Early Paleozoic tectonism within the East Antarctic craton: The final suture between east and west Gondwana?

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ABSTRACT

New U-Pb SHRIMP ages from East Antarctica point to the existence of a laterally continuous orogenic belt that bisects the East Antarctic craton. This orogenic belt juxtaposes Archean crust to the south and east against Neoproterozoic metamorphic rocks to the north and west. It defines the margin of a separate lithospheric block that consists of a large section of East Antarctica and India that did not form part of east Gondwana or Rodinia as they are currently reconstructed. Instead, this Indo-Antarctic continent accreted with west Gondwana along the Mozambique suture shortly before collision and suturing along a second "Pan-African" suture now cropping out in the southern Prince Charles Mountains and Prydz Bay regions of Antarctica. This scenario is consistent with (1) the abrupt termination of ca. 990–900 Ma tectonism recognized in the northern Prince Charles Mountains–Rayner Complex–Eastern Ghats against Paleozoic orogenic belts, (2) the lack of terranes of equivalent age found elsewhere in either Antarctica or other previously adjacent continents, and (3) the distinct detrital-zircon populations obtained from either side of this proposed suture.

Keywords: Gondwana, Rodinia, east Antarctica, SHRIMP data, suture zones, Prince Charles Mountains.

INTRODUCTION

The assembly of the supercontinent Gondwana was not completed until sometime in the Middle to Late Cambrian (Powell et al., 1993; Grunow et al., 1996). It occurred through the gradual closure of several ocean basins to form west Gondwana (consisting of Africa and South America) in the Neoproterozoic, followed by Early Cambrian collision with east Gondwana (consisting of Australia, Antarctica, and India; Fig. 1A). In contrast to west Gondwana, east Gondwana is thought to have formed during the consolidation of Rodinia in the Mesoproterozoic (Rogers, 1996), and it remained tectonically stable until the modern continents rifted from Gondwana in the Mesozoic. The internal stability of east Gondwana (Fig. 1B) has been inferred from the perceived absence of younger events within East Antarctica. Although K-Ar and Rb-Sr mineral ages of late Neoproterozoic to Cambrian age have been obtained widely in East Antarctica (Tingey, 1991), these have been interpreted to be the result of either a static thermal overprint, commonly associated with some granite and pegmatite emplacement, or related to local greenschist- to amphibolite-facies deformation (Sheraton and Black, 1988; Tingey, 1991; Manton et al., 1992; Stüwe and Sandiford, 1993). This view was challenged by Zhao et al. (1992), who obtained Pb-Pb zircon evaporation ages of ca. 550 Ma from Prydz Bay (Fig. 1A). Zhao et al. (1992) argued that at least some of the ductile deformation in Prydz Bay was of Cambrian age. This hypothesis was later supported by U-Pb crystallization ages obtained from syntectonic granites and leucosomes (Carson et al., 1996; Fitzsimons et al., 1997). Because Prydz Bay lies within east Gondwana (Fig. 1, A and B), these ages were anomalous for a coherent east Gondwana model. As a result, some studies suggested that a previously unrecognized Pan-African suture ran through Prydz Bay and linked with equivalent-age tectonism recognized in Lützow-Holm Bay (west) and in the Leewin Complex (east) (Carson et al., 1996; Hensen and Zhou, 1997; Fitzsimons, 1997). Such interpretations imply that orogenesis in Prydz Bay was linked with Lützow-Holm Bay via the northern Prince Charles Mountains–Rayner Complex (Fig. 1C). However, most studies

