An introduction to the crustal evolution of India and Antarctica: the supercontinent connection

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Perhaps the most important advance in our knowledge of the Precambrian Earth over the last three decades has been the general consensus on the episodic nature of the amalgamation and dispersal of supercontinents (e.g. Rogers 1996; Condie & Aster 2010; Nance et al. 2014). The Precambrian history of the Earth is thought to be punctuated by the assembly and breakdown of at least three supercontinents: Columbia (Nena), Rodinia and Gondwana (Fig. 1; e.g. McMenamin & McMenamin 1990; Rogers & Santosh 2002; Meert 2012).

Transcontinental correlation in the Precambrian is a complex endeavour requiring multidisciplinary investigations, primarily involving structure/tectonics, petrology, geochronology and palaeomagnetism. A detailed knowledge of all of these disciplines for regions that were supposedly contiguous as parts of supercontinents is an absolute primary requisite to arrive at any firm conclusion. This is the reason why a wide range of disagreements exists regarding the exact configurations of the supercontinents, despite the overall consensus about their existence. Problems are more acute with the older supercontinents, particularly Columbia and, to some extent, Rodinia.

Both India and Antarctica are important components of all three supercontinent configurations, but their dispositions have been hotly debated (e.g. Rogers & Santosh 2002; Collins & Pisarevsky 2005; Hou et al. 2008). In particular, two previous Geological Society Special Publications (volume 206 (Yoshida et al. 2003) and volume 383 (Harley et al. 2013a)) addressed the many then outstanding issues hindering the unambiguous fitting of India and Antarctica into the supercontinent models. Within each of these continents, the contentious issue is the identification of terrane boundaries and their mutual linkages in the supercontinents (Fig. 2; Harley et al. 2013b). Extensive isotopic work has revealed the existence of several terranes/domains/provinces, each with distinctive geological histories. As a result, no straightforward solution is available regarding their correlations.

Several models predict the repeated juxtaposition of India and Antarctica and subsequent multiple disintegrations over a geological period spanning >1.5 billion years from the accretion of Columbia to the formation of East Gondwana. The big question is how such ‘yo-yo’ tectonics could occur, if at all. Where, why and when did such repeated integrations/disintegrations occur? On an intracontinental scale, how and when were the Proterozoic mobile belts accreted to the cratons?

Convergence of diverse lines of evidence, each with their own uncertainties, for past intra- and transcontinental correlations, especially in the absence of palaeontological data, is a difficult proposition and will continue to be debated as more new data are generated.

Rationale for this Special Publication

There is an increased importance of, and attention paid to, the polar regions, especially Antarctica, on account of the presence of c. 90% of the total freshwater of our planet in the East Antarctic Ice Sheet and a projected sea-level rise of c. 60 m if all of this melts. In addition, the region acts as a major heat sink because it modulates the ocean circulation and the atmospheric temperature. The sub-ice geology controls this behaviour and major scientific programmes have been launched to resolve some of these issues, leading to a better definition of the sub-ice landscape (e.g. the ADMAP and ICECAP and ICECAP2 programmes; Bo et al. 2009; Li et al. 2010; Fretwell et al. 2013). A better understanding of Antarctic history by inferring the sub-ice geology was one of the six priorities identified by the Scientific Committee on Antarctic Research (Kennicutt et al. 2014).

The eastern Gondwana block – consisting of India, Australia and Antarctica – preserves evidence of roughly Grenville age orogens, implying the existence of simultaneous mountain-building processes in a large continental block. These
orogenic belts preserve evidence of Mesoproterozoic crustal evolution, which can be pieced together from currently spatially separated domains to understand the subglacial geology of the east Antarctic shield. It is pertinent to quote from the last Special Publication in this context, wherein Harley et al. (2013b) remarked that:

[Until we resolve the subglacial geometry and tectonic setting of the c. 0.5 and 1.0 Ga metamorphism, there will be no consensus on the configuration of Rodinia, or the size and shape of the continents that existed immediately before and after this supercontinent.]

Some of the contentious issues related to India and Antarctica were discussed and debated at an international seminar under the aegis of the XIII International Symposium on Antarctic Earth Sciences in Goa, India in 2015. The presented work and discussions were focused on India- and Antarctica-centric studies because both of these constitute key land masses for supercontinent reconstructions. It was realized that there has been significant recent regional studies in India with implications for supercontinent evolution, especially during the Proterozoic and in relation to the presently widely separated land masses of India and Antarctica. This volume presents these studies.

**Organization of this volume**

The thirteen papers in this volume are organized into two sections. The first section on Antarctic studies contains two papers on the Dronning Maud Land sector in the western part of East Antarctica and one paper on the rocks from Enderby Land in the eastern part of this terrain. In proportion to the exposed terrain and logistic considerations, the second section has ten papers organized into four sectors of the Indian terrain. The first subsection of four papers describes the Eastern Ghats Mobile Belt, which is considered to be a geological continuation of Antarctica. The Chotanagpur Granite Gneiss Craton (CGGC), located north of the Singhbhum Craton, preserves records of Proterozoic supercontinent activity and two papers illustrate new data from this domain and constitute the second subsection. Another paper focused further north of the
CGGC on the South Khasi Hills in the northeastern sector of India has been included to describe post-Rodinia thermal activity in the third subsection. In the next subsection, two papers on the western Indian craton are followed by a paper presenting an alternative hypothesis of supercontinent amalgamation.

