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Ambiguous correlation of precisely dated coral detritus with the tsunamis of 1861 and 1907 at Simeulue Island, Aceh Province, Indonesia

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ABSTRACT

Precise U–Th dates from coral detritus in two pre-2004 tsunami deposits on Simeulue Island in Aceh Province allow us to correlate the deposits with historically documented tsunamis in the recent few centuries, but because of potential discordance between the death dates of the corals and deposition of the sand layers, ambiguity in this correlation remains. Pits at coastal lowland sites exposed sand layers beneath the 2004 tsunami deposit at Busung and Naibos on southern Simeulue Island. The layers share sedimentological characteristics with the deposit of the 2004 tsunami, and are interpreted as pre-2004 tsunami deposits. Historical accounts document earthquakes and tsunamis in 1907 and 1861 and suggest that the 1907 tsunami was larger locally than any others historically. Nonetheless, U–Th analyses of coral boulders in the younger of two pre-2004 deposits at Busung and in the lone deposit at Naibos yielded dates of death that overlap with 1861, but there were no tsunami layers that could be directly dated to 1907. The younger pre-2004 sand deposit can be attributed to both the 1861 and 1907 events, if the dated corals were killed by uplift in 1861 and subsequently entrained and deposited by the 1907 tsunami. A piece of coral in the older of the two pre-2004 sand layers at Busung dated to around AD 1783, and was deposited by an unknown tsunami that occurred after AD 1783, or possibly by the 1861 tsunami. The nearly equatorial latitude of the study sites minimizes potential for geological confusion between tsunami and storm. Our results show the difficulty in matching known events and geological records when using limiting maximum ages from allochthonous fossils, even with high precision radiometric dates.

1. Introduction

How wide can gaps be between the true age of a layer and ages from its accompanying allochthonous fossils? Researchers commonly use ages of plant or animal fossils in sediment layers to estimate the timing of events such as earthquakes and tsunamis, and to correlate those events with events at other sites, or with events from the historical record. However, in many cases allochthonous fossils may have died decades or centuries before their deposition. For example, leaf fragments from pre-2004 tsunami deposits at Phra Thong Island in southern Thailand gave radiocarbon ages that differed from one another by hundreds of years, despite their occurrence in the same layer (Jankaew et al., 2008). Similarly, Nelson (1992) reported that various materials from the same stratigraphic horizon can differ in radiocarbon age by many hundreds of years. On the other hand, using in-situ plant fossils killed by coseismic subsidence, Nelson et al. (1995) significantly reduced the uncertainty in matching the age of dated material to an earthquake.

In this study, we compare ages of coral detritus entrained in tsunami deposits with ages of historical earthquakes, by using uranium–thorium techniques with much greater precision than would have been afforded by radiocarbon techniques. Our pit excavations exposed pre-2004 tsunami deposits from the past few centuries at two study sites on Simeulue Island, Aceh Province, Indonesia. Although both sites lie atop the 2005 rupture patch, they are exposed to tsunamis from both the 2004 and 2005 patches (Fig. 1).

Large tsunamigenic fault ruptures occur frequently along the Sunda megathrust. Off the coast of northern Sumatra, in the region of the 2004 M_W 9.2 and 2005 (M_W 8.6) ruptures, earthquakes potentially of M ~7.5 or greater occurred in 1861 and 1907 and resulted in tsunamis known to have affected the Acehnese coast (Newcomb and McCann, 1987). The 1861 earthquake caused heavy shaking at Nias Island and was accompanied by a tsunami that affected more than 500 km of the Sumatran coastline; it is regarded as an analog of 2005 in size and spatial extent (Meltzner et al., 2012b) (Fig. 1). Seafloor displacement of the 1907 earthquake caused a tsunami that devastated Simeulue