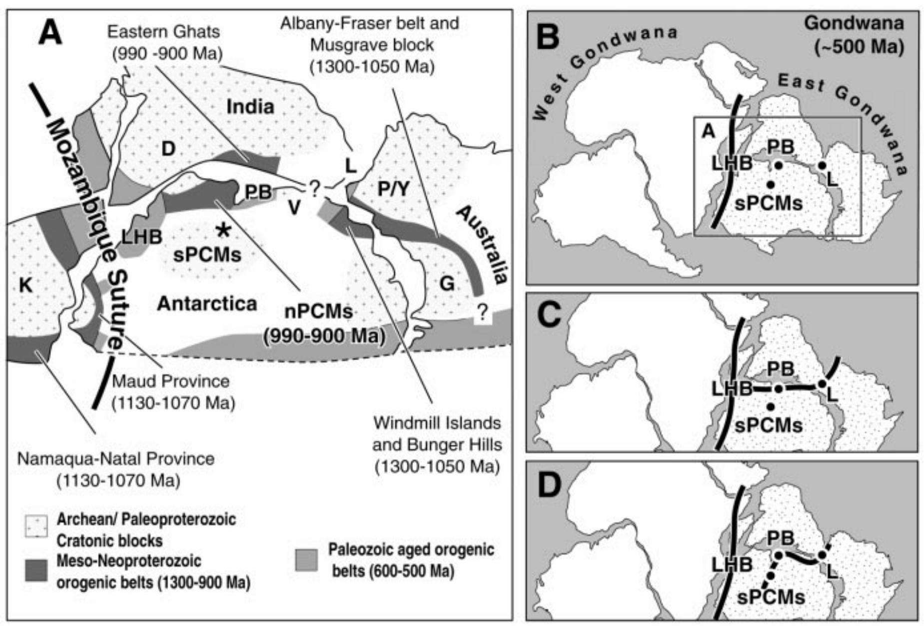

Figure 1. Reconstruction of Gondwana centered on Antarctica at ca. 500 Ma. A: East Antarctica and margins of adjacent continents showing Archean-Paleoproterozoic cratonic blocks and Mesoproterozoic-Neoproterozoic and Paleozoic orogenic belts. Mozambique suture represents proposed boundary between east and west Gondwana. Note position of Cambrian orogenesis in Prydz Bay within east Gondwana. Asterisk shows study area (enlarged in Fig. 2). D—Dwarhar craton, G—Gawler craton, K—Kalahari craton, P/Y—Pilbara/Yilgarn craton, sPCMs—southern Prince Charles Mountains, V—Vestford Hills, LHB—Lützow-Holm Bay, PB—Prydz Bay, L—Leewin Complex, nPCMs—northern Prince Charles Mountains. B: Traditional model of east and west Gondwana, in which east Gondwana is assumed to be tectonically stable. Solid line defines Mozambique suture. Highlighted localities are the same as in A. C: Shows proposed Pan-African suture within east Gondwana linking Leewin Complex (Western Australia) with Lützow-Holm Bay Complex via Prydz Bay (Carson et al., 1996; Hensen and Zhou, 1997; Fitzsimons, 1997). D: Alternate interpretation, in which orogenesis in Prydz Bay and Leewin Complex are continuous, but orogenesis in Prydz Bay trends inland rather than around coast (Fitzsimons, 2000a).

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of these terranes do not support this inference, as they show that neither were significantly deformed during the Cambrian (Young and Black, 1991; Boger et al., 2000; Carson et al., 2000). As a consequence, Fitzsimons (2000a) suggested that orogenesis in Prydz Bay may have extended inland rather than along the coast (Fig. 1D). However, there is only limited isotopic data available from inland localities to support this inference. Thus, the continuation of Cambrian orogenesis beyond Prydz Bay remains somewhat speculative. Similarly, the significance of this orogenic belt within east Gondwana has yet to be properly established. Some argue for an intraplate setting (Wilson et al., 1997), whereas others argue for a suture (Fitzsimons, 2000b). In this paper we present new SHRIMP data obtained from the southern Prince Charles Mountains, East Antarctica. Based on our results we present a new tectonic scenario and discuss the implications that this model has for the reconstruction of both Rodinia and Gondwana.

SHRIMP U-Pb RESULTS

Zircons for SHRIMP (sensitive high-resolution ion microprobe) analysis were separated by conventional heavy-liquid and magnetic procedures and processed using standard SHRIMP analytical procedures (Williams, 1998) at the Australian National University, Canberra. Cathodoluminescent (CL) imaging was conducted to assess the internal structure of the unknown zircons. The isotopic data obtained[1] suggest that the southern Prince Charles Mountains consist of two juxtaposed terranes of distinct origin and age. The older lies to the south of Gibbs Bluff (Fig. 2); the younger lies to the north. The names used for these terranes follow those defined by earlier Russian studies of the region (Kamenev et al., 1993).

