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Structure, evolution and tectonic activity of the eastern Sunda forearc, Indonesia, from marine seismic investigations

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ABSTRACT

Forearc structures of the eastern Sunda Arc are studied by new multichannel reflection seismic profiling. We image a high along-strike variability of the subducting oceanic plate, the interface between subducting and overriding plate, the accretionary wedge, the outer arc high and forearc basins. We highlight ongoing tectonic activity of the entire outer arc high: active out-of-sequence thrust faults connecting the plate interface with the seafloor, slope basins showing tilted sedimentary sequences on the outer arc high, vertical displacement of young seafloor sediments, and tilted sedimentary sequences in the Lombok forearc basin. While frontal accretion plays a minor role, the growth of the outer arc high is mainly attributed to oceanic sediments and crustal fragments, which are attached to the base of the upper plate and recycled within the forearc. We image ongoing large-scale duplex formation of the oceanic crust. The incoming oceanic crust is dissected by normal faulting into 5–10 km wide blocks within a 50–70 km wide belt seaward of the deep sea trench. These blocks determine the geometry and evolution of duplexes attached to the base of the overriding plate landward of the trench. Long-lasting and ongoing subsidence of the Lombok Basin is documented by distinct seismic sequences. In the Lombok Basin we image mud diapirs, fed from deeply buried sediments which may have been mobilized by rising fluids. We propose a wrench fault system in the eastern Lombok forearc basin that decouples the subduction regime of the Sunda Arc from the continent–island arc collision regime of the western Banda Arc. The observed tectonic activity of the entire forearc system reflects a high earthquake and tsunami hazard, similar to the western part of the Sunda Arc.

1. Introduction

The 7000 km long Sunda Arc has long been considered as a classical accretionary margin system where the Indo-Australian oceanic plate is underthrust beneath the South-East Asian continent, active since the Upper Oligocene (Hamilton, 1979, 1988). The accretionary margin has produced an accretionary wedge and a pronounced outer arc high forming the subduction complex landward of the deep sea trench, deep forearc sedimentary basins and a volcanic arc (Dickinson, 1977). These structures evolve in response to a number of key parameters, such as age, composition and structure of the subducting plate, convergence rate and direction, and the thickness and origin of the incoming sediments (e.g. Van der Werff, 1996; and references therein). Mass transfer, backstop and accretionary mechanics of this 'subduction factory' offshore Sumatra and Java, ranging from accretionary to erosive styles, have recently been studied by Kopp and Kukowski (2003) and Kopp et al. (2001, 2006).

At the eastern end of the Sunda Arc the convergent system changes from oceanic subduction to continent–island arc collision of the Scott Plateau, part of the Australian continent, colliding with the Banda island arc and Sumba Island in between. The origin of Sumba Island is still debated (Rutherford et al., 2001; and references therein).

The Sunda Arc is known as an active convergence zone producing tremendous earthquakes, tsunamis and volcanic hazards. The M_w 9.3 Indian Ocean earthquake and tsunami of December 26, 2004 killed more than 250,000 people. Numerous investigations have been commissioned near the epicentre offshore northern Sumatra to evaluate the earthquake and tsunami hazards. These projects have mapped seafloor morphology and imaged deep structures and faults in order to better understand the origin of megathrust earthquakes and tsunamis in the western portion of the Sunda Arc subduction system (e.g. Henstock et al., 2006; Ladage et al., 2006; Singh et al., 2008; Franke et al., 2008). Little attention concerning tectonics, structural geology and risk analysis has been paid recently to the eastern part of the Sunda Arc, south of eastern Java, the islands of Bali, Lombok, Sumbawa and Flores, so far. This area is the focus of the SINDBAD project (Seismic and Geoacustic Investigations Along the Sunda–Banda Arc Transition), a joint German–Indonesian project that

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carried out cruise SO190 with R/V SONNE end of 2006 in two consecutive legs (Fig. 1).

In this paper we present an overview on new seismic images with the main goals (i) to image and characterise the interaction between the subducting and the overriding plate, (ii) to investigate the structure and evolution of the subduction complex and the Lombok forearc basin in response to the variation in age and structure of the incoming oceanic plate (Roo Rise and Argo Abyssal Plain) and (iii) to characterise the transition from ocean–island arc subduction in the eastern Sunda Arc to continent–island arc collision at the western Banda arc. The data comprise 4933 km of multichannel reflection seismic (MCS) profiling, combined with magnetic and gravimetric measurements, sediment echo sounding and swath bathymetry, as well as refraction/wide-angle seismic measurements with ocean bottom seismometers (OBS) for velocity modelling on four corridors coincident with N–S running MCS profiles (Fig. 1). Preliminary interpretations were presented by Müller et al. (2008).

