

The Tectonic Architecture of Central and Northern Madagascar and their Role in the Final Assembly of Gondwana

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Despite forming a large collisional zone fundamental to the amalgamation of Gondwana, the timing and tectonic evolution of the East African Orogen (EAO) is, in the main, still poorly known. One region that is becoming better understood is central and northern Madagascar where recent work has identified five tectonic units: the Antongil block; the Antananarivo block; the Tsaratanana sheet; the Itremo sheet; and the Bemarivo belt. By using the geochronological, lithological, metamorphic and geochemical characteristics of these units and their relationships to each other, central and northern Madagascar is used as a type area for comparison to, and contrast with, the surrounding regions of Gondwana (Collins and Windley, 2002).

The Antananarivo block of central Madagascar forms part of a broad band of pre-1500 Ma crust that is traceable from Yemen through Somalia and eastern Ethiopia into Madagascar and beyond. This band of ancient continental crust is sandwiched between two suture zones that we interpret as marking strands of the Neoproterozoic Mozambique Ocean. The eastern suture connects the Al-Mukalla terrane (Yemen), the Maydh greenstone belt (northern Somalia), the Betsimisaraka suture (east Madagascar) and the Palghat-Cauvery shear zone system (south India). The western suture projects the Al-Bayda terrane (Yemen) through a change in crustal age in Ethiopia to the region west of Madagascar. Our new framework for the central EAO neatly links the Mozambique belt with the Arabian/Nubian Shield and highlights the power of tectonic analysis in unravelling the complex tectonic collage of the EAO.

The Tectonic Units of Central and Northern Madagascar

Collins and co-workers (Collins et al., 2000; Kröner et al., 2000; Collins and Windley, 2002) divided central and north Madagascar into five tectonic units (Fig. 1). All rocks in a unit share a similar tectonic history and each unit is separated from the other units either by a

regionally significant unconformity or by a shear zone. Here we present a slightly modified version of these tectonic units:

1. the Antongil block, consisting of gneiss with ~3200 Ma protoliths intruded by 2600-2500 Ma granite (Tucker et al., 1999b; Collins et al., 2001; Paquette et al., 2003), unmetamorphosed since ~2500 Ma (Collins and Razakamanana, submitted);
2. the Antananarivo block, which consists of gneiss with 2500-2600 Ma protoliths interlayered with 820-740 Ma granitoids and gabbros, pervasively deformed and metamorphosed to amphibolite and granulite-facies conditions between 700 and 550 Ma (Tucker et al., 1999b; Kröner et al., 2000; Collins et al., 2003a);
3. the Tsaratanana sheet, which is formed of 2700-2500 Ma mafic gneiss with Mid-Late Archaean Sm/Nd ages and zircon xenocrysts (Tucker et al., 1999b; Collins et al., 2001). This tectonic unit was deformed and metamorphosed at ~2500 Ma (Goncalves et al., 2000) and cut by 800-760 Ma gabbro intrusions. Later contractional deformation continued until after 630 Ma (Collins et al., 2003a); and
4. the Bemarivo belt, consisting of SE-NW striking metasedimentary rocks, granites and gneisses, overlain by contractionally deformed metavolcanics. Young granulite-facies metamorphism in the Bemarivo belt is dated as 510-520 Ma (Tucker et al., 1999a). North-east Madagascar has been linked with the Seychelles and north-west India because of the presence in each of these areas of ~750 Ma volcanic and/or magmatic rocks (Tucker et al., 1999a; Torsvik et al., 2001; Ashwal et al., 2002).

