Revised plate tectonic history of the west Australian margin reveals how the Gascoyne Terrane docked at West Burma

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SUMMARY

Southeast Asia contains various continental fragments that sequentially rifted from East Gondwana. A number of these fragments were sourced from the northern margin of East Gondwana. East Gondwana's fragmentation was initialised with Late Jurassic rifting along the northwest Australian margin, forming the Argo Abyssal Plain, and followed by Early Cretaceous N-S oriented rifting along the entire western Australian margin, forming the Gascoyne, Cuvier and Perth Abyssal Plains. In a comprehensive study to address the issue of margin formation and terrane drift and docking, we revised the tectonic formation of the entire margin using an integrated analysis of marine magnetic and gravity anomaly data from all abyssal plains involved.

Our model highlights the necessity for a new continental fragment, the Gascoyne Terrane, due to the presence of tectonic features, such as margin age offsets, spreading rates, ridge jumps and isochron orientations, that are distinctly different north and south of the Wallaby Zenith Fracture Zone (WZFZ). Our model suggests that the northern extent of Greater India was limited by the WZFZ. The relative motion between Greater India and Australia formed the Perth Abyssal Plain, while motion of the Gascoyne block, located north of the WZFZ, formed the Cuvier and Gascoyne Abyssal Plains. Following rifting from the northwest margin north of the Exmouth Plateau, Argoland accreted to Burma at ~75 Ma. Our model suggests that in contrast the Gascoyne Terrane was accreted to West Burma at ~55 Ma, following about 20 million years of Tethys seafloor subduction after Argoland's accretion. Our model also suggests that the eastern tip of Greater India collided with West Burma at around 35 Ma. This is consistent with the onset of extrusion of the North Indochina Block around 34 Ma, expressed by left-lateral strike-slip along the Ailao Shan - Red River shear zone between 34 and 17 Ma.

Burma is rich in gems, lead, zinc, iron, tin, chromium, nickel and tungsten deposits, and has oil-bearing fields in its forearc basin. Our model has implications for the formation of the West Burmese margin, as it would also be comprised of a continental terrane once conjugate to the Bernier Platform and Exmouth Plateau, both proven hydrocarbon-rich resources. Advances in modelling the accretion history of Burma will help to distinguish possible continental fragments, which may reveal new resources.

Key words: Gondwana, India, Australia, Burma, Gascoyne

INTRODUCTION

Successful hydrocarbon exploration depends on accurately mapping boundaries between continental and oceanic crust and on understanding the regional tectonic history. The original configuration, breakup and dispersal of East Gondwana, comprising Africa, Australia, India, Antarctica, Madagascar and the Seychelles, which dispersed many continental blocks to SE Asia, is yet to be fully constrained, generally being fit too tightly (Lawver et al., 1998; Reeves et al., 2002).
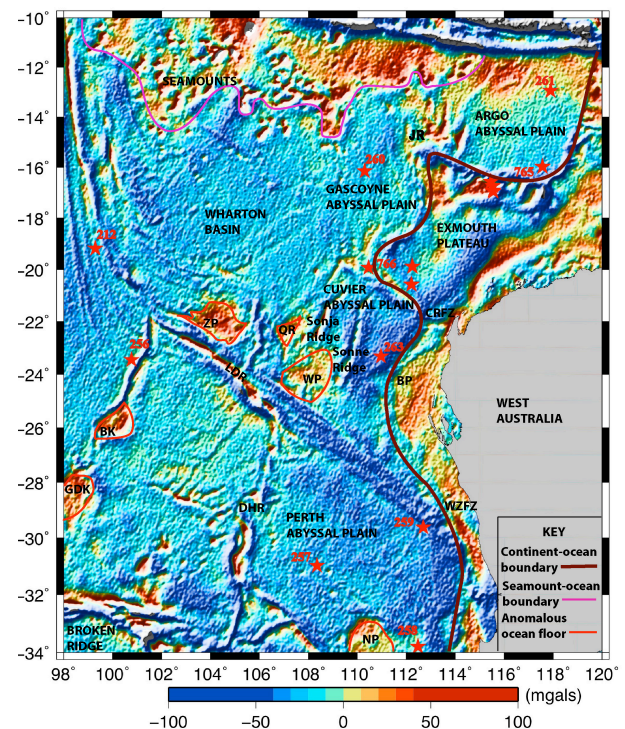
Figure 1. Mercator projection of the eastern Indian Ocean superimposed on the Sandwell and Smith (2007) gravity anomaly grid with exaggerated scale (mgals). Abbreviated features include the Joey Rise (JR), Zenith Plateau (ZP), Quokka Rise (QR), Wallaby Plateau (WP), Wallaby-Zenith Fracture Zone (WZFZ), Naturaliste Plateau (NP), Dirk Hartog Ridge (DHR), Batavia Knoll (BK) and Gulden Draak Knoll (GDK). Abyssal plain drill sites are marked as numbered red stars.

