Gondwana Research 42 (2017) 29–48

Contents lists available at ScienceDirect

Gondwana Research

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

New geophysical compilations link crustal block motion to Jurassic extension and strike-slip faulting in the Weddell Sea Rift System of West Antarctica

T.A. Jordan [a,*], F. Ferraccioli [a], P.T. Leat [a,b]

[a] British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom
[b] Department of Geology, University of Leicester, University Road, Leicester LE1 7RH, United Kingdom

ARTICLE INFO

Article history:
Received 20 May 2016
Received in revised form 6 September 2016
Accepted 17 September 2016
Available online 20 October 2016

Handling Editor: T. Tsunogae

Keywords:
Magnetic anomalies
Gravity anomalies
Continental rifting
Tectonics
Microcontinent

ABSTRACT

Gondwana breakup changed the global continental configuration, leading to opening of major oceanic gateways, shifts in the climate system and significant impacts on the biosphere, hydrosphere and cryosphere. Although of global importance, the earliest stages of the supercontinental fragmentation are poorly understood. Reconstructing the processes driving Gondwana breakup within the ice-covered Weddell Sea Rift System (WSRS) has proven particularly challenging. Paleomagnetic data and tectonic reconstructions of the WSRS region indicate that major Jurassic translation and rotation of microcontinental blocks were a key precursor to Gondwana breakup by seafloor spreading. However, geophysical interpretations have provided little support for major motion of crustal blocks during Jurassic extension in the WSRS. Here we present new compilations of airborne magnetic and airborne gravity data, together with digital enhancements and 2D models, enabling us to re-evaluate the crustal architecture of the WSRS and its tectonic and kinematic evolution. Two provinces are identified within the WSRS, a northern E/W trending province and a southern N/S trending province. A simple extensional or transtensional model including ~500 km of crustal extension and Jurassic magmatism accounts for the observed geophysical patterns. Magmatism is linked with rifting between South Africa and East Antarctica in the north, and associated with back-arc extension in the south. Our tectonic model implies ~30° of Jurassic block rotation and juxtaposes the magnetically similar Haag Block and Shackleton Range, despite differences in both Precambrian and Pan African-age surface geology. Although geophysically favoured our new model cannot easily be reconciled with geological and paleomagnetic interpretations that require ~1500 km of motion and 90° anticlockwise rotation of the Haag-Ellsworth Whitmore block from a pre-rift position adjacent to the Maud Belt. However, our model provides a simpler view of the WSRS as a broad Jurassic extensional/transtensional province within a distributed plate boundary between East and West Antarctica.

1. Introduction

Gondwana breakup changed the global continental configuration, led to the opening of major oceanic gateways, likely triggered major shifts in the climate system and had significant impacts on the biosphere, hydrosphere and cryosphere (Storey et al., 2013). The break-up of Gondwana was initiated along a rift zone which comprised the Somali Basin, the southern Africa-Dronning Maud Land conjugate margins and the Weddell Sea embayment (Dalziel et al., 2013). Seafloor spreading between Africa and East Antarctica had commenced by ca 160 Ma (Roeser et al., 1996; Ghidella et al., 2007; Leinweber and Jokat, 2012). However, continental separation was preceded by emplacement of the Karoo/Ferrar mafic Large Igneous Province (LIP), one of the most voluminous Mesozoic LIP, and the development of the Weddell Sea Rift System (WSRS) (Fig. 1).

The drivers and nature of Gondwana breakup remain contentious. Both the presence of one or more mantle plumes and the location within a back-arc position relative to the Paleo-Pacific margin (Fig. 2a) have been invoked as drivers of plate motion and wider Gondwana breakup (Elliot and Fleming, 2000; Martin, 2007; Dalziel, 2013). One complicating factor in interpretation of the early stages of Gondwana breakup is that it is thought to involve distinct microcontinental fragments. This unusual configuration has been linked in part to the influence of tectonic inheritance, specifically to earlier collisional and indentation tectonic processes responsible for the assembly of East Antarctica and Africa into Gondwana during Pan-African events ca. 600–500 Ma (Jacobs and Thomas, 2004; Jacobs et al., 2015). One key crustal block is the West Antarctic Ellsworth-Whitmore mountains crustal block (Dalziel and Elliot, 1982) referred to here as the Haag-Ellsworth Whitmore block (HEW) (Figs. 1

