Origins of the Banda Arcs Collisional Orogen and the Banda Sea

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Many of the best examples of young arc-continent collision are found in eastern Indonesia, where the northern margin of Australia has been in collision throughout the Neogene with a succession of island arc systems (Charlton, 1991) (*Figure 1*). The Banda Arc is the youngest of these collision zones and forms the present plate boundary in this region. Behind the Banda Arcs, is the Banda Sea oceanic crust with its debatable origin.

Origin of the Banda Arcs Collisional Orogen

The origin of Timor Island and its collisional orogen have been matters of debates. Most authors describe the region as an arc–continent collision zone in which the Banda volcanic arc collided with Australia. Barber (1981) drew attention to the presence of Asian continental crust within the arc. Richardson (1993) proposed that a collision between a microcontinent, forming part of an extended passive margin and an Asian arc preceded collision of the volcanic arc and the Australian margin. Linthout *et al.* (1997) proposed that several microcontinental fragments collided with the Australian margin before the very young arc–continent collision. (Audley – Charles, 2011).

Hamilton (1979) regarded the island as a chaotic mélange. Barber (1981) interpreted Timor as collision result of Lolotoi microcontinent with Australian continent in Pliocene resulting in southward overthrusts over the Australian continental margin, or as upthrusts of Australian continental basement. Three main structural models, resulting mainly from near-surface observations, have been proposed for Timor:

(1) the Imbricate Model (Hamilton, 1979; Audley- Charles, 2011) : Timor is interpreted as an accumulation of chaotic material imbricated against the hanging wall of a subduction trench, the Timor trough, and essentially forms a large accretionary prism,
(2) the Overthrust Model (Carter *et al.*, 1976): Timor is interpreted in terms of Alpine-style thrust sheets where allochthonous units of Timor overthrust the parautochthonous units of the Australian continent.
(3) The Rebound Model (Chamalaun and Grady, 1978): the Australian continental margin entered a subduction zone in the vicinity of the Wetar Strait. Subsequently, the oceanic lithosphere detached from the continental part, resulting in the uplift of Timor by isostatic rebound on steep faults.
(4) Audley- Charles (2011) saw the Banda Trench gradually converted into a Tectonic Collision Zone progressively filled by two highly deformed Australian continental upper crust mega-sequences that were uplifted and raised Timor 3 km above sea level.

Combinations of these models have also been proposed (e.g. Charlton, 1989 and Harris, 1992) in which the parautochthon is divided into two parts, reflecting the step-wise nature of the collision. The main part, the 'underplated parautochthon', is thought to have accreted in the early stages of collision by the sequential addition by underplating of imbricate thrust slices of the outermost Australian continental margin to the base of the forearc complex. A second phase of collision is thought to have commenced in the early Pliocene with the addition to southern Timor of younger parts of the Australian continental margin, the 'frontally accreted' parautochthon. (See also Audey Charles 2011, Figure 6, 7, 8).

A particular controversy has also been the position of the suture (Hall and Wilson, 2000). Audley-Charles (1986a, 1988, and 2011) has advocated that there was a south-dipping suture in the Wetar Strait. Cases can be made for all these suggestions. The base of the Banda allochthon is the boundary between the former Asian Plate and underlying deposits of the former Australian passive margin. The base of the parautochthon is the deformation front and represents the boundary between completely autochthonous deposits of the Australian margin and those that have been displaced. The thrust north of Wetar can be interpreted as the new boundary between the Asian and Australian plates formed after subduction ceased south of Timor, and perhaps in response to slab break-off. Audley-Charles (1986a, 2011) summarised in diagrammatic form the contrast between the principal models. Harris (1991) suggested that each of the different models may be appropriate for different sections through the developing orogen, and each may apply at different stages in the collision process.

Timor has undergone young and severe tectonic activity. Mid-Pliocene limestones are the youngest rock formation to be folded. The deduced mid-Pliocene tectonic event has been interpreted as the collision of the northern margin of Australia with the subduction zone and volcanic arc (Barber, 1981). Sediments as young as early Miocene show some evidence of multiple deformation. In contrast, the Pliocene sediments are simply folded with horizontal fold axes.

