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PAGES 49–60

From Subduction to Collision: The Sunda-Banda Arc Transition

PAGES 49–50

In the aftermath of the M_w 9.3 Indian Ocean earthquake and tsunami of 26 December 2004, which killed more than 250,000 people, numerous investigations have been commissioned near the epicenter offshore northern Sumatra to evaluate future 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 offshore northern Sumatra [e.g., *Henstock et al.*, 2006].

In contrast, the eastern part of the arc has received relatively little attention, even though it may be just as hazardous. Our geophysical data from the eastern Sunda Arc and the transition to the Banda Arc (Figure 1) provide evidence for recent tectonic activity and thus for a similar earthquake and tsunami risk.

Project Goals: Seismic and Geoacoustic Investigations

Our investigations are part of the joint German-Indonesian project SINDBAD (Seismic and Geoacoustic Investigations Along the Sunda-Banda Arc Transition), whose main goal is to quantify key parameters about seafloor sediments, oceanic crust (continental crust at the western Banda Arc), and mantle lithosphere that enter the subduction system at the trench. This study area is quite variable: The Roo Rise, the Argo Abyssal Plain, and the continental lithosphere of Australia highlight variations in morphology and composition of the subducting plate from west to east along the Sunda-Banda arc transition zone (Figure 1).

We investigate the influence of the incoming plate (Roo Rise, Argo Abyssal Plain, and Australian continental lithosphere) on the evolution of the overriding plate by imaging deep and shallow crustal structures using a suite of geophysical methods. These methods include analyses of multichannel reflection seismic (MCS), magnetic, and gravity data, as well as analyses of data collected through ocean bottom seismometers (OBS), swath bathymetry, and sediment echo sounders. Our data were collected on cruise SO190-SINDBAD, which was carried out on the German R/V *Sonne* during two consecutive legs from October until December 2006.

Because modern seismic and acoustic imaging has not been conducted in detail in the area of the Sunda-Banda arc transition, much of our study's efforts were focused on gaining a clearer picture of the area's tectonic setting.

Tectonic Setting

The orientation of the 7000-kilometer-long Sunda Arc gradually bends from east-west along Java to north-south along the Andaman Islands off Myanmar. The relative plate motion between the subducting Indo-Australian plate and the overriding Eurasian plate is thus nearly perpendicular in the study area at the eastern end of the arc, but is highly oblique at the western end, where plate motion is partitioned into thrust and strike-slip movement. The subduction rate of the Indo-Australian plate increases gradually eastward, reaching about 76 millimeters each year at the eastern end of the arc, compared with 60 millimeters each year at Sumatra's northern coast (Figure 1, inset).

While the overriding lithosphere is continental along Sumatra and Java, it is oceanic farther east along Lombok and Sumbawa (see Figure 1 for locations). The subducting oceanic lithosphere is characterized by two

