12th Australian Geological Convention

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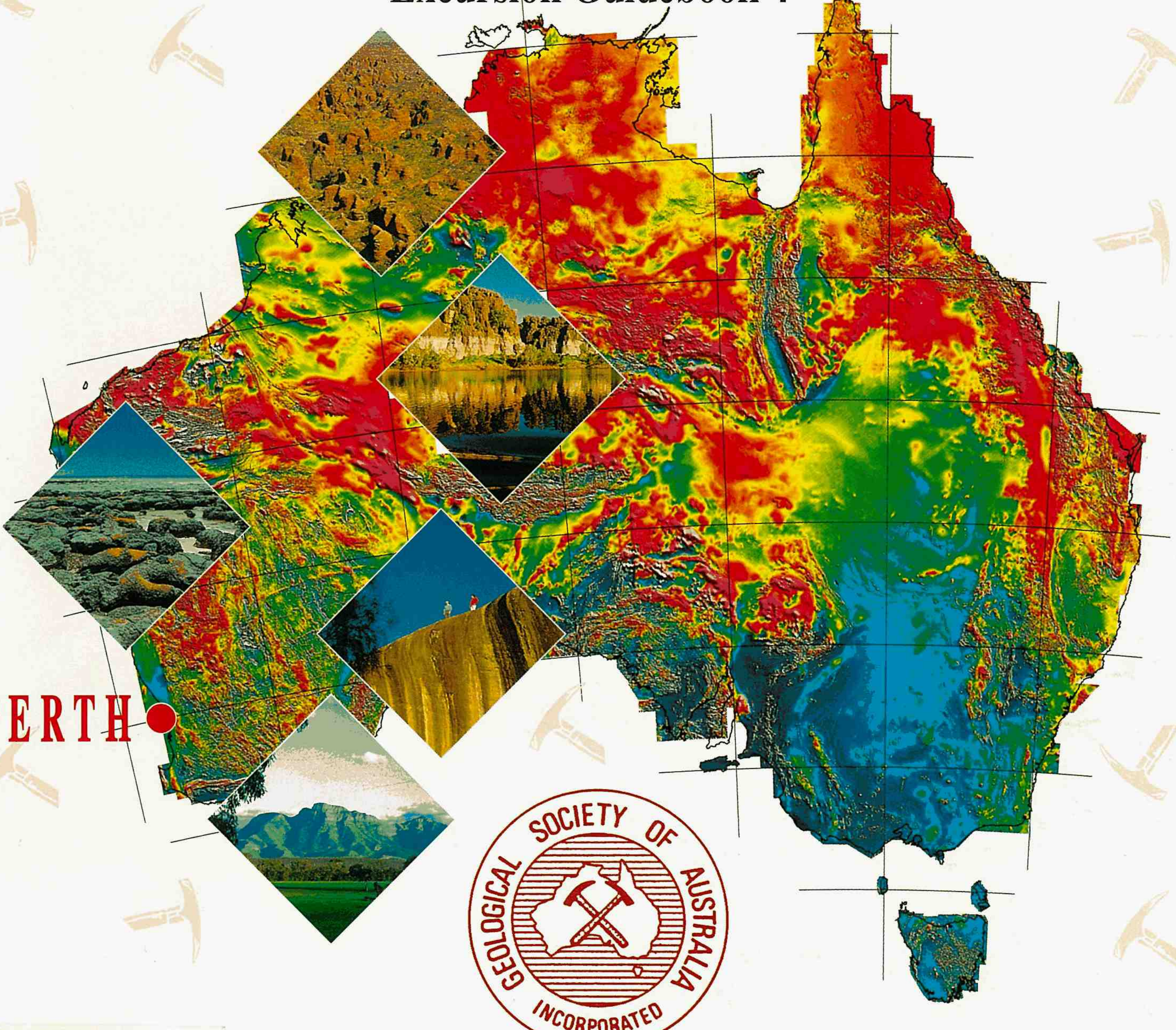
Excursion Guidebook 4



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LATE ARCHAEAN AND EARLY PROTEROZOIC TECTONICS AND BASIN FORMATION OF THE HAMERSLEY RANGES

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EXCURSION GUIDEBOOK No. 4

LATE ARCHAEAN AND EARLY PROTEROZOIC TECTONICS AND BASIN FORMATION OF THE HAMERSLEY RANGES

by

C. McA. Powell and R. C. Horwitz
(with contributions from D. Martin, S. Kiyokawa & A. Taira)

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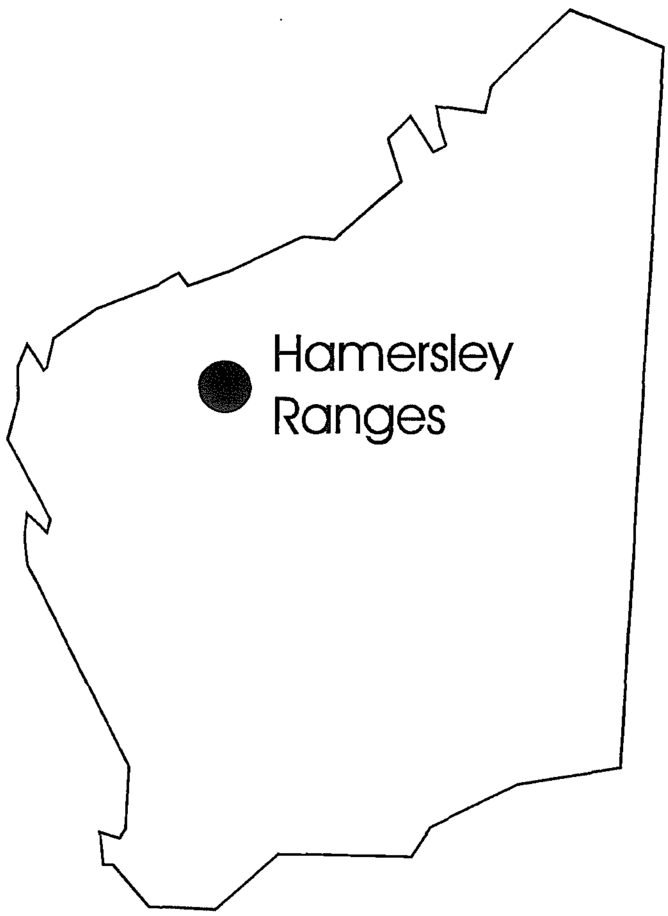
12th Australian Geological Convention
September 1994
Guidebook for the pre-convention excursion E1

12th Australian Geological Convention, Perth, September 1994



Preferred reference for this volume:

Powell, C. McA. and Horwitz, R. C. 1994. Late Archaean and Early Proterozoic tectonics and basin formation of the Hamersley Ranges. *Geological Society of Australia (WA Division) Excursion Guidebook,* 4, 57p.

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ISSN 0819-6613
ISBN 0 909869 90 1

Available for purchase from:

Geological Society of Australia (W. A. Division)
P O Box 6014
East Perth
Australia 6004

Printed by: Optima Press, 32 Kensington Street, East Perth, WA 6004

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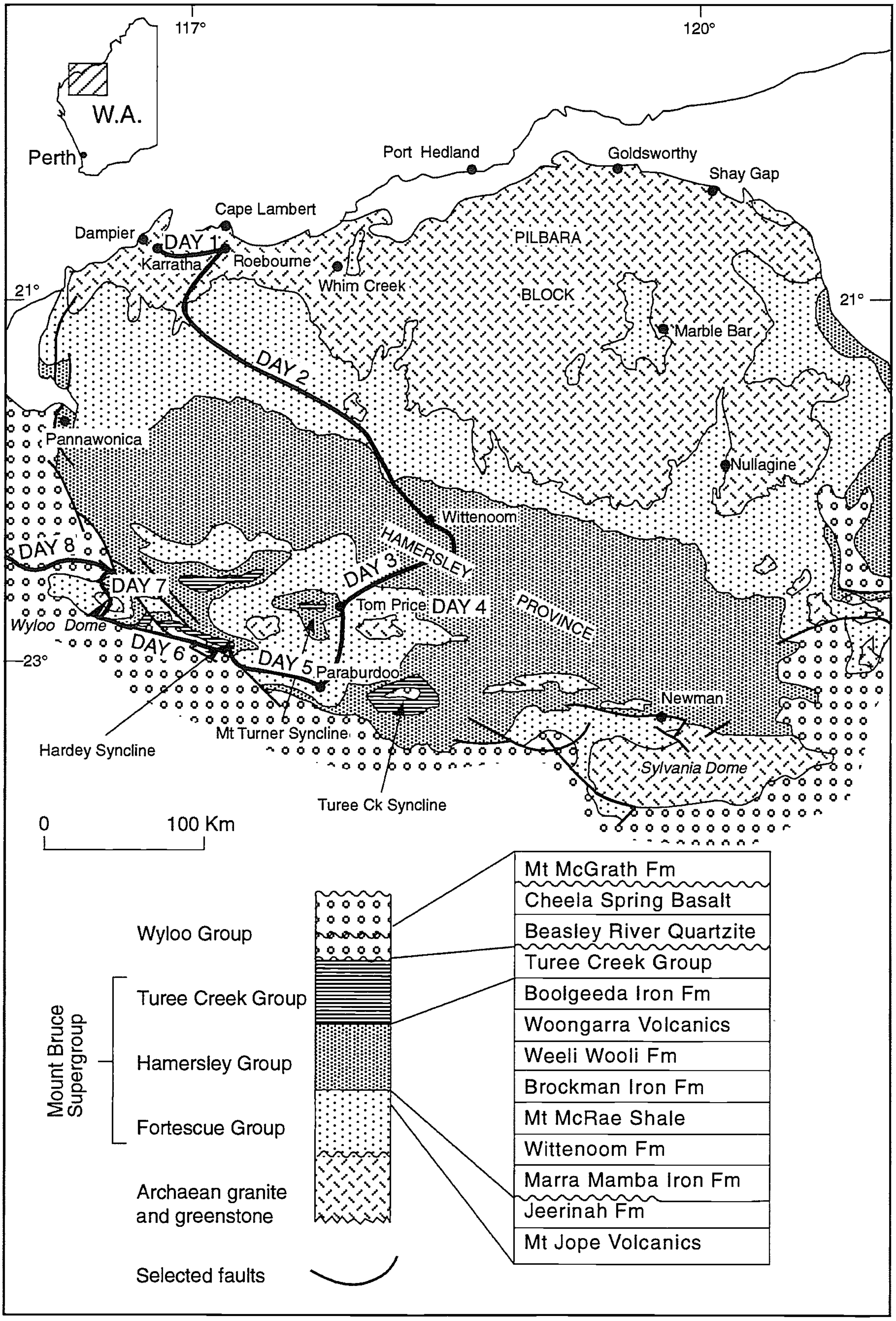

A simplified geological map of the Pilbara craton showing the approximate route of the excursion. Adapted from Li *et al.*, 1993.

Excursion *E1*

LATE ARCHAEAN AND EARLY PROTEROZOIC TECTONICS AND BASIN FORMATION OF THE HAMERSLEY PROVINCE

C. McA. Powell[1] and R. C. Horwitz[1]

with contributions from

D. Martin[1], S. Kiyokawa[2] and A. Taira[2]

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SUMMARY

This safari-style excursion examines the geological history of the Hamersley Province from the late Archaean (~3100 Ma) to the end of the Palaeoproterozoic (~1600 Ma). It starts in a late Archaean mafic volcanic complex near Karratha forming the basement, and works up the stratigraphic section through the extensional-basin volcanogenic succession into disconformably overlying iron formations and associated deposits of the Hamersley Province. The succeeding Wyloo Group comprises deposits of the McGrath Trough, an inferred early Palaeoproterozoic foreland basin, and the Ashburton Basin, a younger extensional basin deformed and thrust northwestward at the end of the Palaeoproterozoic. Particular attention will be paid to whether tectonic settings during the late Archaean – early Proterozoic were similar to those in the Phanerozoic.

OUTLINE OF GEOLOGICAL ITINERARY

Day 1, Sat. 17 Sept   Around Karratha

Examine rocks of the western part of the Pilbara block. Mafic volcanics pass upward into cherty banded iron formation, which has been interpreted as either the remnant of an oceanic island arc accreted to the Pilbara in the late Archaean or the deposits of a rift basin.

Camp or stay in the Roebourne area

Day 2, Sun. 18 Sept   Roebourne to Wittenoom

Examine the unconformity between the Archaean granite–greenstone complex and basal units of the Fortescue Group of the Mt Bruce Supergroup. Most of the day is spent driving through the Chichester Ranges to Wittenoom on the northern side of the Hamersley Ranges. The Kylena Basalt, mafic volcanoclastic sediments and stromatolites in the Tumbiana Formation and Woodiana Sandstone, are seen.

Camp near Wittenoom

Day 3, Mon. 19 Sept   Gorge country in the Wittenoom area

This day is spent in the iron formations exposed in the gorge country on the northern side of the Hamersley Ranges. The Wittenoom Formation and a representative section through the Dales Gorge Member are seen in Wittenoom Gorge. The route then goes to the Yampire asbestos mine in Yampire Gorge, and then chert crosspods, macules and dolomite interbeds, the Hamersley Surface and Channel Iron Deposit (CID) are seen in Dales Gorge. In the late afternoon, the excursion travels to Tom Price.

Stay in Hillview Lodge Motel at Tom Price (Tel: [091] 89 1110; Fax: [091] 89 1625)

Day 4, Tues. 20 Sept   Field conference at Tom Price

In the morning there will be a field conference at Tom Price, during which field trip leaders will outline the current state of knowledge of, and controversies about, the regional geology and the formation of the iron ore deposits. In the afternoon the excursion examines local outcrops around Tom Price. A brief tour of Tom Price Mine may be arranged, if time is available.

Camp near Tom Price

Day 5, Wed. 21 Sept Tom Price to Hardey Syncline

Complete outcrops in the Turner syncline area and drive to Hardey syncline examining, on the way, pillow basalts and komatiites in the Fortescue Group on the southern side of the Rocklea Dome, conglomeratic sandstone at the base of the Upper Wyloo Group and possibly glacigene diamictite in the Turee Creek Group. Reach Woongarra Pool by 3 pm to examine Beasley River section through the Hamersley Group from Marra Mamba Iron Formation to the Boolgeeda Iron Formation in the afternoon light.

Camp near the Beasley River in the Hardey syncline area

Day 6, Thurs. 22 Sept Hardey Syncline to Wyloo Dome

Drive along the east-facing nose of the Hardey syncline in the morning to see the angular unconformity within the Turee Creek Group. The Beasley River Quartzite caps the hill in the synclinal keel. Then examine the Three Corner Conglomerate Member at the base of the Beasley River Quartzite along Paraburdoo–Nanutarra road (AMG 2252–565781). In the afternoon, examine metamorphosed microplaty haematite clasts in the Mt McGrath Formation and olistoliths in a fossil canyon in the Ashburton Formation, both on the southwestern limb of the Wyloo Dome.

Camp near the Barrett-Lennard iron ore placer north of Metawandy Bore

Day 7, Fri. 23 Sept Wyloo Dome to Duck Creek

In the early morning, examine the Proterozoic iron ore placer in the Mt McGrath Formation and adjacent outcrops in the Beasley River Quartzite. Then travel north to see the Duck Creek Dolomite and a Neogene CID on the way to the Duck Creek syncline. In the afternoon, walk a section from the Boolgeeda Iron Formation through the Turee Creek Group [where spectacular columnar stromatolites are exposed] and Beasley River Quartzite [littoral deposits] into the terrestrial clastics and vesicular basalts of the Cheela Springs Basalt.

Camp in Duck Creek syncline.

Day 8, Sat. 24 Sept Duck Creek to Karratha

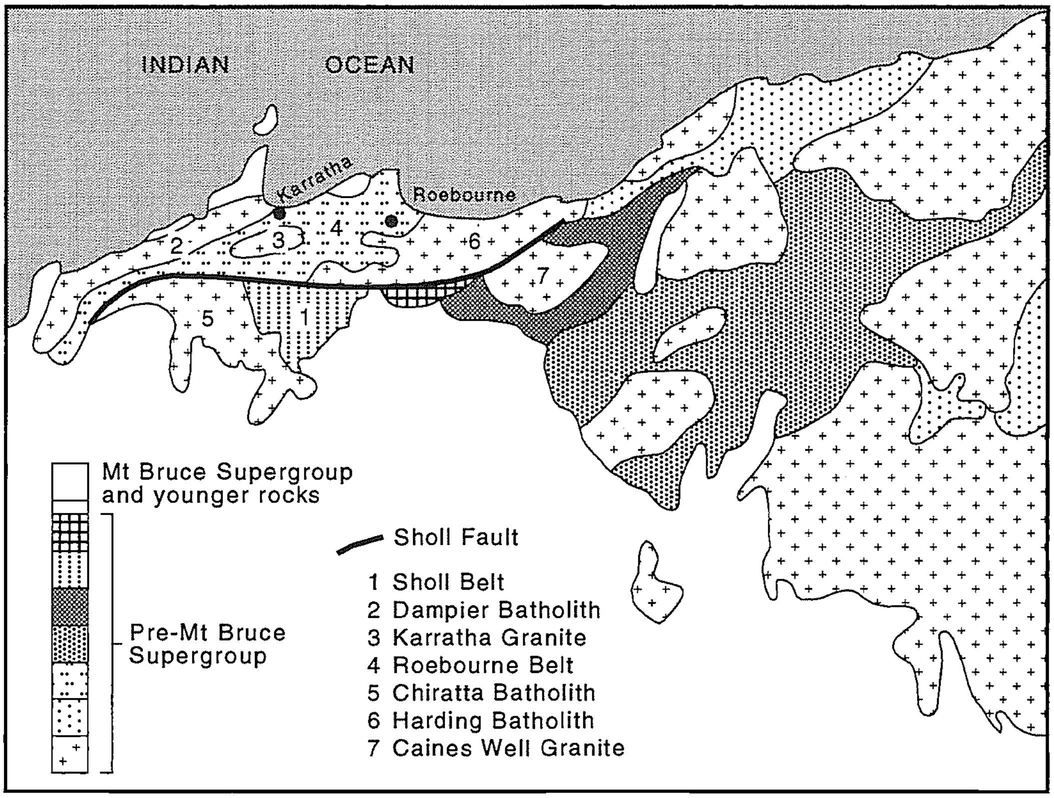
Travel along the Mt Stuart track towards Nanutarra. The rock units to be examined are the June Hill Volcanics, at the base of the Ashburton Trough, the metamorphosed lithic turbidites of the Ashburton Formation which fills the trough, and the Boolaloo Granodiorite [1680 Ma], which intrudes the trough after it has been deformed. The geological part of the trip will conclude at 11.30 am to allow 3 hours to drive to Karratha in order for participants to shower before catching the 4 pm plane to Perth.

Note: Reference to points (AMG) refer to the Australian Map Grid, 1:100 000 National Topographic Map Series, sheets: Cooya Pooya, 2355; Dampier, 2256; Hardey, 2252; Millstream, 2354; Mt Billroth, 2454; Mt George, 2653; Mt Lionel, 2452; Mt. Stuart, 2153; Pinderi Hills, 2255; Roebourne, 2356; Rocklea, 2352; Wittenoom, 2553; Wyloo, 2152.

The region is covered by the following 1:250,000 Geological Maps: Mt Bruce, Pyramid, Roy Hill, Turee Creek, Wyloo and Yarraloola. There is also a 1:500,000 map of the Ashburton Basin (Thorne & Seymour, 1991) covering the southern part of the excursion. Other regional compilations can be found in Trendall and Blockley (1990).

DAY 1: GRANITE-GREENSTONE ROCKS OF THE WEST PILBARA (includes descriptions, maps and sections by S. Kiyokawa and A. Taira)

Units of the West Pilbara Granite Greenstone areas visited on this excursion are essentially from the Roebourne Belt. However, our route crosses or goes near the Dampier, Karratha and Harding granitic Batholiths, all separated by the Sholl Fault from the Sholl Belt and the Chiratta Batholith (Fig. 1.1). Felsic tuffs from the Sholl Belt were dated by Horwitz and Pidgeon (1993) at about 3.1 Ga and unpublished results between 3.1 & 3.0 Ga are quoted in Krapez (1993, p. 17) for the Roebourne Belt.



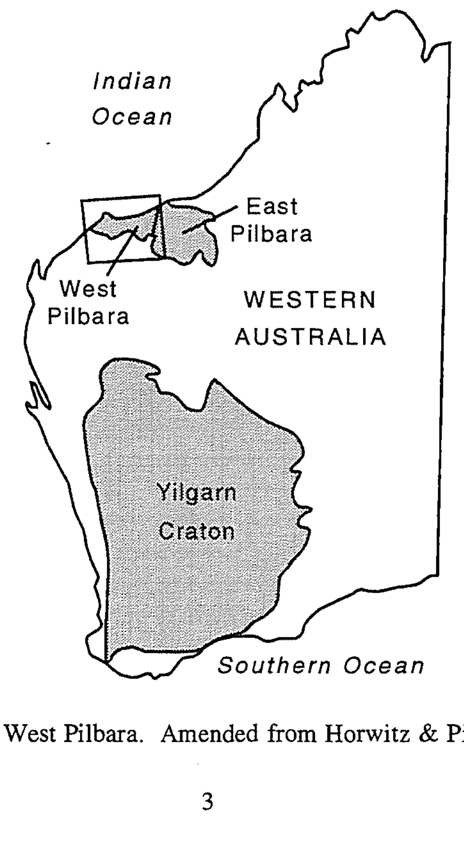


Fig. 1.1 Structural units of the West Pilbara. Amended from Horwitz & Pidgeon (1993).

Geological mapping in the early 1960s by the Geological Survey of Western Australia of the Roebourne Belt on the Dampier-Barrow Island and Roebourne Geological 1:250,000 Sheet areas had recognised a persistent layered succession (Fig. 1.2) composed, at the base, of a complex grouping of felsic, mafic and ultramafic sills, basalts, komatiites (later recognised), felsic volcanics, green fuchsitic as well as pale and dark coloured cherts, and clastic rocks. This complex grouping was later named the Nickol River Formation (Williams, 1968) and is overlain by a persistent association (but of varying thickness) of dolerites and generally well-pillowed basalts, above which there is a group of cherty banded iron formations (BIF), cherts, tuffs and shales. The two last associations were named the Regal and the Cleaverville Formations, respectively (Fig. 1.2; Ryan & Kriewaldt, 1964).

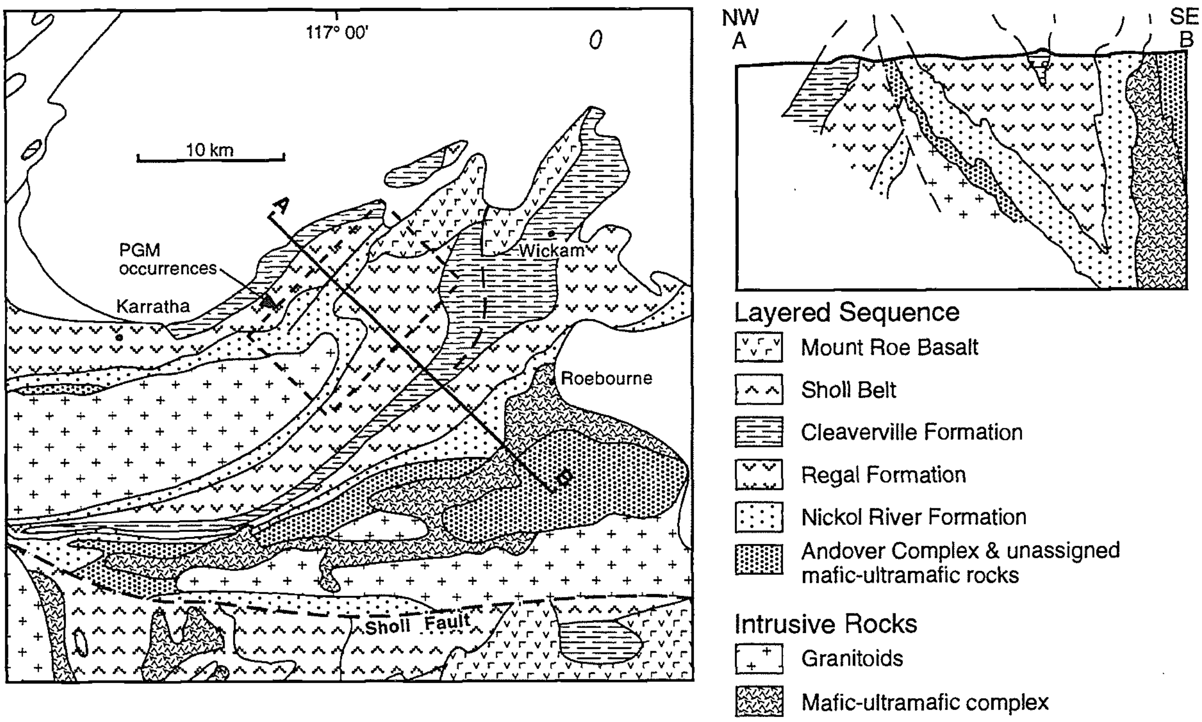


Fig. 1.2 Geological map and section of the Roebourne–Karratha region, West Pilbara. Amended from Hudson & Horwitz (1968).