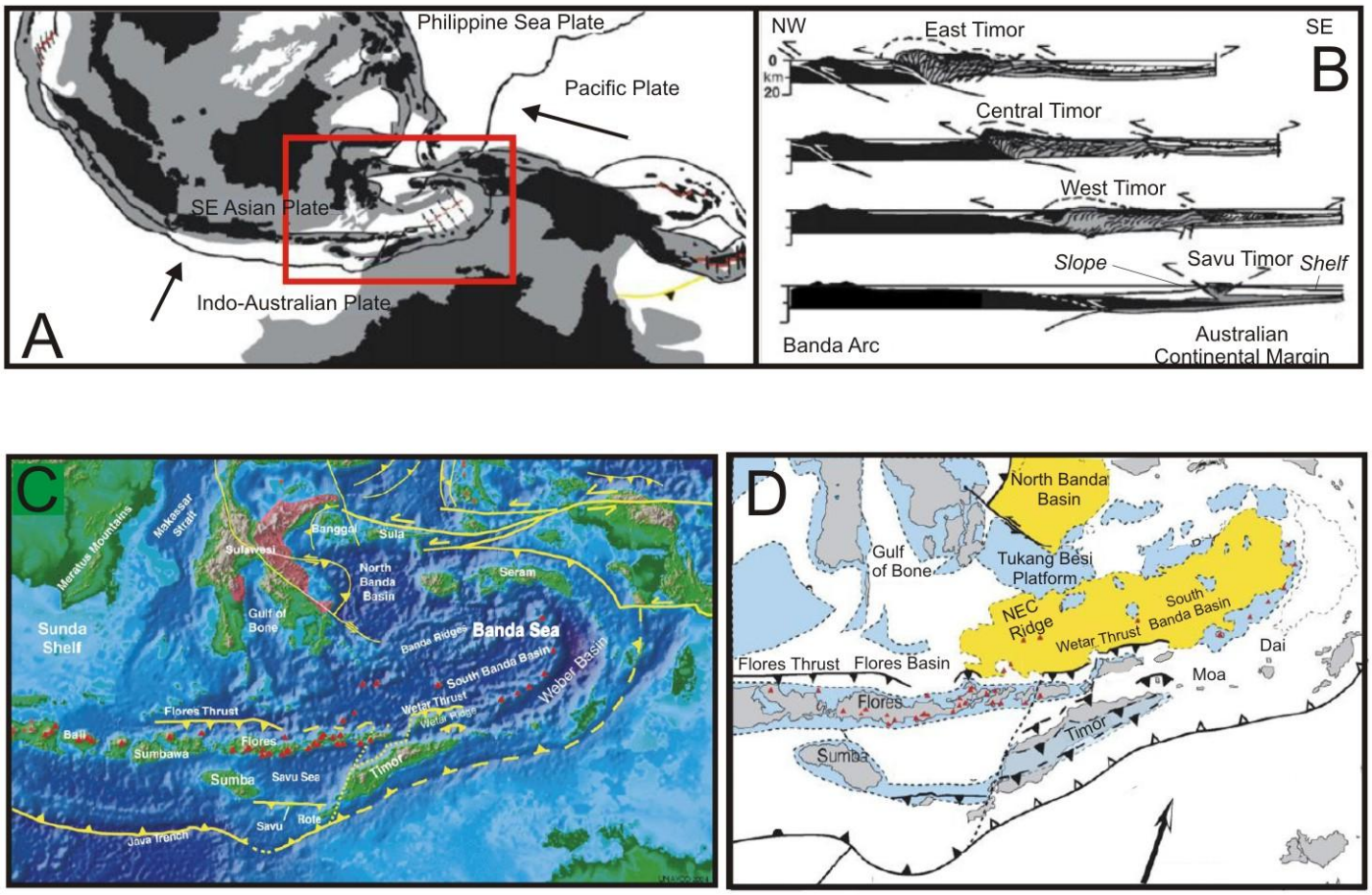


Figure 1. **Maps and serial sections of the Banda Arc region. A) Northern Australasian region. Grey is continental crust and white is oceanic crust. Rectangle is area of map 1C. B) Serial cross-sections through the western Banda Arc from Savu to East Timor. C) Digital elevation model of the Banda Arc region showing active faults (yellow lines), active volcanoes (red triangles), the Sulawesi ophiolite (pink area), and the many fragments embedded in oceanic crust of the Banda Sea floor. D) Location map of distribution of continental and arc fragments (blue),**

