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The Fine Structure of the Subducted Investigator Fracture Zone in Western Sumatra as Seen by Local Seismicity

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ABSTRACT

The Sumatran margin suffered three great earthquakes in recent years (Aceh-Andaman 26 December 2004 Mw = 9.1, Nias 28 March 2005 Mw = 8.7, Bengkulu 12 September 2007 Mw = 8.5). Here we present local earthquake data from a dense, amphibious local seismic network covering a segment of the Sumatran margin that last ruptured in 1797. The occurrence of forearc islands along this part of the Sumatran margin allows the deployment of seismic land-stations above the shallow part of the thrust fault. In combination with ocean bottom seismometers this station geometry provides high quality hypocentre location for the updip end of the seismogenic zone in an area where geodetic data are also available. In this region, the Investigator Fracture Zone (IFZ), which consists of 4 sub-ridges, is subducted below the Sunda plate. This topography appears to influence seismicity at all depth intervals. A well-defined linear streak of seismicity extending from 80 to 200 km depth lies along the prolongation of closely spaced IFZ sub-ridges. More intermediate depth seismicity is located to the southeast of this string of seismicity and is related to subducted rough oceanic seafloor. The plate interface beneath Siberut Island which ruptured last in 1797 is characterised by almost complete absence of seismicity.

1. Introduction

Subducted seamounts and ridge systems have been thought to influence the rupture behavior of major earthquakes (Abercrombie et al., 2001; Bilek et al., 2003). Brittle seismogenic rupture of large faults can be stalled (Robinson et al., 2006; Gahalaut et al., 2010) or inhibited by subducted fracture zones and seamounts (Kodaira et al., 2000). Some authors have proposed enhanced coupling over subducted seamounts (e.g., Scholz & Small, 1997; Park et al., 2004) while recent studies propose weak coupling associated with incoming plate relief (Mochizuki et al., 2008; Sparkes et al., 2010). For the South American subduction zone, Kirby et al. (1996) observed that intermediate earthquakes often occur in roughly linear clusters that connect at the surface to incoming plate heterogeneities, such as coastal embayments and offshore seamounts. In Sumatra, the oceanic Indo-Australian plate subducts obliquely beneath the Eurasian plate (Fig. 1). A ~2500 km long, NS trending topographic feature, the Investigator Fracture zone (IFZ), is situated on the incoming Indo-Australian plate. The oceanic plate west of the IFZ is significantly younger, the age contrast relative to the eastern side being up to ~15 Ma (Müller et al., 1997). The IFZ is subducted at an oblique angle of ~65° and a velocity of 57 mm/yr below the Sumatran mainland, and the direction of the fracture zone trend near the trench is almost parallel to the convergence vector. Just before the trench the IFZ consists of 4 individual ridges, which migrate northwards along the Sumatran margin and lead to kinks in the trend of the deformation front (Kopp et al., 2008). Isolated seamounts are situated on top of the ridges as well as on their flanks.

The Sumatran margin has been the site of a number of great earthquakes in the recent past (Fig. 1): The regions north of Nias ruptured in 2004 (e.g., Krüger & Ohrnberger, 2005) and 2005 (Konca et al., 2007), and the region south of Siberut ruptured partially in 2007 (Konca et al., 2008). There remains an unruptured segment between the sites of these great earthquakes which is located below Siberut Island. This segment ruptured last in 1797 (Newcomb & McCann, 1987; Natawidjaja et al., 2006) and is known to be strongly coupled from GPS and coral data (Chlieh et al., 2008). The 12 September 2007 earthquake only partially ruptured the 1833 earthquake region, the total slip deficit below Siberut and the Pagai Islands since the large

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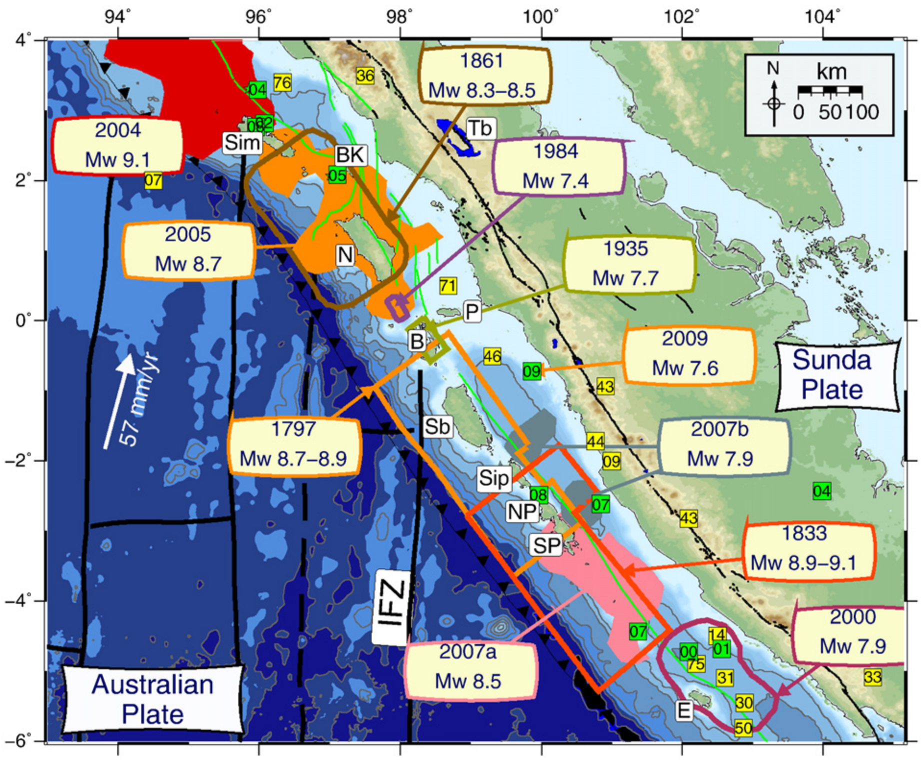

