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The great Sumatra–Andaman earthquakes — Imaging the boundary between the ruptures of the great 2004 and 2005 earthquakes

Dieter Franke [a,*], Michael Schnabel [a], Stefan Ladage [a], David R. Tappin [b], Sönke Neben [a], Yusuf S. Djajadihardja [c], Christian Müller [a], Heidrun Kopp [d], Christoph Gaedicke [a]

[a] Federal Institute for Geosciences and Natural Resources (BGR), Stilleweg 2, 30655 Hannover, Germany
[b] British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham, NG12 5GG, United Kingdom
[c] Agency for the Assessment & Application of Technology (BPPT), Jl. M.H. Thamrin no. 8, Jakarta 10340, Indonesia
[d] IFM-Geomar, Wischhoffstr. 1-3, Kiel, Germany

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Abstract

Segmentation along convergent margins controls earthquake magnitude and location, but the physical causes of segment boundaries, and their impact on earthquake rupture dynamics, are still poorly understood. One aspect of the 2004 and 2005 great Sumatra–Andaman earthquakes is their abrupt termination along a common boundary. This has led to speculation on the nature of the boundary, its origin and why it was not breached.

For the first time the boundary has been imaged and, with newly acquired marine geophysical data, we demonstrate that a ridge on the subducting Indo-Australian oceanic crust may exert a control on margin segmentation. This suggests a lower plate influence on margin structure, particularly its segmentation. The ridge is masked by the sedimentary cover in the trench. Its most likely trend is NNE–SSW. It is interpreted as a fracture zone on the subducting oceanic plate. A ramp or tear along the eastern flank of the subducting fracture zone beneath Simeulue Island may be considered as an intensification factor in terms of rupture propagation barrier.

Keywords: subduction; earthquakes; segmentation; seismic data; Sumatra

1. Introduction

Rupture propagation during earthquakes along convergent margins may commonly be confined to discrete along-strike structural segments. However, it is recognised that rupture propagation across such segment boundaries can result in megathrust earthquakes of considerable destructive power that may generate transoceanic tsunamis. The control on earthquake propagation exerted by segment boundaries is well established (Spence, 1977; Ando, 1975) but the physical causes are poorly understood. As a result we cannot fully determine seismic and tsunami hazard along convergent margins globally. Several mechanisms are recognised as influencing segmentation. These include: discontinuities in the geometry of the subducting plate such as slab tears (Spence, 1977; Aki, 1979); topographic anomalies within the subducting plate, such as ridges, fracture zones and seamount chains (Kodaira et al., 2000; Cummins et al., 2002; Bilek et al., 2003; Collot et al., 2004), major structures crossing the over-riding plate (Ryan and Scholl, 1993; Collot et al., 2004) and large-scale variations in the buoyancy of the subducting plate related to its thermal age (Yáñez and Cembrano, 2004).

In the instance of the great Indian Ocean earthquakes of 2004/5 the southern boundary of the December 26th 2004 event is clearly delineated (e.g. Ammon et al., 2005; Bilham, 2005; Krüger and Ohrnberger, 2005; Lay et al., 2005; Gahalaut et al., 2006). Significantly, this boundary also delineates the northern

* Corresponding author. Tel.: +49 511 643 3235; fax: +49 511 643 3663.
E-mail address: Dieter.Franke@bgr.de (D. Franke).

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termination of the March 28th 2005 earthquake (e.g. Ammon, 2006; Subarya et al., 2006). A large-scale structure near Simeulue Island (Fig. 1) has been suggested as a control on the ruptures, but its specific nature is unknown. Singh et al. (2005) and Kamesh Raju et al. (2007) propose an upper plate control on the segment boundary with the West Andaman Fault as a key structure controlling rupture propagation. DeShon et al. (2005) propose that the boundary of the southern Andaman microplate, in the vicinity of Simeulue Island is a diffuse deformation zone, and that this developing plate boundary served as a barrier to rupture propagation. Dewey et al. (2007) propose a lower plate control, suggesting that a distortion of the plate interface at depth beneath the forearc may be the cause. More specifically, Subarya et al. (2006) suggest that a boundary has formed due to distortion of the plate interface, related to a north–south trending fracture zone on the incoming oceanic plate.

The aim of this study, therefore, is to characterize the plate interface and structural architecture in the vicinity of the segment boundary between the December 26th 2004 and March 28th 2005 mainshocks. To this end, during 2006, we acquired swath bathymetry, multichannel reflection seismic (MCS), and wide-angle/refraction seismic data. Along trench-parallel profiles these data image the oceanic plate subducting beneath the forearc as well as upper plate structures. On the oceanic plate there is a broad N–S trending ridge entering the accretionary wedge SW of Simeulue. The influence of this ridge on segmentation of the upper plate is discussed.