The units are typical of many such formations of other greenstone belts of the Archaean Basement of the Pilbara Craton, and various correlations have been proposed (e.g. Hickman, 1983; Horwitz, 1990). The formation names established here have, in some cases, been extended throughout the Pilbara Craton. Nisbet & Chinner (1981) doubted the correlation of the Roebourne Belt rocks with other stratigraphic units of the Pilbara and believed that the succession contains a slice of Archaean oceanic crust with no known basement. Krapez (1993) has divided the exposed Craton into five tectonostratigraphic domains; the West Pilbara, visited on this excursion, and some adjoining parts were grouped in a single domain. For the purpose of these excursion notes, however, no correlations between greenstone belts are implied and the formation names are retained for the Roebourne Belt only.

The granites of the batholiths occupy the core of anticlines, or the lowest structural position in the layering. Large granite apophyses are known, as are large rafts, or xenoliths; granite has been seen to have intruded as high as the Cleaverville Formation. Contact metamorphic aureoles vary in width and degree of metamorphism. All base metal and gold mines of the Roebourne Belt are in the Nickol River Formation, and prase has been mined from this formation as a semi-precious stone on both the northern and southern limb of the main synclinorium of this belt (Fig. 1.2).

Horwitz contributed to this early mapping and believes that this layering can be followed throughout the Roebourne Belt. Horwitz (1990) suggested an ophiolitic setting for parts of the Nickol River Formation, based on the presence of detrital grains of osmiridium which appear to have been shed from parts of the formation.

Kiyokawa (1993), however, considered that the "West Pilbara Coastal Greenstone (WPCG) Belt" (Roebourne Belt), comprises a pile of nappes including 5 tectonostratigraphic units, which from north to south are:

1) bimodal volcanics and tuff/chert/BIF successions (Cleaverville unit),
2) granitic rocks and associated metasediments (Karratha granitic unit),
3) mafic amphibolite (Nickol Well Amphibolite unit),
4) a highly folded cherty BIF succession (Point Samson BIF-chert unit), and
5) mafic granulite-peridotite and hybridised granite-gabbro succession (Roebourne granulite peridotite unit).

According to Kiyokawa (1993), these units were emplaced structurally from north to south. The ratio, in this succession, of mafic-ultramafic to silicic rocks is about 4:1 and, according to Kiyokawa, the succession resembles very closely the crustal profile of an oceanic island arc such as the Izu-Bonin Island Arc. He suggested that the WPCG Belt represents a crustal section through an accreted oceanic island arc, emplaced as overthrust sheets against the continental block which is represented by the Karratha granitic rock unit (Fig. 1.1).

The rocks of the Roebourne Belt are intruded by the Andover Complex (mafic–ultramafic), which itself is intruded by some granites of the Harding Batholith. The latter contains layers of vanadiferous magnetite. A younger magmatic episode (Millindinna Complex of Fitton *et al.,* 1975), dated at about 2.9 Ga (in Horwitz & Pidgeon, 1993), emplaced ultramafic, mafic or granophyric layered intrusions in parts of all the rocks described in the Sholl Belt and adjoining belts to the east. In the Sholl Belt, a Ni-Cu mine occurs in the Radio Hill Intrusion (De Angelis *et al.*, 1987) whilst a promising Pt prospect occurs in the mafic-ultramafic Munni-Munni Complex (Barnes *et al.*, 1990).

All these units of the West Pilbara form the basement core of an anticlinorium, overlain unconformably to the northwest and southwest by the Fortescue Group of the Mt Bruce Supergroup (Fig. 1.1). To the north, on the Burrup Peninsula, a northwards-dipping layered sill intrudes the basal unconformity on granite of the Dampier Batholith. The sill was named Gidley Granophyre and dated at 2196 ±26 Ma by de Laeter and Trendall (1971). It is differentiated with a gabbroic base (see Stop 1.2).

On the south side of the Sholl Belt, the Cooya Pooya Dolerite, a large complex sill, also intrudes at, or close to, the basal unconformity of the Fortescue Group on units of the Sholl Belt. The dolerite also locally has a granophyric top (and very locally an ultramafic base), and could well equate to the Gidley Granophyre on the south limb of the broad anticlinorium.

Excursion stops – Day 1

Excursion distances are measured from the Karratha turnoff from the main Northern Highway. Travel north along Northern Highway for 19.2 km to where a signpost indicates 13 km to Cleaverville Beach on a dirt road to the left. Drive along this dirt road for 10.5 km to a series of low outcrops in the marshes.

Stop 1.1 Pillow basalts in the Regal Formation (30 mins)

Aphyric pillow basalts in the Regal Formation (= Lagoon Volcanics of Kiyokawa, 1993) have well developed pillows, pillow droops and interpillow sediment indicating bedding dipping 75° towards 335° and younging to the NNW towards the Cleaverville Formation. Vesicles are well developed in the chilled margins of the pillows. Metamorphic grade is prehnite–pumpellyite facies. In Kiyokawa's interpretation, this formation represent the upper part of an oceanic island arc. *Location: 2356–Roebourne 010140*

Continue northwestward on the Cleaverville Beach road. At 1.2 km from Stop 1.1, there is a fork in the road. Take the left branch towards 'Footrot Flats', and drive past mangrove swamps for a further 2.7 km to the end of the track at the beach.

Stop 1.2 Banded Iron Formation (BIF), Cleaverville Formation (60 mins)

The rock platform to the north of the road turnaround is in the cherty BIF of the Cleaverville Formation (= Snapper Beach Formation of Kiyokawa, 1993, who subdivided it into black and white bedded or laminated chert, siliceous shale, bedded silicic tuff, red chert and BIF at the top). The thickness of the unit is at least 300 metres. This formation occupies the uppermost part of the crustal section of the West Pilbara Coastal Greenstone (WPCG) Belt and is considered by Kiyokawa to represent the sedimentary cover of an oceanic island arc.

In the rock platform, the cherty BIF dips ~70° towards 315°, and contains many tight to isoclinal folds with variably plunging axes overprinted by more brittle-style folds with near vertical axes. The latter folds commonly have limbs truncated by small 030°-trending faults with sinistral displacement. Kiyokawa has identified three deformations in

the outcrops: horizontal asymmetric folds (D_1), normal faults (D_2), and strike-slip deformation (D_3). D_1 and D_2 are associated with the initial collision of the island arc, and D_3 is probably related to the late-stage sinistral shearing evident from the regional maps. In the distance to the west is the Burrup Peninsula with the Gidley Granophyre.
Location 2256–Dampier 976146

Retrace the road for 7.8 km past Stop 1.1 to where a line of hills crosses the track. This is 6.6 km from the main Northern Highway.

Stop 1.3 Clastic rocks of the Nickol River Formation (50 mins)

The crest of the ridge is occupied by quartzose gritstone and sandstone with pebbles of clear vein quartz. The unit is iron-stained in places. Bedding dips 53° towards 140°. In a small gully 100 metres to the north of the road, the gritstone can be seen to young upward into cherty bands, which in turn pass eastward into felsic rocks and then into pillow basalts facing eastward. Green fuchsitic stain in the siltstone is caused by chromium (>1000 ppm). The chert is black in places and appears deformed with a lineation pitching ~30° to the SW. The clastic band is locally underlain by basalt and faulted to the north.

The position of this clastic band in the regional succession is very important for interpretation of the regional geology. The original interpretation is that it is part of the Nickol River Formation near, but not at the base of, the formation. The clastic band can be traced both north and south across folds for several kilometres (Stop 1.4), and underlies the pillow basalts which young toward the Cleaverville Formation (Fig. 1.2).

A more recent interpretation by Kiyokawa (1993) regards this band (the Hill 44 member of his Lizard Hills Formation) as part of the cover sequence unconformably overlying the pillow basalts of the Nickol River Formation (Kiyokawa's Lagoon Volcanics). Kiyokawa (1993) considers that this band is the first occurrence of detrital sediment which includes basal conglomerate, well sorted quartz arenite with shallow-water sedimentary structures (e.g., herringbone cross-bedding) and poorly sorted sandstone. In Kiyokawa's interpretation, the formation represents the cover sequence after emplacement of the island arc succession and was involved in later intensive folding. In the alternative interpretation, this band lies near the base of the mafic basalt succession, and represents clastics swept into a basin from the continental crust on the shoulders of the widening rift. In this interpretation the rift would have widened sufficiently to enable the thick pile of overlying mafic volcanics to be deposited prior to the deposition of the Cleaverville Formation. *Location: 2356–Roebourne 008106*

Continue along track a further 3.6 km to where a side track to the southwest turns towards Big Tree Well. Drive for about 1 km along this side track to a series of low hills. These hills are part of the mining lease of Phoenix Gold Pty Ltd*, and permission must be obtained before proceeding on the property.

* Address: Mr D. Rundell, Phoenix Gold Pty Ltd, P.O. Box 810, KARRATHA 6714

Stop 1.4 Deformed rocks of the Nickol River Formation (40 mins)

The rocks in this series of outcrops are highly strained conglomerate, felsic volcanics, chert and basalt. The foliation has a well-developed elongation lineation plunging gently to moderately towards 060°, appears mylonitic in places, and is folded by the regional ENE-trending folds. Regional mapping indicates that the rock units can be traced into the clastic units at Stop 1.3.

Kiyokawa (1993), however, considers this to be part of his amphibolite pillow (AP) unit which consists mainly of amphibolite and metabasite, and a small amount of schistose rhyolite. Original lava flow structures, including pillows, are preserved in some of the amphibolites. In Kiyokawa's interpretation, this succession represents the upper crust of an oceanic island arc. Kiyokawa considers that the klippe structure of this unit is well preserved in the southern part of the Amphibolite unit, where bedded black and white chert lies on the amphibolite across a low-angle thrust. *Location: 2356–Roebourne 013079*

Return to the main Northern Highway. If time permits, additional outcrops of the Karratha Granite and the Gidley Granophyre can be included. The trip may also go to the Harding Dam for spectacular scenery and to examine the Cooya Pooya Dolerite.

Approximately 10 km before (west of) Roebourne, the Northern Highway crosses the keel of the main syncline of Cleaverville Formation BIF and shale. Five-and-a-half kilometres farther towards Roebourne, the workings south of the Northern Highway are the Weeriana Gold Mine in the Nickol River fuchsitic cherts.

The excursion will stay overnight in the Roebourne area.

OVERVIEW OF THE HAMERSLEY PROVINCE

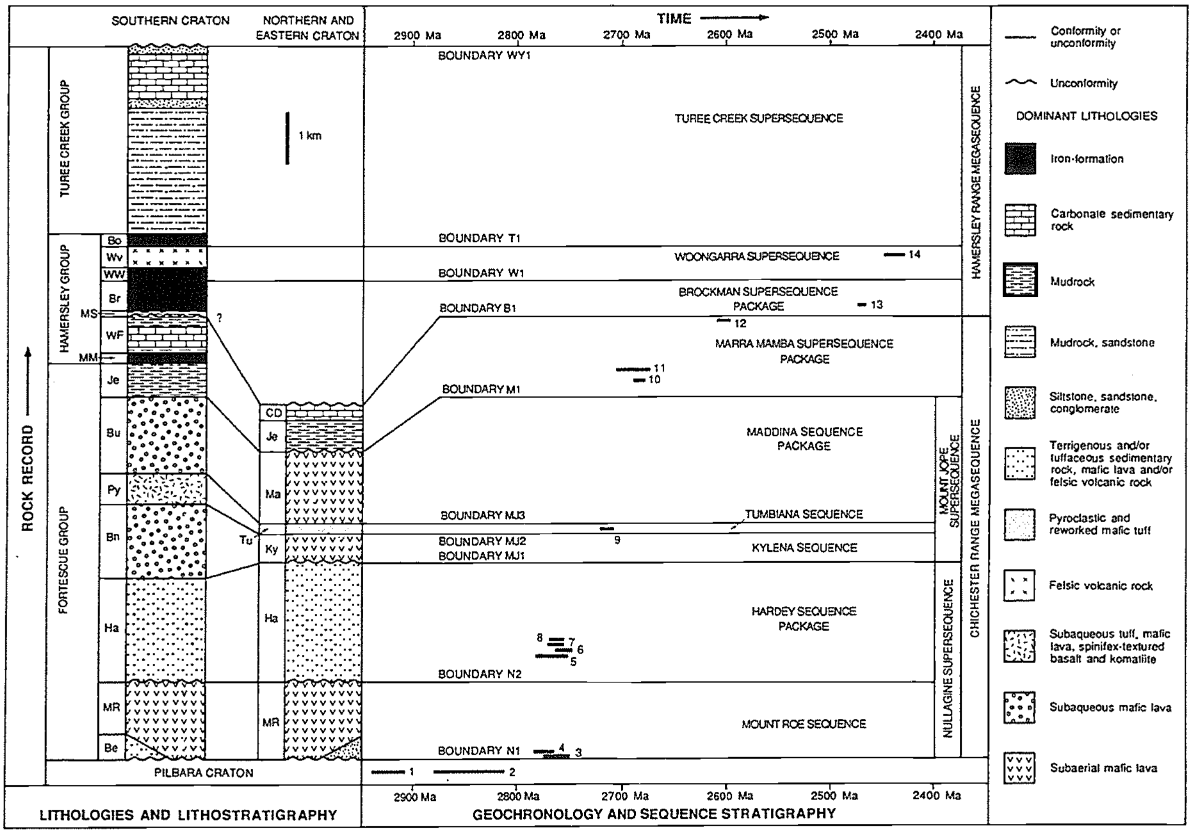
The term, Hamersley Province, refers to the geological region where the Mt Bruce Supergroup, which includes the Hamersley Group, crops out. The Hamersley Province is preferred to the term, Hamersley Basin (of Trendall, 1968), because stratigraphic and geochronological evidence indicates that the Mt Bruce Supergroup (of MacLeod *et al.* 1963, redefined in Trendall, 1979) "...was formed in a succession of distinctly different tectonic settings over a period of more than 330 Ma. In addition, the present outcrop pattern of the Mt Bruce Supergroup is not a primary depositional feature but rather, it is the result of syn- and post-depositional tilting, folding and erosion at several scales, i.e., it is largely structural and not depositional" (Blake, 1993, p.191).

The granite-greenstones of the Pilbara Craton, on which the Mt. Bruce Supergroup rests unconformably, were established as a stable continental nucleus before 2770 Ma. The Fortescue Group at the base is overlain by the Hamersley Group, above which is the Turee Creek Group. These subdivisions are largely based on lithological similarities; indeed, the Fortescue Group is dominantly composed of mafic volcanic flows whereas the Hamersley Group is characterised by cherty, banded iron formations (BIF). The Turee Creek Group contains thick terrigenous turbidites, conglomerates, stromatolitic carbonates and orthoquartzites (and was thus originally considered part of the younger Wyloo Group which contains similar lithologies). But some stratigraphic considerations (e.g. Kriewaldt, 1964) and new geochronological results indicate that these subdivisions do not fit readily into the interpreted tectonic hierarchy, and thus Blake and Barley (1992) and Blake (1993) have proposed new subdivisions based on sequence stratigraphy, which are now often preferred in published works. Both schemes and how they equate are shown in Table 2.1, which contains data on relevant age determinations in the region. The new subdivisions are used here for references pertaining to tectonics whilst the old ones are retained for descriptions and progress in the excursion notes.

The following tectonic synopsis is derived mainly from Blake and Barley (1992) and from Blake (1993). The Archaean Chichester Range Megasequence (Fortescue Group, Marra Mamba IF and Wittenoom Formation, see Table 2.1) is composed of the Nullagine, Mount Jope and Marra Mamba Supersequences. The basal Nullagine Supersequence, composed of the Mt Roe and Hardey Sequences, comprises mainly subaerial basalts and terrigenous sedimentary rocks (with minor felsic volcanics). They were deposited during an episode of WNW-ESE directed crustal extension that was initiated at about 2770 Ma. The overlying Mount Jope Supersequence, which comprises mostly basalt and tuff, was deposited during the subsequent development of a WNW-ESE trending rift before about 2690 Ma. Mudrock, carbonate and cherty-iron formation in the late Archaean (~2690 to 2600 Ma) Marra Mamba Supersequence were deposited on the craton's ensuing passive margin, which was divergent to the south. An unconformity, or condensed succession covering a time span of as much as 130 m.y., separates the top of the Archaean Chichester Range Megasequence from the Early Proterozoic Hamersley Range Megasequence (Mount Sylvia Formation to top of Turee Creek Group, see Table 2.1) during which time an oceanic island arc is interpreted to have collided with the southern Pilbara Craton margin. According to Blake and Barley (1992), the subducting oceanic plate flipped from dipping southwest to dipping northeast, and convergence resulted in the formation of a marginal subduction-related orogen with associated arc and backarc vulcanism. Iron formation and distal arc-derived tuffs of the Brockman Supersequence Package were deposited on a siliciclastic-starved platform in a neutral continental backarc setting at around 2470 Ma, followed by the overlying 2440 Ma Woongarra Supersequence of felsic tuffs, iron formations and probably coeval mafic rocks.

Evidence of compression appears later, during the Turee Creek Supersequence (Boolgeeda Iron Formation and Turee Creek Group, see Table 2.1), with uplift to the south of, and along, the Paraburdoo Hinge Zone and the initiation of the McGrath Trough: a west-northwest trending foreland basin on the southern part of the Craton. The McGrath Trough started during deposition of the Turee Creek Group and possibly the underlying Boolgeeda Iron Formation, and continued during deposition of the lower part of the overlying Wyloo Group.

Table 2.1 Summary of the lithologies, lithostratigraphy, sequence stratigraphy and geochronology of the Mount Bruce Megasequence Set. The lithological columns are cumulative average maximum thicknesses and show dominant rock types and lithostratigraphic nomenclature (groups and formations). Formations in the Fortescue and Hamersley Groups are abbreviated as follows: *Be* = Bellary Formation, *MR* = Mount Roe Basalt, *Ha* = Hardey Formation, *Bn* = Boongal Formation, *Ky* = Kylena Basalt, *Py* = Pyradie Formation, *Tu* = Tumbiana Formation, *Bu* = Bunjinah Formation, *Ma* = Maddina Basalt, *Je* = Jeerinah Formation, *MM* = Marra Mamba Formation, *WF* = Wittenoon Formation, *CD* = Carawine Dolomite, *MS* = Mount Sylvia Formation and Mount McRae Shale, *Br* = Brockman Iron Formation, *WW* = Weeli Wolli Formation, *WV* = Woongarra Volcanics, *Bo* = Boolgeeda Iron Formation. The stratigraphy of the Turee Creek Group is for the Hardey syncline, amended according to this field guide. The right part of the figure shows the sequence stratigraphy and contains a summary of the most precise geochronology available (ages are represented by error bars). Age 1 is the age of the youngest rock unit in the basement that is known to be unconformably overlain by the Mount Bruce Megasequence Set and age 2 is the youngest age from a basement granitoid batholith. Sources and methods of age determinations are as follows: 1, 3, 4, 6, 7, 8, 9, 10, 11, Arndt *et al.* 1991 (U–Pb zircon, SHRIMP); 2, Bickle *et al.* 1989 (Pb–Pb whole rock); 5 Pidgeon, 1984 (conventional U–Pb zircon); Hassler, 1993 (conventional U–Pb), 13, Trendall *et al.*, 1990 (U–Pb zircon, SHRIMP); Pidgeon and Horwitz, 1991 (conventional U–Pb zircon). (Extract from Blake, 1993, fig. 3)



DAY 2 FORTESCUE AND BASAL HAMERSLEY GROUPS

Most of this day will be spent driving from Roebourne to Wittenoom through the Chichester Ranges. The first stop will illustrate the profound unconformity between the flat-lying Fortescue Group and the variably deformed and metamorphosed terrain of the Sholl Belt. The route then traverses a scenic route through the Cooya Pooya Dolerite and the Fortescue Group, which is dominantly three mafic volcanic units separated by quartzose clastic bands. The entire succession is flat-lying in the northern part of the Pilbara, but there is an important low-angle unconformity between the Mt Roe Basalt, which forms the base of the succession, and overlying units. Another important disconformity occurs at the base of the Jeerinah Formation which marks the beginning of a conformable succession that continues upward into the Hamersley Group.

Starting from Roebourne, join the main Northern Highway and turn SW towards the Harding Dam direction. After about 1 km a road turns left towards the Harding Dam. Reset odometer to 0 km and follow the Harding Dam road but do not turn off to Harding Dam. Cross the Robe River Mining Co. railway line from Pannawonica to Cape Lambert and, at 10.6 km, low hills to the left are even-grained gabbro, part of the Andover Complex. At 22.2 km, the road crosses the Sholl Fault.

There is a cross-road at 22.6 km; keep straight ahead. Cross the headwaters of the Nickol River at 27.3 km. At 34.6 km, the flat-topped hills on the right, Twin Table Hills, are Tertiary laterite mesas. Mt Sholl on the left is part of an outlier of Mt Bruce Supergroup. At 40.6 km, cross the railway from Tom Price to Dampier (owned by Hamersley Iron Pty Ltd), and turn left along the private road. The Radio Hill Mine is at 44.1 km. Continue to 56 km where a track turns off to the right towards the abandoned Yannery Mine. Follow track for 3.0 km to where it climbs to the crest of a ridge overlooking a plain to the south where there is another abandoned base metal mine, the Whundo Mine. Stop at the ridge crest.

Stop 2.1 Basal Fortescue Group unconformity (45 mins)

The rocks in the road cut are complexly deformed phyllites of the Sholl Belt, with a crenulation cleavage dipping 65° towards 040°. There are deformed quartz veins elongated in the crenulation cleavage. The protolith is considered to be a silicic volcanic rock. About 25 metres above road level are gently southward-dipping medium- to fine-grained sandstone beds which here form the basal succession of the Fortescue Group. The unit is assigned to the Hardey Sandstone. It contains sporadic chert pebbles, some cross-bedding and a parting lineation trending 195°. In other places, the basal unit in the Fortescue Group is the vesicular Mt Roe Basalt emplaced under subaerial conditions in most areas. Relief on the basal Fortescue unconformity is locally up to several tens of metres; in this location, it is ~20 metres.

About 100 m to the north are the abandoned workings of the Yannery Hill Mine (Pinderi Hills 929696), where copper-zinc mineralisation was exploited in the metamorphosed felsic volcanics. According to Hickman et al. (1990, p.26) the ore lode is "... a stratabound 1 to 3 m thick horizon in the trough of a northwesterly plunging synform. Ore minerals are secondary, and include malachite, chalcocite and cuprite. Total production from Yannery Hill during the period 1920 to 1968 was 482 tonnes of copper from 1133 tonnes of copper ore and 1912 tonnes of cupreous ore."

Location: 2255–Pinderi Hills 928695

Retrace the path back along the access track to the Hamersley railroad and reset odometer to 0 km. Turn right towards the southeast and follow the track with the railroad on the right. At 6.5 km, the rubbly ridges across the road are part of the Proterozoic Cooya Pooya Dolerite, which has intruded along the unconformity at the base of the Mt Bruce Supergroup after deposition of the Mt Roe Basalt and the Hardey Sandstone.

Continue southeast; at 18.4 km, a sign indicates that the road has entered the Chichester–Millstream National Park. The rocks are subhorizontally jointed mafic clastic units, part of the Lyre Creek Agglomerate Member of the Mt Roe Basalt. At 20.7 km, near the intersection with the high-vehicle detour road from the north, there are exposures of subhorizontal mafic sandstone of the Cliff Springs Formation (= Hardey Sandstone equivalent). Bedding is subhorizontal with planar beds, although some crossbeds occur in coarse-grained lenses. Sporadic crossbeds indicate transport to the southeast. This unit is derived from the underlying Mt Roe Basalt, and was deposited in a fluvio-lacustrine environment.

At 21.6 km, the road to Pannawonica crosses the railway line and turns off to the southwest. Continue along the unsealed road to the southeast. At 22.4 km, the Robe River Iron Associates railway crosses above the Hamersley Iron rail line, the order of superposition giving the relative age of the rail lines!

At 33.1 km, there is a railway bridge with a concrete culvert over the Harding River. The surrounding flat-topped hills are capped by the Pillingini Tuff, which overlies the Kylena Basalt, which in turn overlies a complex sedimentary and volcanic association of the Cliff Springs Formation. Sporadic spinifex texture has been found in the Kylena Basalt, which is a vesicular terrestrial basalt.

Table 2.2 Summary of the development of the Nullagine and Mount Jope Supersequences, and their boundaries (From Blake, 1993, table 3).