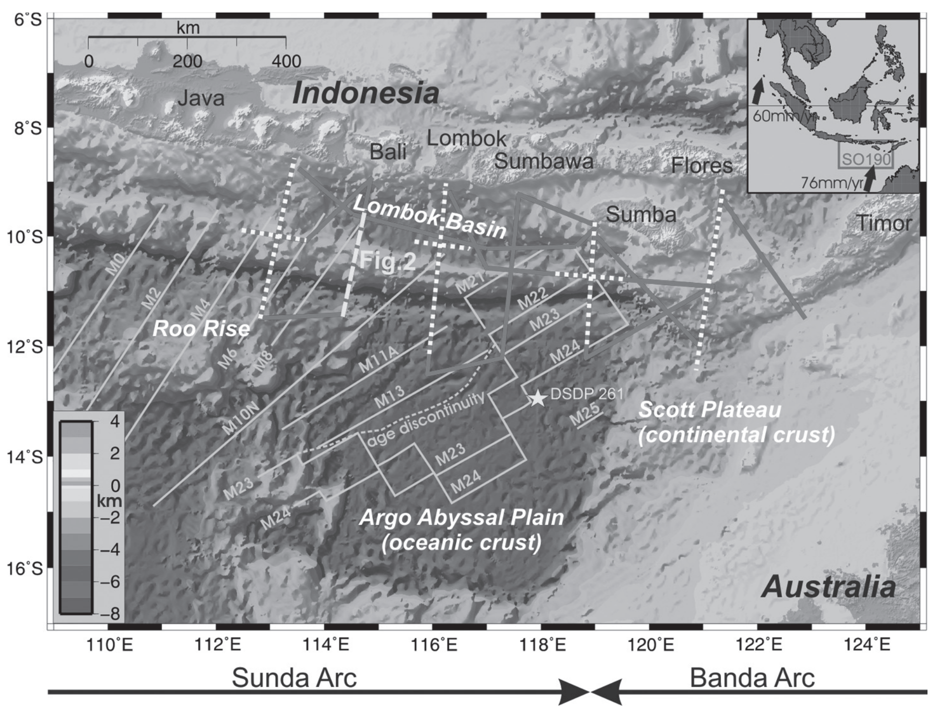

Fig. 1. Location map of the SO190-SINDBAD survey area with 4933 kilometers of geophysical lines (red) and reinterpreted magnetic anomalies modified from Heine et al. *[2004] in orange. Dotted lines (white) indicate the locations of seven refraction seismic lines augmented with ocean bottom seismometer stations. The locations of the multichannel reflection seismic section shown in Figure 2 are marked yellow. The inset shows the location of the survey area and convergence rates according to a global velocity model (NUVEL-1A). Original color image appears at the back of this volume.*

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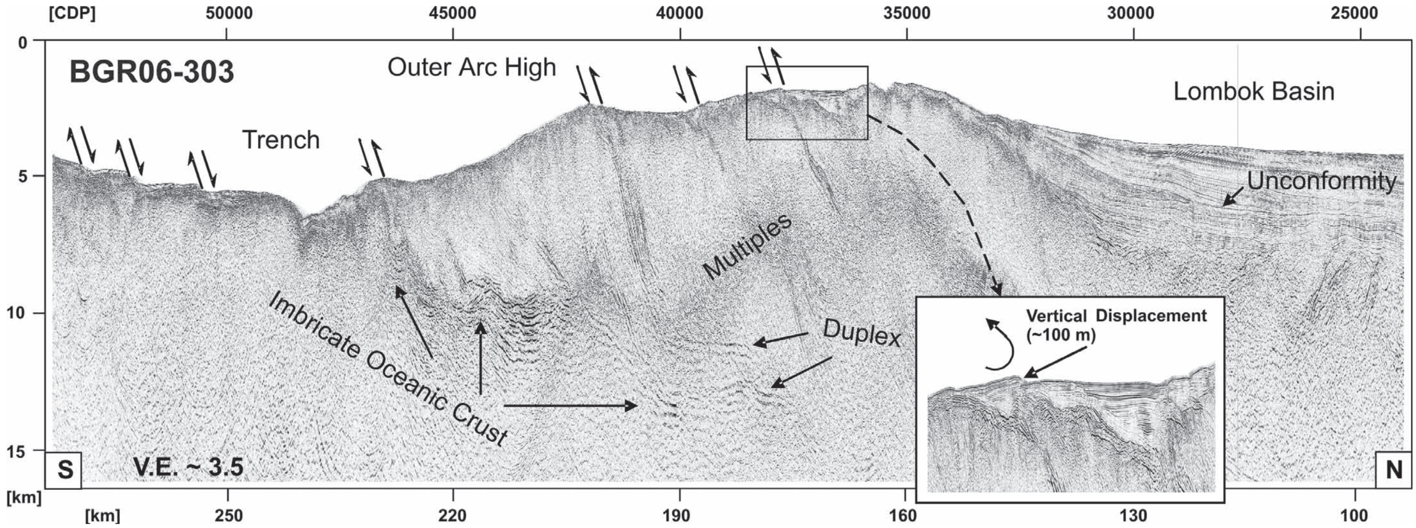

