Stratigraphic and tectonic significance of eight local unconformities in the Fortescue Group, Pear Creek Centrocline, Pilbara Craton, Western Australia

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Abstract

Detailed geological mapping shows that the late Archaean Fortescue Group in the Pear Creek Centrocline of the Marble Bar Sub-basin, Hamersley Basin, consists of four distinct, unconformity-bound formations. From base to top these are the Mount Roe Basalt, Hardey Formation, Kylena Formation, and the newly defined Pear Creek Formation, which consists of five unnamed units equivalent to member rank. Each formation, as well as the units of the Pear Creek Formation, is separated by disconformable to unconformable contacts with underlying units, brought about by periods of tilting and faulting with or without folding.

The eight sets of structures recognized can be ascribed to three styles of deformation. Local tight folds of sets 1 and 2 resulted from two episodes of approximately easterly trending shortening across the centrocline before deposition of the Kylena Formation. Set 3 structures include approximately west-southwesterly trending extensional faults that affect the Kylena Formation. A series of northeast-trending, northwest-side-down normal faults of structure sets 4 to 7 step to the southeast. These were probably active throughout deposition of the lower four units of the Pear Creek Formation, and include the long-lived Pear Creek Fault. They controlled deposition within, and modified the geometry of, the Pear Creek Centrocline. Structure set 8 resulted in a subordinate, separate centrocline south of the Pear Creek Fault, outlined by the stratigraphically highest unit 5 of the Pear Creek Formation. The deformation documented in the Pear Creek Centrocline is interpreted as due to reactivation of adjacent granitoid domes.

KEYWORDS: Archaean, Fortescue Group, Marble Bar Sub-basin, stratigraphy, structural geology.

Introduction

The 2.77 – 2.63 Ga Fortescue Group of the Hamersley Basin represents a flood basalt province that erupted onto older basement rocks of the Pilbara Craton, after cratonization at c. 2.85 Ga (Blake, 1993, 2001; Thorne and Trendall, 2001; Van Kranendonk et al., 2002). Most of the Fortescue Group is preserved above a shallow-dipping, regionally extensive unconformity along the southern margin of the main outcrop of granitoid rocks and greenstones in the northern part of the Pilbara Craton (Van Kranendonk et al., 2002). However, outliers of the group are preserved in centroclines (equidimensional basins) between domical granitoid complexes in the basement, and show the same general structural style as flanking basement greenstones, with basal formations of the group recording bedding dips of up to 75° (e.g. Hickman and Lipple, 1978; Hickman, 1984; Van Kranendonk, 2000).

This paper presents the results of detailed mapping of the Fortescue Group in the northern part of the Marble Bar Sub-basin of the Hamersley Basin (Fig. 1; Thorne and Trendall, 2001). The data show that the stratigraphy of the Marble Bar Sub-basin should be revised, and that deposition of the Fortescue Group in this area occurred during ongoing local deformation related to the continued rise of adjacent basement granitoid domes.

Regional geology

The Archaean Pilbara Craton is composed of a metamorphosed basement of granitoid rocks and greenstones that evolved from before 3515 to 2830 Ma (Van Kranendonk et al., 2002), and an overlying cover succession known as the Mount Bruce Supergroup that was deposited in the Hamersley Basin from c. 2770 to 2400 Ma (Trendall, 1990). The cover succession is divided from base to top into the Fortescue Group, Hamersley Group, and Turee Creek Group (Thorne and Trendall, 2001), but only the Fortescue Group is discussed here.

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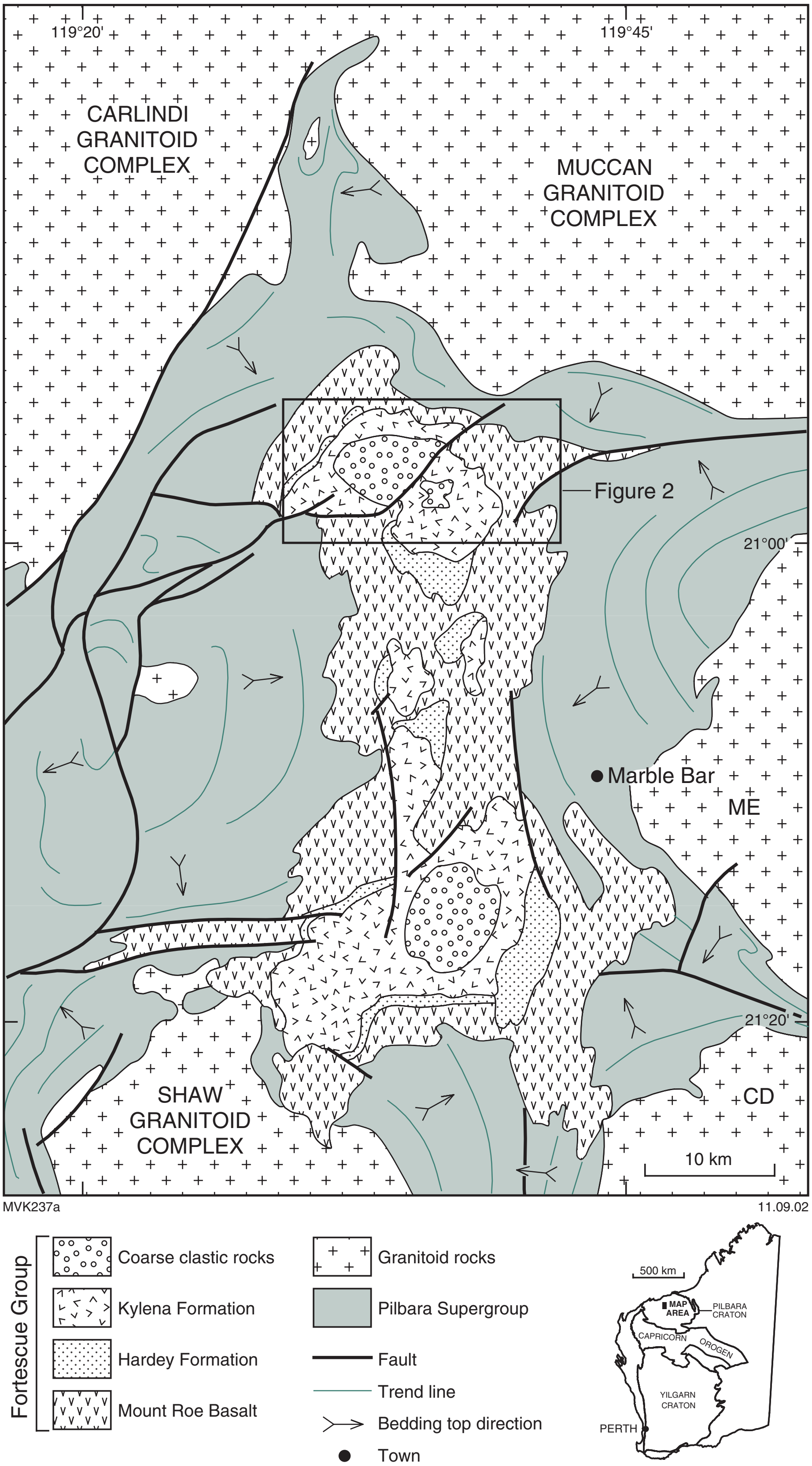


