Effects of the Mesoproterozoic Albany–Fraser Orogeny on the southeastern margin of the Yilgarn Craton

by S. A. Jones

Abstract

The YARDILLA 1:100 000 map sheet, in the southeastern Eastern Goldfields, includes parts of the Archaean Yilgarn Craton and the Proterozoic Albany–Fraser Orogen. Five deformation events were recognized in the Archaean rocks: D_1 recumbent folding; tight upright folding due to east-northeast–west-southwest compression during the D_2 event; regional scale D_3–D_4 faulting; and D_5 Albany–Fraser Orogeny-related deformation. The last event is subdivided into D_{5a} open, northeast-plunging folds and warps; D_{5b} clockwise rotation of D_1 to D_{5a} structures; development of a steep cleavage parallel to the boundary between the Yilgarn Craton and Albany–Fraser Orogen during D_{5c} with an increase in metamorphic grade towards the boundary; and late crosscutting D_{5d} brittle structures. Three deformation events (D_{F1}–D_{F3}) identified in the Proterozoic gneisses of the Fraser Range comprise: D_{F1} gneissic banding associated with a shallowly plunging lineation and dextral shear sense indicators; steep, northeast-striking D_{F2} shear bands with steep lineations; and late, subvertical, northwest-striking D_{F3} faults.

Clockwise rotation of Archaean rocks adjacent to the Yilgarn Craton – Albany–Fraser Orogen boundary and dextral shear sense indicators in gneisses of the Fraser Range are consistent with dextral transpression during a Mesoproterozoic collision event. The craton–orogen boundary represents a Mesoproterozoic suture zone. Intracrustal reactivation during renewed northwest–southeast compression is suggested by the steep D_{F2} shear bands and crosscutting, northwest-striking D_{F3} faults in the Fraser Range, and by late D_{5d} faults in the adjacent Archaean rocks.

KEYWORDS: deformation, transpression, Albany–Fraser Orogeny, Yilgarn Craton.

Introduction

The YARDILLA * 1:100 000 sheet (Jones and Ross, in prep.) is located at the southeastern margin of the Yilgarn Craton and covers parts of the Archaean Eastern Goldfields Granite–Greenstone Terrane and the Proterozoic Albany–Fraser Orogen (Fig. 1). YARDILLA is dominated by Archaean metasedimentary, metavolcanic, and intrusive rocks. Proterozoic amphibolite- to granulite-facies gneisses form the Fraser Range in the southeastern corner of the map sheet, with quartz conglomerates and quartz sandstones of the Proterozoic Woodline Formation overlying Archaean rocks in the northwest (Jones, in prep. a).

Structural trends differ markedly from the regional Archaean structural grain of the Eastern Goldfields, and reveal a complex tectonic history related to overprinting during the Mesoproterozoic Albany–Fraser Orogeny (Fig. 2). 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 mafic to felsic gneisses and granites (Myers, 1990, 1995). Myers et al. (1996) identified the boundary between the Yilgarn Craton and Albany–Fraser Orogen as a suture zone based on the intense deformation and marked differences in age and metamorphic grades of the Proterozoic and Archaean rocks. This suture represents the part of the Mesoproterozoic assembly of Rodinia that involved the collision of the Yilgarn Craton with the South Australian Craton (Myers et al., 1996).

This paper describes structures recognized in Archaean rocks and Proterozoic rocks of the Fraser Range and Woodline Formation, and discusses their relationships and the implications for the nature of the boundary between the Yilgarn Craton and the Albany–Fraser Orogen.

