EARTHQUAKE RECURRENCE AND LONG-TERM SEGMENTATION NEAR THE BOUNDARY OF THE 2004 & 2005 SUNDA MEGATHRUST RUPTURES

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ABSTRACT

Simeulue Island, off the west coast of northern Sumatra, straddles the boundary of the 2004 and 2005 Sunda megathrust ruptures. The 2004 and 2005 earthquakes nucleated northwest and southeast of Simeulue, respectively, and each ruptured bilaterally toward the 100-km-long island. Cumulative uplift was 1.5 m at both the northwest and southeast tips of the island but diminished toward the island's center, where uplift was 0.5 m or less. Hence, although the 2004 and 2005 uplifts overlapped, there was an uplift deficit, or saddle, on central Simeulue.

Postseismic and long-term interseismic behavior, as revealed by coral microatolls, suggests that the Simeulue Saddle is more than a transient feature. The Saddle was partially, but far from completely, filled in by postseismic slip through 2007. As much as ~20 cm of uplift occurred in the Saddle region during both the Nov 2002 and Feb 2008 M ~ 7.3 earthquakes, although even those contributions fail to erase the deficit. Microatoll morphologies indicate that, averaged over decades and longer, interseismic strain accumulation rates are lower in central Simeulue than at the island's ends.

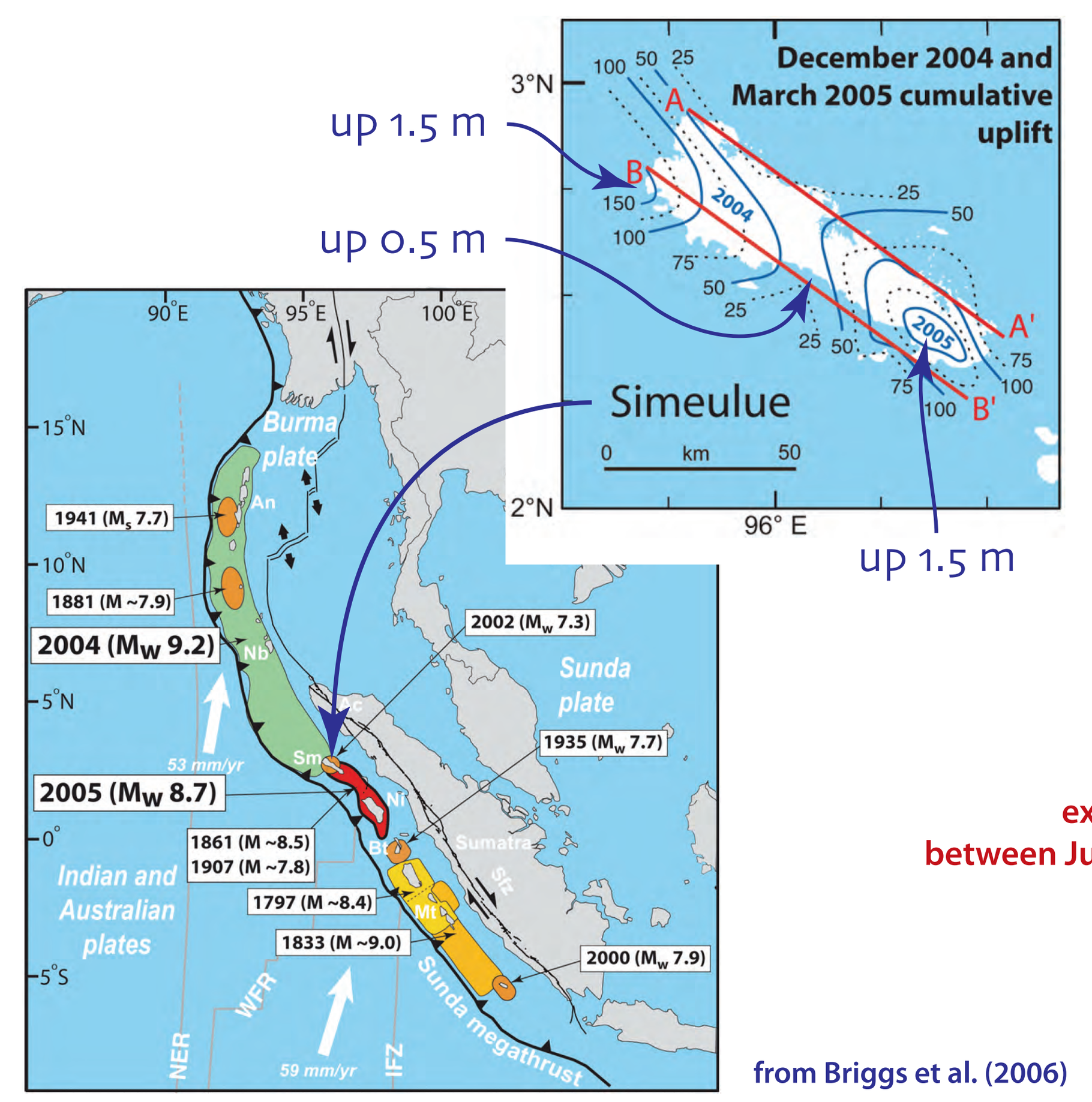
U-Th dates of fossil coral microatolls suggest that northern Simeulue, which was uplifted in 2004, experienced an earthquake couplet or triplet in the 14th-15th centuries. Sites there experienced modest uplifts in ~AD 1394 and substantially larger uplifts in ~AD 1454. Some evidence exists for a third event, earlier in the 14th century, that uplifted northern Simeulue, but there is no evidence for prehistorical events after ~1454. The apparent lack of coral living on any of the reefs of northern Simeulue between ~AD 1454 and the early 20th century suggests that the reefs were above sea level during that entire period.

