PROTEROZOIC GEODYNAMICS OF AUSTRALIA

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Summary

Whether Proterozoic Australia was assembled by plate tectonic processes that involved large-scale horizontal motions, or whether it evolved as an essentially intact block of crust, remains a subject of contention. Proterozoic rocks of Australia comprise three main cratonic areas, each containing blocks of Archean crust and Paleo- to Mesoproterozoic mobile belts. The three cratons may have formed independently, and are thought to have been united during late Mesoproterozoic (1.3 – 1.1 Ga) assembly of Rodinia, although the previous amounts of separation between them remain unknown. The current paleomagnetic database, however, suggests that the North and West Australian Cratons may have been in their present relative positions since at least ~1.7 Ga, and were joined to the South Australian Craton since at least ~1.5 Ga. Until this apparent contradiction is resolved, the hypothesis that the Proterozoic cratons of Australia evolved in essentially their present relative positions should not be discarded.

Introduction

Several models have been proposed, based on geological, geochemical, and geophysical evidence, for the Proterozoic evolution of Australia as a single continent, by processes of mainly intracratonic rifting and vertical tectonics (Rutland 1973; Etheridge *et al.* 1987, Drummond 1988; and others). Consistent with such a model is the observation that a single apparent polar wander (APW) path can be drawn through all the Australian paleopoles even though they are derived from different tectonic units (Veevers and McElhinny 1976; McElhinny & Embleton 1976; Idnurm and Giddings 1988; Idnurm *et al.* 1995; and others). Recently, however, Australian geology has been reinterpreted on the assumption that Phanerozoic plate tectonic styles are applicable to the Proterozoic (Myers 1990; Myers *et al.* 1996; Tyler *et al.* 1998; and others). These models invoke processes, such as subduction, terrane accretion, and continent-continent collision, that involve large horizontal displacements, in apparent contradiction with paleomagnetic evidence. This contribution will summarise recent geological and paleomagnetic information for Proterozoic Australia, and reassess the competing models for the continent's evolution.

Plate tectonic interpretations

Recent syntheses portray the assembly of Australia as a protracted and complex series of events (Myers *et al.* 1996; Tyler *et al.* 1998). Three main areas of continental crust: the North, West, and South Australian Cratons (Fig. 1A), are thought to have assembled independently during the early Proterozoic, and to have been joined after ~1.3 Ga (Fig. 2).

The West Australian Craton contains three geologically-distinct terranes inferred to have been assembled by about 1.8 Ga. The Paleoproterozoic Gascoyne Complex is joined to the northern Yilgarn Craton along the 2.0 to 1.96 Ga Glenburgh orogen; Sheppard *et al.* (1999) interpreted the spatial distribution of granitoids as indicating N-dipping subduction, and Myers (1989) suggested that a thrust sheet of deformed and metamorphosed gabbro and ultramafic rocks (Trillbar Complex) represents the lower part of an ophiolite sequence. Structural and magmatic observations were interpreted to indicate that an ocean basin was consumed by N-S oblique convergence and S-dipping subduction between the Yilgarn and Pilbara Cratons during the 1.83 to 1.78 Ma Capricorn orogeny (Tyler & Thorne 1990; Tyler 1999). Subsequent intracratonic deformation included westward extrusion of material caught between the Pilbara and Yilgarn Cratons (Tyler & Thorne 1990) and regional extension after ~1.65 Ga (Nelson 1995) to accommodate sediments of the Bangemall Basin, which subsequently were strongly folded in the latest Mesoproterozoic (Myers *et al.* 1996).