SEQUENCES, SEQUENCE PACKAGES AND BOUNDARIES		DOMINANT ROCK TYPES	REGIONAL EVENTS		LOCAL EVENTS
	BOUNDARY M1		Some degradation of the northern Craton, subsidence of the southern Craton	Divergent southern craton margin	?
MOUNT JOPE SUPERSEQUENCE	MADDINA SEQUENCE PACKAGE	Basalt	Flood basalt aggradation	Rifting of the southern craton margin	Reactivation of some Nullagine Supersequence faults, local gentle centroclinal folding caused by differential vertical movements in the basement
	BOUNDARY MJ3		Non-deposition ?		
	TUMBIANA SEQUENCE	Mafic tuff, reworked tuff and basalt	Pyroclastic and sedimentary aggradation		
	BOUNDARY MJ2		Non-deposition and some degradation ?		
	KYLENA SEQUENCE	Basalt	Flood basalt aggradation		
	BOUNDARY MJ1		Some degradation of the northern Craton		
NULLAGINE SUPERSEQUENCE	HARDEY SEQUENCE PACKAGE	Terrigenous clastic sedimentary rock, subordinate mafic and felsic volcanic rock	Dominantly sedimentary aggradation, extensional sedimentary basins and felsic volcanism related to WNW-ESE crustal extension	Rifting to the west of the present craton ?	Reactivation of basement faults, NNE-trending mafic dykes in lower part
	BOUNDARY N2		Regional degradation, block faulting related to WNW-ESE crustal extension		Local folding caused by differential vertical movements in the basement, reactivation of basement faults
	MOUNT ROE SEQUENCE	Basalt, local significant basal terrigenous sedimentary rock	Flood basalt aggradation, oldest record of WNW-ESE directed crustal extension		Local basal extensional sedimentary basins, reactivation of basement faults, NNE-trending mafic dykes
	BOUNDARY N1		Regional degradation before onset of Nullagine Supersequence deposition		?

At 36.8 km, cross over the Hamersley Iron rail line, and drive on to 40.4 km where there is a series of road cuts in the Pillingini Tuff. The road here follows incised streams draining to the north off the Chichester Ranges scarp, and at 46.8 km the road climbs out of the gorge country onto a plateau on the Pillingini Tuff. The Fortescue plains extend to the Hamersley Ranges, which can just be seen in the distance to the south. Note the termite mounds on the south side of the road.

At 55.0 km, there is a T-junction intersection of a road from the north and south (the road to Millstream). Turn left (to the north) across the railroad. The road follows across the plateau to the scarp at the edge of the Chichester Ranges. At 68.8 km, stop near Mt Herbert near the top of the descent to the plains to the north. Stops 2.2, 2.3 and the optional stop are in National Parks. Pet dogs, lucifers and geological picks must remain in the bus!

Stop 2.2 Tumbiana Sandstone (25 mins)

The outcrop of Tumbiana Sandstone in a small turning area to the southeast of the road contains a stromatolite-bearing carbonate lens in the otherwise mafic sandstone. The stromatolites are small (1 to 3 cm amplitude) oncolitic forms. The sandstone contains flakes of white mica, possibly derived from erosion of granite in the older Pilbara terrain. From this vantage point, there is a clear view of the gentle south dip (~1°) of the Fortescue Group, and the high-energy younger erosion by the northeast-flowing streams at the headwaters of the Gorge and other rivers. The uplift which rejuvenated the drainage in the Hamersley Province is mid-Cainozoic and could be related to buckling of the Australian continental crust associated with the Early Miocene collision of Australia with the Sunda Arc and Philippine Plate. The small pyramidal hill to the northeast is Pyramid Hill, from which the name of the 1:250,000 geological map name derives. The dark rock in some hills in the middle distance is the flat-lying Cooya Pooya Dolerite.
Location: 2355–Cooya Pooya 226417

Continue north down the road for a few kilometres to 73.7 km where there is a track to the right to Python Pool. Walk ~200 m to the pool at the foot of a 20m fall in the stream bed.

Stop 2.3 Kylena Basalt (25 mins)

The Kylena Basalt forms a ledge indicating a dip of the bedding ~20° to the southwest. In the pool there are three common species of freshwater fish, which appear to populate most pools in the region. The most common is the western rainbow fish (Melanotaenia splendida australis) *which can be seen near the surface. The others are spangled perch* (Leiopotherapon unicolor) *–a larger fish seen on the pool bottom, and barred grunter* (Amniataba percoides).
Location: 2355–Cooya Pooya 245407

Reset odometer and return to the railway T-junction intersection (19.2 km). The flat-topped hill to the southeast of the intersection is part of the laterite of the Hamersley Surface.

Continue southeast towards Millstream. At 33.6 km, flaggy outcrops on the left (eastern) side of the road are fine- to very fine-grained sandstones at the top of the Woodiana Sandstone which lies at the base of the Jeerinah Formation (Table 2.1). The beds contain ripple marks, and elsewhere coarse sandstone is present in the Woodiana Sandstone, which represents an important clastic intercalation near the top of the dominantly mafic volcanic Fortescue Group. The Woodiana Sandstone passes up into cherty bands intercalated with thin clastic bands. Elsewhere, stromatolites are found at this level (see Stop 2.4).

At 38.9 km on the main Wittenoom road, the road to Millstream turns off to the southwest. There is excellent exposure of the Jeerinah Formation in the Fortescue River crossing at Millstream, which may be visited if time permits. Follow the signs towards Millstream, and take the track on the northern side of the Fortescue River signposted to Crossing Pool. Follow the track past Crossing Pool to where it crosses the Fortescue River in a concrete causeway.

Optional stop Jeerinah Formation ash beds, Millstream (45 mins)

Outcrops of Jeerinah Formation are well exposed in the Fortescue River on the northern bank west of the causeway. At a bar which is ~200 m downstream from the causeway, there is a decametre-sized fold-and-thrust structure. The fold hinge is subhorizontal and trends towards 008°, and the folds are brittle–ductile box folds representing accommodation structures in an otherwise flat-lying succession. The orientation of the folds is unlike the common ESE trend for the major regional folds, but close to the NNE trend of basement faults which controlled the distribution and facies of various units in the Fortescue Group. The folds could reflect reactivation of these basement structures during the younger folding events.

Two ash beds within the Jeerinah Formation are exposed on the eastern side of the box-fold structure. The upper bed is a fine-grained graded tuff. The majority of fragments consist of angular quartz grains and shards, which contain obvious volcanic textures (such as resorbed margins). The matrix consists of fine-grained quartz and sericite. The lower ash bed consists of an accretionary lapilli tuff overlain by ashfall tuff. Both concentrically banded and massive lapilli are present. The nature of the rims is unclear due to weathering and replacement of the matrix by iron oxides.

The overlying tuff does not appear to be graded, and consists of angular fragments and devitrified shards in an iron oxide matrix. *Location: 2354–Millstream 086138*

Return to the main Roebourne–Wittenoom Road and continue to the southeast towards Mt Florance Station. Reset the odometer at the Mt Florance homestead turnoff. At 4.6 km southeast of the Mt. Florance turn-off (approximately 100 m before a cattle grid), turn left on a track that heads north from the main road. After approximately 800 m, the track crosses a fence and heads east towards the Sherlock River. The main outcrop forms a prominent hill west of the track, where it crosses a small creek approximately 3 km from the main road.

Stop 2.4 Unconformity at the base of the Woodiana Sandstone (45 mins)

The Maddina Basalt Member is exposed in the creek and on the lower slopes of the hill, and is overlain by approximately 10 m of Woodiana Sandstone at the base of the Jeerinah Formation at this locality. The basalt is medium-grained, vesicular, and highly weathered, and consists of kaolinised feldspar and goethitic laths, possibly after pyroxene or spinel. A silicified matrix-supported conglomerate consisting of angular fragments in a fine-grained matrix is developed at the base of the Woodiana Sandstone. This conglomerate is overlain by graded cycles of small-pebble conglomerate, fine-grained sandstone and siltstone. The sandstones commonly overlie a graded basal conglomerate, and pass upward into finely laminated silicified siltstone and mudstone with sporadic stromatolite beds. A bed of digitate stromatolites is well exposed at the top of the hill, and is overlain by medium-grained quartz arenite. *Location: 2454–Mt Billroth 945876*

Return to the main Wittenoom road and proceed east-southeast towards Wittenoom. The prominent hill to the south is Mt Margaret. About 4 km out from Wittenoom, the road bends towards the south giving a panoramic view of the Hamersley Ranges.

The geomorphology comprises two geomorphic provinces: (a) the rounded hill tops are part of the Hamersley Surface, which developed from the ?Cretaceous to the mid-Tertiary, and (b) the gorges are incised into the Hamersley Surface by rejuvenation from the Miocene on. The Hamersley Surface has laterite developed along it, and in hollows there are lateritic gravels. The first uplift of the Hamersley Surface gave a drainage to the northwest in which the CID Robe River pisolitic iron ores were deposited. Detrital iron ore deposits of several generations have formed above the Hamersley Surface. In the Hamersley Province, the rounded hills are formed by BIF of the Brockman Iron Formation with the valleys following interbedded shales or mafic volcanic rocks, or the less resistant Wittenoom Formation.

The excursion will stay overnight in the Wittenoom area. In the evening a visit may be made to the Wittenoom Gem Shop in Sixth Avenue, Wittenoom (Tel: 89-7096) where there is a range of local semi-precious stone, polished iron ore, souvenirs and other artefacts available for sale. Note that this will be the last opportunity to buy film for the spectacular scenery of the days to follow.

DAY 3 THE HAMERSLEY RANGES GORGE COUNTRY

The Hamersley Ranges gorge country is some of the most spectacular scenery in the Pilbara, and is now part of the Karijini National Park. Visitors are expected to respect the National Park rules, which prohibit hammering or sampling rocks or vegetation. The National Park has been established only in the past five years, and previously mining of the blue asbestos fibre, crocidolite, occurred at several places. Visitors should note that exposure to asbestos fibres may be injurious to long-term health, and take precautions not to handle or breath in air containing fibres. Many of the former asbestos mines are located in Wittenoom Gorge, and were the reason for establishing the township. The waste from the mines was used as land and road fill, and visitors will notice the shining blue fibres in some of the road metal. Areas where asbestos fibre is prevalent are signposted.

The main geological features to be seen occur in the Wittenoom Formation and the overlying Brockman Iron Formation. Asbestos fibres, early extensional boudins known as "cross-pods" and banding in the iron formations at several scales will be illustrated (Trendall, 1968; Trendall & Blockley, 1970).

Reset the odometer at the Wittenoom Post Office, and proceed up the Wittenoom Gorge. The outcrops along the side of the road are in Wittenoom Formation. At 7.7 km at Crossing Pool, turn off the road to the car park on the right (western) side of the gorge.

Stop 3.1 Wittenoom Formation (40 mins)

The Wittenoom Formation is an extensive carbonate, shale and minor epiclastic unit which overlies the Marra Mamba Iron Formation and passes conformably upward into the Mt Sylvia Formation (Simonsen et al., 1993). In this outcrop, there is a small coset of T_{B-C} turbidites with grading and cross-lamination indicating transport to the south-southwest. There is also a zone of open-cast slump folds immediately below a T_C cross-lamination zone, suggesting that slumping here could have been triggered by traction of the turbidity current during deposition of the overlying bed. The importance of these structures is that they represent one of the rare places in the entire Hamersley Group where any palaeocurrent information can be obtained. Analysis of the regional distribution of the sparse palaeocurrents in the Wittenoom Formation indicates a slope to the southwest, with indications that some currents in the southern part of the Hamersley Province may be reflected from the southern margin of the depositional trough to flow westward along an east-southeasterly trending trough axis (Hasler, 1993).

Location: 2553–Wittenoom 362335

Continue up the gorge, passing the small settlement. At 10.6 km, park at the end of the road and walk ~500 m up the gorge to the old machine shed, and climb up on the old tramway on the western side of the gorge.

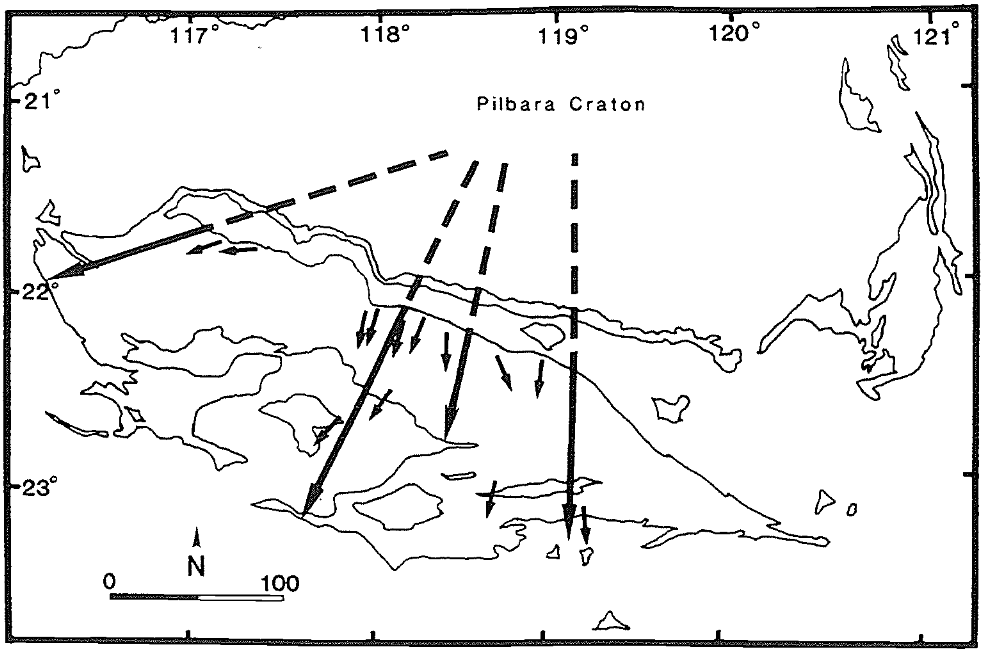


Fig. 3.1 Location of proposed source area of the Main Tuff Interval (MTI) of the Wittenoom Formation. Thick arrows represent vector mean palaeocurrents for each depositional area. Small arrows show mean transport directions at MTI sections where more than 4 vectors were measured. Note convergence of trends on an area in the north central Pilbara Block, suggesting that the MTI source volcano was located on the northern craton. From Hassler (1993, fig. 11).

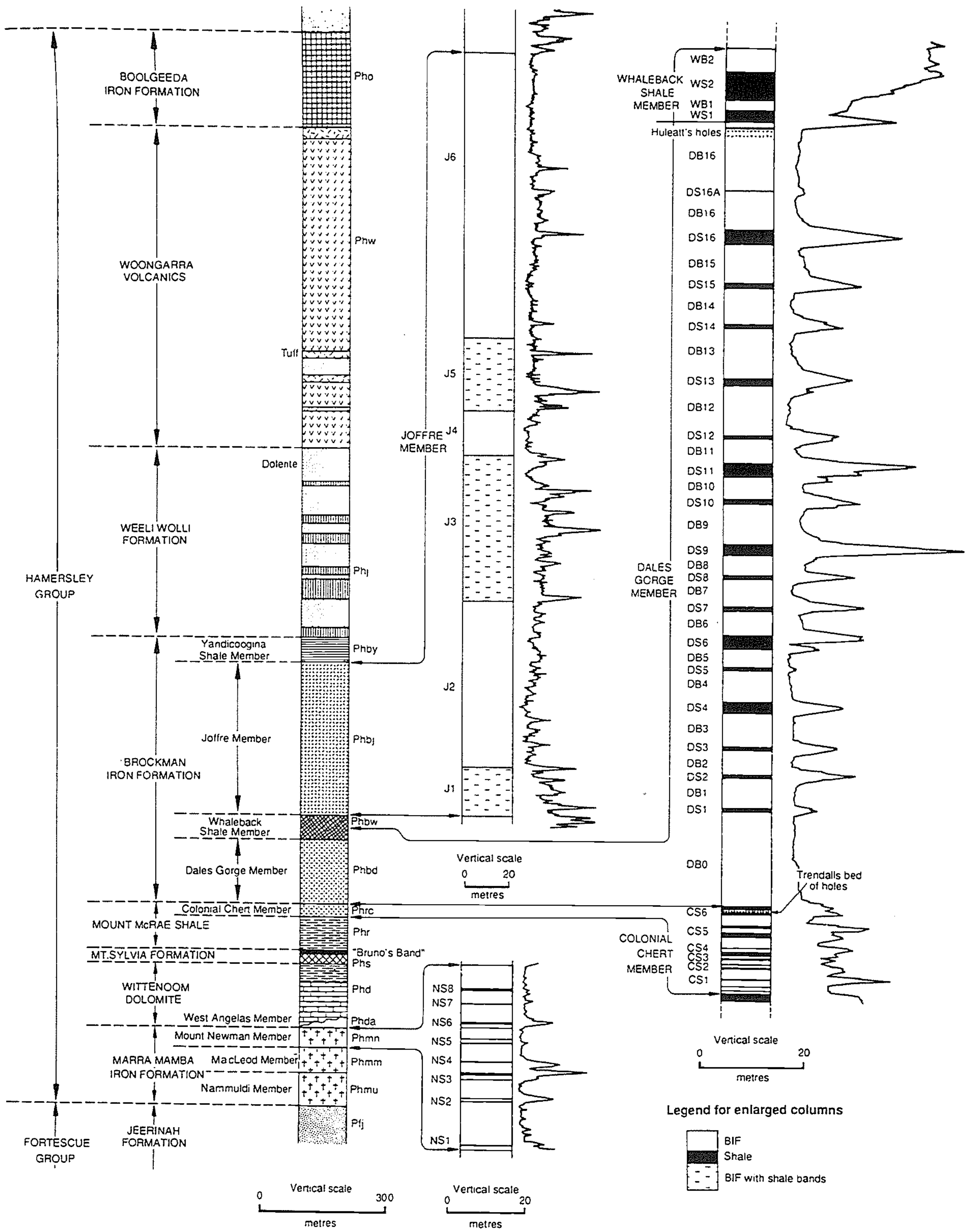


Fig. 3.2 Stratigraphic columns for the Hamersley Group including internal lithological unit numbering systems used by the major iron ore companies in the Hamersley Province, and the appropriate gamma log profiles (from Harmsworth *et al.*, 1990, fig. 4).

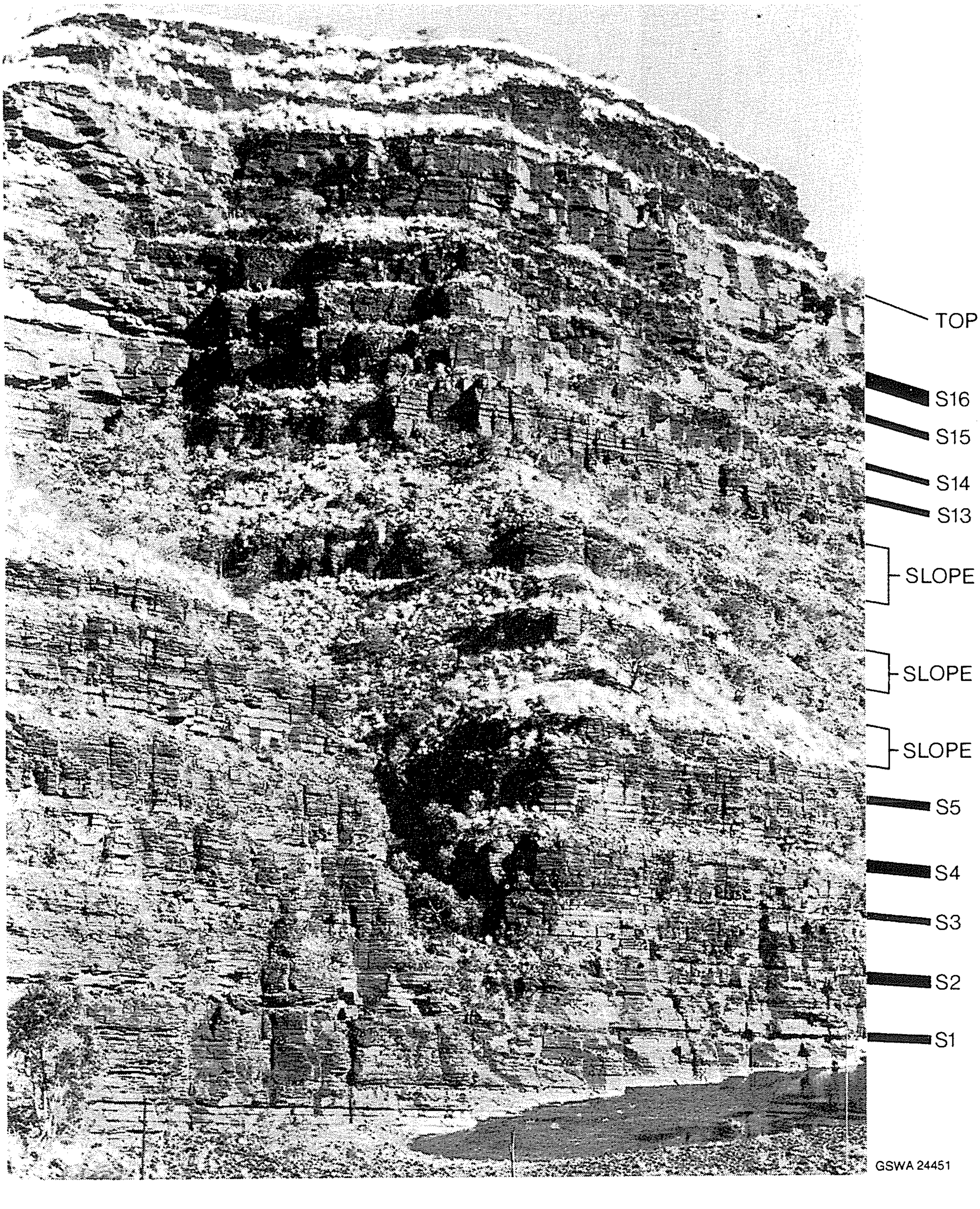


Fig. 3.3 View of the eastern side of Wittenoom Gorge immediately north of the old Wittenoom mine buildings, showing the macrobands of the Dales Gorge Member. The base of the cliff is at about the mid-point of BIF0, and the S macroband sequence up the cliff is marked. The groups S6 and S7, S8 and S9, and S10, 11 and 12 tend to merge into single grassy slopes, which are marked. From Trendall and Blockley (1990, fig. 4).

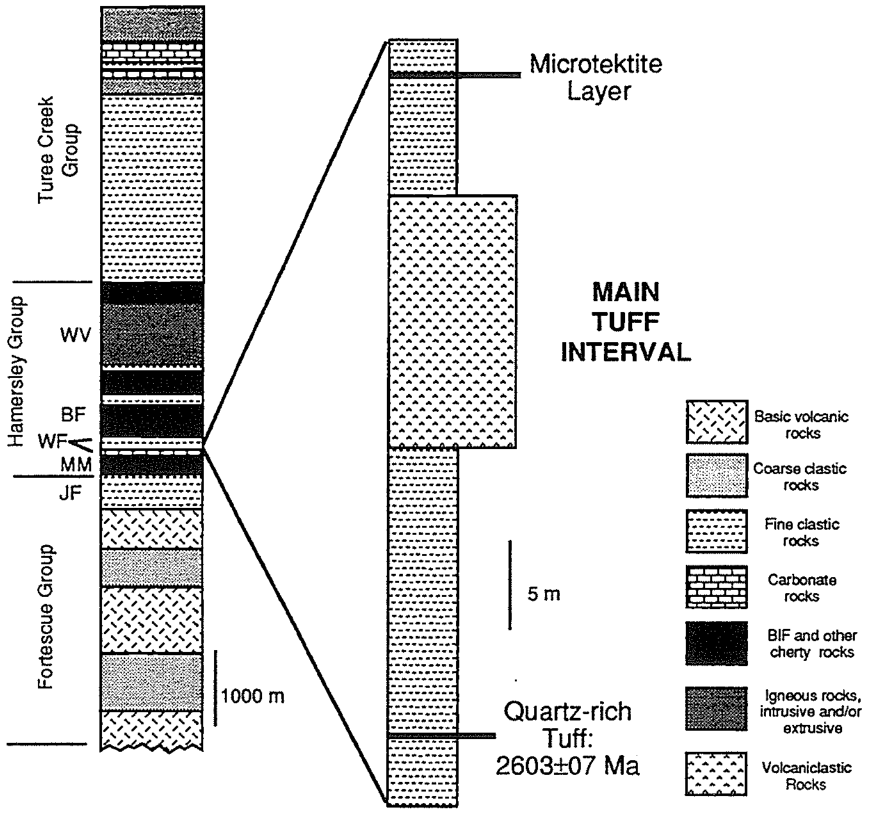


Fig. 3.4 Stratigraphy of the Mount Bruce Supergroup showing the position of the MTI in the Wittenoom Formation. The MTI is located between 2 marker beds, an overlying bed containing microtektites and underlying quartz-rich fallout tuff. Stratigraphic thickness after Trendall (1983). JF = Jeerinah Formation, MM = Marra Mamba Iron Formation, WF = Wittenoom Formation, BF = Brockman Iron Formation, and WV = Woongara Volcanics.