South of the Saddle, prior uplifts occurred in AD 1907, 1861, 1843, and around 1799. The 1861 earthquake appears to have been the closest analog to 2005 in size and extent, with 1843 and ~1799 being smaller, and with 1907 apparently occurring updip.

The spatiotemporal distribution of coral diedowns around Simeulue indicates that earthquakes have repeatedly propagated into the Saddle from both the north and the south, but there is no evidence of any rupture that has ever propagated through the Saddle. Altogether, observations of the behavior of central Simeulue during the recent and older earthquakes, and during postseismic and interseismic periods, suggest that the Simeulue Saddle is a poorly coupled segment of the megathrust that serves as a persistent barrier to rupture.

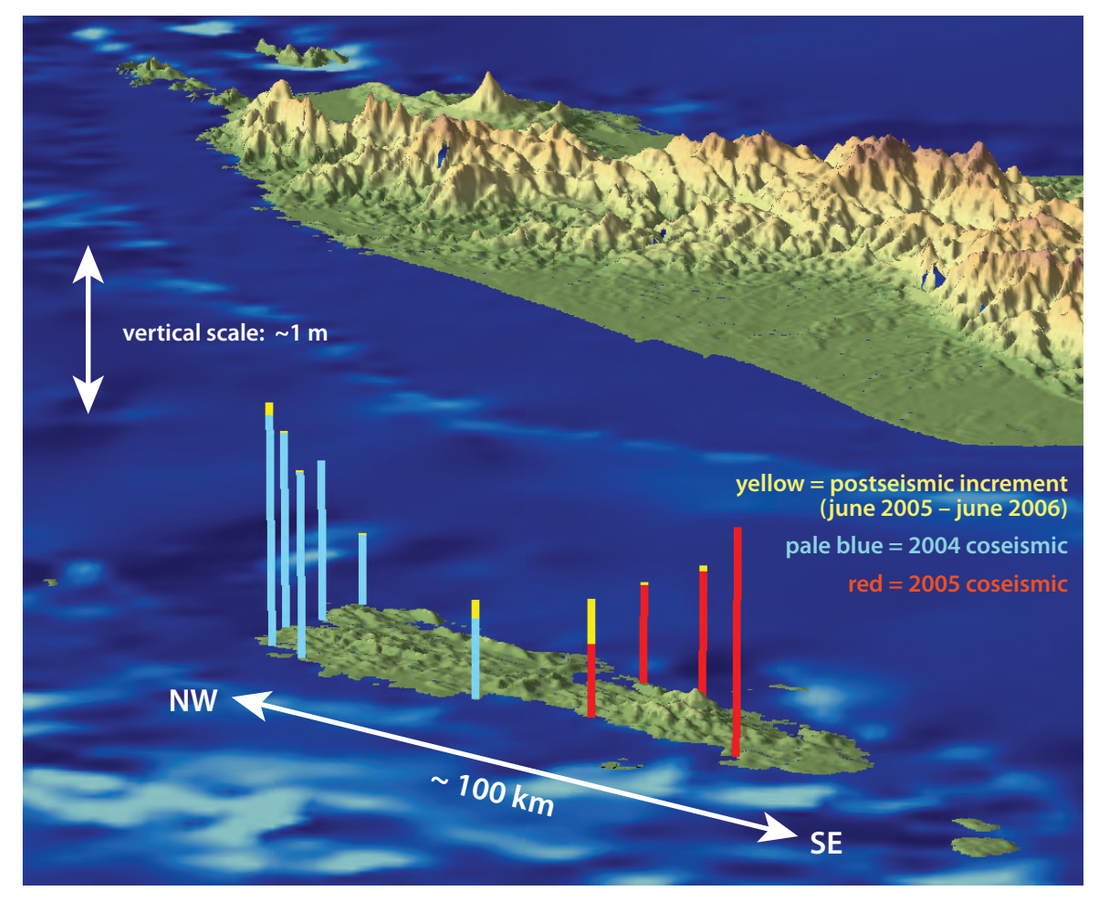
The Simeulue Saddle: A Region of Poor Coupling and a Persistent Barrier to Rupture?