Synchronous deformation, metamorphism, and magmatism in the North Australian Craton, including the Pine Creek, Arnhem, Tennant Creek, Mt Isa, and Arunta blocks (Etheridge *et al.* 1987; Page 1988), during the 1.89 to 1.87 Ga Barramundi orogeny, suggests either amalgamation or prior tectonic coherence of these terrranes at that time. The Kimberley block was accreted to the North Australian Craton along the Halls Creek orogen at ~1.85 to 1.82 Ga (Bodorkos *et al.* 1999). The Strangways orogeny (1.78 - 1.73 Ga) in the northern Arunta Inlier was inferred by Myers *et al.* (1996) to indicate oblique convergence and accretion of magmatic arcs along the southern margin. The Argilke (1.68 - 1.66 Ga) event may reflect accretion of a strip of continental crust to the same margin. On geochemical grounds, Zhao & Cooper (1992) argued for subduction and consumption of oceanic crust, although this was questioned by Collins & Shaw (1995), who cited the scarcity of diagnostic subduction-related rock types and apparent correlations of strata across the Arunta and Tennant Creek blocks, as evidence against accretion. Compression during the ~1.6 Ga Chewings orogeny in the southern Arunta Inlier was intracratonic (Myers *et al.* 1996). Deformation in the Mt Isa and Georgetown regions at 1.55 Ga may reflect accretion of the latter block to the eastern margin (Myers *et al.* 1996).

The South Australian Craton (Daly *et al.* 1998) contains two main cratonic blocks, the Gawler and Curnamona Cratons, separated by the 1.85 to 1.7 Ga Kimban orogen. The eastern margin was deformed during the 1.7 to 1.6 Ga Olarian orogeny. The Coompana block (known in the subsurface only) may have accreted to the western Gawler Craton during the 1.65 to 1.54 Ga Kararan event.

The North, South, and West Australian Cratons are united along the Albany-Fraser - Paterson-Musgrave orogenic system, which was active during the inferred 1.3 to 1.1 Ga assembly of Rodinia (Nelson 1995; Nelson *et al.* 1995; Myers et al. 1996). Recent zircon geochronology suggests that this "Grenville-age" belt extends into the Cape River and Iron Range provinces of northeast Australia (Blewett *et al.* 1998).

Sedimentation in the continent-wide Centralian Superbasin and initial rifting along eastern Australia (Figure 1B) commenced at 850 to 830 Ma (Walter *et al.* 1995; Wingate *et al.* 1998). Although Australia remained essentially intact during breakup

