THE METALLOGENY AND MINERAL DEPOSITS OF MADAGASCAR

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Since 2003, Madagascar has been the site of three major projects by an international consortium of geoscience agencies that have provided a wealth of new information on the geology and mineral resource potential of the island. In this talk we review the major tectonic domains of Madagascar, describe the known mineral deposits, and outline potential regions of interest for future exploration. We also apply modern metallogenic concepts to evaluate competing hypotheses for the tectonic assembly of Madagascar.

With a landmass of ~587,000 square kilometers, Madagascar is the world's fourth largest island. The interior two-thirds consists of crystalline rocks of the Precambrian shield, whereas the perimeter of the island, particularly its western third, consists of Permian and younger strata deposited during the island's isolation from Africa and Greater India. The Precambrian shield is divided into eight tectonic domains. They are, from northeast to southwest, the Bemarivo, Antongil/Masora, Anaboriana-Manampotsy, Antananarivo, Itremo-Ikalamavony, Anosyen, Androyen, and Vohibory domains. Each domain is defined by distinctive meta-igneous or metasedimentary rocks, or a unique history of Neoproterozoic reworking.

The exotic Bemarivo domain consists of Neoproterozoic intrusive granitic and volcanosedimentary rocks, interpreted as a juvenile magmatic arc thrust southward over central Madagascar in latest Neoproterozoic-Cambrian time. The domain is divided into a northern and southern sub-domain, each consisting of distinctive volcanosedimentary rocks (Archean? and Proterozoic) and contrasting suites of early Neoproterozoic calc-alkaline granitoids (750-720 Ma, and 718-705 Ma).

The Antongil/Masora domain includes the sub-domain of Antongil (north of Tamatave to the Bay of Antongil), as well as the smaller southern sub-domain of Masora (east of Mananjary). The Antongil/Masora domain contains the oldest rocks in Madagascar which are Paleo-Mesoarchean migmatitic gneisses of trondhjemite-tonalite-granodiorite composition (TTG), and in the Antongil, a package of migmatitic stratified rocks including psammitic gneiss, garnet-magnetite quartzite (BIF), and felsic and mafic metavolcanic gneiss. In the Antongil, these are overlain by a younger of package of stratified rocks (greenschist, semipelitic schist and quartzite, and interleaved amphibolite and meta-ultramafites) intruded by abundant stocks and sheets of weakly-deformed Neoarchean granite (2.56-2.50 Ga). Paleoproterozoic mafic dikes (2.45 Ga) intrude the entire sequence. In the Masora sub-domain, the Mesoarchean migmatites are overlain by stratified gneisses of presumed Archean age and a sequence of medial Proterozoic supracrustal rocks, all of which are intruded by voluminous early Neoproterozoic meta-igneous rocks. In contrast to the Antongil, the Masora sub-domain has been penetratively deformed and strongly metamorphosed in latest Neoproterozoic time.

The Anaboriana-Manampotsy domain resides between the ancient rocks of Antongil/Masora and the largely Neoarchean juvenile gneisses of the Antananarivo domain. Also known as the Betsimisaraka suture zone, the Anaboriana-Manampotsy domain is a belt of highly-deformed, amphibolite grade, Neoproterozoic sediments (830-740 Ma), intruded by Neoproterozoic granitoids (830-780 Ma), containing disrupted blocks of mafic and ultramafic gneiss. Stratified rocks of the Anaboriana-Manampotsy domain are alternatively interpreted as a mélange of volcaniclastic-dominated oceanic rocks (representing elements of the former Mozambique ocean), or highly-sheared and inverted rift basins filled with terrigenous detritus from the Greater Dharwar Craton (India).

