Earth and Planetary Science Letters 478 (2017) 132–142

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

The kinematic evolution of the Macquarie Plate: A case study for the fragmentation of oceanic lithosphere

Hakkyum Choi [a,b], Seung-Sep Kim [b,*], Jérôme Dyment [c], Roi Granot [d], Sung-Hyun Park [a], Jong Kuk Hong [a]

[a] Korea Polar Research Institute, Incheon 21990, South Korea
[b] Department of Astronomy, Space Science and Geology, Chungnam National University, Daejeon 34134, South Korea
[c] Institut de Physique du Globe de Paris, CNRS UMR 7154, Sorbonne Paris Cité, Université Paris Diderot, Paris 75005, France
[d] Department of Geological and Environmental Sciences, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel

ARTICLE INFO

Article history:
Received 27 April 2017
Received in revised form 23 August 2017
Accepted 25 August 2017
Available online 19 September 2017
Editor: P. Shearer

Keywords:
marine magnetics
tectonics
plate reconstruction
Macquarie Plate

ABSTRACT

The tectonic evolution of the Southeast Indian Ridge (SEIR), and in particular of its easternmost edge, has not been constrained by high-resolution shipboard data and therefore the kinematic details of its behavior are uncertain. Using new shipboard magnetic data obtained by R/VIB *Araon* and M/V *L'Astrolabe* along the easternmost SEIR and available archived magnetic data, we estimated the finite rotation parameters of the Macquarie–Antarctic and Australian–Antarctic motions for eight anomalies (1o, 2, 2Ay, 2Ao, 3y, 3o, 3Ay, and 3Ao). These new finite rotations indicate that the Macquarie Plate since its creation ∼6.24 million years ago behaved as an independent and rigid plate, confirming previous estimates. The change in the Australian–Antarctic spreading direction from N–S to NW–SE appears to coincide with the formation of the Macquarie Plate at ∼6.24 Ma. Analysis of the estimated plate motions indicates that the initiation and growth stages of the Macquarie Plate resemble the kinematic evolution of other microplates and continental breakup, whereby a rapid acceleration in angular velocity took place after its initial formation, followed by a slow decay, suggesting that a decrease in the resistive strength force might have played a significant role in the kinematic evolution of the microplate. The motions of the Macquarie Plate during its growth stages may have been further enhanced by the increased subducting rates along the Hjort Trench, while the Macquarie Plate has exhibited constant growth by seafloor spreading.

1. Introduction

The south-easternmost corner of the Australian Plate was shaped by complex tectonic processes, including the fragmentation and formation of the Macquarie Plate (Fig. 1) (Cande and Stock, 2004a; DeMets et al., 1988). The major evidence for its formation some 6 Myr ago derives from inconsistencies between the rotation parameters describing the Australia–Antarctica relative motion across the easternmost Southeast Indian Ridge (SEIR), east of the George V Fracture Zone (FZ), compared with those calculated for the rest of the SEIR (Cande and Stock, 2004a). In particular, Cande and Stock (2004a) tested the fit of conjugate magnetic anomalies and fracture zones east of the George V FZ, and found that the Australian–Antarctic rotation produces growing, clockwise misfits on the Australian Plate, suggesting that the Macquarie Plate has moved ∼30 km east with respect to the Australian Plate. They concluded that the Macquarie Plate has remained a rigid and independent plate since 6 Ma. The formation of the Macquarie Plate might have resulted from a change in the direction of relative motion between the Australian and Pacific plates, which led to the subduction of young and buoyant oceanic crust into the Hjort Trench (Cande and Stock, 2004a; Hayes et al., 2009).