Most plate tectonic models of the west Australian margin (Figure 1), which formed when Greater India/associated terranes and Australia separated, feature two separate tectonic blocks moving away from Australia: Argoland, forming the

Argo Abyssal Plain, and Greater India, forming at least the Perth Abyssal Plain, and sometimes the Cuvier abyssal plain depending on the model. Argoland accreted to West Burma in the Late Cretaceous (Heine and Müller, 2005) while Greater India collided with the south Eurasian margin in the Tertiary (Replumaz and Tapponnier, 2003). Due to this collision, the original extent of Greater India has proved difficult to constrain; some authors extend it to the tip of the Exmouth Plateau (Lee and Lawver, 1995) while others believe the WZFZ (Figure 1) delineates the northern limit (Ali and Aitchison, 2005). Our model supports both these views in that there was continental material rifting from the entire margin, but in the form of two independently-moving plates: the Gascoyne block, north of WZFZ, and Greater India, south of the WZFZ (Figure 2a, appendix). Relative motion between the Gascoyne and Greater India blocks caused the unusually wide (c. 50 km), transtensional WZFZ, until a ridge jump at 120 Ma coincided with a spreading reorganisation that caused Greater India's rapid northward motion (Muller, 2007). If our revised model is correct, then what became of the Gascoyne block?

METHOD AND RESULTS

Our reconstruction model (GPlates) incorporates rotations computed using magnetic anomaly identifications and a visual fitting method, where conjugate anomalies are aligned as well as possible. A visual, interactive method, as opposed to a quantitative method of fitting data from conjugate plates, is necessary in this case, as the only preserved segments of Early Cretaceous Indian ocean floor were accreted to the Australian plate due to a series of complex jumps and propagations of the spreading ridge, leaving a variety of tectonic boundaries on the seafloor which are difficult to decipher. Rotation poles for Greater India were derived iteratively by visually aligning our magnetic anomaly identifications with contemporaneous magnetic lineations in the Antarctic Enderby Basin (Gaina et al., 2007). To date the ocean floor, we used GEODAS (Geophysical Data System) marine magnetic data from the National Geophysical Data Centre (NGDC), passed through high and low-pass filters before plotting it in GMT (Wessel and Smith, 1998). New magnetic and multibeam bathymetry profiles were also obtained during the August-September 2008 IFM-Geomar CHRISP (CHRistmas Island Seamount Province) research cruise. The magnetic data were plotted on the latest version (18) of the 1-minute satellite gravity anomaly grid (Sandwell and Smith, 1997). Magnetic anomaly identifications were made using the Modmag software (Mendel et al., 2005). We used the combined timescale of (Cande and Kent, 1995), for Cenozoic anomalies, and (Channell, 1995) and (Gradstein et al., 1994) for Mesozoic anomalies. Our magnetic anomaly picks follow the young ends of normal-polarity portions of magnetic chrons. The age of the continent-ocean boundary and pseudofaults were extrapolated using spreading rates from the nearest isochron. Variations in the marine gravity grid helped identify extinct ridges, pseudofaults and fracture zones as well as the location of the continent-ocean boundary prominent anomalies proximal to the shorebreak.

