GEODYNAMICS

Complex subduction

Eastern Indonesia hosts one of the most complex and fascinating tectonic systems on the planet. Palaeogeographical reconstructions indicate that subduction and deformation of a single slab of oceanic crust created the complicated configuration.

Mike Sandiford

Sandwiched at the junction of four significant tectonic plates, eastern Indonesia has long fascinated those interested in tectonic processes. Perhaps the most dramatic tectonic feature is the remarkable set of curved island arcs around the eastern end of the Banda Sea. From Timor in the south, to Buru in the north, two parallel arcs — an inner volcanic and an outer non-volcanic island chain — bend through 180° with a radius of curvature of little more than 200 km (Fig. 1). The inner arc is the volcanic expression of a complex subduction system, but there is debate as to whether the system represents subduction of a single slab of oceanic crust or two separate slabs subducting from the north and south[1]. Writing in *Nature Geoscience*, Spakman and Hall[2] reconstruct the tectonic history of the region and reveal the influence of the pre-existing crustal structure on eastern Indonesia's geology.

Incredibly, the shape of the surface volcanism is mirrored by seismic activity in the crust and upper mantle. An almost continuous belt of seismicity defines a canoe-like prow structure pointing eastward, outlining a giant fold in the lithosphere some 450 km across and plunging westward beneath the Banda Sea for more than 500 km. The seismic activity provides a snap-shot of the complex morphology of a subduction system unlike any other. At the eastern end, sandwiched between the two Banda arcs is one of the world's deepest basins — the Weber Deep. The Weber Deep is a forearc basin — a depression in the sea floor between the subduction zone and the volcanic arc. The basin is unusually deep, reaching more than 7 km in depth, yet the geodynamic details of its formation have eluded scientists.

The deep-level seismicity and associated volcanism of the inner Banda arc shows subduction to be the key process that has operated in this region, but debate has long raged about the origin of the apparent slab curvature. If it is one coherent slab then it is unclear how the Australian crust can be subducting both northward and southward.

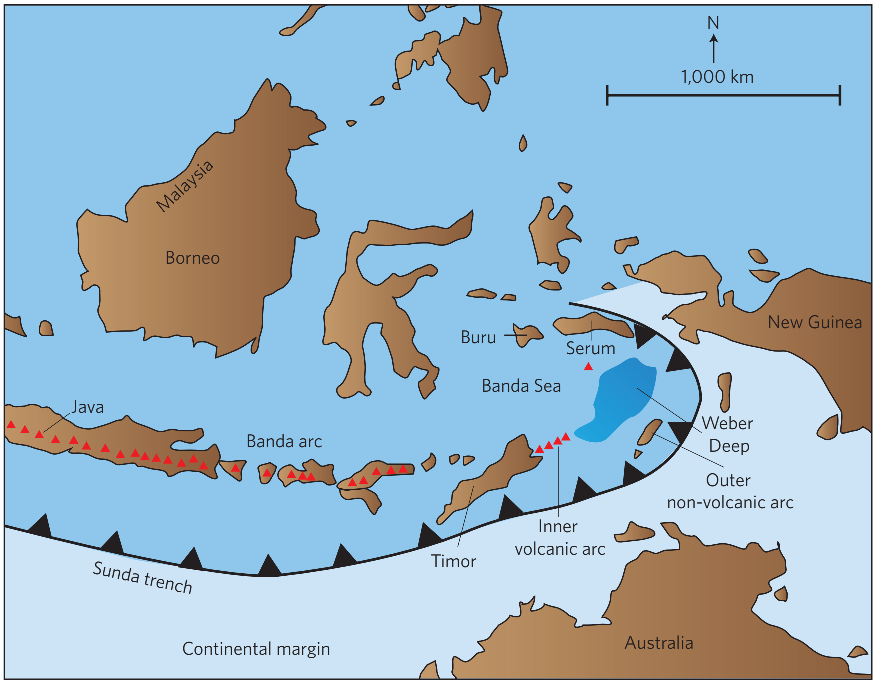

Figure 1 | The Banda arc region represents the surface expression of a complex and remarkably curved subduction system. Tomographic data and palaeogeographical reconstructions presented by Spakman and Hall[2] reveal subduction of a single slab. The unusual shape of the subducted slab is partly inherited from the curved Australian continental margin (shown in light blue) to which it is attached, but also reflects the resistance of the mantle to the northward motion of the Australian plate and the subducting slab.

