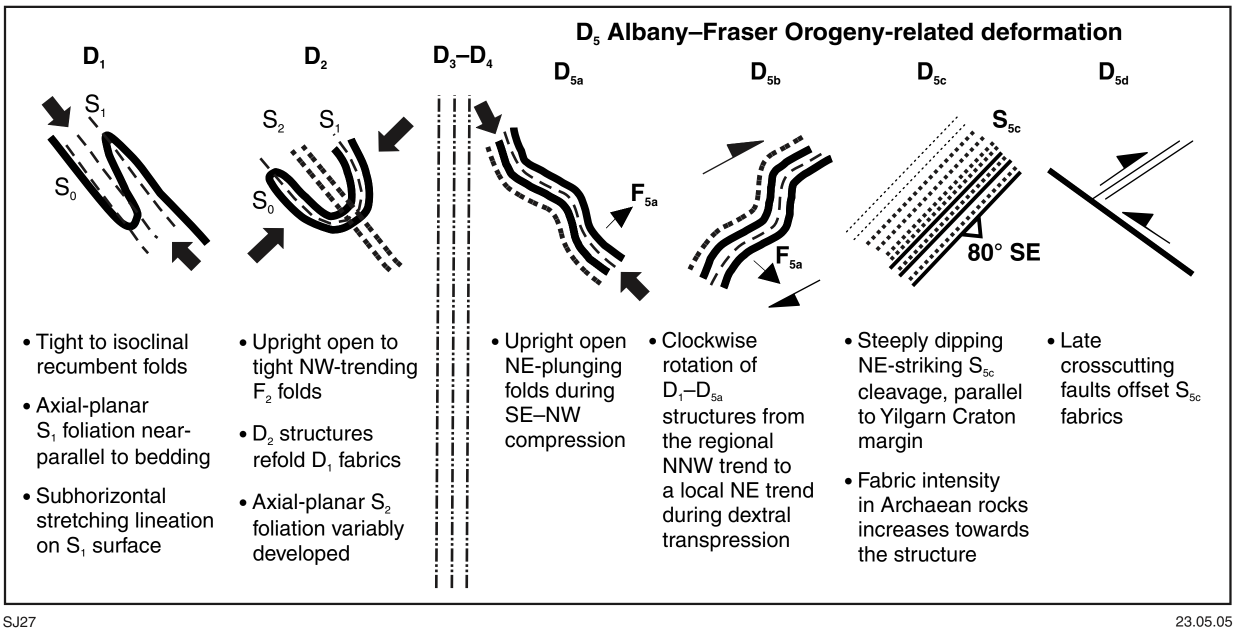

Figure 5. Deformation sequence in Archaean rocks on Yardilla

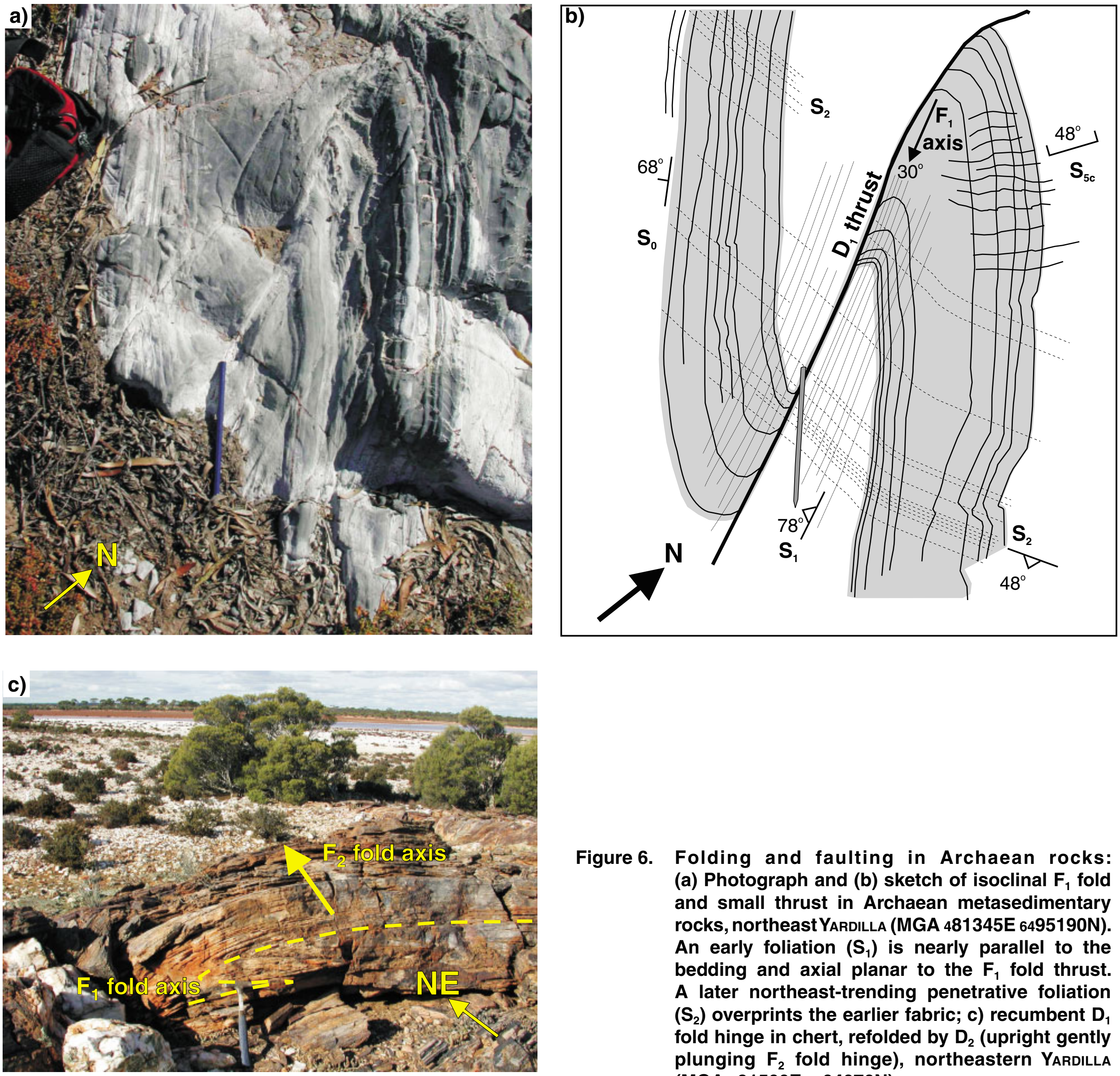

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Figure 6. Folding and faulting in Archaean rocks: (a) Photograph and (b) sketch of isoclinal F_1 fold and small thrust in Archaean metasedimentary rocks, northeast YARDILLA (MGA 481345E 6495190N). An early foliation (S_1) is nearly parallel to the bedding and axial planar to the F_1 fold thrust. A later northeast-trending penetrative foliation (S_2) overprints the earlier fabric; c) recumbent D_1 fold hinge in chert, refolded by D_2 (upright gently plunging F_2 fold hinge), northeastern YARDILLA (MGA 491500E 6504070N)

folding and the associated crenulation cleavage (S_2) on YARDILLA are similar to regional D_2 structures observed elsewhere in the Eastern Goldfields Granite–Greenstone Terrane. However, on YARDILLA F_2 fold axes and S_2 fabrics display northeasterly trends, rather than the more typical regional north-northwesterly trends, reflecting the overprinting effects of deformation related to the Albany–Fraser Orogeny.

The D_3 and D_4 events

Transpression during D_3 and D_4 resulted in largely reverse vertical and sinistral lateral movement on regional north-northwesterly trending faults (Nelson, 1997; Swager, 1997). These regional structures were not observed on YARDILLA, probably because of the lack of outcrop away from the playa lake system in the northeast. However, a large northwest-trending structure, with apparent sinistral offset in the western part of YARDILLA, can be seen on aeromagnetic images, and may represent a D_3 or D_4 fault because it is truncated by the Albany–Fraser Orogeny deformation front. This structure could represent an extension of the Cowarna Fault from MOUNT BELCHES to the northwest.

The M_1 event

The M_1 event in the Archaean rocks is characterized by lower greenschist-facies mineral assemblages of muscovite, quartz, chlorite and feldspar in metasedimentary rocks. These minerals define the bedding-parallel penetrative S_1 foliation. The alignment of the metamorphic mineral assemblage, parallel to S_1, suggests that peak M_1 metamorphic conditions were most likely

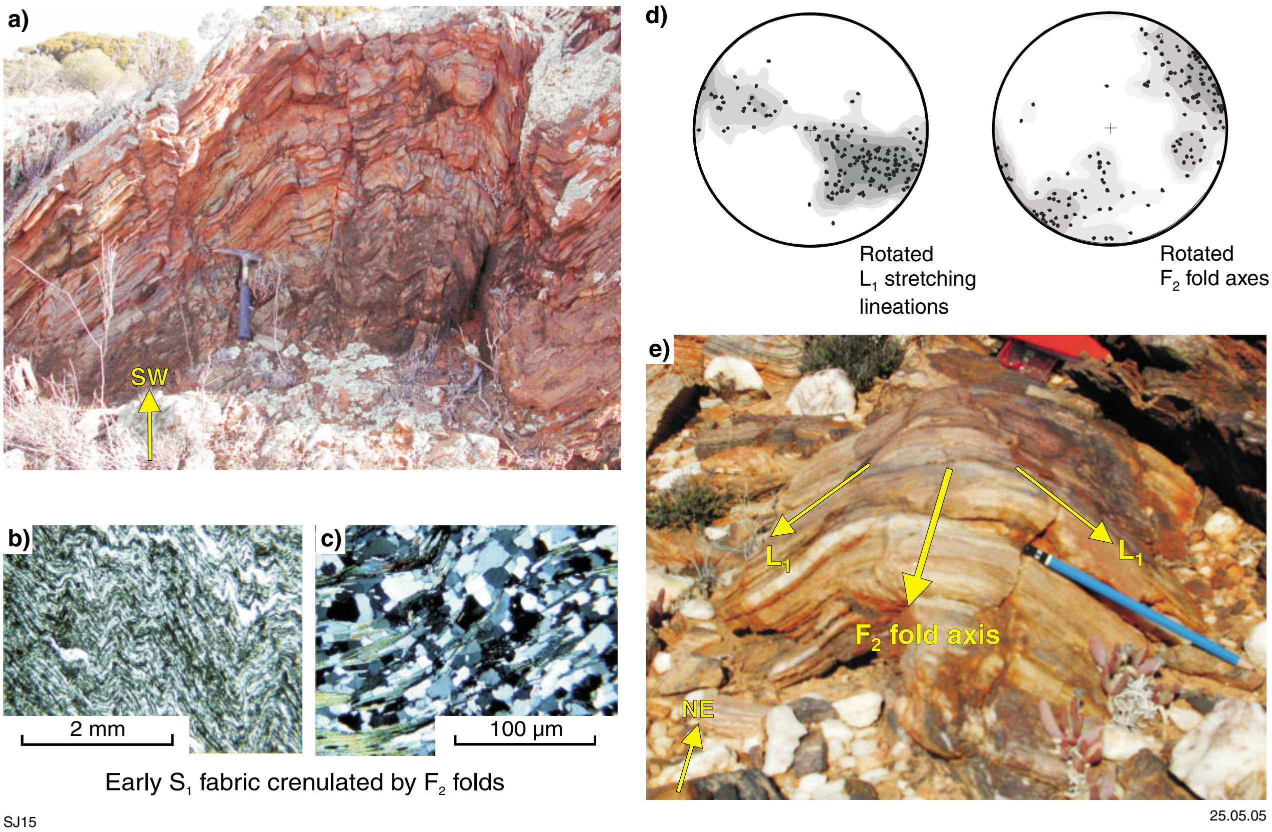

Figure 7. Deformation features from the D_1 and D_2 events: a) Typical upright D_2 folds in interbedded siltstone–sandstone, northeastern YARDILLA (MGA 487610E 6511290N); b) photomicrograph illustrating the bedding-parallel S_1 fabric being refolded by D_2 folds, with a weak crenulation cleavage developing in places, northeastern YARDILLA (GSWA 165122, cross-polarized light); c) photomicrograph illustrating D_2 folding of the S_1 fabric which is defined by aligned muscovite and quartz, northeastern YARDILLA (GSWA 179122, cross-polarized light); d) stereoplots illustrating the spread of the lineations due to D_2 folding, northeastern YARDILLA; e) an F_2 fold refolds the L_1 stretching lineation on the S_1 surface (MGA 491500E 6504070N)

Figure 8. Dome-and-basin fold-interference structures representing F_1 folds refolded by D_2 folds, northern YARDILLA (MGA 480260E 6509160N)

contemporaneous with deformation during the D_1 event. The precise timing of 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).

The M_2 event

A regional low- to medium-grade event (M_2) partially overprints the earlier metamorphism with a similar mineral assemblage of quartz–muscovite–chlorite–feldspar. Metamorphic mineral assemblages in metabasalts on northern YARDILLA are dominated by chlorite and feldspar. The dominance of chlorite and the lack of biotite and amphibole in metasedimentary and mafic rocks on YARDILLA suggests lower greenschist-facies conditions. A weak alignment of muscovite, quartz, and chlorite, parallel to the S_2 crenulation cleavage, suggests that peak M_2 metamorphic conditions were coeval with deformation during the D_2 event. This regional low- to medium-grade event is common throughout the Eastern Goldfields Granite–Greenstone Terrane and is thought to broadly reflect the distribution of granitic rocks (Witt, 1991; Ridley, 1993; Swager 1997). Deformation during the

D_2 event was most probably contemporaneous with the majority of granite emplacement at 2665–2640 Ma (Witt, 1991; Nelson, 1997; Swager et al., 1997).

The M_3 event

M_3 contact metamorphism in Archaean metasedimentary rocks adjacent to Proterozoic mafic dykes, reported on MOUNT BELCHES to the north, is not observed on YARDILLA because the dykes typically intrude granite.

Proterozoic geology

Proterozoic rocks make up about one-third of the exposed rocks on YARDILLA and include the Widgiemooltha Dyke Suite and the Fraser dyke swarm in the west and northwest, scattered outcrops of Woodline Formation sedimentary rocks in the northwest, and the granulite- to amphibolite-facies gneisses of the Albany–Fraser Orogen in the southeast.