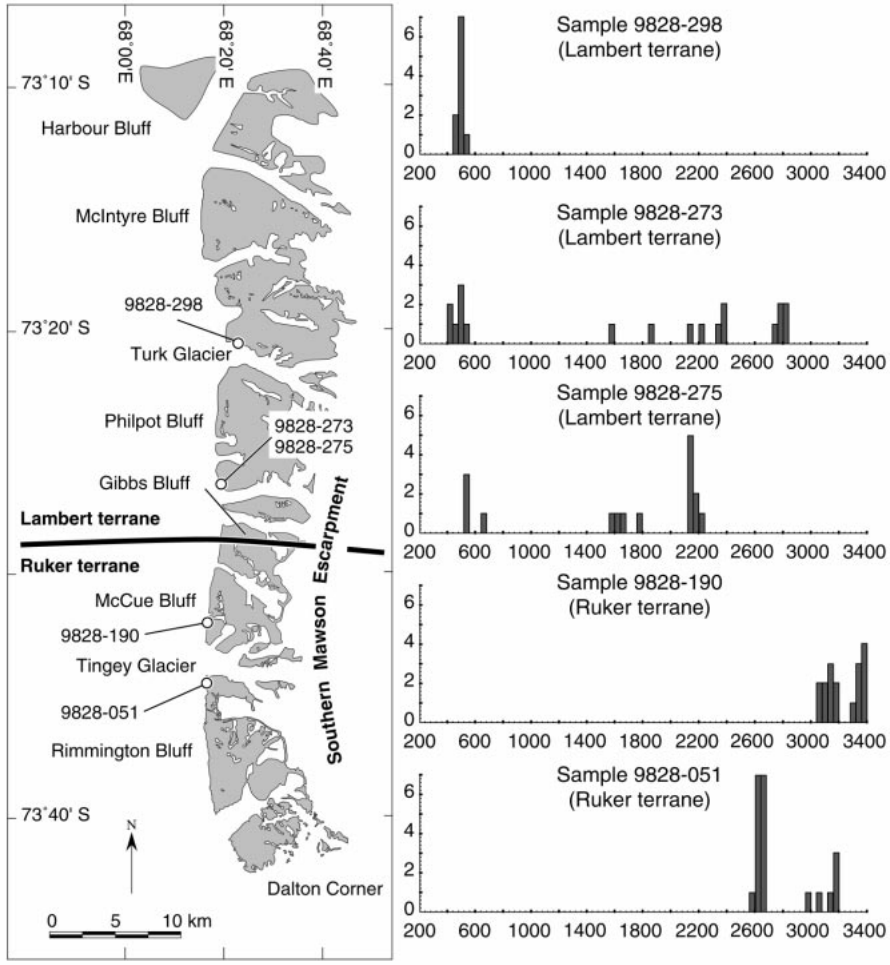

Figure 2. Study area illustrating boundary between Ruker and Lambert terranes, sample localities, and U-Pb SHRIMP data obtained from these samples. Histograms of age (x axis) versus number of analyses (y axis) illustrate distribution of individual analyses for each sample.

Ruker (Southern) Terrane

Sample 9828-190 was collected from a well-foliated hornblende- and biotite-bearing gneissic granite that cropped out at McCue Bluff (Fig. 2). This granite was deformed by all phases of deformation recognized in the Ruker terrane and thus is interpreted to place a maximum age on deformation.

Seventeen analyses from 10 zircon grains were obtained. The isotopic data show two distinct zircon populations that yielded ^{207}Pb/^{206}Pb ages of ca. 3370 Ma and ca. 3160 (Fig. 2). The older population was obtained from zircon cores; the younger was from the zircon rims. We interpret the core ages to reflect inheritance from a Middle Archean source and the rim population to represent the age of crystallization of this sample. Thus, we consider deformation in the Ruker terrane to be no older than ca. 3160 Ma.