Figure 1. Simplified geological sketch map of the Marble Bar Sub-basin of the Fortescue Group, Hamersley Basin, showing its location between surrounding dome-shaped basement granitoid complexes. Box indicates Pear Creek Centrocline. CD = Corunna Downs Granitoid Complex; ME = Mount Edgar Granitoid Complex (after Hickman and Lipple, 1978; and Hickman and Gibson, 1981)

The basement underlying and surrounding the Marble Bar Sub-basin of the Hamersley Basin is part of the East Pilbara Granite–Greenstone Terrane (Van Kranendonk et al., 2002). This terrane is characterized by a large-scale (60–120 km) dome-and-keel structural pattern (Fig. 1) comprising domical, multicomponent granitoid complexes and intervening synclines containing up to five groups of volcano-sedimentary rocks (Van Kranendonk et al., 2002). Formation of the dome-and-keel structure commenced with the emplacement of synvolcanic laccoliths during a voluminous episode of felsic magmatism at 3490–3430 Ma, and then became pronounced as a result of partial convective overturn of the upper and middle crust at 3325–3310 Ma following the eruption of the 5–9 km-thick Euro Basalt (Hickman, 1984; Williams and Collins, 1990; Van Kranendonk et al., 2002; Sandiford et al., in prep.). Partial convective overturn of the basement continued during punctuated intervals until at least 2930 Ma, but also affected the Fortescue Group (Hickman, 1984; Van Kranendonk, 2000) as described below.

In the northern part of the Hamersley Basin the Fortescue Group is divided into six formations, with three thick, dominantly basaltic formations alternating with sedimentary rocks (Thorne and Trendall, 2001). The contact between the basement and the Fortescue Group is marked by a pronounced, commonly high-angle unconformity and includes restricted areas of basal conglomerate infilling relict topography in the basement (Blake, 1984, 1993; Thorne and Trendall, 2001).

Two contrasting interpretations of the stratigraphy of the Marble Bar Sub-basin have been proposed (Table 1). In one view, Hickman and Lipple (1978) and Hickman and Gibson (1981) suggested that the Fortescue Group consisted of the basal Mount Roe Basalt, the overlying clastic sedimentary rocks of the Hardey Formation, and a second main basaltic unit belonging to the Kylena Formation (Kojan and Hickman, 1998) that includes overlying sedimentary rocks. Alternatively, Blake (1993) suggested that the stratigraphy consists of the basal Mount Roe Sequence and the overlying Hardey Sequence Package. In this model the Hardey Sequence Package was interpreted to consist of the lower Glen Herring Sequence of basal clastic sedimentary rocks and a basaltic unit, and the overlying Pear Creek Sequence of clastic sedimentary rocks. In the following sections a lithostratigraphic nomenclature for the Fortescue Group is used following the reasons given in Thorne and Trendall (2001).

Pear Creek Centrocline

Lithostratigraphy

The results of detailed geological mapping in the northern part of the Marble Bar Sub-basin — the Pear Creek Centrocline (Blake, 1993) — are shown in Figure 2. Basement rocks flanking the sub-basin include folded, low-grade volcanic and sedimentary rocks of the Warrawoona, Gorge Creek, and De Grey Groups, whereas small, fault-bound basement inliers in the south-central and northeast-central parts of the map area consist of unassigned, highly altered basalt and subvertically dipping quartzite.

