New Nd-isotopic and geochemical data from the west Pilbara

Implications for Archaean crustal accretion and shear zone movement

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Neodymium-isotope model ages of felsic igneous rocks offer information about the crustal residence times of their source rocks. Integrated with igneous emplacement ages from SHRIMP zircon U–Pb dating, this information reveals that juvenile crust formed at different times in the east and west Pilbara Craton. Geochemical characteristics of felsic and mafic igneous rocks from the west Pilbara, combined with the new isotopic data, offer some constraints for resolving outstanding issues: (1) Did plate teconics and terrane accretion play major roles in the formation of the Pilbara Craton?; and (2) How important is the Sholl Shear Zone as a geological boundary in the west Pilbara?

The 'North Pilbara' NGMA project* has been combining regional geological mapping and SHRIMP zircon U–Pb dating (Nelson 1996, 1997: Geological Survey of Western Australia, GSWA, Records 1996/5 and 1997/2) with research carried out at the University of Western Australia. As a result, it has demonstrated that most (if not all) rock sequences in the west Pilbara have no stratigraphic equivalents in the east Pilbara; clarification of this observation awaits geochronological and geochemical data for specific east Pilbara volcanic contemporaries (e.g., from the Strelley and Gorge Creek Groups) of the west Pilbara (Roebourne Group).

In the west Pilbara, Hickman (1997: GSWA, Annual Report, 76-81) has revised the greenstone stratigraphy of the Roebourne–Whundo area (Fig. 27). The oldest dated rocks, 3270 to 3250 Ma, are restricted to the area north of the Sholl Shear Zone (SSZ), a major structural feature between Port Hedland and Karratha. Between 3270 and 3260 Ma, the Karratha Granodiorite (Smith et al. in press: Precambrian Research; Nelson in press: GSWA, Records) intruded an older supracrustal sequence (Ruth Well Formation, part of the Roebourne Group) containing aluminium-depleted komatiites. Smith et al. (in press: op. cit.) suggest that this igneous complex was formed in an island-arc setting. The Ruth Well Formation must exceed 3270 Ma, but as it is conformable with the overlying ca 3270 Ma Nickol River Formation (Hickman 1997: op. cit.) it is probably not much older.

These rocks are ~200 Ma younger than the oldest dated rocks in the east Pilbara, represented by the widespread Warrawoona Group (3430–3470; e.g., Krapez 1993: Precambrian Research, 60, 1–45).

In the Roebourne area, the SSZ separates the Roebourne Group from the younger Whundo Group (Fig. 27). There is no consensus about the total distance of its movement and tectonic significance. GSWA work indicates a major early (pre-3020 Ma) sinistral movement followed by (post-2925 Ma) dextral movement of 30 to 40 km (Hickman in preparation: Explanatory notes for the Dampier 1:250 000 geological map, GSWA). According to SHRIMP zircon U–Pb dating of granites in the SSZ and rocks on both sides of it, Smith et al. (in press: op. cit.) suggest that two domains were juxtaposed at about 2960 Ma by the largely sinistral SSZ. This interpretation implies that the SSZ is a terrane boundary dating from that time, but GSWA geochronological data indicate that the two crustal segments have a common intrusive and depositional history from at least 3020 Ma.

In the Cleaverville area, east of Karratha (Fig. 27), tholeiitic amphibolites with MORB-like geochemistry (Ohta et al. 1996: Lithos, 37, 199–221) occur in a greenstone succession containing subordinate chert/banded iron formation and clastic rocks (sandstone, mudstone, and conglomerate) interpreted to have been deposited in an intraplate environment. Influenced by the unpublished results of field mapping by Y. Isozaki, Ohta et al. (1996: op. cit.) interpreted the amphibolite and chert/BIF sequences as tectonically repeated slices of oceanic crust in an accretionary complex associated with the subduction of oceanic lithosphere. According to Hickman (1997: op. cit.), the depositional age of the entire succession is loosely constrained between 3020 and 3260 Ma. Yet the style of tectonism proposed by Ohta et al. (1996: op. cit.) must have postdated deposition of the youngest components (3020 Ma), and therefore have been later than the main sinistral movement on the SSZ. If the alleged accretionary complex was emplaced by 3020 Ma, then some modification to their model is required.