* Capitalized names refer to standard 1:100 000 map sheets

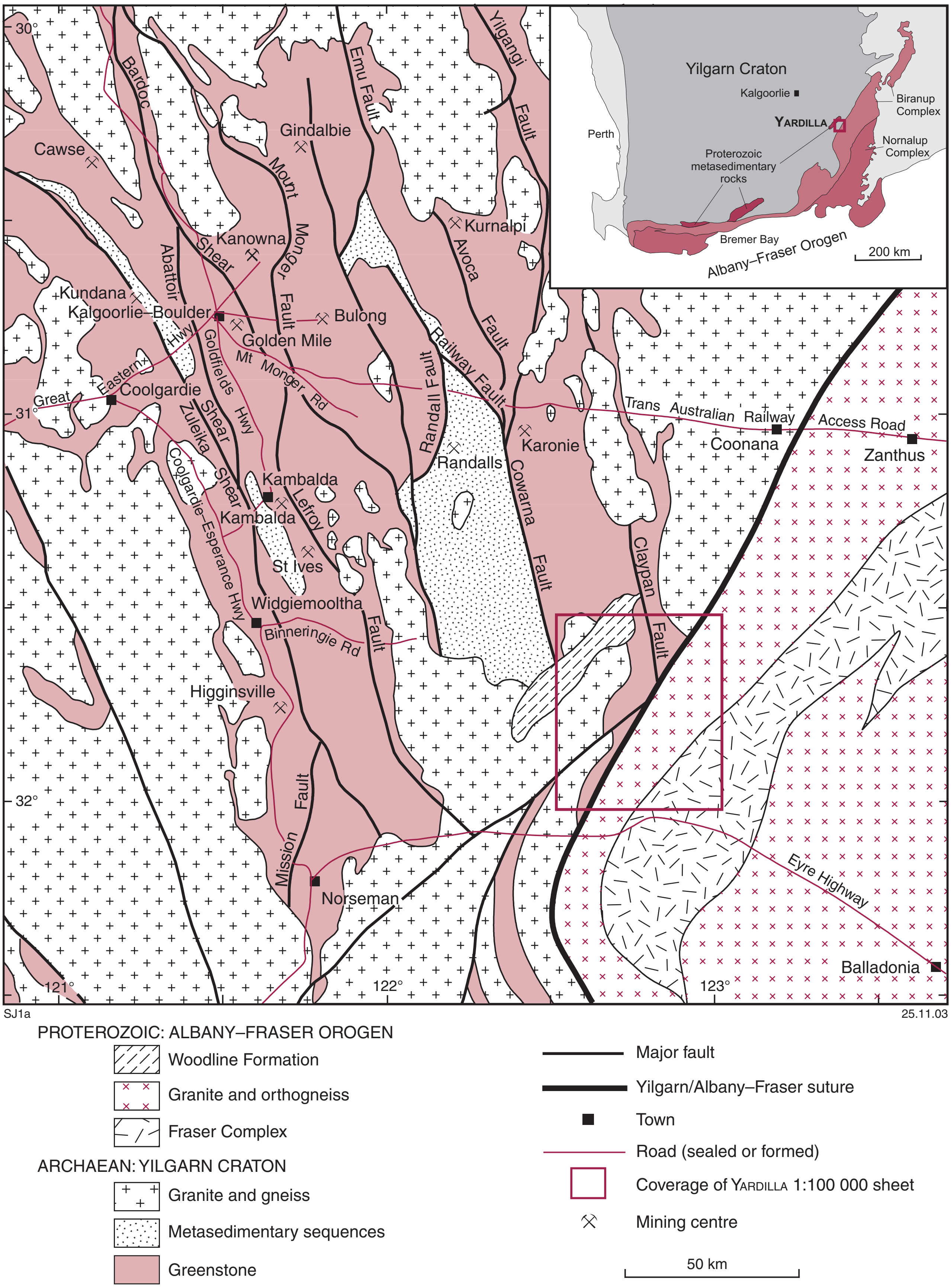

Figure 1. Location map of YARDILLA *and regional geology of the southeastern Eastern Goldfields Granite–Greenstone Terrane*