Widgiemooltha Dyke Suite (*ꟑWIbi-od, ꟑWIji-od, ꟑWIji-ax, ꟑWIji-ow*)

The easterly trending Palaeoproterozoic Widgiemooltha Dyke Suite (Sofoulis, 1966) intrudes rocks of the Yilgarn Craton, and includes the Binneringie and Jimberlana Dykes (Fig. 3) that extend onto YARDILLA. The Binneringie Dyke (*ꟑWIbi-od*) is the largest dyke in the Widgiemooltha Dyke Suite and is about 320 km in length with a maximum width of 3.2 km near Lake Cowan. Although it does not outcrop, a small part of the Binneringie Dyke is interpreted from magnetic data to extend into the extreme northwest corner of YARDILLA. The Jimberlana Dyke (*ꟑWIji-od*) is 180 km long, up to 2.5 km wide, and extends from the southwest corner to the central part of YARDILLA with a few reasonable exposures.

The dykes are relatively narrow within the granite 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, against the largest dykes (McCall and Peers, 1971).

Flow layering parallel to the dyke margins is rare along the Jimberlana Dyke on YARDILLA (e.g. MGA 462595E 6473181N), but is more common in the smaller dykes (Hallberg, 1987). Vertical magmatic layering with both cryptic and rhythmic layering is 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 Jimberlana Dyke is interpreted to be funnel-shaped in cross section with an internal lopolithic structure formed by canoe-like structures, analogous to the Great Dyke of Zimbabwe (Campbell et al., 1970; Campbell, 1991). At Bronzite Ridge near Norseman, three distinct successions have been interpreted in vertical sections based on scattered diamond drillhole intersections. Eight separate canoe-shaped complexes are recognized along about 100 km of the Jimberlana Dyke (Campbell et al., 1970; Campbell, 1991; Hallberg, 1987; McClay and Campbell, 1976).

On YARDILLA, exposures of the Jimberlana Dyke are separated into three units as follows: undivided Jimberlana Dyke (*ꟑWIji-od*) comprising dolerite, gabbro, gabbronorite, and norite in areas with poor exposure; pyroxenite with only minor norite and gabbro (*ꟑWIji-ax*); and norite with only minor pyroxenite (*ꟑWIji-ow*).

The most precise age for the Widgiemooltha Dyke Suite 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 error of, and more precise than, the SHRIMP U–Pb baddeleyite age of 2420 ± 7 Ma (Nemchin and Pidgeon, 1998). The age is also within error of the combined Rb–Sr age of 2420 ± 30 Ma for the Celebration and Jimberlana Dykes (Turek, 1966) and the Sm–Nd isochron age of 2411 ± 52 Ma for the Jimberlana Dyke (Fletcher et al., 1987).

Woodline Formation (*ꟑwo-s, ꟑwo-stq, ꟑwo-sxc*)

The Woodline Formation (*ꟑwo-s*; formerly known as the Woodline Beds; Griffin, 1989) forms low ridges and scattered outcrops in a northeast-trending belt more than 50 km long in the northwestern part of YARDILLA. The unit is about 250 m thick, based on drillhole data (Asarco Limited, 1969, 1971; WMC Limited, 1991), and consists predominantly of quartz arenite (*ꟑwo-stq*), siltstone, and minor quartz conglomerate and mudstone (Figs 3 and 9). In places, matrix- to clast-supported chert breccias (*ꟑwo-sxc*), with chert clast sizes ranging from to 1 to 20 cm, are interbedded with finer grained, well-sorted quartz-rich sandstone, minor chert, and mudstones. Although the base of the Woodline Formation is poorly exposed, there is an angular unconformity between the formation and the underlying Archaean rocks on ERAYINIA to the north (Jones, in prep.; Hall and Jones, 2005), and a similar relationship was reported by Griffin (1989) on YARDINA to the west.

Woodline Formation rocks are gently folded with a weak to moderately developed spaced cleavage, and are metamorphosed at lower greenschist facies. Although weakly deformed, outcrops are typically relatively fresh and sedimentary structures such as tabular bedding, trough cross-bedding, rip-up clasts, ripple marks, sole marks, scour marks, and graded beds are well preserved (Fig. 10). Graded bedding, scoured bases, and truncated cross-bedding indicate upright bedding.

The well-sorted, well-rounded, and quartz-rich nature of the sandstone units of the Woodline Formation indicates deposition distal from the source. The conglomerates, cross-bedded sandstones, ripple marks, and sole marks indicate a relatively high energy, possibly fluvial, depositional environment, such as a braided stream system. Trough cross-beds and ripple marks in Woodline Formation rocks on ERAYINIA to the north indicate a

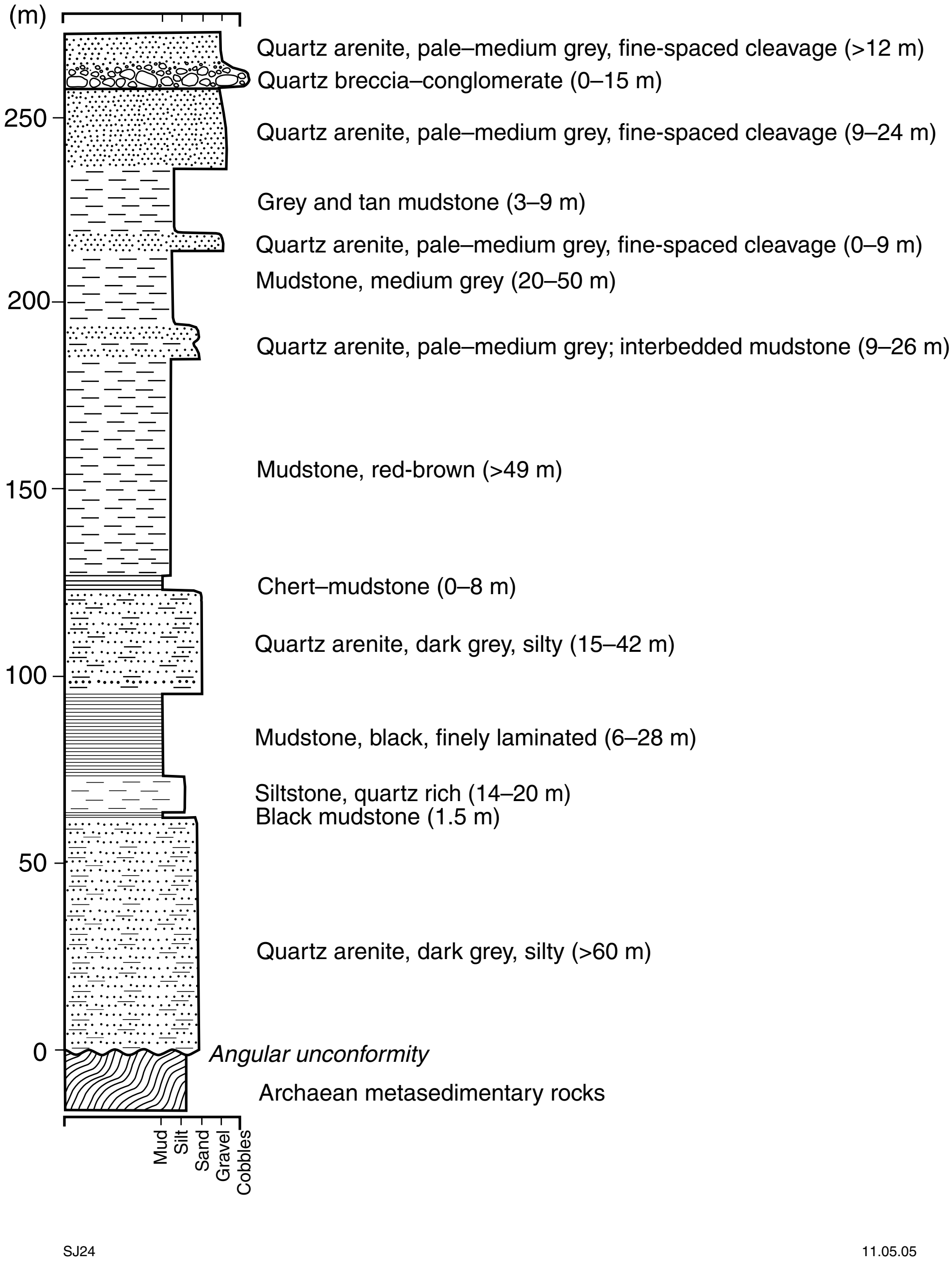

Figure 9. Graphic log illustrating the general stratigraphy of the Woodline Formation from drillhole data (Asarco Limited, 1971)

predominantly northwest to southeast flow direction (Hall and Jones, 2005).

A maximum deposition age is provided by a SHRIMP U–Pb age of 1737 Ma from detrital zircons from the Woodline Formation (Hall and Jones, 2005) and a Rb–Sr isochron age of 1620 ± 100 Ma was obtained for the Woodline Formation by Turek (1966). These ages are similar to a recent date (1696 ± 7 Ma) obtained for the Mount Barren Group about 400 km to the southwest (Dawson et al., 2002), which may be a lateral equivalent of the Woodline Formation. The Woodline Formation was previously thought to represent an allochthonous block thrust onto the Yilgarn Craton during the Albany–Fraser Orogeny (Myers, 1990). However, as most of the activity during the Albany–Fraser Orogeny occurred between 1300 and 1100 Ma, deposition of the Woodline Formation pre-dates the orogeny by 300–500 million years. The unconformable basal contact of the Woodline Formation and the lack of strong deformation also indicate fluvial sedimentation on the Archaean basement, rather than an allochthonous thrust sheet.

Fraser dyke swarm

The northeast-trending Fraser dyke swarm intrudes the southeastern Yilgarn Craton, parallel to the Albany–Fraser

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Figure 10. Subhorizontal tabular beds in the Woodline Formation, northwest YARDILLA (MGA 456800E 6497706N)

Orogen. These dykes are predominantly composed of undeformed dolerite (Wingate et al., 2000). The Fraser dyke swarm does not outcrop on YARDILLA, but north-northeasterly trending dykes are inferred from aeromagnetic images.

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 northwest. This is similar to the average age (1210 Ma; Evans, 1999) of the east-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 coevally with the 1300–1100 Ma Albany–Fraser Orogeny, subparallel to the suture in a zone of flexure formed by crustal loading during orogenesis.

Albany–Fraser Orogen

The Albany–Fraser Orogen is an arcuate belt extending along the southern and southeastern margin of the Yilgarn Craton, and is characterized by high-grade gneisses and granitic rocks (Myers, 1990, 1995a). The belt records the Mesoproterozoic collision between the Yilgarn and east Antarctic Cratons between 1345 and 1100 Ma (Baksi and Wilson, 1980; Myers, 1995a; Nelson et al., 1995; Clark et al., 1999, 2000). Myers (1990) divided the orogen into the Biranup and Nornalup Complexes, based on lithology and structure.

The Biranup Complex, which forms the northern part of the Orogen (Tyler and Hocking, 2001, 2002), consists of intensely deformed, tectonically interleaved quartzofeldspathic gneisses and mafic granulites. In the Fraser Range area in the southeastern corner of YARDILLA, the Biranup Complex includes mafic granulites that are part of a 35 × 400 km belt called the Fraser Complex by Myers (1985). The Nornalup Complex forms the southern and southeastern part of the Albany–Fraser Orogen. It is less intensely deformed than the Biranup Complex, and comprises orthogneiss and paragneiss intruded by granite. The metamorphic grade of the Nornalup Complex is typically upper amphibolite facies, with local hornblende–granulite facies (Myers, 1990). The Nornalup Complex does not outcrop on YARDILLA.

Biranup Complex

The Biranup Complex on YARDILLA includes minor quartzofeldspathic gneisses interleaved with more abundant mafic granulites. Myers (1985) defined the Fraser Complex to include only the metamorphosed basic igneous rocks, and specifically excluded the intercalated felsic gneisses. This terminology is followed here.

Dalyup Gneiss (*Ꝑda-mgn*)

The Dalyup Gneiss (*Ꝑda-mgn*) is a granitic gneiss along the northwestern edge of the Albany–Fraser Orogen (Myers, 1995b) that in places is interleaved with Archaean rocks of the Yilgarn Craton. A U–Pb zircon age of 1670 ± 15 Ma was obtained for granitic gneiss at 10 Mile Rocks (part of the Dalyup Gneiss), just southwest of YARDILLA (Nelson et al., 1995).

Metasedimentary gneiss (*ꝐmdnBR*)

Metasedimentary gneiss or paragneiss (*ꝐmdnBR*) in the northwestern part of the Fraser Range on YARDILLA is intensely deformed with well-developed gneissic banding throughout. Granoblastic textures dominate and the gneissic bands are defined predominantly by polygonized quartz ribbons and minor garnets, ranging in size from 1 to 5 mm. The unit is dominated by quartz (up to 95–100%) with scattered garnet-rich zones, suggesting that the protolith may have been quartz-rich, such as a quartz sandstone. Some layers contain up to 20% feldspar and minor biotite, indicating a feldspathic protolith. The paragneiss typically forms wide outcrops, up to 50 m wide (e.g. MGA 499550E 6476840N), but is also interlayered at a metre scale with amphibolite gneiss and minor pyroxene gneiss.

Fraser Complex (*Ꝑfr-moa*, *Ꝑfr-moo*, *Ꝑfr-moom*, *Ꝑfr-xmoo-mg*)

The Fraser Complex is dominated by mafic granulites interpreted to be derived from layered intrusions that

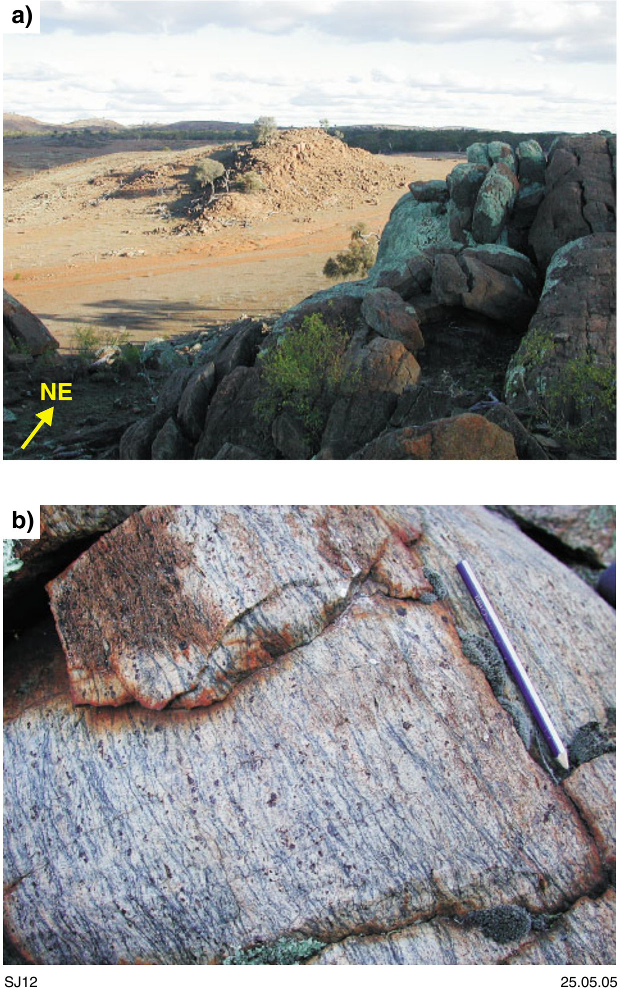

Figure 11. Outcrops and textures of the Proterozoic Fraser Complex in the Fraser Range: a) typical outcrops, southeast Yardilla (MGA 486388E 6463167N); b) typical gneissose textures of quartz–feldspar–garnet-rich gneiss, Fraser Range (MGA 493575E 6468090N)

included gabbros, anorthosite, and ultramafic rocks (Myers, 1985, 1995a). Most rocks are deformed and strongly recrystallized at granulite facies, or have retrogressed to upper amphibolite facies, but igneous textures and layering are rarely preserved. Myers (1985) identified the following tectono-stratigraphic units:

- unit 1: garnet amphibolite, including ultramafic igneous rocks, melanogabbro, and anorthosite;
- unit 2: pyroxene granulite, with relict igneous textures suggesting derivation from gabbro or norite;
- unit 3: metamorphosed leucogabbro, anorthosite, minor gabbro, and melanogabbro;
- unit 4: mafic granulite, similar to unit 2;
- unit 5: mainly gabbro and metagabbro, possibly the precursor to units 2 and 4.