2. Tectonic setting

Along the convergent margin off Sumatra the oceanic Indo-Australian Plate subducts under the Eurasian Plate (Fig. 1). As the former plate moves northward, convergence becomes increasingly oblique from south to north. In the vicinity of the December 2004 epicentre the azimuth of convergence is N10°E at 4°N, 95°E, (Delescluse and Chamot-Rooke, 2007). The result is large-scale strain partitioning with trench-normal and trench-parallel shear components. Along the leading edge of the Eurasian Plate, the trench-parallel shear results in large-scale, dextral strike-slip fault systems within the forearc basins and on Sumatra. Along the plate margin continental sliver plates have formed (Malod and Kemal, 1996; Simandjuntak and Barber,

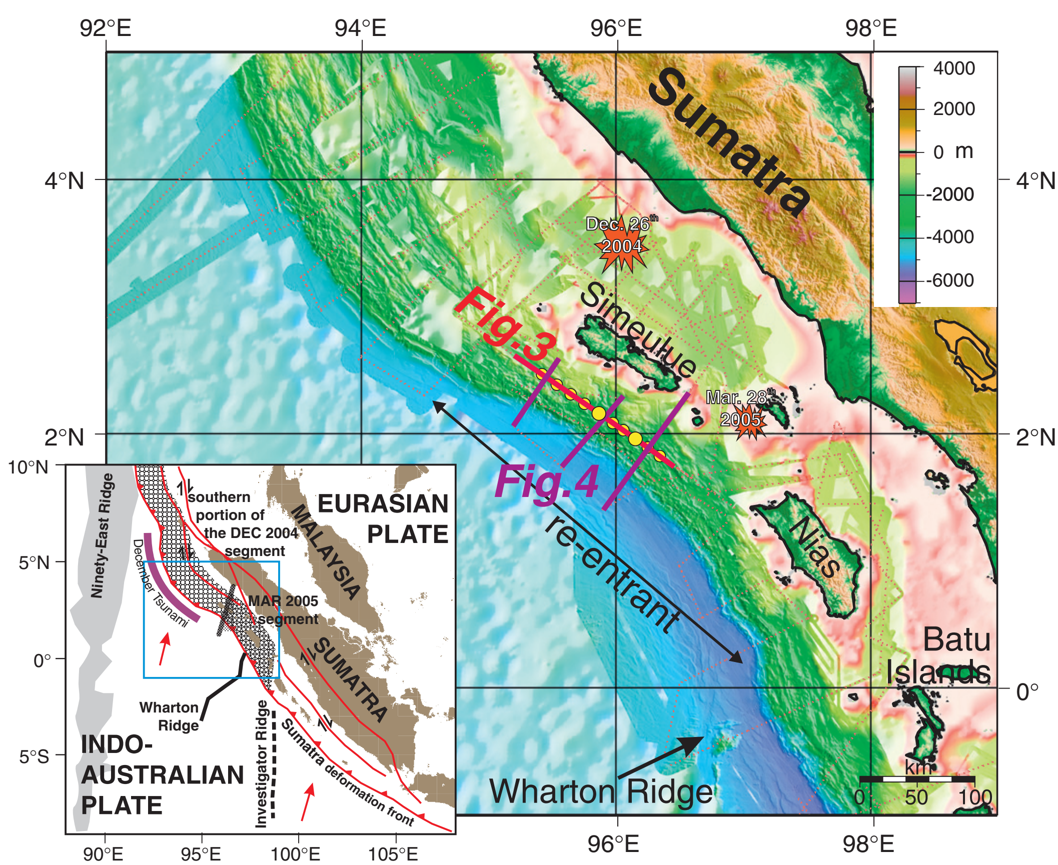

Fig. 1. Bathymetry off Sumatra underlain by satellite altimetry (Smith and Sandwell, 1997). Yellow dots mark positions of ocean-bottom hydrophone/seismometer stations and enlarged the two example stations shown in Fig. 2. Light red dashed lines give location of MCS profiles acquired during RV Sonne cruises and thick red and purple lines indicate location of multichannel seismic profile shown in Figs. 3 and 4, respectively. The locations of the initiation of rupture of the December 26th 2004 and March 28th 2005 great Sumatra–Andaman earthquakes are indicated. The only striking feature entering the subduction zone is the extinct Wharton spreading ridge southwest of Nias Island. The inset shows the tectonic situation with the Sumatra deformation front (red line with teeth) and major structures on- and offshore. The red arrows indicate the convergence direction of the Indo-Australian and Eurasian plates. The December 2004 and March 2005 rupture zones are indicated by different shades. The location of major structures on the Indo-Australian oceanic plate as the Ninetyeast, Wharton and Investigator ridges are indicated.