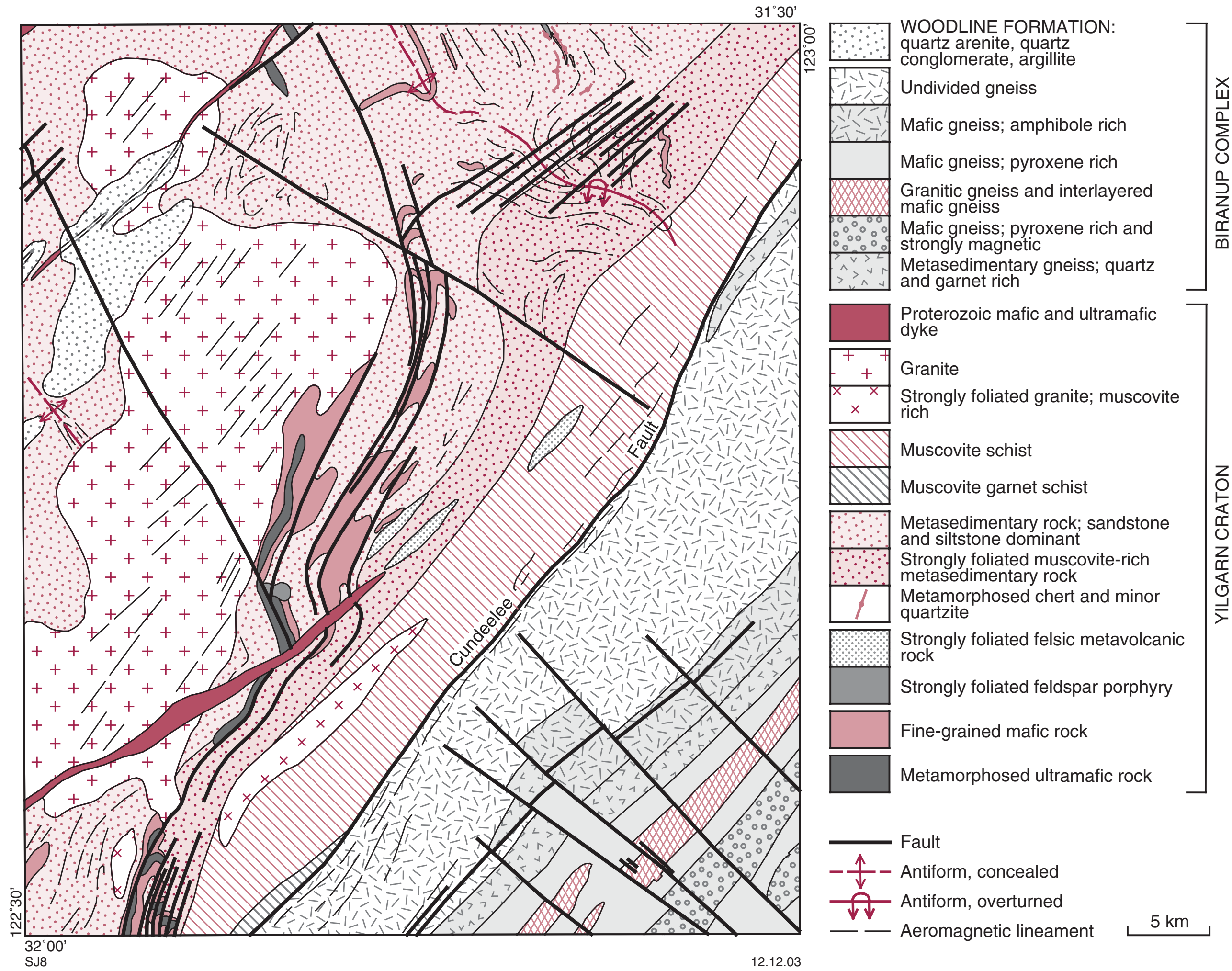

Figure 2. Interpreted geology of YARDILLA

Deformation in Archaean rocks

In northeastern YARDILLA, outcrops along the western edge of a small lake system reveal five deformation events (D_1 to D_5) in the Archaean rocks (Fig. 3): recumbent folding (D_1); upright open to tight folding (D_2); regional scale faults (D_3–D_4, observed only on aeromagnetic images); and Albany–Fraser Orogeny-related deformation (D_5).

The D_1 event is identified on YARDILLA by the development of a fine penetrative foliation (S_1), commonly parallel to bedding, and rare tight to isoclinal recumbent F_1 folds (Fig. 4a). A subhorizontal stretching lineation is commonly developed on the S_1 surface parallel to F_1 fold hinges, and is defined by recrystallized quartz and rodded quartz veins.

Deformation during the D_2 event resulted in open to tight upright folds and variable development of a penetrative foliation (S_2) during east–west compression (Fig. 4b). The S_2 fabric forms a well-developed crenulation cleavage, defined by aligned mica in hinge zones, and is best developed in fine-grained pelitic units (Fig. 4c,d). The F_2 structures refold earlier D_1 structures (Fig. 4e), and Ramsay (1967) type-1 and type-2 fold interference patterns are locally observed.

Regional scale north-northwesterly striking brittle structures (D_3 and D_4) were not observed in the field, but are visible on aeromagnetic images (Jones, in prep. a). A large north-northwesterly trending structure in the western part of YARDILLA may represent a D_3 fault, as it is truncated by the Albany–Fraser deformation front, and is most likely the southern extension of the Cowarna Fault (Fig. 1).

The D_5 event, attributed to the Albany–Fraser Orogeny, is subdivided into D_{5a}, D_{5b}, D_{5c}, and D_{5d}. D_{5a} is characterized by shallow to moderately northeasterly plunging open folds formed by southeast–northwest compression.

The D_{5b} event produced clockwise rotation of D_1 to D_{5a} structures in the Archaean rocks adjacent to the boundary between the Yilgarn Craton

