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Tectonic evolution of forearc nappes of the active Banda arc-continent collision: Origin, age, metamorphic history and structure of the Lolotoi Complex, East Timor

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ABSTRACT

An integrated multidisciplinary investigation of the Lolotoi Complex of East Timor (Timor Leste) indicates that it is part of the Banda forearc that was metamorphosed and rapidly exhumed during the Eocene and accreted to the NW Australian continental margin during Late Miocene to present arc–continent collision. Greenschist, graphitic phyllite, quartz–mica schist, amphibolite and pelitic schist dominate metamorphic rock types. Mineral, whole rock, and trace element geochemical analyses of metabasites indicate protolith compositions consistent with tholeiitic basalt and basaltic andesite with mixed MORB and oceanic arc affinities. Metapelite schist is mostly composed of metasedimentary units derived from mafic to intermediate rocks with oceanic to continental volcanic arc provenance.

Thermobarometric calculations show peak metamorphic conditions of 530 °C to 680 °C for garnet–biotite pairs and amphibole, and peak pressures of 5 to 10 kbar for garnet–aluminosilicate–quartz–plagioclase assemblages. Peak metamorphism occurred at 45.36 ± 0.63 Ma, as indicated by Lu–Hf analyses of garnet. Detrital zircon grains have a U/Pb age distribution with spikes at 663, 120 and 87 Ma, which is typical of detrital zircon ages throughout the Great Indonesian Arc of Asia, but is distinct from Australian affinity units. These data indicate deposition and later metamorphism occurred after 87 Ma.

Structural analyses of the metamorphic rocks and their sedimentary and volcanic cover units reveals 5–6 deformational phases of alternating shortening and extension. There is little to no evidence of strike-slip deformation. Phases 1–4 are inferred as pre-Oligocene from age determinations. Phases 5 and 6 are most likely related to latest Miocene to Pliocene nappe emplacement and Pliocene to present collisional deformation. Kinematic indicators show mostly top to the SE directed shortening and top to the south and SE extension. Structural mapping indicates that the Lolotoi Complex and some of its cover units are in thrust contact with underlying Gondwana Sequence rocks. Asian affinity volcanic and sedimentary cover units are found mostly in normal fault contact with metamorphic rocks.

These data indicate that the Lolotoi Complex of Timor Leste is correlative with the Mutis Complex of West Timor and both form part of the Banda Terrane, which is composed mostly of dispersed fragments of the eastern Great Indonesian Arc. The study demonstrates the complex nature and deformational history of forearc basement.

1. Introduction

The accretion of volcanic arcs to continents is a fundamental process of continental growth (e.g. Bailey, 1940; Taylor and McClennan, 1985; Jahn et al., 1998). Most commonly it involves the partial subduction of a passive continental margin, which results in accretion of large fragments of the upper plate, or even the complete arc–forearc system itself, to the continental margin. These processes can be investigated directly in the active arc–continent collision of the NW Australian continental margin with the Banda Arc of the SE Asian plate (Fig. 1). However, most studies of arc-related units in this region are only reconnaissance in nature due to inaccessibility and political unrest. For example, lack of reliable age constraints on metamorphic rocks in the Timor region have led to speculation that their origin ranges from Pre-Cambrian Australian basement (Grady, 1975; Chamalaun and Grady, 1978; Charlton, 2002) to Miocene collision-related complexes (Hamilton, 1979; Kaneko et al., 2007). Each of these interpretations requires vastly different arc-continent collisional models to explain. To better understand how best to use the Banda arc-continent collision as an analog for the numerous ancient arc-collisions that are responsible for most of Earth's continental crust, we have conducted an integrated multidisciplinary investigation of the Lolotoi Complex in Timor Leste. This unit exposes poly-deformed metamorphic rocks with sedimentary and volcanic cover units (Audley-Charles, 1968). Its origin and tectonic affinity is related to similar units in West Timor that are interpreted as slabs of the Banda forearc, but no data is available to test this correlation.