2. Regional tectonic setting

The subduction of the Indo-Australian plate along the Java Trench is active since the late Oligocene (e.g. Hamilton, 1979). The overriding plate is continental including Sumatra and western Java (Kopp et al., 2001) and the basement below the forearc basin offshore Bali and Lombok is probably rifted crust of continental character in transition to oceanic character at Sumbawa and further east (Banda Sea) (Van der Werff, 1996). The convergence rate increased from 5 cm/a to 7 cm/a during the last 10 Ma (7.3 cm/a today according to the global velocity model MORVEL, DeMets et al., 2010) and is almost perpendicular to the Java Trench, in contrast to oblique convergence offshore Sumatra, where plate motion is partitioned into thrust and strike-slip movements. The volcanism of the island arc was initiated during the Pliocene and changes from an intermediate composition on East Java to a mafic composition on Sumbawa, which documents a transition from a continental to an oceanic overriding upper plate (Hamilton, 1988). The present-day configuration of plate boundaries in South-East Asia shows a quite complex history of interaction of the Pacific, the Indo-Australian and the Eurasian plate. Reconstructions and modelling by Hall (2002, with a comprehensive literature list) and Hall and Smyth (2008) suggest major plate reorganisations at 45, 25 and 5 Ma. Seismological mantle tomography indicates seismic velocity anomalies to a depth of 1500 km attributed to the subducted lithospheric slab, which is probably continuous below Java but discontinuous and detached from the seismogenic slab below Sumatra (Widiyantoro and Van der Hilst, 1997). Seismicity is present in clusters tracing the Wadati–Benioff zone from the outer-trench bulge of the subducting oceanic plate to maximum 300 km depth beneath Sumatra and even 600 km depth beneath the eastern Sunda Arc (e.g. Widiyantoro and Van der Hilst, 1997; Spicák et al., 2007).

The subducting oceanic Indo-Australian plate in the study area (Fig. 1) can be subdivided into three distinct provinces: Roo Rise, Argo Abyssal Plain and Scott Plateau. The Roo Rise offshore Java is characterized by a rough morphology more than 1500 m above the surrounding seafloor level. The subduction of seamounts with their irregular relief contributes to subduction erosion and to the block structure of the outer arc high (Kopp et al., 2006). The trench here is less deep in comparison to adjacent regions, 5600 m to 6000 m versus 7000 m, respectively (Masson et al., 1990). The Argo Abyssal Plain offshore Lombok and Sumbawa (Fig. 1) is smooth at water depths of 5000–5500 m and has a pelagic sediment cover of about 600 m, which

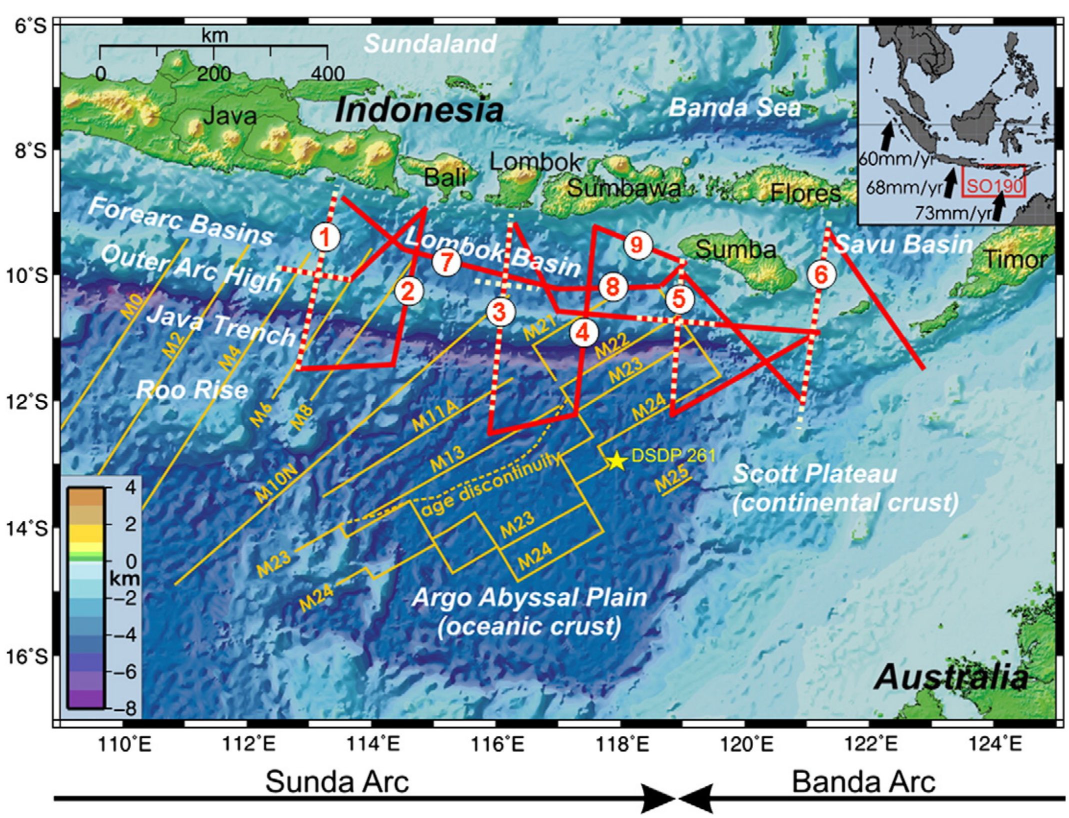

Fig. 1. Location map and inset (upper right) of the SINDBAD survey SO190 with 4933 km of multichannel reflection seismic (MCS) profiling (red lines) and 4 corridors of wide-angle/refraction seismic measurements with ocean bottom seismometers (OBS, red/white dotted lines). Yellow lines are magnetic lineations of reinterpreted anomalies based on studies of Heine et al. (2004) and SO190 measurements. Age of the oceanic plate ranges from early Cretaceous (M0) to late Jurassic (M25). Convergence rates (inset, upper right) of 73 mm/yr in the study area are according to the global velocity model MORVEL (DeMets et al., 2010). Bathymetry from Sandwell and Smith (1997) is based mainly on satellite gravity data. Lines discussed in the text: North–South: 1 = BGR06-305, 2 = BGR06-303, 3 = BGR06-313, 4 = BGR06-311, 5 = BGR06-317, 6 = BGR06-319; East–west: 7 = BGR06-307, 8 = BGR06-308, 9 = BGR06-310.