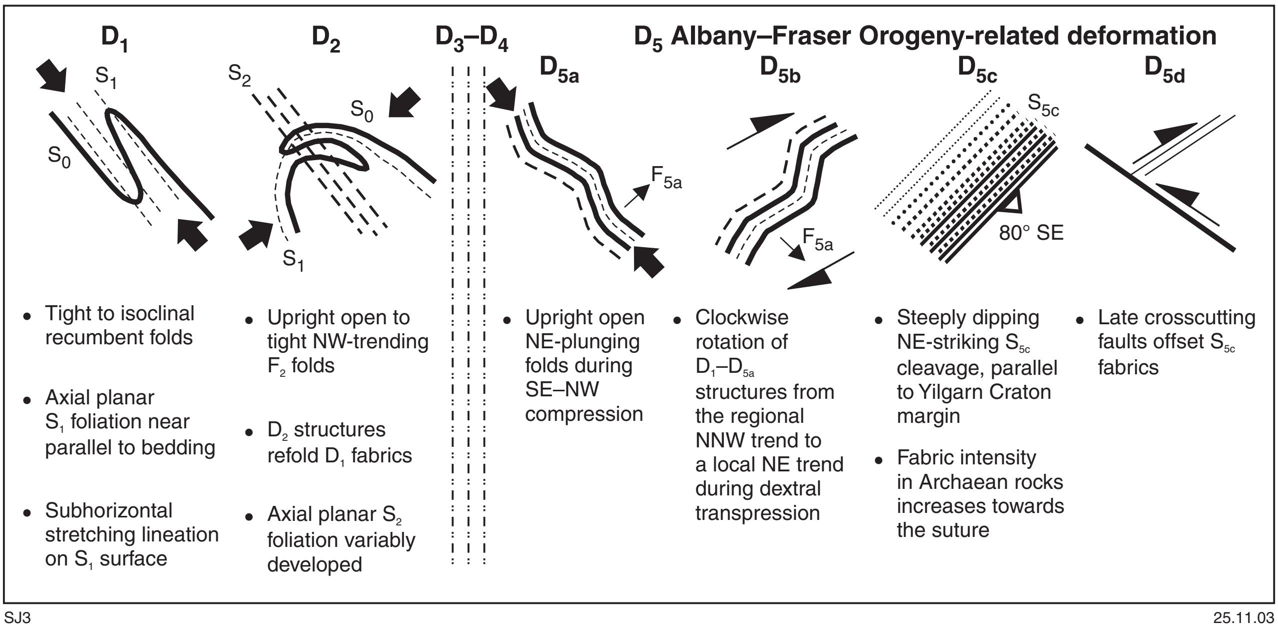

Figure 3. Deformation sequence in the Archaean rocks on YARDILLA

and Albany–Fraser Orogen. The stereoplots (Fig. 5) illustrate the change from the regional north-northwesterly structural grain in northern YARDILLA and ERAYINIA in the north, to the dominantly northeasterly, boundary-parallel trend. The foliation data also show a much greater spread in the area close to the boundary, reflecting increased F_{5a} folding in this zone.

Continued northwest–southeast directed compression during D_{5c} resulted in the development of a strong northeasterly striking, steeply dipping foliation (S_{5c}) in the highly strained Archaean rocks adjacent to the boundary. The foliation is first seen as a spaced cleavage that grades into highly schistose rocks towards the boundary, where the rocks typically become strongly recrystallized and the cleavage is defined predominantly by aligned mica and quartz ribbons. Earlier D_1 and D_2 fabrics are typically destroyed or obscured by the late S_{5c} foliation. The increasing fabric intensity is also accompanied by an increase in metamorphic grade with garnet present in metapelites close to the craton margin.

Late offset of the rotated boundary-parallel fabrics along a large west-northwesterly striking brittle structure and possible antithetic northeasterly trending structures characterize the D_{5d} event in northeastern YARDILLA (Fig. 2).

Deformation in Proterozoic rocks

Woodline Formation

Scattered outcrops of the Proterozoic Woodline Formation unconformably overlie Archaean rocks in northwestern YARDILLA and ERAYINIA (Jones, in prep. b), and consist of quartz sandstone, quartz conglomerate, and mudstone. The Woodline Formation is weakly deformed, with gentle upright folding and warping, and a weakly to moderately developed subvertical cleavage in places (Hall and Jones, in prep.). Beds predominantly have shallow dips and are well preserved, with clear younging indicators showing that beds are not overturned. Small-scale thrusts are present, but show only minimal movement with little effect on the stratigraphy. Southeast–northwest compression is suggested by generally northeasterly trending fold axes, consistent with Albany–Fraser Orogeny-related deformation (D_5) in the underlying Archaean rocks.

The Woodline Formation was thought by Myers (1995) to represent an allochthonous sequence thrust onto the Yilgarn Craton. However, the lack of strong deformation, the unconformable basal contact, and a Rb–Sr age of 1620 ± 100 Ma (Turek, 1966) suggest that deposition of these sedimentary rocks pre-dated the 1300–1100 Ma Albany–Fraser Orogeny (Nelson et al., 1995; Clark et al., 2000). Trough cross-beds and ripples in Woodline Formation rocks on ERAYINIA to the north indicate a predominantly northwest to southeast flow direction (Hall and Jones, in prep.). These sedimentary rocks could be similar in age to the Mount Barren Group in the southern part of the Albany–Fraser Orogen, recently dated at 1696 ± 7 Ma (Dawson et al., 2002), and suggest a prolonged history of tectonic activity along this margin.

