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# A geological synthesis of the Precambrian shield in Madagascar

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ABSTRACT

Available U–Pb geochronology of the Precambrian shield of Madagascar is summarized and integrated into a synthesis of the region's geological history. The shield is described in terms of six geodynamic domains, from northeast to southwest, the Bemarivo, Antongil–Masora, Antananarivo, Ikalamavony, Androyan–Anosyan, and Vohibory domains. Each domain is defined by distinctive suites of metaigneous rocks and metasedimentary groups, and a unique history of Archean (∼2.5 Ga) and Proterozoic (∼1.0 Ga, ∼0.80 Ga, and ∼0.55 Ga) reworking. Superimposed within and across these domains are scores of Neoproterozoic granitic stocks and batholiths as well as kilometer long zones of steeply dipping, highly strained rocks that record the effects of Gondwana's amalgamation and shortening in latest Neoproterozoic time (0.560–0.520 Ga).

The present-day shield of Madagascar is best viewed as part of the Greater Dharwar Craton, of Archean age, to which three exotic terranes were added in Proterozoic time. The domains in Madagascar representing the Greater Dharwar Craton include the Antongil–Masora domain, a fragment of the Western Dharwar of India, and the Neoarchean Antananarivo domain (with its Tsaratanana Complex) which is broadly analogous to the Eastern Dharwar of India. In its reconstructed position, the Greater Dharwar Craton consists of a central nucleus of Paleo-Mesoarchean age (>3.1 Ga), the combined Western Dharwar and Antongil–Masora domain, flanked by mostly juvenile "granite–greenstone belts" of Neoarchean age (2.70–2.56 Ga). The age of the accretionary event that formed this craton is approximately 2.5–2.45 Ga. The three domains in Madagascar exotic to the Greater Dharwar Craton are the Androyan–Anosyan, Vohibory, and Bemarivo. The basement to the Androyan–Anosyan domain is a continental terrane of Paleoproterozoic age (2.0–1.78 Ga) that was accreted to the southern margin (present-day direction) of the Greater Dharwar Craton in pre-Stratherian time (>1.6 Ga), and rejuvenated at 1.03–0.93 Ga with the creation of the Ikalamavony domain. The Vohibory domain, an oceanic terrane of Neoproterozoic age was accreted to the Androyan–Anosyan domain in Cryogenian time (∼0.63–0.60 Ga). The Bemarivo domain of north Madagascar is a terrane of Cryogenian igneous rocks, with a cryptic Paleoproterozoic basement, that was accreted to the Greater Dharwar Craton in latest Ediacaran to earliest Cambrian time (0.53–0.51 Ga).

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## 1. Introduction

In late Precambrian time, the tectonic building-blocks of Madagascar, as well as fragments of oceanic terranes within the paleo-Mozambique Ocean, became trapped by orogenic convergence between two great continental masses, East Gondwana (now India–Antarctica–Australia) and West Gondwana (now South America and Africa). Although the broad outline of this history has been known for many years, new concepts have come to light as a result of two recent projects both completed under the auspices of the *Projet de Gouvernance des Ressources Minerales, Madagascar* (PGRM) and funded by the World Bank. The first of these projects (PRSM-2), was a 4-year survey, initiated in 2004 and completed in 2008, by a consortium of scientists from France (BRGM), Germany (GAF-BGR), Great Britain (BGS), Madagascar (PGM), South Africa (CGS) and the United States (USGS). The second was a 2-year synthesis (2008–2009) of the previous work – also known as the *Madagascar Synthesis Project* – which is the source of ideas for this contribution.