Nd-isotope model ages — tectonic significance of the SSZ and a comparison of Nd model ages between the east and west Pilbara

The oldest dated rocks in the west Pilbara include dacite from the Nickol River Formation near Mount Regal (3251 ± 6 Ma) and the Karratha Granodiorite (3261 ± 4 Ma) near Karratha, north of the SSZ. Their Nd T_{DM} model ages (3430–3480 Ma; Table 3) are 180–220 Ma older than the respective emplacement ages, suggesting that magma generation involved older basement rocks, enriched lithospheric mantle, and/or sedimentary rocks derived from older terrains through subduction. They are also ca 100 Ma or more younger than the Nd T_{DM} model ages of 3520–3670 Ma for some granitoid complexes and rock units emplaced at ~3470 Ma in the east Pilbara, but are similar to the Nd T_{DM} model ages of other units in the east (Table 3). This contrast of Nd model ages between the east and west Pilbara lends support to a model of generally westward growth of the Pilbara Craton (e.g., Krapez 1993: op. cit.). However, we cannot rule out the possibility that some older crust may have existed in parts of the west Pilbara not yet studied.

South of the SSZ in the Roebourne area, felsic igneous rocks of the 3120-Ma Whundo Group have Nd T_{DM} model ages of 3150–3250 Ma, 30–130 Ma older than the emplacement age. Small differences in model and emplacement ages suggest that these rocks were not generated by the melting of ~3260-Ma-type source rocks (e.g., Karratha Granodiorite) north of the SSZ. Instead, they suggest that juvenile crust formed at ~3120 Ma generated the Whundo Group rocks. The same can be said about the 3090–2925-Ma Caines Well Granite Complex to the east. The Cherratta Granitoid Complex (~3100–2925 Ma), which intrudes the Whundo Group in the south of the SSZ, covers a large area and includes several intrusive bodies (e.g., the Gregory Well and Marcia

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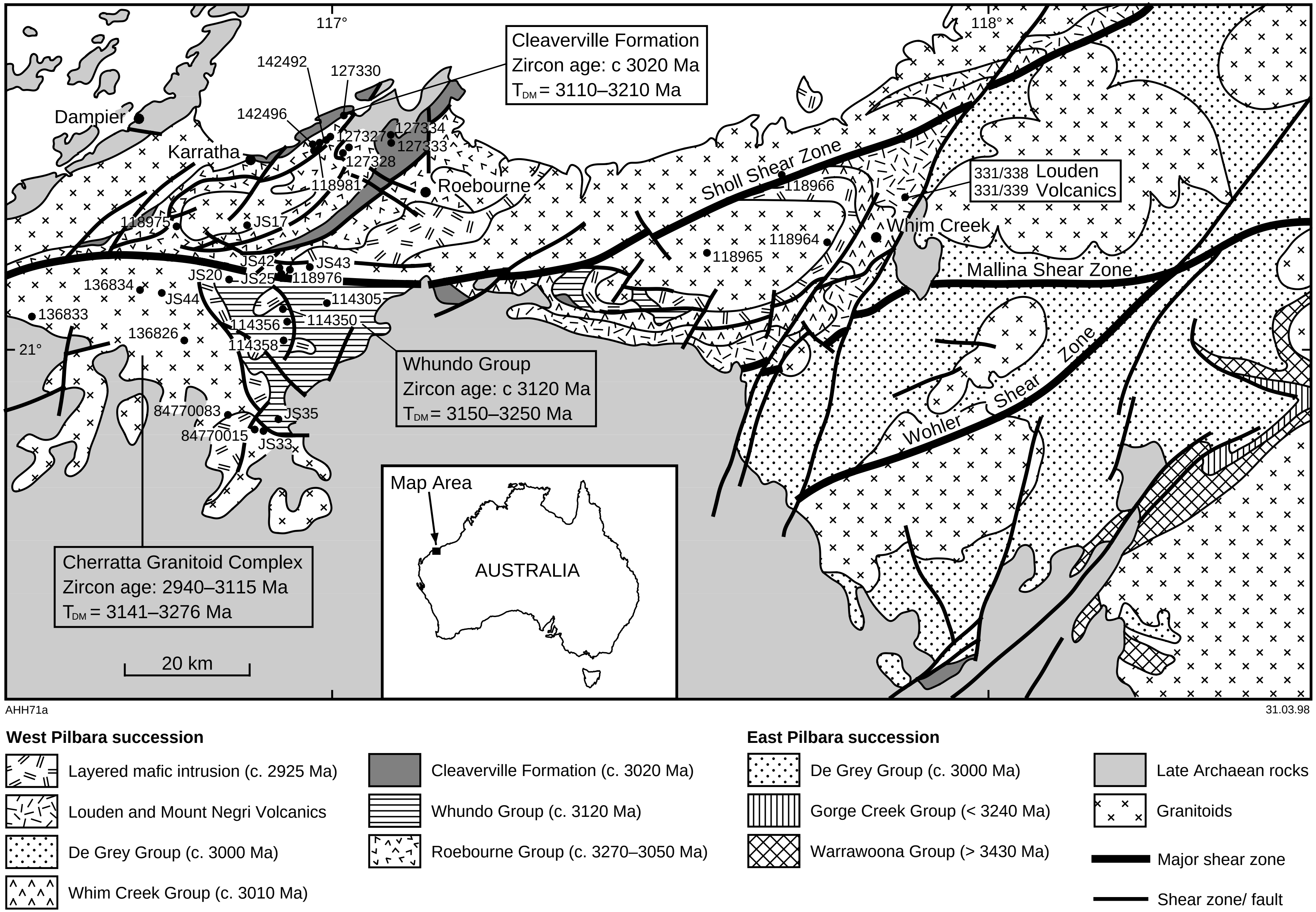