On Yardilla these commonly interlayered units are too small to map at 1:100 000 scale, therefore they have been grouped into broad zones, about 150 to 300 m wide, based on the dominant gneiss type and magnetic characteristics (Fig. 11).

Crystallization, under granulite-facies conditions at 1291 ± 21 Ma, occurred just before tectonic emplacement of the Biranup Complex into the upper crust at 1268 ± 20 Ma, and was associated with the major continent–continent collision event between the Yilgarn Craton margin and east Antarctica at c. 1300 Ma (Fletcher et al., 1991; Clark et al., 1999; 2000; Nelson, 1995; Nelson et al., 1995).

Medium- to coarse-grained amphibolite (*Ꝑfr-moa*) is common in the northwestern part of the Fraser Range, forming large rounded outcrops on ridges just northwest of the Fraser Range Station boundary. The amphibolite is typically strongly banded and intensely deformed, with pale quartz–feldspar–garnet-rich bands interlayered with hornblende- and hornblende–garnet-rich layers (millimetres to centimetres wide). In thin section granoblastic textures dominate, with typical mineralogy including hornblende, quartz, garnet, plagioclase, and epidote, with or without biotite, representing a possible retrograde assemblage. Myers (1990) suggested that the granulite-facies rocks along the northwestern edge of the Fraser Complex were downgraded to amphibolite facies during emplacement at a higher crustal level. Throughout the northwestern part of the Fraser Range, the amphibolite is interlayered with abundant quartz- and quartz–garnet-rich metasedimentary gneiss layers.

Pyroxene-rich mafic granulite (*Ꝑfr-moo*) is the most widespread unit in the Fraser Range and consists of a range of mafic igneous protoliths, including gabbro, melanogabbro, and leucogabbro, commonly interlayered with charnockite. The mafic units are medium to coarse grained, weakly to moderately magnetic, and variably deformed. Granoblastic textures dominate with completely recrystallized polygonal plagioclase, orthopyroxene, and clinopyroxene, but igneous textures are rarely preserved (Fig. 12a). Retrograde metamorphic reactions are indicated by amphibole and biotite in some samples (Fig. 12b).

In the centre of the Fraser Range a broad unit of pyroxene granulite is interlayered with numerous bands of granitic gneiss (*Ꝑfr-xmoo-mg*), ranging from 0.5 to 40 m wide. The proportion of granitic gneiss is much greater in this area and is reflected by a zone of relatively low magnetic intensity on aeromagnetic images. The granitic gneiss bands commonly have abundant large augen and are composed of quartz, feldspar, and garnet, with accessory apatite and titanite.

A band of high magnetic intensity in the southeastern corner of the map sheet marks a zone dominated by medium- to coarse-grained pyroxene-rich rocks (*Ꝑfr-moom*) that have higher magnetic intensity than adjacent mafic granulite. In the field the mafic granulite units (*Ꝑfr-moo* and *Ꝑfr-moom*) are very similar.

Other Biranup Complex rocks (*ꝐmnBR*, *ꝐmgnBR*, *ꝐmguBR*)

Undivided gneiss (*ꝐmnBR*) is used only for areas covered by thin colluvium where the strong northeast structural grain of the Fraser Complex is visible on aerial photographs and Landsat imagery.

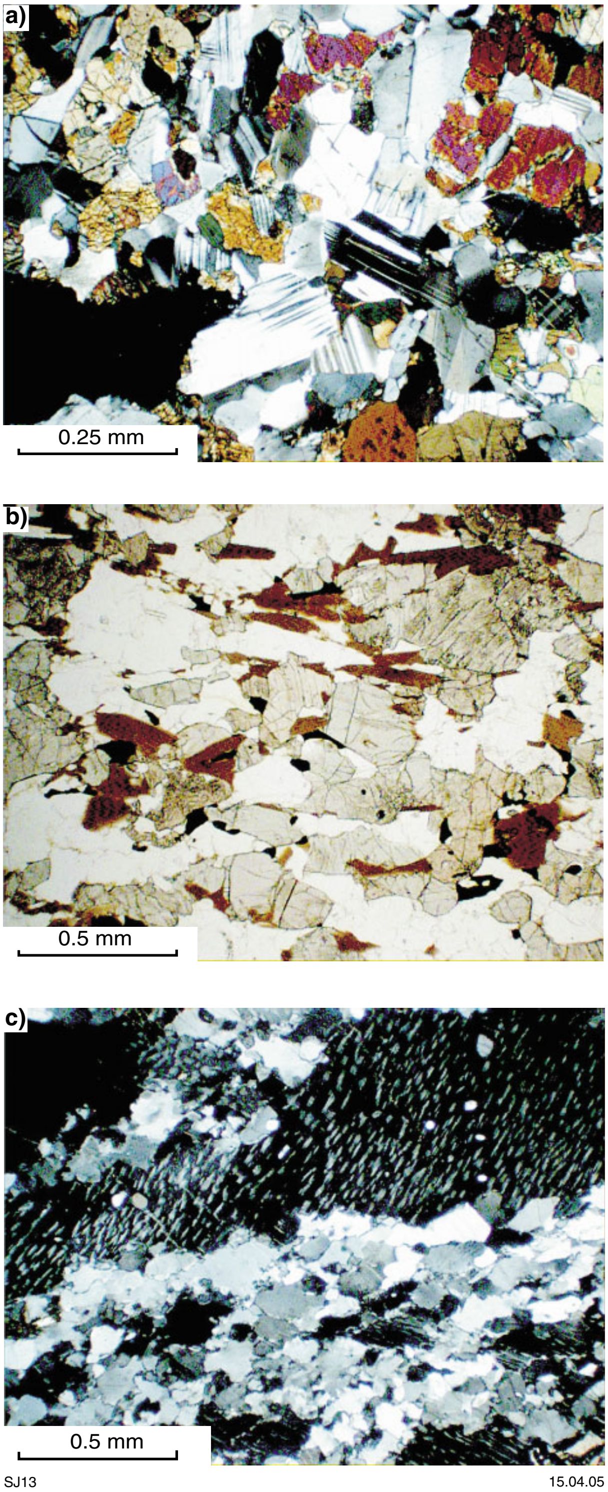

Figure 12. Petrographic textures in Fraser Range gneisses: a) relict igneous texture of interlocking subhedral plagioclase and pyroxene in a mafic gneiss, Fraser Range (GSWA 179149, cross-polarized light); b) ubiquitous biotite in a pyroxene gneiss may indicate retrograde metamorphism, Fraser Range (GSWA 179152, plane-polarized light); c) antiperthite texture in a large feldspar grain in a strongly recrystallized groundmass in granitic gneiss, Fraser Range (GSWA 179142, cross-polarized light)

Granitic gneiss (*ᵽmgnBR*) and granitic augen gneiss (*ᵽmguBR*) form abundant narrow bands (0.5 – 1 m wide) interlayered with mafic pyroxene granulite throughout the area, particularly within the central part of the Fraser Range, where several 5–40 m-wide bands can be traced for several kilometres (e.g. MGA 491120E 6465370N and 481170E 6458816N). Another granitic gneiss band (30 m wide) is in the northeastern part of the Fraser Range (e.g. MGA 497435E 6478420N). These bands form useful marker horizons to measure offset on northwesterly faults that are common throughout the area.

The granitic gneiss is typically composed of quartz, feldspar, garnet, and biotite, with accessory apatite, titanite, and opaque minerals (Fig. 11b). Feldspar augen are common, ranging in size from 0.5 to 5 cm. Textures are dominantly granoblastic with intensely recrystallized quartz and feldspar forming a compact mosaic. Gneissic banding is defined by aligned quartz ribbons, biotite, and fine-grained garnet. Undulose extinction, deformation twins, and subgrain growth are common throughout. Larger feldspar grains commonly display antiperthite textures (Fig. 12c), but these could be of metamorphic rather than igneous origin (cf. Spry, 1976). The presence of biotite in many samples could reflect retrograde reactions.

Albany–Fraser Orogeny

The Albany–Fraser Orogen is characterized by a northeast-trending belt of high-grade gneisses and granitic rocks that truncate the north-northwesterly trending greenstone belts of the Yilgarn Craton (Gee, 1979; Myers, 1995a).

Multiple deformation episodes are recorded in the orogen, with the main activity (the Albany–Fraser Orogeny) thought to have occurred between 1345 and 1100 Ma (Myers, 1995a; Nelson et al., 1995; Clark et al., 2000). Clark et al. (2000) recognized a two-stage history of the eastern part of the Albany–Fraser Orogen (east of Bremer Bay) based on structure, petrology, and geochronology. Two discrete thermotectonic stages between c. 1345 and 1260 Ma (Stage I) and between c. 1214 and 1140 Ma (Stage II) have been identified. These authors suggested that initial continent–continent collision at c. 1300 Ma was followed by intracratonic reactivation affecting basement and cover at c. 1200 Ma.

However, Dawson et al. (2003) suggested that peak thermal metamorphism was at 1205 ± 10 Ma, post-dating peak dynamic metamorphism (c. 1260 Ma; Clark et al., 2000; Nelson, 1995) by at least 45 Ma. They related the peak thermal metamorphism to regional heating associated with the emplacement of 1215–1202 Ma dyke swarms and emplacement of 1200–1180 Ma granites into the orogen and the adjacent Yilgarn Craton. Dawson et al. (2003) suggested three tectonic settings for the Albany–Fraser Orogen, including a Stage I collision environment as a result of tectonic emplacement of the ‘Albany–Fraser Province’, an early Stage II anorogenic environment defined by a craton-scale thermal anomaly, and late Stage II reactivation of the orogen caused by renewed convergence.

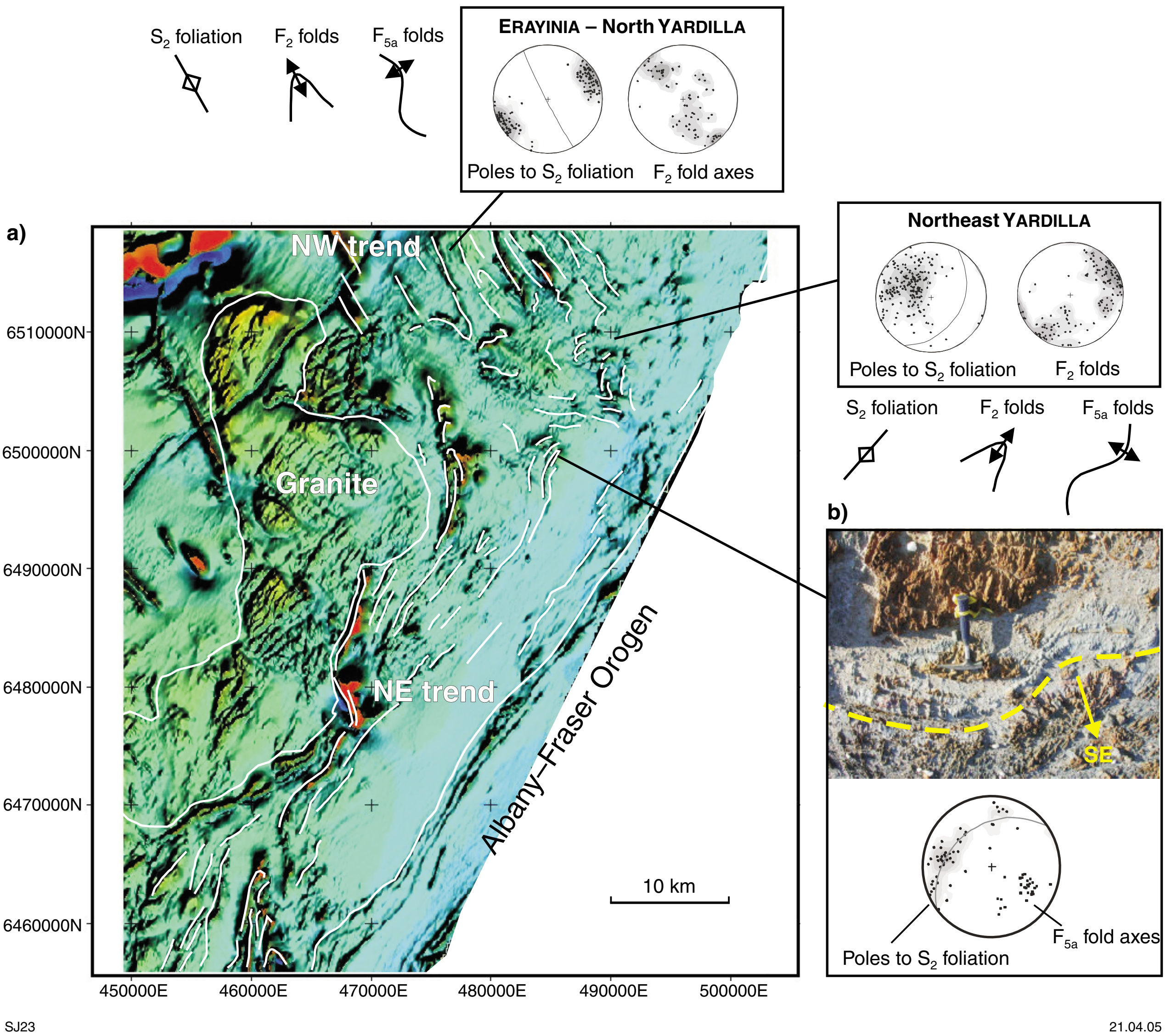

Figure 13. a) The stereoplots and interpreted aeromagnetic image (image courtesy of Fugro Airborne Surveys) illustrate the broad shift from regional north-northwest trends of metasedimentary rocks in northern YARDILLA and ERAYINIA to a local northeast trend, parallel to the Yilgarn Craton margin, in southern and northeastern YARDILLA. Clockwise rotation of the regional northwest trend of Archaean metasedimentary rocks into a local northeast trend parallel to the Yilgarn Craton margin suggests a large component of dextral displacement during the Albany–Fraser Orogeny. The wide spread of the S_2 foliations and F_2 fold axes in the rotated zone is probably a result of D_{5a} folding; b) typical D_{5a} open fold in lake pavement, northeastern YARDILLA (MGA 481840E 6495660N) with the poles to S_2 foliation and F_{5a} fold axes shown on the stereoplot below

Deformation in Archaean rocks (the D_5 event)

The D_5 event marks the onset of deformation related to the Albany–Fraser Orogeny in the Archaean rocks and is subdivided into the D_{5a}, D_{5b}, D_{5c}, and D_{5d} events. The D_{5a} event is characterized by shallow to moderately northeasterly plunging open folds and warping during southeast–northwest compression. Large F_{5a} folds defined by chert ridges in the north are visible on aerial photographs and aeromagnetic images. In the area close to the Yilgarn Craton margin, these folds plunge to the southeast as a result of clockwise rotation during the D_{5b} event (Fig. 13a). A typical F_{5a} fold of the S_2 foliation in the northeastern part of YARDILLA is shown in Figure 13b, with measured F_{5a} fold axes lying very close to the estimated β axis.

