Clarifying collisional contradictions: provenance of the Aileu Complex, Timor-Leste

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ABSTRACT

The Aileu Complex on the north coast of Timor-Leste yields detrital zircon age spectra dominated by Palaeozoic zircons, with lesser Proterozoic input, reflecting a Sundaland, rather than Australian, source. Contrary to most current interpretations, its Asian affinity removes the requirement to account for early–mid Neogene metamorphism as a consequence of collision between the Australian continental margin and the volcanic Banda Arc. Rather, metamorphism can be attributed to a magmatic arc setting prior to mid-Pliocene (3–4 Ma) collision, thereby resolving many seemingly contradictory observations. Specifically, it suggests mid-Pliocene emplacement of the leading edge of the Australian continent into the forearc was accompanied by detachment of the subducting slab, cessation of volcanism and incipient reversal of subduction polarity, all within less than 1 million years. Subsequent dynamic uplift of the region evident in widespread Quaternary coral terraces reflects, at least in part, stress release from the detached slab.

Keywords: zircon geochronology, provenance, Timor, Banda Arc, arc–continent collision

INTRODUCTION

The Banda Arc (Fig. 1) is one of the world's youngest arc–continent collision zones, and presents an exceptional opportunity to investigate the early stages of arc–continental collision, evidence of which is obscured in older orogens (Hall and Wilson, 2000). However, the relationship between the evolution of topography (Chappell and Veeh, 1978), magmatism (Elburg et al., 2005) and processes acting in the subducting slab (Price and Audley-Charles, 1987), including polarity reversal, and collision in the Banda Arc is marred by uncertainties relating to the significance of metamorphic ages of the Aileu Complex on the northern coast of Timor-Leste (Fig. 1). While many observations point to the onset of collision coincident with the Pliocene cessation of volcanism on Wetar and Alor, north of Timor (Elburg et al., 2005; Hall, 1996), the Miocene amphibolite-facies metamorphism of the Aileu Complex (Berry and McDougall, 1986; Charlton, 1991) demands much earlier collision if, as commonly assumed, it derives from Australian margin sediments (Charlton et al., 1991, Harris, 2000). While much of Timor has a well demonstrated Australian continental margin affinity (Harris, 2006), the absence of any diagnostic faunal assemblages has meant that the affinity of the Aileu Complex remains unclear, and earlier studies used stratigraphic considerations to suggest an Asian affinity (Barber et al., 1977; Carter et al., 1976). Importantly, an Asian affinity would allow the setting of Miocene metamorphism within the magmatic arc prior to collision.

Here we present new detrital zircon age data for the Aileu Complex that demonstrate an Asian provenance. In allowing mid-Pliocene (3–4 Ma) collision, this new constraint resolves many existing contradictions and thereby provides for a more robust understanding of the links between slab rupture, polarity reversal, volcanism and topographic evolution in this unique setting.

METHODS AND RESULTS

Samples collected from the low metamorphic grade western and central parts of the Aileu Complex were crushed and zircons separated using standard heavy liquid and magnetic techniques. Zircons were mounted onto glass slides and polished to expose a section though the centre of the crystals. Samples were imaged using cathodoluminscence and transmitted light. U/Pb ages of individual grains were obtained using a laser ablation inductively coupled plasma–mass spectrometer (LA-ICPMS) system at the School of Earth Sciences, University of Melbourne, utilising a 193 nm excimer laser ablation system and following procedures similar to those of Black et al. (2004). Each zircon was analysed with a single spot, targeted at inclusion and crack free regions.