Fig. 1. Location map showing the oblique subduction and historical earthquakes along the Sumatran margin. Arrow shows convergence rate from Natawidjaja et al. (2006). The continuous line on the land surface indicates the Sumatran Fault Zone (SFZ), green lines indicate crustal faults offshore (Sieh & Natawidjaja, 2000). Oceanic fracture zones are shown in black (Cande et al., 1989), dashed black line indicates hypothesised fracture zone from Barckhausen & SeaCause Scientific Party (2006). Rupture zones of the great 1797 and 1833 earthquakes are based on uplift of coral micro-atolls (Natawidjaja et al., 2006). Rupture areas from the 1861, 1935 and 1984 earthquakes are given by Rivera et al. (2002). Slip distribution of 2004 earthquake from Chlieh et al. (2007). Yellow squares represent historical shallow events between 1903 and 1984 with M≥7, where the year is indicated by the number in the square (Newcomb & McCann, 1987). Green squares indicate earthquakes with M≥7 since 1985 from the NEIC catalogue. Slip distribution from the 2005 and 2007 earthquake from Konca et al. (2007, 2008). The rupture zone of the 2000 earthquake is based on high seismic aftershock activity mapped by Abercrombie et al. (2003). Sim: Simeulue; BK: Banyak Islands; Tb: Toba; N: Nias; B: Batu Islands; P: Pulau Pini; Sb: Siberut Island; Sip: Sipora; NP: North Pagai; SP: South Pagai; E: Enggano.

ruptures from 1797 and 1833 is approximately 8 m, equivalent to a moment deficit corresponding to an M_w=8.8 earthquake (Sieh et al., 2008). Therefore, the segment is in an advanced stage of the seismic cycle (Konca et al., 2008).

Here, we use high-resolution local observations from an amphibious network of seismometers in the region where the IFZ subducts below the Sumatran mainland to characterise the lateral change of seismicity, and relate the intermediate and shallow seismicity to the structure of the incoming oceanic plate. The serendipitous occurrence of forearc islands along this part of the Sumatran margin allows the deployment of seismic land-stations above the shallow part of the thrust fault. These island stations, together with ocean bottom seismometers (OBS), provide high quality locations for the up-dip end of the seismogenic zone where the coupling of the plate interface is known (Chlieh et al., 2008; Prawirodirdjo et al., 2010).

2. Experiment and Data

A dense seismic network was installed along the west Sumatran margin in April 2008 between 1.8°S and 1.8°N (Fig. 2). The land network comprised 52 continuously recording three component stations running at 50 and 100 Hz, including 7 broadband stations. To improve resolution of the offshore part the network was complemented by 10 three-component ocean bottom seismometers with differential pressure gauge channel (OBS) in June 2008. During October 2008, 10 stations were removed from the Sumatran mainland such that 42 land-stations (short period: 34; 7 broadband) and 10 OBS stations remained until February 2009. In addition to the temporary deployment we included the data from 8 permanent stations operated by BMG and 2 permanent stations operated by GEOFON in the analysis. For strong and deep events we incorporated the data from a temporary deployment of 39 stations to the north of our deployment (GFZ network) and 27 stations from an adjacent temporary network to the south (Mentawai stations, Collings et al., 2009). For the time span of 14 days between 25 May and 10 June 2008 the data from an active experiment comprising 46 OBS stations were also included into this study. Tab. ST1 summarises the networks and instruments used for the study.

3. Data Processing and Inversion for 1-D Velocity Model

Event detection was carried out on the continuous data using a grid search in time and space (Drew et al., 2005). Preliminary automated P-arrival times were picked using the MPX picking algorithm (Aldersons, 2004) and the automatic picks and detections were then revised manually. Around 750,000 seismograms were inspected for potential events and 27,077 P-arrivals and 14,676 S-arrivals from 1783 events were picked manually. Most events and stations are located on the mainland along the Sumatran Fault Zone (SFZ, Fig. 3). Then we determined a local one dimensional (1-D) velocity model, station corrections and accurate locations simultaneously by performing a joint inversion of the picked travel times (VELEST, Kissling et al., 1994) following the procedure described in Husen et al. (1999). We first inverted for a minimum RMS 1-D P-wave velocity model using a constant v_p/v_s ratio of 1.77 derived from Wadati diagrams. For this inversion we use a high quality subset of events with GAP(=largest azimuth range with no observations)≤180° and more than 10 P- and 8 S-wave observations. This procedure reduced the number of events to 588 with a total of 11,771 P- and 7,580 S-wave travel time observations. A wide range of initial P-wave velocity models (indicated in