Fraser Range

The Fraser Range in the southeastern corner of YARDILLA is composed of high-grade quartzofeldspathic gneisses and layered mafic intrusions of the Fraser Complex, which Myers (1990)

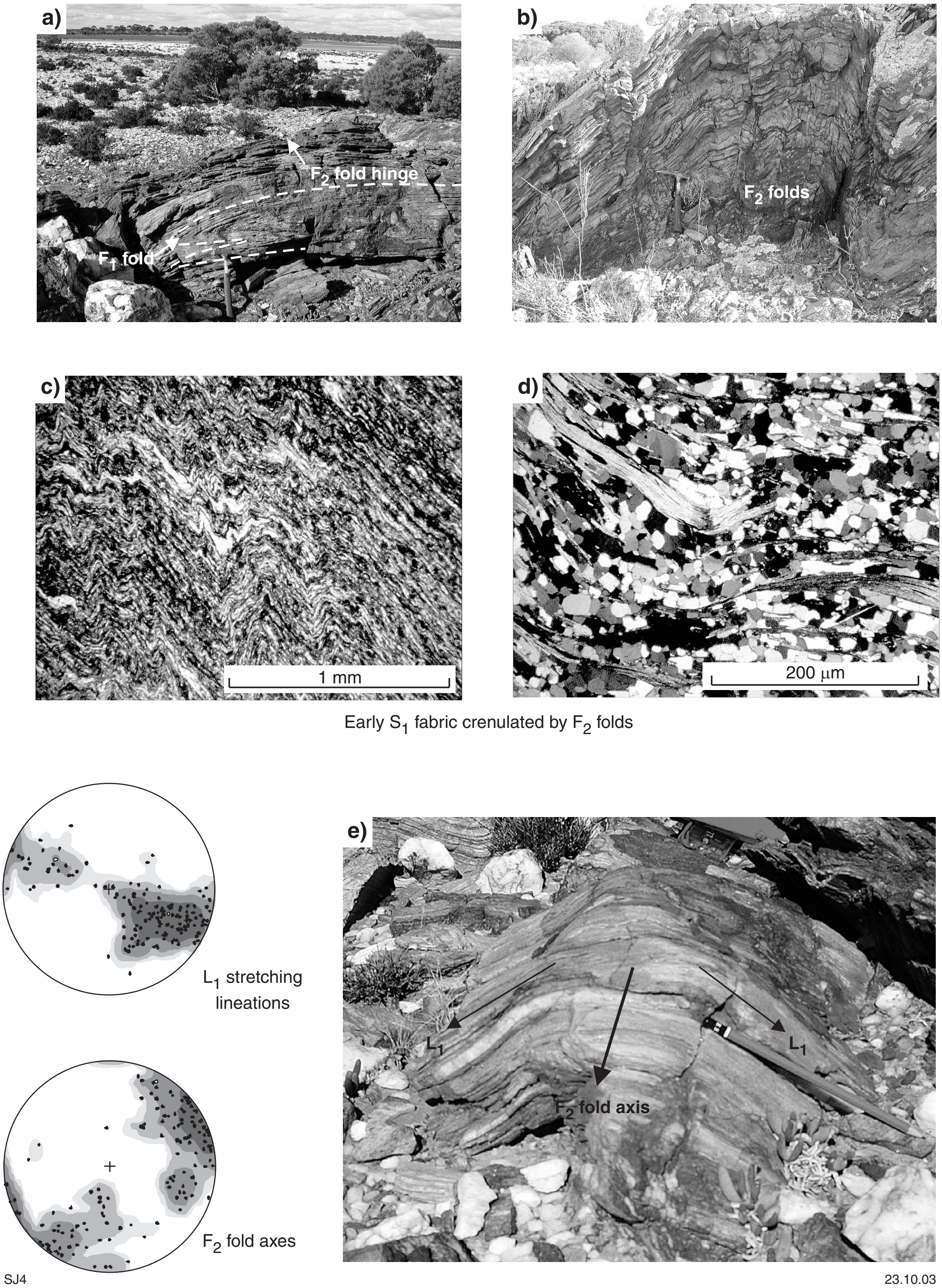

Figure 4. a) Isoclinal recumbent F_1 fold hinge, northeastern YARDILLA*; b) upright F_2 folds, northeastern* YARDILLA*; c) S_1 foliation crenulated by F_2 folding in metasiltstone, northeastern* YARDILLA*; d) early S_1 fabric defined by aligned micas refolded by F_2 folds; e) stereoplots and photograph illustrating the L_1 stretching lineation being refolded by upright F_2 folds*