In the sample from the western end of the Aileu Complex, 145 zircons analysed yielded 103 ages > 95% concordant, and, from the central sample, analysis of 121 zircons yielded 62 concordant ages. Age distributions are very similar for both samples, with major age modes occurring at 270–440 Ma, 860–1240 Ma and 1460–1870 Ma (Fig. 2). Grains younger than 270 Ma comprise only 3% of the population, as do grains older than 1900 Ma, and no Archean grains were found. The measured Th/U ratio for most grains is in the range 0.1 – 1.6, typical of normal felsic igneous zircons (Williams and Claesson, 1987). Using the method described by Dodson et al. (1988), where the probability of analysing a sample component of a certain frequency is a function of the number of analyses undertaken, the probability of analysing a component that formed up to 5% of the zircon age population is greater than 95% for each of these samples. When the samples are combined (n=165), this probability increases to 99.9%, therefore we are confident that all significant zircon age populations have been analysed. Analytical results are provided in the GSA Data Repository.

AILEU PROVENANCE

Detrital zircon age spectra are a useful discriminant between potential sediment source areas (Cawood and Nemchin, 2000). Comparison of the Aileu Complex detrital zircon age signature with Australian source areas reveals a poor match. Regions of north western Australia proximal to the North West Shelf (Fig. 1) comprise Proterozoic terranes that yield Proterozoic and Archean zircons (e.g. (Bodorkos et al., 2000). Harris (2006) suggested the Capricorn Orogen as a potential source for Aileu sediment, however while some similar Proterozoic-aged zircons are found in both localities, the Capricorn Orogen cannot account for the Paleozoic zircon population that dominates the Aileu Complex spectrum. Further, detrital zircons of the Capricorn Orogen include Archean (3.4–2.5 Ga) and Paleoproterozoic (2.4–1.8 Ga) populations (Halilovic et al., 2004), respectively absent and poorly represented in the Aileu Complex sediments.

The Perth Basin, representing a broad western Australian continental sediment source, contains abundant earliest Paleozoic detrital zircons. However, Archean zircons are also present throughout these rocks and the mid-Paleozoic population that dominates the Aileu Complex zircons is poorly represented (Sircombe and Freeman, 1999; Fig. 2). Other northern Australian terranes that yield Paleozoic zircons include the Georgetown and Coen regions of the Cape York Peninsula, northern Queensland (Blewett and Black, 1998). Although the Paleozoic intrusions of these regions do yield similar ages to some Aileu Complex zircons, the euhedral younger zircons of the Aileu Complex are unlikely to have undergone extensive transport. Again, these regions also yield Paleoproterozoic and Archean inherited and detrital zircons not present in the Aileu Complex sediments (Blewett et al., 1998).

A Sundaland source is well represented by detrital zircons of the Crocker Fan of northwest Borneo. A provenance study of five stratigraphic levels demonstrated a sediment source yielding Phanerozoic and Proterozoic zircons was an important contributor of sediment to the sequence (van Hattum et al., 2006; Fig. 2). Granites of the Malay Peninsula, which yield Permian–Triassic magmatic zircons and inherited zircons indicating older underlying crust of 1100–1400 Ma and 1500–1700 Ma (Liew and McCulloch, 1985), were identified as the sediment source. The similarity of the Aileu and Borneo spectra suggest that Sundaland is a likely source for Aileu Complex sediments.

DISCUSSION

In the context of our understanding of the evolution of the Banda collision zone, the recognition of a Sundaland provenance for the Aileu Complex sediments is crucial as it removes the requirement to account for Neogene metamorphism of the Aileu Complex as a consequence of collision. As such it helps resolve many contradictions in our understanding of the sequence of collision between the Australian margin and the volcanic Banda Arc, and provides a much simpler framework for collision commencing in the mid-Pliocene, as outlined below.

