Comparisons to Onshore Paleoseismology

We directly compare our results with records of earthquakes in the form of sandy deposits interpreted to be paleotsunami deposits, records of uplifted abrasion platforms, and records of coseismic paleodeformation recorded by coral microatolls. Our turbidite based evidence suggests that the ages of the 7 earthquakes prior to 2004 were ca. 390 ± 260, 630 ± 110, 740 ± 120, 820 ± 130, 940 ± 180, 1,080 ± 140, and 1,220 ± 220 (cal yr BP). Based on paleotsunami evidence in Thailand, the penultimate tsunamigenic earthquake recorded onshore in Phra Thong was younger than 370 ± 100 cal yr BP (Fujino et al., 2009; may correlate with T-2, aged 390 ± 260 cal yr BP) and the ante-penultimate tsunami was younger than 580 ± 50 cal yr BP (Jankaew et al., 2008; may correlate with T-3, aged 630 ± 110 cal yr BP; Fig. 11); also, paleotsunami younger than 1,210 ± 90 cal yr BP (Fujino et al., 2009) may correlate with T-8 (aged 1,220 ± 210 cal yr BP). Based on uplifted marine abrasion platforms, penultimate and ante-penultimate earthquakes occurred 690 ± 150 and 960 ± 220 cal yr BP respectively in the Andaman-Nicobar Islands (Rajendran et al., 2008; may correlate with T-4, aged 740 ± 120 cal yr BP, and T-6, aged 940 ± 180 cal yr BP;). Similarly, paleotsunami evidence in Aceh, Sumatra, suggests the penultimate large tsunami timing was 600 ± 60 cal yr BP and the ante-penultimate tsunami timing was 1,020 ± 110 (Monecke et al., 2008; may correlate with T-3, aged 630 ± 110 cal yr BP, and T-7, aged 1,080 ± 140 cal yr BP). These data shown in Fig. 11 suggest a strong possibility that the deep water turbidite record and regional tsunami records of the last ~ 1,500 years are a good match.

The terrestrial record of paleotsunami is sparse prior to 1,220 cal yr BP, but we make some preliminary comparisons. Paleotsunami records are less reliably linked to individual fault segments, though some sites are more likely to represent earthquakes in the region of the 2004 SASZ earthquake (e.g. Thailand, India). Our turbidite T-10 (aged 1,500 ± 110 cal yr BP) may be linked to a tsunami in East India at 1,470 ± 70 cal yr BP (Rajendran et al., 2008). Our T-26 (aged 3,720 ± 340 cal yr BP) may correlate with another East India tsunami with an age of 3,710 ± 200 cal yr BP (Nair et al., 2010). Similarly, T-20 and T-35 (aged 2,520 ± 200 and 4,720 ± 220 cal yr BP, respectively) may correlate with evidence from Thailand tsunami with ages of 2,630 ± 120 cal yr BP and 4,780 ± 70 cal yr BP (Rhodes et al., 2011).

Meltzner et al., (2010, 2012) have demonstrated that precisely aged local uplifts on Simeulue Island were the result of slip on the Sumatra megathrust for the 2004 and 2005 earthquakes and highly likely for a number of prior earthquakes. They also show that earthquakes on the northern and southern parts of the island are distinct and thus define a segment boundary that was observed in the 2004-2004 and prior earthquakes. Meltzner et al. (2012) interpret that the magnitude of vertical paleodeformation relates to the magnitude for those paleoearthquakes, for the past ~1,100 years. Larger paleoearthquakes are reported in northern Simeulue for the following times: 500 ± 3, 556 ± 2, and 994 ± 16 cal yr BP (1450, 1394, and 956 AD). Smaller paleoearthquakes are reported in northern Simeulue for the following times: 520 ± 3 and 462 ± 3 cal yr BP (1430 and 1488 AD). The three larger paleoearthquakes aged 500 ± 3, 556 ± 2, and 994 ± 16 cal yr BP (1450, 1394, and 956 AD) may correlate with T-2, T-3, and T-6, aged 390 ± 260, 630 ± 110, and 940 ± 180 cal yr BP (1560, 1320, and 1010 AD; Table 7) respectively (Meltzner et al., 2010, 2012). The ages for T-2, T-3, and T-6 support the hypothesis that there were at least three earthquakes that were recorded by both microatoll corals and in deep sea sediments. Two uplift event ages (462 ± 3 and 520 ± 3 cal yr BP; 1488 ± 3 and 1430 ± 3 AD; Meltzner et al., 2012) do not overlap with any turbidite ages. These two northern Simeulue uplift events have smaller magnitudes of uplift and may be the result of smaller subduction zone earthquakes (e.g. the 2002 November and 2008 February earthquakes; Briggs et al., 2006;