Interested readers will find our new geological map of Madagascar (1:1,000,000 scale) in Roig et al. (2012), and a full description of the lithostratigraphic units and economic mineral

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resources in Tucker et al. (2012) and Peters et al. (2012a, 2012b). We define the basic building blocks – or geologic domains – of the Precambrian shield as the Bemarivo, Antongil–Masora, Antananarivo, Ikalamavony, Androyan–Anosyan, and Vohibory domains (Fig. 1). Each domain is defined by distinctive suites of metaigneous rocks and metasedimentary groups, and a unique history of Archean (~2.5 Ga) and Proterozoic (~1.0 Ga, ~0.80 Ga, and ~0.55 Ga) reworking (Fig. 2). Superimposed within and across these domains are scores of Neoproterozoic granitic stocks and batholiths as well as kilometer-long zones of steeply-dipping, highly-strained rocks that record the effects of Gondwana's amalgamation and shortening in latest Neoproterozoic and earliest Cambrian time (0.560–0.520 Ga).

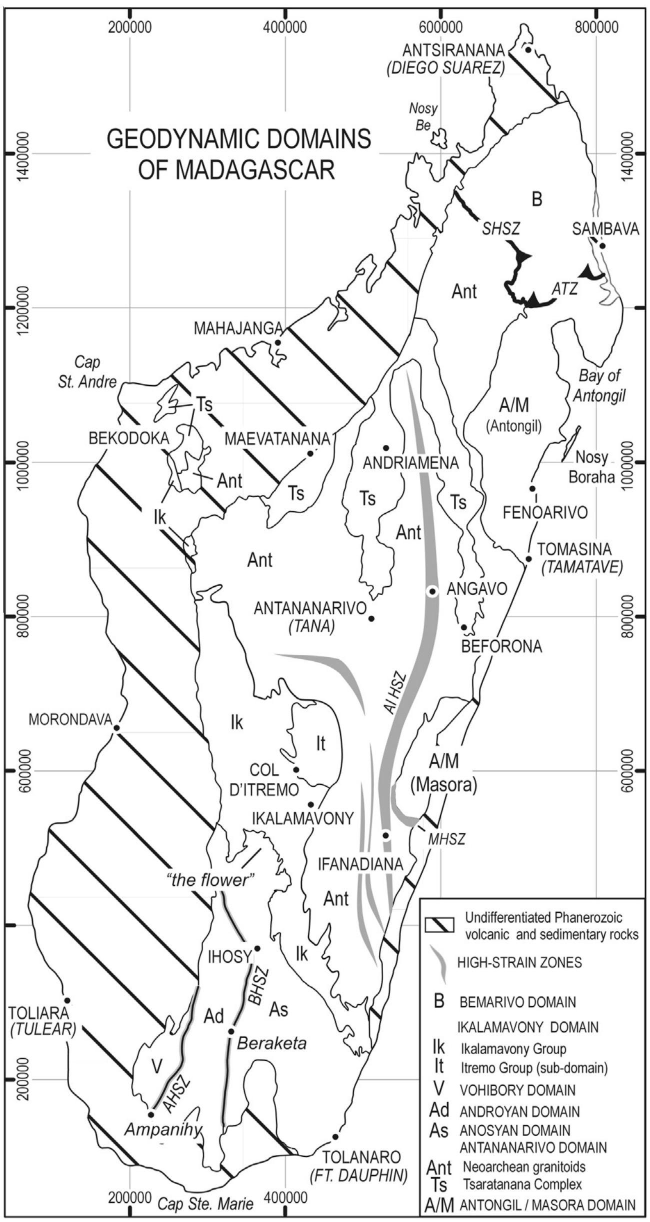


**Fig. 1.** The geodynamic domains of the Precambrian shield of Madagascar after Roig et al. (2012). A/M = Antongil–Masora domain; Ant = Antananarivo domain (includes the Neoarchean "greenstone" belts of the Tsaratanana Complex); Ad = Androyan domain; As = Anosyan domain; B = Bemarivo domain. Ik = Ikalamavony domain; It = Itremo sub-domain; V = Vohibory domain. Idealized structural features described in the text and in Fig. 2 include: AHSZ = Ampanihy high strain zone; AIHSZ = Angavo–Ifanadiana high strain zone; ATZ = Andaparaty thrust zone; BHSZ = Beraketa high strain zone; MHSZ = Maroala high strain zone; SHSZ = Sandrakota–Antsaba high strain zone. See Roig et al. (2012) and Tucker et al. (2012) for a full description of the lithostratigraphic units.

