Tectonophysics 636 (2014) 244–256

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Early opening of Australia and Antarctica: New inferences and regional consequences

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ARTICLE INFO

Article history:
Received 10 May 2014
Received in revised form 23 August 2014
Accepted 30 August 2014
Available online 6 September 2014

Keywords:
Passive margins
Plate tectonics
Plate reconstructions
Australia–Antarctica
Zelandia
Trans-Antarctic Mountains

ABSTRACT

Both continental margins of Australia and Antarctica exhibit a very clear gravity anomaly on the satellite free-air gravity data. The detailed sinuosity of these first-order conjugate features matches perfectly, suggesting that they are the signature of the initial continental breakup and mark the ocean–continent boundary. Another weaker, still clearly deciphered, pair of symmetrical gravity anomalies is identified oceanward. These anomalies are considered as pseudo-isochrons F and G and tentatively dated 128 and 94 Ma. Precise reconstructions of pseudo-isochron F are achieved over three sections of the margin, denoting the relative motion of Australia and East Antarctica, the Polda Block and East Antarctica, and Tasmania and West Antarctica. The Polda Block and Tasmania are transient micro-continents. Tasmania and Australia are reconstructed to align their linear eastern margin. The eastern margins of reconstructed Australia, Tasmania, and West Antarctica on one hand, the western margin of reconstructed Lord Howe Rise and Campbell Plateau on the other hand, fit a small circle of radius 15°, which suggests a transform motion between 128 and 83 Ma along this plate boundary. The reconstruction predicts a gap between East and West Antarctica, probably filled by non-cratonic continental crust compressively deformed and thickened by the SW motion of East Antarctica and participating to the formation of the Trans-Antarctic Mountains. The initial extension between Australia and East Antarctica may be related to the inception of the Kerguelen hotspot, ~1000 km to the west. The different rheology of cratons and orogenic terranes has played a role in the style and localization of both extensional and compressional deformations.

1. Introduction

Previous studies propose different interpretations of the conjugate continent oceanic boundary (COB) of Australia and Antarctica (e.g. Ball et al., 2013; Lawver et al, 1998; Veevers, 1986). The exact location of this COB is still debated and its reconstruction is therefore controversial and uncertain.

Bullard et al (1965) noted the complementarity of Australia and Antarctica conjugate margins but noted that “since the fitted parts are approximately arcs of circles the solution is somewhat ill defined in one direction”. McKenzie and Sclater (1971) alleviated this difficulty by jointly reconstructing “the 1-km contours of each continent and the escarpments of Broken Ridge and Kerguelen Plateau”, although it was later shown that the opening of these features is not synchronous events (Cande and Mutter, 1982; Mutter and Cande, 1983). Cande and Mutter (1982) re-identified the older magnetic anomalies found in the Australian–Antarctic Basin as anomalies 20 to 34 and open “the possibility that part of the magnetic quiet zone south of Australia formed during the Cretaceous long normal polarity interval”. Veevers (1986) re-interpreted magnetic anomaly 34 about 50 km southward (on the Australian side) and used the seismic character of the basement to define the COB at the location of Cande and Mutter's (1982) anomaly 34. Using this interpretation, he dates the breakup at 95 +−5 Ma. Veevers's (1986) COB for the South Australian margin and its Antarctic conjugate delineated from seismic data by Colwell et al. (2006) has been used in many subsequent works (Direen et al., 2011; Espurt et al., 2009; Gohl, 2007; O'Brien and Stagg, 2007; Powell et al., 1988; Stagg and Reading, 2007; Veevers and Li, 1991; Veevers et al., 1991; Williams et al., 2011). A revised interpretation of the COB was proposed by Ball et al. (2013) who moves it ~100 km-further oceanward. Conversely, a “tight fit” reconstruction model based on satellite free-air gravity anomalies or their horizontal gradient was proposed by Lawver et al (1998) (for Gondwana). This model suggests that the Southern Australian and its conjugate Antarctic COB is located near the shelf break, about 150 km toward continent with respect to the ones proposed by Veevers (1986) and Colwell et al. (2006). A “tight fit”, however, does not preclude a wide, hyper-extended continental crust and a COB toward the ocean, as suggested by the reconstruction model based on palinspatic restoration proposed by Williams et al (2011). Looking more specifically to the less sedimented Southwest Australian margin, Beslier et al. (2004) dredged basalt, gabbro and peridotite in the area located between the continental slope and the first marine magnetic anomalies. By analogy with the Iberian margin (e.g. Boillot et al., 1988), they interpreted these rocks as