While 8 Ma is generally cited as the cooling age for the Aileu Complex, available data is limited and poorly constrains the timing of metamorphism. K/Ar and $^{40}Ar/^{39}Ar$ dating of the Aileu Complex yielded ages as old as 70 Ma, with most samples producing argon release spectra indicating early–mid Neogene cooling ages of 10–20 Ma (Berry and Grady, 1981; Berry and McDougall, 1986). From the palaeogeographic perspective, an early Neogene metamorphism has always presented particular problems if the Aileu Complex represented part of the Australian margin, as the ~65 mm/yr relative motion between Australian Plate and Sunda Block would require initial collision with a narrow promontory extending more than 1000 km north of Australia's North West Shelf. Moreover, since the continental crust comprising this putative promontory must now be imbricated in the orogenic complex that comprises Timor, the across strike width of ~100 km implies a shortening in the order of 1000%. The highest point in Timor is only 3 km above sea level and much of the island is less than 1 km ASL, suggesting present crustal thickness is less than ~50 km. The implied crustal thickness of such a promontory must therefore be, on average, less than ~5 km. This contrasts with the 25 km thickness of the present North West Shelf margin (Petkovic et al., 2000), and the absence of any analogue for this type of extraordinarily thin continental crust anywhere else on Earth seemingly rules against its likelihood.

The Asian affinity suggests that metamorphism of the Aileu Complex is better attributed to the volcanic arc setting which has a long history of activity (Elburg et al., 2005), extending back at least until the early Cenozoic. In this context, along with Sumba further west (van der Werff et al., 1994), the Aileu Complex is simply one of a number of fragments of Asian continental crust now trapped in the Banda forearc region. Incorporation of these fragments into the Banda arc can be attributed to the extensive tectonic rearrangement that occurred in the region during the Tertiary (Hall, 2002), and has obvious analogues in Sulawesi, which is comprised in part of rifted slivers of Sundaland continental crust (van Leeuwen et al., 2007). This suggests an association of the Aileu Complex with the other Asian origin metamorphic complexes of Timor that together constitute the Banda Terrane.

As noted above, with no requirement to account for Neogene metamorphism of the Aileu Complex as a consequence of collision, the onset of arc–continent collision is better constrained by other evidence. Several key observations inform the timing of collision. Firstly, dating of the lavas of Wetar and Atauro islands north of Timor, yields youngest ages of ~3 Ma (Abbott and Chamalaun, 1981), implying subduction continued at least until this time. As a result of ongoing collision, the inactive sector of the volcanic arc has since expanded to include Romang, Alor and the Pantar Strait islands (Elburg et al., 2005). Intriguingly, seismic profiles beneath the Banda Arc reveal a 200 km wide aseismic gap in the intermediate depth range of 100–300 km (Fig. 3), which equates to 3 million years of relative subduction. Attributing the top of the seismically active segment to the upper most part of the detached slab segment places slab rupture approximately at 3 Ma.

Secondly, the deposition of the largely bathyal Pliocene Viqueque Megasequence, now exposed as a relatively undeformed unit over large areas of Timor-Leste, records abrupt changes at ~3.3–3.4 Ma. The lower parts of this sequence comprises pelagic carbonates deposited in a tectonically quiet period during ~5.6–3.4 Ma (Haig and McCartain, 2007), and can be attributed to rapid foundering of the Australian margin as it approached the trench. At 3.35 Ma, the first turbidite beds of the sequence were deposited, heralding the emergence of Timor (Haig and McCartain, 2007) and arguably reflecting the first passage of the Australian margin through the trench.

The revised scenario presented here, involving collision at 3–4 Ma, allows for clarification of many important aspects of the incipient collision process. Specifically, it suggests that emplacement of the leading edge of the Australian continent into the forearc was accompanied, within a few hundred thousand years, by the detachment of the subducting slab and cessation of volcanism. Presently much of convergence between Australia and Sunda is inferred to be accommodated along the south-dipping Wetar Thrust, implying a polarity reversal is underway, but has not yet advanced sufficiently to have resulted in resurgence of volcanic activity.

A notable feature of this part of the Banda Orogen is the widespread, ongoing uplift of Quaternary coral terraces to elevations of ~700 m evident on slopes of the volcanic islands such as Atauro and Alor (Hantoro et al., 1994) and both terrace development and uplifted limestone plateaus on Timor-Leste. Dynamic uplift of the region reflects, at least in part, stress release from the detached slab (Price and Audley-Charles, 1987). Both closure of the forearc and emergence of larger land masses, as a result of collision and dynamic process in the mantle beneath, are likely to have influenced ocean circulation in the region, with potential global climatic implications of relevance to the evolution of our own species (Cane and Molnar, 2001).

