Proterozoic East Gondwana: Supercontinent Assembly and Breakup

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Proterozoic East Gondwana: Supercontinent Assembly and Breakup

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Preface

Supercontinent assembly and breakup has been an important topic since Wagener's discovery of Pangaea in the early twentieth century and has been recognized as an important process of the Wilson Cycle since the late 1960s. The separate proposals of a Mesoproterozoic Rodinia supercontinent by Dalziel (1991) and Hofmann (1991) concentrated the attention of many geoscientists on this topic.

The UNESCO–IUGS–IGCP-288 project 'Assembly of Gondwanaland' (1990–1996) focused on the subject of Rodinia to Gondwanaland, and was followed by IGCP-368 'Proterozoic Events in East Gondwana' (1995–2001) and by IGCP-440 'Rodinia Assembly and Breakup' (1999–2003). At the 31st IGC in Rio de Janeiro in October 2000, IGCP-368 organized a general session entitled 'Proterozoic Events in East Gondwana' to which many contributions came from both IGCP-368 and IGCP-440. This session provided the impetus in collating the present volume.

East Gondwana was traditionally thought to have formed as a major part of Rodinia during the Mesoproterozoic Grenvillian–Circum-East Antarctic Orogeny (Yoshida 1995; Unrug 1997) and survived until the Middle–Late Mesozoic when Pangaea broke up. An ice-covered Antarctica is the key component of this long-lived subsupercontinent. West Gondwana, on the other hand, assembled during the Neoproterozoic and collided with pre-existing East Gondwana at this time.

However, the accumulation of Pan-African zircon ages, mostly from Antarctica since the early 1990s, coupled with an increase in the number of reliable palaeomagnetic data from various parts of the globe, has resulted in a re-evaluation of the above classical model, creating a radical new model. According to this new model, East Gondwana did not exist during the Neoproterozoic – along with West Gondwana it was assembled during the Pan-African Orogeny and, accordingly, the whole of Gondwanaland was amalgamated at this time (e.g. Meert & Powell 2001; Powell *et al.* 2001). Both models still command strong support and further data are required to constrain their future viability, although the new model is becoming increasingly popular.

The present volume assembles papers on Grenvillian–Circum-East Antarctic and Pan-African events in various parts of East Gondwana (Fig. 1), and presents a comprehensive review of related areas and topics. Although all papers give balanced reviews related to their topics, some stand more or less on the classical model, while others support the new model. This reflects the present debate on this subject.

The volume deals with five topics – one general and four regional. The general papers address global issues on crustal–mantle processes in Proterozoic to Early Palaeozoic times. The regional papers include comprehensive time–space–event diagrams to help provide a general overview of Late Proterozoic–Early Palaeozoic geology of the regions concerned.

Tectonics of Rodinia and Gondwana: continental growth, supercontinent assembly and breakup

Among four papers under this topic, two papers are concerned with continental growth and mantle plume activity. **Condie** discusses the role of superplumes in relation to the rate of crust formation, and concludes that a superplume event was absent during the assembly and breakup of supercontinents during Neoproterozoic time. The author suggests a possibility that the absence of the superplume activity might reflect incomplete breakup of a Palaeoproterozoic supercontinent, which was followed by the formation of Rodinia. **Windley** presents three tectonic environments for the growth of continents, namely accretionary orogens, in which juvenile material is added to pre-existing continental blocks, collisional orogens, and rifts in supercontinents. In addition to plate tectonics, mantle plume tectonics is emphasized as a major contributor to the growth of the continents.

In the following two papers, one stresses the new model for Gondwanaland assembly, whereas the second points out some shortcomings. **Pisarevsky *et al.*** synthesized recent palaeomagnetic and geological data, and produced a thoroughly new model of Rodinia assembly and breakup, which they propose as a working hypothesis for future work. One of their important proposals divides East Gondwana into three dispersed blocks. Their model was encouraged by the radical proposal of Fitzsimons (2000) that the Late Mesoproterozoic terrains fringing East Antarctica could be composed of three different blocks separated by two Pan-African orogenic belts. **Yoshida *et al.*** present a balanced overview of the Grenvillian–Circum-East Antarctic Orogen and of the Pan-African Orogen surrounding East Antarctica. They conclude that present data are insufficient to replace the classical model with the new one, and that both models require further examination and constraints. They specifically point out the importance of careful examination of geochronological data in both geological and palaeomagnetic studies, special attention being given to the lower temperature resetting of U–Pb zircon as well as Sm–Nd garnet ages.