Based on deep seismic reflection profiles across the zone of convergence between Australia and the Banda arc east of Timor, Richardson and Blundell (1996) (see Figure 2) reveal the structures formed during lithosphere deformation in response to continental collision. Australian continental crust is bent down to the north to form the lower lithospheric plate. The immediately overlying upper plate is made up of a former outlier of the Australian continental shelf, now squeezed between the Australian continent to the south and the Banda arc to the north. The outlier began to accrete to the upper plate in the late Miocene. Near the Timor Trough, at the junction between the two plates, the upper plate to be cut by north-dipping structures interpreted as thrusts in an accretionary prism formed since the arrival of the Australian continental shelf at the collision zone at about 2.5 Ma.

The northern part of the collision zone is dominated by structures dipping southwards, antithetic to subduction, which penetrate the lithosphere to depths of at least 50 km, dividing the upper plate into imbricate slices. The oldest thrusts are presumably the more southerly ones. Since then the locus of activity has propagated northwards in a normal fashion until it has reached the backarc region where thrusts are active at the present day. Uplift is currently continuing as evidenced by several hundred meters of elevation of Pliocene coral reef of terraces on Alor, Atauro and Wetar and Sumba. In this collision, both oceanic and continental material is being shortened, thickened and uplifted. The overall, large-scale character of the collision zone is dominated by two sets of divergent structures. The southern set is related to the subducting (lower) plate and dips in the same direction as subduction. The northern set, in the upper plate, is antithetic to this.

Origin of the Banda Sea

The Banda Sea (South Banda Basin) is an oceanic crust. The origin and age of the Banda Sea has long been debated. Both low heat flow values and depth of basement greater than 4500 meters are in agreement with a creation of the oceanic crust during Mesozoic or Early Cenozoic time now trapped by the volcanic and non-volcanic arcs (Lapouille *et al.*, 1985). The hypothesis of a trapped Mesozoic origin for the Banda Sea is uncertain because there are controversies on ages determined from magnetic lineaments. The 'old' Banda Sea floor hypothesis was challenged by Honthaas *et al.* (1998) who recovered 9.4–7.3 Ma backarc basalt from fault scarp exposures of the basement of the North Banda Basin. They also recovered pelitic metamorphic rocks from the Sinta and Tukang Besi Ridges, and Lower Miocene limestone from the Rama Ridge further to the south. Other