* Corresponding author.
E-mail address: tomj@bas.ac.uk (T.A. Jordan).

http://dx.doi.org/10.1016/j.gr.2016.09.009
1342-937X/

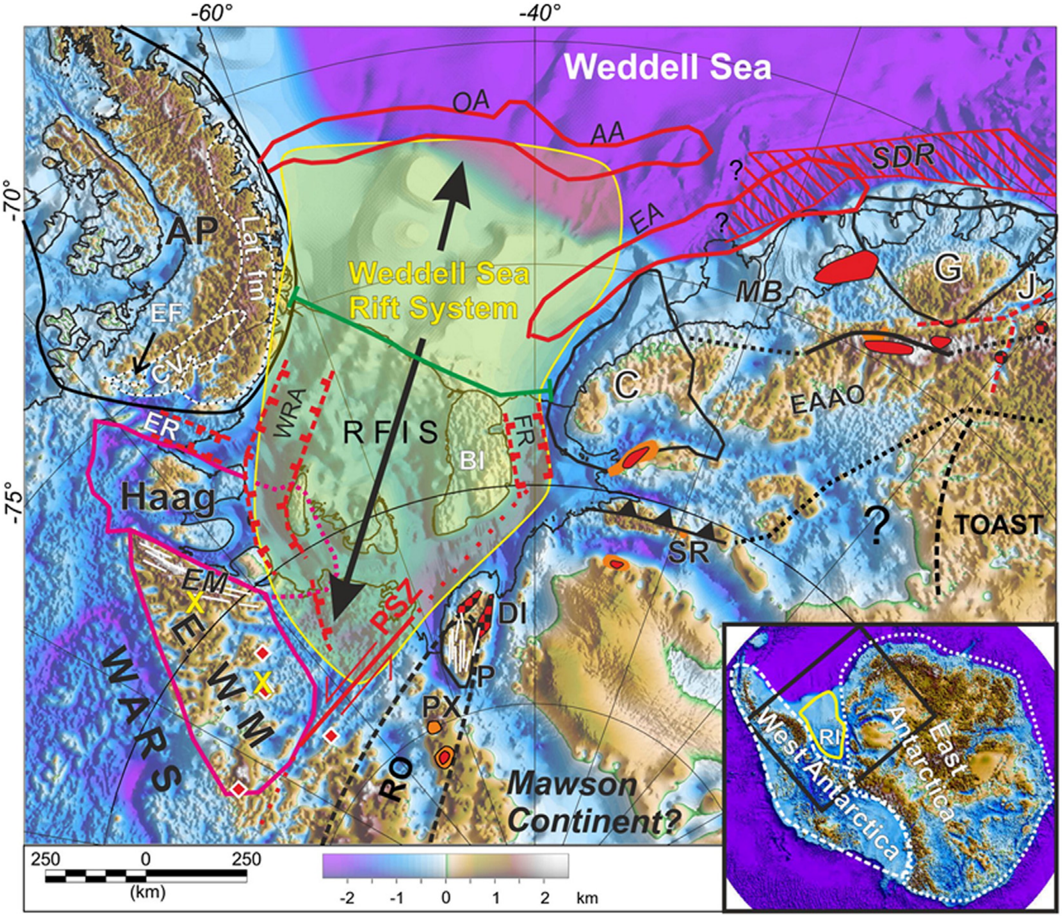

Fig. 1. Regional topography and geological sketch map of the Weddell Sea Rift System (WSRS) (yellow outline). Note displaced Haag and Ellsworth Whitmore Mountains (EWM) crustal block (purple outlines). Key Jurassic features associated with Gondwana breakup include: widespread Ferrar tholeiitic rocks (solid red blocks) (Elliot and Fleming, 2004); Dufek Intrusion (DI) (black/red check) (Ferris et al., 1998); Jurassic granites (red diamonds) (Storey et al., 1988b); Seismically imaged seaward dipping reflector sequences (SDR) (red hatch) (Kristoffersen et al., 2014); Orion, Andenes and Explora magnetic anomalies (OA, AA and EA) linked to Jurassic magmatism (Golynsky and Aleshkova, 1997a; Ferris et al., 2000); Localised rifts including the Evans Rift (ER), Weddell Rift Anomaly (WRA), Filchner Rift (FR), and Jutulstraumen Rift (J) (dashed lines) (Aleshkova et al., 1997; Jones et al., 2002; Ferraccioli et al., 2005a, 2005b); The strike-slip Pagano Shear Zone (PSZ) (Jordan et al., 2013). West of the WSRS the Antarctic Peninsula (AP) geological provinces (Burton-Johnson and Riley, 2015) include Permian sediments at Erehwon Nunatak and FitzGerald Bluffs (EF) (Elliot et al., 2016), the Jurassic Chon Aike Volcanic group (CV) (Riley et al., 2001), and Jurassic to Cretaceous back-arc Latady formation sediments (Lat. Fm.) (Laudon, 1992). East of the WSRS East Antarctica's geological provinces include the Coats Land Block (C) (Studinger and Miller, 1999), Grunehogna cratonic fragment (G) (Marschall et al., 2013) and inferred Tonian age Oceanic Arc Super Terrane (TOAST) (Jacobs et al., 2015), which are separated by the Mesoproterozoic Maud Belt (MB), and late Neoproterozoic to Cambrian East African Antarctic Orogen (EAAO) and Ross Orogen (RO) (Mieth and Jokat, 2014; Jacobs et al., 2015). White lines mark Permo-Triassic Gondwanide fold trends in the Ellsworth (EM) (Curtis, 1997) and Pensacola (P) (Storey et al., 1996a) mountains. Orange blocks mark undeformed Paleozoic sediments (Beacon Supergroup and correlatives) (Bradshaw, 2013). Other abbreviations: Berkner Island (BI), Patuxent Range (PX), Shackleton Range (SR), and the West Antarctic Rift System (WARS). Green line marks seismic refraction study along front of the Ronne Filchner Ice Shelf (RFIS) (Leitchenkov and Kudryavtzev, 1997). Yellow crosses locate sites of EWM paleomagnetic studies (Watts and Bramall, 1981; Grunow et al., 1987; Randall and MacNiocaill, 2004). Inset locates study area (black box) within Antarctica. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and 2). The HEW is generally regarded as a far travelled allochthonous block that was transferred from an original pre-breakup position close to the East Antarctic plate and/or to South Africa (in the Natal Embayment) (Fig. 2a) to its current position in West Antarctica, south of the WSRS (Schopf, 1969; Randall and MacNiocaill, 2004; Dalziel, 2013). The movement of a far travelled crustal block in the WSRS region during Gondwana breakup is widely accepted. However, the relationships between the formation of the Jurassic LIP, intracontinental extension in the WSRS, possible triple junctions and postulated crustal block movements have remained largely elusive (Studinger and Miller, 1999; Ferris et al., 2000).

Several geophysical studies investigated the WSRS during the 1980s and 90s, each using different techniques to assess the structure, crustal architecture and kinematics of the region (Hübscher et al., 1996; King and Bell, 1996; Aleshkova et al., 1997; Leitchenkov and Kudryavtzev, 1997; Golynsky and Aleshkova, 1997b; Studinger and Miller, 1999; Ferris et al., 2000). These studies, although in general agreement that the WSRS reflects a broad continental rift, did not clearly recognise major faults or identify large-scale mechanisms that could have enabled crustal block movements or rotations compatible with those required by conventional far travelled tectonic models. A recent aerogeophysical survey over the inland extent of the WSRS has, however, imaged a major strike slip fault system, the Pagano Shear Zone (PSZ) separating East and West Antarctica (Fig. 1), which may have accommodated at least some of the proposed Jurassic crustal block motion (Jordan et al., 2013).

Here we present new compilations of enhanced airborne magnetic and airborne gravity data across the WSRS and adjacent regions. These datasets are interpreted, together with limited existing seismic data, satellite magnetic data, and with reference to the geological literature, to re-investigate the crustal architecture of the WSRS and to re-assess its tectonic and kinematic evolution with respect to the early phases of Gondwana breakup. Our new integrated interpretation of the crustal architecture of the WSRS indicates the southern WSRS is a highly extended terrane, with voluminous rift-related Jurassic magmatism, as suggested by some previous authors (Studinger and Miller, 1999; Dalziel et al., 2000). We discuss a range of tectonic scenarios for WSRS evolution based on our geophysical interpretations. We find no geophysical evidence for significant (~1500 km) crustal block translation and ~90°