The Antananarivo domain of central Madagascar consists of extensive tracts of Neoarchean-Paleoproterozoic migmatitic paragneiss and orthogneiss overlain (possibly allochthonously) by four large synformal belts of Neoarchean mafic gneiss and schist (Tsaratanana Complex). Both the Neoarchean felsic and mafic gneisses were partially melted and polydeformed between 2.53 Ga and 2.45 Ga, and both are intruded by Early (840-760) and Late (560-520) Neoproterozoic igneous rocks. In contrast to the Antongil/Masora domain, the Antananarivo domain is devoid of Mesoarchean rocks, although Nd and Sr isotopic data suggest its Neoarchean gneisses were derived from, or mixed with, Mesoarchean material. A package of Neoproterozoic metaclastic rocks, enriched in alluvial gold and deposited between 1.06 and 0.82 Ga, forms a N-striking belt up the central spine of the island.

The Itremo-Ikalamavony domain consists of a fold-and-thrust belt and a stack of allochthonous sheets emplaced eastward over the Antananarivo domain during latest Neoproterozoic convergence. Two sub-domains are present: 1) the eastern Itremo domain, consisting of medial Proterozoic meta-sedimentary rocks, and their Neoarchean basement, all of which have been translated eastward as giant fold-thrust nappes, and 2) the western Ikalamavony sub-domain, consisting of higher-grade Mesoproterozoic and Neoproterozoic metasedimentary rocks, thrust eastward as truly allochthonous sheets. Both the Itremo and Ikalamavony are intruded by batholiths and stocks of Early and Late Neoproterozoic age, but uniquely, the Ikalamavony is also intruded by Neoproterozoic igneous rocks (Dabolava Suite; 1.0 Ga) and hosts mesothermal gold deposits.

The Neoproterozoic Anosyen and Androyen domains of southern Madagascar are a vast area of Proterozoic metasedimentary rocks that lack an Archean basement, were metamorphosed at high temperature (1000°-800° C) and modest pressure (4-7 kbar), and are delineated by ductile shear zones. These domains are traditionally separated from the Itremo-Ikalamavony domain by the Ranotsara shear zone, although recent work suggests that the Ranotsara is not an important domain-forming boundary. The Vohibory domain of southwestern Madagascar consists of early Neoproterozoic pelites, marbles, extensive amphibolites and granites thought to represent an accretionary mélange of oceanic crust and island arcs.

Historic and current mineral production in Madagascar is of small scale and is limited to: (1) chromite from dismembered layered ultramafic complexes, primarily in the Andriamena belt of the Tsaratanana Complex, and in smaller bodies scattered throughout the Antongil and Antananarivo domains, (2) graphite, mainly from the Manampotsy domain, although widespread throughout the amphibolite to granulite facies paragneissic units of Madagascar, (3) titanium from shoreline placer deposits at Tolagnaro and Tulear in the Anosyen domain and Moromandia (Phanerozoic) basin, respectively, (4) nickel in both (ultra)mafic rock and laterite in early Neoproterozoic and mid-Cretaceous intrusions, and (5) mica from high-grade metamorphic rocks, and 6) uranium in sandstone and pegmatite. A widespread artisanal and small-scale mining sector produces gemstones of sapphire, ruby, emerald, and tourmaline (from placer, basalt, pegmatite, and hydrothermal sources) and about 2 tonnes of gold per year, mainly from alluvial placers. Gold from primary mesothermal (orogenic) sources are concentrated in the greenstone belts of the Antananarivo and Antongil domains, and Neoproterozoic schist of the Bemarivo domain. Epithermal gold near the basal Phanerozoic unconformity in north Madagascar (Andavakoera) may be related to either polymetallic vein deposits related to early Jurassic rifting or microsyenite stocks of probable Cenozoic age.

Biography

Cliff Taylor is a Research Geologist with the United States Geological Survey in Denver, Colorado. He received his Ph.D. from the Colorado School of Mines in 1999 where he studied under Richard W. Hutchinson. During his 25 year career he has led mineral deposit research projects in Alaska, the Rocky Mountains, and Mauritania and has extensive experience leading mineral resource assessments in the western U.S., Africa, Australia, and Europe. He is currently the Global Mineral Resources Assessment Project-global sediment-hosted copper assessment team leader, and coordinator for the African continent. He was a principal member of the USGS Madagascar Pre-assessment team of 2003, and the North Zone “gitologist” for the BGS/USGS Madagascar mapping project of 2005-2008.