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http://dx.doi.org/10.1016/j.tecto.2014.08.020
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Table 1
Age of the isochron (numbers) or pseudo-isochrons (F, G). For the magnetic chrons, from Cande and Kent (1995); for the pseudo-isochrons, extrapolated assuming a constant (full) spreading rates of 11 km/Ma between Australia and Antarctica.

Name	Age
F	128 Ma
G	94 Ma
34 young	83 Ma
33 old	79.075 Ma
33 young	73.619 Ma
32 young	71.071 Ma
31 old	68.737 Ma
27 young	60.920 Ma
24 old	53.347 Ma
21 young	46.264 Ma

reflecting a wide ocean–continent transition; however, these rocks would also be consistent with amagmatic ultraslow seafloor spreading, as observed on the present Southwest Indian Ridge (Cannat et al., 2006). Similar serpentinized mantle rocks have been interpreted on the conjugate Antarctic margin (Close et al., 2009). The crustal nature of the 150 km-wide sedimented area between the foot of the continental slope, on one hand, and the location of Cande and Mutter's (1982) magnetic anomaly 34 and Veevers's (1986) COB, on the other hand, therefore remains uncertain.

In this paper we re-analyze the early history of Australia–Antarctica separation using satellite free-air gravity anomaly (Sandwell and Smith, 2009, version 18.1) and published magnetic anomaly identifications (Tikku and Cande, 2000; Whittaker et al, 2007). On both the southern Australian margin and its Antarctic conjugate, the main gravity anomaly is associated with the continental slope; the sinuous shape of these anomalies exhibit a striking similarity. Using this and another younger and weaker gravity anomaly as markers gives us a chance to address the early evolution of the Australia–Antarctica plate boundary. We further evaluate the consequences of our Australia–Antarctica reconstructions on adjacent plates and plate boundaries, including the Trans-Antarctic Mountains, and investigate the initial position and motion of Tasmania and Zelandia (i.e. the continent made of New Zealand, Lord Howe Rise, Chatham Rise and the Campbell Plateau).

Table 2
Finite rotation parameters for all plates involved in the reconstruction with respect to Australia. RMS error is indicated when computed by Bullard contour fit method. * is from Gaina et al. (1998); ** uses Eagles et al. (2004) between South Zelandia and West Antarctica.

	Latitude (deg.)	Longitude (deg.)	Angle (deg.)	RMS error (km)
East Antarctica/Australia				
Pseudo-isochron F	−7.40	40.10	31.195	9.2
Pseudo-isochron G	−3.50	45.00	28.100	6.1
Chron 34 young	5.10	40.90	27.252	6.7
Chron 33 old	5.00	39.80	26.471	8.1
Chron 32 young	6.60	38.60	25.988	7.1
Chron 31 old	7.10	38.10	25.644	9.2
Chron 27 young	8.60	37.50	25.482	6.4
Chron 24 old	9.60	35.70	25.079	3.1
Chron 21 young	13.90	33.30	24.690	1.3
Tasmania/Australia				
Pseudo-isochron F	−35.20	137.36	7.470	
Pseudo-isochron G	−35.20	137.36	7.470	
Chron 33 old	−40.20	142.36	4.470	
West Antarctica (West of Adare Trough)/Australia				
Pseudo-isochron F	−3.50	45.00	28.100	
Pseudo-isochron G	−3.50	45.00	28.100	
Chron 33 old	5.00	39.80	26.471	
West Antarctica (East of Adare Trough)/Australia				
Pseudo-isochron F	14.90	34.90	32.200	
Pseudo-isochron G	14.90	34.90	32.200	
Chron 33 old	22.68	30.22	32.243	
North Zealandia/Australia				
Pseudo-isochron F	28.50	−14.10	55.800	
Pseudo-isochron G	20.40	−30.75	27.200	
Chron 33 young*	9.53	−42.80	12.937	
South Zealandia/Australia				
Pseudo-isochron F	43.60	−15.00	109.000	
Pseudo-isochron G	47.50	−17.30	78.900	
Chron 33 young**	49.72	−16.28	72.059	