The Simeulue Saddle was first recognized as a feature that arrested rupture in both 2004 and 2005 and had less cumulative slip overall in the 2004-2005 sequence....



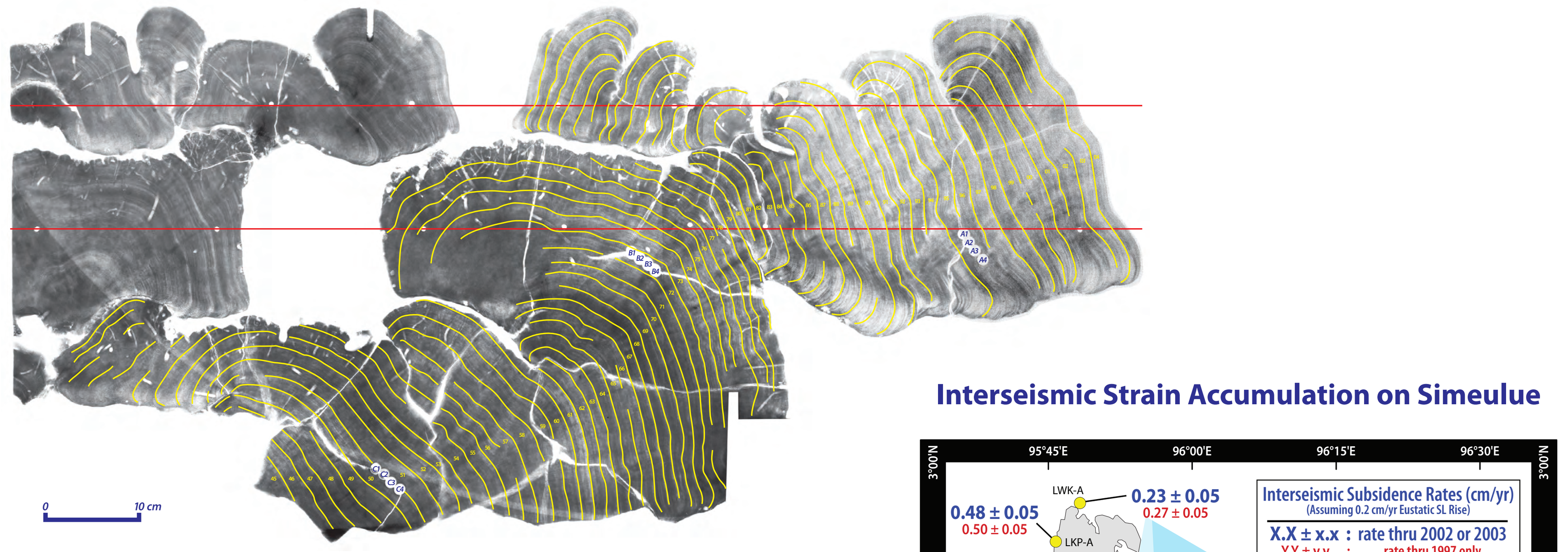
from Briggs et al. (2006)

Postseismic Uplift on Simeulue between June 2005 and June 2006



The Simeulue Saddle continued to exhibit anomalous behavior, experience substantially more postseismic uplift than surrounding areas between June 2005 and June 2006, yet the uplift deficit persisted through 2007....