Unconformably overlying the basement (e.g. A and B on Fig. 2) is the Mount Roe Basalt that is up to 3 km thick in the map area. Most of the unit is composed of thick flows of massive to vesicular (locally amygdaloidal), and commonly plagioclase-glomeroporphyritic, basalt, in places with pillows at the base of the formation. A wedge of coarse conglomerate to sandstone, and massive basaltic agglomerate belonging to the basal part of the Mount Roe Basalt, lies on the basement with a sharp angular unconformity in the far eastern part of the map area (A on Fig. 2), and is disconformably overlain by the main basaltic flows of the formation. The Mount Roe Basalt is tightly folded south of the main Pear Creek Fault, with bedding dips of up to 75°, but the formation dips less than 30° north of the fault (Fig. 2).

Yellowish-orange weathering, well-bedded conglomerate, sandstone, and minor grey-green or brown shale of the Hardey Formation unconformably overlie the folded Mount Roe Basalt, in places across a high-angle unconformity (C on Fig. 2). Lateral thickness variations in the Hardey Formation indicate a relict topography in the Mount Roe Basalt during deposition of this clastic succession, which Blake (1993) suggested was laid down by fluvial transport. The dominant rock type is thickly bedded, very pure quartz sandstone with local cross-

Table 1. Previous interpretations of the stratigraphy of the Fortescue Group in the Pear Creek Centrocline

Hickman and Lipple (1978), Hickman and Gibson (1981)	*Lithology*	*Blake (1993)*	
Kylena Formation	Conglomerate and sandstone	Pear Creek Sequence	Hardey Sequence Package
	Basalt	Glen Herring Sequence	
Hardey Formation	Conglomerate and sandstone		
Mount Roe Basalt	Basalt	Mount Roe Sequence	
	Conglomerate and sandstone		

bedding. The sandstone overlies a basal unit of cobble conglomerate up to 10 m thick, and may contain 1–3 m-thick conglomerate interbeds. Clasts in the conglomerate include predominantly white vein quartz and black and layered cherts, indicating derivation from erosion of the basement, but also include cobbles of Mount Roe Basalt.

A thick, regionally persistent, unit of coarse, blocky basaltic agglomerate assigned to the Kylena Formation was deposited unconformably on the Hardey Formation and locally cuts down through this unit to the Mount Roe Basalt (D and E on Fig. 2). The base of the agglomerate has local pillow basalt and brecciated flows that are transitional into the agglomerate, indicating subaqueous eruption, although probably in shallow water. The upper part of the unit is composed of metre-thick massive to vesicular flows, suggesting subaerial eruption, and includes a unit of plagioclase-glomeroporphyritic basalt. Two dolerite sills are possibly associated with the eruption of this unit: one was emplaced into the Hardey Formation, and the other intruded more massive parts of the Kylena Formation (Fig. 2). Dips of the Kylena Formation are distinctly steeper north of the Pear Creek Fault (20–52°) than to the south (10–15°), in contrast to the underlying Mount Roe Basalt (Fig. 2).

Unconformably overlying the Kylena Formation is an approximately 1 km-thick succession of brown- to green-weathering, very well preserved clastic sedimentary rocks. These rocks can be subdivided into four distinct but unnamed units, equivalent to member rank, based on grain size, contact relationships, and clast composition. Relationships along the northern side of the Pear Creek Centrocline indicate that there was a significant episode of faulting and tilting of the Kylena Formation before deposition of the overlying clastic succession (F on Fig. 2; see **Structural geology**). For this reason the clastic rocks are separated from the underlying Kylena Formation and assigned formation status, but because they differ in composition and depositional environment from rocks typical of the Tumbiana Formation (which would normally overlie the Kylena Formation) they are given a new formation name — the Pear Creek Formation. This is equivalent to the Pear Creek Sequence of Blake (1993; Table 1).

Unit 1 at the base of the Pear Creek Formation is 375 m thick and includes a basal unit of fine-grained, thin-bedded, green-brown siltstone and minor sandstone. Beds with rip-up clasts of mudstone are common (Fig. 3a) and there are also rare, 10 cm-thick beds of cobble conglomerate with well-developed cross-bedding. Green sandstone in the upper part of the unit is commonly homogeneous, with 10–30 cm-thick planar bedding, and is lithologically indistinguishable from the overlying unit 2.

