The tectonic context of the Early Palaeozoic southern margin of Gondwana

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Abstract

The oceanic southern margin of Gondwana, from southern South America through South Africa, West Antarctica, New Zealand (in its pre break-up position), and Victoria Land to Eastern Australia is one of the longest and longest-lived active continental margins known. Its construction was initiated in late Neoproterozoic times following the break-up of the pre-existing supercontinent of Rodinia. Gondwana was established by the amalgamation of Australian, Indian, Antarctic, African and South American continental fragments mostly derived from Rodinia. Its 'Pacific' margin continued to develop as the site of the 18,000 km Terra Australis orogen, predominantly facing subducting ocean floor and involving some terrane accretion events, through Palaeozoic and Mesozoic times until, and during, the eventual break-up of Gondwana itself.

Break-up of Rodinia

Although the exact configuration of Rodinia is debatable, the existence of a Neoproterozoic supercontinent is consistent with the widespread occurrence of orogenic belts in the age range 1000–1200 Ma (Fig. 1), i.e., coetaneous with the Grenville Belt that runs all the way along the present eastern coast of North America (Laurentia in the Precambrian context). These belts have been interpreted as collision zones during the formation of Rodinia (Hoffman 1991). Such belts criss-cross Antarctica (Fitzsimons 2000, 2003) (Fig. 1) and together with palaeomagnetic data (Pisarevsky *et al.* 2003) seem to require the conjunction of the East Antarctica, Australia, Laurentia, Baltica, India, Siberia and South China blocks by about 1000 Ma. The exact configuration of Rodinia has been disputed, and Cordani *et al.* (2003) for example, have proposed that some of the cratonic elements now in NW Brazil and W Africa were never part of Rodinia. However, 'Grenville-age' lithological assemblages are now being found in the western Sierras Pampeanas of Argentina (Casquet *et al.* 2005; 2006) and as far north as Columbia Cordani *et al.* (2005) (Fig. 1): they appear to present a conjugate collisional margin with Laurentia, which thus seems to have subsequently split apart along the main axis of this Grenville belt. The timing of Rodinia break-up and the paths followed by the disrupted masses are at present poorly constrained by geochronology or palaeomagnetic studies, respectively.   Evidence from igneous activity is rare, but the occurrence of passive margin sedimentary sequences, mafic dykes swarms, alkaline igneous complexes, and occasionally ophiolites, in the age range 850–700 Ma in Laurentia (e.g. Heaman *et al.* 1992) Africa (de Kock *et al.* 2000), Australia (Wingate & Giddings 2000) and Brazil (Paixão *et al.* 2008) generally suggest a rifting environment consistent with the predominant presence of intermediate oceanic basins during this interval. Final rifting between Laurentia, Baltica and Amazonia did not occur until about 600 Ma (Pisarevsky *et al.* 2008).

Formation of Gondwana

The cratonic fragments, derived directly from Rodinia or otherwise, were gradually realigned to form Gondwana from about 650 Ma onwards. Interpretations of the stages involved are based on the constraints of palaeomagnetism and the correlation of dated orogenic belts. According to one such model (Boger & Miller 2004), India (and Dronning Maud Land, the region of East Antarctica now nearest to South Africa) was accreted to eastern Africa along the Mozambique Belt at 590–560 Ma (Fig. 1) (the Kuunga Orogen of Cawood & Buchan (2007) (Fig. 1)), followed by the collision of Australia and the bulk of East Antarctica (Mawson Craton; Fig. 1) at 535–520 Ma along the Pinjarra Orogen (Cawood & Buchan 2007) (Fig. 1), these collisions causing the series of orogenies known as Pan-African, often equated with the amalgamation of 'East' and 'West' Gondwana. The main suture is sometimes referred to as the East African or East African-Antarctic orogen (e.g. Jacobs & Thomas 2004). However the process must have started even earlier in the Neoproterozoic, since the Arabian Nubian shield (Fig. 1) was already in place north of the Mozambique Belt, possibly by ~700 Ma. Moreover, West Gondwana includes the South American sector, where a collage of cratonic and accretionary fragments were similarly colliding with the western side of the proto-African continent through closure of the Adamastor Ocean (Brito Neves *et al.* 1999); this occurred from around 600 Ma, producing in an equivalent series of Brasiliano–Pan-African orogenies (Fig. 1) (see contributions in Pankhurst *et al.* (2008) for an up-to-date review), which also culminate in the mid-Cambrian. The main elements constituting the southern margin of the new supercontinent were essentially in place by the mid-Cambrian, from which time onwards erosion of the newly formed orogenic belts became a significant and continuous process. However, the tectonic development of the margin was far from over.