D_{5b} dextral displacement along the Yilgarn Craton margin during the Mesoproterozoic collision is recognized by regional drag features on aeromagnetic images (Fig. 13a). The dextral displacement resulted in a large clockwise rotation (almost 90°) of the Archaean rocks adjacent to the boundary zone. In this area the north-northwesterly trending D_1 and D_2 structures were rotated parallel to the suture and now display a local northeast trend, whereas D_{5a} folds plunge to the southeast in the boundary zone. The stereoplots (Fig. 13a) illustrate the change from a regional north-northwest structural grain on northern YARDILLA and ERAYINIA to the dominantly

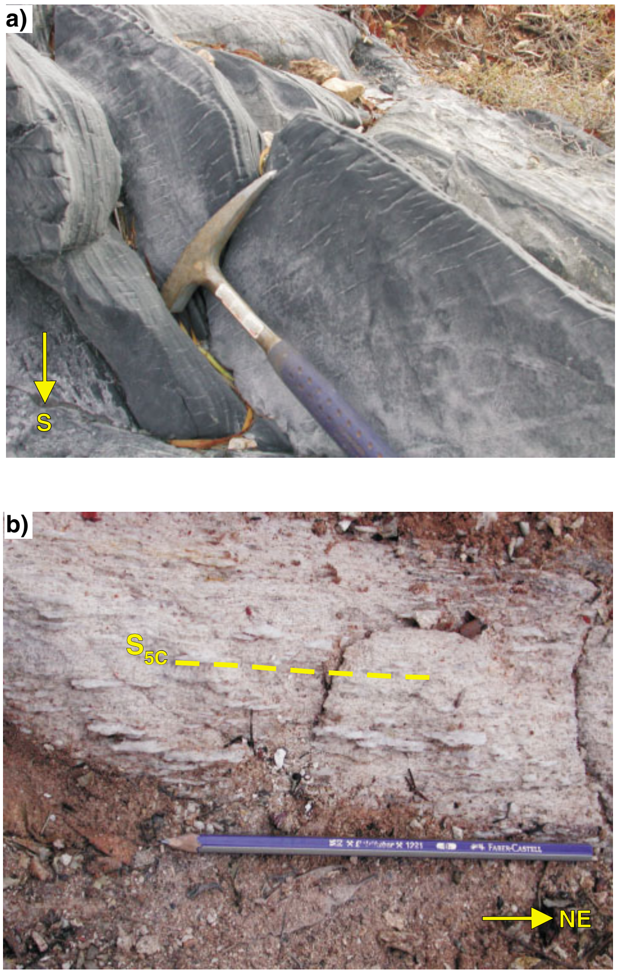

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Figure 14. a) Spaced S_{5c} cleavage in laminated mudstone (cleavage orientation 008°/42° NW; bedding orientation 122°/70°S), northeastern YARDILLA (MGA 481345E 6495189N); b) intensely foliated quartz-rich muscovite schist (*Alqm*) in eastern YARDILLA (MGA 485720E 6510420N). The S_{5c} fabric is defined by elongate quartz ribbons and aligned mica

northeasterly trend adjacent to the suture. The foliation data also show a much greater spread in the area close to the suture zone, reflecting increased F_{5a} folding in this zone.

Continued northwest–southeast compression during D_{5c} resulted in the development of a strong northeast-striking steeply dipping cleavage (S_5) in the highly strained Archaean rocks in the suture zone. The rocks here were typically strongly recrystallized and the cleavage is defined predominantly by aligned quartz ribbons and mica. Earlier D_1 and D_2 fabrics were typically destroyed or obscured by the late S_5 cleavage. The fabric is first seen as a spaced cleavage (Fig. 14a), which increases in intensity towards the high-strain zone (Fig. 14b). This increase in fabric development was also accompanied by an increase in metamorphic grade towards the suture zone (see **Metamorphism in Archaean rocks**).

Late offset of the rotated boundary-parallel fabrics along a large west-northwesterly striking brittle structure and possible antithetic northeast-trending faults in northeastern YARDILLA characterize the D_{5d} event (Fig. 3). Abundant northeast-striking lineaments in granites seen on aeromagnetic images, and ubiquitous subvertical northeast-striking joints in outcrops, may also be related to this event.

Deformation in the Woodline Formation

The Woodline Formation is typically only weakly deformed, with open upright folding and warping, and a weak to moderate cleavage developed locally. The formation predominantly has shallow to moderate dips and bedding is well preserved, with clear younging indicators indicating that beds are not overturned. Minor small thrusts are observed, but have a minimal effect on the stratigraphy. Southeast–northwest compression is suggested by broad fold axes, consistent with Albany–Fraser Orogeny deformation associated with the D_5 event in the underlying Archaean rocks (Hall and Jones, 2005).

Deformation in the Biranup Complex

The Biranup Complex on YARDILLA comprises subvertical tectonic slices of mafic granulites and interlayered felsic gneisses ranging from 2 to 5 km in thickness. Gee (1979) and Myers (1995) suggested that this northeastern part of the Albany–Fraser Orogen, adjacent to the suture zone, may contain tectonically reworked remnants of the Yilgarn Craton interleaved with the younger rocks.

Three deformation events (D_{F1} to D_{F3}) are recognized in the rocks of the Biranup Complex in the Fraser Range on YARDILLA, and they record the complex deformation history of these high-grade rocks (Fig. 15). The deformation events recognized in the Biranup Complex of the Fraser Range on YARDILLA are similar to structures observed elsewhere in the Albany–Fraser Orogen. Deformation events throughout the Albany–Fraser Orogen are summarized for comparison in Table 2.

The D_{F1} event

The D_{F1} event is characterized by intense deformation that produced the northeast-striking, moderately to steeply dipping gneissic banding that is the dominant fabric in the Biranup Complex of the Fraser Range (Fig. 16a). The orientation of this fabric is consistent across the area, but the intensity of the fabric varies markedly from strongly deformed and completely recrystallized rocks to weakly banded zones displaying relict igneous textures. The well-developed fabric appears to be axial planar to rare isoclinal folds. A weakly developed, gently to moderately northeasterly plunging lineation (L_{F1}) associated with the gneissic banding is best observed in the granitic augen gneiss, in which it is defined by an alignment of feldspar augen (Fig. 16g). The gneiss is dominated by a strong flattening strain indicated by symmetric augen, but in places asymmetric tails on augen provide good shear-sense indicators (Fig. 16b,c), suggesting that

Table 2. Deformation events in the Albany–Fraser Orogen

	Western Albany–Fraser Orogen				*Eastern Albany–Fraser Orogen*	
	Duebendorfer (2002)	*Beeson et al. (1988)*	*Holden (1994)*	*Harris (1995)*	*Myers (1995a); Nelson (1995); Clark et al. (2000)*	*This study*
D_1	Subhorizontal (S_1) foliation and recumbent folds, no L_1 NW–SE shortening Coeval with peak granulite-facies metamorphism	Rare compositional layering (C_{1a}) preserved in hinge zones, no L_1 Dextral transcurrent with NW shortening	Weak subhorizontal S_1 compositional banding, no L_1 Subvertical shortening dominates	S_{1a} axial-planar foliation to isoclinal folds; S_{1b} ductile extensional shear zones, no L_1 NW thrusting followed by extension (orogenic collapse) $D_1 \cong M_1 \cong 1190 \pm 8$ Ma (Black et al., 1992)	S_1 layer-parallel foliation, slightly precedes subhorizontal S_1/S_2 axial-planar fabric to recumbent folds; no L_1 NW–SE shortening, 1st phase of Stage I deformation (Clark et al., 2000)	None recognized
D_2	Upright NW-vergent folds and subvertical NE-striking foliation Sparse L_2 mineral elongation Dextral transpression	ENE-striking steep S_{2a} shears Sparse L_2 mineral elongation, 25–45°E pitch Open to isoclinal kilometre-scale folds, overturned to NNW Dextral transcurrent with NNW–SSE shortening component	ENE-striking S_{2a} fabric, axial-planar to variably plunging F_2 folds; subhorizontal L_2 Local S_{2b} LS tectonite at granite contacts (no S_2 fabric at Herald Point) Dextral shearing, NNW shortening	Upright F_{1c} open NE–SW trending folds, no S_{1c}; no L_2 NW-striking normal shear zones (S_{1d}); F_{1d} open folds NW–SE shortening followed by NE–SE extension (?); 1190–1170 Ma (Black et al., 1992)	NE-striking steeply SE-dipping S_3 fabric of Clark et al. (2000), axial-planar to upright regional-scale NE-trending folds, some dextral asymmetry No lineations reported NW–SE bulk shortening — last phase of Stage I deformation of Clark et al. (2000) 1315–1260 Ma (Black et al., 1992)	NE-striking steeply dipping foliation, D_{F1} event (this study) Weak shallow NE-plunging (L_{F1}) lineation; dextral shear-sense indicators Dextral transpression
$D_{2b?}$	?	?	?	?	Discrete NE-striking subvertical to steeply SE-dipping shear zones (S_4 of Clark et al., 2000), axial-planar to NW-verging isoclinal folds; steeply plunging lineations NW–SE shortening — early phase of Stage II deformation of Clark et al. (2000)	Subvertical NE-striking shears, steep fine lineations — D_{F2} (this study) NW–SE shortening
D_3	Brittle–ductile conjugate WNW-striking dextral and NNE-striking sinistral shear zones, dextral shears dominate Dextral transpressive regime	Conjugate brittle–ductile shear bands (C_{2a}), variable sense of displacement; Conjugate brittle–ductile shear bands (C_{2b}); WNW-striking dextral N- to NNE-striking sinistral, no L_3 Dextral transpression with NNW–SSE shortening	S_3 shear zones and bands EW- to WNW –striking dextral, NNE-striking sinistral Subhorizontal L_3 Dextral transcurrent shearing	Conjugate brittle–ductile shears, no L_3 NW–SE shortening, minimum age $\cong 1182 \pm 12$ Ma (Black et al., 1992)	?	NW-striking subvertical brittle–ductile shears, D_{F3} (this study)
D_4	S_4 joints and extension fractures, trending N–S and W–NW NW–SE shortening	None reported	Extension fractures oriented at 316°	None reported	None reported	None observed

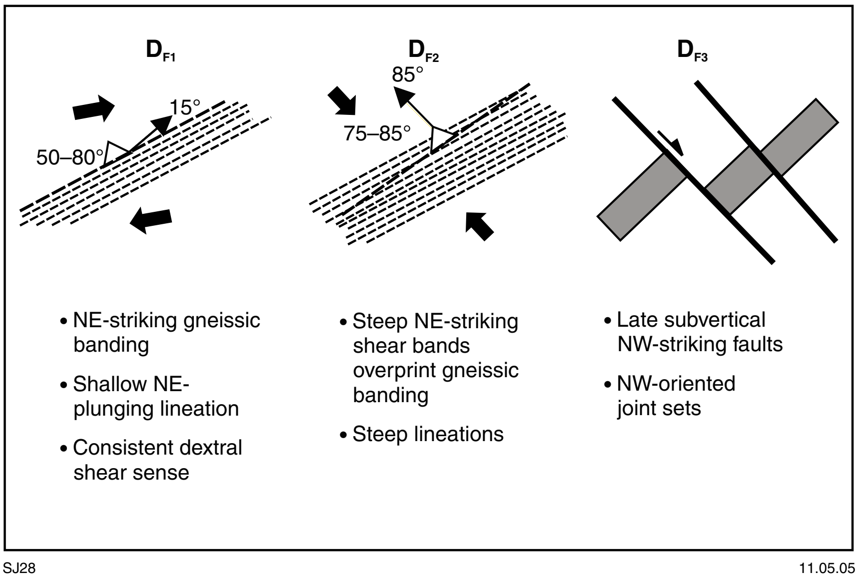

Figure 15. Deformation sequence in the Proterozoic gneisses of the Fraser Range, southeastern YARDILLA

dextral displacement accompanied northwest–southeast compression during the D_{F1} event.

The steep D_{F1} fabrics can be correlated with the regional D_2 event of the Albany–Fraser Orogen (late Stage I of Clark et al., 2000). Dextral shear-sense indicators in D_{F1} fabrics in the Fraser Range gneisses and the clockwise rotation of D_1–D_{5a} fabrics in the Archaean rocks adjacent to the boundary are consistent with dextral transpression during the regional Albany–Fraser Orogeny D_2 event (Clark et al., 2000).

Regional Albany–Fraser Orogeny D_1 structures are not recognized on YARDILLA, and are generally only partially preserved in other parts of the orogen as a weak compositional layering, axial planar to recumbent folds, and formed during northwest–southeast shortening (e.g. Beeson et al., 1988; Clark et al., 2000; Duebendorfer, 2002; Holden, 1994). This event was reported as an early phase of Stage I Albany–Fraser Orogeny deformation by Clark et al. (2000).