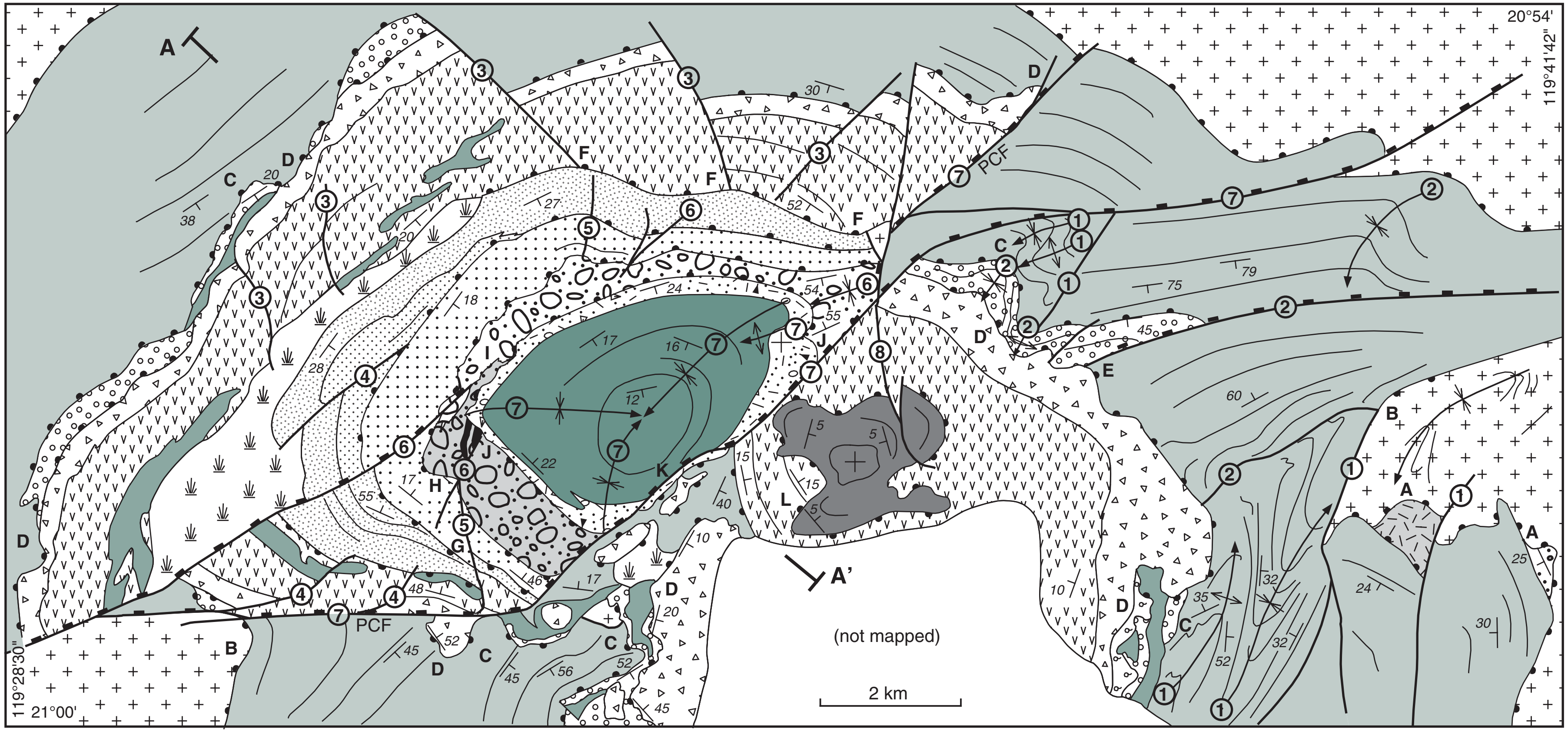
Unit 2 is about 250 m thick and cuts down-section through almost all of unit 1 along the southwestern side of the centrocline to the underlying Kylena Formation (G on Fig. 2). Unit 2 fines upwards from orange-weathering, medium-bedded, coarse sandstone at the base, through brown-weathering, green-grey, coarse- to medium-grained turbiditic sandstone with thin pebbly beds and some trough cross-bedding, to an upper unit of siltstone and mudstone with beds of rip-up clasts.

Unit 3 is composed of brown-weathering boulder to pebble conglomerate and sandstone that lies disconformably on unit 2 (H on Fig. 2). In places the basal contact of unit 3 with unit 2 varies from knife-sharp (Fig. 3b) to gradational (Fig. 3c) over a distance of only a few metres. Unit 3 consists of two distinct components, identified on the basis of clast compositions. In the southwest, unit 3 is composed of poorly bedded, oligomictic cobble to boulder conglomerate and breccia that contains angular to very well rounded clasts, up to 80 cm across, of solely basaltic composition in a fine- to medium-grained, quartz-bearing, sandy matrix (Fig. 3d). The basaltic clasts are undeformed and have a variety of textures, including massive, doleritic, vesicular, and plagioclase glomeroporphyritic; these basalt types are common in the underlying Mount Roe Basalt and Kylena Formation. The clasts show an increase in angularity with decreasing size, with boulder-sized clasts always well rounded. The unit is very coarse grained and massive at its thickest point in the southwest, and becomes finer grained and poorly bedded along strike to the north, where it includes brown sandstone beds near the top of the unit (western point J on Fig. 2).

Across the northern side of the centrocline (I on Fig. 2), the basalt-cobble conglomerate of unit 3 is interfingered with polymictic cobble to pebble conglomerate (<200 m thick) containing the same assortment of basaltic clasts as the oligomictic conglomerate to the south, but also containing well-rounded clasts of quartzite and other basement rocks, including dominantly black chert and white vein quartz, foliated and gneissic granites, and felsic volcanic rocks (Fig. 3e). In the southwest the lower part of the unit contains 95–98% basalt clasts, with less than 5% clasts of chert and sandstone, whereas towards the top the unit contains a more even mixture of chert, quartzite, granite, and basalt clasts. Clasts of basement rocks are more common to the northeast, where unit 3 has a sharp erosional contact with the underlying unit 2. A unit of pebbly sandstone at the top of unit 3 separates it from the overlying unit 4.

Unit 4 includes 75 m of basal, polymictic, matrix-supported conglomerate and about 390 m of medium-grained to pebbly sandstone. Clasts are well rounded and consist of both basalt- and basement-derived detritus, although basement material — particularly granitic clasts — is far more abundant than in the underlying units (Fig. 3f). Unit 4 is largely conformable on the underlying unit 3, but a high-angle unconformity is developed between these units in two places (J on Fig. 2). At the eastern locality the polymictic basal conglomerate of unit 4 dips 20° to the southwest, and overlies basalt-cobble breccia and sandstone that dip 50–60° to the north-northwest. On the southern side of the Pear Creek Fault, basal conglomerate of unit 4 lies unconformably on the Mount Roe Basalt across 0.4 – 1 m of iron-altered basalt and ferruginous grit and up to 4 m of fine-grained ?mafic tuff and ?vitric crystal tuff with accretionary lapilli that probably belongs to unit 1 (K on Fig. 2).