Subsequent development of the southern margin of Gondwana

During the early Palaeozoic much of the margin was dominated by successive episodes of subduction-accretion.

In Eastern Australia the Neoproterozoic Adelaide Rift system changed into an active, and then collisional, margin during the Cambro-Ordovician Delamerian orogeny forming the Adelaide Fold Belt (Cawood & Buchan 2007) (Fig. 1). Continued accretionary events resulted in the margin stepping out to include the Lachlan and New England fold belts (see review by Glen 2005) (Fig. 1). Late Ordovician to Devonian granites dominated the Lachlan Fold Belt, with several deformation phases, the most important being near the Ordovician-Silurian boundary. This is the region in which the concept of I- and S-types granites was established (Chappell & White 1971; 2001), although any inference that the substrate is predominantly (or even partly) crystalline continental basement is now highly contentious. Accretion of already-developed magmatic arcs appears the most likely process of continental growth (Gray & Foster 2004). The New England Fold Belt further outboard and to the north, also consists of accreted sedimentary sequences and copious mica-rich granites, with Late Devonian – Carboniferous deformation, followed by Permian rifting and a Triassic subduction regime.

The Early Palaeozoic margin of Gondwana continued through the Antarctica to South America. Northern Victoria Land (Fig. 1) and extensive parts of the Transantarctic Mountains (Fig. 1) also record the first of these two events – the Cambro-Ordovician Ross-Delamerian orogeny (Fig. 1), with the intrusion of a widespread suite of granites. The innermost, autochthonous (?) part of Northern Victoria Land – the Wilson terrane – consists of Neoproterozoic crystalline basement, but there are two further accreted terranes of unknown origin (Tessensohn & Henjes-Kunst 2005): the Bowers terrane, which in part has the character of a Cambrian island arc, and the possibly allochthonous Robertson Bay terrane, which consists of an Ordovician turbidite sequence. Remnants of Ordovician turbidites intruded by granites are also found in the Ross Province of Marie Byrd Land (Pankhurst *et al.* 1998b) (Fig. 1) and the Antarctic Peninsula (Millar *et al.* 2002) (deformed in the latter case) and these areas constitute the innermost 'Eastern Domain' of Vaughan & Storey (2000) (Fig. 1). The outer (Central and Western) domains (Fig. 1) are considered to represent Palaeozoic to Mesozoic accreted oceanic and island arc material. Taken all together they comprise the Terra Australis accretionary orogen of Cawood (2005); the Mesozoic parts were also separately termed the Australides by Vaughan *et al.* (2005).

Similar tectonic elements are recognized at the South American end of the margin, where the Cambrian Pampean orogeny (Fig. 1) occurred with dextral strike-slip along the western edge of the 2200 Ma Rio de la Plata craton (Fig. 1); much of the sedimentary material in the Pampean metasedimentary sequences may be derived from erosion of the Brasiliano–Pan-African collisional orogens (Fig. 1) rather than from cratonic elements of Gondwana (Rapela *et al.* 2007). This was followed by an