The D_{F2} event

D_{F2} produced steeply dipping shear bands, with a steeply plunging lineation that overprints the gneissic banding (Fig. 16d). The stereoplots (Fig. 16e,f) illustrate this fabric and the marked contrast in the plunge of lineations compared to the shallow lineations of the dominant D_{F1} gneissic banding. A reverse sense of shear has been observed on many of the shear bands, but further work is necessary to establish the dominant sense of shear. This event could be a result of a slight rotation in the stress axes during the collision event, and may represent a reactivation of the pre-existing planar fabric during continued compression. The discrete northeast-striking D_{F2} shear bands on YARDILLA are similar to shear bands documented by Myers (1995a) and Clark et al. (2000), and are attributed to an early phase of Stage II deformation during renewed northwest–southeast shortening.

The D_{F3} event

The youngest structures observed in the Biranup Complex of the Fraser Range are subvertical planar northwest-striking D_{F3} faults. Apparent offsets on these structures range from centimetres to 100 m as estimated from aeromagnetic images and field observations. Abundant fault-parallel fracture sets are also a common feature of many outcrops (Fig. 17a,b) and at one location (MGA 484790E 6460720N) small aplite dykes intrude along the northwest-trending structures (Fig. 17c). The late crosscutting northwest-striking faults on YARDILLA appear most similar to conjugate D_3 shears recognized in the western part of the Albany–Fraser Orogen (Duebendorfer, 2002; Beeson et al., 1988; Holden, 1994; Harris, 1995).

Metamorphism in Archaean rocks (the M_4 event)

The M_4 event is associated with deformation related to the Albany–Fraser Orogen and is characterized by a greenschist- to amphibolite-facies overprint in Archaean rocks, and greenschist-facies metamorphism of the Proterozoic Woodline Formation. The metamorphic grade of Archaean rocks adjacent to the contact between the Yilgarn Craton and the Albany–Fraser Orogen increases from greenschist to amphibolite facies and is characterized by a distinct coarsening of mica from less than 0.5 to 2 mm, and an associated increase in schistocity. This boundary is not a true isograd because there is no change in the mineral assemblage, but original features, such as bedding and other sedimentary structures common in rocks to the north and west, are obscured by the increasing schistosity. On the western side of the playa lakes on

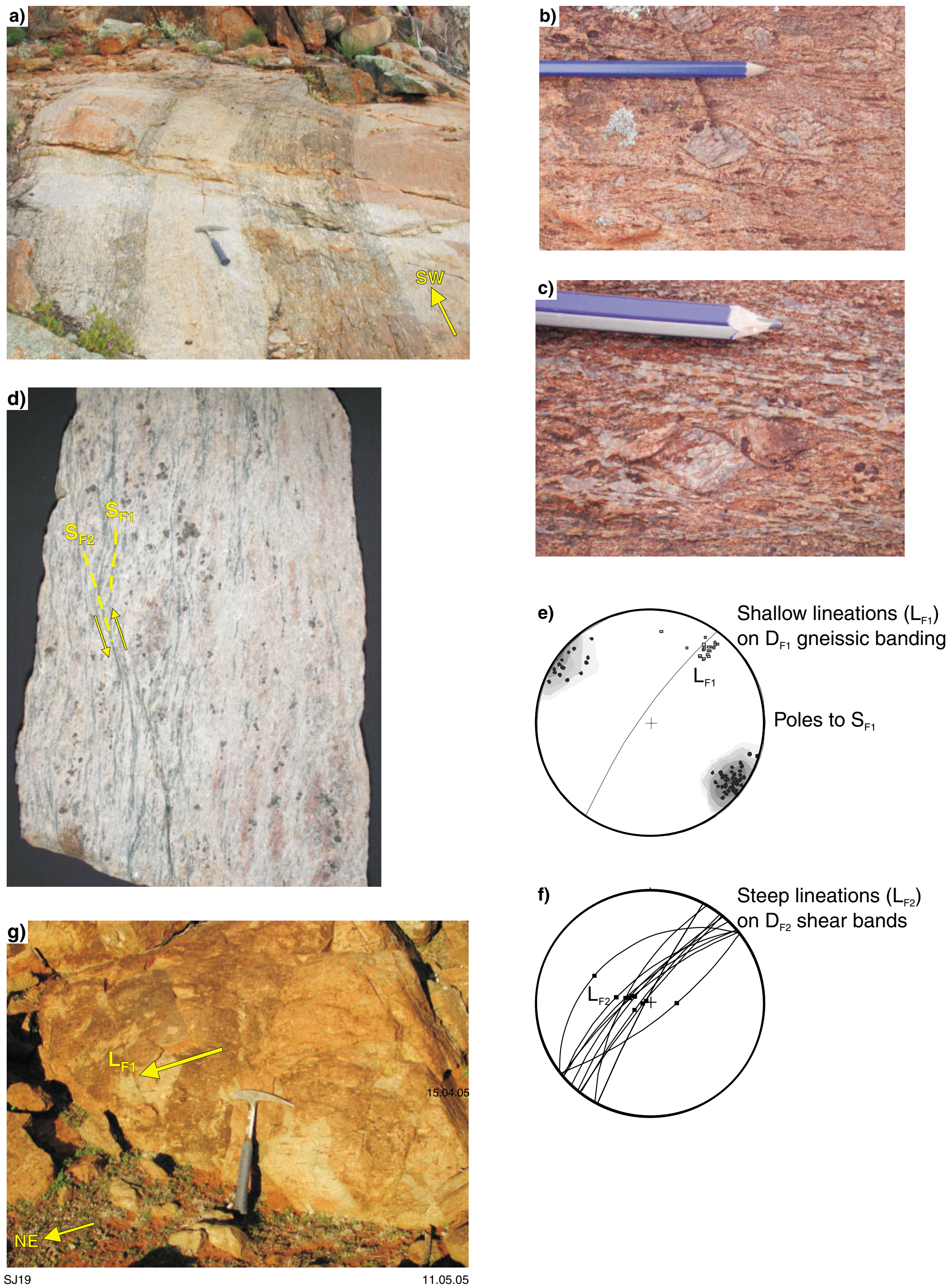

Figure 16. a) Gneissic banding in granitic augen gneiss, Fraser Range (MGA 491070E 6465360N); b–c) asymmetric augen provide dextral shear-sense indicators in northeast-striking, steeply north-dipping granitic augen gneiss, Fraser Range (MGA 491070E 6465360N); d) steep S_{F2} shear bands with steep lineations overprint the dominant gneissic banding (S_{F1}) in Fraser Range gneisses (MGA 491260E 6465550N); arrows indicate sense of movement; e–f) stereoplots illustrate the differences between the early gneissic banding (D_{F1}) and the overprinting D_{F2} shear bands with the steep lineations; g) gneissic banding (D_{F1}) displays a weak gently northeast-plunging lineation defined by an alignment of large elongate feldspar augen (MGA 485880E 6463105N)

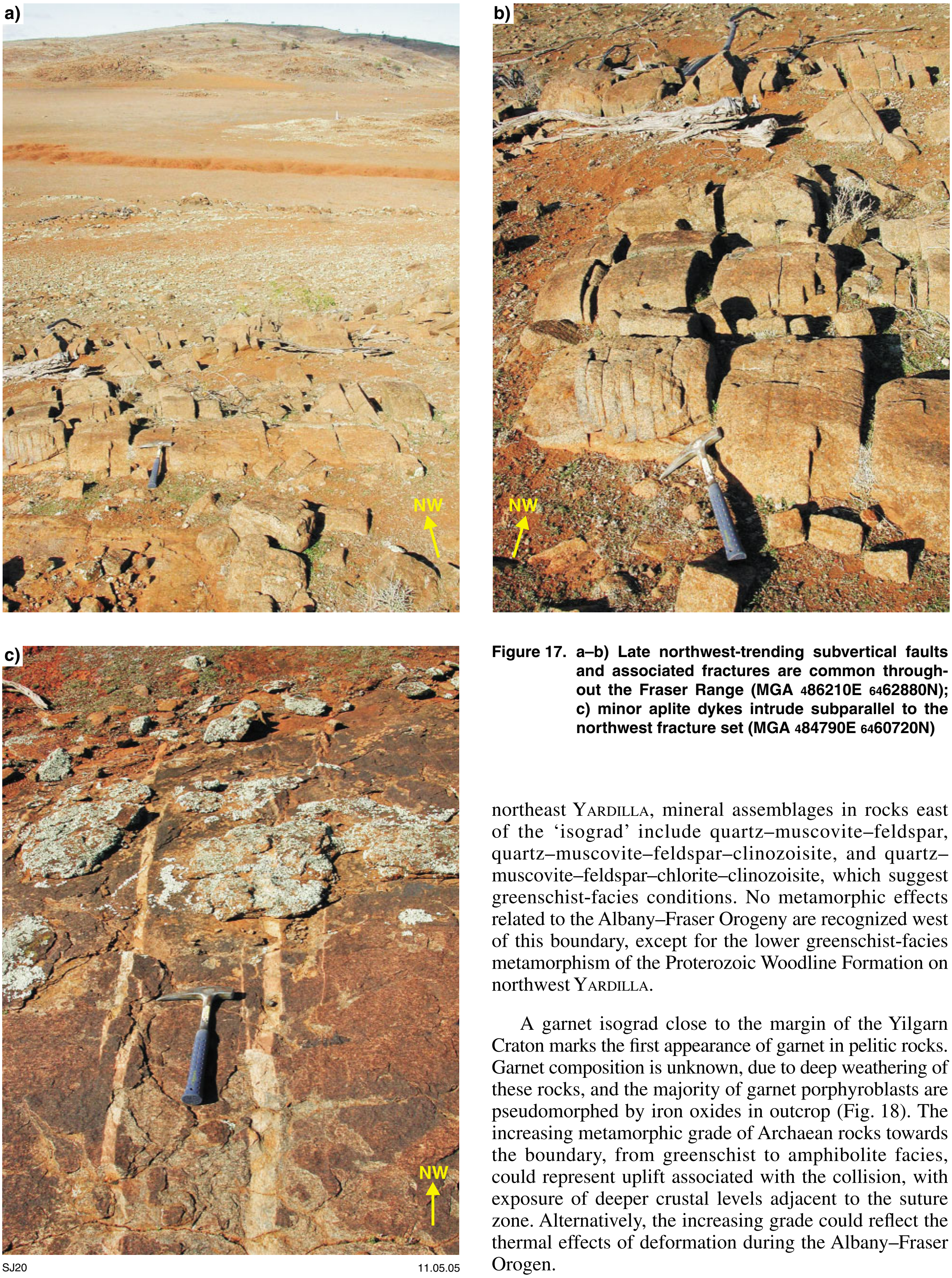

Figure 17. a–b) Late northwest-trending subvertical faults and associated fractures are common throughout the Fraser Range (MGA 486210E 6462880N); c) minor aplite dykes intrude subparallel to the northwest fracture set (MGA 484790E 6460720N)

northeast YARDILLA, mineral assemblages in rocks east of the ‘isograd’ include quartz–muscovite–feldspar, quartz–muscovite–feldspar–clinozoisite, and quartz–muscovite–feldspar–chlorite–clinozoisite, which suggest greenschist-facies conditions. No metamorphic effects related to the Albany–Fraser Orogeny are recognized west of this boundary, except for the lower greenschist-facies metamorphism of the Proterozoic Woodline Formation on northwest YARDILLA.

A garnet isograd close to the margin of the Yilgarn Craton marks the first appearance of garnet in pelitic rocks. Garnet composition is unknown, due to deep weathering of these rocks, and the majority of garnet porphyroblasts are pseudomorphed by iron oxides in outcrop (Fig. 18). The increasing metamorphic grade of Archaean rocks towards the boundary, from greenschist to amphibolite facies, could represent uplift associated with the collision, with exposure of deeper crustal levels adjacent to the suture zone. Alternatively, the increasing grade could reflect the thermal effects of deformation during the Albany–Fraser Orogen.

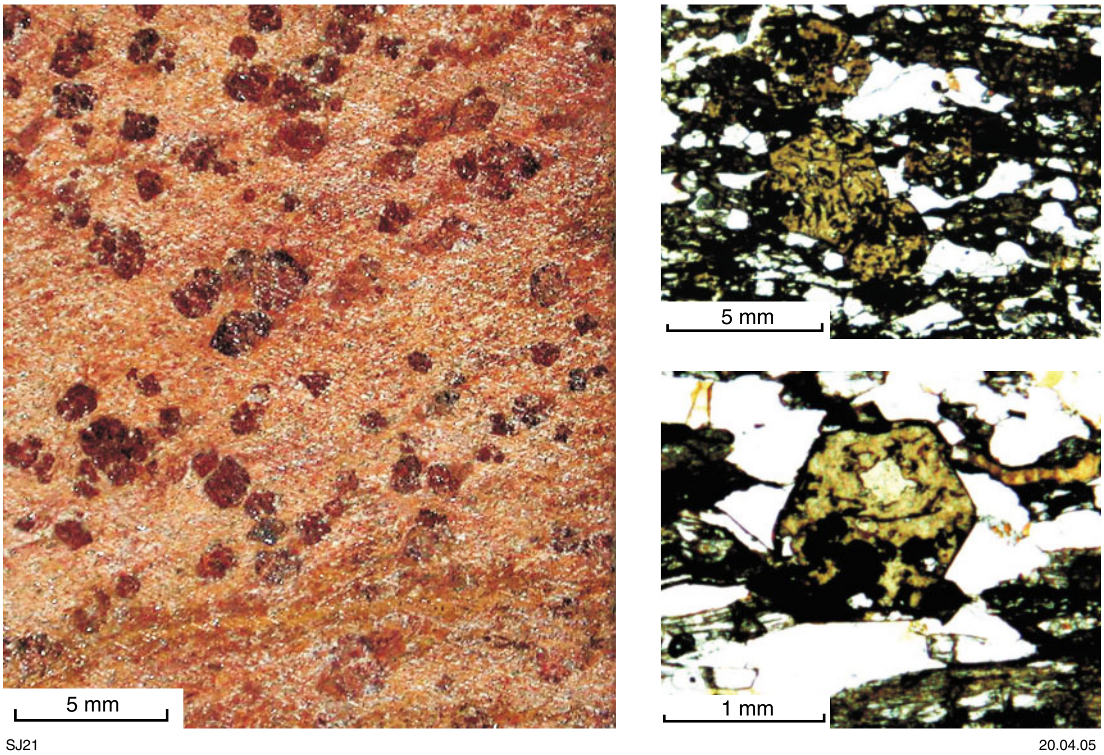

Figure 18. Pseudomorphs after garnet in metasiltstone indicate an increase in metamorphic grade to amphibolite facies along the southeastern margin of the Yilgarn Craton (MGA 465950E 6460000N, GSWA 179136, plane-polarized light)

Metamorphism in the Biranup Complex

The Proterozoic rocks of the Biranup Complex in the Fraser Range are predominantly at granulite facies, reflecting the considerable exhumation associated with the Albany–Fraser Orogeny. Medium- to coarse-grained granoblastic textures dominate, but the degree of textural modification differs markedly between narrow zones of intense deformation and broad, weakly deformed zones, where some igneous textures are preserved (Fig. 12a). The intensity of deformation and recrystallization also increases markedly towards the boundary zone, with mylonitic fabrics commonly developed. Metamorphic mineral assemblages in the mafic gneisses are typically orthopyroxene, clinopyroxene, albite, quartz, garnet, and minor biotite. Quartzofeldspathic gneisses typically consist of quartz, albite, garnet, and minor biotite. The presence of biotite suggests some retrograde reactions (Fig. 12b). Although irregular bleb-like inclusions that are common in the larger feldspar grains may represent relict igneous perthite or antiperthite textures (Fig. 12c), the dominantly granoblastic textures of these rocks indicate recrystallization and the bleb-like inclusions are more likely to represent exsolution during deformation and metamorphism. Antiperthitic textures are a common feature of granulites and charnockites (Spry, 1976).