In the centre of the island, a series of Proterozoic metasedimentary and metabasic rocks and gneisses were combined as the Itremo Sheet by Collins et al. (2000). The metasedimentary rocks of this unit consist of quartzites, dolomites and pelites of the ~1700 Ma - 800 Ma Itremo Group (Cox et al., 1998, 2000; Huber, 2000) interleaved with Neoproterozoic quartzites of the Molo Series (Cox et al., 2001). These metasedimentary rocks have also been called the "Séries Schisto-Quartzo-Calcaire" (Besairie, 1968-1971) and the "Série Schisto-Quartzo-Dolomitique" (Moine, 1968a). Metasedimentary rocks of the western Amborompotsy-Ikalamavony Group were interpreted by Moine (1968b) as high-grade equivalents of the Itremo Group and were also included by Collins et al (2000) in their Itremo Sheet (Fig. 1). Rocks within this Itremo Sheet experienced considerably Neoproterozoic E-W shortening (Collins et al., 2003b) and lie in a similar structural position to the Tsaratanana Sheet — that is, directly above the Antananarivo Block. The boundary between the Itremo Sheet and the Antananarivo Block was split into two domains based on kinematic and structural style by Collins et al. (2000). West of Antsirabe (Fig. 1), the boundary is imbricated and preserves evidence of contractional deformation (top-to-the-east — up-foliation — shear sense). South of Antsirabe, the boundary forms an extensional shear zone (the Betsileo shear zone) of >200km strike length (Collins et al., 2000). However, metasedimentary rocks of the Itremo Group unconformably overlie gneisses (Cox et al., 1998) that have elsewhere been dated as of equivalent age (Tucker et al., 1999b) as those in the Antananarivo Block. In addition, quartzites and pelites occur beneath the Betsileo shear zone, interlayered with granitic gneisses of Antananarivo Block (Collins et al., 2003b) These

observations suggest that the Itremo Group may have originally been deposited on the Antananarivo Block and that, therefore, it may not be appropriate to consider rocks of the Itremo Sheet as a separate tectonic unit, distinct from the Antananarivo Block (c.f. Collins et al., 2000). Central and northern Madagascar are separated from southern Madagascar by the sinistral Ranotsara shear zone (Fig. 1; Windley et al., 1994). This natural boundary forms the southern limit of our study area.

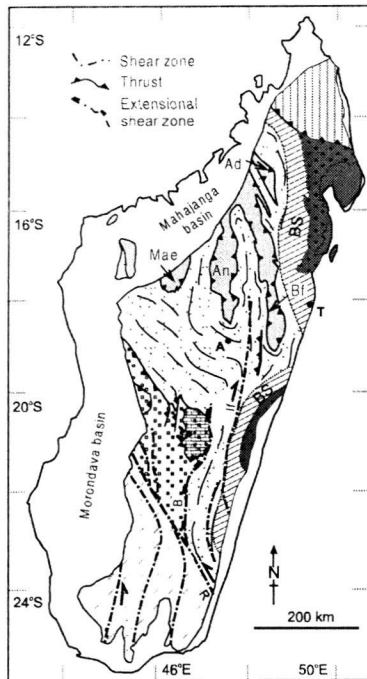


Figure 1. Map of Madagascar with major tectonic units (after Moine, 1968a; Hottin, 1976; Collins et al., 2000; Kröner et al., 2000; Martelat et al., 2000; Nédélec et al., 2000). A = Antananarivo; T = Toamasina; Antongil = Bay of Antongil; B = Betsileo shear zone; R = Ranotsara shear zone; Ad = Androna belt; Bf = Beforona belt; An = Andriamena belt; Mae = Maevatanana belt; If = Ifanadiana/Angavo shear zone

Madagascar and its Relationship to Southern India

Many similarities exist between the geology of the Antongil block and the western Dharwar craton in India (Fig. 2). These include: (1) ortho- and para-gneisses with protoliths that date back to over 3000 Ma (Nutman et al., 1992; Peucat et al., 1993; Nutman et al.,

1996; Tucker et al., 1999b; Chadwick et al., 2000; Collins et al., 2001); (2) granitoid intrusion between 2510-2550 Ma (Tucker et al., 1999b; Chadwick et al., 2000; Jayananda et al., 2000); (3) preservation of Archaean Rb/Sr whole-rock and Nd model ages (Vachette and Hottin, 1971; Harris et al., 1994; Bartlett et al., 1998; Tucker et al., 1999b). In contrast, the Antananarivo Block and Itremo Sheet preserve no known rocks older than 2600 Ma (Tucker et al., 1999b; Kröner et al., 2000). Detrital zircons in the metasedimentary rocks of the Itremo sheet have age populations that differ markedly from the known geology of the Dharwar Craton, which led Cox et al. (1998) to suggest an East African source for these rocks.