2. Markers

The oldest unambiguous magnetic anomaly identified on both sides of the Australian–Antarctic Basin is anomaly 33 (~79.5 Ma; Fig. 1, top) adopted from Tikku and Cande (2000) and Whittaker et al. (2007). Beyond this anomaly, we have to rely on other markers in order to achieve plate reconstructions. Such markers are coming from satellite-derived free-air gravity anomalies (Sandwell and Smith, 2009) which display two pairs of conjugate anomalies:

1) a continuous gravity feature observed along both continental margins of Australia and Antarctica (Fig. 1, medium). This strong anomaly corresponds to the continental shelf break. As it is the only first-order feature observed along the margins, we interpret it as marking the COB. Unlike the seafloor spreading magnetic anomalies, which unambiguously represent isochrons, structural features such as those depicted by these gravity anomalies may either mark a synchronous separation – and therefore would correspond to an isochron – or a progressive separation – and therefore do not correspond to an isochron. For instance, full opening of the Central Atlantic Ocean, South Atlantic Ocean and Gulf of Aden took respectively 15, 12 and 4 Myr, as shown by the marine magnetic anomalies (e.g., Fournier et al., 2010; Rabinowitz and LaBrecque, 1979; Schettino and Turco, 2009), although the North Atlantic seems to have opened more synchronously at 54 Ma (e.g., Gaina et al., 2009). Noting that magnetic anomalies 34 and younger are parallel to this gravity anomaly off Western and Southern Australia, we assume that the opening of Australia and Antarctica is (geologically) synchronous and consider this gravity anomaly as a tentative isochron, or pseudo-isochron. Whether the plate reconstructions relying on this feature will produce finite rotation parameters consistent with those of subsequent isochrons built from marine magnetic anomalies or not will confirm or infirm this hypothesis. We name it pseudo-isochron F.
2) A weaker, although clearly identifiable gravity anomaly is observed about 150 km from pseudo-isochron F oceanward on both Australian and Antarctic margins (Fig. 1, top). In the area investigated by Beslier et al. (2004) southwest of Australia, this feature corresponds to the limit between smooth bathymetry, quiet magnetics, and ultramafic rock samples to the north, and rough bathymetry, magnetic anomalies 34 to 20, and basaltic rock samples to the south. This gravity anomaly is parallel to pseudo-isochron F and the magnetic anomalies off Western and Southern Australia: we therefore use it as another tentative isochron. We name it pseudo-isochron G.

In order to estimate the approximate age of these pseudo-isochrons and the corresponding reconstructions, and in the absence of any other constraint, we extrapolate spreading rates observed between younger isochrons. We adopt the geomagnetic polarity time scale of Cande and Kent (1995) and the full spreading rate of 11 km/Myr determined by Jacob et al. (2014) between Chrons 31 (61 Ma) and 34 (83 Ma). We obtain ages of 94 Ma for pseudo-isochron G and 128 Ma for pseudo-isochron F. Interestingly, the age of 94 Ma is similar to the age of 96 Ma obtained by Powell et al. (1988) for their breakup anomaly, which is similar to our pseudo-isochron G. A major reorganization is