Our tectonic model confirms that Late Jurassic northward rifting of Argoland (Figure 2a) from northwest Australia continued until a southward ridge jump occurred at 136 Ma, initialising spreading along the western Australian margin. The Joey Rise formed with the northwest motion of an oceanic Argo plate, while the Perth Abyssal Plain formed due to Greater India's anticlockwise westward migration. Separation

of the Gascoyne block started with the onset of seafloor spreading in the Cuvier at 132 Ma, and was complete when the break-up occurred at the Exmouth Plateau (Figure 2a) finally forming the Gascoyne margin at 130 Ma. The Gascoyne block migrated northwest until about 100 Ma. Following this, based on our preliminary results, it migrated further northward across the Tethys and accreted to West Burma at 55 Ma (Figure 2c) some 20 million years after Argoland (Figure 2b). Greater India adopted a more northerly migration from 90 Ma and its eastern point collided with West Burma at 35 Ma (Figure 2d).

DISCUSSION AND CONCLUSIONS

Our model indicates that Burma collided with at least three continental terranes that originate from the west Australian margin. These are Argoland, the Gascoyne block and eastern Greater India, with 20 million years of seafloor subduction occurring between the accretion of Argoland (75 Ma) and the Gascoyne block (55 Ma).

Fan and Ko (1994), provide a detailed description of Burma's resources and three terranes: Arakan Yoma (west), Central Burma Basin and Shan-West Malaysia-Sumatra (east). The latter is divided into three subterranes: West Kachin (north), East Kachin-Shan and Karen-Tenasserim (south) (Howell, 1985). Arakan Yoma bears late Cretaceous-early Tertiary chromium and nickel within its ultramafic belts, the Central Burma Basin has oil-bearing fields in its forearc basin, west of the volcanic arc, and Shan-West Malaysia-Sumatra is rich in gems, lead, zinc, iron, tin and tungsten deposits.

The Arakan Yoma terrane is an Eocene-uplifted subduction system, formed of Cretaceous to Eocene pelagic sediments. The Central Burma Basin contains a volcanic arc formed from late Mesozoic subduction of oceanic lithosphere. Drag from Greater India caused 425 km northward strike-slip of both terranes along the Sagaing fault, producing the Phuket Tenasserian plutonic arc. Shan-West Malaysia-Sumatra has been assigned to the Sibumasu block, originating from the Cimmerian continent, which separated from East Gondwana by Late Permian time (Metcalfe, 2006). Its northern subterrane, West Kachin, consists of Mesozoic clastics, turbidites and Cretaceous limestone, with ophiolites near its surrounding faults and could be a Gondwana fragment.

There is still much debate about Burma's accreted terranes, for example, Fan and Ko (1994), only mention West Kachin as a Gondwana fragment. Heine and Müller (2005), and Metcalfe (2006), also relate the West Burma Block (Arakan Yoma and the Central Burma Basin) as a continental fragment, suturing to Sibumasu in the Cretaceous (Metcalfe, 1990), though it has been attributed to Indochina, already insitu by the Carboniferous (Barber and Crow, 2009). Our model suggests that two distinct terranes (Argoland and Gascoyne/Greater India) constitute the West Kachin and the West Burma Block, respectively, but our preliminary model requires further analysis in terms of the match of the terranes modelled here to the regional crustal structure and the age of key events, especially as West Kachin may have sutured in the Late Permian. Our modelled collision age between the northeastern extension of Greater India and the Burma Block around 35 Ma correlates quite well with the history of southeastward extrusion of the North Indochina Block. The onset of this process is dated by left-lateral strike-slip activity along the Ailao Shan - Red River shear zone, which is dated to have lasted from 34 to 17 Ma (Leloup et al., 2007). This timing is

constrained by mapped geological offsets along the shear zone, as well as structural, petrological and geochronological studies of the shear zone, palaeomagnetic measurements in South China and Indochina (see Leloup et al., 2007, for details), magnetic anomalies in the South China Sea (Briais et al. 1993), and the timing of sedimentation and tectonic style in the YinGeHai pull-apart basin (Clift and Sun 2006).