Fig. 2. Section of seismic line BGR06-303 (location shown in Figure 1) imaging major splay faults originating from duplex structures at the boundary between the overriding and the subducting plate and connecting to the seafloor, where they control small sedimentary basins. One of these basins is characterized by a pronounced vertical seafloor displacement of about 100 meters (inset). The fore-arc Lombok Basin is characterized by a major unconformity and tilted sedimentary strata. Data acquisition has been carried out using a 51-liter tuned airgun array, a 50-meter shot point interval, and a 3-kilometer active streamer length with 240 recording channels. Seismic data processing including poststack Kirchhoff-time migration was followed by time-to-depth conversion. Original color image appears at the back of this volume.

distinct provinces at the eastern part of the Sunda Arc. Offshore eastern Java, the oceanic Roo Rise is characterized by rough and high relief, while offshore Lombok and Sumbawa the Argo Abyssal Plain is smooth and about 1500 meters deeper. Still farther to the east, the continental lithosphere of Australia is colliding with the western Banda Arc along the islands of Flores, Sumba, and Timor.

The thickness of the sediment covering the incoming oceanic lithosphere, including the deep sea trench, decreases with increasing distance from the thick alluvial fan at the northern end of the Bay of Bengal (Bengal Fan), from about 4 kilometers offshore Sumatra to about 1.3 kilometers offshore western Java, and finally to less than 1 kilometer along the eastern Sunda Arc. Both sediment thickness and the nature of the underlying lithosphere are important factors affecting the tectonics of the arc.

A thick sedimentary section, composed mainly of deposits from the Bengal Fan, enters the subduction system at the trench offshore Sumatra and is largely accreted to the overlying Eurasian plate. This sedimentary section clearly contributes to the growth of the outer arc in the western part of the Sunda Arc. In the eastern part, incoming sediment is derived mostly from normal ocean sedimentation (pelagic), is about an order of magnitude thinner, and proportionally less of it may be accreted.

Subduction Factory and Tsunami Hazard

Despite major and systematic differences in kinematic and geologic parameters, the sizes and rates of earthquakes and tsunamis appear to be similar along all parts of the Sunda Arc [e.g., *Puspito*, 2002]. While the huge earthquake and tsunami disaster of 2004 as well as the recent 12 September 2007 M_w 8.4 event are still fresh in the minds of people worldwide, the 17 July 2006 M_w 7.8 tsunamigenic earthquake offshore Java is a reminder that 2004-like events may occur elsewhere along the Sunda Arc.

Magnetic seafloor-spreading anomalies of Late Jurassic age (155–145 million years ago) in the Argo Abyssal Plain represent the oldest crust along the entire Sunda Arc. Our magnetic data generally confirm the overall interpretation of the magnetic anomalies by *Heine et al.* [2004], but we suggest some significant modifications to Heine et al.'s conclusions. For example, through interpretation of our data, anomalies on the subducting crust can now be traced landward of the trench: In the northeastern part of the Argo Abyssal Plain, we map several Late Jurassic magnetic reversals (M24 through M21; see Figure 1) between two fracture zones.

Our MCS profiles image the bending of the oceanic crust down into the Earth's mantle as well as the associated normal faulting that results from this bending. Landward of the trench, profiles image the subducting slab beneath the outer arc high (highest elevation of seafloor in front of the volcanic arc), where the former bending-related normal faults (where the hanging block moves down) appear to be reactivated as reverse faults (where the hanging block is thrust up), causing vertical displacement and relief on the subducting slab. The accretionary prism and the outer arc high are characterized by a northward dipping system of overlapping (imbricate) thrust sheets with major thrust faults connecting seafloor and detachment (see fault structure in Figure 2).