A gradational change to lower grade amphibolite-facies rocks towards the northwestern margin of the Proterozoic Albany–Fraser Orogen reflects retrogressive metamorphism associated with uplift and emplacement of granulite-facies rocks into the upper crust, against the lower grade rocks of the Yilgarn Craton margin. Metamorphic mineral assemblages in mafic gneiss include hornblende, quartz, feldspar, garnet, biotite, and epidote, and felsic gneisses contain quartz, feldspar, garnet, and minor biotite. Granoblastic textures dominate, with most rocks being strongly recrystallized, and relict igneous or sedimentary textures are absent.

Cainozoic geology

The Cainozoic geology of YARDILLA is characterized by deposits of deltaic to marine sediments in palaeodrainage channels that had formed before the Jurassic, and by deep weathering profiles and lateritization. The deposition of deltaic to marine sediments 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 sediments form the Eundynie Group, whereas the deep weathering profiles are assigned to assorted regolith units.

Eundynie Group (*EeEU-s*, *EeEU-kl*)

The Eocene Eundynie Group comprises fluviodeltaic, estuarine to marine sediments, and is observed throughout the southern Eastern Goldfields Granite–Greenstone Terrane, predominantly within large dendritic palaeodrainage channels such as the Cowan and Lefroy palaeodrainages, which formed at the margins of the Eucla Basin. On YARDILLA the palaeodrainage channels are spatially associated with the present-day drainage systems. Chains of small playa lakes near the western edge and the northeast of YARDILLA outline palaeodrainage channels flowing north and east towards the confluence of the Lefroy and Cowan palaeodrainage channels. This drainage system is also described in the hydrogeology report of WIDGIEMOOLTHA (1:250 000; 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 convergence with the Lefroy system (Hocking and Cockbain, 1990; and Clarke, 1994). Reversal of the Cowan Palaeochannel, as a result of uplift along the Jarrahwood Axis between the Cowan and Lefroy palaeochannels, 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 northern YARDILLA, and similar dips are observed farther north on MOUNT BELCHES (Painter and Groenewald, 2001).

Outcrops of undivided Eundynie Group (*EeEU-s*) are most common in the northeastern and central parts of YARDILLA, 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, and iron-cemented gravel lenses, and spongolite. The outcrops are typically deeply weathered, with ubiquitous iron staining and silicification obscuring many original features. The sediments are only weakly to moderately consolidated and silcrete or calcrete commonly forms a cap over the outcrops. Poorly sorted, variably spongolitic sandstone is the most common Eocene unit, and is typically massive to weakly bedded with flat-lying metre-scale tabular beds. The flat-lying nature of the Eundynie Group and the silcrete and calcrete caps result in the formation of scarps and 'mesa-type' outcrops. This unit is more than 30 m thick, forming scarps up to 20 m high beside the playa lakes in the northeast and northwest, with similar thicknesses recorded in RAB drillholes on northern YARDILLA. Sponge spicules and fine irregular burrows, predominantly 1–2 mm wide (?feeding traces), are the only fossils observed in this unit, whereas bivalve fragments are relatively common in the semiconsolidated sandstone farther north on ERAYINIA (Jones, in prep.).

The iron-rich variably spongolitic sandstone unit unconformably overlies a lower unit of white clay and cross-bedded and channelized quartz sand, with scattered plant rootlets in situ and carbonized wood fragments within white clay-rich layers, carbonized silt, and lignite horizons. This unit is only observed in rare vertical sections exposed along the western edge of the northeastern playa lake system, and in drillholes targeting lignite deposits in the southwest and northeast of YARDILLA. A sharp angular unconformity between this basal clay-rich unit and the underlying Archaean basement is well exposed along the western edge of the playa lakes on northeast YARDILLA (Fig. 19).

Minor limestone (*EeEU-kl*) outcrops in the most northern part of the map, on the northern shore of the northeastern playa lake system. This is a clastic nonfossiliferous limestone with laminated mudstone clasts, nodules, and detrital quartz grains. The limestone is massive to weakly bedded with metre-scale tabular bedding, and weathered outcrops have a fluted appearance.

SJ14 11.05.05

Figure 19. Sharp angular unconformity between the white kaolin-rich North Royal Formation and steeply dipping strongly foliated Archaean saprock, northeastern YARDILLA (MGA 482210E 6501525N)

The Cainozoic stratigraphy of the Eucla Basin presented by Clarke et al. (2003) is summarized in Figure 20. On YARDILLA the majority of outcrops of undivided Eundynie Group comprise spongolitic sandstone and associated sedimentary rocks that most likely correlate with the Late Eocene Pallinup Formation (Cowan Palaeochannel) or Princess Royal Member and Hampton Sandstone (Lefroy Palaeochannel; Clarke et al., 2003). In the Lefroy Palaeochannel the Hampton Sandstone interfingers with the spongolitic Princess Royal Member and was described by Clarke (1994) as a fine-grained to gravelly glauconitic sand, locally weakly cemented to sandstone. The unit contains a marine fauna with the most common fossils being siliceous sponge spicules.

The underlying quartz sands, clay, and lignite units that are observed in rare vertical sections adjacent to the playa lakes most likely belong to the nonmarine to marginal-marine Middle Eocene North Royal Formation (or Pidinga Formation, Lefroy Palaeochannel; Lower Werrillup Formation, Cowan Palaeochannel). Clarke et al. (2003) suggested that the North Royal Formation includes all Middle Eocene clastic rocks and lignites deposited in nonmarine to marginal-marine environments along the margins of the Eucla Basin in Western Australia. These sediments most likely represent floodplain and channel sedimentation, with the abundant in situ plant roots indicating a predominantly well-drained environment supporting rainforest (Clarke, 1994).

It is difficult to correlate the limestone unit in the northern part of YARDILLA with other limestones in the

Epoch	Marine trans-gression	Group	Existing stratigraphy: Cowan Palaeovalley	Existing stratigraphy: Lefroy Palaeovalley	Proposed stratigraphy (Clarke et al., 2003): Cowan Palaeovalley	Proposed stratigraphy (Clarke et al., 2003): Lefroy Palaeovalley
Oligocene to Holocene		Redmine Group				
Late Eocene	Tuketja	Eundynie Group	Princess Royal Spongolite	Princess Royal Spongolite and Hampton Sandstone	Pallinup Formation (Princess Royal Member)	Pallinup Formation (Princess Royal Member)
Mid–Upper Eocene			Upper Werrillup Formation	Pidinga Formation	Werrillup Formation	Werrillup Formation
	Tortachilla		Norseman Formation	Pidinga Formation	Norseman Formation	No unit recognized
Middle Eocene			Lower Werrillup Formation	Pidinga Formation	North Royal Formation	North Royal Formation

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Figure 20. Stratigraphy of the Eocene Eundynie Group in the Cowan and Lefroy palaeodrainage channels on Yardilla (after Clarke, 1994). It is likely that most outcrops of Cainozoic sedimentary rocks on Yardilla belong to the Princess Royal Member (or Pallinup Formation) and the North Royal Formation

Lefroy palaeodrainage system due to the discontinuous nature of the outcrop and the absence of fossils. Painter and Groenewald (2001) reported a limestone in the upper part of the Hampton Sandstone with similarities to the Norseman Limestone and to the limestone unit on Yardilla.

The Cainozoic sedimentary sequence reflects two marine transgressions during the Middle to Late Eocene (Clarke, 1994; Clarke et al., 2003). The first transgression, the Tortichilla, resulted in the deposition of fluviodeltaic to estuarine sediments (Werrillup Formation) on the lignitic sediments of the North Royal Formation. The second transgression, the Tuketja, was more extensive, and during the high stand the spongolitic Princess Royal Formation was deposited in an estuarine environment. 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). The limestone on the northern shore of the playa lake system on Yardilla was probably deposited during a high stand, but the absence of fossils and the discontinuous nature of the outcrop make it difficult to determine the timing of deposition.

Regolith

The prolonged stability of the Yilgarn Craton, combined with marked climate change from wet, humid conditions in the Palaeogene to semi-arid conditions that have prevailed from the Neogene has resulted in deep weathering and the development of complex regolith profiles (Anand and Paine, 2002). On Yardilla much of the area is covered by thick sheetwash or eolian deposits (or both). The lack of significant relief and the dense vegetation cover on Yardilla limited the effectiveness of satellite imagery and aerial photograph interpretation during the mapping of regolith units.

Residual and relict units (*Rf*, *Rgp$_g$*, *Rmp*, *Rk*, *Rs*, *Rz*, *Rzi*, *Rzu*)

Residual lateritic profiles are best exposed in breakaways in the northern part of Yardilla, where the deeply weathered bedrock grades upward 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 only this duricrust is observed.

Ferruginous duricrust (*Rf*) is observed over a range of rock types, from Proterozoic gneisses in the Fraser Range to Archaean metasedimentary rocks and Cainozoic sedimentary rocks. Ferruginous duricrust typically comprises hematite with lesser amounts of goethite and minor siliceous lenses, and forms low ridges of massive to rubbly outcrops that are particularly common above the Cainozoic Eundynie Group on northern Yardilla.

Residual material over granite (*Rg*, *Rgp$_g$*) is predominantly clay- and quartz-sand-rich soil of granitic composition, with minor silcrete, calcrete, and poorly exposed weathered granite boulders. These deposits are common in the western part of Yardilla and over granites in the boundary zone between the Yilgarn Craton margin and the Proterozoic gneisses.

Residual deep-red unconsolidated soil overlying mafic and ultramafic Proterozoic rocks (*Rmu*) is restricted to areas overlying the Jimberlana Dyke in the southwestern corner of the map sheet.

Residual calcrete (*Rk*) is common on YARDILLA, particularly in the south and east, and forms low ridges and rubbly outcrops that are commonly surrounded by colluvium with abundant loose calcrete nodules and fragments (*Ck*).

Quartz-rich residual sand (*Rs*) is predominantly above granitic units and deeply weathered quartz-rich gneisses in the high-strain zone at the edge of the Yilgarn Craton in the central and northeastern parts of YARDILLA.

Silcrete (*Rz*) and ferruginous silcrete (*Rzi*) are most commonly formed over the Cainozoic Eundynie Group sedimentary rocks on northern and eastern parts of YARDILLA, and also over granites on western YARDILLA. The silcrete typically forms rubbly outcrops on low hills and small breakaways and is predominantly milky-white and cream to red-brown, depending on the iron content. Silcrete is also developed over ultramafic rocks (*Rzu*) of the Jimberlana Dyke on southwestern YARDILLA.

Colluvium and sheetwash (*C*, *Cf*, *Cg*, *Ck*, *Cm*, *Cq*, *Ct*, *Cts*, *W*, *Wf*, *Wg*, *Wk*, *Wq*)

On YARDILLA the distinction between colluvium and sheetwash is based on slope. 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 ferruginous granules and nodules. Iron-rich colluvium (*Cf*) and sheetwash (*Wf*) predominantly consists of fine ferruginous granules and lateritic gravel, and are most common adjacent to the Proterozoic mafic dyke on southwestern YARDILLA.

Quartzofeldspathic colluvium (*Cg*) and sheetwash (*Wg*), above and adjacent to granitic rocks on western YARDILLA, are composed predominantly of clay, quartz sand, and lithic fragments of granitic composition. Calcrete-rich colluvium (*Ck*) and sheetwash (*Wk*) deposits have significant proportions of calcrete nodules and fragments, and the colluvial deposits commonly form low ridges, particularly in the southern and eastern parts of YARDILLA. Colluvium derived from ferromagnesian rocks (*Cm*) overlies, and is adjacent to, outcrops of the Jimberlana Dyke on southwestern YARDILLA. Quartz-rich colluvium (*Cq*) and sheetwash (*Wq*) are composed of angular vein-quartz fragments and are common on the edges of the playa lakes and around large quartz veins.

Lithic-rich colluvium (*Ct*) lies on slopes immediately adjacent to outcrops and contains a high proportion of lithic clasts. This unit is common beneath the low scarps formed by the Cainozoic Eundynie Group on northern YARDILLA. Colluvium adjacent to the Woodline Formation (*Cts*) on northwestern YARDILLA forms a distinct apron around these quartz-rich outcrops.

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

Two playa-lake systems on YARDILLA form tributaries of the Lefroy Palaeochannel (Clarke, 1994), with one extending northwards from the southwestern corner and a larger system covering northeastern YARDILLA. Both systems drain to the north and include playas (L_p), undivided dunes (L_d), active dunes (L_d1), stabilized dunes (L_d2), and areas of mixed deposits (L_m). The playa lake systems are made up of chains of small lakes, separated by sand dunes, alluvial deposits, and small channels, and the 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 nonvegetated or have only minor vegetation consisting predominantly of 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 on broad plains adjacent to the playa lakes consist of closely interspersed dunes, small lakes, and alluvial deposits.

Sandplain deposits (*S*) are predominantly composed of orange quartz sand and form an undulating terrain with scattered dunes, most commonly in the northeast of YARDILLA, east of the playa lakes.

Alluvial units (*A*, A_p)

Quaternary alluvium (*A*) on YARDILLA includes ephemeral stream-channel, overbank, and deltaic deposits. Alluvium consists of clay, silt, sand, and gravel of mixed composition. Nonvegetated to semivegetated clay- and silt-filled claypans (A_p) are relatively common along the drainage systems throughout YARDILLA.