Stop 3.2 Dales Gorge Member (90 mins)

The cliff face on the eastern side of the gorge is a representative section through the Dales Gorge Member of the Brockman Iron Formation (Fig. 3.3, from Trendall & Blockley, 1970, fig. 4). The Dales Gorge Member contains 17 BIF horizons (BIF 0 to 16) separated by 16 shale intervals (S 1 to 16), which can be mapped throughout the Hamersley Province and form the basis for detailed correlation by exploration geologists. In the cliff face, S1 is just above the spray paint marks, and BIF 0 is the thick BIF unit below. In S1 there is a 2-m graded clastic band, which is likely to be a tuffaceous band. Zircons collected from S13 give a U-Pb age of 2603 ±7 Ma (Arndt et al., 1981). The tramway on the western side of the gorge leads to a number of drives from which blue asbsetos has been mined. The fibres are generally oriented at a high angle to the bedding, and appear to have formed by growth in dilatational sites during deformation. Some of the fibres are kinked indicating response to some of the minor later deformational events. In BIF 0 on the eastern side of the gorge are some "cross-pods" trending towards 050°. The cross-pods reflect early extension in the Hamersley Province, arguably during sedimentation of the upper stratigraphic units.

Location: 2553–Wittenoom 366302

Return to the parking area. Note the abundant asbestos fibres in the bitumen on the old road! Return to Wittenoom, reset odometer at the Post Office and drive east towards Yampire Gorge. About 10 km east of Wittenoom, note the view on the Hamersley Surface. The bitumen road starts at 17.1 km, and, at 22.7 km east of Wittenoom, turn south along the road to Yampire Gorge. Reset the odometer to 0 km.

At 11.3 km, the prominent band on the left of the track is Brunós Band, named in recognition of Brunó Campana, one of the pioneering CRA geologists whose work before there were any roads in the region set forth the stratigraphic framework of the Hamersley Province (Campana *et al.*, 1964).

At 16.8 km, there is an old railway carriage on the left. Stop at 17.1 km near the big cadjeput (paperbark) trees and walk to the old Yampire Mine workings.

Stop 3.3 **Asbestos fibres and cross-pods in the Yampire Mine** **(30 mins)**

The abandoned Yampire Mine was developed to mine crocidolite seams in the Dales Gorge Member. The Yampire Riebeckite Zone embraces the lowermost six BIF macrobands in the formation, with most of the economically important seams being restricted to BIF1 and BIF2 (Trendall & Blockley, 1970). Approximately 1,000 tons of crocidolite were mined from along the 6 km length of the Yampire Gorge workings, most of which was from the Yampire Mine. Structure contours on the Upper Seam show that it is folded by a broad fold trending easterly (Trendall & Blockley, 1970, plate 9). Interestingly, the enrichment in both Upper and Lower Seams trends 035°, which is oblique to the fold trend but approximately parallel to the early cross-pod structures. At this location, there is well-developed massive riebeckite in the roof of the adit and abundant kinked asbestos fibres in veins up to 4 cm thick. On the exposure in the main valley wall around from the adit, there are NE-trending cross-pods with internal imbrication inclined to the northwest. *Location: 2552–Wittenoom 491203*

Continue up Yampire Gorge. The incision of the gorge decreases as the road climbs up onto laterite of the Hamersley Surface at 22.3 km. Note the rounded landforms. At 27.8 km, turn left to Dales Gorge and drive to the car park. Walk down the track towards the Circular Pool. Note that there is one place where a short iron ladder is part of the track. The ladder is not difficult to negotiate, but those who prefer not to go down the track to the bottom of the gorge can observe features by walking along the plateau rim.

Stop 3.4 **Dales Gorge Member** **(100 mins)**

The Dales Gorge Member here is relatively flat-lying with "regional ripples" (Trendall & Blockley, 1970, p. 164–7) trending 100 ±10°. These structures are cm-sized microfolds related to the first and only major phase of regional folding to affect the northern part of the Hamersley Province – F_2 *in the terminology used in this field guide. Asymmetry of the "regional ripples" is such that the south limb of the microfolds is generally steeper than the north limb. The steepening is caused by solution removal and thinning on the steep south-facing fold limbs of the microfolds (see Trendall & Blockley, 1970, fig. 43). The axial surfaces of the microfolds commonly extend through several metres of thinly-bedded BIF and constitute a form of crenulation cleavage. "Cross-pods" and early diagenetic chert "macules" (Trendall & Blockley, 1970, p. 160–2) are also present in the outcrops in the floor of the gorge. The cross-pods trend northeasterly, and in cross-section the chert microbanding can be seen to be inclined to the northwest with relation to the enclosing microbanding. This inclination of the internal laminations of the cross-pods to the northwest is developed on a regional scale, with ≥80% of such cross-pods inclined that way. The reasons for this are not clear, but suggest a regional basement structural control on their formation.*

The present-day stream has dissected an older mid-Tertiary valley infilled with a Channel Iron Deposit (CID). A coarse boulder conglomerate exposed on the northeastern wall of the gorge on the way to Circular Pool possibly represents a point bar in the old mid-Tertiary river valley. *Location: 2653–Mt George 605134*

Return to the car park and, if time permits, go over to Fortescue Falls where there is a fine view of the incision into the Dales Gorge Member with a thin veneer of Robe River pisolite at the top of the lookout.

Reset odometer and proceed west on the Tom Price road towards Hancock Gorge. There are many examples of the recent incision of the old Hamersley Surface by headwall retreat of the gorges. The rounded hills on the left (south) are in the Joffre Formation, which commonly forms the summits in the region.

At the road intersection at 10.7 km, turn right towards Wittenoom, and then at 11.0 km turn left towards Weano Gorge. At 29.8 km, there is a turnoff to Kalamina Gorge. Keep straight ahead and at 40.5 km turn right to Knox Gorge. Drive to the Knox Gorge parking area.

Stop 3.5 **Knox Gorge** **(20 mins)**

Knox Gorge is the headwaters of Wittenoom Gorge and is deeply incised along vertical joints. It is retreating by headwall undercutting and rock falls. On the way to the lookout, note the "grey billy" – a form of silicified sandstone formed on the former Hamersley Surface as part of the laterite on which the CID was later deposited. Surface silicification associated with the Hamersley Surface is well developed here. The regional drainage prior to Miocene uplift of the Hamersley Province was ENE–WSW, parallel to the strike of the resistant ridges in the folded Hamersley Group rocks. The Hamersley gorges have formed by headwall retreat along steep north-facing erosional scarps, and there are many examples of stream capture in various stages of progress. Note the chert pods trending 050°. *Location: 2553–Wittenoom 333254*

Return to the Tom Price road and reset odometer. At 2.7 km, there is a junction with Weano Gorge road. Turn left towards Tom Price.

At 5.9 km, a rounded hill in the Hamersley Surface is being cut into by the rejuvenated erosion. The undulating Hamersley Surface comes down to road level in the Hamersley synclinorium in the foreground to the southwest.

At 10.0 km, where the road bends to the right, note the steep dips in the hill on the right (northwest) reflecting asymmetric F_2 folds facing to the north. This is part of the foreland fold-and-thrust belt that has displaced the Hamersley Group cover rocks to the north (Tyler & Thorne, 1990). Units likely to have detachment surfaces related to the fold-and-thrust belt would be shales in the Mt McRae Shale, the Wittenoom Formation and the Jeerinah Formation.

Continue along road towards Tom Price and admire Mt Bruce, the second highest peak in W.A. (1236 m). At the T-junction, take the branch to the right towards Tom Price. At 29.6 km, meet new road to Tom Price; turn left off old road. At 35.0 km, turn right (west) towards Tom Price on new bitumen road. Between 50 and 52 km there are extensive new road cuts in the Jeerinah Formation, which is composed here of basalt, vesicular in parts near the top of the hill, and dolerite sills and dykes.

At 61.0 km, there are more outcrops in the Jeerinah Formation, which overlies the Mt Jope Volcanics. The junction with the Paraburdoo–Tom Price road is reached at 69.2 km about 10 km south of the Shell Garage at the entrance to Tom Price township.

The excursion will stay overnight in Tom Price.

The excursion will spend the morning in a field conference outlining current ideas on the geology and tectonic evolution of the Hamersley Province. In the early afternoon there will be a short tour of the Hamersley Iron Pty Ltd mining operations and, depending on access, some of the spectacular fold structures in the Wittenoom Formation and in the Mt Sylvia Formation on the roads around the northern tailings dam may be visited.

Geological outline

Accumulation of the Mount Bruce Supergroup started in late Archaean times (~2.77 Ga: Pidgeon, 1984; Arndt *et al.*, 1991), through rifting with associated vulcanicity on a large craton (Blake & Groves, 1987). By Upper Fortescue Group times (~2.69 Ga: Arndt *et al.*, 1991), a shelf environment was established on a WNW-trending, passive margin, indicated by deeper facies and an increase in submarine mafic vulcanicity towards the SSW. During deposition of the Hamersley Group, the shelf developed into a submerged platform, marginal to an ocean in the general south and west (Morris & Horwitz, 1983).

Evidence for compression appears later with uplift in the southwest and the formation of the McGrath Trough: a foreland basin on the southern part of the Pilbara Craton (Daniels, 1975; Horwitz, 1983). The trough started during deposition of the Turee Creek Group (some time after ~2.4 Ga, which is the age of the upper part of the Hamersley Group, see Pidgeon and Horwitz, 1991) and continued during the Lower Wyloo Group. Upper Turee Creek Group and Lower Wyloo Group clastics and carbonates, and the Cheela Springs Basalt of the Lower Wyloo Group, are restricted to the McGrath Trough. There were hiati and unconformities on the southern, uplifted and warped margin of this foreland basin. To the north, there is concordancy of units; in places, possibly even continuity of sedimentation in the middle of the trough (see Stop 7.3). Palaeocurrents in fluvial units in the upper part of the Turee Creek Group indicate sources to the south and west (Powell & Li, 1991; Horwitz & Powell, 1992).

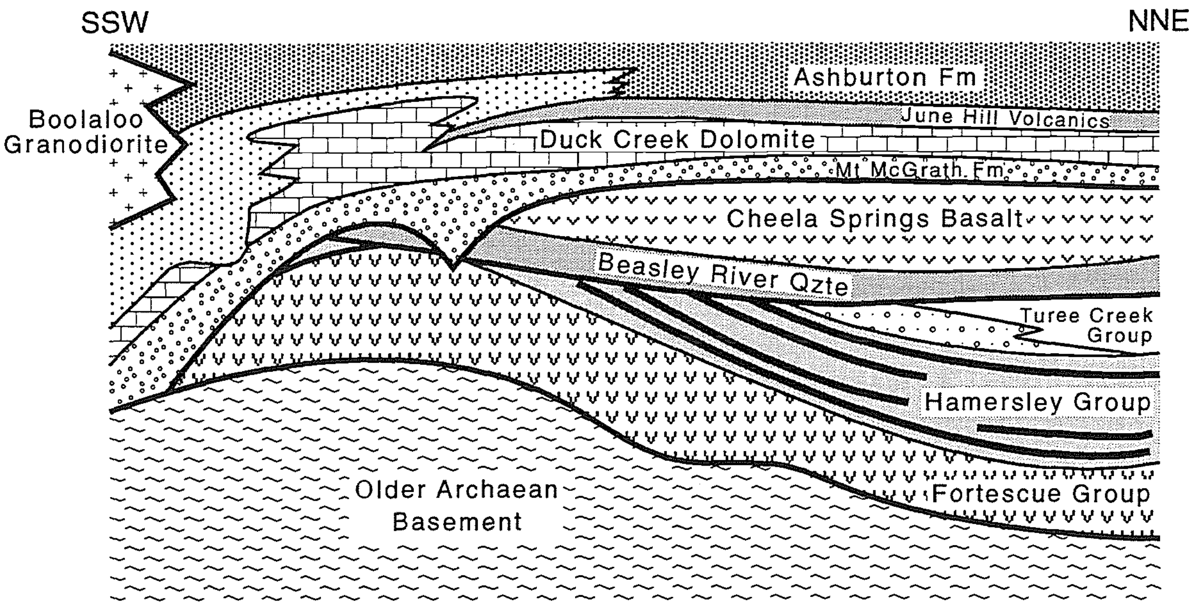


Fig. 4.1 Diagrammatic rock relationships in the Southwestern Hamersley Province.

A marked unconformity exists at the base of the Lower Wyloo Group along the southern margin of the Hamersley Province (Fig. 4.1). The basal unit, the Beasley River Quartzite, lies unconformably on units as young as the upper part of the Turee Creek Group and as old as mafic volcanics of the Fortescue Group. Mapping in the Hardey syncline region (Stop 6.1) shows that there was open 110°-trending folding prior to the deposition of the Beasley River Quartzite there, with a continuation of folding about the same axis after deposition of the Lower Wyloo Group (Powell & Li, 1991). These folds are parallel to the inferred trend of the McGrath Trough (Horwitz, 1983).

ESE-trending folds in the Turee Creek Group are truncated by the Beasley River Quartzite at the Lower Wyloo Group unconformity in the Hardey syncline. Tyler and Thorne (1990, p. 690) interpreted this relationship as indicating that the ESE-trending folding in the southwestern Opthalmia Fold Belt was older than folding with the same trend along strike in the Turee Creek syncline southeast of Paraburdoo, where the Turee Creek Group, the Beasley River Quartzite and the Cheela Springs Basalt are folded about an E-W axis. Powell and Li (1991) pointed out that the ESE-trending folds in the Hardey syncline also fold the Beasley River Quartzite and that there is only one axial-plane cleavage which extends from the Turee Creek Group into the Beasley River Quartzite. These relationships are interpreted by Powell and Li as indicating that there is only one set of ESE-trending folds which

Table 4.1 Structural relations in Opthalmia Fold Belt.

STRUCTURE	AXIAL TREND	CLEAVAGE	COMMENT
Strike-slip Faults Late Folds Normal Faults Kink Folds	100° NE ENE NE	No	Various late-stage structures, in part along reactivated older structures
F_3 folds	135 ±5°	Rare, only in tight hinges	Folds commonly concentrated near dykes; brittle-ductile structures
Dolerite Dykes	135 ±5°	No	Dykes cut F_2 folds. Dykes could be feeders to mafic volcanic units in Lower Wyloo Group
F_2 folds	100 ±10°	Upright in N to inclined & nearly recumbent in SE	Folds and cleavage decrease in intensity northward
Extensional structures in BIFs	NE	Bedding-parallel foliation	Chert pods formed by listric normal fault rotation. Rare recumbent isoclinal F_1 folds (SE Opthalmia FB)

Table 4.2 Tectonic relationships, Wyloo—Mt Bruce area.

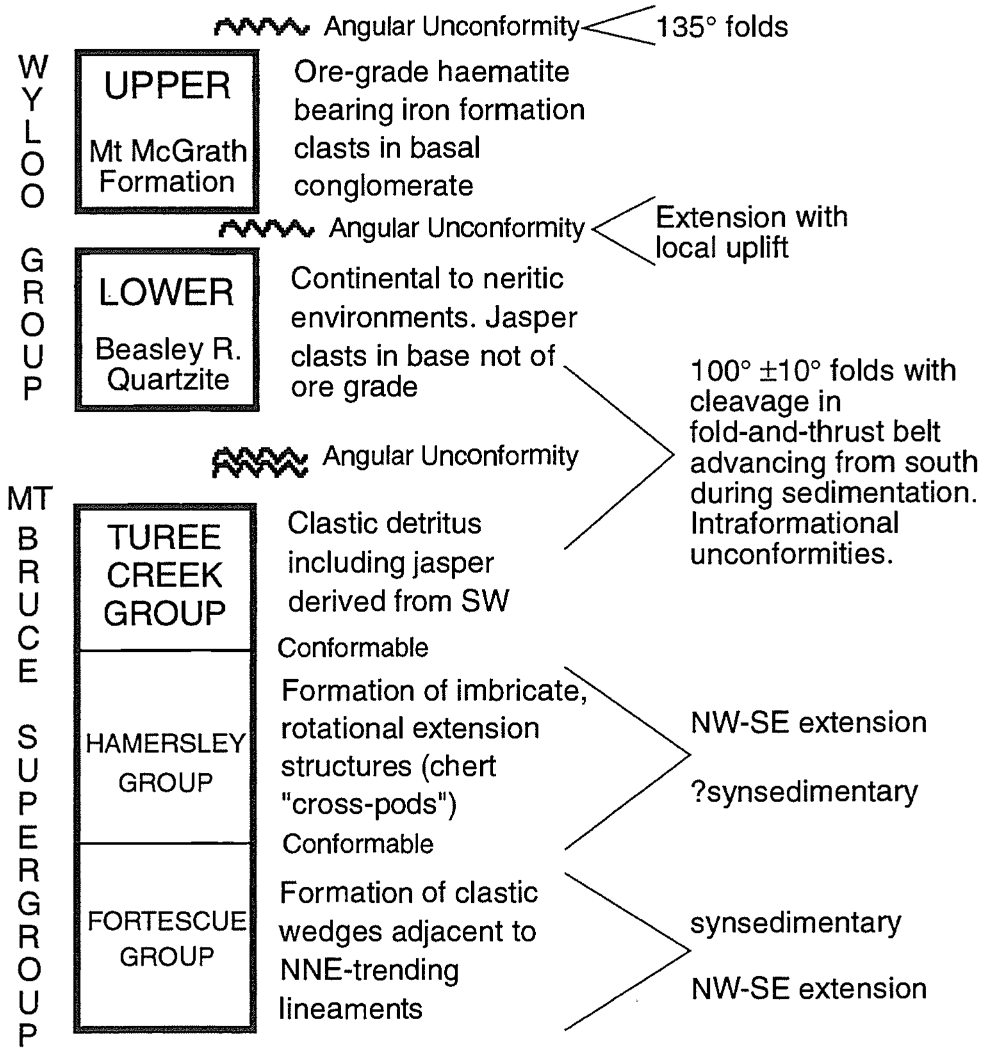
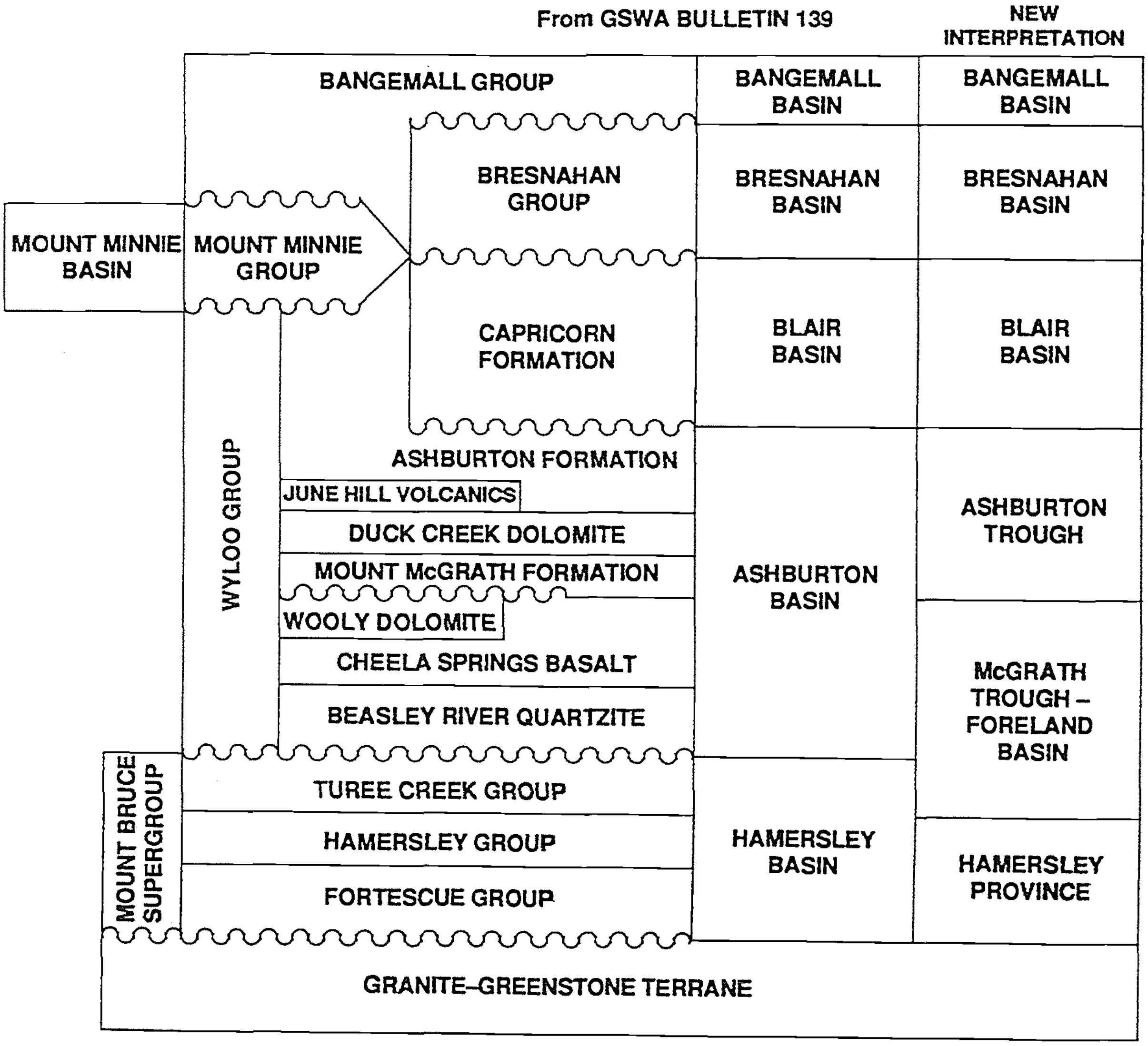


Table 4.3 Stratigraphic subdivisions of the southwestern Pilbara, after Thorne and Seymour (1991). Stratigraphic schemes are shown for comparison. Revised tectonic scheme shown at right.



started to form during Turee Creek times and continued to form after the Beasley River Quartzite had been deposited. Continuing progressive deformation of this type is characteristic of foreland fold-and-thrust belts where depocentres form and move in front of the growing orogen. Local unconformities, commonly with high angularity, form near the deformation front while conformable sedimentation continues in the axis of the trough.

Tyler and Thorne (1990) based their conclusions about the Hardey syncline on mapping by Trendall (1979) who did not recognise any Beasley River Quartzite in the core of the Hardey syncline. Our observations suggest that de la Hunty's original (1965) mapping was correct, and that the Beasley River Quartzite and its basal unconformity are both folded and preserved in the keel of the Hardey syncline (Stop 6.1). Evidence for uplift and erosion in the south is given by the observations that the Beasley River Quartzite rests on progressively older units as one progresses southwestwards (compare, for instance, Stops 6.1, 6.2, 7.1a, 7.3), and palaeocurrents indicate a southwestwards source for the fluvial facies in the upper Turee Creek Group (Powell & Li, 1991).

The Ashburton Trough is the depository of the Upper Wyloo Group, now dated at ~1.8 Ga (Pidgeon & Horwitz, 1991). The Trough limits the Hamersley Province to the south and the west, following two trends:

A) To the SSW, following the Paraburdoo Hinge Zone, and occupying the southern uplifted margin of the McGrath Trough, the Upper Wyloo Group is unconformable on the older units. It starts with clastics (Mt McGrath Formation), then carbonates (Duck Creek Dolomite), which are overlain by thick proximal turbidites with coarse fractions (Mininer Turbidite Member of the Ashburton Formation) on the north flank of the Ashburton Trough. No volcanicity is recorded along this margin.

B) To the west, along a more northerly trend, the trough margin is also marked by clastics of the Mt McGrath Formation which are unconformable on the Lower Wyloo and older units. This is followed by the Duck Creek Dolomite but this margin has distinguishing features including: a) large normal faults which truncate the Hamersley Province and McGrath Trough, b) the occurrence of mafic to felsic volcanism and BIF, c) scattered base-metal mineralisation, d) large-scale slumping, and e) later thrusting along some of the (listric?) normal faults.

The deformational history of the region is polyphase (Tables 4.1 & 4.2). There are at least three intervals of folding and four periods of extension accompanied by mafic dyke intrusion, and several episodes of faulting and minor brittle-fold formation (Dettbarn, 1991; Powell & Dettbarn, 1992). The oldest two extensions relate to the ESE extension during accumulation of the Nullagine Supersequence, and the succeeding SSW extension during deposition of the Mount Jope Supersequence (Blake & Barley, 1993). The oldest folds, F_1, relate to a series of extensional structures in BIFs, commonly known as "cross-pods" or "northeast structures" (Trendall & Blockley, 1970). These chert pods are formed by rotation on listric normal faults, combined with compaction (and considerable water loss) and solution removal of silica. They are particularly well developed in the Marra Mamba Formation, and have a regional northeasterly trend. The Brockman syncline, Beasley antiform and other NE-trending broad regional folds are parallel to these structures (Powell & Dettbarn, 1992). Small-scale recumbent isoclinal folds in the southeastern Hamersley Province (Tyler & Thorne, 1990) could relate to this extensional deformation (Styles, 1991).

