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Submarine slope failures at the eastern Sunda Arc: bathymetry analysis and tsunami modeling

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Introduction

Tsunamis pose a major threat to coastal communities in Indonesia. Most tsunamis are generated by underwater earthquakes and this danger can be adequately addressed by tsunami early warning systems. Submarine slope failures, however, can be responsible for localized high-amplitude tsunamis as well. Here, we address three fundamental questions: (1) Where in Indonesia can we expect submarine landslides? (2) Are they large enough to produce significant tsunamis? (3) Was the largest event triggered by the 1977 Sumba earthquake?

1. Where in Indonesia can we expect submarine landslides?

By triggering submarine mass failures, even moderate earthquakes can generate locally disastrous tsunamis. We estimate the tsunami hazard of landslides in Indonesia by analyzing past events. This can be done via two means: the study of historical tsunami catalogs and the identification of slope failures in available bathymetry data.

Tsunamigenic slope failures have been observed multiple times in Indonesian history (see stars in Figure 1): (1) 1815 north of Bali (RYNN 2002), (2) 1899 off Seram (www.ngdc.noaa.gov), (3) 1979 near Lomblen Island (SOLOVIEV 1992), (4) 1982 at Flores (RYNN 2002), and (5) 1992 again at Flores (YEH et al. 1993, TSUJI et al. 1995). Another disastrous event (6) took place 1998 in Papua New Guinea, 130 km east of the Indonesian border (TAPPIN et al. 1999, OKAL 1999). These events probably constitute only a small subset of landslide generated tsunamis in the Indonesian region, as the contribution of landslides to tsunami generation, especially in

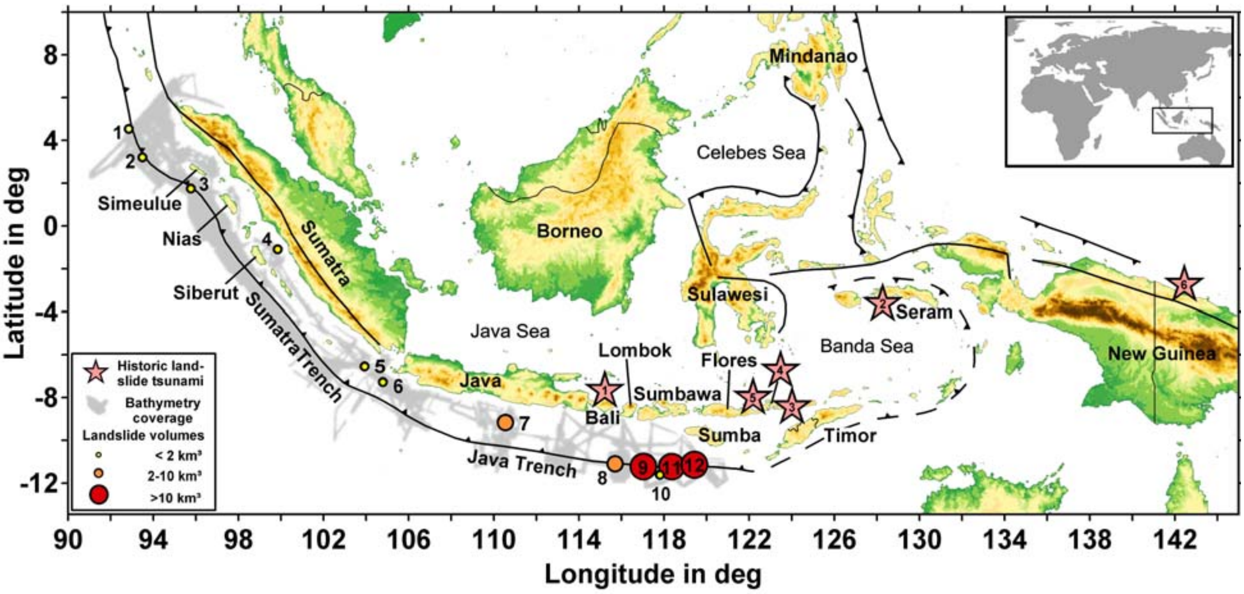

Figure 1. Overview map. Historic landslide tsunamis are marked by stars. Submarine landslides identified in bathymetry data are depicted as circles. For further information on specific events see BRUNE et al. 2010.