To reconstruct the tectonic history of the Macquarie Plate, it is crucial to gather shipboard geophysical data along the eastern SEIR, where few data currently exist (e.g., Seton et al., 2014). In this study, we first estimate rotation parameters for eight anomalies (1o, 2, 2Ay, 2Ao, 3y, 3o, 3Ay, and 3Ao, where 'y' represents the 'young end' of the normal polarity interval and 'o' the 'old end') identified across the eastern SEIR, using newly acquired shipboard magnetic data between 148°E and 166°E (red lines in Fig. 1). These results constrain the motion between the Macquarie–Antarctic plates for the last 7 Myr and reveal that segment KR1 (east of Balleny FZ, following the segment numbering of Crowley et al. (2015)) of the SEIR (Fig. 1) exhibits a major change in plate motion at ∼6.24 Ma, coinciding with the formation of

* Corresponding author.
E-mail address: seungsep@cnu.ac.kr (S.-S. Kim).

http://dx.doi.org/10.1016/j.epsl.2017.08.035

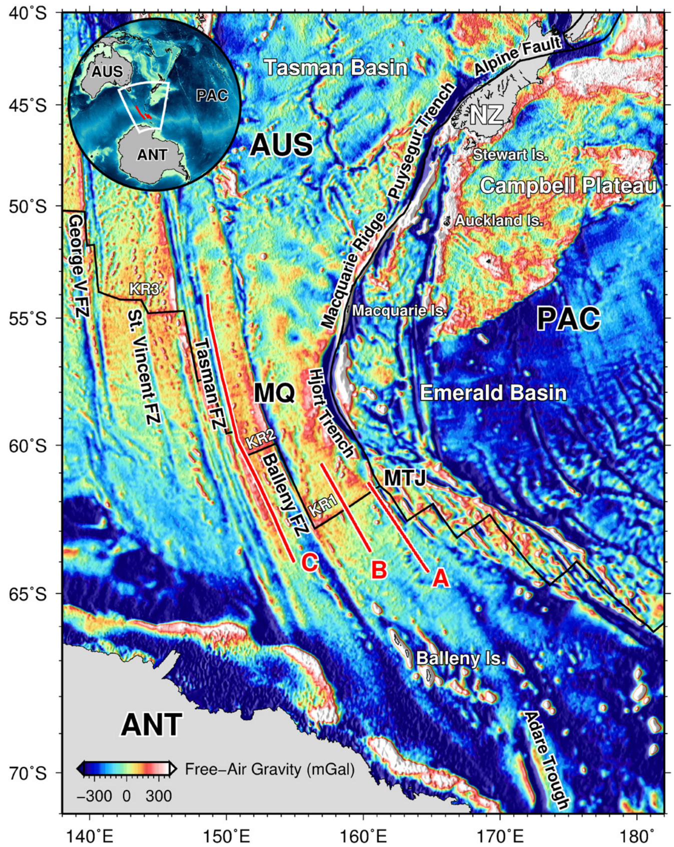

Fig. 1. Major tectonic features near the Southeast Indian Ridge (SEIR) and Macquarie Plate. New shipboard magnetic data were acquired along the red lines. The inset map provides a global perspective of the study region. PAC = Pacific Plate; AUS = Australian Plate; ANT = Antarctic Plate; NZ = New Zealand. The background map is the free-air gravity anomaly field (Sandwell et al., 2014). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the Macquarie Plate. To investigate the Australian–Macquarie and Macquarie–Pacific plate motions, we also compute the Australian–Antarctic rotations (along the SEIR, west of ∼140°E) for the same eight anomalies. These new rotation parameters for the Australian–Macquarie–Antarctic plate motions enable us to better understand the formation and kinematic evolution of the Macquarie Plate.

2. Magnetic anomalies across the eastern SEIR

We conducted a series of interdisciplinary surveys between 2011 and 2015, over the eastern SEIR using the R/VIB *Araon*, collecting geological, geochemical, geophysical, hydrothermal, and biological data (Hahm et al., 2015). To constrain the tectonic history of the Macquarie Plate, two 400 km-long sea surface total field magnetic profiles (Lines A and B in Fig. 1) were obtained across segment KR1 in 2015. Each survey line was planned to gather at least 10 Myr of seafloor spreading records. For segment KR2 (west of the Balleny FZ), we acquired the magnetic data (Line C in Fig. 1) as part of the TACT (Tasmania–Adelie land Corridor Transect) program, using the M/V *L'Astrolabe* during the austral summer of 2012.