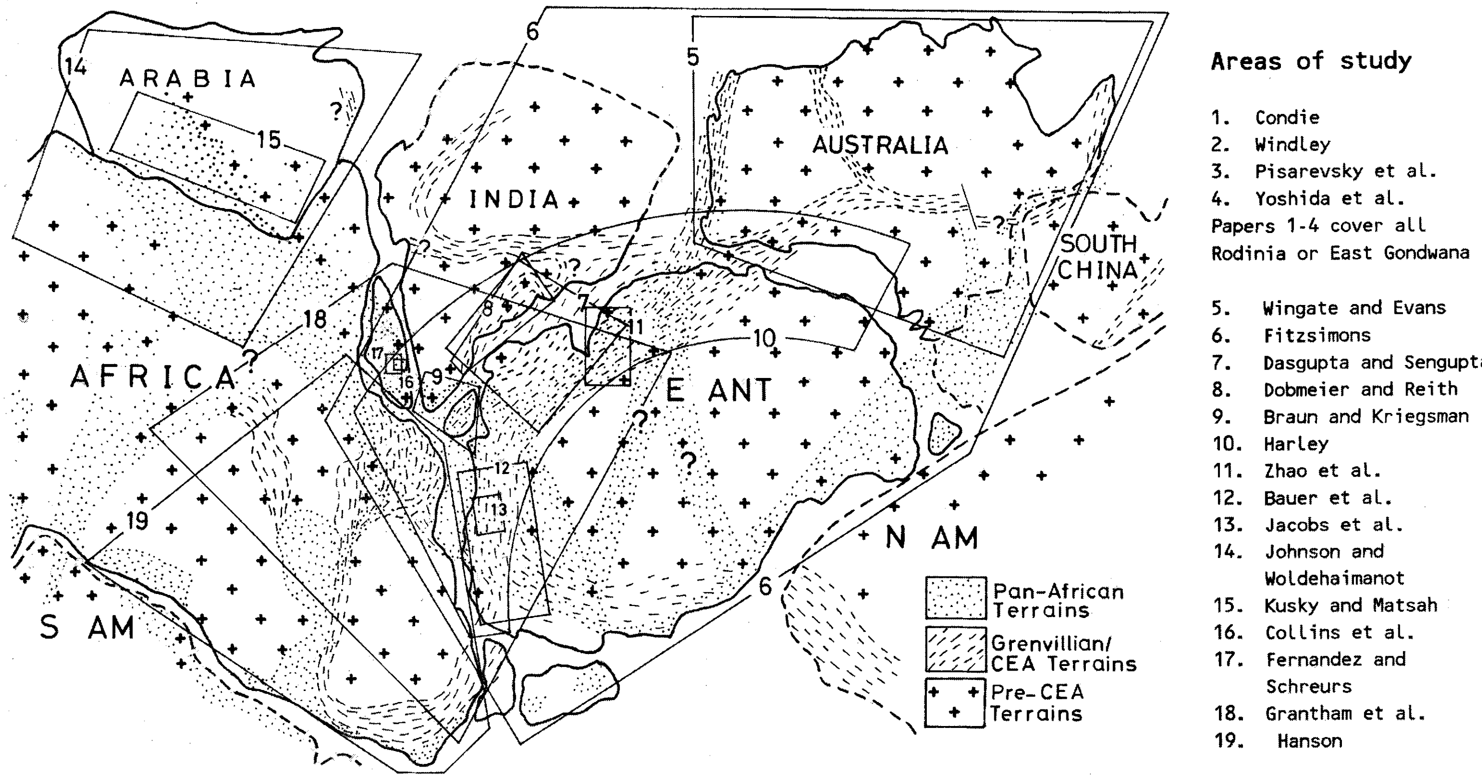

Fig. 1. Pan-African and Circum-East Antarctic (Grenvillian) terrains in East Gondwana, during ca. 1000/Ma–500/Ma. Summarized from papers in the present volume by Bauer *et al.* Fitzsimons *et al.*, Kusky & Matsah and Yoshida *et al.* Yoshida (1995) and Unrug (1997) were also used as a base map. Broken outline of crustal blocks indicates uncertainty. Areas of study covered by papers in the present volume are also indicated. CEA: Circum-East Antarctic, N AM: North America, S AM: South America.