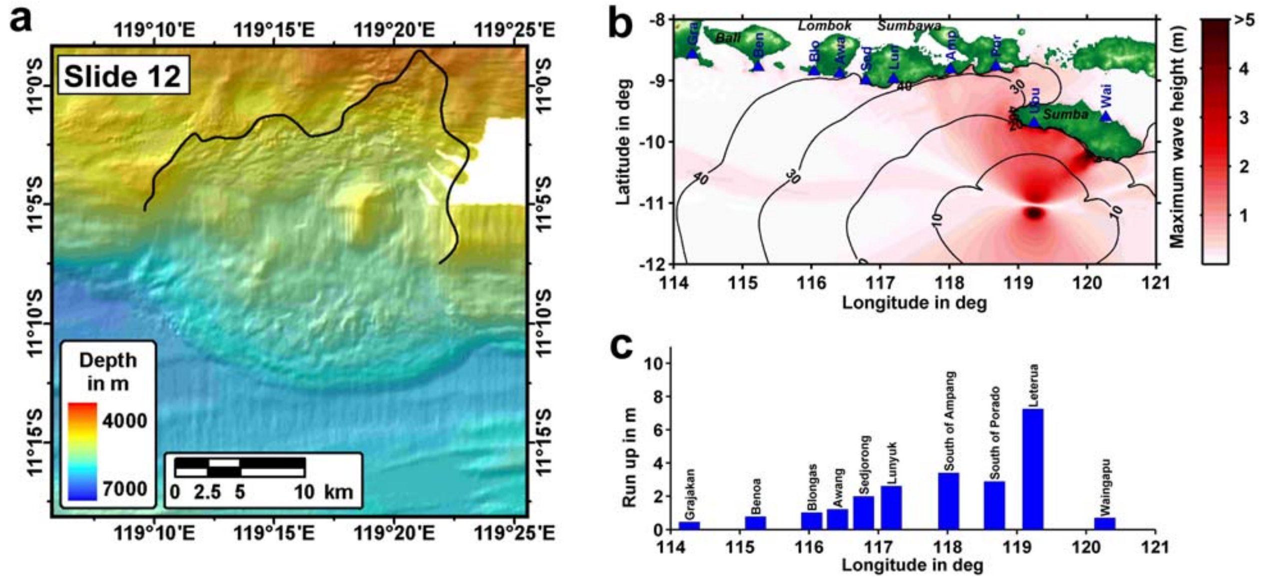

Figure 2. (a) Bathymetry image of slide 12. The event exhibits a large depositional lobe of 20 km width and up to 300 m thickness. The black line depicts the assumed head scarp. (b) Maximum offshore wave heights and tsunami travel times (in minutes). It takes the tsunami 20 minutes to reach the 130 km distant Sumba Island. (c) Run-up distribution. Locations are mapped in (b) as blue triangles.

historic cases, is not obvious and often matter of debate (GUSIAKOV 2002).

To assess the distribution and the size of submarine mass movements in the Indonesian region, we analyze available bathymetry data searching for characteristic landslide features: cauliflower-shaped escarpments and mass movement deposits. Our bathymetry compilation covers large portions of the Sunda Margin. Data were recorded during several cruises of German, British, Japanese, French, American and Indonesian vessels and compiled at BGR, Hannover. We identify submarine landslides at 12 distinct locations that are mapped in Figure 1 (BRUNE et al. 2010). Some of them are quite small (1 km^3) but others exhibit volumes up to 20 km^3 (Figure 2a). Especially at the eastern Sunda Margin, south of Sumbawa and Sumba Island, several large events are located in close vicinity.

2. Are these landslides large enough to produce significant tsunamis?

We numerically modeled the tsunamis that were generated by the identified landslides. The applied numerical techniques are discussed in BRUNE et al. (2009a, 2009b). At Sumatra, the largest computed wave heights on land (i.e. run-up) were 3 m for landslide location number 4, situated near the large city Padang. The largest events at the eastern Sunda Margin, however, resulted in run-up of up to 7 m at the closest islands. Maximum offshore wave heights, tsunami travel times and coastal run-up for slide number 12 are shown in Figure 2b and 2c.