Fig. 2. Map showing the locations of the different study areas in India and East Antarctica. Indian tectonic zones redrawn from Ramakrishnan and Vaidyanadhan (2008). East Antarctica in its reconstructed Gondwana context, redrawn from Fitzsimons (2000) and Harley et al. (2013b).

The outcomes

Section 1: Antarctica

Mikhalsky et al. (2017) investigate and provide new geochronological data from the Thala Hills area of western Enderby Land, which represents...
a key link between the Indo-Antarctic and Afro-Antarctic regions. They distinguish three tectonomagmatic events at c. 980–970, c. 780–720 and c. 545–530 Ma.

Roy et al. (2017) provide a detailed investigation of a small nunatak, Baalsrudfjellet, in central Dronning Maud Land. They describe a two-stage metamorphic evolution through the study of granulites at c. 680–660 and c. 580 Ma and provide evidence for the inland continuation of the extension of East African Orogen as the suture between the east and the west Gondwanaland blocks during the Neoproterozoic.

Further west within the east Antarctic shield, Moabi et al. (2017) describe the Straumsnutane Formation lavas in western Dronning Maud Land and compare these with the Espungabera Formation lavas of central Mozambique and the Borgmassivet intrusions in Dronning Maud Land, Antarctica. They suggest correlation with the c. 1100 Ma Umkondo Igneous Province of South Africa.

Section II: India

Eastern Ghats Mobile Belt. Dasgupta et al. (2017) present a review of the current status of petrological and geochronological data from the Eastern Ghats Mobile Belt, showing the presence of several assembled crustal units with their own complex and often polymetamorphic histories. For example, the Palaeoproterozoic Ongole domain is linked to the formation of the Columbia supercontinent. The authors identify four domains within the Eastern Ghats Mobile Belt and describe the evolution of this belt until the Neoproterozoic.

Petrological, geochemical and geochronological investigations of a suite of granulites occurring along the western boundary of the Eastern Ghats Belt by Chatterjee et al. (2017) reveal a complex polymetamorphic history of protoliths containing Archean crustal components. The major granulite metamorphism took place at 950–930 Ma, followed by decompression at 780–750 Ma and a late thermal overprint at 525–510 Ma. The 780–750 Ma episode is interpreted to be related to the break-up of Rodinia, whereas the youngest is inferred to coincide with the timing of the final amalgamation of East Gondwana.

Petrological and geochronological studies of two new localities from the Eastern Ghats Belt lead Das et al. (2017) to assign a slightly older age (c. 1180 Ma) to the ultra-high-temperature metamorphism at lower crustal depths on a counterclockwise pressure–temperature path than that commonly accepted (c. 1030 Ma, Bose et al. 2011). The isobarically cooled ultra-high-temperature granulites were exhumed at c. 980 Ma by another collisional orogeny related to the amalgamation of the Eastern Ghats Belt in Rodinia.

Using electron back-scattered diffraction and field data, Sawant et al. (2017) interpret an east–west shear zone between the Eastern Ghats Province and the Rengali Province as a strike-slip fault juxtaposing these rocks against Archean cratonic granulites. The authors correlate this shear zone with similar Archean–Proterozoic intercalations in the Rauer Group of East Antarctica.

Chotanagpur Granite Gneiss Craton. Mukherjee et al. (2017) investigate a variably retrogressed granulitic orthogneiss and associated lithologies and infer a c. 943 Ma continent–continent collision event of the Mesoproterozoic CGGC rocks, linking this to the formation of the Rodinia supercontinent. They suggest the Proterozoic geothermal gradient to be similar to the present day continental geothermal gradient.

Saikia et al. (2017) describe a volcano-sedimentary sequence, the Bathani sequence, from the northern CGGC and relate it to island arc magmatism. Based on petrological and geochronological considerations, these authors infer the Bathani sequence to be the eastern continuation of the Mahakoshal Mobile Belt of central India.

Using petrological, geochemical and geochronological data, Kumar et al. (2017), in their study of microgranular enclaves and granites from the South Khasi Hills of the Meghalaya Plateau, infer mixing of felsic and mafic magma formed during the later stages of the assembly of east Gondwanaland as an integral part of a Pan-Indian–African–Brasiliano orogenic cycle.

Western Indian Craton. Bose et al. (2017) investigate a mid-crustal section in the South Delhi Fold Belt that shows remarkable similarity in the style of petrological evolution to the basement granulites. Pelitic rocks in the amphibolite facies rocks develop a Barrovian sequence, metamorphosed at c. 980 Ma. This Grenvillian imprint is thought to have affected both the deeper and middle crust in the Aravalli–Delhi Mobile Belt during the formation of Greater India.

Arora et al. (2017) demonstrate evidence for a post-Delhi orogeny, the Sirohi orogeny, preserving evidence of rapid changes in configuration during the Rodinia assembly to Cryogenian time. The basement for these rocks is the post-Delhi, Erinpur granite and the metamorphism is dated to be c. 820 Ma.

An alternative hypothesis. Meert et al. (2017) propose an alternative view of supercontinent assembly based on palaeomagnetic data. Using the Mesozoic East Gondwana configuration, they provide
potential links between India and east Antarctica and suggest that East Gondwana did not exist prior to the Ediacaran–Cambrian.

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