Economic geology

The only commodity produced on YARDILLA is dimension stone from the Fraser Range gneisses. Surface and near-surface exploration has been carried out for many commodities, including gold, base metals, uranium, diamonds, and lignite. Various techniques have been employed, including rotary air blast (RAB), reverse circulation (RC), and diamond drilling, geological mapping, geophysics, and rock-chip and soil sampling.

Kimberlite and lamproite mineralization

Precious mineral — diamond

On YARDILLA diamond exploration activity has concentrated on aeromagnetic and gravity anomalies within the suture zone and along the Fraser Range. Magnetic anomalies in this area were tested by RC and aircore drilling by CRA Exploration Pty Limited (1994), but did not intersect any kimberlitic rocks. Diamond exploration has also been undertaken along the southeastern margin of the Yilgarn Craton by a number of companies, including Quadrant Resources – Stockdale Limited (1999), but no kimberlitic indicator minerals were found.

Pegmatitic mineralization

Speciality metal — tantalum

Tantalite [$(Fe,Mn)(Ta,Nb)_2O_6$] is mined from pegmatites at the Bald Hill tantalum mine, east of Widgiemooltha, on the adjacent map sheet (YARDINA), but similar occurrences have not been discovered on YARDILLA. A single specimen of euxenite [$(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$] was reported from a pegmatite in the Fraser Range (Miles et al., 1945).

Orthomagmatic mafic and ultramafic mineralization — layered-mafic intrusions

Precious metal — platinum group elements

Avoca Resources Ltd are currently exploring around the Jimberlana Dyke for platinum group elements (PGE).

The PGE potential of the Fraser Complex has been discussed by Gibson (1989) based on the lithological and chronological similarities with the Bushveld Complex of Africa. In an area 100 km east of the Fraser Range Homestead, pyroxenite, gabbro and anorthosite with more than 5% Cr_2O_3 returned platinum values between 58 and 800 ppb, which Gibson (1989) recognized as similar to abundances in the Bushveld Complex. A GSWA geochemical mapping project (Morris et al., 2000) indicated that PGE values were predominantly low in the regolith, but higher values were reported in regolith with higher Cr, Ni, and MgO associated with the Jimberlana Dyke in the southwest of YARDILLA.

Base metal and steel industry metals — copper and nickel

There has been sporadic exploration activity for copper, lead, zinc, and nickel across YARDILLA. The only anomalous results reported are from within a narrow zone close to the western margin or ‘front’ of the Fraser Range. Minor disseminated copper–nickel sulfide mineralization in mafic–ultramafic rocks of the Fraser Complex, just south of YARDILLA, was recognized by Newmont Pty Ltd in the 1960s (Newmont Proprietary Limited, 1972; Tyrwhitt and Orridge, 1975).

Exploration for nickel–copper sulfides in the Proterozoic Jimberlana Dyke was carried out by a number of companies, with the most significant exploration programs by WMC Ltd and Newmont Pty Ltd in the late 1960s to early 1970s and middle–late 1980s (Newmont Proprietary Limited, 1972; WMC Limited, 1972).

Vein and hydrothermal mineralization — undivided

Precious metal — gold

Although gold deposits and prospects have been reported on adjacent sheets, including the Karonie gold mine and French Kiss prospect to the north on ERAYINIA, and anomalous gold grades have been reported from soil, rock-chip, and drillhole samples, no intersections of economic grade have been reported on YARDILLA. Regional geochemical mapping of the Fraser Range region (Morris et al., 2000) covering YARDILLA assayed typically low gold concentrations in the regolith, with the most significant anomaly of 26 ppb identified near the southern extension of the Cowarna Fault in the central part of YARDILLA.

There have been limited RAB drilling programs following up gold anomalies in soil or rock-chip samples, and testing structural targets identified by geophysical surveys, with the most extensive programs on northern YARDILLA (Kilkenny Gold NL, 1997), central YARDILLA (Aztec Mining Company Limited, 1994), and eastern YARDILLA, about 10 km northwest of Fraser Range Station (Sipa–Ashling Joint Venture, 1990). Kilkenny Gold NL explored the northern Woodline Formation for gold and base metals during the 1990s (Kilkenny Gold NL, 1997).

Stratabound sedimentary — clastic-hosted mineralization

Energy mineral — uranium

Exploration for fossil placer-type uranium or gold (or both) in the Proterozoic Woodline Formation was carried out from 1969 to 1971 by Asarco Limited (1971) based on geological mapping, rock-chip sampling, radioactivity surveys, SP logging, and RC and diamond drilling, but no significant radioactivity was reported. Core from diamond drillholes DDH1 and DDH2 are stored at GSWA’s Kalgoorlie Core Library.

Sedimentary — basin mineralization

Energy mineral — lignite

Brown coal or lignite of Eocene age is observed within deposits of the Eucla Basin and the drainage channel deposits overlying the crystalline rocks of the Albany–Fraser Orogen and the southeastern part of the Yilgarn Craton (Le Blanc Smith, 1990). Lignite typically forms a single seam up to 12 m thick within siltstone and claystone of the Lower Werrillup Formation (Cowan Palaeochannel) and the Pindinga Formation (Lefroy Palaeochannel), which have been recently grouped into the North Royal Formation (Clarke et al., 2003).

Exploration drilling by CRA Exploration Pty Ltd during the 1980s, in the southeastern part of YARDILLA and on YARDINA, delineated limited resources in small isolated basins within a wider north-striking Cainozoic palaeochannel system (CRA Exploration Proprietary Limited , 1982). An overall resource of 30 Mt of lignite and 115 Mt of low-yield material was estimated, but the resources were downgraded after RC drilling because the lignite had high ash, salt, and sulfur contents, and the seam thickness and quality were too variable.

Undivided mineralization

Construction material — dimension stone

About 4840 t of dimension stone has been quarried from metamorphic rocks of the Albany–Fraser Orogen since 1991 by Fraser Range Granite NL. Various types of dimension stone have been identified, including epidote–pyroxene–magnetite augen gneiss (known as 'Verde Austral'), microgabbro ('Gold Leaf Black'), intercalated garnet–pyroxene augen gneiss and foliated pyroxene granulite ('Fantasia'), garnetiferous gneissic granite ('Garnet Ice'), and fine-grained gabbro ('Fraser Range Black'). The 'Verde Austral' type has proven reserves in excess of 1 million m^3 (Maritana Gold NL, 1991)

Hydrogeology

Kern (1996) discussed the hydrogeology of WIDGIEMOOLTHA (1:250 000; including YARDILLA). Most of the groundwater on YARDILLA is saline to hypersaline with limited low-salinity groundwater in upland areas of granitic rocks and metamorphic rocks of the Fraser Range. Fresh water for pastoralists is almost entirely derived from surface waters, with most dams along drainages and alluvial flats, and to a lesser extent from contour dams and rock walls. Kern (1996) identified the most prospective aquifers on WIDGIEMOOLTHA (1:250 000) as the Cainozoic sandstone, carbonate, and spongolite units in the large palaeochannels. WMC Ltd drilled a single RC drillhole through the Woodline Formation during a nickel–gold exploration program between 1989 and 1991, with the aim of assessing the groundwater potential of the area (WMC Limited, 1991).

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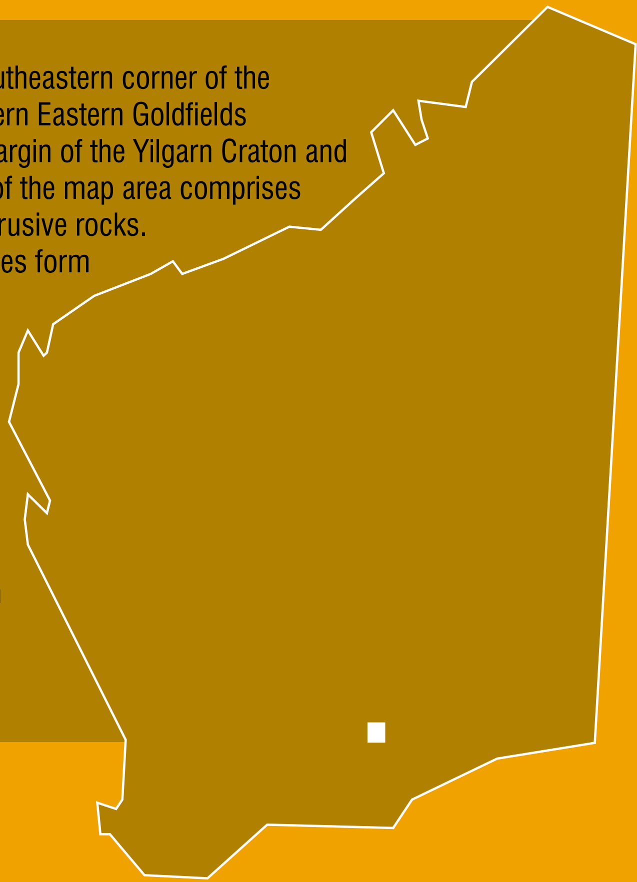
The YARDILLA 1:100 000 map sheet covers the southeastern corner of the WIDGIEMOOLTHA 1:250 000 sheet, in the southeastern Eastern Goldfields Granite–Greenstone Terrane. The area is on the margin of the Yilgarn Craton and includes part of the Albany–Fraser Orogen. Most of the map area comprises Archaean metasedimentary, metavolcanic, and intrusive rocks. Proterozoic granulite- to amphibolite-facies gneisses form the Fraser Range in the southeast corner, and the Proterozoic Woodline Formation overlies the Archaean rocks in a northeast-trending belt on northwest YARDILLA. Structural trends on YARDILLA differ markedly from the regional structural grain of the Eastern Goldfields Granite–Greenstone Terrane and reflect the effects of the Mesoproterozoic Albany–Fraser Orogen. The Yardilla area has produced dimension stone and been explored for gold, base metals, uranium, diamond, and lignite.



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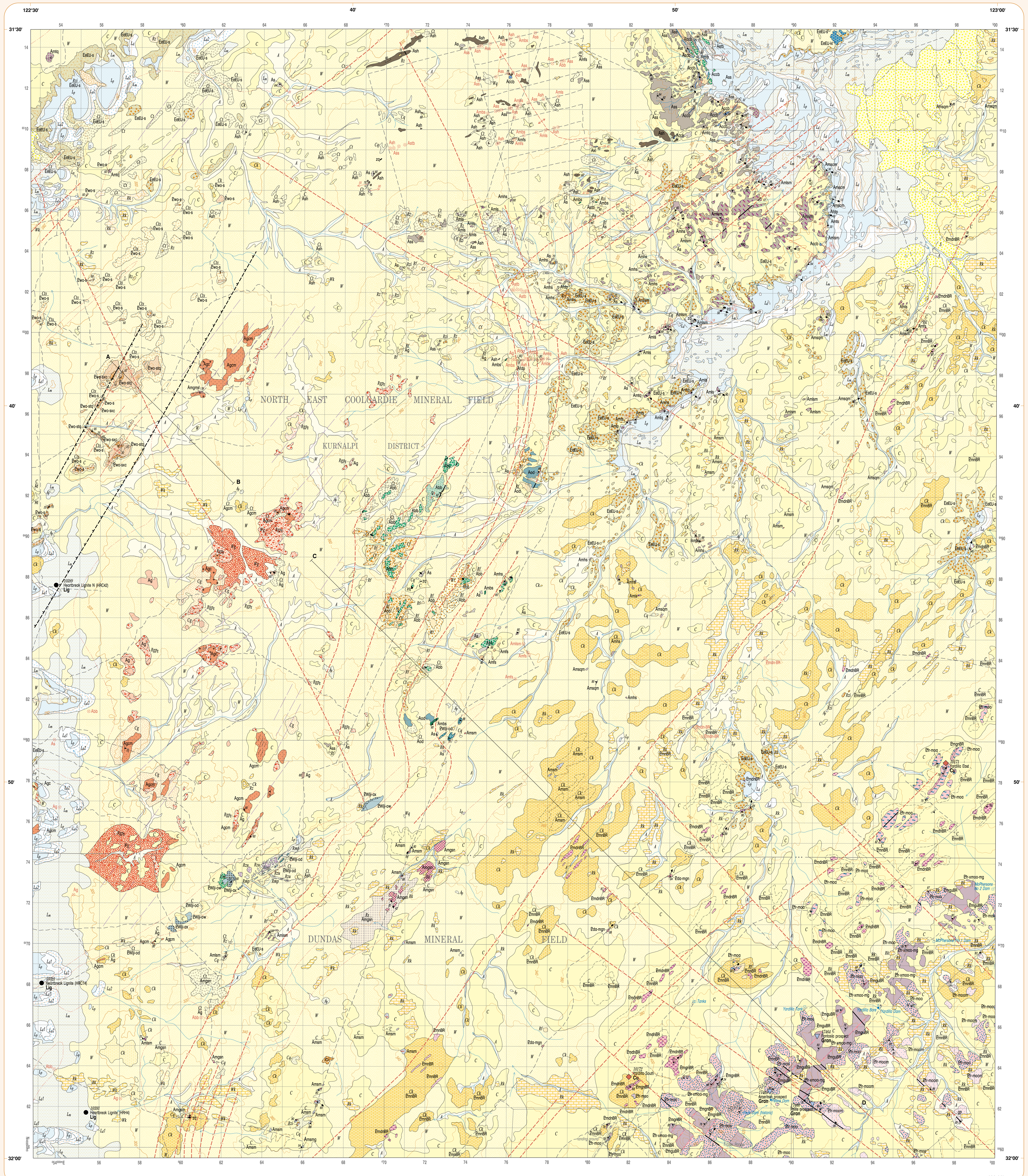
JONES

Geology of the Yardilla 1:100 000 sheet

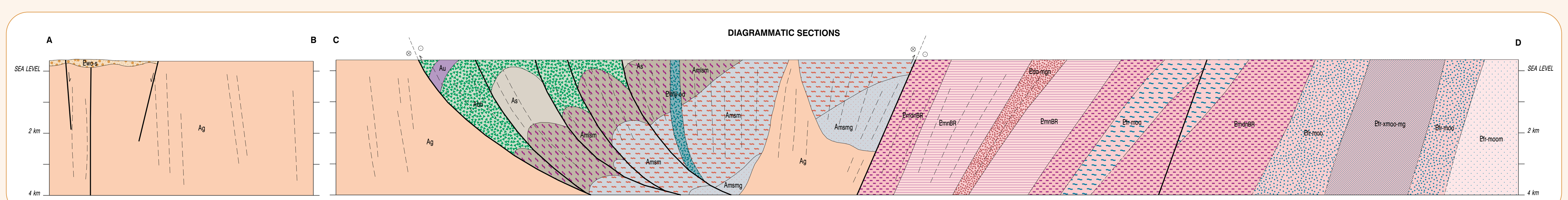
EXPLANATORY NOTES

YARDILLA

AUSTRALIA 1:100 000 GEOLOGICAL SERIES — GEOLOGICAL SURVEY OF WESTERN AUSTRALIA — SHEET 3434



DIAGRAMMATIC SECTIONS



C | Cf | Cg | Ck | Cm | Cq | Ct | Cts

W | Wf | Wg | Wk | Wq | A | Ap

Ld | Ld1 | Lp | Lm

Colluvial units
- *C* Colluvium derived from different rock types; includes gravel, sand, and silt
- *Cf* Ferruginous gravel and reworked ferruginous duricrust
- *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
- *Cm* Colluvium derived from ferromagnesion rock
- *Cq* Quartz-vein debris
- *Ct* Lithic-rich colluvium
- *Cts* Lithic-rich colluvium predominantly from the Proterozoic **WOODLINE FORMATION**