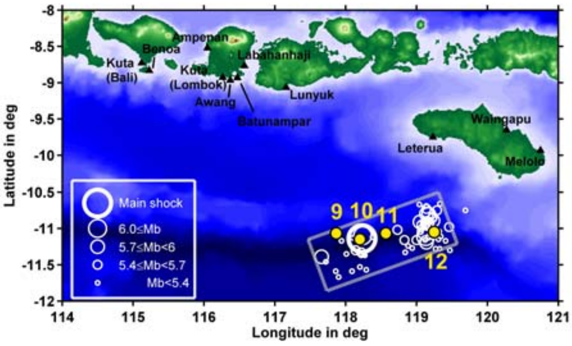

Figure 3. The Sumba Earthquake (Mw=8.3) is one of the largest normal fault type earthquakes ever recorded. The fault plane spreads beneath the slides 9, 10, 11 and 12 with many after-shocks localizing at the position of slide 12. Black triangles indicate the places of run-up measurement shown in Figure 4.

3. Was the largest event triggered by the 1977 Sumba earthquake?

Four slides are located directly above the fault plane of the 1977 Sumba Mw=8.3 earthquake (Figure 3). Here, we discuss whether the large slide 12 could have been triggered by this tsunamigenic earthquake. Therefore, we compare the calculated run-up distribution of the earthquake as well as the landslide tsunami to run-up measurements that were collected shortly after the earthquake (Figure 4).

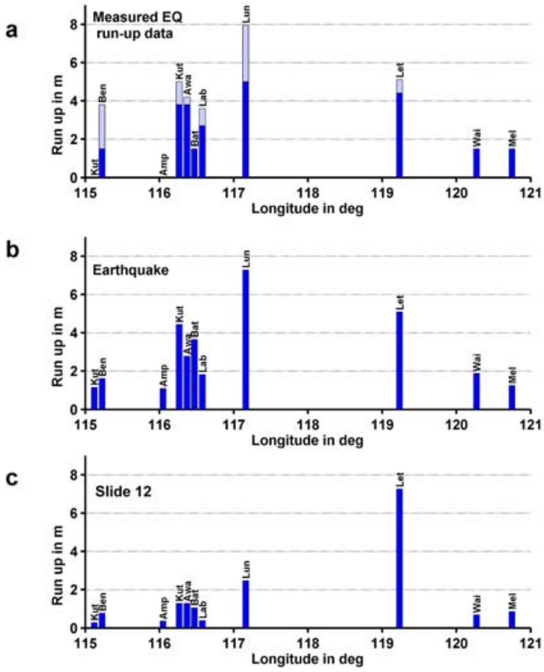

Figure 4. Run-up comparison. (a) Tsunami run-up has been measured following the event (ITIC, 1977). Depicted values have been corrected for tides by Kato & Tsuji (1995). If more than one value was measured at a location, light blue bars show the maximum run-up, while dark blue bars correspond to the minimum run-up. Abbreviations stand for sites of run-up measurements mapped in Figure 3: Amp: Ampenan, Awa: Awang, Bat: Batunampar, Ben: Benoa, Kut: Kuta (Bali & Lombok), Lab: Labahanhaji, Let: Leterua, Lun: Lunyuk, Mel: Melolo, Wai: Waingapu. (b) The computed run-up of the earthquake-generated tsunami adequately explains the measured data in (a). (c) Tsunami run-up of slide 12.

However, the earthquake tsunami model alone adequately explains most observations (Brune et al. 2009b). This fact cannot, however, exclude co-seismic landslide triggering: the potential landslide tsunami might have propagated some time after the earthquake tsunami so that the waves did not measurably superpose at the survey points. Hence, based on the available data, we can neither support, nor decline the hypothesis that one or more slides were triggered by the 1977 Sumba earthquake.

Conclusions

Historic events and the results of our numerical modeling studies indicate a large hazard potential of landslide tsunamis in Indonesia. The available bathymetry displays 12 locations where landslides took place with volumes ranging between 1 km³ off Sumatra up to 20 km³ at the eastern Sunda Trench. Numerical tsunami modeling suggests that the generated tsunamis of the largest event reached maximum run-up of 7 m at Sumba Island. Several large slides are located close to the epicenter of the 1977 Sumba earthquake. Available data do not allow a decision whether this earthquake was involved in triggering one or more of the landslides.

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