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This study follows-up on an earlier, more regional investigation of the Banda Terrane published by Harris (2006). This paper provides age constraints ($^{40}Ar/^{39}Ar$, U/Pb and Rb/Sr) for metamorphic rocks at the highest structural levels in mostly West Timor, which indicate Oligocene igneous and metamorphic cooling and exhumation. Harris (2006) relates these events to the collisional demise and extensional collapse of the eastern Great Indonesian Arc, which was the eastern extension of the Sunda Arc. These events pre-date the Late Miocene to present arc-continent collision between the Banda Arc and the NW Australian passive continental margin.

The Banda arc-continent collision is used as a modern analog for many diverse types of collisional settings throughout time, including settings for the origin and emplacement of Oman-type ophiolites (e.g. Searle and Stevens, 1984; Harris, 1992).

However, recent investigations (Harris and Long, 2000), including this paper, reveal that most forearc thrust sheets on Timor are not ophiolites, and require a different model for their origin, although emplacement mechanisms may be similar to those of ophiolites (Harris, 1992). Questions about the origin and tectonic evolution of forearc regions that we address here are relevant not only to understanding the tectonic history of the Banda Orogen, but arc-continent collisional processes in general.

The regional significance of this study is that it tests for similarities and differences between the Lolotoi Complex of Timor Leste and other parts of the Banda Terrane throughout the Timor region. The Banda Terrane consists of fault-bounded rock bodies with compositions and ages that correlate with *in situ* units found in Sumba and the Banda Sea region (Audley-Charles and Harris, 1990). These rocks are currently part of the SE Asian Plate and mostly consist of fragments of the eastern Great Indonesian Arc. However, some parts of the Banda Terrane may have been derived from pieces of Australia and other parts of Gondwana (Milsom et al., 2001) that accreted to the Great Indonesian Arc before its extensional collapse in the Paleogene (Harris, 2006). In this paper we investigate this question by conducting a variety of age determinations, including U/Pb age analysis of detrital zircon grains in order to constrain whether units are derived from Australian or Asia.

2. Previous studies

Early studies of metamorphic rocks of the Banda Terrane in West Timor, which is known as the Mutis Complex, were conducted on a series of high-standing metamorphic and igneous massifs (Fig. 1B and C) that include: Lalan Asu (de Waard, 1954a,b, 1957), Mutis (de Roever, 1940; Sopaheluwaken, 1990; Harris, 1991, 1992; Harris and Long, 2000), Miomoffo (van West, 1941; Sopaheluwaken, 1989), Boi (Earle 1981; Brown and Earle, 1983), Mollo (Tappenbeck, 1939; Earle, 1980), Usu (de Waard, 1959), and Ocussi (Harris, 1992; Harris and Long, 2000). Most of these studies conclude that the metamorphic rocks and their cover successions are of Asian affinity and are thrust onto Australian continental margin units in an 'Alpine-style' of deformation, although emplacement age interpretations vary.

The Lolotoi Complex has received little attention. Although reconnaissance studies demonstrate that it is similar in composition and structural setting to Banda Terrane massifs in West Timor and other places (Audley-Charles, 1968; Harris, 1991, 1992), they are interpreted in widely differing ways (i.e. Charlton, 2002; Kaneko et al., 2007). This paper aims to provide the necessary petrologic, geochemical,