Unit 5 is a shallow-dipping (~5°) unit of orange-weathering, coarse sandstone and pebble conglomerate that lies unconformably on the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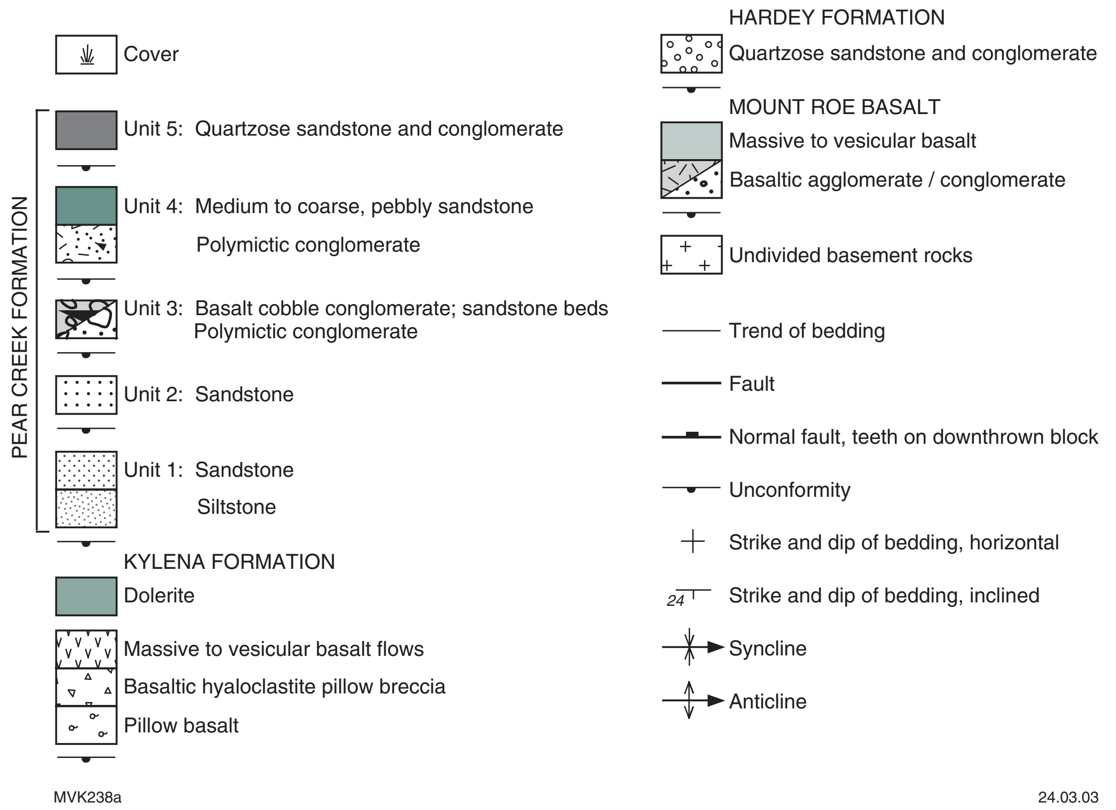

Figure 2. Geological map of the Pear Creek Centrocline. Bold letters indicate localities described in the text. Circled numbers refer to structure sets described in the text and in Table 2. PCF = Pear Creek Fault. Line A–A′ is line of cross-section shown in Figure 4

Kylena Formation south of the Pear Creek Fault (L on Fig. 2; Fig. 3g). This unit contains only basement clasts, and is thereby distinct from other units of the Pear Creek Formation, as well as physically separate and more shallowly dipping. The bedding dips in this unit outline a separate centrocline of unknown age relative to the Pear Creek Centrocline to the north, although it can be argued that structural considerations favour a younger age relative to the rest of the Pear Creek Formation (see below).

Structural geology

Eight sets of structures have been identified in the Fortescue Group of the Pear Creek Centrocline (Table 2). Sets 1, 2, and 8 are restricted to south of the Pear Creek Fault, whereas sets 3 to 7 are only to the north of this fault (Fig. 2).

The first set of structures include tight folds of bedding in the Mount Roe Basalt south of the Pear Creek Fault, where dips on fold limbs reach up to 75° (central-eastern part of Fig. 2). In the northeastern part of the map area the axial zone of a set 1 fold contains a set 1 fault.

Set 1 folds are unconformably overlain by the Hardey Formation (C on Fig. 2), which is folded on axial planes subparallel to, but different from, set 1 folds. Folding (set 2) of the Hardey Formation was followed by the development of two east-northeasterly trending, north-side-down normal faults (set 2) in the eastern part of the map area (labelled 2 on Fig. 2). Basal agglomerate of the Kylena Formation unconformably overlies set 2 structures (D on Fig. 2), and is unaffected by them. The geometry of set 1 and 2 folds indicate approximately west-northwest – east-southeast shortening across the centrocline, whereas late set 2 faults indicate the onset of north- to northwest-side-down normal faulting.