Australia and Gondwanaland

This section includes two papers, one with a palaeomagnetic theme and one with a geotectonic theme. **Wingate & Evans** have assembled reliable palaeomagnetic data that overlap palaeopoles from 1.7 to 1.8 Ga and 1.5 to 1.6 Ga. They conclude that the North and West Australian Cratons have occupied their present relative positions since at least *c.* 1.7 Ga, and that they have been joined to the South Australian Craton since at least *c.* 1.5 Ga, although further data are required to examine the width of the oceans between the continental blocks. **Fitzsimons** gives a comprehensive review of Proterozoic southern and western Australia and of their correlations with Antarctica. The Australia– Antarctic sector in East Gondwana is divided into the Archaean–Palaeoproterozoic Mawson Craton, the Mesoproterozoic Albany–Fraser Orogen, and the Pan-African Pinjarra Orogen. The last orogen includes Late Mesoproterozoic allochthonous blocks, which divide East Gondwana into Australo-Antarctic and Indo-Antarctic domains. The Pinjarra Orogen extends further south into ice-covered, inland Antarctica. This paper will surely encourage geoscientists to improve the new model of Gondwanaland assembly during Pan-African time.

South Asia within the Gondwanaland ensemble

All three papers in this section provide geochronological and petrological constraints on high-grade rocks occurring in India and Sri Lanka and explore different models of correlation within the framework of Rodinia. **Dasgupta & Sengupta** review the tectonothermal history of the Eastern Ghats Belt in the light of recently published isotopic data that established different geochronologic provinces in this belt, and discuss its significance in the context of Indo-Antarctic correlation. **Dobmeier & Raith** present a new provocative idea of subdivision of the crustal architecture of the Eastern Ghats Belt in eastern and southern India, and consider low-grade schist belts bordering the high-grade mobile belt as integral parts of evolution of this terrane. **Braun & Kriegsman** present an updated review of the high-grade terranes of southern India and Sri Lanka, which provides stronger support for correlation of these terranes with the Lutzow-Holm Bay area of East Antarctica.

Antarctica and its role in the Gondwanaland assembly

This section includes four papers that highlight the importance of the Pan-African orogeny in the assembly of Gondwanaland. **Harley** presents an exhaustive, updated review of history of different crustal provinces within the East Antarctic Shield. He concludes that these provinces have records of different isotopic events and were amalgamated during the Pan-African Orogeny characterized by high- to very-high-grade metamorphism. This questions the concept of an older model of a continuous Grenvillian province (e.g. Yoshida 1995) that supported the SWEAT hypothesis (Moores 1991). ***Zhao et al.*** promote an accretionary model and amalgamation of different blocks during the Pan-African Orogeny to explain the evolution of the Prydz Bay region of East Antarctica, discarding the traditional model of polyorogenic history (Harley & Fitzsimons 1995). This paper has major implications for the new models of configuration of Rodinia and East Gondwana, and strongly supports Fitzsimons' (2000) suggestion mentioned above. **Bauer *et al.*** deal with the Proterozoic–Cambrian history of both the central and western Dronning Maud Land, and present evidence of Mesoproterozoic accretionary history of the orogens to the Archaean craton. They also emphasize the strong Pan-African metamorphism and tectonism in these sectors, leading to the development of the East Antarctic Orogen (Jacobs *et al.* 1999) as a continuation of the East African Orogen (Stern 1994), resulting in the assembly of Gondwanaland.

Jacobs *et al.* characterize a 530–510 Ma Late Pan-African extensional event in the central Dronning Maud Land through interpretation of structural, petrological and isotopic data, and compare this with similar events in Madagascar and the Arabian–Nubian Shield, indicating that this event is a reflection of Pan-African collisional tectonics.

The East African Orogen

The papers in this section include two on the Arabian–Nubian Shield, two on Madagascar and two on eastern and southern Africa.

Johnson and Woldehaimanot produce the most detailed synthesis yet of the Arabian–Nubian Shield, which forms the suture between East and West Gondwana at the northern end of the East African Orogen. Subduction started at 870 Ma in the Mozambique Ocean, with arc–arc convergence and terrane suturing at 780 Ma marking the start of ocean closure and Gondwana assembly. Terrane amalgamation continued until 600 Ma, resulting in juxtaposition of East and West Gondwana, with final assembly of Gondwana being achieved by 550 Ma.

Kusky & Matsah report that dextral offset up to 10 km on one of the major faults belonging to the Najd Fault System has a maximum age of 625 ± 4.2 Ma, which provides the earliest age for the collision of East and West Gondwana. These dextral movements later switched to sinistral, when accreted terranes caught between the two continents were transported towards an oceanic margin to the north. These results provide important constraints on the terminal history of the Mozambique Ocean.