The second fold deformation produced the main generation of 100° ±10° F_2 folds which can be traced throughout the Hamersley Province. These ESE-trending folds are upright and open to broad in the north, and become increasingly inclined to northerly overturned in the south. At Newman these folds are recumbent, verging towards the north (Tyler & Thorne, 1990). These ESE-trending folds have a well-developed axial-plane crenulation cleavage and are associated with metamorphic mineral growth in the BIF.

The third extension deformation was oriented NE–SW and led to the emplacement of the 135° ±5° dolerite dykes so common in the southwestern part of the Hamersley Province. These dykes cut the ESE-trending folds and could be feeders to mafic volcanic units in the Wyloo Group. They could be related to the opening of the Ashburton Trough.

The third fold deformation was a NE–SW shortening which deformed the Ashburton Formation and all older rocks. The 135°-trending F_3 folds are well developed along the Paraburdoo Hinge Zone, and are responsible for the fold-interference pattern in the Hardey syncline region. Around the Turner syncline, mesoscopic folds of this generation are localised along the margins of the NW-trending dolerite dykes. The folds generally lack axial-plane cleavage except in rare, tight fold-hinge regions, have concentric or Class 1B fold style, and were formed in a brittle-ductile deformational environment.

Later deformation is generally not important in controlling the outcrop pattern, except locally. There is a variety of NE-trending kink folds, ENE-trending normal faults and ESE-trending dextral strike-slip faults (Dettbarn, 1991; Cummins, 1992). These structures postdate the NW-trending folds and thus presumably are related to Mesoproterozoic or younger deformational events.

Iron mineralisation is described in Morris (1985) (see Figs 4.2 & 4.3). He interpreted it as a result of supergene alteration of Hamersley Group BIF during periods of subaerial exposure, first at the Lower Wyloo Group unconformity, and best marked along the margins of the McGrath Trough. After burial, and metamorphism of the ore, it was re-exposed in places along the margin of this trough at the Upper Wyloo Group unconformity, resulting, in parts of the southern margin, in erosion and deposition of mature ore, as pebbles in the Mt McGrath Formation

(Stop 7.1). Following subsidence and burial of the southern part of this margin beneath the Mininer Turbidite Member, this sequence and the mature ore pebbles were further metamorphosed (Stop 6.3). Observations and descriptions in these notes which pertain to iron mineralisation are from R. C. Morris (1980, 1985 and *pers. comm.*).

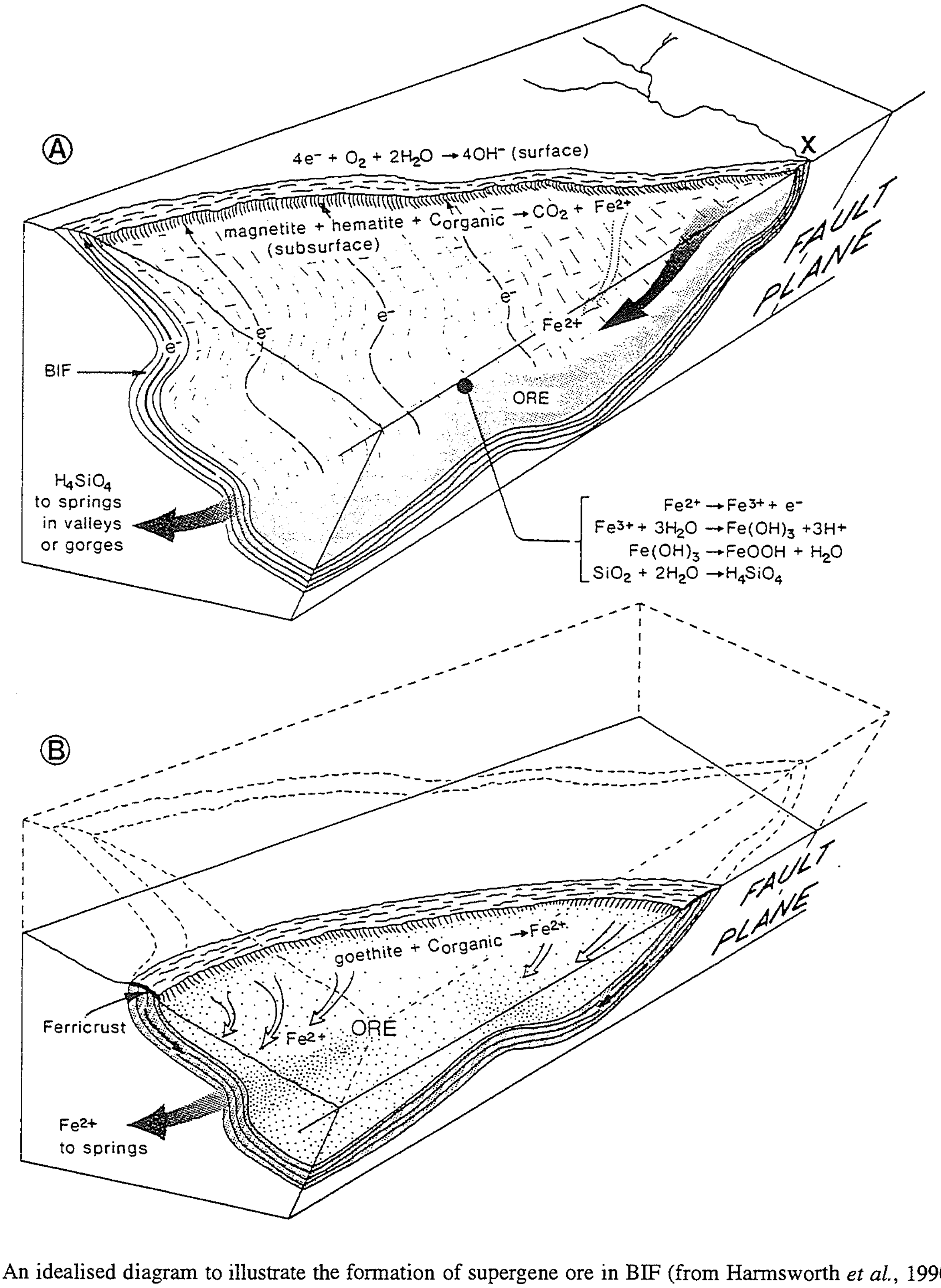


Fig. 4.2 An idealised diagram to illustrate the formation of supergene ore in BIF (from Harmsworth *et al.*, 1990, fig. 5).

A. Initial reactions at X lead eventually to deep access of groundwater along the fault and the beginnings of an artesian system. Reduction of oxygen on wet magnetite surfaces in the outcrop zone (cathode) draws electrons from ferrous to ferric reactions occurring in the vicinity of exposed surfaces of magnetite at depth (anode), promoting growth of ore laterally and upward in BIF. The fault could be any feature, such as a cross fold, which would allow deep access of groundwater.

B. Eventually the upward growth of the ore would be stopped by the downward progression of erosion, and further groundwater movement would now progressively leach goethite from the deposit, producing more and more friable ore.

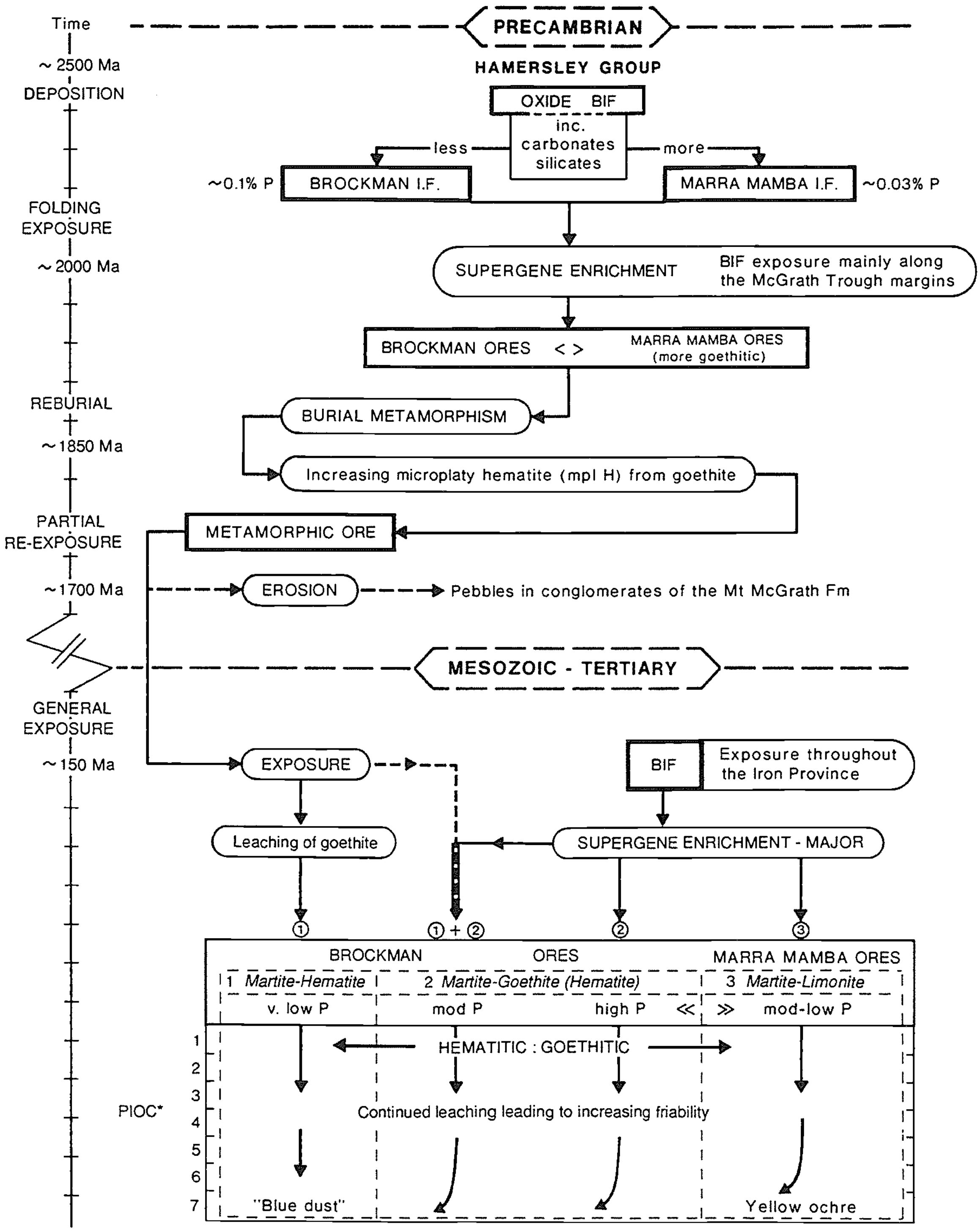


Fig. 4.3 Combined genetic-chronological schematic diagram to illustrate the CSIRO—AMIRA model for BIF-derived iron ore showing the relationship to the Pilbara Iron Ore Classification (PIOC) at the foot of the diagram (from Harmsworth *et al.*, 1990, fig. 6).

Brief history of Exploration and Mining

Low-grade iron ore deposits have been known from the Pilbara since 1890 when the State Government geologist, Woodward, reported that the Pilbara was 'essentially an iron country' (O'Leary, 1993). However, serious exploration for commercial iron ore did not occur until the early 1960s because of a combination of political and economic circumstances. First was the Federal Government embargo on the export of iron ore, which had been in place since 1938 when, in the economic uncertainty leading up to the Second World War, the government sought to protect Australia's source of iron ore for strategic purposes. At that time, the only known economic iron ore deposits were in Iron Knob, Iron Monarch and Iron Duke in the Middleback Ranges of the Eyre Peninsula of South Australia, and small deposits at Yampi in the Kimberley, Western Australia. The second factor was that the Pilbara was regarded as a remote and inhospitable area for exploration and development, as it was a long way from potential markets, and thus transport costs would have been high. Thus, although the presence of extensive iron deposits in the Pilbara was known to some people, there was no incentive to explore them.

The position changed due to two economic factors. The first was the post-war growth of the Japanese economy, which in the mid-1950s had just entered the heavy industrial phase. Japan, with limited domestic mineral resources, was seeking stable long-term supplies. The second was the development of the large bulk carriers for international trade, which reduced the cost of transporting iron ore dramatically. In December 1960, the Federal Government partially lifted its embargo on iron ore export, and the rest is history. The first iron ore shipped was from Goldsworthy in the northern Pilbara, and this was followed by ore from Mt Tom Price in 1966 and Mt Whaleback in 1969. Shipments of ore grew rapidly from ~18 Mt in 1968 to over 80 Mt in 1974. There was then a phase of consolidation, largely influenced by industrial problems, during which the annual export tonnage declined slightly remaining around 80 Mt until 1987.

Current exports are well over 100 Mt per annum and there are plans to increase the exports by a further 20%. By 1990, 1,514 Mt of iron ore had been exported for a total value of $23.7 billion. Exports are now worth approximately $3 billion per year, and are designed to increase following the successful development of a new process to produce iron briquettes from iron ore dust. The new process, recently announced by BHP Iron Ore, will use natural gas from the Northwest Shelf to reduce by solid state reduction the iron ore fines, previously regarded as a waste product.

The initial growth of the iron ore export trade focussed heavily on Japan, but in the last decade there has been growing diversification of the iron ore markets. Whereas in 1982 Japan accounted for 65% of the iron ore export market, by 1988 the proportion bound for Japan had fallen to 50%. Negotiations with the Peoples Republic of China created the Channar Joint Venture between Hamersley Iron and the China Metallurgical Import and Export Corporation. Recently, new markets have been opening in many developing East and Southeast Asian markets, for which the new BHP pellet ore is designed.

Modern exploration for iron ore commenced in earnest in 1961, with preliminary surveys by Conzinc Riotinto of Australia Ltd geologists in January–March and reconnaissance mapping in August–September of the same year. Large tonnage of mesa-forming limonitic ore, ranging in grade from 50 to 57% and with low impurity content were determined from the preliminary survey, and it was recognised that there was potential for high-grade haematitic mineralisation (Campana *et al.*, 1964). Initial drilling revealed several hundred Mt of haematitic iron ore in the Mt Samson–Mt Brockman area and in October 1962 the regional investigation led to the discovery of the rich Mt Tom Price deposit with haematitic iron ore averaging 64–66% iron content. Campana's team of geologists found not only the rich Mt Tom Price ore body, but also defined the basic stratigraphic units for the region. These units formed the basis for the stratigraphy formally published in reports and maps of the Geological Survey of Western Australia in the early to mid-1960s.

The Mt Whaleback deposit near Newman is the largest known single continuous iron ore deposit in Australia, initially having a measured reserve in excess of 1,700 Mt of low phosphorous, lumpy iron ore (Ashby *et al.*, 1993). The ore body was originally a ridge some 240 m above plain level, but is now an open cut over 5 km in length and 150 m below the plain level. Remaining provable mining reserves are 900 Mt at 64.1% iron and low phosphorous (Ashby *et al.*, 1993). Other large deposits occur in the Marra Mamba Iron Formation at Marandoo, and on the northern limb of the Weeli Wolli anticline in the northern part of the Hamersley Province. There is currently a renewed exploration effort by several of the major iron ore companies to find new concealed ore bodies and to define new reserves.

Geological excursion (Outside Mt Tom Price Mining area)

Depart from Tom Price, and set the odometer at 0 km at the Shell Service Station. Drive southwestward towards the mine along the eastern side of the railway. On the right at 2.9 km, on the E-facing side of Mt Nameless, a 4-metre-thick BIF in the Mt Sylvia Formation (Brunós Band) contains a group of open folds overturned to the north. These folds are part of the 135°-trending F_3 fold generation. At 4.0 km, turn right across the railway line and take the public road towards the Mt Nameless lookout. Drive to 6.4 km, where steep slopes appear on the right. Park and climb up to a series of outcrops about 50 m above the road level. In this outcrop (Stop 4.1, 2452-Mt Lionel 770865) there is excellent development of tight F_2 folds refolded by F_3.

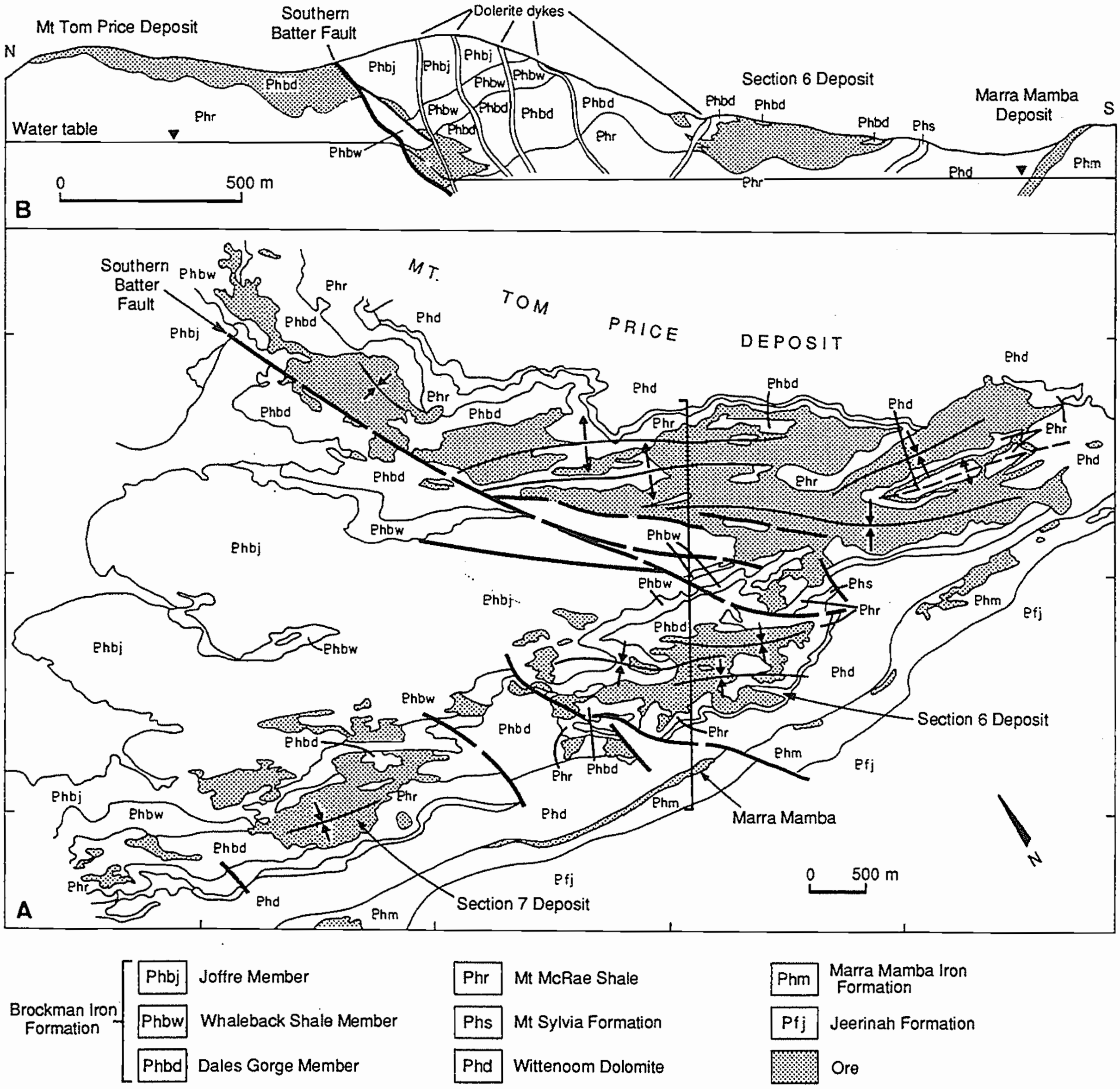


Fig. 4.4 Tom Price area (from Harmsworth *et al.*, 1990, fig. 9).
A. Geological sketch map of the M-mpl H Mount Tom Price deposit, with the M-G Section 6 deposit and the M-oG Marra Mamba deposit to the south.
B. Cross-section through the deposits in A, looking E. The Southern Batter Fault truncates the E-trending F_2 folds and appears to be related to F_3 or younger deformation.

Stop 4.1 — Refolding in the Mt Sylvia Formation (30 mins)

F_3 refolding F_2. The F_2 folds trend 115° and are tight to isoclinal layer-parallel structures. They have rounded Class 1C hinges in the chert layers and Class 3 hinges in the interbedded pelite, the combination of styles giving an overall Class 2 (similar) fold geometry. Cleavage is sporadically developed parallel to the F_2 axial planes. F_3 folds trend 130° and are open, upright, box- to kink-like folds which deform the F_2 axial planes from recumbent to upright attitudes. Note the quartz-fibre growth in extension fissures radiating around the F_3 axial planes. F_2 have formed under ductile conditions but F_3 appear to have formed around the brittle-ductile transition, presumably reflecting deeper burial and higher metamorphic grades when F_2 formed. *Location: 2452–Mt Lionel 770865*

If time permits, drive up to the lookout on top of Mt Nameless. On the way up, observe to the west a typical expression of the Hamersley Surface on Brockman Iron Formation in this part of the ranges where it is folded: at the top, a smooth, bold, domal shape on Joffre Member, bound downhill by a breakaway scarp on Whaleback Shale Member, then steep, ribbed Hamersley Surface remnants on the Dales Gorge Member. Further up, past the first saddle of the road, observe the difference on the dip slope which is a more even surface that projects below the plains in the keel of the Turner syncline.

About half-way up, at 7.4 km, where a small gully comes in from the right (northeast), one of the NW-trending dolerite dykes is exposed with a concentric-style NW-trending F_3 fold developed along its margin. The F_3 fold has nucleated along the margins of the dyke, which thus is older than this generation of folds. At the lookout at 10.1 km, and over towards the northeastern side of the hill, there are excellent examples of microfolds related to the two generations of folds. Microfolds of this type are referred to as "regional ripples" by Trendall and Blockley (1970).

Return towards Tom Price, reset the odometer at the Shell Service Station, and take the sealed road towards Paraburdoo. At ~11.5 km along the Paraburdoo road take a dirt track to the right, which heads towards the west. Follow this track for 1 to 2 km under the railway line and past an old quarry until the track ends up in Spring Creek at the foot of CID. Park and walk up the creek for about 1.3 km taking the left (westerly) fork in the creek until a narrow gorge in the Marra Mamba Formation is reached (Stop 4.2).

Stop 4.2 Nammuldi Member, Marra Mamba Iron Formation (70 mins)

Broad F_2 folds in the creek bed trend 105° and deform a series of chert pods trending 058°. These chert pods, termed "cross-pods" by Trendall and Blockley (1970) are extensional structures in the silica-rich layers. They reflect an early NW–SE extension prior to the first penetrative folding. Cross-pods are best developed at this level in the Marra Mamba Iron Formation but also occur in the Brockman Iron Formation. They are less common in the Joffre Member and the Weeli Wolli Formation. This upward decrease in chert pod abundance suggests that the extension could have been coeval with deposition of the Hamersley Group. The northeast trend could reflect basement structure control. *Location: 2452–Mt Lionel 852820*

The excursion will stay in the Tom Price area overnight.