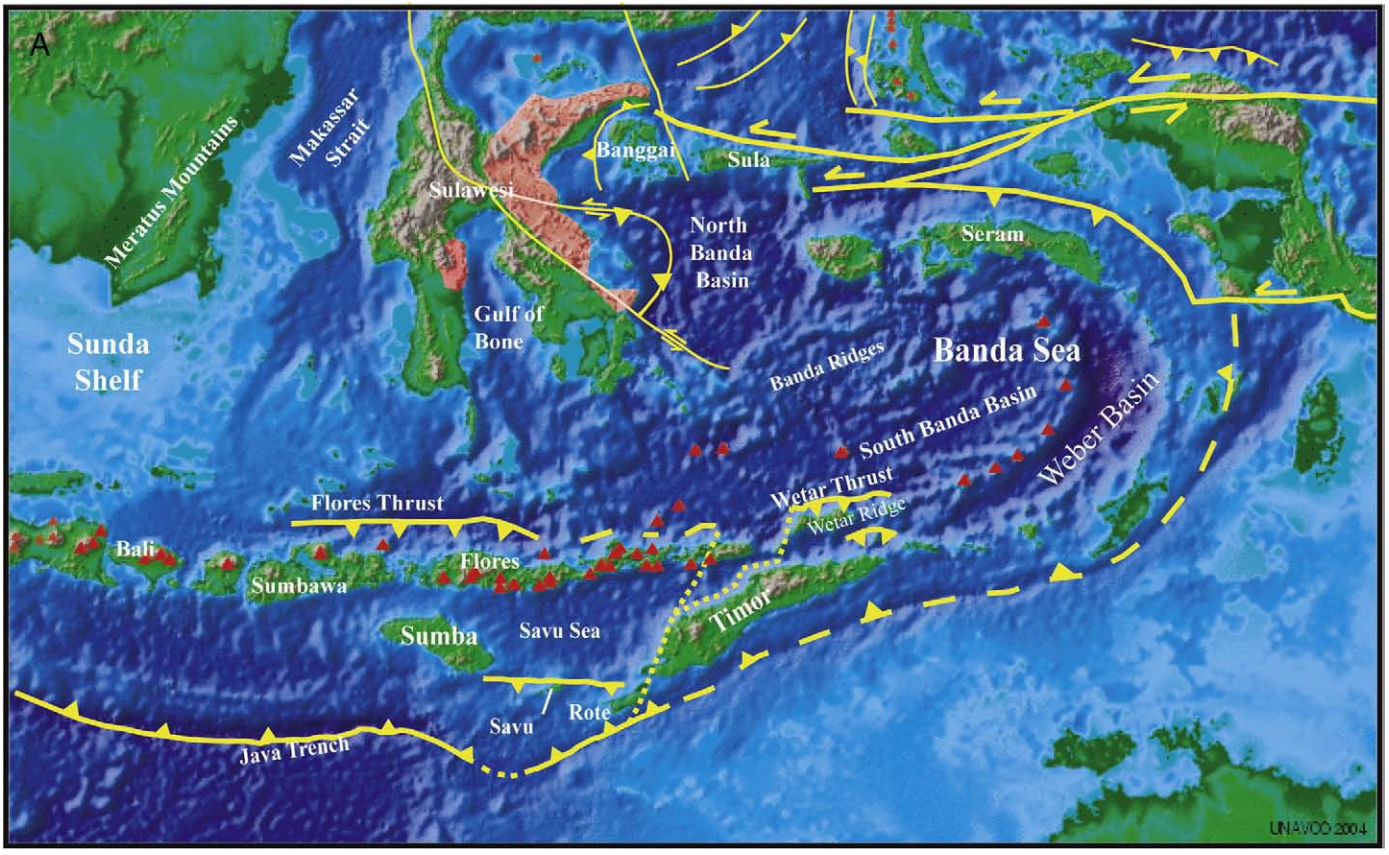

Fig. 1. A) Digital elevation model of the Banda Arc region. Active faults are shown in yellow, red triangles are active volcanoes, pink areas are regions of mafic and ultramafic rocks. The Makassar Strait, Gulf of Bone and Banda Sea occupy a region that was formerly the Cretaceous to Paleogene Great Indonesian Arc. Arc fragments, known as the Banda Terrane (Harris, 2006) are found in Sulawesi, the Banda Ridges, Sumba, Savu, Rote, Timor, and the volcanic islands around Flores and Wetar. B) Generalized geologic map of Timor taken mostly from Audley-Charles (1968) and Harris et al. (2000) showing various Banda Terrane massifs interpreted as structurally overlying Australian affinity Gondwana Sequence units. C) Cross section modified from Harris (1991) showing Timor as a young accretionary fold and thrust belt formed by underthrusting of Australian continental margin units beneath the Banda forearc.