The two papers on Madagascar are concerned with the central part of that island. **Collins *et al.*** give a detailed structural section across the upper crustal metasedimentary Itremo Group and eastwards through the underlying high-grade gneissic mid-crustal Antananarivo Block. They consider that Gondwana accretion in this part of the East African Orogen occurred between 720 and 570Ma. After contractional deformation the orogen collapsed, producing an extensional shear zone between the Itremo Group and the underlying gneissic block. **Fernandez & Schreurs** present a structural-based study of the tectonic evolution of the metasedimentary Itremo Group. This paper is highly controversial in comparison with the results of several other research groups studying this part of central Madagascar.

Grantham *et al.* summarize and review the evolution of the Mozambique orogenic belt and its extensions in Antarctica, Sri Lanka, India and Mozambique. They conclude that amalgamation of East and West Gondwana between 600 and 460Ma occurred in a continent-scale transpressional setting during closure of the Mozambique Ocean.

Hanson presents a detailed synthesis of the Proterozoic orogenic belts on the present eastern, western and northern margins of southern Africa south of the equator. He concludes that Rodinia was assembled at 1.0Ga and broke-up at 920–700Ma, with rifting and within-plate magmatism into crustal blocks that amalgamated into Gondwana at 570–510Ma, along with formation of the collisional Mozambique and Kaoko–Gariep–Saldania orogenic belts. The Damara–Lufilian–Zambezi Orogen developed largely by closure of linked, narrow ocean basins.

In closing this introduction, we recall with heartfelt gratitude the late Raphael Unrug, co-leader of IGCP-288 and 440, and Chris McA Powell, secretary of IGCP-368 and co-leader of IGCP-440. The successful activities of IGCP-368 and IGCP-440, which are reflected in the present volume, owe a great deal to their valuable collaboration and encouragement. Powell initially joined the co-editors of the present volume, and contributed much in formulating ideas on its make-up. The six years of fruitful activity of IGCP-368 were funded by UNESCO and IUGS, as well as by several Grants-in-Aid for Scientific Research of the Japan Ministry of Education, Science, Sports and Culture, to which we express our thanks.

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References

DALZIEL, I. W. D. 1991. Pacific margins of Laurentia and East Antarctica–Australia as a conjugate rift pair: evidence and implications for an Eocambrian supercontinent. *Geology*, **19**, 598–601.

FITZSIMONS, I. C. W. 2000. Grenville age basement provinces in East Antarctica: evidence for three separate collisional orogens. *Geology*, **28**, 879–882.

HARLEY, S. L. & FITZSIMONS, I. C. W. 1995. High-grade metamorphism and deformation in the Prydz Bay region, East Antarctica: terrains, events and regional correlations. *In*: YOSHIDA, M. & SANTOSH, M. (eds) *Indiana and Antarctica during the Precambrian.* Geological Society of India, Memoir, **34**, 73–100.

HOFFMAN, P. 1991. Did the breakup out of Laurentia turn Gondwana inside out? *Science*, **252**, 1409–1412.

JACOBS, J., HANSEN, B. T., HENJES-KUNST, F., *ET AL.* 1999. New age constraints on the Proterozoic/Lower Palaeozoic evolution of Heimefrontfjella, East Antarctica, and its bearing on Rodinia/Gondwana correlation. *Terra Antarctica*, **6**, 377–389.

MEERT, J. G. & POWELL, C.MCA. 2001. Assembly and break-up of Rodinia: introduction to the special volume. *In*: POWELL, C.MCA. & MEERT, J. (eds) *Assembly and Breakup of Rodinia. Precambrian Research*, Special Issue, **110**, 1–8.

MOORES, E. M. 1991. Southwest US–East Antarctica (SEWEAT) connection: a hypothesis. *Geology*, **19**, 425–428.

POWELL, C.MCA., PISAREVSKY, S. & WINGATE, M. T. D. 2001. New shape for Rodinia. *Gondwana Research*, **4**, 736–737.

STERN, R. J. 1994. Arc assembly and continental collision in the Neoproterozoic east African Orogen: implications for the consolidation of Gondwanaland. *Annual Review of Earth and Planetary Science*, **22**, 319–351.

UNRUG, R. 1997. Rodinia to Gondwana; the geodynamic map of Gondwana supercontinent assembly. *GSA Today*, **7**, 1–6.

YOSHIDA, M. 1995. Assembly of East Gondwana during the Mesoproterozoic and its rejuvenation during the Pan-African period. *In*: YOSHIDA, M. & SANTOSH, M. (eds) *India and Antarctica during the Precambrian.* Geological Society of India, Memoir, **34**, 25–45.

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