We reduced the magnetic data to anomalies using the International Geomagnetic Reference Field (IGRF) model 12 (Thébault et al., 2015). Then, we identified geomagnetic reversals by constructing forward magnetic models (Mendel et al., 2005), and estimated spreading parameters for the surveyed ridge segments (Fig. 2; see the detailed model parameters in Table S1 of the supplementary material). Following Cande and Stock (2004a) and Croon et al. (2008), who investigated the SEIR and the Pacific–Antarctic Ridge east of the study area, respectively, we adopted the geomagnetic polarity time scale of Cande and Kent (1995), except for C3Ay and C3Ao for which we used the updated ages of Krijgsman et al. (1999).

Fig. 2 shows the geomagnetic reversals identified from the observed marine magnetic data. Line A lies mostly on the southern flank of segment KR1 (Fig. 2a) (i.e., the Antarctic Plate), next to the Macquarie Triple Junction (MTJ) of the Australian–Antarctic–Pacific plates (Fig. 1). The identified magnetic anomalies along Line A show the spreading records from the ridge axis to anomaly 5o (10.95 Ma) southward, and to anomaly 1o (0.78 Ma) northward. The average full-spreading rates are estimated to be 63∼65 mm/yr (Table S1). Interestingly, a doubled crust, requiring a northward ridge-jump, is identified at ∼6.24 Ma on Line A, which is consistent with the previously proposed timing for the initiation of the Macquarie Plate (Cande and Stock, 2004a). Line B intersects the central part of segment KR1 (Fig. 1), where active hydrothermal venting sites have been reported (Hahm et al., 2015). Full-spreading rates estimated from Line B are relatively constant at 64∼66 mm/yr, similarly to Line A (Table S1). The geomagnetic polarities on Line B are symmetric and exhibit magnetic anomalies up to 3o (5.23 Ma) southward, and to 3Ay (6.04 Ma) northward (Fig. 2b). Line C was acquired along the western KR2 segment, and reveals geomagnetic anomalies up to 5o (10.95 Ma) for both its northern and southern flanks (Figs. 1 and 2c). For Line C, unlike Line A, no complicated crustal accretion history was required for forward modeling.

3. Revised Macquarie–Antarctic and Australian–Antarctic rotation parameters

3.1. Methodology

We computed finite rotation parameters for eight anomalies (1o, 2, 2Ay, 2Ao, 3y, 3o, 3Ay, and 3Ao) for the Macquarie–Antarctic motion using the newly acquired magnetic data, and the traces of fracture zones determined from the satellite-derived gravity grid (version 23) of Sandwell et al. (2014) (Fig. 3a). In addition, we employed archived magnetic data to expand the spatial and temporal coverage of our analysis, which are listed in the supplementary material. Although useful for filling gaps, we carefully assessed the quality of the archived data before conducting the subsequent analyses. Lastly, a set of short magnetic lines, collected in 2013 from the R/VIB *Araon*, were included in this study (red dashed lines with red shaded areas, perpendicular to the ridge in Fig. 3a). These data only extend to anomaly 1o (0.78 Ma).

The identified magnetic anomalies and fracture zone crossings were then utilized for computing finite rotation parameters for the Macquarie Plate relative to the Antarctic Plate using the Hellinger method (Hellinger, 1981; Kirkwood et al., 1999; Royer and Chang, 1991). We assigned a 1 km uncertainty to the locations of the new and well-navigated magnetic picks, and 4 km uncertainty to the picks that originated from the poorly navigated archives. Because the location of a FZ trace might be influenced by a long-term deformation integrated over several million years (Lonsdale, 1994), we assigned larger uncertainties to the FZ locations than for the magnetic picks (8 km for the long Balleny FZ and 5 km for the relatively short Tasman FZ; gray dashed lines in Fig. 3a).

Fig. 3 and Table 1 show the best-fit parameters and covariance matrices for the eight finite rotations describing the Macquarie–Antarctica motion. In this study, the second plate in all the considered plate pairs is held fixed, and hence used as the reference frame for each rotation. For example, the Antarctic Plate is fixed for the Macquarie–Antarctic motion. The solutions obtained from the