On seismic profile BGR06-303 (Figure 2), a broad fault zone around kilometer 170 approaches the seafloor of the outer arc high. Evidence for recent deformation suggests this is an out-of-sequence splay fault (a fault that branches from the megathrust between the subducting and the overriding plate). The strong reflectivity of this fault can be related to alteration of the sediment by fluids rising along this fault. These fluids originate from subducted sediments as they lose their water at depth through dewatering processes such as those, for example, observed on the northern Barbados Ridge [*Shipley et al.*, 1994]. Close to the seafloor, this fault system controls a small basin (Figure 2, inset) that piggybacks the outer arc high. This piggyback basin is characterized by seaward-tilted sediment layers and a pronounced vertical seafloor displacement of about 100 meters.

Compression results in the shortening and steepening of the imbricate thrust sheets, contributing to buildup of the outer arc high. This continuing process is represented in tilted piggyback basin sediments and the observed seafloor displacement. North of the outer arc high, a thick upper sequence of landward-tilted sediments characterizes the southern Lombok Basin (Figure 2). This sequence of steeper dipping strata terminates against an underlying sedimentary sequence of lower dip (a pronounced unconformity) and also gives evidence for recent relative uplift of the landward and thus oldest part of the outer arc high. These clear seismic indications of continuous and abrupt uplift create the hazard for major earthquakes and tsunamis in the eastern part of the Sunda Arc.

Future Work

One of the general goals of this and other recent projects along the Sunda subduction system is the improved characterization of future damaging earthquakes. Additionally, fore-arc basin evolution and the potential for hydrocarbon resources will be addressed in subsequent stages of our project. Geometries and dimensions of key elements of the subduction system will be obtained by the integration of depth models from MCS and OBS data. Our findings may also provide targets for in situ probing of active thrust faults.

Acknowledgments

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NEWS

Science News for the U.S. Hispanic Audience

PAGE 50

A science and health news service targeted toward the U.S. Hispanic community was launched on 23 January. ConCiencia, billed as the first Spanish-language science newswire service in the United States, provides free weekly news feeds to media targeting the U.S. Hispanic population. The news feeds, available to Spanish-language newspapers and radio stations, include newspaper features, radio segments, and online news content.

ConCiencia science advisor Bob Russell said it is critical to provide Hispanic media with an ongoing source of high-quality science news that meets the needs and interests of Hispanics. He noted that “Latinos currently achieve lower-than-average math and science scores in public schools and are significantly underrepresented in science and engineering professions.”

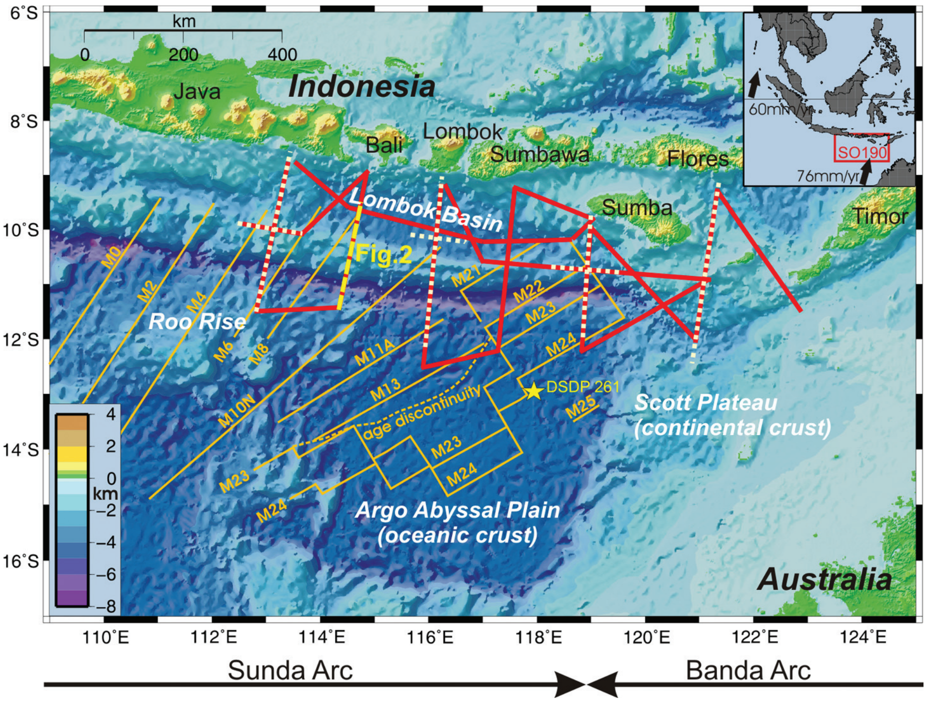
AGU education program manager Inés Cifuentes, who received the Hispanic Heritage Foundation’s 2007 Math and Science Hispanic Heritage Award, also addressed the media at the ConCiencia launch. She said there are a lot of bright schoolchildren whose talents are being wasted, and she hopes that the news service helps to educate them about science.