Fig. 27. Simplified geological map of the west Pilbara showing Hickman's (1997: op. cit.) revised stratigraphy, sample locations, and emplacement ages (based on SHRIMP zircon U–Pb ages) and Nd-depleted-mantle model ages (T_{DM}) for the main rock units.

Bore gneisses). They have Nd T_{DM} ages of 3150–3276 Ma, similar to those of the Whundo Goup.

The foregoing data reveal marked contrasts in both emplacement ages of igneous rocks and Nd T_{DM} ages either side of the SSZ. If these differences are further confirmed by Nd-isotope model ages of major units such as the Dampier Granitoid Complex (2997 Ma) to the north of the SSZ, they will lend strong support to the idea that the SSZ separates crustal segments containing different basement rocks. This juxtaposition of contrasting basement rocks could have been achieved by sinistral movement along the SSZ. If so, then the bulk of the Roebourne Group may be dislocated Strelley-type rocks from the east.

In the Cleaverville area, north of the SSZ (Fig. 27), felsic volcanics and dykes emplaced ca 3000 Ma have Nd T_{DM} ages of 3110–3210 Ma (Table 3), a 100–200-Ma difference in common with other samples of ~3000-Ma felsic igneous rocks elsewhere in the west Pilbara. Despite their frequency in the west Pilbara, Nd T_{DM} ages of 3200–3250 Ma are not a simple reflection of the emplacement ages of their source rocks, even though inherited zircons yielding such ages are a common occurrence in younger rocks. Melting of pre-existing 3250-Ma older crust does not explain the generation of these ~3000-Ma igneous rocks with Nd T_{DM} ages of ~3200 Ma; instead, they represent juvenile crust formed after 3250 Ma.

From our Pilbara Craton Nd T_{DM} data (Table 3), we expect that late Archaean felsic igneous rocks (e.g., the 2925-Ma Bookingarra Granite, 2950-Ma Satirist Granite, and 2765-Ma Opaline Well Leucogranite) distributed in areas dominated by 3000–3100 Ma rocks with Nd T_{DM} ages of ~3200 Ma in the west Pilbara would have similar Nd T_{DM} ages if they were generated by melting of these source rocks. This expectation is fulfilled by new data we have obtained for these rocks. In contrast, late Archaean felsic igneous rocks associated with early Archaean (~3450 Ma) basement rocks in the east Pilbara have correspondingly older Nd T_{DM} ages — ca 3350–3600 Ma or even older (Table 3).

Geochemical arguments for subduction-related processes

The genesis of Archaean calc-alkaline volcanic rocks, some with tonalite–trondhjemite and granodiorite associations, in a subduction zone environment in the Pilbara Craton is open to debate. Unlike many other Archaean terrains in the world where subduction models have been applied, the Pilbara has no single well-defined greenstone belt. Moreover, the various component greenstone belts of the craton show no regional alignment or preferred orientation; instead, most greenstone belt boundaries have been structurally controlled by the emplacement of circular or ovoid granitoid complexes. We suggest that geochemical characteristics of mantle-derived mafic rocks can be used to shed some light on this issue.