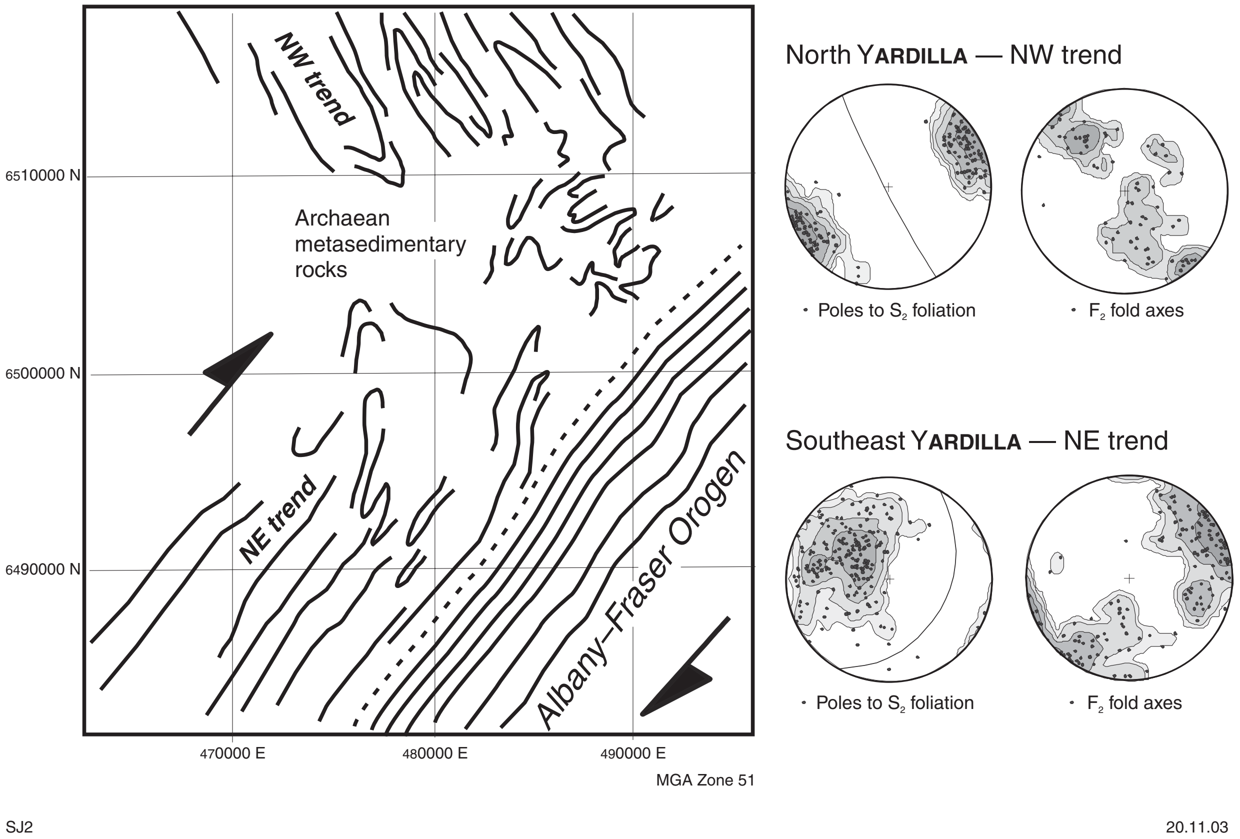

Figure 5. Map and stereoplots demonstrating the marked change from the regional north-northwesterly structural trend in northern YARDILLA *to the local northeast trend in the area adjacent to the suture zone. The foliation data and fold axes show a much greater spread in the lower stereoplots as a result of D_{5a} folding*

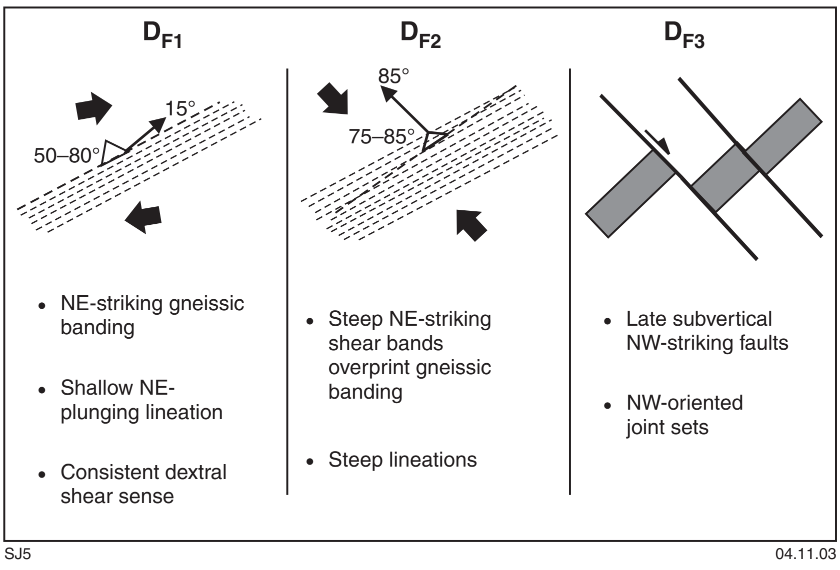

Figure 6. Deformation sequence in the Proterozoic gneisses of the Fraser Range

included in the Biranup Complex in the northwestern part of the eastern Albany–Fraser Orogen.