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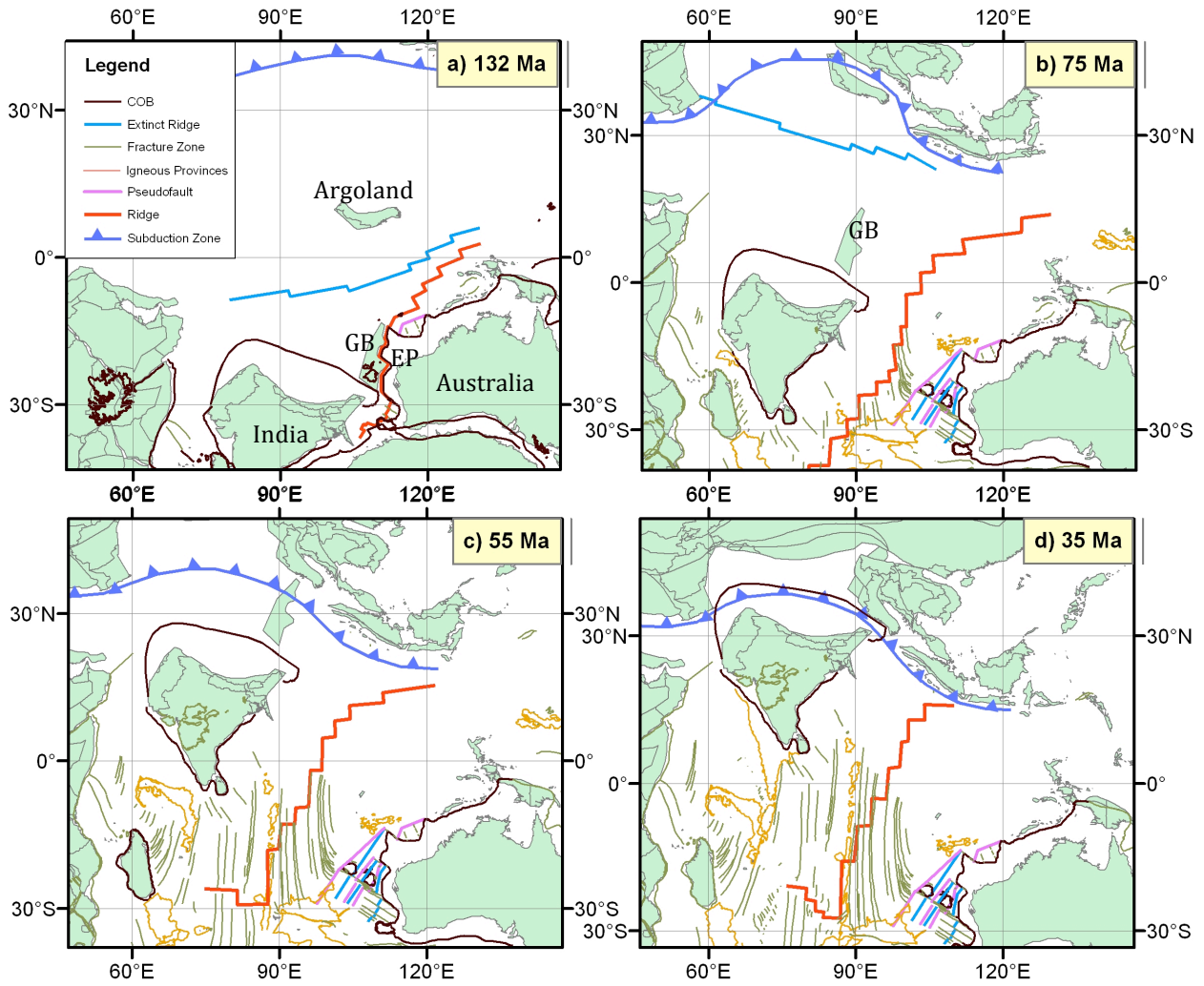
Figure 2. Palaeogeographic reconstructions of East Gondwana at; a) 132 Ma – showing the northward motion of Argoland and the recent formation of the west Australian margin, including the Exmouth Plateau (EP), b) 75 Ma - the northward motion of Greater India and the Gascoyne Block (GB), c) 55 Ma - accretion of the Gascoyne Block to Burma and, d) 35 Ma - the onset of Greater India and Eurasia collision. Legend highlights continent-ocean boundary (COB) in black, active mid-ocean ridge in red, extinct ridges in light blue, pseudofaults in pink, igneous provinces in orange, fracture zones in grey-green and subduction zones in serrated dark blue.