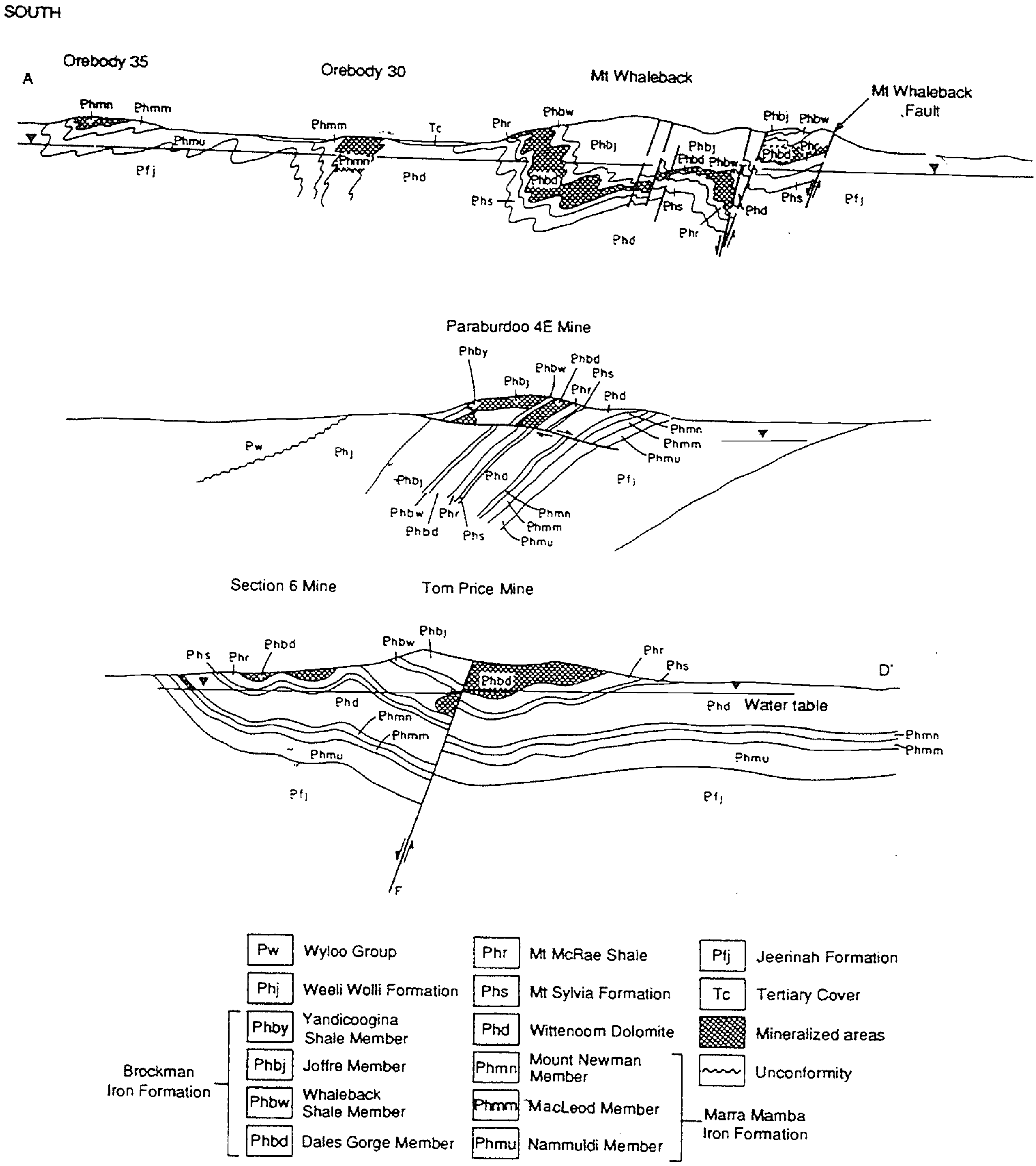


Fig. 4.5 Regional cross-sections for Mt Whaleback, Newman (top), Paraburdoo (middle) and Tom Price (bottom). All sections viewed looking W; scales vary. From: Harmsworth *et al.* (1990, fig. 3).

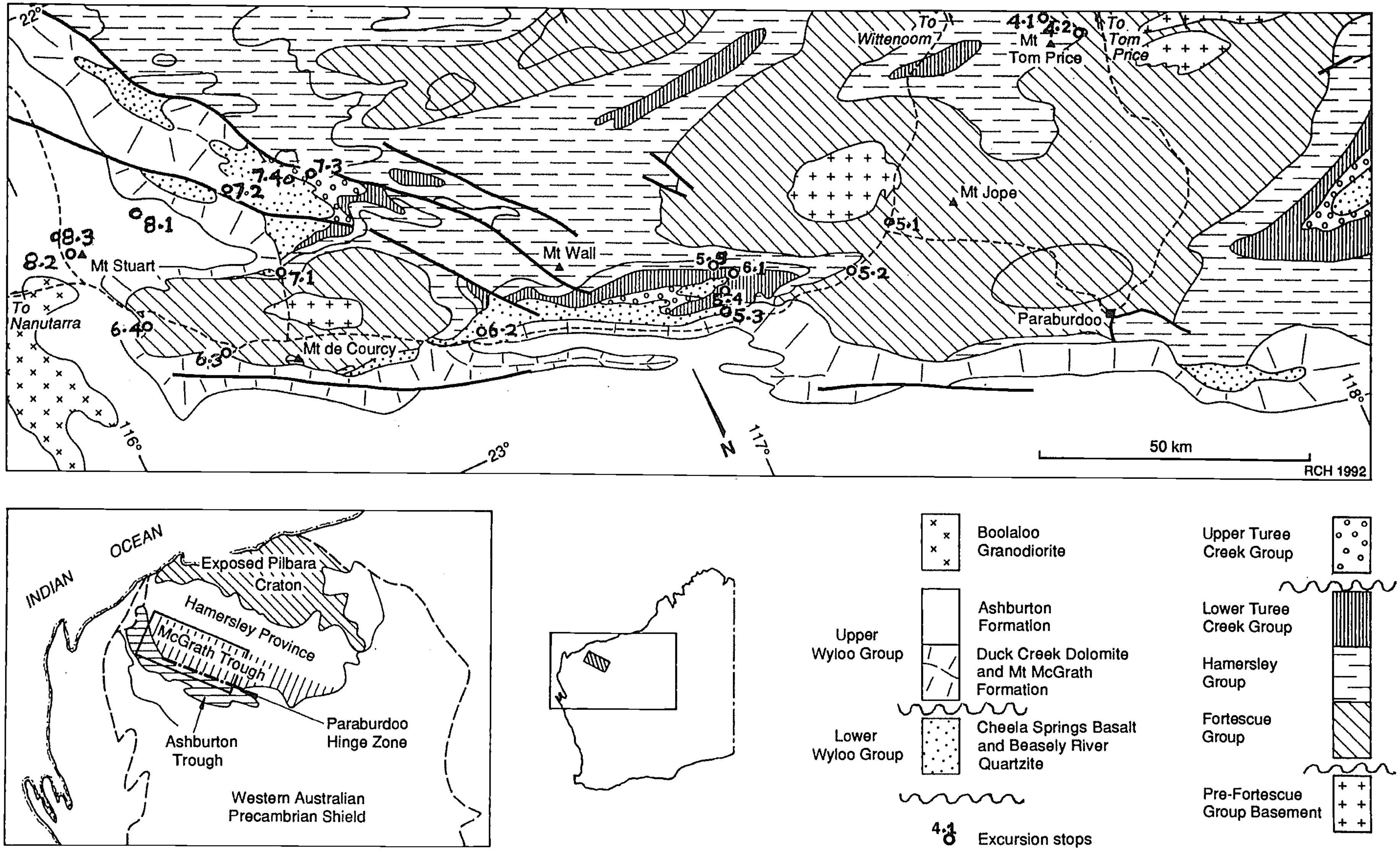


Fig. 4.6 Southwestern margin of the Pilbara Craton and Excursion Route.

GEOLOGICAL NOTES

DAY 5 TOM PRICE TO WOONGARRA POOL

On this day, the stratigraphy of the Hamersley Province from the Fortescue Group up into the Wyloo Group is examined. There are two possible routes which can be followed to the first outcrop. The first is along the unsealed road along the northern limb of the Turner Syncline where the folded Brockman Formation dominates the skyline, and prominent upright folds, tight to close in profile, can be seen near Mt Samson. The second is to follow the sealed road to Paraburdoo, and thence to travel west towards Nanutarra. Both routes meet at the T-Junction near the first outcrop. The description below follows the sealed road through Paraburdoo.

Return to the main road and drive to Paraburdoo. Most of the drive is through metabasalts and clastic sediments of the Fortescue Group. Ranges to the southeast are formed by the resistant Marra Mamba and Brockman Iron Formations. Depart from Paraburdoo along the road to Nanutarra. Drive northwestwards for ~52 km to the T-junction with the Nanutarra to Wittenoom road (Nanutarra road). The drive is initially through basalts and clastic rocks of the lower part of the Mt Roe and Mt Jope Volcanics, then crosses the Bellary Dome, and then continues across the Mt Jope Volcanics.

From the T-junction onwards, all distances along the Nanutarra road to turn-offs to stops are given in distances from this Paraburdoo turn-off, a T-junction, which is 52 km from Paraburdoo, and 199 km from the North West Coastal Highway (5 km north of Nanutarra Roadhouse).

At the T-junction, turn north along the road towards Wittenoom. At 0.6 km from the T-Junction, stop at a road cut where there is a thick doleritic flow.

Stop 5.1 Doleritic flow, Mt Jope Volcanics (30 mins)

The doleritic flow ~25 metres thick is sandwiched between slate beds dipping 60° towards 196°. A cleavage in the slate dips 82° towards 187° and is part of the regional cleavage developed parallel to the axial surface of the F_2 folds. The flow shows structures consistent with its younging to the south. At the top, there is a zone of vesicles above a columnar-jointed section beneath which a doleritic texture is developed. The flow is cleaved in its lower part with tremolite/anthophyllite present. Komatiitic flows with spinifex texture have been found in this part of the Mt Jope Volcanics. *Location: 2352–Rocklea 370643*

Hickman et al. (1990, p. 51) give a good description of these rocks 4 km east of our stop. The succession at their stop (Locality 10.4, Pyradie Formation) comprises three ultramafic flows separated by hyaloclastic breccia and laminated tuff. Lava flows are up to 30 m thick and display sharp planar bases and irregular tops. Lower parts of the flows are dominated by randomly oriented blades and needles of former pyroxene. The unit passes upward into a mixed assemblage of random blades of relic pyroxene and plates of former olivine locally inter-layered with vertical pyroxene sheaves. Flow tops are fine grained and highly irregular, and in places have cusp-like protrusions into the overlying breccia. The top of the uppermost flow is vesicular.

Turn back to the T-Junction and reset the odometer. Proceed south-southwestwards along the main road towards Nanutarra. The first outcrop on the left (south), at 0.5 km (AMG 2352-364631), is of very coarse tuff, or mafic volcanic fragmental rock, in the upper part of the Mt Jope Basalt. The hill to the west is Marra Mamba BIF in the keel of the Hardey syncline. From 2.5 to about 16 km, the road follows the Jeerinah Formation on the south limb of the Hardey syncline and the Hardey River. Well-preserved pillow lavas are exposed in road cuttings 5.5 km from the T-Junction.

Stop 5.2 Jeerinah Formation pillow lavas (20 mins)

In contrast to the Jeerinah Formation of the northern part of the Hamersley Province, where it is composed essentially of shale with a prominent chert band and a sandstone at the base, in the SSW the Jeerinah contains a thick sequence of alternating pillow basalt and dolerite with minor tuff. Furthermore, here in the Hardey syncline, the sandstone, shale and chert are believed to have been removed to the west by slumping (Horwitz & Ramanaidou, 1993). Pillows face north. There are a few vesicles in the outer part of the pillows just inside the chilled rims. *Location: 2352–Rocklea 335605*

Continue west along the Nanutarra road. Pillow lavas are also well exposed 16.1 km from the T-Junction. Past 24 km from the T-junction, the drive is through Upper Wyloo Group with conglomerates of the Mt McGrath Formation to the north, and the Duck Creek Dolomite to the south, of the road. The turn-off to Stops 5.3 to 5.5 is at 41.5 km (AMG 2352-047602). Note that these outcrops are on private property, and the permission of the owners of Wyloo Station (Mr & Mrs Penzini, Box 17, Moonooyooka, GERALDTON, WA 6532; Tel: (099) 43-0530 [GERALDTON] or (099) 43–0585 [Wyloo Homestead]) should be obtained before entering the property.

Turn off the sealed road onto a station track and drive through a gate ~0.5 km off the road. The outcrops in the ridges immediately to the northeast are in a conglomeratic sandstone shown by de la Hunty (1965) as the Karlathundra Conglomerate.

Stop 5.3 ***Karlathundra Conglomerate*** ***(30 mins)***

Coarse fluvial sandstone and polymictic conglomerate at this location is part of the Mt McGrath Formation, the base of the Upper Wyloo Group. Pebbles up to 5 cm are dominantly of vein quartz, but the presence of jaspilite (BIF) pebbles indicates that the Hamersley Group BIFs were being eroded in the source region. Palaeocurrents measured in this locality indicate a palaeoslope to the south towards the Ashburton Trough which was opening at the time the Mt McGrath Formation was being deposited. Elsewhere (Stop 7.1) pebbles of microplaty haematite ore have been found at this stratigraphic level, indicating that at least some iron ore deposits had formed by this stage (Morris, 1980). *Location: 2352–Rocklea 047607*

Drive north for 5 km, first through the wide gap in Mt McGrath Formation, then along the foot of hills of Cheela Springs Basalt (of variolitic lavas), across the sandy bed of the Beasley River, and, at 3.7 km, take the left fork in the track to the Meteorite Bore airstrip. Follow the airstrip and continue northwards to low outcrops.

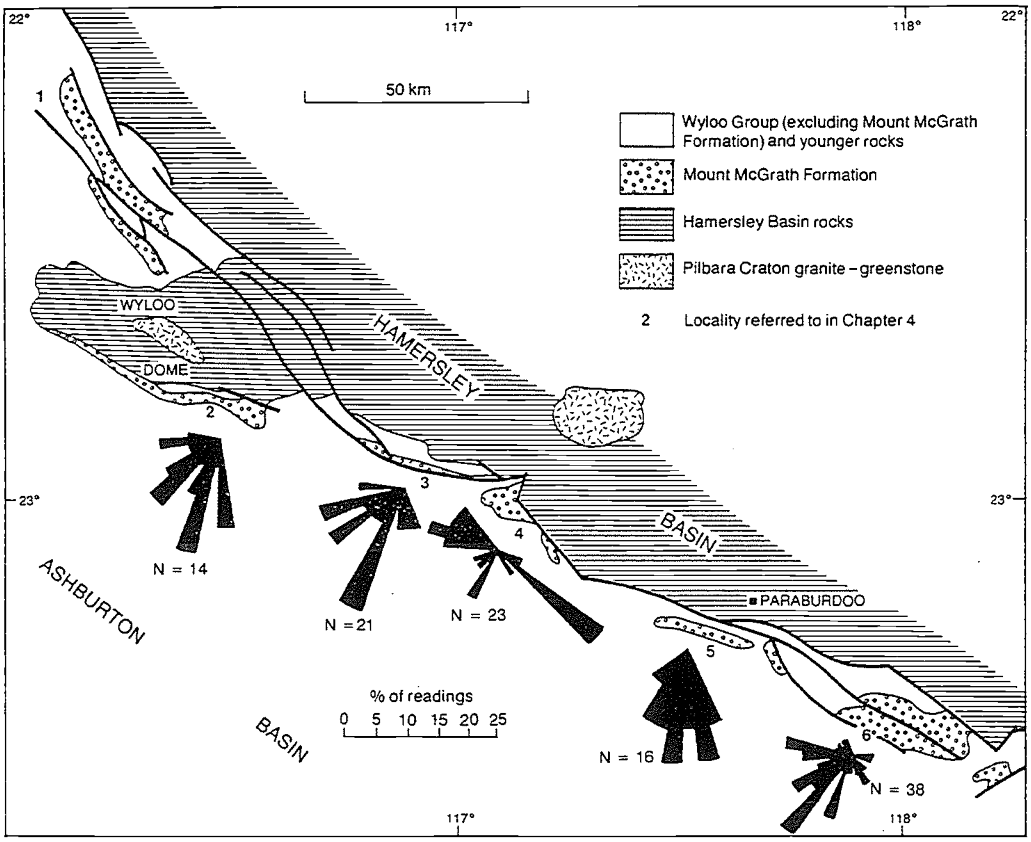


Fig. 5.1 Distributary-channel facies palaeocurrent data (from trough cross-strata), Mount McGrath Formation, localities 3 and 4. From: Thorne and Seymour (1991, fig. 29).

Stop 5.4 ***Meteorite Bore Member*** ***(40 mins)***

The Meteorite Bore Member is a diamictite of the lower Turee Creek Group. Clasts, some polished and faceted, are scattered in a cleaved, silty mudrock. A feature of the composition of the erratics is the absence of banded iron-formation (BIF). Porphyry, resembling facies in the Woongarra Volcanics dominates, but mafic volcanics, dolerite, arkosic metasandstone, banded chert and rare small-stromatolite dolomite, which could all originate from the Fortescue Group, also occur. Debate exists about whether the diamictite is a glacigene deposit (Trendall, 1976) or whether it is a pebbly mudstone deposited by normal mass-flow processes. The two environments are not mutually exclusive, because the diamictite could have been deposited by submarine mass-flow processes triggered by, or sourced from, material derived form glaciers. The age of the unit is not well established, other than it lies above the 2.4 Ga Woongarra Volcanics and below the 1.8 Ga June Hill Volcanics. If it is a glacigene deposit, it could be the correlative with the Huronian glacigene deposits in North America (Trendall, 1976) The high hill to the north *comprises unconformably overlying Upper Turee Creek Group quartzite and shale, capped by the unconformably overlying Lower Wyloo Group, the Beasley River Quartzite.* *Location: 2352-Rocklea 045650*

Return to the track along the Beasley River and drive north-northeast for ~8 km to the Woongarra Pool and Gorge on the Beasley River.

Stop 5.5 Hamersley Group section, esp. Woongarra Volcanics (3 hours)

The entire Hamersley Group is exposed in a 2-km section along the Beasley River. The upstream part of the section where the river first enters the gorge is in Brockman Iron Formation, with some Marra Mamba Iron Formation cropping out in the N-facing hill slopes to the west of the river bed. Minor folds in the Brockman Iron Formation indicate that the regional structure is an upright syncline plunging at ~20° to WNW. The section through the Woongarra Volcanics is well exposed on the eastern side of the river, and is best examined in the afternoon light. The unit contains several flows of different thickness. The basal part of the lowest thick unit contains dark chloritic fragments and cobble- to boulder-sized breccia clasts with some feldspar phenocrysts. This is overlain by a rather massive rock with sparse feldspar phenocrysts in a dark blue/grey matrix and sporadic angular cobble-sized clasts, some of which are flow-banded. Large cooling columns at a high angle to bedding (which dips ~60° to SSW) can be seen in the middle third of the section, at the upper part of which there is an increase in dark wispy lenticular inclusions probably representing fiamme (pumice fragments). This lenticle-tuff unit has been dated here at 2439 ±10 Ma by Pidgeon & Horwitz (1991). Some intrusive phases have been observed in the general area. The overall aspect of the section is remarkably similar to Devonian ash-flow tuffs of the eastern Lachlan Fold Belt, interpreted to have been produced by resurgent cauldron activity in a setting similar to the modern Taupo Zone of North Island, New Zealand (Cas & Jones, 1979). A different interpretation is given by Trendall (1994) who considers the "Woongarra Rhyolite" to be a very large synsedimentary sill with peperite margins. The top of the Woongarra Volcanics is marked by a 5-metre band of intercalated graded beds (turbidites) and some iron formation. This passes upward into monotonous planar-bedded pelite with no internal bedding structure, which, in turn, passes into the main part of the Boolgeeda Iron Formation. *Location: 2352-Rocklea 102694*

The excursion will camp on the flats of the Beasley River southeast of Woongarra Pool.

GEOLOGICAL NOTES

DAY 6 HARDEY SYNCLINE TO WYLOO DOME

Introduction

The main purpose of this day is to examine the Wyloo Group stratigraphy which spans two tectonic settings:

(a) The McGrath Trough – foreland basin marginal to an fold belt advancing from the south, and
(b) The Ashburton Basin – a divergent margin basin to the south and west of the Hamersley Province.

The first generation of regional E-trending fold structures, F_2, formed during sedimentation in the McGrath Trough, which is represented stratigraphically by the Turee Creek and Lower Wyloo Groups. Evidence for the time of formation of the E-trending F_2 folds varies across the Hamersley Province. In the eastern part of the Hardey syncline area, most of the folding occurred during deposition of the Turee Creek Group. Thus, the main angular unconformity lies within the Turee Creek Group, and the overlying Beasley River Quartzite is disconformable to locally unconformable on the uppermost units in the Turee Creek Group. In the Turee Creek syncline to the east of Paraburdoo, there is paraconformity from the Boolgeeda Iron Formation through the Turee Creek Group and into the Beasley River Quartzite. The evidence there is that the E-trending folds are younger than the Beasley River Quartzite. Both relationships are compatible with long-lived development of the fold belt during sedimentation, and the intraformational unconformities in the Hardey syncline area are to be expected on the orogen side of a foreland basin.

Onset of the divergence associated with the Ashburton Trough is marked by deposition of the Mt McGrath Formation, which lies with marked unconformity on many of the older units. The palaeoslope was to the south, and the overlying Ashburton Formation comprises various submarine mass flow units deposited in a deepening trough. The June Hill Volcanics are intercalated with the basal part of the Ashburton Formation in the Mt Stuart area, and reflect bimodal volcanism along the northwestern margin of the Hamersley Province. They occur only on the northwestern side of the Wyloo Dome, and could reflect WSW-directed continental divergence along the western margin of the Hamersley Province. According to Krapez (1993, *pers. comm.*), the upper half of the Ashburton Formation reflects deposition in a contracting basin, possibly as a prelude to the late Palaeoproterozoic NW-trending F_3 folds which overprint all the Wyloo Group units.

Field stops

Return towards the main Nanutarra road along the track down the Beasley River. On the way (~2 km), stop for a view of the Hardey syncline keel where the Beasley River Quartzite and uppermost Turee Creek Group rest unconformably on the lower Turee Creek Group (Figs 6.1 & 6.2). This view (Figs 6.3, AMG 2352-075678) is best seen in the early morning. Park vehicles on the east side of the Beasley River and walk west towards the foot of the hill. The unconformity is about 100 m above the general elevation of the plain and the top of the hill is approximately 230 m. If you plan to climb the hill, take a water bottle and count on spending at least 3 hours on the walk.

Stop 6.1 — Unconformity at the nose of the Hardey Syncline (30 mins)

The rocks on the lower slopes of the hillslope are siltstone and slate of the lower Turee Creek Group. They dip uniformly at 55° towards 210°. A near-vertical, disjunctive, reticulate to slaty cleavage dips towards 190° and is parallel to the axial-plane cleavage in the overlying uppermost Turee Creek Group (Fig. 6.4). Ribs of fine-grained indurated quartzarenite interbedded with cleaved olive-green mudrock can be traced up the hill where they are erosionally truncated by fhe overlying flat-lying units. The rocks above the contact are siltstone with some fine-grained cross-bedded sandstone. A few scattered pebbles and cobbles up to 10 cm diameter can be found in the fine-grained quartzite. Decimetre-scale cross-beds in the sandstone are herring-bone style with bipolar current directions oriented NNW-SSE. About 90 m above the basal contact there is a thin (3 m) discontinuous horizon of coarse-grained poorly-sorted lithic conglomerate containing angular fragments of Weeli Wolli Iron Formation; this correlates with the Three Corner Conglomerate Member which further west lies at the base of the Beasley River Quartzite (Trendall, 1979). The conglomerate grades upward into a 3.5 m thick medium-grained quartzose sandstone. The overall aspect of the 6.5m coset is of braided-stream or sheetflood-sandstone facies (c.f. Thorne & Seymour, 1991), in contrast to the inferred shallow-marine or deltaic facies of rocks below. Cross-beds measured 3 to 10 km to the west in this jasper-bearing unit give a mean flow direction towards NE (Fig. 6.5). Immediately overlying the discontinuous conglomerate are cosets of fine to very fine-grained well-sorted quartzarenite with abundant ripple marks and quadripolar cross-bedding indicating a shallow-marine environment with a NNW-SSE trending strandline (Fig. 6.4, syncline nose). Disjunctive cleavage is present both above and below the unconformity contact; this cleavage is axial-planar to the 110°-trending F_2 folds to which the Hardey syncline belongs.