“Science is lots of fun, and kids love it, especially between the ages of three and when hormones hit,” Cifuentes said. “It’s not that we want to make all of them scientists, but we want to make all of them thinkers, and [ConCiencia] is a good way to do that.”

ConCiencia, which is funded by the U.S. National Science Foundation, is a project of the Self-Reliance Foundation and the Hispanic Communications Network.

For more information, contact Duly Fernandez at duly.fernandez@hcnmedia.com.

—Randy Showstack, Staff Writer



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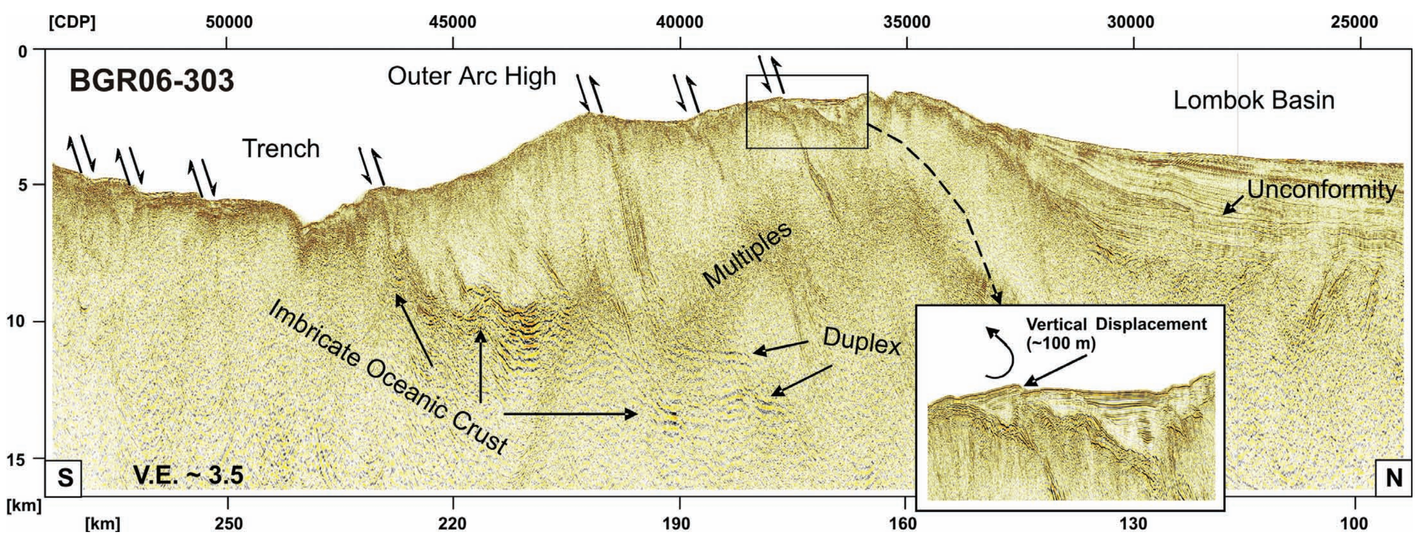
Page 49



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