The amphibolites with MORB-like geochemistry around Cleaverville were previously studied by Glikson et al. (1986: BMR/AGSO Record 1986/14) and Ohta et al. (1996: op. cit.). Ohta et al. suggested that they and their associated cherts and clastic rocks represent an accretionary complex generated by the subduction of oceanic lithosphere. Our new geochemical (ICP–MS) data confirm the MORB-like features of these amphibolites (Fig. 28). Later mafic dykes (ca. 3000 Ma?) intruding them evince strong light REE, Th enrichment, and Nb depletion, similar to ~3.0-Ga high-magnesian basalts of the Louden Volcanics (Fig. 28; mistakenly called 'Negri Volcanics' by Sun et al. (1989: *in* A.J. Crawford, Editor, Boninites and related rocks, Unwin Hyman, 148–173). Samples of the Louden Volcanics have an initial εNd value of –1.8 at 3.0 Ga, which is considerably lower than that (~+3) of the depleted mantle at that time and of some of the Cleaverville amphibolites. A reasonable explanation for this low initial εNd value and trace-element spidergram pattern of the Louden Volcanics is that the mantle source was contaminated by sediments derived mainly from ~3250-Ma source rocks in the region. We suggest that mantle sources of ~3.0-Ga mafic dykes in the Cleaverville area have also been modified by subduction processes (Sun, Nakamura, & Hickman, research in progress). Similarly, geochemical data for basalts in the Whundo Group (Glikson et al. 1986: op. cit.) are consistent with juvenile crust generated in a subduction zone environment (as suggested by Smith et al. in press: op. cit.).

The geochemical characteristics of the ~3.0-Ga Louden Volcanics and mafic dykes cutting Cleaverville MORB-like amphibolites are shared by other light-REE-enriched Archaean mafic igneous rocks in the Pilbara, including 2760–2690-Ma Fortescue Group flood basalts (Fig. 28). Nelson et al. (1992: Precambrian Research, 54, 231–256) suggested that the Fortescue flood basalts were generated in an intraplate environment through interaction of asthenospheric mantle plumes with lithospheric mantle metasomatised by a subduction zone process several hundred millions of years before 2.7 Ga. A literature survey indicates that basalts from various parts of the Pilbara have geochemical features consistent with subduction-related environments. Some of the better examples offer strong support for the idea that lithospheric plate subduction is an important process in crustal growth of the Pilbara Craton.

A corollary of this consideration concerns the tectonic environment of volcanic-hosted massive sulphide (VMS) deposits associated with Archaean volcanic sequences. In some of these deposits, basalts have trace-element characteristics, such as Nb and Ta

Table 3. Comparison of Nd model ages and emplacement ages of igneous rocks between the east and west Pilbara

Location	*Emplacement age (Ma)*	*εNd$_I$*	*T_{DM} (Ma)*	*T_{DM} –T (Ma)*	*Data sources*
East Pilbara					
North Shaw regional suite	3470	1.7 to –0.5	3520–3670	50–200	McCulloch (1987); Bickle et al. (1993)
Duffer Formation	3460	0.6	3590	130	McCulloch (1987)
Mount Edgar Granitoid Complex	3310	0.6	3460	150	McCulloch (1987)
Boobina Porphyry	3305	0.4	3466	161	McCulloch (1987)
Bamboo Springs pluton	2950	–2.8	3380	430	Bickle et al. (1989)
Mulgadinnah Hill leucoadamellite	2943	–4.0	3462	519	Bickle et al. (1989)
Pilga Station leucoadamellite	2943	–4.1	3470	527	Bickle et al. (1989)
Garden Creek adamellite	3007	–4.3	3537	530	Bickle et al. (1989)
Kurrana Downs Granitoid Complex	2900	–3.2	3372	472	Tyler et al. (1992)
Ballinooka inlier, post-tectonic granite	2900	–1.0	3220	320	Tyler et al. (1992)
Cooglegong Adamellite, Shaw Granitoid Complex	2850	–4.2 to –8.0	3390–3650	540–800	Bickle et al. (1989)
West Pilbara					
North of SSZ					
Karratha Granodiorite, Harding Granite, and Mount Regal dacite (JS17, JS43, 118975)	ca 3260	0 to –0.4	3430–3480	170–220	This study; Smith et al. (in press)
Nickol River dacite, lower succession (118976)	3023	–0.6	3298	275	This study
Felsic porphyry in Regal Basalt (127327, 127328), Cleaverville Fm (127333, 127334), Lagoon rhyolite (118981)	ca 3000	0.4 to 1.8	3110–3210	110–210	This study
Louden Volcanics (331/338, 331/339)	ca 3000	–1.8	3368	ca 370	Sun et al. (1989)
Forestier Bay gneiss (118966)	3014	–0.4	3276	262	This study
Sholl Shear Zone (JS25, JS42)	3024	–0.9 to –1.5	3316–3355	292–331	Smith et al. (in press)
South of SSZ					
Whundo Group volcanics (114305, 114350, 114356, 114358, JS20)	3120	1.3 to 2.6	3150–3250	30–130	This study; Smith et al. (in press)
Cherratta Granitoid Complex (JS33); Marcia Bore gneiss* (136833), Gregory Well gneiss* (136834)	3115	0.8 to 2.6	3141–3276	26–161	Smith et al. (in press); this study
Sholl belt (JS 35)	3013	0.5	3211	198	Smith et al. (in press)
Cherratta Granitoid Complex (136826, 84770115, 84770083, JS44),	2990	0.2 to 0.9	3150–3215	160–225	This study; Sun & Hoatson (1992); Smith et al. (in press)
Caines Well Granitoid Complex (118965)	3093	2.8	3118	25	This study
Bookingarra Granite (118964)	2925	0.1	3164	239	This study