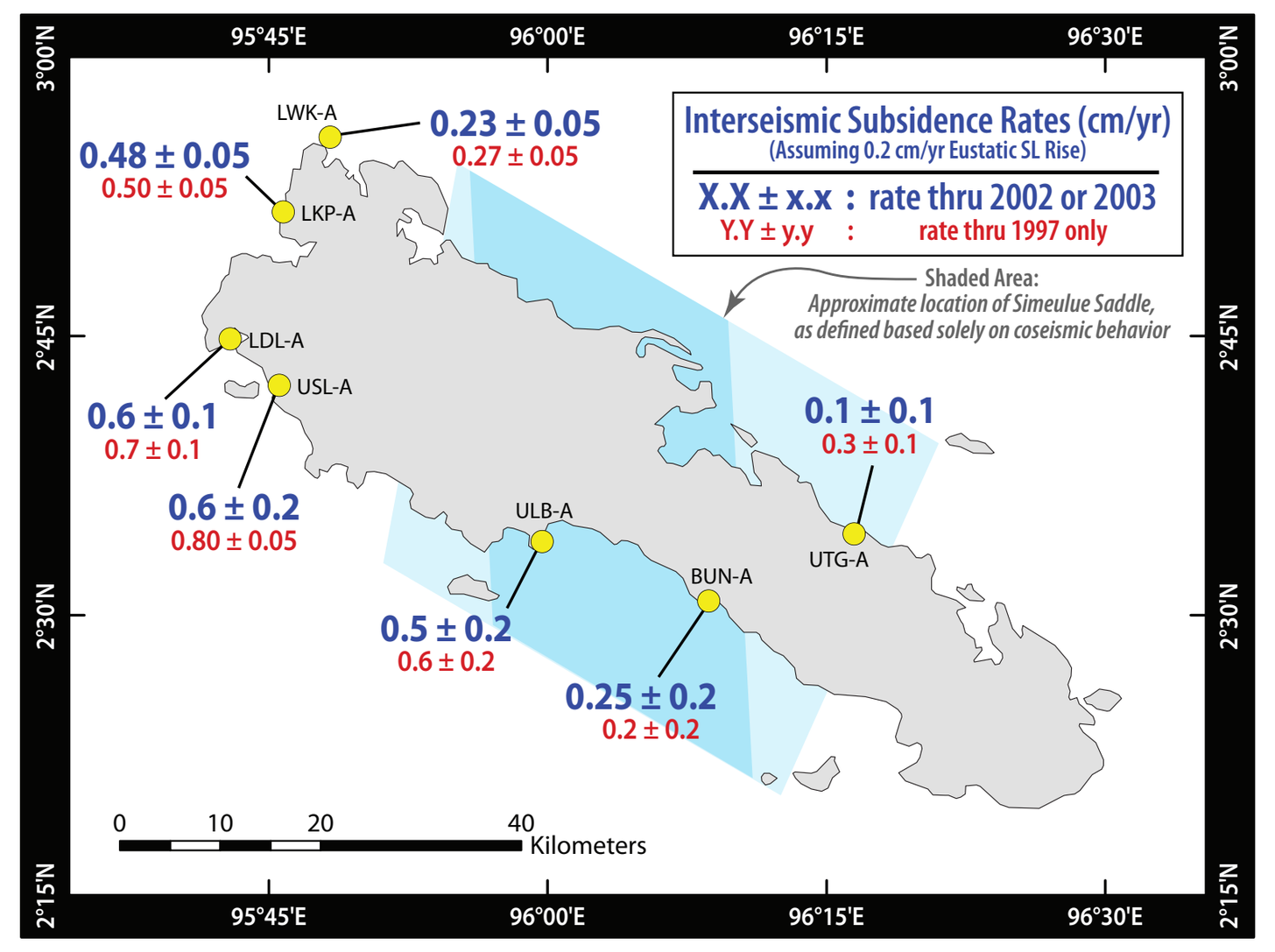
Briggs, R.W., K. Sieh, A.J. Meltzner, D. Natawidjaja, J. Galetzka, B. Suwargadi, Y. Hsu, M. Simons, N. Hananto, I. Suprihanto, D. Prayudi, J.-P. Avouac, L. Prawirodirdjo, and Y. Bock (2006). Deformation and slip along the Sunda megathrust in the great 2005 Nias-Simeulue earthquake, *Science* **311**, 1897-1901.