Location: 2352–Rocklea 075678

Return to the vehicles and drive back to the Nanutarra road along the track down the Beasley River. Rejoin the Nanutarra road at 41.5 km (AMG 2352-047602) from the T-junction and proceed westwards along the main road to the turn-off to Stop 6.2 at 86 km from the T-junction. The drive is mainly through poorly outcropping Upper

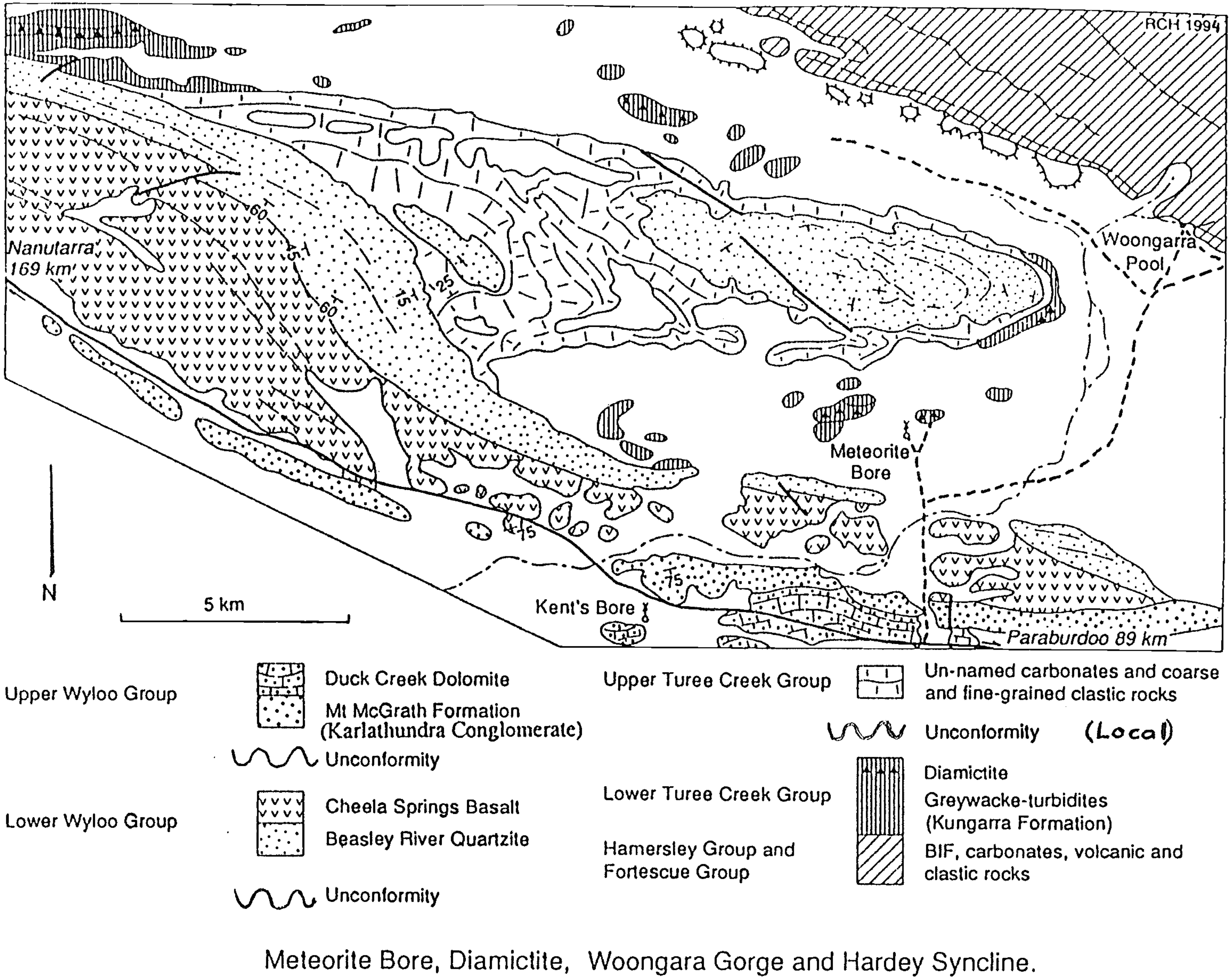


Fig. 6.1 Meteorite Bore diamictite, Woongarra Pool and Hardey syncline. Amended from Horwitz & Powell (1992, fig. 2).

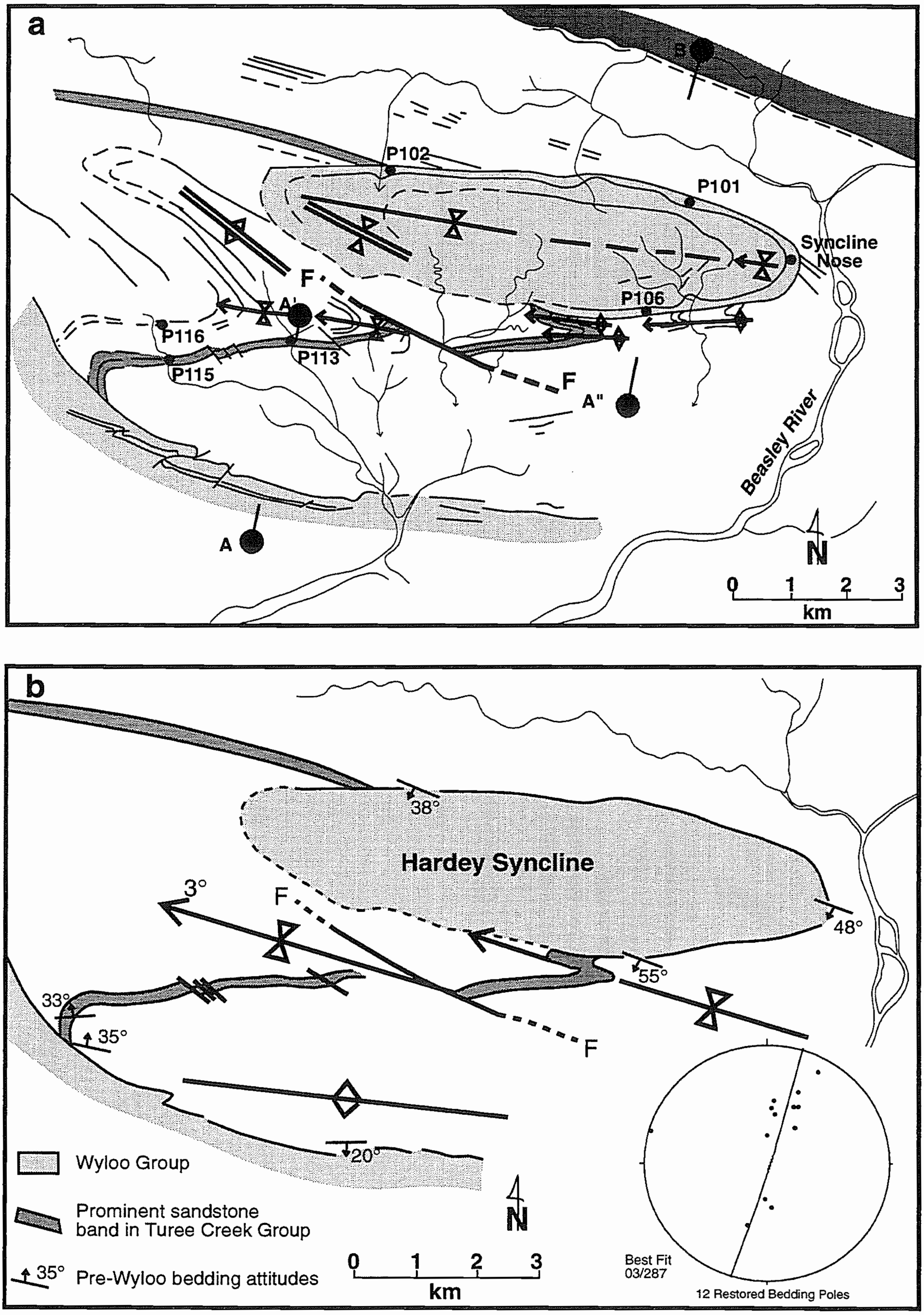


Fig. 6.2 (a) Structural sketch of the Hardey Syncline. F_2, single lines; F_3, double lines. A—A' A"—B is line of cross-section in Fig. 6.3. (b) Pre-Wyloo Group F_2 folds and dips, after Beasley River Quartzite is restored to horizontal.

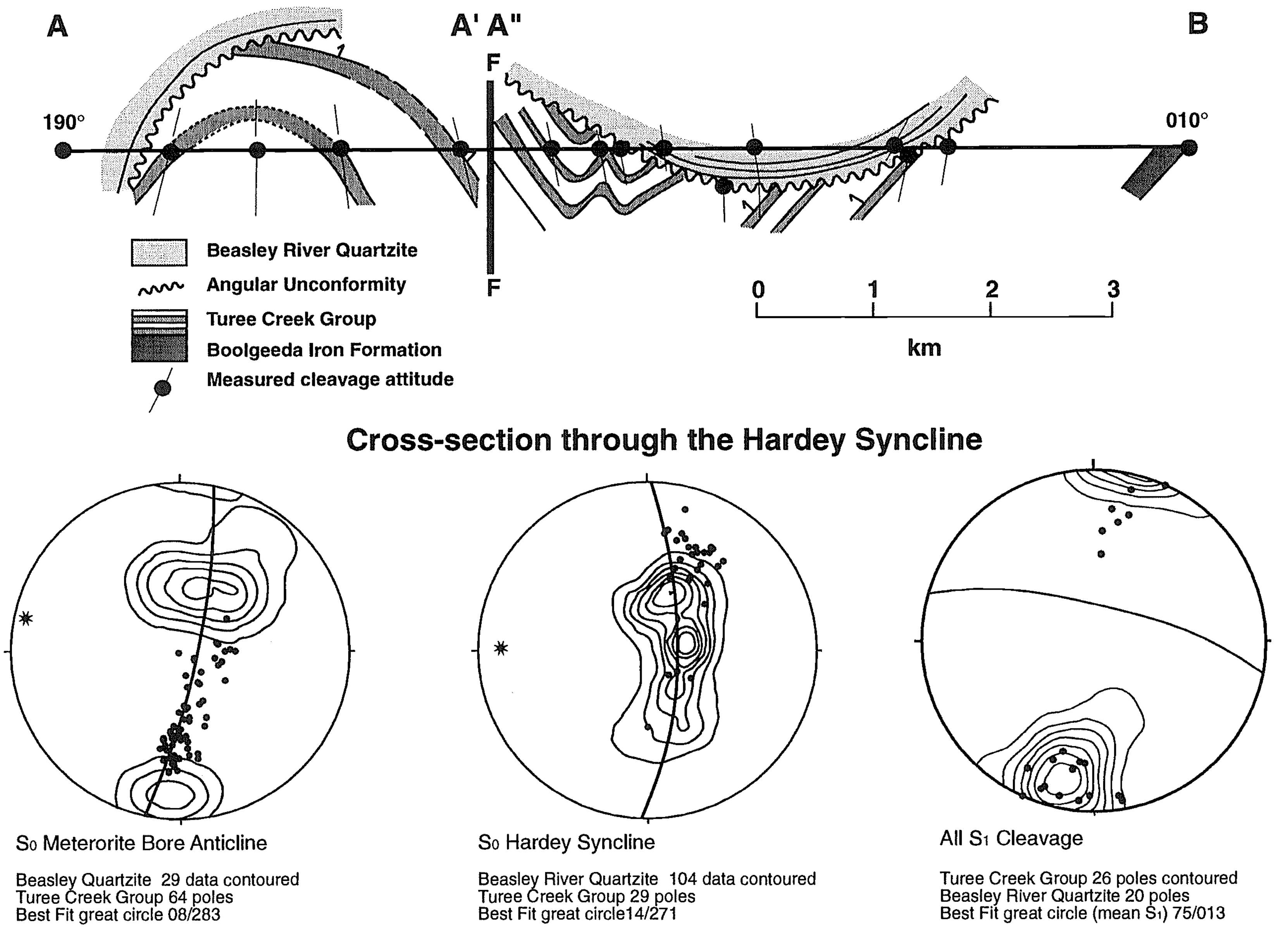


Fig. 6.3 Cross-section through Hardey syncline and adjacent Meteorite Bore anticline. Equal-area stereonets show structural elements.

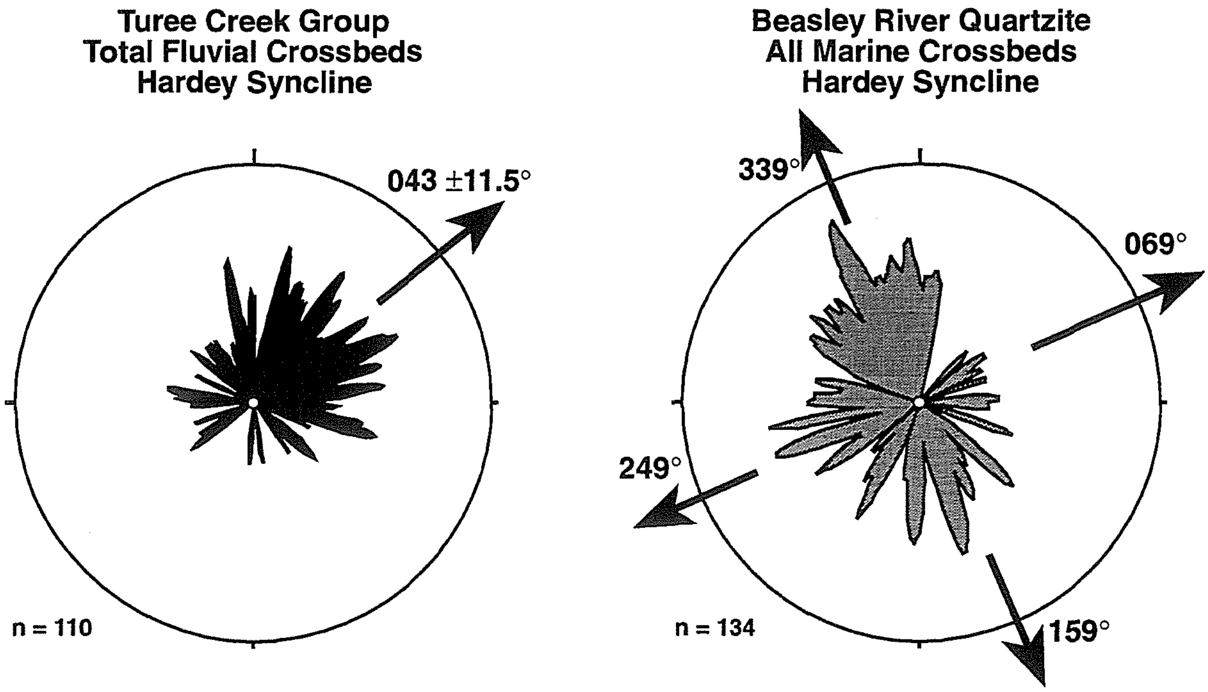


Fig. 6.4 Summary palaeocurrents in Upper Turee Creek Group fluvial units (left) and the marine quartzarenite of the Beasley River Quartzite (right) in the Hardey syncline area. The inferred shoreline trends NW-SE with a fluvial input from the southwest.

Wyloo Group. The prominent bun-topped hill seen to the north on the way is Mt Wall, capped by Joffre Member of the Brockman Iron Formation. Note the irregular smooth topography of the dissected Hamersley Surface. At 86 km, drive north for one kilometre to a gully with a hill of Cheela Springs Basalt on the west bank.

Stop 6.2 *Unconformity at the base of the Lower Wyloo Group* *(40 mins)*

Underlying the Cheela Springs Basalt are quartzite and phyllite of the top of the Beasley River Quartzite. A walk up the creek shows a spectacular section of the rest of the Beasley River Quartzite, comprising ~140 m of the main quartzite (with palaeocurrents mainly from the south), 20 m of impure, sandy phyllite, and 20 m of pebbly quartzite with cross-bedded sandy facies of iron-rich heavy-mineral concentrates (currents from the north-west, see *Thorne & Seymour, 1991, fig. 11). Pebbles include Woongarra Volcanics and Weeli Wolli Formation. The Beasley River Quartzite here rests on cleaved Woongarra Volcanics. Towards the south-west, this unconformity rests on increasingly older units, reaching down, at the eastern closure of the Wyloo Dome, to the top of the Fortescue Group with small remnants of Marra Mamba Iron Formation. Note that there is no evidence of iron-ore pebbles. Iron-rich fragments are BIF remnants.* *Location: 2252-Hardey 586776*

Alternate Stop 6.2

A less complete section, but with vehicle access from the main road by an old driller's track; is two kilometres further west. *Location: 2252-Hardey 565781*

Return to the Nanutarra Road and proceed westwards. From about 107 km onwards, note the ragged outcrops, caused by a well-developed northwest-trending cleavage imposed on all rocks west of here. This cleavage is accompanied by a dextral shear displacement, and is interpreted as an escape structure during convergence between the Hamersley Province and the Gascoyne block. The bridge across Metawandy Creek is at 120 km. The drive is across volcanic and sedimentary rocks of the Fortescue Group in the core of the Wyloo Dome. Continue westwards along the bitumen. From here onwards, observe the Marra Mamba Iron Formation ridge of the south limb of the Wyloo Dome and note the absence in places of the usually prominent chert band beneath it in the Roy Hill Shale Member of the Jeerinah Formation. Hiati in this formation, in this region, are attributed to slumping (Horwitz & Ramanaidou, 1993). Proceed to the turn-off south to Wyloo Station (130.5 km from T-junction). Turn south towards the homestead along the access road for 1.2 km (AMG 2152-Wyloo 205920) and bear right (west) on a track across alluvial flats up to a gate after 1.1 km (AMG 2152-Wyloo 196923). Past the gate, take the south branch of the track across a creek, and follow for 0.9 km to Stop 6.3.

Stop 6.3 *Metamorphosed Upper Wyloo Group units* *40 mins)*

Mt McGrath Formation on the south flank of the Wyloo Dome (Paraburdoo Hinge Zone) was covered by 8 to 10 km of Upper Wyloo Group sediments (Duck Creek Dolomite and Mininer Turbidite Member), resulting in burial metamorphism of the Mt McGrath Formation and the underlying units. The unconformity is of "sparkling", ferruginous conglomerate of the former, resting on phyllitic shale of the Jeerinah Formation. By following the contact a few metres westwards, the irregular nature of the contact is illustrated by abutments and overlaps in the ferruginous conglomerate bands. The "sparkling" character of the conglomerate here and elsewhere along this southern flank results from the growth of secondary magnetite, in and across pebble boundaries. This texture cannot be related to any dyke intrusion, nor to the younger granitoids. It is attributed to the effects of deep burial and the necessary presence of a reductant to convert haematite to magnetite. The deep burial can be substantiated, but the source of the reductant is less certain. One possibility is percolation of organic matter into the porous conglomerate from the organic activity that led to formation of the overlying Duck Creek Dolomite (see *Morris, 1985).*

Location: 2152-Wyloo 190922

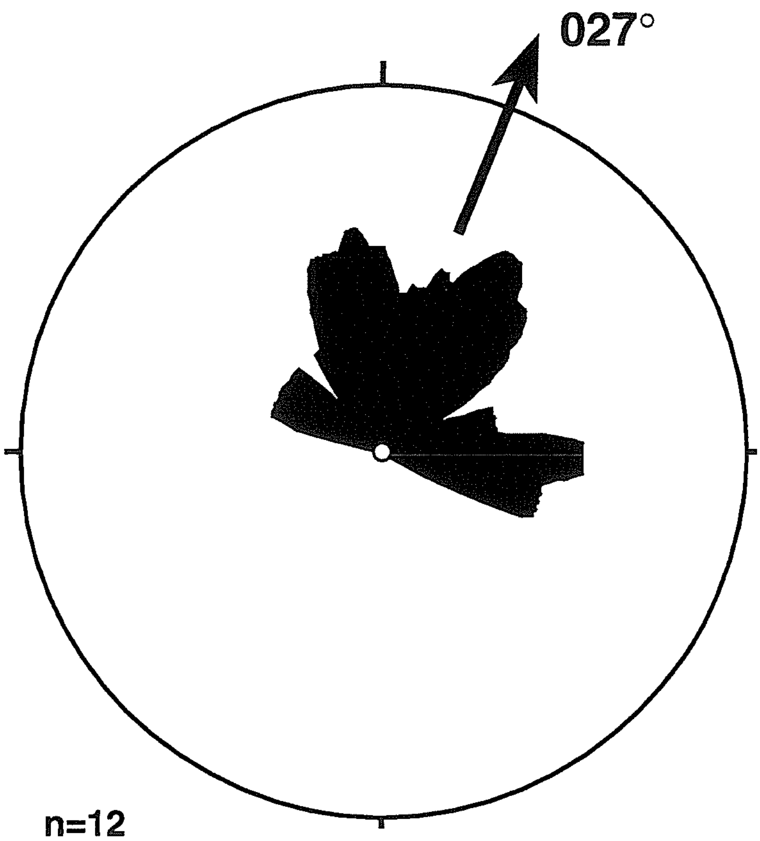


Fig. 6.5 Cross-bedding measured in the fluvial jasper-bearing unit of the Beasley River Quartzite at P106 (Fig. 6.2a).

Return to the Nanutarra Road and proceed northwestwards to 148.5 km from the T-junction. The drive is across Fortescue Group basalt for about 15 km. Then, past a fault-line scarp for about 3 km, the road follows (north of) a perched outlier of Beasley River Quartzite (Daniels & Halligan, *in* Daniels, 1970) conglomerate and sandstone (approx. 2152-Wyloo 100050). This formation is folded in a syncline; it abuts the Fortescue basement to the north with a thick, north-dipping, south-limb of conglomerate and a near-flat, reduced north-limb. There are no clasts derived from the Hamersley Group in the Beasley River Quartzite at this locality, consistent with the interpretation that the palaeoslope during Beasley Quartzite time was to the northeast.

At 148.5 km from the T-junction (2152-Wyloo 087060), turn south along a track (opposite direction to Mindle Bore) for approximately 1.6 km to Stop 6.4, where olistoliths occur in a fossil, submarine canyon, filled with Ashburton Formation turbidites.

Stop 6.4 *Fossil canyon olistoliths* *(60 mins)*

A fossil canyon, grooved in the Duck Creek Dolomite and underlying Mt McGrath Formation, occurs on the northwestern rim of the Wyloo Dome, on the western edge of the Hamersley Province against the Ashburton Trough. The canyon is about 4 km wide, floored with a conglomerate which is overlain by turbidites with *olistoliths essentially of Duck Creek Dolomite. Some olistoliths are very large rafts of several tens of metres in length. Amongst those examined at this stop, the one highest in the sequence consists of grits and resembles a facies in the Mt McGrath Formation of the northwestern part of the Wyloo Dome. A single volcanic fragment was noted higher in the sequence in the canyon. The order of deposition of these clasts is thus inverse to the original stratigraphic order and could be the result of progressive stripping of that layering. The turbidites and their contained fragments are strongly folded and cleaved; fold axes plunge to the NNW. Sedimentary facing, or way-up criteria, are decipherable by graded bedding. Reconstruction of bedding attitudes indicates that the sediment abutted the canyon margins (Horwitz, 1981, p. 397–8).* *Location: 2152-Wyloo 080045*

Return to the main Nanutarra road and return to the Metawandy Creek Bridge, east bank, 120 km east of the T-Junction. Turn north off the main road, drive north to cross the old-abandoned part of the main road and follow the track north for 14.5 km. The track crosses Metawandy Creek, goes past Metawandy Well and west of Billeroo Bore, to Stop 7.1, which is at the prominent gap in the hills formed by Hamersley Group BIFs of the northern flank of the Wyloo Dome. This is the Barrett-Lennard Palaeoproterozoic placer iron deposit.

The excursion will camp on the flats overnight and examine the outcrop in the morning.

GEOLOGICAL NOTES

DAY 7 TUREE CREEK AND WYLOO GROUPS, DUCK CREEK SYNCLINE

The objectives on this day are first to examine the unconformity at the base of the Mt McGrath Formation, the basal unit in the Ashburton Trough succession, and then to proceed north to the Duck Creek syncline where a paraconformable relationship exists between the Hamersley Group, the Turee Creek Group and the Lower Wyloo Group. In palaeogeographic terms, the Duck Creek syncline contains Turee Group and Beasley Creek Quartzite units towards the middle or northern part of the McGrath Trough, which, by its foreland-basin nature, would have been an asymmetric basin thickest along the southwestern margin adjacent to the emerging fold-and-thrust belt and tapering in thickness away to the northeast.

Along the way, a stop will be made in the Duck Creek Dolomite – a carbonate unit near the top of the foreland basin, and examples of Channel Iron Deposits will be seen. Many of these outcrops are on Mt Stuart Station. Permission to go into the area should be obtained from the Manager of Mt Stuart Station; telephone: (099) 43–0530.