Sample 9828-051 was collected from a pegmatite dike located at the northern end of the Rimmington Bluff (Fig. 2). The pegmatite is internally undeformed and appears to postdate all periods of deformation recorded in the Ruker terrane. It thus places a minimum age on the timing of orogenesis.

We obtained 21 analyses of 16 zircon grains; six were of zircon cores, and the remaining 15 analyses were of zircon rims. Core analyses yielded an age of ca. 3150 Ma (Fig. 2). All 15 rim analyses yielded a single age of ca. 2645 Ma (Fig. 2). The ages obtained from the core analyses are interpreted to be of inherited origin, the age of which is similar to the emplacement age obtained from sample 9828-190. The age obtained from the rim analyses is interpreted to date the age of pegmatite crystallization (ca. 2650 Ma) and by inference places a minimum age on the timing of deformation in the Ruker terrane.

Lambert (Northern) Terrane

Sample 9828-275 was collected from a garnet- and biotite-bearing granitic gneiss that cropped out at Philpot Bluff. Similar to the gneissic granites from the Ruker terrane, this Lambert terrane granite was well foliated and deformed during all phases of deformation. The isotopic results obtained from 16 analyses of nine zircon grains indicate the existence of four distinct zircon populations. Core analyses were obtained from eight of the nine zircon grains. These analyses yielded an age of ca. 2120 Ma. The seven rim analyses yielded ages suggestive of three subsequent periods of zircon growth at ca. 1800 Ma, 1600 Ma, and ca. 550 Ma (Fig. 2). We interpret the zircon cores to be of detrital origin. We also consider the oldest two rim populations to be of inherited origin, reflecting periods of Proterozoic zircon growth undergone by the source rocks. The youngest rims (ca. 550 Ma) we consider likely to date the emplacement of the granite, or as

[1]GSA Data Repository item 2001049, Full tabulation of U-Th-Pb isotopic data from zircons from the southern Prince Charles Mountains, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/ft2001.htm.

a minimum, to date the most recent metamorphic event in the Lambert terrane.

Sample 9828-298 was collected from a syntectonic garnet-leucogneiss sampled from a steeply dipping high-strain zone located in the Turk Glacier valley. The leucogneiss is interpreted to be the product of partial melting associated with deformation. Isotopic data obtained from the 10 zircon grains show that all form a single population that yielded an age of ca. 510 Ma (Fig. 2). This age is inferred to date both leucogneiss formation and deformation in the Lambert terrane.

Sample 9828-273 was collected from a fine-grained biotite-bearing granitic dike located near the southern end of Philpot Bluff (Fig. 2). Equivalent dikes are observed from Philpot Bluff through to the Manning Glacier and continuing to the north. They crosscut all structural features and intrusive features observed in the Lambert terrane and are interpreted to set the minimum age of deformation. We obtained 19 analyses of 15 zircons. Of those analyzed, five age groupings were apparent. Analyses from zircon cores yielded an age of 2790 Ma (Fig. 2). Of the 15 analyses of zircon rims, populations at ca. 2350, 2150, 1850, 1600, and 490 Ma were obtained (Fig. 2). The ca. 2350 Ma grouping may be an artifact of lead loss, as these analyses are quite discordant. However, the remaining groupings are all defined by near-concordant analyses and define ages roughly equivalent to the older zircon populations obtained from sample 9828-275. Similar to sample 9828-275, these results are interpreted to show a protracted history of zircon growth in the Late Archean and Proterozoic. The youngest period of zircon growth (ca. 490 Ma) is interpreted to date the emplacement of the granitic dike and is inferred to place a minimum age on deformation in the Lambert terrane.