At the start of this synthesis, convention held that the Precambrian shield of Madagascar hosted a major boundary – the Betsimisaraka Suture, reportedly a convergent continental margin – where vast sections of oceanic crust were consumed in latest Neoproterozoic time (e.g., Collins et al., 2000; Kröner et al., 2000; Rambeloson et al., 2003). This boundary is reported to delineate terranes derived from East Africa and India (Collins, 2000, 2006; Collins and Pisarevsky, 2005; Collins and Windley, 2002; Cox et al., 2004; Fitzsimons and Hulscher, 2005; Fritz et al., 2013; Key et al., 2011; Raharimahefa and Kusky, 2006) and is the suture between the Dharwar Craton (India) and the postulated microcontinent of Azania. According to some, an allochthonous sheet of Archean mafic gneiss and schist (Tsaratanana Complex) was emplaced onto Azania during this period of Neoproterozoic convergence (Collins et al., 2003a; Goncalves et al., 2003). Other authors, still adhering to the concept of a paleo-suture in east Madagascar, have proposed that the Betsimisaraka Suture is part of an accretionary zone of Rodinian age (1.38–0.75 Ga) that extends into western India (Ishwar-Kumar et al., 2013).

Our geological synthesis and maps of the economic mineral resources (Roig et al., 2012; Tucker et al., 2011a, 2011b, 2012; Peters et al., 2012a, 2012b) represent a marked departure from these perspectives. In their place we propose that the Archean rocks of Madagascar, which consist of the Antongil–Masora and Antananarivo domains, were part of the Greater Dharwar Craton (Fig. 3) from its birth nearly 3 billion years ago until its fragmentation about 100 million years ago. Unlike the Dharwar Craton of India, however, the Archean rocks of Madagascar have been extensively reworked by multiple orogenic events throughout the Proterozoic. In the Paleoproterozoic, the reworking involved failed fragmentation of its northern part, and accretion and subsequent exhumation of a southern continental terrane with widespread deposition of sedimentary rocks across the stable craton. The Mesoproterozoic witnessed the initiation of calc-alkaline magmatism along the southern edge of the Archean shield, and in the early Neoproterozoic, the reworking involved coeval deposition of continental sediments and intrusion of syenogranite and LILE-enriched gabbro (large-ion lithophile elements, e.g. K, Ba, Sr). At the close of the Proterozoic, the reworking was most intense and involved the accretion of an oceanic terrane, and oblique continental convergence between East and West Gondwana. This oblique convergence was most intense in south and west Madagascar, but its effects can been seen throughout the Malagasy shield, particularly in the zones of very high strain that traverse the island, and in the many spectacular granite massifs that punctuate the landscape.

Our synthesis draws extensively from the data base of published U–Pb ages (zircon, monazite, sphene, and baddeleyite) determined by ID-TIMS and SHRIMP methods, but it also includes ages determined by other methods (e.g. CHIME, Pb evaporation, and LA-ICPMS techniques) as well as geochronological data within contract reports to the PGRM which are not widely distributed to the public. The most important of the last are those of BGS et al. (2008), CGS (2009a, 2009b), GAF-BGR (2008a, 2008b, 2008c, 2008d, 2008e), and JICA (2012). To help the reader understand our synthesis, all of the U–Pb data – the sample locations and the various ages reported (e.g. crystallization, metamorphic, detrital, inheritance, etc) – are illustrated in our figures and tabulated in Appendix A. Our synthesis, which is influenced by our interpretation of these data, begins first with a discussion of Archean developments and ends with the close of Neoproterozoic developments and the amalgamation of Gondwanaland.