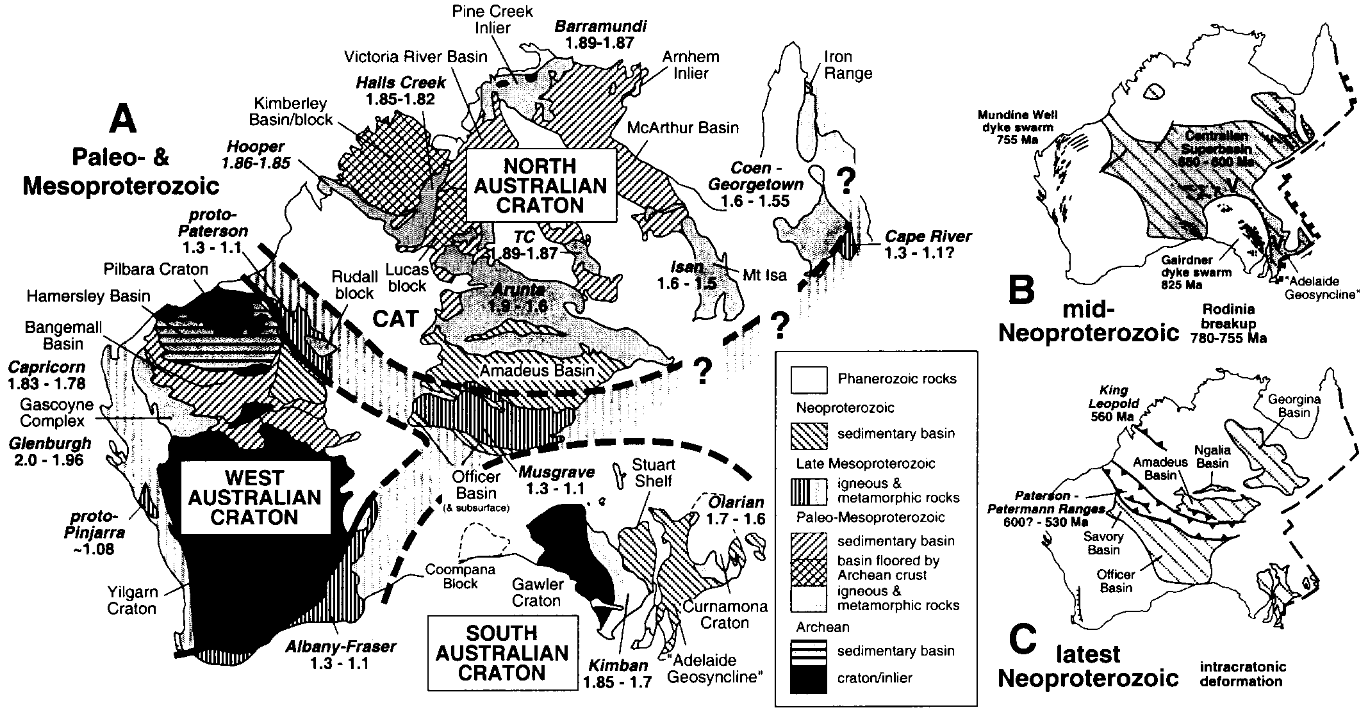

Fig. 1: (A) Exposed Precambrian rocks of mainland Australia, illustrating 1.3 to 1.1 Ga orogenic belts along which the three main cratons are inferred to have amalgamated during Rodinia assembly. Orogens (italics) and associated times of tectonic activity are indicated (ages in Ga). TC, Tennant Creek block; CAT, central Australian terranes. (B) Sedimentation in the Centralian Superbasin started at ~850 Ma (Walter *et al.* 1995). Rift-related magmatism preceding breakup along eastern Australia commenced at ~830 Ma with emplacement of the Gairdner dyke swarm and associated volcanic rocks (Wingate *et al.* 1998). (C) Mainly intracratonic deformation occurred along latest Proterozoic belts, exhuming the Musgrave and Arunta blocks and disrupting the Centralian Superbasin.

from Rodinia between 780 and 755 Ma (Wingate & Giddings, in press), several intracratonic events occurred in the latest Neoproterozoic and Paleozoic (Fig. 1C). The ~600 to 530 Ma Paterson-Petermann Range orogeny, which involved reactivation of the Paterson-Musgrave orogen, with N-directed thrusting in the Musgrave Block and SW-directed thrusting at the eastern edge of the Pilbara Craton and in the King Leopold

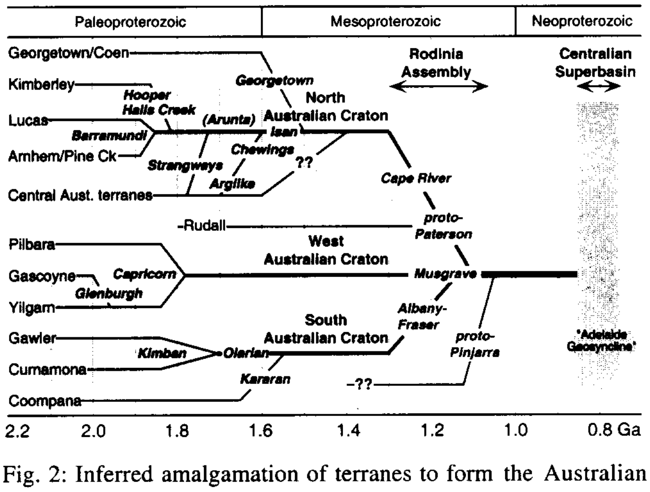

Fig. 2: Inferred amalgamation of terranes to form the Australian continent. Names of orogenic belts are in italics.

orogen, may reflect CCW rotation of northern Australia (Powell *et al.* 1994; Tyler *et al.* 1998). Between ~850 and 450 Ma, the eastern margin of Australia experienced several orogenic events, and some effects extended well into the continent. Extensive thrusting occurred in the Arunta Block during the 400 to 300 Ma Alice Springs orogeny (Collins & Shaw 1995).