Sheetwash units
- *W* Clay, silt, and sand in extensive fans; local ferruginous gravel
- *Wf* Clay, silt, and sand with abundant ferruginous grit
- *Wg* Clay, silt, and sand commonly derived from granitic rock
- *Wk* Clay, silt, and sand with abundant partially eroded calcrete nodules
- *Wq* Clay, silt, and sand with abundant quartz-vein debris

Alluvial units
- *A* Clay, silt, sand, and gravel in channels and on floodplains
- *Ap* Clay and silt in claypans

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

Ld2 | S

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

Rf | Rgpg | Rk | Rmp | Rs | Rz | Rzi | Rzu

Residual and 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 of residual origin; includes reworked carbonate products
- *Rmp* Residual, deep red, unconsolidated soil, overlying Proterozoic mafic and ultramafic rock
- *Rs* Quartz-rich residual sand; locally with an eolian component
- *Rz* Silcrete
- *Rzi* Ferruginous silcrete
- *Rzu* Silica caprock over ultramafic rock; local chalcedony and chrysoprase

PHANEROZOIC — CAINOZOIC

PALAEOGENE — EOCENE — Eundynie Group — EUCLA BASIN

EeEU-s | EeEU-kl

- EeEU-s **Eundynie Group:** undivided; dominant sandstone; includes conglomerate, siltstone, mudstone, spongolitic or bituminous siltstone, calcareous sandstone, and bioclastic calcarenite; generally poorly indurated, locally silicified and with common ferruginous cappings
- EeEU-kl Limestone, massive to weakly bedded; locally fossiliferous with gastropod, brachiopod, and bivalve fossils

Albany–Fraser Orogeny, Stage 1 (1345–1260 Ma[1 2 3])

PROTEROZOIC — MESOPROTEROZOIC — BIRANUP COMPLEX

c. 1293 Ma[4] — ƐmnBR | ƐmgnBR | ƐmguBR

- ƐmnBR Undivided gneiss
- ƐmgnBR Granitic gneiss
- ƐmguBR Granitic augen gneiss

c. 1301 Ma[4] — Ɛfr-moa | Ɛfr-moo | Ɛfr-xmoo-mg | Ɛfr-moom

FRASER COMPLEX
- Ɛfr-moa Mafic gneiss, amphibole rich
- Ɛfr-moo Mafic granulite, orthopyroxene rich
- Ɛfr-xmoo-mg Mafic granulite, orthopyroxene rich and garnet-abundant metagranitic layers
- Ɛfr-moom Mafic granulite, orthopyroxene and magnetite rich

c. 1388 Ma[4] — ƐmdnBR Metasedimentary gneiss; quartz and garnet rich

PALAEOPROTEROZOIC

c. 1670 Ma[5] — Ɛda-mgn **DALYUP GNEISS:** granitic gneiss

>1620 Ma[6] — Ɛwo-s | Ɛwo-stq | Ɛwo-sxc

- Ɛwo-s **WOODLINE FORMATION:** undivided; quartz sandstone, quartz conglomerate, and mudstone
- Ɛwo-stq Quartz sandstone; minor conglomerate
- Ɛwo-sxc Breccia composed of angular chert clasts

Widgiemooltha Dyke Suite — ƐWIji-ax | ƐWIji-od | ƐWIji-ow

JIMBERLANA DYKE
- ƐWIji-ax Pyroxenite
- ƐWIji-od Dolerite, gabbro, gabbronorite, and norite
- ƐWIji-ow Norite

zq | g | gp

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

ARCHAEAN — YILGARN CRATON

Amscm | Amsm | Amsmg | Amsqm

- Amscm Chlorite–muscovite schist
- Amsm Muscovite schist
- Amsmg Muscovite–garnet schist
- Amsqm Quartz–muscovite(–feldspar) schist

2660–2645 Ma[8 9] — Amgms | Amgsn | Amgsm | Ag | Agc | Agcm

- Amgms Foliated biotite monzogranite, medium to coarse grained; minor granodiorite and pegmatite dykes
- Amgsn Foliated and gneissic granitic rock; moderately to strongly foliated granite with local gneissic component
- Amgsm Foliated, muscovite-rich granite
- Ag Granitic rock, undivided; includes deeply weathered rock
- Agc Quartz monzonite; commonly porphyritic
- Agcm Quartz monzonite, medium grained

Amhs | Amls | Amlsm | Amts | Amtq

As | Ash | Ass | Ast | Astb | Akl | Accb

- Amhs Psammitic and pelitic rocks: banded quartzofeldspathic to chloritic schist, with interlayered quartz–mica schist derived from felsic and mafic igneous rocks
- Amls Pelitic rocks: includes minor psammite; commonly schistose
- Amlsm Pelitic rocks: commonly schistose with coarse-grained muscovite
- Amts Psammitic rocks: banded quartzofeldspathic schist
- Amtq Medium-grained quartzite: locally metamorphosed quartz siltstone and quartz–muscovite schist
- As Sedimentary rock, undivided; includes sandstone, siltstone, shale, and chert; metamorphosed; commonly deeply weathered
- Ash Shale with subordinate chert; minor siltstone and sandstone; variably foliated; commonly silicified; metamorphosed; may include some slate and phyllite
- Ass Sandstone to siltstone; metamorphosed
- Ast Sandstone; local siltstone; metamorphosed
- Astb Sandstone derived from mafic rock; metamorphosed
- Akl Limestone; metamorphosed
- Accb Grey-white banded chert, locally iron-rich; metamorphosed

Amfs | Af | Afdp

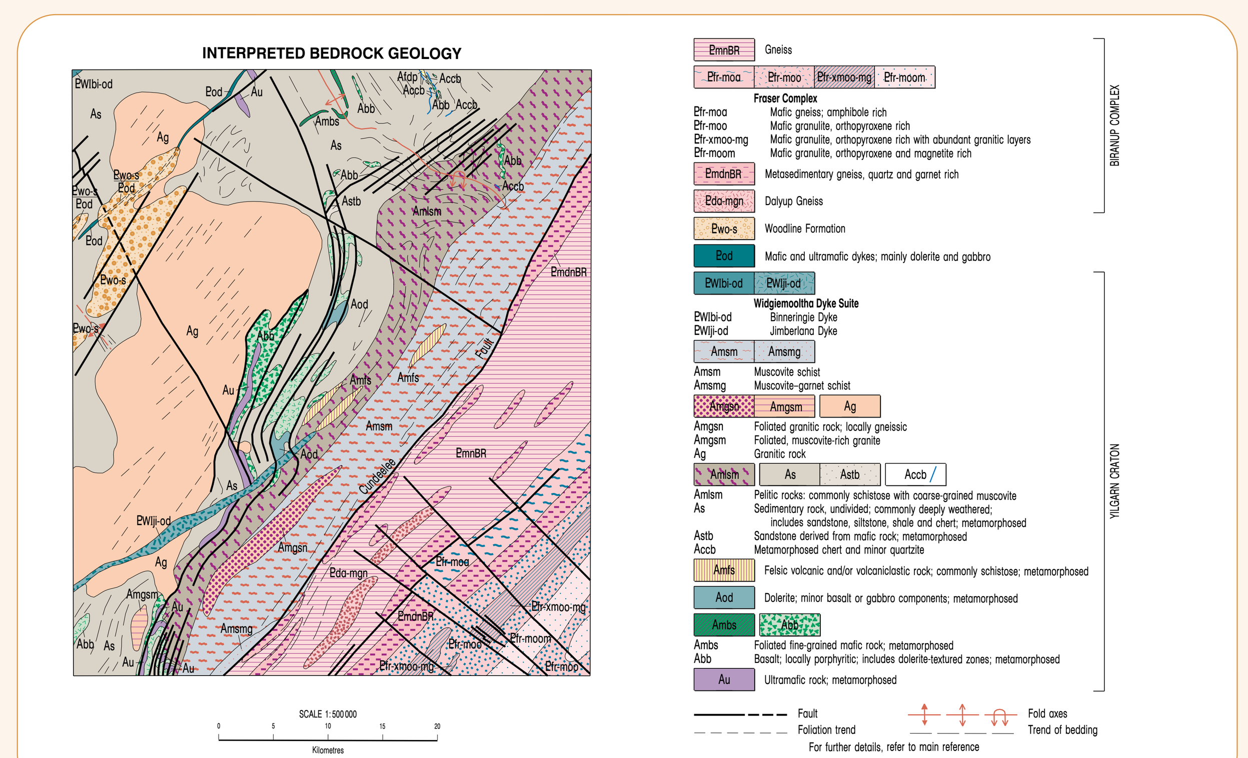
- Amfs Quartzofeldspathic micaceous schist derived from felsic volcanic or volcaniclastic protolith
- Af Felsic volcanic and volcaniclastic rocks; metamorphosed; commonly deeply weathered and kaolinized
- Afdp Feldspar–quartz porphyritic rock; dacitic to rhyolitic; volcanic or subvolcanic; metamorphosed; locally schistose

Aod Dolerite; minor basalt or gabbro components; metamorphosed

Ambs | Abb

- Ambs Foliated, fine-grained mafic rock; metamorphosed
- Abb Basalt; locally porphyritic; metamorphosed; includes dolerite-textured zones and feldspar–hornblende or chlorite schist

INTERPRETED BEDROCK GEOLOGY



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

Structural symbols are labelled according to the sequence of deformation events, where known
- local deformation events
  - D2
  - D5

Fault or shear
- exposed
- normal, tick on downthrown side
- concealed
- normal, concealed, tick on downthrown side
- concealed, interpreted from aeromagnetic data

Fold, showing axial trace
- anticline, concealed
- overturned anticline; exposed, concealed
- antiform, concealed

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

Bedding, showing strike and dip
- inclined
- vertical
- horizontal
- way-up not known, inclined

Trend of bedding or foliation

Igneous layering, showing strike and dip
- inclined

Foliation, showing strike and dip
- inclined
- vertical

Gneissic banding, showing strike and dip
- inclined

Cleavage, showing strike and dip
- inclined
- vertical

Crenulation cleavage, showing strike and dip
- inclined
- vertical

Mineral lineation, showing trend and plunge
- inclined

Joint or fracture, showing strike and dip
- inclined
- vertical

Airphoto lineament

Aeromagnetic lineament

Track
Fence, generally with track
Locality — Fraser Range
Building
Yard — Yard
Microwave repeater station
Breakaway
Sand dune
Contour line, height in metres — 380
Contour, depression

Watercourse
Bore — Bore
Windpump
Dam, tank — Dam, Tank

Mineral field boundary
Subsurafce data from drillhole, costean, or shallow trench — Ash

MINERAL OCCURRENCES

MINERALIZATION STYLES
- Vein and hydrothermal
- Undivided
- Basin hosted

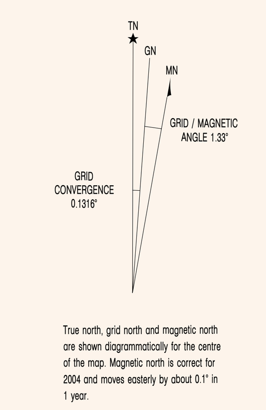
MINERAL AND ROCK COMMODITY GROUPS
- Energy
- Base Metal
- Construction Material

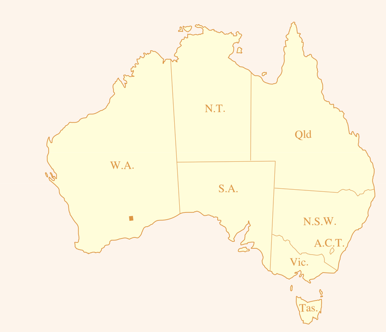
MINERAL AND ROCK COMMODITIES
- Lignite — **Lig**
- Copper — **Cu**
- Granite; Granitoid — **Gran**

OPERATING STATUS AND SITE IDENTIFICATION NUMBER

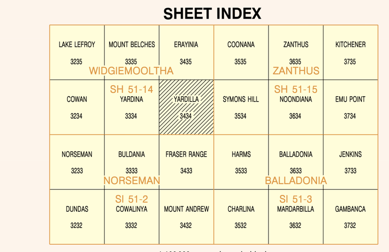
Mineral occurrence or prospect — e.g. *17466*

Mineral occurrences and numbers are from the GSWA WAMIN database.





SHEET INDEX



1:100 000 maps shown in black
1:250 000 maps shown in brown

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DATA DIRECTORY

Theme	Data Source	Data Currency	Agency
Geology	GSWA	2002	Dept of Industry and Resources
Structural data	WAROX	APR 2004	Dept of Industry and Resources
Mineral occurrences (non-confidential)	MINDEX	APR 2004	Dept of Industry and Resources
	WAMIN	APR 2004	Dept of Industry and Resources
Cadastre	TENGRAPH	2004	Dept of Industry and Resources
Horizontal control	GESMAR	2004	Dept of Land Information
Topographic nomenclature	GEONOMA	2004	Dept of Land Information
Topography	DLI and GSWA field survey	2002	Dept of Land Information

Department of Industry and Resources
ALAN CARPENTER, M.L.A. — MINISTER FOR STATE DEVELOPMENT
JIM LIMERICK — DIRECTOR GENERAL

Geological Survey of Western Australia
TIM GRIFFIN — DIRECTOR

SCALE 1:100 000

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

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

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

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

Geology by S. A. Jones and A. A. Ross 2002

Geochronology by:

(1) D. J. Clark et al., 2000, Precambrian Research, v. 102, p. 155–183.
(2) I. R. Fletcher et al., 1991, Chemical Geology, v. 87, p. 187–216.
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(4) D. J. Clark et al., 1999, Australian Journal of Earth Sciences, v. 46, p. 923-932.
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(6) A. Turek, 1966, Australian National University, PhD thesis (unpublished).
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(8) K. F. Cassidy and D. C. Champion, 2001, MERIWA Project No. M281/AMIRA Project P482, p. 3.1–3.52, (unpublished)

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