Philibosian et al., 2014), crustal earthquakes (local to Simeulue), or slow earthquakes that would not coincide with ground motion–triggered submarine slides. There is a temporal gap (462-20 cal yr BP, i.e. 1488-1930 AD) in the Meltzner et al. (2012) microatoll record during which we do not observe any correlated turbidites. Meltzner et al. (2010, 2012) speculated about possible missing earthquakes that may have occurred between their penultimate earthquake and the 2004 earthquake although we suggest that large earthquakes in this period are unlikely due to the absence of turbidites. Thresholds for recording earthquakes with coral microatolls are likely different than those for recording earthquakes in sedimentary deposits, making event comparisons problematic at this stage of development in the Sumatra margin paleoseismic record.

We note that the timing of the paleoearthquake record of the Siberut and Enggano segments (Kopp et al., 2008; Sieh et al., 2008, Philibosian et al., 2012, 2014) and the Meltzner et al. (2012) record overlap in age range with the penultimate (T-2) and antepenultimate (T-3) turbidite ages from this study. However these uplift event ages from the Siberut and Enggano segments do not overlap with uplift event ages from Simeulue (Sieh et al., 2008; Meltzner et al., 2010, 2012; Philibosian et al., 2012). The overlap with turbidite ages is therefore due to the larger uncertainties for the turbidite ages, since the coral ages do not overlap. While long earthquake sequences such as the 2004-2010 sequence along Sumatra may have occurred in the past (Sieh et al., 2008), they are not necessarily the rule over the 6,500 year span in the turbidite record.

Although these comparisons are somewhat coarse, the offshore evidence is broadly compatible with the onshore paleoseismic events. Paleotsunami, microatoll, and uplifted reefs may not record all earthquakes and thus may also represent maximum intervals for recurrence of Great earthquakes sensitive to the recording thresholds of the different methods.

Temporal Pattern

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When we consider the turbidite correlation standards for the same time period, there is 1 seismoturbidite that meets standard 1, 3 seismoturbidites that meet standard 2 or higher, and 7 turbidites total, 3 of which only meet standard 3. The RIs for these three standards are 1080, 540, and 180 yr, respectively. The seismoturbidites of standard 2 or higher (3 earthquakes) match the Simeulue record in number and the total number of turbidites (7) is similar to the Simeulue record (6); however, the individual age overlaps are poor. Only T-1 and T-6 have good age matches. Four Simeulue events closely spaced in time between the mean ages of T-2 and T-3 overlap both those turbidite ages at the 95.4% uncertainty level (Fig. 11). Other turbidites (e.g. T-4 and T-5) appear not to have good matches with the microatoll record, possibly because these turbidites were deposited during a temporal gap in the microatoll record (Meltzner et al., 2012). Given that our RI estimates and those of Meltzner et al. (2012) describe earthquakes that generate observable records, these estimates are maximum recurrence intervals representing an unknown completeness of record in both cases. The turbidite record for the 2004 rupture area covers ~270 km of strike length between the persistent (Meltzner et al., 2012) Simeulue segment boundary and the Indian border, while the tsunami record includes the entire Indian Ocean basin. We speculate that both the tsunami and turbidite records are more spatially extensive, and may be less subject to any spatial bias related to long-term slip heterogeneity (or lack thereof) or site location relative to past slip patches that might exist for what is essentially a single site at the north end of Simeulue Island. Given these factors, there is a good temporal fit between the turbidite record and the records of earthquakes in the form of paleotsunami deposits, uplifted abrasion platforms, and paleodeformation recorded by coral microatolls.