Despite abundant evidence for compressional deformation, and for the prior truncation and subsequent juxtaposition of terranes of contrasting age and structural and metamorphic characteristics, there is no compelling evidence for oceanic crust having been consumed between those terranes, and no information on how widely separated the terranes might have been prior to their inferred amalgamation. Gravity and aeromagnetic data are not dominated by the linear features expected from accretionary processes (Drummond 1988). Hence, although the geology can be interpreted in terms of plate tectonics, no evidence exists for large horizontal motions of crustal fragments in Australia during the Proterozoic.

Paleomagnetism

Paleomagnetism is the only method for determining quantitatively the relative positions of continental fragments during Precambrian time. Paleomagnetic directions yield information about the latitude and orientation of a sampling locality relative to the paleomagnetic pole at the time the magnetisation was acquired. Figure 3 shows the positions of

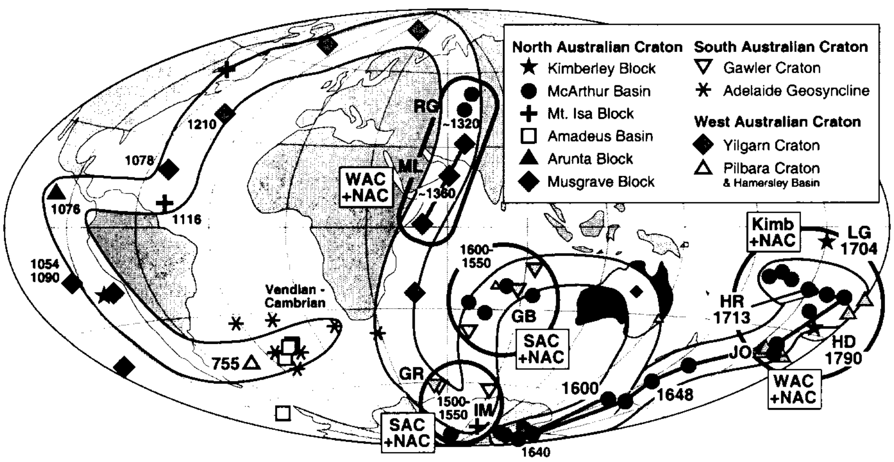

Fig. 3: Apparent polar wander path for Australia between 1.8 and 0.5 Ga. Grey symbols indicate overprint paleopoles. Small symbols denote poles for which geographic polarity is ambiguous. Times >1.3 Ga at which poles from different cratonic blocks overlap are circled. Ages are in Ma (more reliable results are in larger font). Updated from Idnurm & Giddings (1988) and Idnurm *et al.* (1995) with data from Li (1999, and in press), Pisarevsky & Harris (1999), Wingate & Giddings (in press). N,W,SAC, North, West, South Australian Craton; Kimb, Kimberley. See text for paleopole abbreviations.

paleopoles relative to Australia between 1.8 and 0.5 Ga. The apparent polar wander (APW) path is constructed by joining paleopoles, backwards through time, by the shortest possible segments. Although this is the simplest approach, the result is not unique. Lack of a continuous record of field reversals back to the Proterozoic leads to ambiguity in choosing a pole versus its anti-pole, and, because of large age gaps between adjacent poles, it is inevitable that some important features of the path are overlooked. Another critically important uncertainty is the lack of well-dated paleopoles. Many are dated imprecisely, and/or their magnetisations cannot be demonstrated to be primary. Nevertheless, all paleopoles from a single block will help to define the APW path for that block; those reflecting secondary overprints will lie on a younger segment than primary poles for the same rocks. Most intracratonic deformation, including formation or destruction of small (≤1500 km) ocean basins, will not be detectable within typical uncertainties in pole determination (5 to 20°). With these uncertainties in mind, the data can be explored in three ways:

1. Matching of APW paths from two or more tectonic blocks over an interval of time enables, in principle, a unique reconstruction of their relative positions. There are insufficient data, however, to construct adequate APW paths for the different blocks. The only well-defined paths are those for the 1.72 to 1.65 Ga McArthur Basin and the imprecisely-dated ~1.36 Ga Morawa lavas (ML, Fig. 3).