Deposition of the Kylena Formation occurred under stable conditions, as indicated by texturally distinct basalt flows conformable on one another throughout the formation. Following deposition of the formation, these rocks were affected by set 3 extensional faults across the northern part of the map area (Fig. 2). The geometry of the faults suggests approximately east–west extension across this part of the centrocline.

Unit 1 of the Pear Creek Formation has a well-exposed basal contact across the northern part of the centrocline, where it unconformably overlies the Kylena Formation and set 3 faults (F on Fig. 2). Unit 1 is affected by northeast-trending set 4 faults (labelled 4 on Fig. 2) that are the oldest of a succession of faults with this same trend (sets 4 to 7) that migrated to the southeast throughout the deposition of the Pear Creek Formation (Fig. 4; Table 2). Set 4 faults extend either partway up through unit 1 (southwestern map area) or through all of unit 1 to the base of unit 2 (west-central map area), which is unaffected by these

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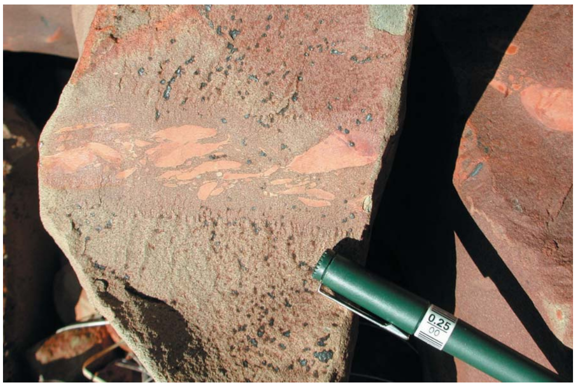

b)


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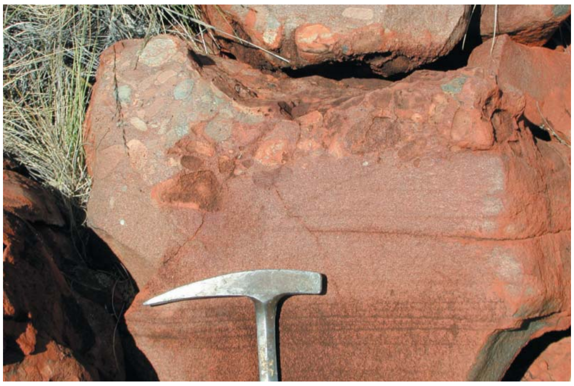

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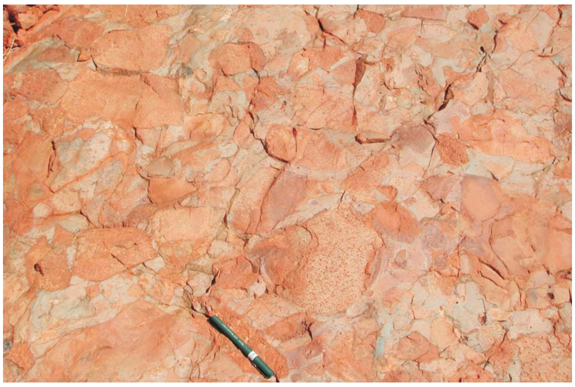

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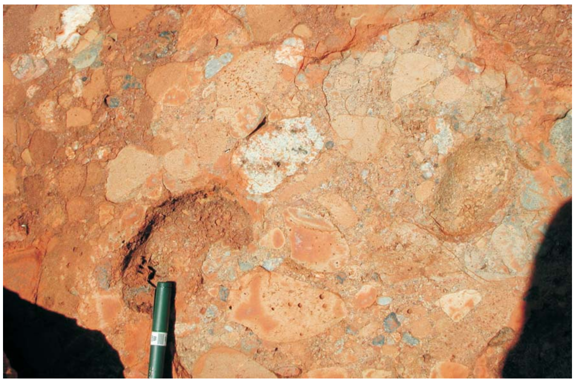

f)


g)


Figure 3. Outcrop features of the Pear Creek Formation: a) Mud rip-ups in unit 1; b) sharp basal contact between unit 2 and overlying polymictic conglomerate of unit 3; c) downcutting, but gradational contact between unit 2 and overlying polymictic conglomerate of unit 3; d) basaltic conglomerate of unit 3; e) polymictic conglomerate of unit 3, with basaltic and basement clasts; f) polymictic conglomerate of unit 4 at the unconformity with the underlying unit 3 at the eastern point J in Figure 2 (see Fig. 4). Note the black chert pebbles in the lower right and the strongly foliated granite boulder above left of the pen; g) view looking east of unit 5 south of the Pear Creek Fault, showing the shallow north dip (<5°) of this unit and its unconformable relationship on the Kylena Formation in the foreground, which dips 15° to the north (arrows)

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Table 2. Relationship between structures and lithostratigraphic units of the Fortescue Group in the Pear Creek Centrocline

Formation	*Member*	*Basal contact*	*Structure set*	*Structures*
			8	Gently tilted strata and younger E-side-down faults
Pear Creek	Unit 5	Unconformity on Kylena Formation		
			7	Tilted strata and NW-side-down faults
	Unit 4	Disconformity to angular unconformity on Member 3 and (locally) Mount Roe Basalt		
			6	Tilted strata and NW-side-down faults
	Unit 3	Conformity to low-angle unconformity on Member 2		
			5	Tilted strata and NW-side-down faults
	Unit 2	Disconformity to low-angle unconformity on Member 1		
			4	Tilted strata and NW-side-down faults
	Unit 1	Disconformity to angular unconformity on Kylena Formation		
			3	Tilted strata and extensional faults
Kylena		Conformity to angular unconformity on Hardey Formation and Mount Roe Basalt		
			2	NE-trending folds, younger N-side-down faults
Hardey		Disconformity to angular unconformity on Mount Roe Basalt		
			1	Tilting, NE-trending folds, and W- to NW-side-down faults
Mount Roe Basalt		Disconformity to angular unconformity on basement rocks		

faults. Unit 2 is affected by set 5 faults and overlain by unit 3, which is affected by set 6 faults. Unit 4 is affected only by the Pear Creek Fault, which was probably active throughout the deposition of the Pear Creek Formation, and by gentle downwarping in the core of the centrocline.