Stop 7.1 Lower Wyloo Group unconformity, mature iron ore pebbles in the Mt McGrath Formation, and metamorphism by a younger dolerite dyke ***(2 hours)***

a) The basal unconformity of the Lower Wyloo Group, Beasley River Quartzite is well illustrated in the first gully west of the gap (2152-Wyloo 333032). The contact is on an eroded, irregular surface of the Woongarra Volcanics, on a dense, cherty porphyritic facies. Coarse basal conglomerate and arenite vary significantly in thickness along strike and illustrate the unevenness of the basement surface. They are overlain by cross-bedded, cleaner orthoquartzite, followed by recurring conglomerate, greywacke and siltstone. *Location: 2152–Wyloo 333032*

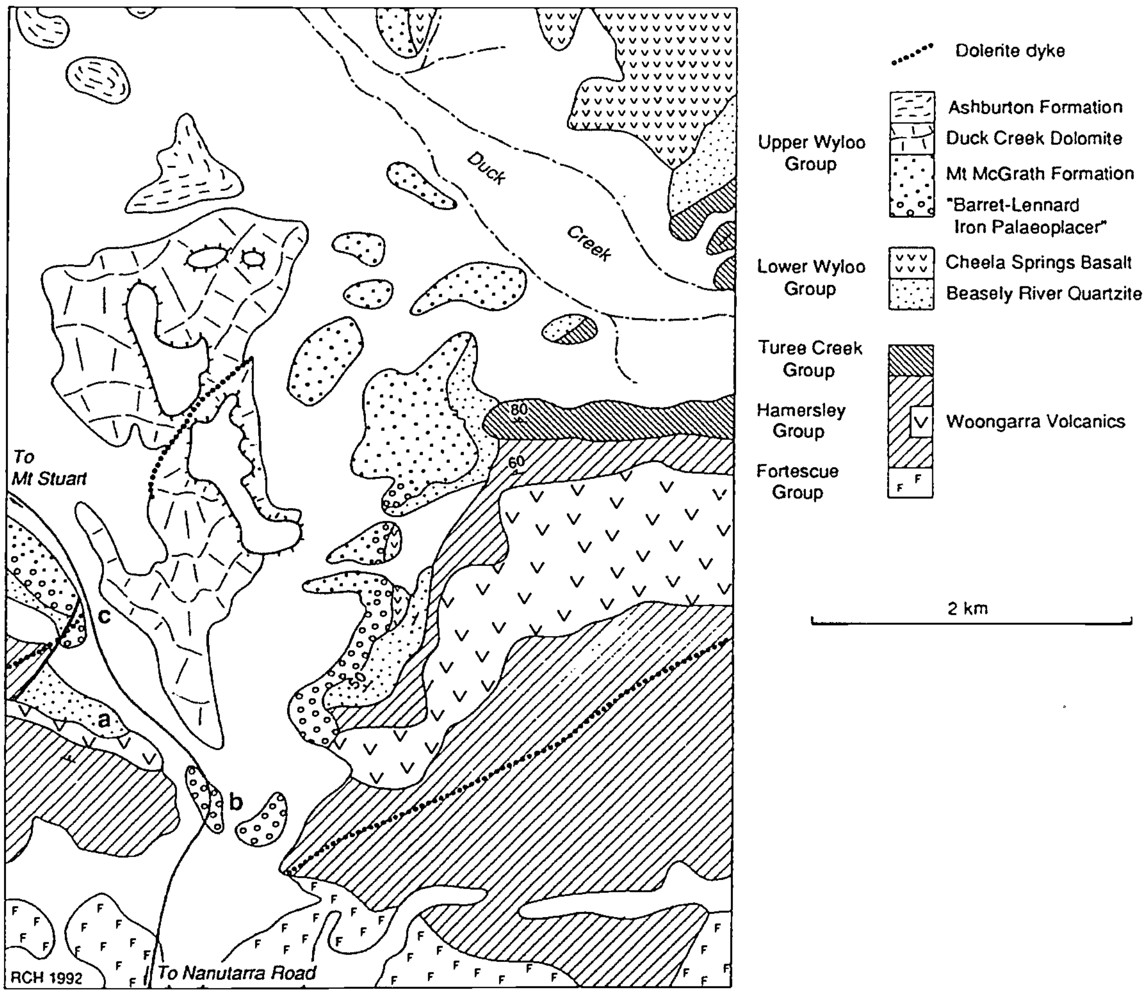


Fig. 7.1 Geological map of Stop 7.1 showing (a) the Lower Wyloo Group unconformity, (b) mature iron ore pebbles in the Mt McGrath Formation, and (c) metamorphism by a younger dolerite dyke. Modified from Horwitz and Morris (1990).

b) The unconformity of the Upper Wyloo Mt McGrath Formation on the underlying units is not well exposed (2152-Wyloo 340025) but is demonstrated by the regional distribution of features (Fig. 4.6). In this locality, the formation appears to occupy a deep channel and contains abundant mature ore-pebbles, derived from the south, resulting in a near ore-grade clastic deposit.

The precise stratigraphic source of the haematite is not known. In the Paraburdoo region, Weeli Wolli-like BIF pebbles with microplaty hematite ore are prominent in the Mt McGrath Formation. Here, however, the BIF pebbles could be from anywhere in the succession since the unconformity cuts deep down to at least the Marra Mamba Iron Formation. Though more compacted than in the deposits themselves, the textures of the pebbles are "microplaty" type. However, there is no evidence of alignment of metamorphic features in the pebbles, and it appears most likely the pebbles went into the deposit as metamorphosed ore and were little-affected further by the relatively shallow burial of this area (Morris in *Horwitz & Morris, 1990).* *Location: 2152–Wyloo 340025*

c) The Mt McGrath Formation and encasing units are contact-metamorphosed against a NE-striking, post-Wyloo, mafic dyke, 2 km north-west of the gap. Note the etched lateritised dolerite dyke on the Hamersley Surface skyline to the south-west.

Channar, and the Barrett-Lennard deposit, are the only areas in the Hamersley Province in which dyke-related contact metamorphism of ore has been found (Morris, 1985). The age of the dyke is not known precisely; it is younger than the Bangemall Basin, possibly ~1000 Ma. *Location: 2152-Wyloo 331036*

Drive northwestwards from the Barrett–Lennard palaeoplacer along the track towards Duck Creek. The Duck Creek Dolomite is exposed in two small hills to the east and west of the track at Duck Creek (2153–Mt Stuart 300130). The western outcrop consists of massive and laminated dolomitic mudstone facies. East of the track, the outcrop consists of 10-15 m of carbonate slump-breccia that is overlain by predominantly massive dolomitic mudstone. Breccia fragments range in diameter from centimetres to large blocks up to 2–3m across. Clasts are supported in a matrix of dolomitic mudstone. Bedding-parallel stylolites are well-developed within the overlying mudstone, which grades upward into laminated dolomite. These facies are interpreted as slope and basin carbonates deposited seaward of a shallow-water platform to the north (cf. Thorne & Seymour, 1991). The description below is by D. Martin, based on information generated by D. Thorne (1985, Loc. WYL. 39).

Stop 7.2 **Duck Creek Dolomite** ***(60 mins)***

The track from Barrett-Lennard crosses Duck Creek at the western end of a gorge where the Duck Creek Dolomite is well exposed in cliff faces on the southern side of the creek and in low hills to the north. These exposures are described in detail by Daniels (1970), Grey (1985), Thorne (1985), and Thorne and Seymour (1991). Slope, barrier-bar, lagoon, intertidal, and supratidal facies have been identified and are arranged in shallowing-upward cycles. Domical and branching-columnar stromatolites overlie erosively-based grainstones at the base of cycles at the eastern end of the gorge. The stromatolites are conformably overlain by lagoonal laminated-dolomite. Cycles are capped by sabkha facies consisting of tepees, disrupted domes, cuspate stromatolites, and domical stromatolites (Thorne, 1985). The lower and upper portions of the Duck Creek Dolomite are dominated by slope carbonates, with shallower-water facies predominating in the middle 50-300 m (Seymour et al., 1988).

An upward-shallowing succession, from massive dolomite-mudstone to subtidal grainstones and stromatolites, is exposed east of the track in a cliff face on the southern bank of the creek. Southwest-dipping dolomite-mudstones at the base of the section are cut by a northwest-trending normal fault with a throw of approximately 10-20 m to the northeast. Numerous anastomosing quartz veins are developed sub-parallel to the fault in the hangingwall and footwall. Dolomites to the west of the fault contain isolated domical bioherms and algal lamination, and are overlain by planar- and ripple-laminated grainstones. A second upward-shallowing cycle commences with laminated shale at the base, overlain by massive dolomite-mudstone and capped by columnar stromatolites.
Location: 2153–Mt Stuart 300130

Proceed north along the track. One hundred metres beyond the northern bank of the creek the track bears right, and must be followed for approximately 8 km to the intersection with the track between the Mt. Stuart and Duck Creek homesteads. Reset odometer.

Turn right on station track towards old Duck Creek homestead. After ~1 km, the track climbs a small ridge. This is one of the CID which can be followed around the countryside as an old palaeo-channel. Note the replaced wood fragments and the oolite texture.

At 18.1 km, the track to Mt Berry takes off to the right. Continue on the left branch of the track. The ridge to the south contains Beasley River Quartzite and Cheela Springs Basalt.

Drive though the gap in the ridges and turn to southeast. Follow the track to 25.6 km.

Stop 7.3 *Turee Creek Group* *(70 mins)*

This stop involves walking a section through the Turee Creek Group from the Boolgeeda Iron Formation to the base of the Beasley River Quartzite (Figure 7.2). The outcrops are located on the northeastern limb of a SE-trending syncline. The high ridges to the northeast contain the upper part of the Hamersley Group. The steep-sided massive unit is the Woongarra Volcanics which is overlain by the banded Boolgeeda Iron Formation. The passage upward into Turee Creek Group is transitional with gradual decrease in the cherty BIFs, although some finely banded cherty ironstone does occur in the Turee Creek Group. Much of the non-outcropping area is shale, fine-grained lithic, micaceous sandstone and, in places, carbonate rock.

The low outcropping ridges to the southwest of the track are carbonate bands. The first ridge contains planar beds of dolomite, which elsewhere are stromatolitic. Walk down the small creek to the upper part of the second ridge where there is a spectacular exposure of stromatolitic carbonate in the cliff face on the west bank. The stromatolites have various forms ranging from low-amplitude small mounds to upright columns that have a polygonal interference pattern in plan view. In part of the outcrop there are "sharpening stone" conglomerates, suggesting periodic desiccation of the sedimentary environment. Taking all features into account the rocks are likely to have been shallow marine at this level in the Turee Creek Group.

The high ridge to the southwest is the upper Turee Creek Group capped by the white indurated quartzite of the Beasley River Quartzite. Outcrops on the lower slope of the ridge are thin siltstones intercalated with dolomitic beds up to 1 m thick. Some silty bands have small-scale ripple cross-lamination indicating currents to the southeast. The passage into the Beasley River Quartzite appears conformable and transitional.

Location: 2153–Mt Stuart 450197 to 443191

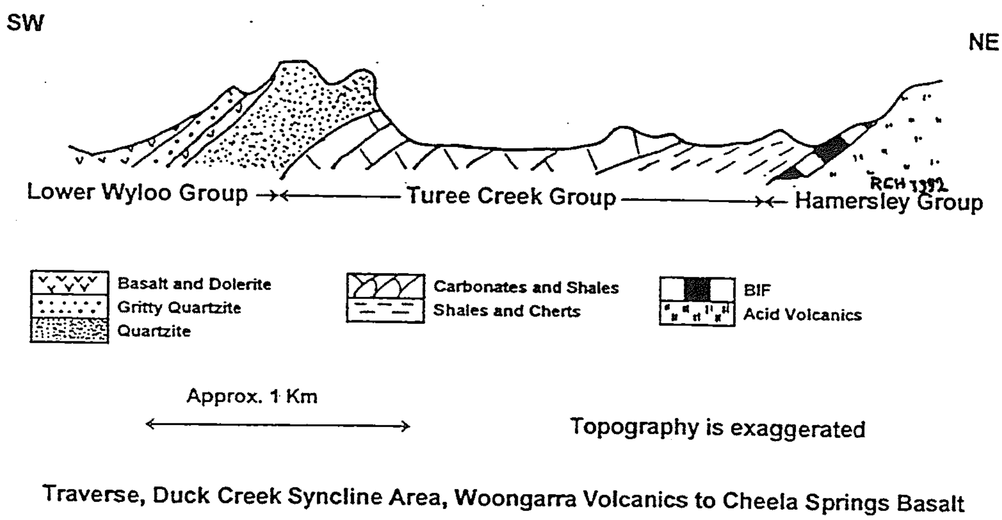


Figure 7.2 Traverse through the Turee Creek Group, Duck Creek area. From: Anonymous (1992)

Return to the track and retrace about 4 km to the southwestern side of the Beasley Quartzite ridge.

Stop 7.4 *Lower Wyloo Group* *(80 mins)*

The section in the ridges to the southeast of the track starts in the cross-bedded medium- to fine-grained orthoquartzite of the Beasley River Quartzite, which is immediately overlain by a series of basalt flows in the Cheela Springs Basalt. The Beasley River Quartzite contains abundant decimetre-sized crossbeds, from which polymodal palaeocurrent patterns have been determined in other locations. There are also abundant ripple marks. The sedimentary environment is inferred to have been shallow marine, possibly a strandline deposit.

The overlying basalt flows appear to be conformable on the quartzite. In the lower part of the hill side, there are possibly three flows with fine-grained lower parts and vesicular tops. This lower part is separated by a band of crossbedded fine-grained micaceous quartzarenite 2–3 m thick. The thickness of each flow is only a few metres. Above this level is a thicker flow (~20 m) with a crystalline, partly doleritic lower part and a vesicular top. At the crest of the smaller ridge to the southwest of the main Beasley River Quartzite ridge, there is a 5-m interval of fine-grained crossbedded sandstone containing sporadic pebble-sized intraclasts of red mudstone. Possibly two channels are preserved in the interval, as there is a zone of plane-laminated sandstone dividing the 5-m band. Above the sandstone interval there are at least 10 m of red siltstone and shale, with thin rippled bands. These laminated deposits are interpreted as the overbank deposits related to the stream channels preserved in the sandstone cosets. In *the rippled siltstone and fine-grained sandstone at the top of the sandy interval, small desiccation cracks are preserved on some of the ripple-marked layers.*

Above this level there are two more sandstone intervals, which are distinctly lensoidal if traced along strike. The first band is a 2-m thick interval of planar-laminated fine-grained sandstone with no crossbeds. The second interval is a medium- to coarse-grained in places and contains a local granule conglomerate. Interestingly, this uppermost band contains dominantly quartz with some feldspar suggesting a plutonic source, and appears to have been derived from the northeast.

The transition from the Beasley River Quartzite to the Cheela Springs Basalt is interpreted as conformable, although there is no information as to whether any time or section is lost at the contact between the strandline deposits and the overlying basalt. The association of vesicular basalts with channel-and-overbank deposits is a natural one to expect where streams and basalts both flow down valleys. The little palaeocurrent evidence available suggests that there could be sources from both the southwest and northeast, but this conclusion needs to be treated with caution until a more regional basin analysis, currently in progress, is completed. Interestingly, the presence of mica and feldspar indicates that a granitic or gneissic terrain is present in the source terrain, which thus could have been to the north (or south) of the Hamersley Province. None of the Mt Bruce Supergroup rocks are likely sources for such materials. *Location: 2153–Mt Stuart 413202*

After completing the walk though the section, return to the vehicles.

The excursion will camp in this region overnight.

DAY 8 THE ASHBURTON TROUGH

The final half day of the excursion offers a brief view of the fill and state of deformation of the Ashburton Trough. The route is along the track to the Mt Stuart homestead and thence to the Paraburdoo–Nanutarra road, with the last two outcrops between Mt Stuart and Nanutarra.

The Ashburton Trough is a thick largely turbidite-filled sedimentary basin with marginal facies preserved along the southern and western margin of the Hamersley Province. The basal units are known as the Mt McGrath Formation, and have been examined on the excursion as the Karlathundra Conglomerate Member (Stop 5.3) and the Barrett–Lennard palaeoplacer (Stop 7.1). In other places, there are carbonate banks preserved as the Duck Creek Dolomite (Stop 7.2). Slumping along the northern margin of the Ashburton Trough emplaced olistoliths in the palaeocanyon at Stop 6.4. For most of the Ashburton Formation, the rocks are mass-flow deposits of various kinds, commonly showing well-preserved turbidite features, including fining- and coarsening-upward cycles.

Thorne and Seymour (1991) have carried out a regional reconnaissance analysis of the Ashburton Basin, and interpret it as having developed marginally to an emerging fold-and-thrust belt to the south and east. Their interpretation is somewhat different from what is being presented here in that firstly we regard the Ashburton Basin not to have formed until after the Lower Wyloo Group, and secondly we consider that the fold-and-thrust belt (to which the McGrath Trough and our F_2 belongs) was already emplaced prior to formation of the Ashburton Basin.

In this traverse to the west the excursion crosses first the June Hill Volcanics – a bimodal suite of volcanics deposited in graben related to WSW-directed extension along the northwestern margin of the Hamersley Province. The excursion then examines typical turbidite deposits in the main part of the Ashburton Trough at a locality where the later Boolaloo Granodiorite is intruded, and finally stops at a relatively non-deformed outcrop of the late Palaeoproterozoic Boolaloo Granodiorite on the main Nanutarra–Paraburdoo road.

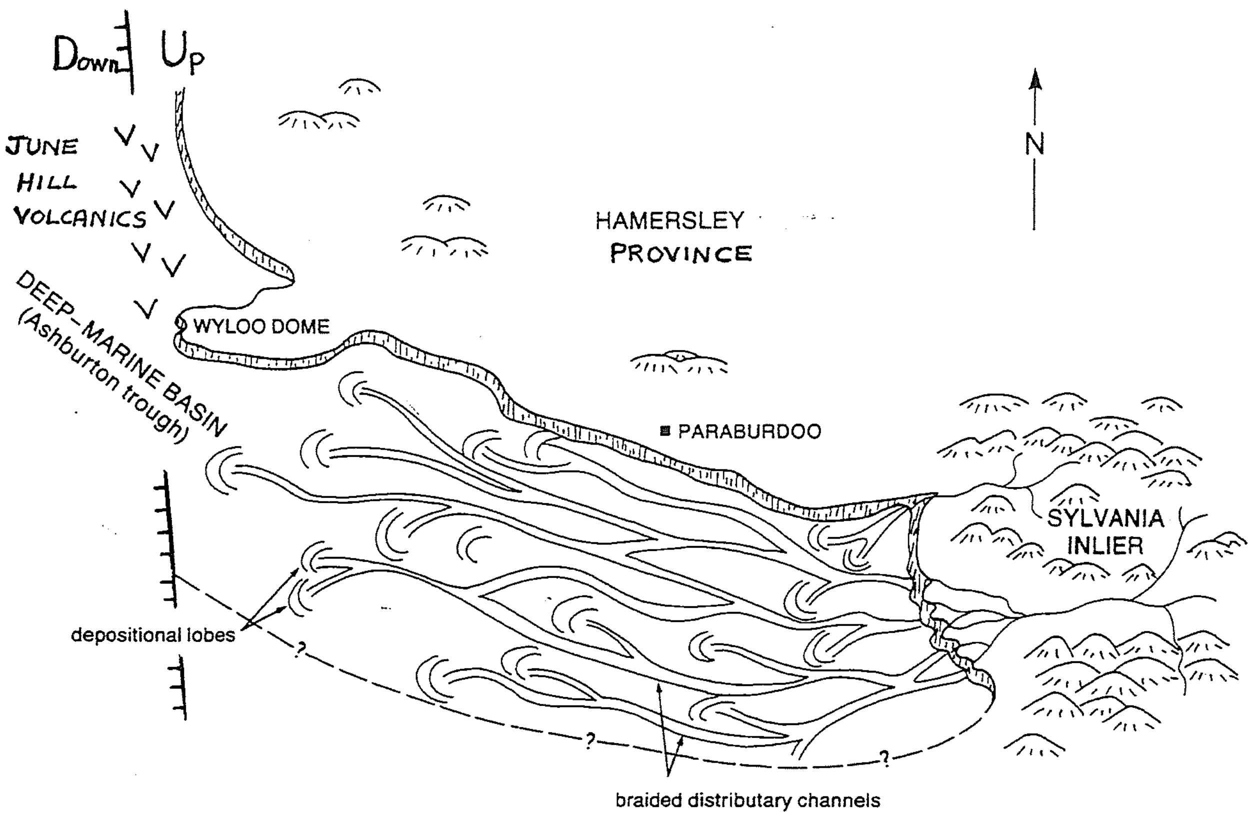


Fig. 8.1 Palaeogeographic reconstruction of the southwestern Pilbara during deposition of the lower Ashburton Formation, showing opening to the west along the western margin of the Hamersley Province. June Hill Volcanics are restricted to the western margin. Modified from Thorne and Seymour (1991, fig. 69).

Stop 8.1 **June Hill Volcanics** **(40 mins)**

Bimodal volcanics occur in stratigraphic proximity to the Duck Creek Dolomite on the western margin of the Hamersley Province. In this locality, the volcanics are of coarse-grained mafic tuffs. The volcanics, the dolomites, and the BIF and shales, which form the bulk of the surrounding hills, all recur as large slumped fragments, in places contorted, within the Ashburton Formation. *Location: 2153–Mt Stuart 232193*

Proceed westwards for about 24 km towards Mt Stuart, but do not turn southwards through the Station. Drive past the foot of the hill and turn left (south) (2153-Mt Stuart 000188). The prominent hills passed on the right are considered to be allochthonous; they are a large contorted mass of BIF and carbonate, from the Upper Wyloo Group, which has slumped in the Ashburton Formation turbidites. The allochthonous mass has been folded in with the Ashburton Formation turbidites into a north-plunging syncline. The orange-coloured rock southwest of the hill (structurally below it) is a large felsic tuff fragment of the June Hill Volcanics; it has been dated at ~1825 Ma by Pidgeon & Horwitz (1991).

Continue south for 2 km to the Nanutarra road, and turn left (east) for 1.0 km to outcrops in a small ridge of the northern side of the road.

Stop 8.2 **Ashburton Formation** **(30 mins)**

The low outcrops on the northern side of the road show a strongly sheared granodiorite in a gully, with a vertical foliation striking 148°. The outcrops through the fence are of typical Ashburton turbidites with bedding in one part dipping 50 to 70° to the north and grading indicating that the rocks are right-way up. Apophyses of granodiorite intruding the turbidite produce only a relatively narrow contact effects. *Location: 2153–Mt Stuart 000160*

Turn vehicles around and proceed west for 3 km to an outcrop of granodiorite.

Stop 8.3 **Boolaloo Granodiorite** **(30 mins)**

The rounded boulders either side of the road are part of the Boolaloo Granodiorite intruded during, or after, the closure of the Ashburton Trough. The rock is a hornblende granodiorite, and, in most parts of this outcrop, is massive with mafic enclaves. There is, however, a weakly developed foliation which elsewhere (e.g. Stop 8.2) is much more intensely developed. The age of the Boolaloo Granodiorite is not well constrained; a Rb-Sr whole rock date of 1684 Ma has been obtained (in Daniels, 1970) but experience in Western Australia has shown that when other techniques, such as U–Pb dating using SHRIMP on single zircon grains, have been used the Rb-Sr dates tend to be younger reset dates and not primary crystallisation ages. It should be noted that there is a quite intense, young NNW-trending deformation affecting the Mesoproterozoic Bangemall Beds just west of this locality.

Location: 2153–Mt Stuart 977172

For vehicles not driving to Karratha to catch the scheduled afternoon flight to Perth, an additional stop is worth visiting. Return eastwards along the bitumen road for about 14.5 km to 148.5 km from the T-junction (2152–Wyloo 087060) and turn south along a track (opposite direction from Mindle Bore) for ~10 km to Mt Edith.

Extra stop **Abutment at Upper Wyloo Group unconformity and chaotic nature of Jeerinah Formation on south limb of Wyloo Dome** **(40 mins)**

On the eastern end of the hill, the Mt McGrath Formation rests with marked angular unconformity on the Jeerinah Formation and abuts to the west, with a marked fossil scarp, onto the Marra Mamba Iron Formation. Very large blocks of Marra Mamba Iron Formation can be observed in the Mt McGrath Formation at the contact, and can be seen to decrease in size away from the abutment along strike to the east. The matrix enclosing the large angular blocks of Marra Mamba Iron Formation is smaller rounded boulders and pebbles. Along the contact in one place there is a deep red fine-grained weathered rock representing a NNE-trending dolerite dyke. In other places around Mt Edith, near the contact between the Jeerinah Formation and the Marra Mamba Formation there are contorted BIF and chert mixed in what is thought to be an olistostrome.

The Mt McGrath Formation dips ~40° towards 165° and the Marra Mamba Iron Formation dips 45° towards 200°. Restoration of the attitude of the Mt McGrath Formation to horizontal leaves a residual dip in the older Marra Mamba Iron Formation of ~22° towards 250°. A strongly developed cleavage dipping ~60° towards 240° occurs in the shaly units of the Jeerinah Formation, where there are also some minor folds. As noted between Stops 6.2 and 6.3, this prominent cleavage is characteristic of the southwestern half of the Wyloo Dome.

******* END OF EXCURSION *******

ACKNOWLEDGEMENTS

Horwitz' work was supported by CSIRO and AMIRA research contracts. Horwitz is grateful to CSIRO's Division of Mining and Exploration for providing a field vehicle to conduct a pre-run of the excursion in June 1994. Powell's work was supported by a UWA Individual Research Grant in 1990-91 and ARC Grant A39030719 in 1991-2, and by UWA since then. The support of Hamersley Iron Pty Ltd for thesis work of Cummins (1992), Dettbarn (1991) and Goddard (1992), and of RGC for the thesis work of Styles (1991) is greatly appreciated. Some of the costs of preparing this field guide have been met by Robe River Mining Company Pty Ltd. Information for Stops 5.1 and 5.2 is described more fully in Dettbarn (1991). Part of the excursion is based on a preliminary field guide prepared under the auspices of the Specialist Group in Tectonics and Structural Geology (SGTSG) of the Geological Society of Australia for a field excursion in May 1992 (Tyler *et al.*, 1992). Information for other stops has been gained from excursion notes prepared by Hickman *et al.* (1990) and Anonymous (1992). Ms A. Meakins provided information for Stop 2.4. Ms Renée Stienstra assisted with preparation of the final camera-ready typescript.

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