2. If the constituent terranes of Australia assembled via large horizontal motions, such as those which characterise Phanerozoic plate tectonic regimes, then it is most unlikely that the poles from all the different blocks would fall on a single APW path. In particular, if large oceans closed between the North, West, and South Australian Cratons at 1.3 Ga, the APW paths should be dissimilar prior to that time and should converge to produce a common path when the blocks are joined. Although different segments tend to be defined by data from different regions, Figure 3 shows that is possible to construct a single APW path for all Proterozic poles. This is consistent with the different regions of Australia having evolved in their present relative positions since ~1.8 Ga.

3. If two or more blocks are in their correct relative positions for a particular time, the paleopoles of that age from the different blocks should overlap. Note that when matching individual pole positions, rather than APW paths, longitude is unconstrained, hence relative E-W motion between blocks cannot be discerned. There are several segments of the APW path where data from different blocks overlap (Fig. 3):

1720 - 1700 Ma Primary and overprint poles from the McArthur Basin at ~1715 Ma (pole HR) are similar to those for the 1704 Ma Elgee Fm (LG) and 1790 Hart Dolerite (HD) of the Kimberley block, consistent with accretion of the latter to the North Australian Craton by 1820 Ma. Recent structural and paleomagnetic studies (Li, 1999) indicate that a Pilbara syn-folding overprint pole (JO, Schmidt & Embleton 1985) was acquired during the 1.83 – 1.79 Ga Capricorn orogeny. Proximity of this pole, and similar poles from Pilbara iron-ore deposits, to the McArthur Basin and Kimberley poles implies that the North and West Australian Cratons were in their present relative positions since at least 1.7 Ga (Li, 1999).

1600 - 1550 Ma Four overprint poles (<1.59, >1.5 Ga) from the McArthur Basin overlap with poles from South Australian iron ore deposits and 1.6 - 1.55 Ga dykes (GB; Rb-Sr, Mortimer *et al.* 1988). This permits the West and South Australian Cratons to have been joined at this time.

1550 - 1500 Ma A post-metamorphic cooling pole (IM) from Mt Isa and a McArthur Basin overprint pole are close to poles from the South Australian Craton. Although the Gawler Range Volcanics are well-dated at 1592 Ma, the pole (GR) reflects a post-folding overprint (Schmidt & Clarke 1992), possibly acquired at ~1.53 Ga (Rb-Sr, Compston & Arriens 1968). These data suggest assembly of the North and South Australian Cratons by ~1.5 Ga.

1360 - 1320 Ma A stratigraphically-constrained study of the Morawa lavas (ML), and underlying and overlying sedimentary rocks, yielded an APW vector for the Yilgarn Craton at ~1360 Ma. Intrusion of dolerite at ~1320 Ma (J. Claoué-Long, pers. comm. 1997) was likely responsible for overprints in the Roper Group sedimentary rocks (RG). These results are consistent with a connection between the North and West Australian Cratons prior to 1.3 to 1.1 Ga orogenic events.

Conclusions

The available paleomagnetic data suggest that the North, West, and South Australian Cratons were in their present relative positions since at least 1.5 Ga, and possibly the North and

West Australian Cratons were assembled prior to ~1.7 Ga. There is no compelling evidence for large large ocean basins between any of the Australian fragments during the Proterozoic. Ideally, APW paths need to be defined for each crustal block. Current studies, however, should focus on obtaining well-dated poles of precisely the same age from different blocks at several key points in time. If plate tectonic models are correct, support is likely to be found eventually from paleomagnetism. Until then, the "single-continent" model should not be discarded.

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