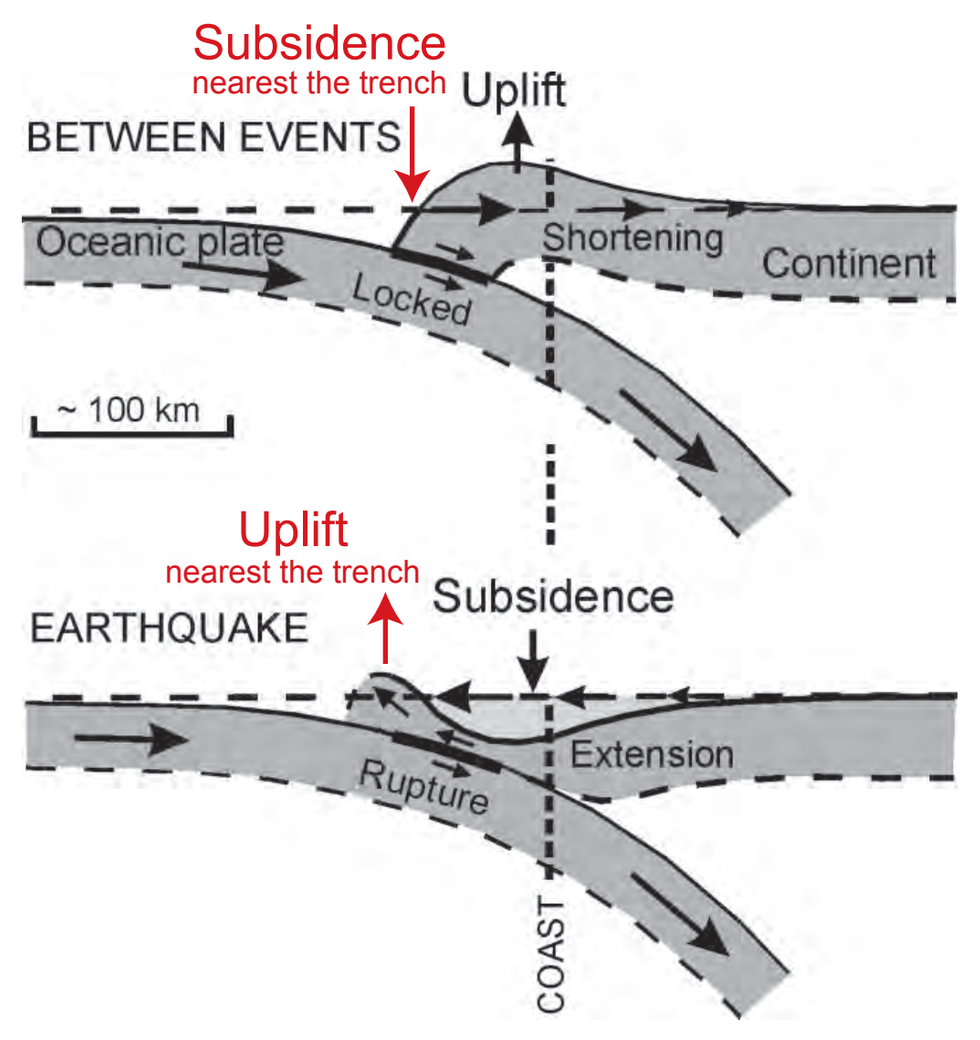
Example interpreted slab of microatoll LKP06-1

X-ray radiographs of coral microatoll slabs tell us about interseismic strain accumulation around Simeulue during the decades leading up to the 2004-2005 sequence, and they suggest that strain accumulation rates are slower in the Saddle, all other things being equal....