Ordovician active margin, also with intense granite/rhyolite magmatism (Famatinian; Fig. 1), which is now known to extend from Ecuador to northeast Patagonia (Pankhurst *et al.* 1998a; Chew *et al.* 2007). Since the early tectonic analysis of Ramos (1988), much of the western part of the South American margin has been regarded as composed of exotic/ suspect terranes and these were recently reviewed from a palaeomagnetic perspective by Rapalini (2005); the geology of the northernmost Arequipa–Antofalla and Marañón blocks (Fig. 1) were recently reviewed by Ramos (2008). The best known of these is the Precordillera terrane, or Cuyania (Fig. 1), of central western Argentina; the identification of which is based largely on the deposition of passive margin sediments, including limestones, during the Cambro-Ordovician interval when the rest of the margin was undergoing intense orogenesis; the fauna have been described as showing a Cambrian–Ordovician transition from Laurentia to Gondwanan (Benedetto 1998), and these passive margin sedimentary rocks are overlapped by Late Ordovician and Silurian sandstones of orogenic provenance. This is consistent with a Laurentian origin and mid-Ordovician collision (see Thomas & Astini 2003). However, this scenario was disputed by Aceñolaza *et al*. (2002) who favour an origin from the Antarctic/South African region of the Gondwana margin itself, an alternative theory that has also been promoted on the basis of detrital zircon evidence. (see Finney, this volume, for the latest summary of this argument). Collision of a further terrane (‘Chilenia’; Fig. 1)) to the west of the Argentine Precordillera was also inferred by Ramos (1988), principally on the basis of Devonian granite magmatism in the Sierras Pampeanas to the east. In southernmost South America there is very little direct evidence for Palaeozoic orogenesis, the principal deformation and metamorphism registered is of much later age. On the southern edge of the Rio de la Plata craton, the Sierra de la Ventana (Fig. 1) is comprised of a sequence of Cambrian? to Permian quartz-rich sediments and turbidites (Limarino *et al.* 1999). Some of the folding appears to be of Permian age, but there is also a significant unconformity/structural break in the Mid Carboniferous (von Gosen *et al.* 1991). Together with the Cape fold belt of South Africa (Fig. 1) and the Ellsworth–Whitmore Mountains of West Antarctica, this 'Gondwana fold belt system' seems to represent a passive margin during the Early Palaeozoic, with the accumulation of predominantly reworked continental sedimentary deposits (the 'Samfrau Geosyncline' of Du Toit 1937), and the elements have been grouped into the final stage of the Terra Australis ~~Orogne~~ by Cawood (2005) (Fig. 1). The cause of that deformation has long been a mystery. One school of thought favours a far-field effect of subduction at the southern Gondwana margin (Lock 1980; Johnston 2000), although this lay some 1500 km away beyond the landmasses of Patagonia (Fig. 1) and the Antarctic Peninsula. The alternative view is of a Carboniferous collision of such landmasses during ocean closure, albeit with different ideas about the details of the timing, direction of subduction and location of the sutures, and without any evidence of obducted oceanic crust (Ramos 1984; Ramos 2004; Pankhurst *et al.* 2006). The accretionary orogen model of Cawood (2005) may offer a form of compromise between these two alternative types of model.

In many of the outer areas, accretion and intense granitic/rhyolitic magmatism continued during the Late Palaeozoic, e.g., the New England orogen in Eastern Australia, southern Patagonia, and (possibly) Chilenia in the South American–South African sectors, and the Western Province and Median Batholith terranes of New Zealand. The immense rhyolitic LIP of southern South America represents a Permo-Triassic switch to extensional tectonics and the establishment of the Andean subduction margin, interpreted by Pankhurst *et al.* (2006) as a response to post-collisional slab ‘tear-off’. Elsewhere at this time the margin largely became passive, with terrane accretion continuing in New Zealand, which finally rifted off from the West Antarctic sector of the margin during the break-up of Gondwana in Cretaceous times.

This extended abstract is partly based on a *Gondwana Research* Focus Paper (Vaughan & Pankhurst 2007), to which the reader is referred for more extensive information and bibliography. We are grateful to Mike Bassett for the opportunity to contribute to the present volume.

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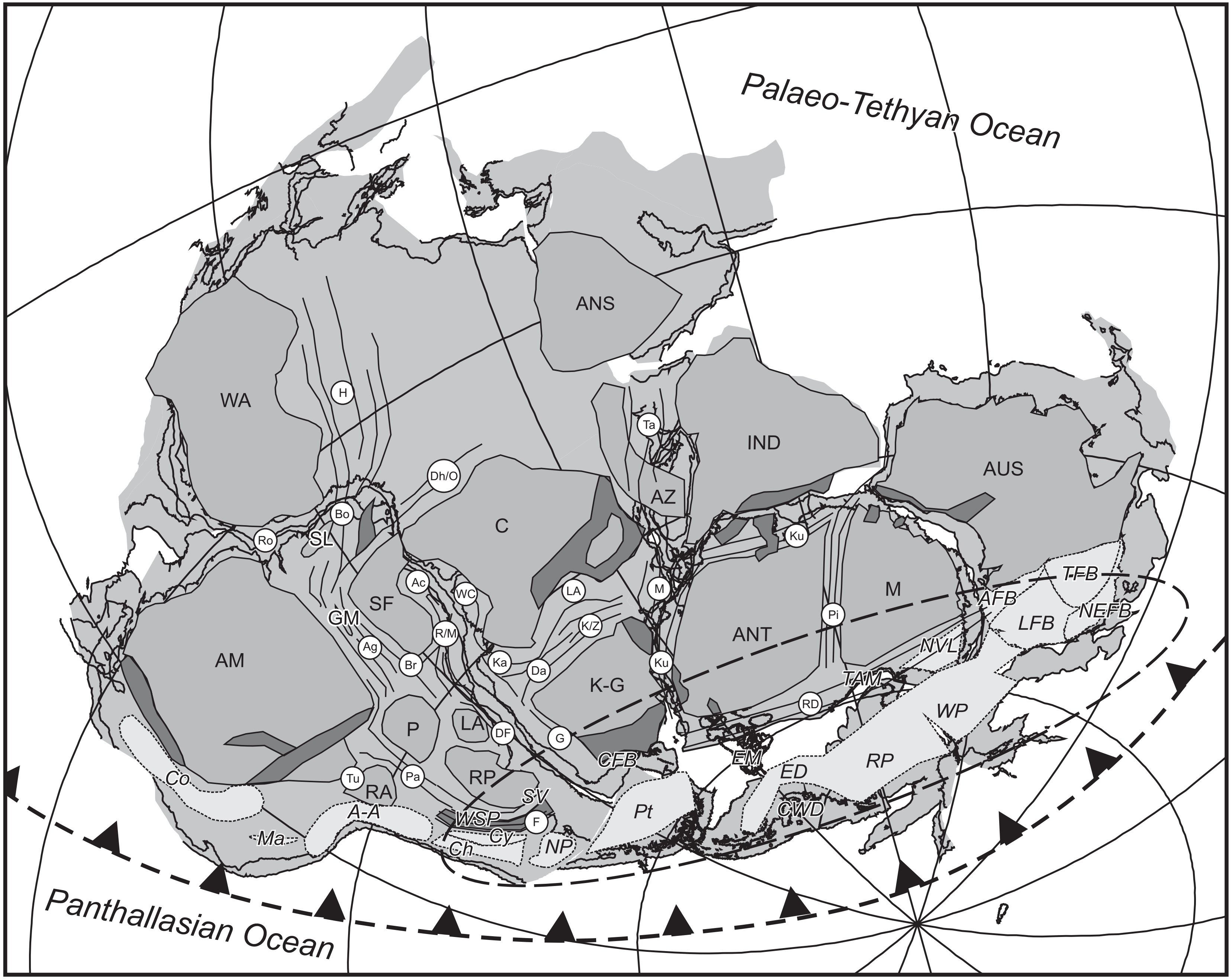
Figure Captions:

Figure 1: Reconstruction of West Gondwana after Tohver *et al.* (2006) and East Gondwana after Cawood & Buchan (2007) showing cratonic and Brasiliano–Panafrican–Early Palaeozoic elements. Cratons shown in medium grey: Am, Amazonia; ANS, Arabian–Nubian Shield; Ant, Antarctic; Aus, Australian (inc. Yilgarn, Pilbara, Gawler and Musgrave); Az, Azania; C, Congo; GM, Goias

Massif; Ind, India (inc. Bundelkhand, Dharwar, Bastar and Singhbhum); K-G, Kalahari–Grunehogna; LA, Luis Alves; M, Mawson; P, Paraná; RA, Río Apa; SF, São Francisco; SL, São Lius; WA, West Africa. 1200–1000 Ma "Grenville" belts shown in dark-grey: West Gondwana from Tohver *et al.* (2006) and East Gondwana from Fitzsimons (2000); WSP, Western Sierras Pampeanas. Brasiliano–Panafrican–Early Palaeozoic belts (ringed): Ac, Araçuaí; Ag, Araguaia; Bo, Borborema; Br, Brasilía; Da, Damara; DF, Dom Feliciano; Dh/O, Dahomeides/Oubangides; F, Famatinian; G, Gariep; H, Hoggar; Ka, Kaoko; K/Z, Katangan/Zambezi; Ku, Kuunga; LA, Lufilian Arc; M, Mozambique; P, Paraguai; Pi, Pinjarra; RD. Ross-Delamerian; R/M, Ribeira/Mantequeira; Ro, Rockelides; Ta, Tanzania; Tu, Tucavaca; WC, West Congo. Terranes with Early Palaeozoic elements shown in light grey; Eastern Australia after Cawood & Buchan (2007): A–A, Arequipa-Antofalla massif (Ramos 2008); AFB, Adelaide Fold Belt; Ch, Chilenia; Co, Colombian Terranes (Cordani *et al.* 2005); CWD. Central and Western domains; Cy, Cuyania; Ma, Marañón massif (Chew *et al.* 2007); ED, Eastern Domain (Vaughan & Storey 2000); LFB, Lachlan Fold Belt; NEFB, New England Fold Belt; NP, North Patagonian Massif; NVL, Northern Victoria Land; Pa, Pampia Terrane; Pt, Patagonia; RP, Ross Province (Pankhurst *et al.* 1998b); TAM, Transantarctic Mountains; TFB, Thompson Fold Belt; WP, Western Province (after Adams *et al.* 2005). Large dashed ellipse indicates area affected by the Terra Australis Orogen of Cawood (Cawood 2005): CFB, Cape Fold Belt; EM, Ellsworth–Whitmore Mountains; SV, Sierra de la Ventana.



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