Unit 5, south of the Pear Creek Fault, dips radially inward at point 5 (set 8) and unconformably overlies more steeply dipping bedding in the Kylena Formation (Fig. 3g). The shallowly dipping bedding of unit 5 is cut by north-striking faults (set 8) with east-side-down displacement. The structure of unit 5 defines a second centrocline, which probably formed after the Pear Creek Centrocline as suggested by the southerly shift in deformation through sets 4 to 7.

Interplay between deformation and sedimentation

Relationships between units in the Fortescue Group and sets of folds and faults indicate that the Pear Creek Centrocline developed progressively throughout deposition of the group. The deformation style changed from northwest–southeast

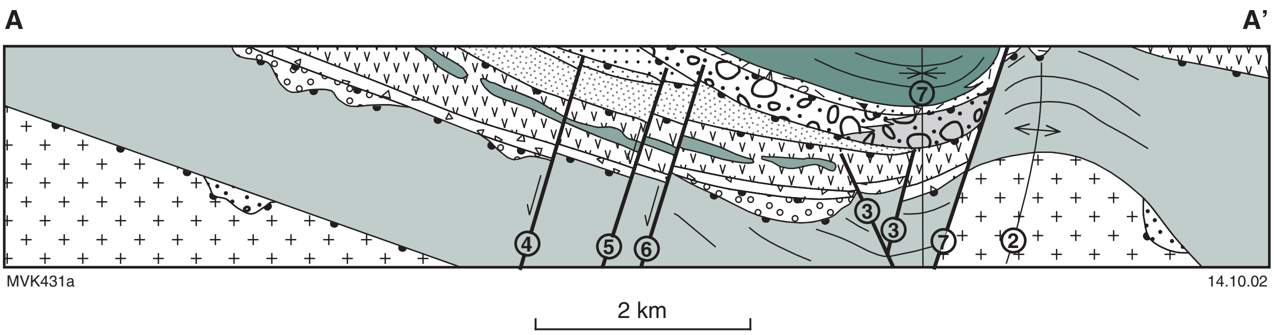

Figure 4. Northwest–southeast cross-section A–A' (from Fig. 2, but note different scale) of the Fortescue Group in the Pear Creek Centrocline, Marble Bar Sub-basin. Legend as in Figure 2

shortening during sets 1 and 2, to east–west extension during set 3, to northwest–southeast extension during sets 4 to 7.

Previous work in the Hamersley Basin has shown that the Mount Roe Basalt and underlying sedimentary rocks of the basal Fortescue Group were deposited on a relict topography in the basement that was caused by topographically high granitoid domes during west-northwesterly directed extension (Fig. 5a: Blake, 1993; Thorne and Trendall, 2001). Set 1 structures in the Pear Creek Centrocline, as well as in the southwestern part of the Marble Bar Sub-basin (Van Kranendonk, 2000), are consistent with a significant amount of shortening between reactivated granitoid domes after deposition of the Mount Roe Basalt, but before deposition of the Hardey Formation. Data from the two areas indicate different orientations of shortening at this time (northwest–southeast in the Pear Creek Centrocline versus north–south in the southwestern part of the Marble Bar Sub-basin), similar to the orientation of structures in the underlying greenstones. Although this style of deformation is inconsistent with regional orogenesis due to plate interactions, it is consistent with folding of the Fortescue Group as a result of bed-length shortening in synclines between reactivated granitoid domes during diapirism (Fig. 5b; Dixon and Summers, 1983; Hickman, 1984; Van Kranendonk et al., 2002).

Uplift and erosion of granitoid rocks and flanking greenstones provided detritus for the Hardey Formation that was deposited in shallow basins between granitoid domes (Fig. 5b). Deposition was coeval with continued uplift, which caused folding of these clastic rocks on set 2 fold axes that are subparallel to set 1 folds.

This period of uplift and erosion was followed by the deposition of the Kylena Formation and a period of extension that affected the Fortescue Group throughout the Hamersley Basin (Thorne and Trendall, 2001). In the Pear Creek Centrocline this extension was manifest as set 3 faults (Fig. 5c).