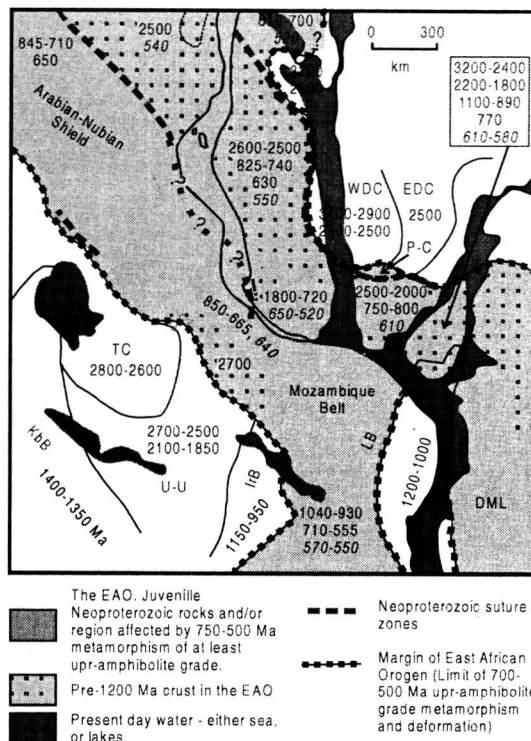


Figure 2. Reconstruction of a part of Gondwana (Lawver et al., 1998) showing the interpreted extent of the East African Orogen (after Collins and Windley, 2002) and the range of published U-Pb zircon ages from the regions surrounding Gondwanan Madagascar (Paquette et al., 1993; Hölzl et al., 1994; Lenoir et al., 1994b; Lenoir et al., 1994a; Kröner et al., 1996; Kröner et al., 1997a; Kröner et al., 1997b; Ring et al., 1997; Teklay et al., 1998; Borg and Krogh, 1999; Tucker et al., 1999a; Tucker et al., 1999b; Chadwick et al., 2000; Kröner et al., 2000; Möller et al., 2000; Sacchi et al., 2000; Collins et al., 2001; de Wit et al., 2001; Kröner et al., 2001; Muhongo et al., 2001; Tucker et al., 2001; Braun and Kriegsman, 2003; Reddy et al., in press; Rivers and Johnson, in press). All numbers refer to ages in Ma, italics refer to the timing of high-grade metamorphism. DML = Dronning-Maud Land, LB = Lurio Belt, IrB = Irumide Belt, U-U = Usagaran-Ubende Belt, TC = Tanzanian Craton, KdB = Kibaran Belt, WDC = Western Domain of the Dharwar Craton, EDC = Eastern Domain of the Dharwar Craton, P-C = Palghat-Cauvery shear zone system, EAO = East African Orogen.

These correlations imply a boundary zone between the Antananarivo block and the Antongil block separating Archaean crustal blocks of different origins. This boundary zone is today a highly strained paragneiss belt with emerald mineralisation and entrained podiform ultramafic-mafic bodies (Besairie, 1970; Hottin, 1976). Contractional deformation along this zone is interpreted to have occurred between 630 and 527 Ma (Collins et al., 2003a).

U-Pb Sensitive High-mass Resolution Microprobe (SHRIMP) and Pb evaporation analyses of detrital zircons from metasedimentary rocks in eastern Madagascar (Collins et al., in press-c) reveal that: (1) The protoliths of many of these rocks were deposited between ~800 and 550 Ma; (2) these rocks are sourced from regions with rocks that date back to over 3400 Ma, with dominant age populations of 3200-3000 Ma, ~2650 Ma, ~2500 Ma, and 800-700 Ma.

The Dharwar Craton of southern India is a potential source region for these sediments, as here rocks date back to over 3400 Ma and include abundant gneissic rocks with protoliths older than 3000 Ma, sedimentary rocks deposited at 3000-2600 Ma and granitoids that crystallised at 2513-2552 Ma. The 800-700 Ma zircons could potentially be sourced from elsewhere in India or from the Antananarivo Block of central Madagascar in the latter stages of closure of the Mozambique Ocean. The region of East Africa adjacent to Madagascar in Gondwana reconstructions (the Tanzania craton) is rejected as a potential source as there are no known rocks here older than 3000 Ma, and no detrital grains in our samples sourced from Mesoproterozoic and early Neoproterozoic rocks that are common throughout central east Africa. In contrast, coeval sediments 200 km west, in the Itremo sheet of central Madagascar, have detrital zircon age profiles consistent with a central East African source, suggesting that two late Neoproterozoic provenance fronts pass through east Madagascar at approximately the position of the Betsimisaraka suture. These observations support an interpretation that the Betsimisaraka suture separates rocks that were derived from different locations within, or at the margins of, the Mozambique Ocean basin and therefore, that the suture is the site of subduction of a strand of Mozambique Ocean crust.

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