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Figures

Figure 1. Timor-Leste occupies the eastern half of the island of Timor in the Banda Arc, southeast Asia. Potential zircon source regions, shaded dark gray, include the Crocker Fan of Borneo (CF), north western Australia (NW), Capricorn Orogen (CO), Perth Basin (PB), and Coen (C) and Georgetown (GT) regions. SU = Sumba, SW = Sulawesi. Lines labelled (a) and (b) show the location of Figure 3 cross sections. Inset shows the location of the Aileu Complex (AC) on the north coast of Timor. The volcanic Banda Arc lies to the north. Triangles are active volcanoes. Volcanic activity has ceased between the Pantar Strait (PS) and the island of Romang (R).

Figure 2. Detrital zircon age probability density plots for the Aileu Complex and potential source terranes. Aileu Complex sample locations indicated by arrows on inset maps. Aileu Complex data from this study is compared with a Sundaland source represented by the Crocker Fan of Borneo (van Hattum et al., 2006) and Western Australian detrital zircons from the Perth Basin (Sircombe and Freeman, 1999). Grey shading highlights significant detrital zircon populations of the Aileu Complex.

Figure 3. N-S depth sections showing seismicity of the subducting slabs, using the 1960–2004 events listed in the ANSS seismic database (ftp://www.ncedc.org/pub/catalogs/cnss), and associated topography. The Sumbawa section demonstrates continuity of the subducting oceanic crust beneath the Sunda Arc, whereas in the Timor section, a 200 km gap in intermediate depth seismicity is evident.

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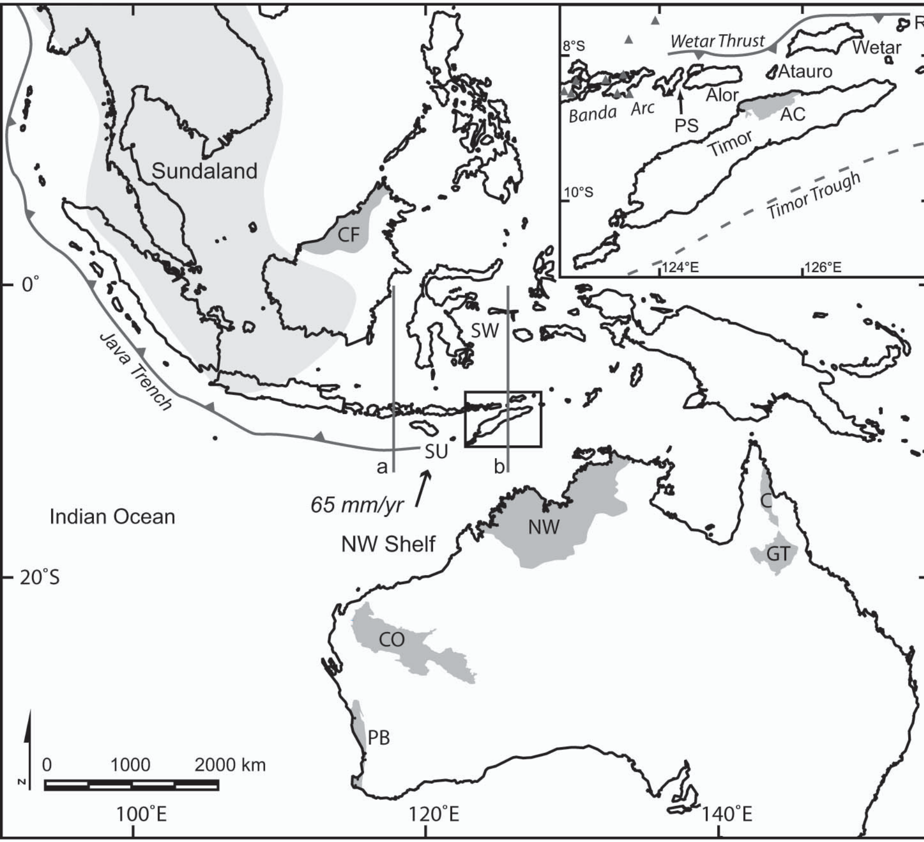
Figure 1