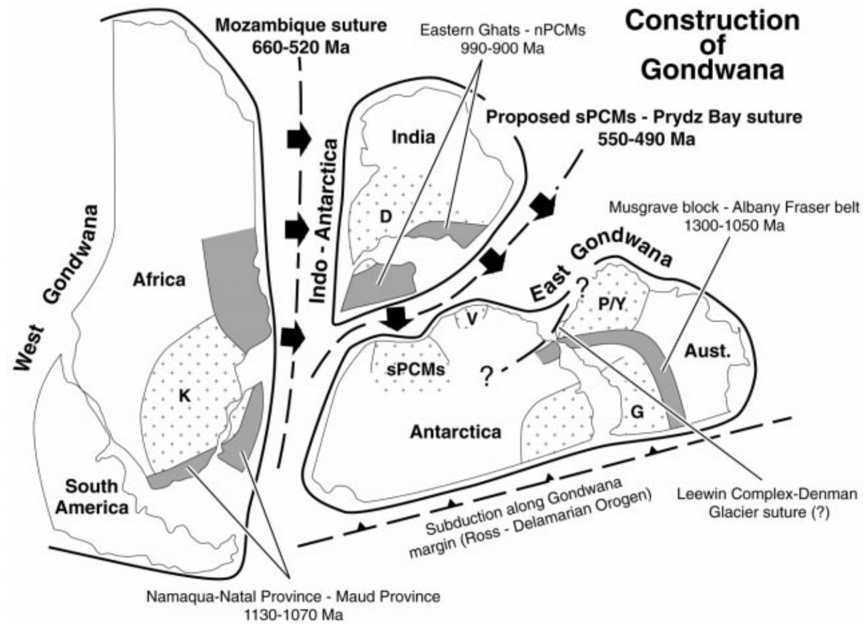

Figure 3. Schematic illustration of proposed construction of Gondwana, showing the three proposed cratonic blocks: west Gondwana (South America-Africa), Indo-Antarctica (India–nPCMs–Lambert terrane of southern Prince Charles Mountains) and east Gondwana (east Antarctica–Australia). Accretion of the component blocks youngs to the east. Abbreviations as in Figure 1.

DISCUSSION

The isotopic results obtained demonstrate that the southern Prince Charles Mountains consist of two distinct terranes of different age. The southernmost (Ruker) preserves a Middle Archean tectonic history between ca. 3160 and 2650 Ma. In contrast, the northern (Lambert) terrane was deformed during the Cambrian (~550–490 Ma) and contains detrital zircons of Late Archean to Mesoproterozoic age.

Our age data from the Lambert terrane suggest that deformation in this terrane occurred in the Cambrian and is the same age as that recognized in Prydz Bay (ca. 550–500 Ma). Given the overlap of age data from these two localities, it is inferred that the Lambert terrane provides an inland continuation of the tectonism recognized in Prydz Bay, consistent with the inference of Fitzsimons (2000a), who argued that orogenesis in Prydz Bay trended inland rather than around the coast. If this correlation is correct, then it implies that a <700-km-long Cambrian-age orogenic belt crosses the east Antarctic craton (Fig. 3).

Identifying the continuation of this belt beyond the southern Prince Charles Mountains and Prydz Bay is problematical. In the mountains, the belt trends east-west, parallel to the dominant structural trend in the adjacent basement. On the basis of the distribution of Archean granitoids and metamorphic isogrades (Tingey, 1991; Kamenev et al., 1993), the belt can be traced across the outcropping regions of the mountains. If this trend is maintained, the belt will link with the continuation of the Mozambique suture identified in central Dronning Maud Land (Jacobs et al., 1998). Whether this belt continues in the opposite direction beyond Prydz Bay is unknown. Both the northern Prince Charles Mountains (Antarctica) and the Eastern Ghats (India) record minor intrusive activity and some evidence of isotopic disturbance during the Cambrian (Mezger and Cosca, 1999; Carson et al., 2000). These events suggest that both were largely unaffected by deformation in the Cambrian, but that they may well have lain in a position marginal to this belt. Thus, orogenesis in Prydz Bay may have continued into India, and the evidence may lie somewhere to the north of the Eastern Ghats. Although no such evidence has been reported, signs of Cambrian orogenesis could be obscured by the deposits of the Ganges and Brahmaputra Rivers. Other studies have linked deformation in Prydz Bay with that of similar age recognized in the Denman Glacier–Leewin Complex (Carson et al., 1996; Hensen and Zhou, 1997; Fitzsimons, 1997, 2000a). However, this terrane could equally represent a Cambrian belt separate from that described here.