Three deformation events (D_{F1} to D_{F3}) were recognized in the gneisses of the Fraser Range (Fig. 6). D_{F1} is characterized by well-developed, northeast-striking, steeply dipping gneissic banding formed during northwest–southeast shortening (Fig. 7a). A weakly developed, gently to moderately northeast plunging lineation (L_{F1}) is associated with this fabric (Fig. 7d), and is defined by aligned feldspar augen in granitic augen gneiss. In places, asymmetric tails on augen (Figs 7b,c) provide good dextral shear sense indicators, suggesting a component of dextral shear during D_{F1}.

Subvertical to steeply northwest dipping, northeast-striking D_{F2} shear bands with steeply plunging lineations overprint the gneissic banding (Fig. 7e). Both reverse and normal shear sense have been recorded on these structures and further work is necessary to establish the dominant sense of shear. This event most likely marks a slight rotation in the stress axes, and may represent a reactivation of the pre-existing planar fabric during continued compression.

The youngest structures recognized in the Fraser Range are subvertical, planar, northwest-striking D_{F3} faults. Displacement on these structures ranges from centimetres to several hundred metres, and many structures are associated with abundant fault-parallel fracture sets.

Discussion

On YARDILLA, the marked change from the regional north-northwesterly trend to a local boundary-parallel trend in the area adjacent to the boundary between the Yilgarn Craton and Albany–Fraser Orogen is interpreted as the effect of continent–continent collision during the Mesoproterozoic Albany–Fraser Orogeny. The clockwise rotation of the Archaean rocks suggests a large component of dextral shear during the collision, and this is consistent with dextral shear sense indicators in the gneisses of the Fraser Range. The suture-parallel S_{5c} fabric in the Archaean rocks is near parallel to the D_{F1} gneissic banding in the Fraser Range and may be related to the same event. Renewed northwest–southeast compression and reactivation is suggested by the D_{F2} and D_{F3} overprinting structures in the Fraser Range and the crosscutting D_{5d} brittle structures in the Archaean rocks in northeastern YARDILLA.

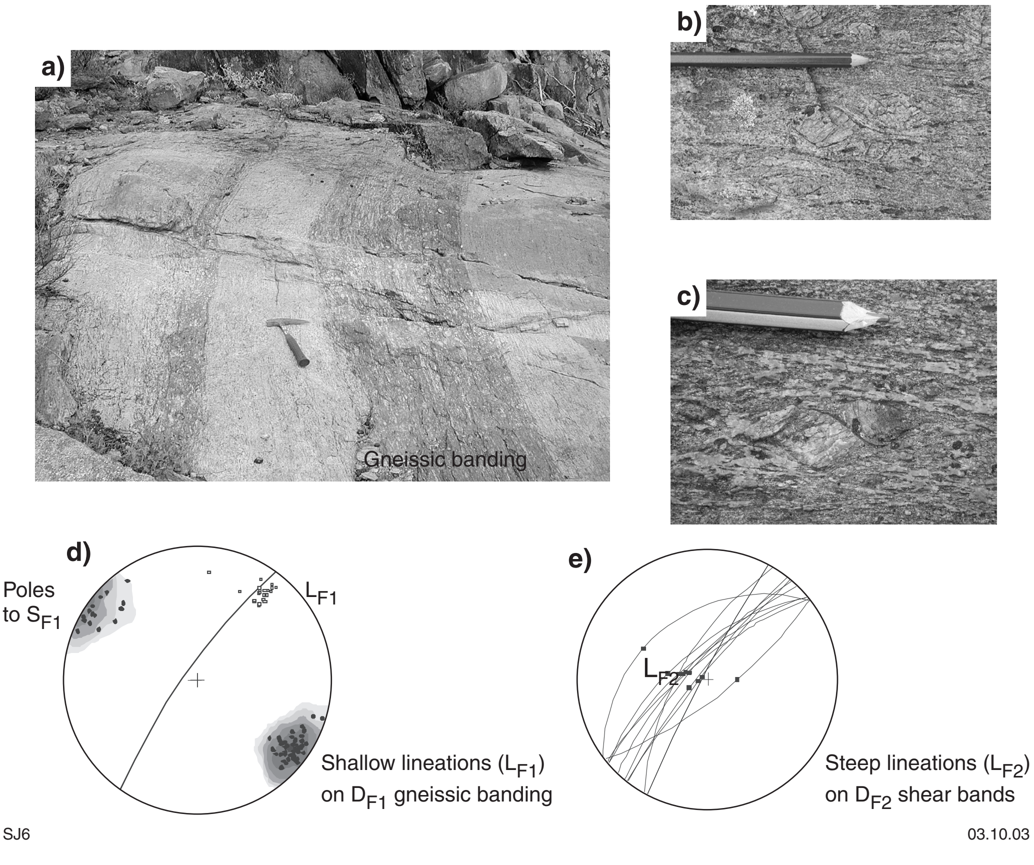

Figure 7. a) Gneissic banding in granitic augen gneiss, Fraser Range; b) and c) asymmetric augen indicating a dextral sense of shear; d) stereoplot illustrating the northeast-trending D_{F1} fabrics in the Fraser Range; e) stereoplot illustrating the northeast-trending D_{F2} fabrics with steep lineations