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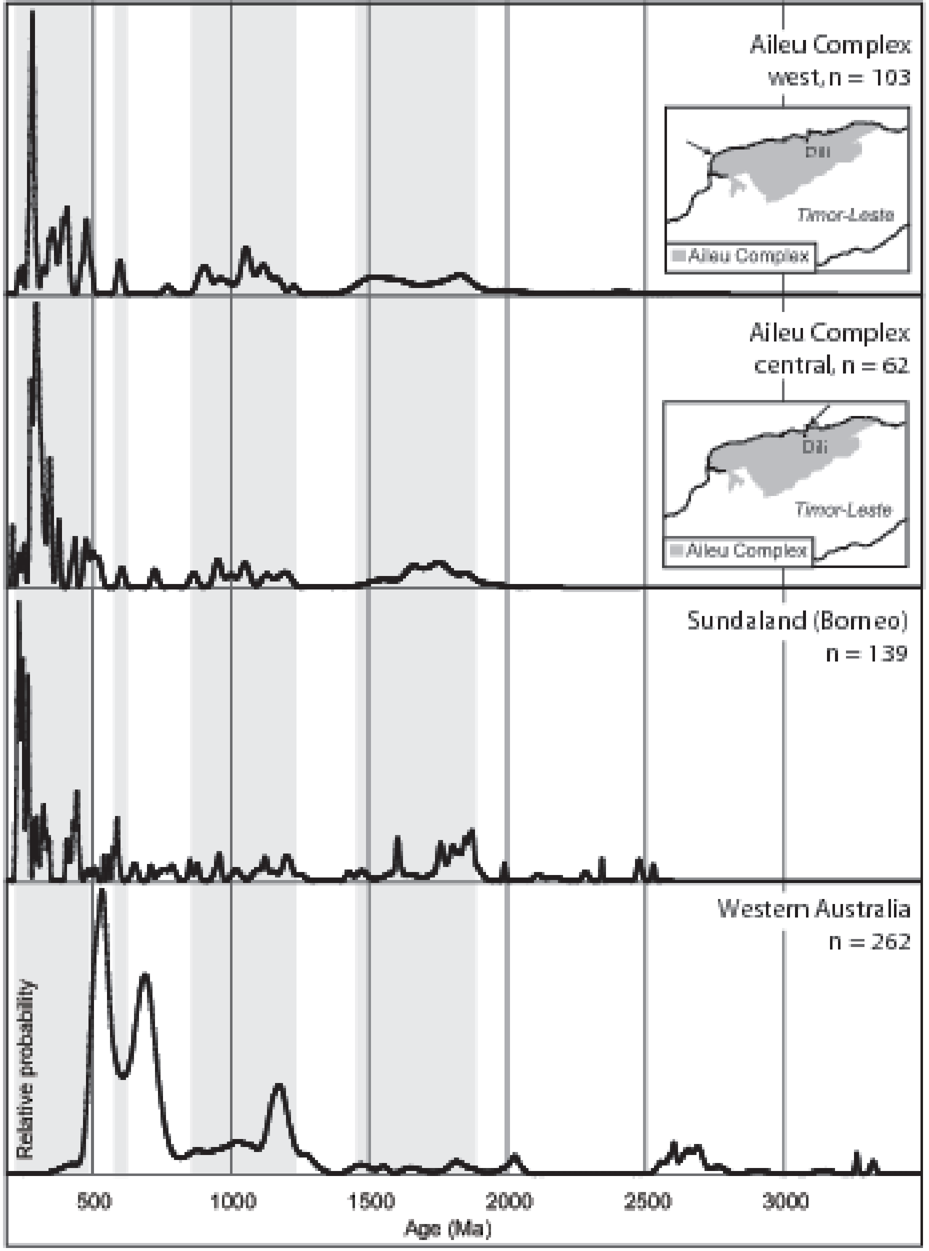