Having defined the probable extension of the Prydz Bay orogenic belt in the southern Prince Charles Mountains, the question still remains as to whether this belt defines a suture (Fitzsimons, 2000b) or an intraplate orogen (Wilson et al., 1997). If the southern Prince Charles Mountains–Prydz Bay belt does indeed define a ''Pan-African'' suture, then it implies that this belt would define the eastern margin of a distinct Indo-Antarctic craton (Fig. 3). This lithospheric block would have consisted of part of East Antarctica, including the northern Prince Charles Mountains, the Rayner and Napier Complexes, as well as potentially most of cratonic India (Fig. 3). Cambrian suturing along the eastern margin of this Indo-Antarctic block implies that it did not form part of Gondwana until the Cambrian. Such an interpretation contradicts most current reconstructions of Rodinia and Gondwana.

The data obtained from this study strongly support this inference. Both Cambrian belts in the southern Prince Charles Mountains and Prydz Bay separate cratonized Archean rocks from the Neoproterozoic metamorphic rocks of the northern Prince Charles Mountains (Fig. 3). Orogenesis in Prydz Bay defines the western boundary of the Archean rocks of the Rauer Group (2800–2550 Ma) (Harley et al., 1998) and the Vestfold Hills (2480 Ma)

(Snape et al., 1997), whereas Cambrian orogenesis in the southern Prince Charles Mountains defines the northern boundary of the Archean Ruker terrane (3160–2650 Ma) (Fig. 3). Although these Archean terranes are not of the same age, they potentially belong to the same stable proto-Antarctic margin of Archean or Paleoproterozoic age (Fig. 3). Furthermore, Neoproterozoic orogenesis (ca. 990–900 Ma) recognized in the northern Prince Charles Mountains, Rayner Complex, and Eastern Ghats (Mezger and Cosca, 1999; Boger et al., 2000; Carson et al., 2000) is distinctly different in age from the Maud-Natal provinces to the west and the Windmill Islands and Bunger Hills to the east (Boger et al., 2000; Fitzsimons, 2000b) (Fig. 3). These belts represent three separate fragments of isotopically distinct Mesoproterozoic to Neoproterozoic orogenic belts that in each instance are separated by Pan-African orogenic belts (Fitzsimons, 2000b). This is consistent with these Mesoproterozoic to Neoproterozoic belts lying on separate and unrelated lithospheric blocks prior to the Cambrian (Fig. 3).

The existence of a separate Indo-Antarctic block is further supported by the distinct detrital ages obtained from the two terranes identified in the southern Prince Charles Mountains. Inherited zircons from the Lambert terrane yielded ages of ca. 2800, 2200, 2120, 1800, and 1600 Ma. These ages are generally younger and do not overlap with the zircon ages obtained from the Ruker terrane (ca. 3160 to ca. 2650 Ma). These data suggest that the Lambert terrane did not derive its sediments from the Ruker terrane, nor did those terranes produce sedimentary material from the other proto-Antarctic Archean blocks exposed in the Vestfold Hills or Rauer Islands. Instead, the detrital zircons appear to have originated from rocks that record a protracted history of Late Archean to Mesoproterozoic zircon growth that is not found in the cratonic interior of Antarctica, again consistent with these rocks not having formed part of Antarctica until the Cambrian.

Finally, continental collision along the Mozambique suture is inferred to have occurred between ca. 570 and 520 Ma (Grunow et al., 1996), although ages greater than ca. 600 Ma are obtained from many localities (Shiraishi et al., 1994; Jacobs et al., 1998). In contrast, most of the syntectonic ages from Prydz Bay and the southern Prince Charles Mountains fall between ca. 550 and 490 Ma. Thus, deformation along the Mozambique suture was partly coeval with, but also predated suturing along the southern Prince Charles Mountains–Prydz Bay belt. This difference in age is consistent with the eastward younging of Pan-African orogenesis recognized within west Gondwana (Grunow et al., 1996) and further supports the inference that orogenesis in the southern Prince Charles Mountains and Prydz Bay is related to progressive ocean closure and the eastward amalgamation of Gondwana.

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