Alternatively, the slab could be a mirage, formed by the coalescence of two or more distinct slabs with different histories. Because of the difficulty in access to this remote and politically turbulent region, detailed geological and geophysical studies have been few and far between.

Spakman and Hall[2] present tomographic images of the subducting Banda slab, as well as measurements of the active deformation of the surface, combined with remarkable south-east Asian palaeogeographic reconstructions[3]. They provide a compelling account of how the present-day configuration can be explained by the subduction of a single slab. In particular, they show that a horseshoe-shaped oceanic embayment once existed in the Australian plate. The embayment comprised dense oceanic crust surrounded by an arc of buoyant continental crust. Before about 15 million years ago, the dense oceanic crust began to sink and subduct into the mantle. Initially, subduction was focused along a continuation of the Sunda subduction trench, which aligned with the northern edge of the Australian plate and passed north of New Guinea. Oceanic crust was rapidly consumed by subduction until the buoyant Australian continental crust reached the trench, resisting further northward subduction. Instead, subduction progressed eastward along the continental margin, carving into the curved embayment and creating the Banda Sea. Thus, the pre-existing crustal structure played a key role in controlling the unusual geometry of subduction.

According to Spakman and Hall[1], as subduction progressed, the Australian plate continued its overall northward migration, dragging with it the attached subducting slab. The underlying mantle resisted the northward motion of the slab, causing the slab to roll backwards towards the south-east, folding the slab and causing the crust to peel away from the underlying mantle. Roll-back of the subducted slab ceased some time after about four million years ago when there was virtually no more embayment to be subducted. Since then, ongoing convergence between the Australian, Sunda and Pacific tectonic plates has squeezed the already strongly curved slab into an even more tightly folded geometry.

In some way the arguments have come full circle. The palaeogeographic reconstructions pick up threads of insight that were first alluded to almost thirty years ago[4] and have been further developed since then[1]. Still, interesting conundrums remain. The Australian continental crust has been nestled up against almost the entire Banda arc since at least four million years ago. The slab remnants seem to have been left dangling, rather than actively subducting, for several million years. Subduction must have halted quite abruptly and the question arises as to why the slab has not broken free from the trailing continent and continued to sink. Intense intermediate-depth seismicity seems to point to active slab-rupture processes occurring today[5,6]. The largest recorded earthquakes in the region probably severed the slab over several hundred kilometres and progressive slab tear could be responsible for the observed rise and fall of segments of the volcanic arc on the surface[6].

The evolution of the Banda Sea is not just of academic interest. The seismic history of the region includes the moment magnitude (M_w) 8.5 great Banda Sea earthquake of 1938, which almost certainly ruptured the eastern-most part of the slab, and the M_w 8.3 earthquake of 1963. These are two of the largest earthquakes ever recorded at intermediate depths of around 100 km below the surface. The region has since experienced six $M_w > 7$ events making it the most active intermediate-depth earthquake zone on the planet. Although these deeper earthquakes seem to relate to the progressive dismemberment of the slab[5,6], we know almost nothing about how slab removal might affect shallow-level seismicity. Shallow earthquakes in this region may have the potential to create tsunamis that can travel as far as Darwin, Australia.

Spakman and Hall[2] provide a compelling account of the formation of the Banda arc system through subduction of a single slab. The extreme curvature of the surface volcanoes and the spectacular shape of the deformed slab can be explained as a result of the pre-existing crustal structure and the interactions between the migrating plates, the subducting slab and the mantle. ❒

Mike Sandiford is in the School of Earth Sciences, University of Melbourne, Victoria 3010, Australia. e-mail: mikes@unimelb.edu.au

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