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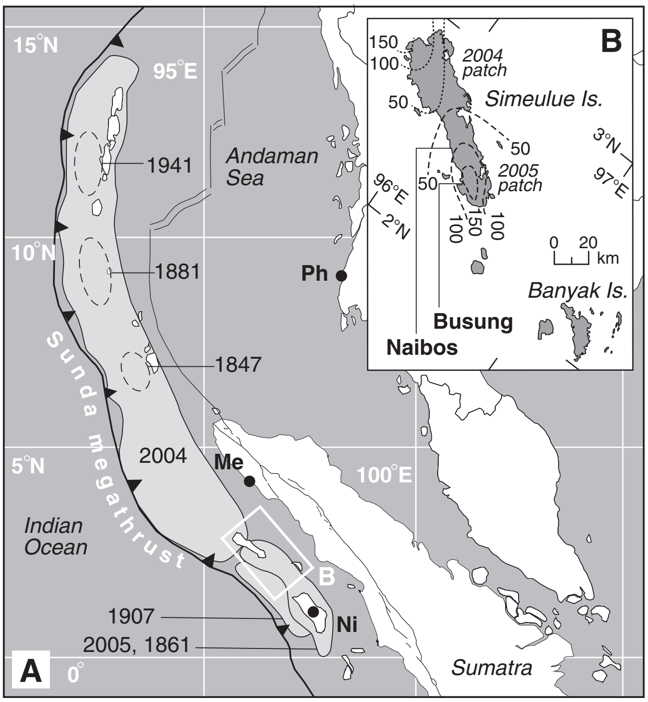

Fig. 1. Selected ruptures since the 19th century along the Sunda megathrust (A), and locations of the study sites (B). Rupture zones are from Bilham et al. (2005), Briggs et al. (2006) and Meltzner et al. (2010). The 1907 location is speculative. Ph, Phra Thong Island; Me, Meulaboh; Ni, Nias Island. Dotted lines show 2004 and 2005 uplift contours in centimeters, from Meltzner et al. (2012a).

Island and extended over 950 km along the Sumatran coast (Newcomb and McCann, 1987; McAdoo et al., 2006; Yogaswara and Yulianto, 2006; Yulianto et al., 2010). Recent analysis of old seismograms suggests that the 1907 earthquake was a tsunami earthquake, with a magnitude of M_S 7.8 ± 0.25 (Kanamori et al., 2010).

2. Pre-2004 sand layers at Busung

The Busung site is located in southwestern Simeulue Island. It is a small strand plain developed on a coral reef basement, and located at the head of an embayment, Teluk Gosong (Gosong Bay). Because of its location inside the bay, protected behind a sandbar that has emerged to become a small islet following tectonic uplift, the Busung site experiences lower wave energy than open coasts. The Busung reef flat subsided gradually before the 2005 Nias–Simeulue earthquake but rose more than 100 cm during the 2005 earthquake to be emerged above high tide (Briggs et al., 2006) (Fig. 2). Interseismic subsidence in the decades prior to the earthquake gradually eroded the beach berm on the strand plain, but the coseismic uplift left the eroded beach berm sequestered from further wave action on the emerged reef flat (Fig. 2). Palm trees that had grown on the reef flat following an earlier uplift were killed by the pre-2005 subsidence, but are now emerged as snags above high tide (Fig. 2). Both the 2004 and 2005 tsunamis surged through Gosong Bay, though the 2005 tsunami was not high enough to fully inundate the flat across the berm, according to local eyewitnesses. The 30–40 m wide plain behind the beach berm was a swampy flat before the 2004 tsunami but changed to grassland because of the 2005 uplift and deposition of the 2004 tsunami sand. An aerial photo taken just after the 2005 earthquake shows white sand deposited on the swampy flat by the tsunamis (Fig. 2A).

Many coral boulders lie on the plain behind the beach berm. They were buried by the 2004 tsunami sand but still project above the ground surface (Fig. 3). Some of them were transported from the reef by the 2004 tsunami, though others could have been transported by one or more prior tsunami. In addition, some limestone boulders derived from an alluvium apron behind the plain now lie atop the plain itself. These limestone boulders are re-crystallized and therefore can be distinguished from corals transported by a tsunami.