Deformation changed to northwest-side-down normal faulting throughout deposition of the Pear Creek Formation (structure sets 4 to 7:

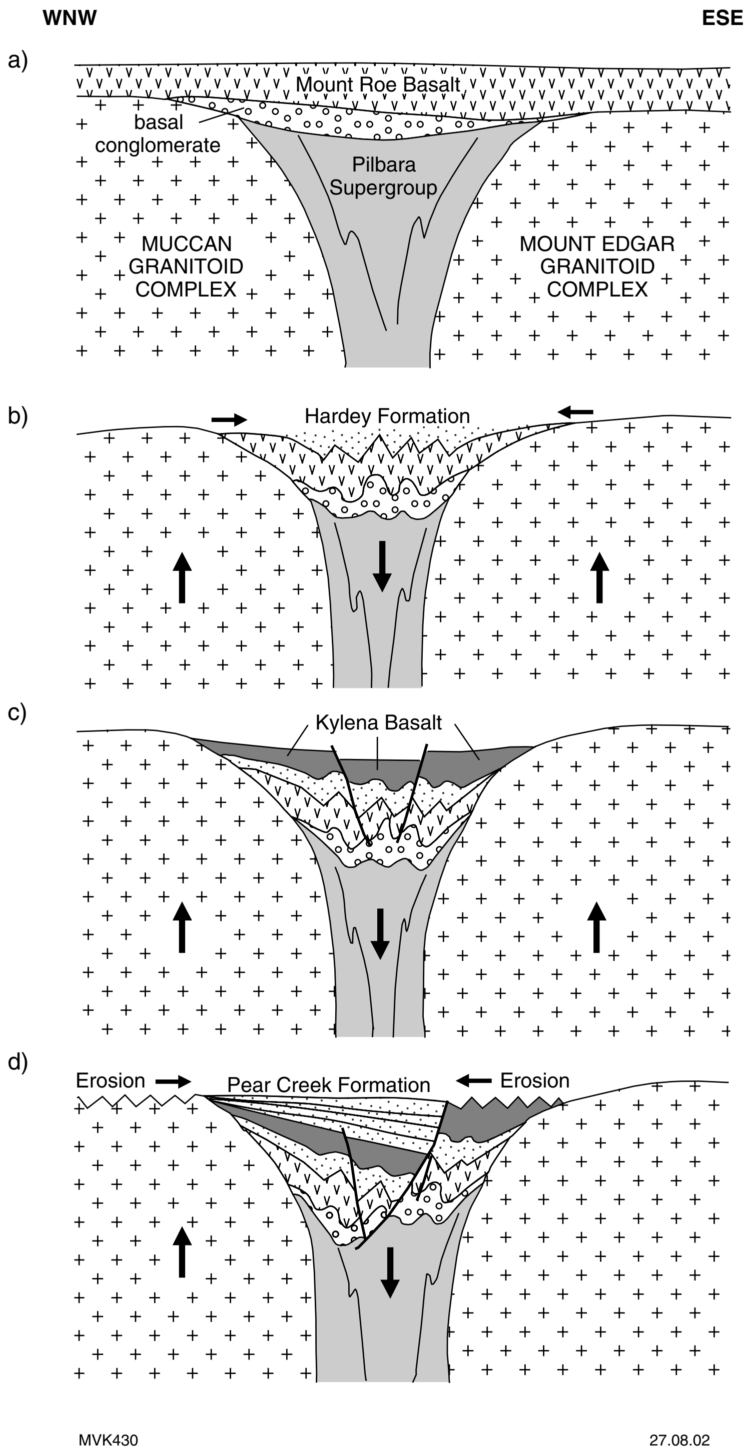

Figure 5. Schematic evolution of the Pear Creek Centrocline: a) deposition of the Mount Roe Basalt and basal conglomerates on a basement with relict topography defined by domical granitoid complexes; b) deformation of the Mount Roe Basalt due to shortening between uplifted granitoid domes, which were eroded to provide detritus for deposition in the unconformably overlying Hardey Formation; c) deposition of the Kylena Formation followed by extension; d) asymmetric downdrop across the Pear Creek Fault results in deposition of the Pear Creek Formation in the Pear Creek Centrocline

Fig. 5d). A decrease in clast size from southeast to northwest in the basalt-cobble conglomerate of unit 3 on the southern side of the centrocline provides evidence for a structural control on sedimentation, indicating a source from the uplifted block on the southern side of the Pear Creek Fault. Additionally, the change from basalt-cobble to polymictic conglomerate to the north and east within unit 3 is consistent with the structural history outlined above. This indicates that the Pear Creek Centrocline formed through southeast-side-down tilting of the northern block across the Pear Creek Fault and associated structures, resulting in uplifted basement rocks in the northwest and an uplifted area of the Mount Roe Basalt and Kylena Formation in the footwall to the southeast (Figs 4 and 5).

Conclusions

Detailed geological mapping of the Pear Creek Centrocline has shown that the composition and depositional style of the sedimentary rocks overlying and underlying the Kylena Formation in the core of the Pear Creek Centrocline are distinctly different. On this basis it is proposed that the stratigraphy of the Pear Creek Centrocline be revised to include, from base to top, the Mount Roe Basalt, Hardey Formation, Kylena Formation, and Pear Creek Formation, the latter consisting of five sedimentary units bound by locally disconformable to unconformable contacts.

The mapping shows that local deformation affected the Pear Creek Centrocline throughout deposition of the Fortescue Group, and that this deformation was controlled by the reactivation of granitoid domes. Early deformation (structure sets 1 and 2) involved local tight folding due to west-northwest – east-southeast compression between rising domes. This was followed by deposition of the Kylena Formation and subsequent east–west extension. Deposition of the Pear Creek Formation was accompanied, and probably controlled, by northwest-side-down normal faulting across the Pear Creek Fault and associated splays, which stepped back to the southeast through time. The final deformation resulted in the formation of a second, gentle centrocline south of the Pear Creek Fault in which unit 5 was deposited.

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