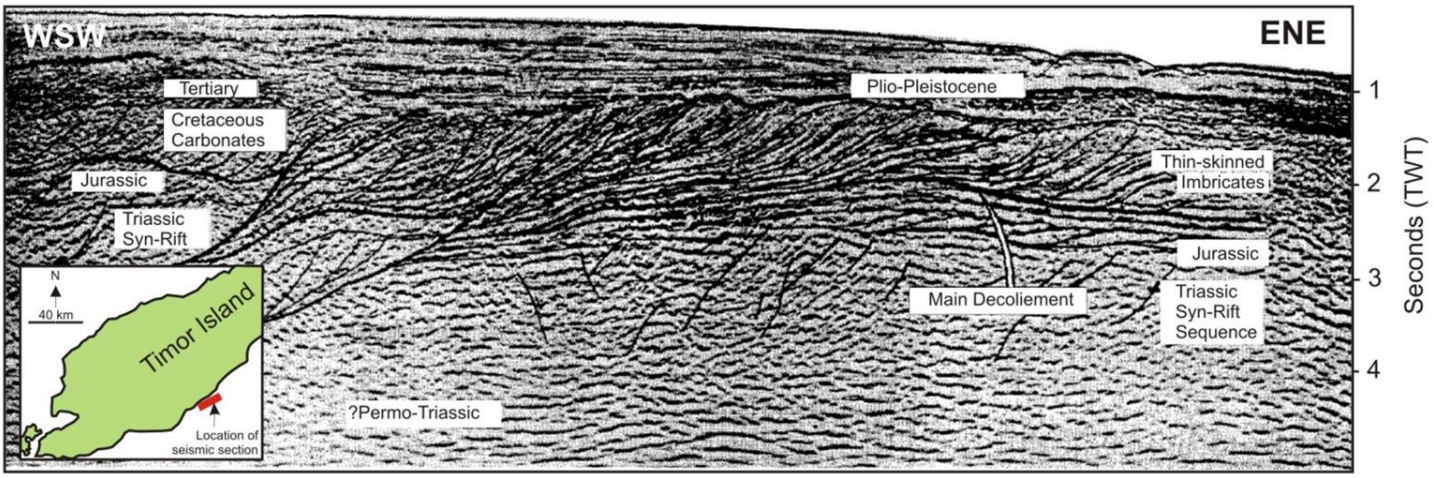


Figure 2. **Migrated seismic line from offshore south of the Kolbano fold and thrust belt shows thin-skinned thrust imbricates overlying a gently deformed stratigraphic sequence (Sani et al., 1995).**

dredged samples from the Lucipara and Nieuwerkerk Emperor of China ridges, and volcanic islands within the South Banda Basin, include Late Miocene to Early Pliocene backarc basalt, and cordierite-and sillimanite-bearing andesite. The occurrence of cordierite and sillimanite xenocrysts, and high Sr and low Nd ratios of samples throughout the region require that volcanic units are mounted on, and erupted up through continental crust with similar mineral assemblages to the Banda Terrane metamorphic basement.

These results led Honthaas *et al.* (1998) to also interpret the Banda Ridges as foundered continental crust pulled from the edge of Sulawesi by intra-arc spreading. The arc complex is mounted on the southern edge of the detached continental fragment, which was repeatedly pulled apart by diffuse spreading and the opening of intra-arc basins. According to this model, the eastern Sunda and western Banda Arc islands from Pantar to Damar are volcanic constructs mounted on a continental fragment that was rifted from the Tukang–Besi platform and Banda Ridges during the Late Miocene to Early Pliocene opening of the South Banda Basin. The Wetar segment and the Lucipara Ridge at the south and north of the South Banda Sea, respectively represented a single volcanic arc at 8-7 Ma resulted from high dip subduction of the Indian oceanic lithosphere beneath continental blocks originated from New Guinea. The rifting of the South Banda Basin at about 6 Ma separated the Wetar and the Lucipara volcanic arc, and intra-arc opening processes occurred from about 6.5 to 3.5 Ma (Late Miocene-Early Pliocene) forming the present Banda Sea. The spreading ceased at about 3 Ma due to the arc-continent collision occurred to the south and north of Wetar and Lucipara arc. The young age of the South Banda Sea Basin is contradictory with its great depth. Hinschberger *et al.* (2001) offered three mechanisms causing this great depth : rapid thermal subsidence due to a heat loss in the small basin, induced tectonic subsidence due to compressive tectonic setting, and increased tectonic subsidence due to drag stress of two downgoing slabs (Banda and Seram slabs) converging at depth.

A recent paper by Harris (2006) considered that the Banda Sea was initially related to subduction rollback of the old oceanic lithosphere of the Australian/Indian Plate. The upper plate was forced to extend, which resulted in suprasubduction zone seafloor spreading to form the Banda Sea basin. Trench retreat eventually brought the southernmost rifted ridge of Banda Terrane into collision with the Australian continental margin. As the cover sequences of the Australian slope and rise stacked up in the collision zone the Banda collisional terrane was folded, detached, and uplifted, during accretion to the edge of Australia. Now the southernmost part of the Banda Terrane forms an allochthonous thrust sheet that acts as the structural lid of the Timor fold and thrust belt. As the collision progressed it widened and the plate boundary localized in the thermally weakened backarc where the southern Banda Sea Basin underthrusts the Banda Arc. Closing of the Banda Sea basins puts the allochthonous part of the Banda Terrane on a collision course with autochthonous Banda Terrane fragments imbedded in the Banda Sea floor, and eventually with Sulawesi, where most of these fragments started their journey over 50 Ma.***

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