Shallow pit excavations and a trench made for a port construction at Busung exposed two bioclastic sand layers (Units B1, B2) in muddy sediments beneath the 2004 tsunami deposit (Pits A and F, Figs. 2, 4, 5). Fieldwork included stratigraphic logging of the pit walls, geochronologic sample collection and GPS mapping.

Approximately 1 m of sediment lies atop the mid-Holocene coral reef basement and consists of layers of coral rubble, blue sandy silt, the lower bioclastic sand layer, black organic-rich peaty silt with abundant rootlets, the upper bioclastic sand layer, more of the black organic-rich peaty silt, and finally the 2004 tsunami sand, in ascending order (Figs. 4, 5). The older bioclastic sand layer (Unit B1) separates organic-rich silt and underlying blue sandy silt, and the younger one (Unit B2) is bounded both above and below by organic-rich silt.

The coral rubble is composed of pieces of corals, articulated and disarticulated bivalves and calcareous algae. The blue sandy silt contains fragments of shell and calcareous algae, and has abundant burrows. Rootlets are observed in the sandy silt but are much less common than in the peaty silt. Some or all of the rootlets in the sandy silt grew downward from horizons in the peaty silt to penetrate Unit B1. The sandy silt is massive and does not show any laminations. The presence

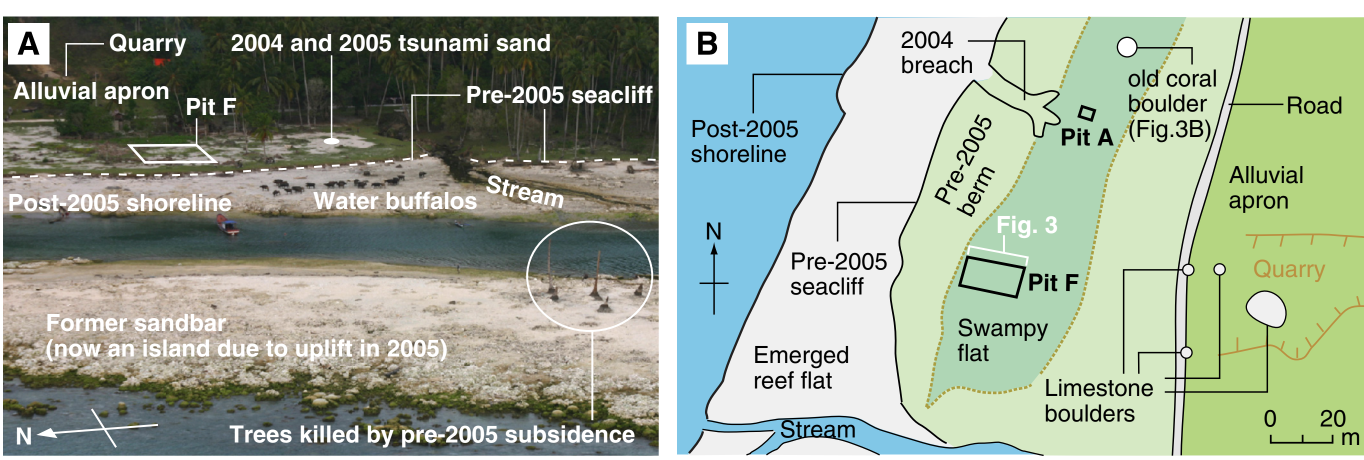

Fig. 2. (A) Aerial photo of the Busung study site, taken in May 2005. The coral reef flat emerged due to uplift in the 2005 Nias–Simeulue earthquake. Palm tree that had been killed by pre-2005 subsidence stand on the emerged reef. White patches on the grassy coastal plain are sand from the 2004 (and, if any, 2005) tsunami. (B) Locations of excavated pits and selected boulders at Busung. Note that the orientation is different from (A). The former sandbar (post-2005 island) in the foreground in (A) is just off the map in (B).