Additional references: Bickle et al. (1989: Contribution to Mineralogy & Petrology, 101, 361–376); Bickle et al. (1993: Precambrian Research, 60, 117–149); McCulloch (1987: American Geophysical Union, Geodynamics Series, 17, 115–130); Sun & Hoatson (1992: AGSO Bulletin 242, 141–149); Tyler et al. (1992: Precambrian Research, 54, 211–229).

* On the basis of field occurrence and chemical composition, we suggest that the Marcia Bore and Gregory Well gneisses belong to the 3100-Ma age group.

depletion and Th and Ba enrichment (cf. Fig. 28), which may be generated by subduction zone processes. However, an island-arc or cordilleran environment is not essential for the generation of these basalts; rather, many basalts originating in an intraplate environment, such as the Fortescue Group basalts, could have had their mantle source regions modified by prior subduction processes. A closer examination of all pertinent geological information and an integrated interpretation of the data might reveal the evidence for such processes.

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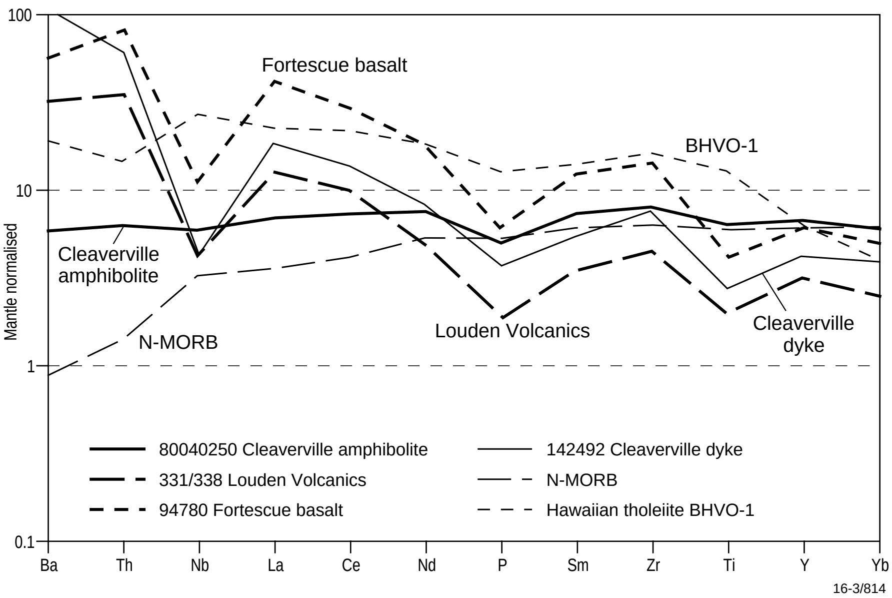

Fig. 28. Mantle-normalised trace-element diagram for MORB-like Cleaverville amphibolite; ~3.0-Ga high-magnesian Louden Volcanics; later mafic dykes intruding Cleaverville amphibolites; and 2760–2690-Ma intraplate Fortescue Group flood basalts (showing strong light REE, Th enrichment, and Nb depletion).