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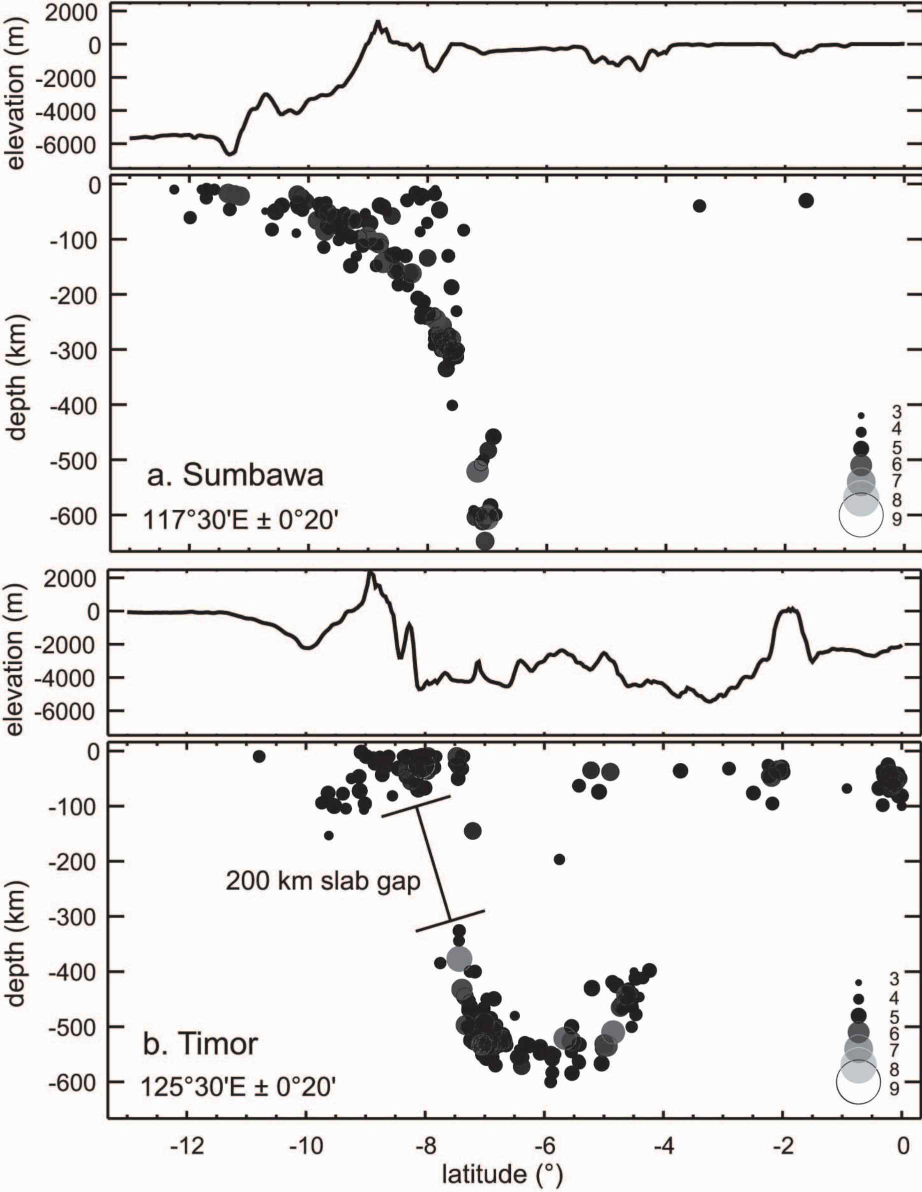

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