Table 1. Summary table of 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 (1995); 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–SE 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) $D_1 \approx M_1 \approx 1190 \pm 8$ 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 km-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 Pt) Dextral shearing, NNW–SSE shortening	Upright F_{1c} open NE-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, NS 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 $\approx 1182 \pm 12$ Ma (Black et al., 1992)	?	NW-striking subvertical brittle–ductile shears, D_{F3} (this study)
D_4	S_4 joints and extension fractures, conjugate NS and WNW NW–SE shortening	None reported	Extension fractures oriented at 316°	None reported	None reported	None observed

NOTE: The eastern part of the Albany–Fraser Orogen is the area east of Bremer Bay

The deformation sequence observed in the Fraser Range has many similarities to the deformation history recognized elsewhere in the Albany–Fraser Orogen (Table 1). Two thermotectonic stages between 1345 and 1260 Ma (Stage I) and 1214 and 1140 Ma (Stage II) have been proposed for the eastern part of the Albany–Fraser Orogen (east of Bremer Bay), based on structure, petrology, and geochronology (Clark et al., 2000). These authors suggest that an initial continent–continent collision at c. 1300 Ma was followed by intracratonic reactivation at c. 1200 Ma. However, a recent paper by Dawson et al. (2003) suggests that peak thermal metamorphism was at 1205 ± 10 Ma, post-dating peak dynamic metamorphism at c. 1260 Ma (Clark et al., 2000; Nelson, 1995) by at least 45 million years. Dawson et al. (2003) relate the peak thermal metamorphism to regional heating associated with the emplacement of 1215–1202 Ma dyke swarms and 1200–1180 Ma granites into the orogen and the adjacent Yilgarn Craton. They suggest three tectonic settings for the Albany–Fraser Orogen: 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.

Although regional Albany–Fraser Orogen D_1 structures (Table 1; Clark et al., 2000; Duebendorfer, 2002 and references therein) have not been recognized on YARDILLA, regional Albany–Fraser Orogen D_2 structures can be correlated with D_{F1} fabrics in the Fraser Range. The D_2 event is characterized by dextral transpression and is thought to represent the last phase of Stage I deformation (Clark et al., 2000).

In the Fraser Range, the steep, northeast-striking shear bands with steep lineations (D_{F3} structures) are similar to structures documented by Myers (1995) and Clark et al. (2000) as an early phase of Stage II deformation that involved renewed northwest–southeast shortening and reactivation. Reactivation is also suggested by the late, northwest-oriented D_{F3} faults in the Fraser Range and the D_{5d} brittle structures in the adjacent Archaean rocks. These structures may be related to the regional D_3 event recognized in western parts of the orogen (Duebendorfer, 2002). Regional D_4 extension fractures in the western parts of the orogen (Table 1) were not observed on YARDILLA.

Conclusion

Five deformation events (D_1–D_5) were recognized in Archaean rocks, with D_5 structures representing the local effect of collision along the Yilgarn Craton margin during the Albany–Fraser Orogeny. Initial folding and warping of Archaean rocks during D_{5a} was followed by clockwise rotation of D_1–D_{5a} structures from a regional north-northwesterly trend to a local boundary-parallel northeasterly trend, then by development of a boundary-parallel foliation (S_{5c}) associated with an increase in metamorphic grade, and subsequently by late, conjugate D_{5d} brittle faulting.

The three deformation events (D_{F1}–D_{F3}) observed in the Proterozoic gneiss of the Fraser Range are: well-developed D_{F1} gneissic banding associated with a shallow-plunging lineation and dextral shear sense indicators; steep, northeast-striking D_{F2} shear bands with steep lineations; and late, subvertical, northwest-striking D_{F3} faults.

The clockwise rotation of Archaean rocks adjacent to the boundary and D_{F1} dextral shear sense indicators in Fraser Range gneisses are consistent with dextral transpression during the regional Albany–Fraser Orogen D_2 event (last phase of the Stage I event of Clark et al., 2000). The near-parallel S_{5c} fabric in Archaean rocks and the D_{F1} gneissic banding in the Fraser Range may be related to the same event. The increasing metamorphic grade of Archaean rocks towards the boundary could represent uplift associated with the collision, with exposure of deeper crustal levels adjacent to the suture zone, or the thermal effects of deformation during the Albany–Fraser Orogen.

On YARDILLA, deformation associated with renewed northwest–southeast shortening and intracrustal reactivation (Stage II of Clark et al., 2000; Dawson et al., 2003), may be represented by the steep northeast-striking D_{F2} shear bands and subvertical northwest-striking D_{F3} faults in the Fraser Range, and by the late D_{5d} brittle structures in Archaean rocks.

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