Interseismic Strain Accumulation on Simeulue



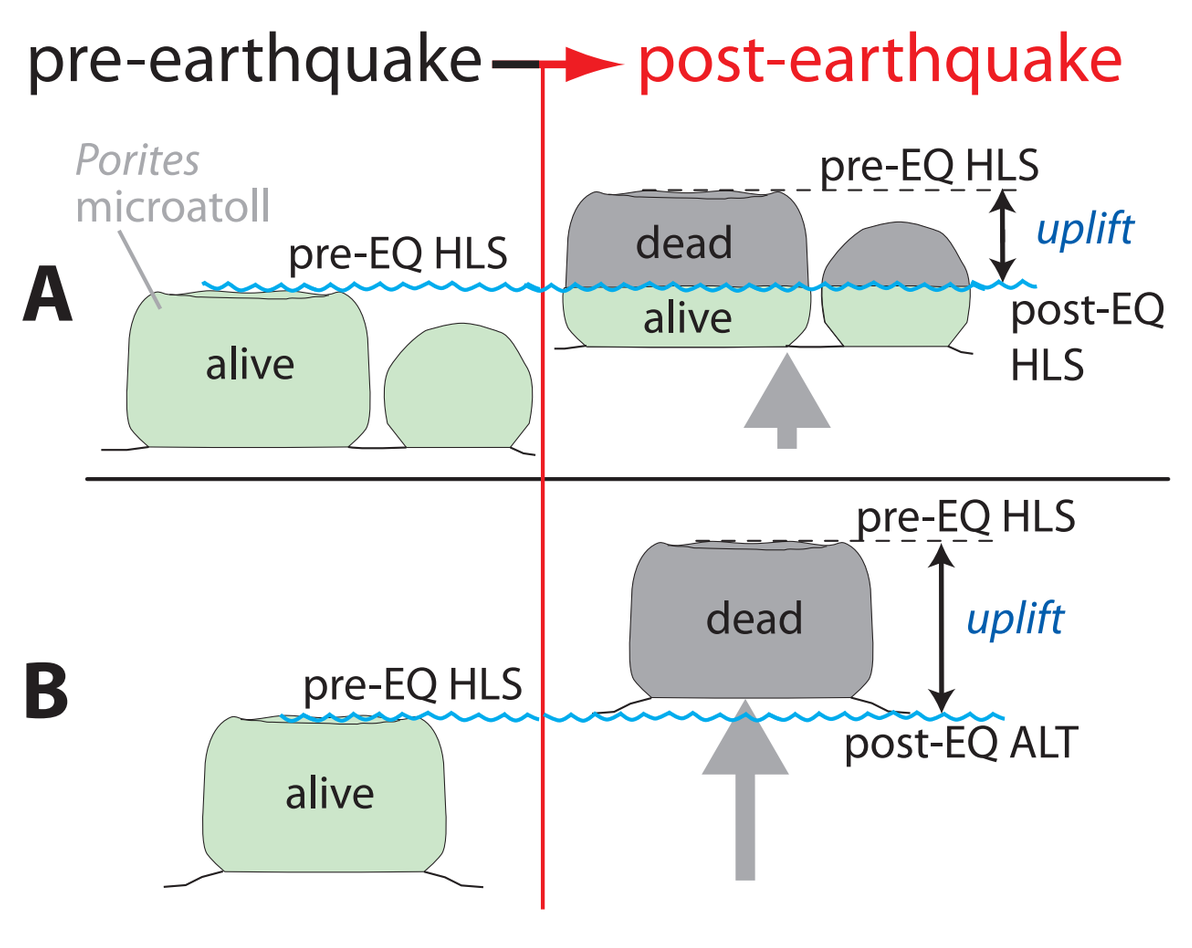
The Elastic Slip Dislocation Model



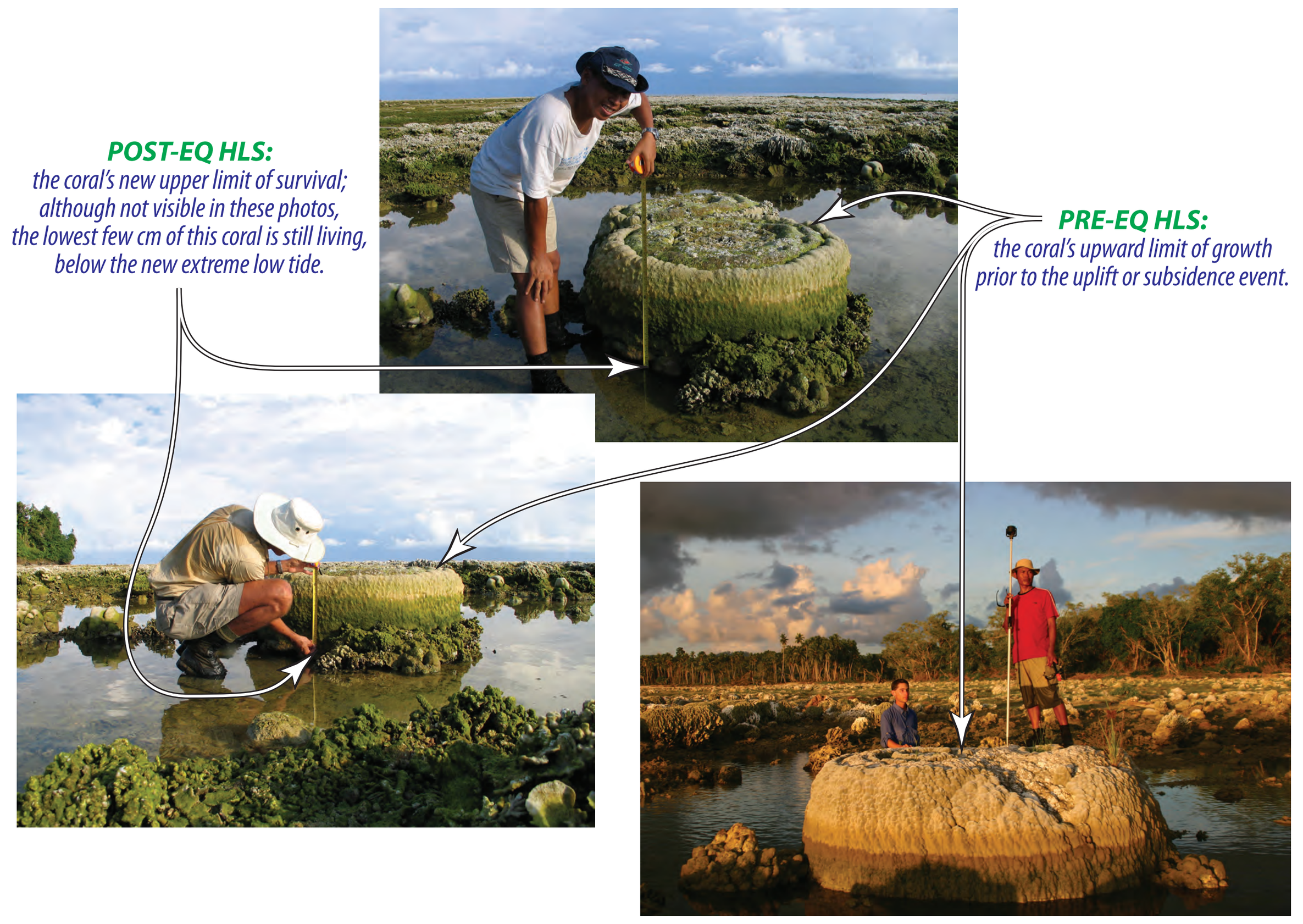
Pattern of interseismic and coseismic deformation expected with a subduction megathrust (from Leonard et al., 2004).

Leonard, L.J., R.D. Hyndman, and S. Mazzotti (2004). Coseismic subsidence in the 1700 great Cascadia earthquake: Coastal estimates versus elastic dislocation models, *Geol. Soc. Am. Bull.* **116**, 655-670.

Measuring Uplift with Coral Microatolls

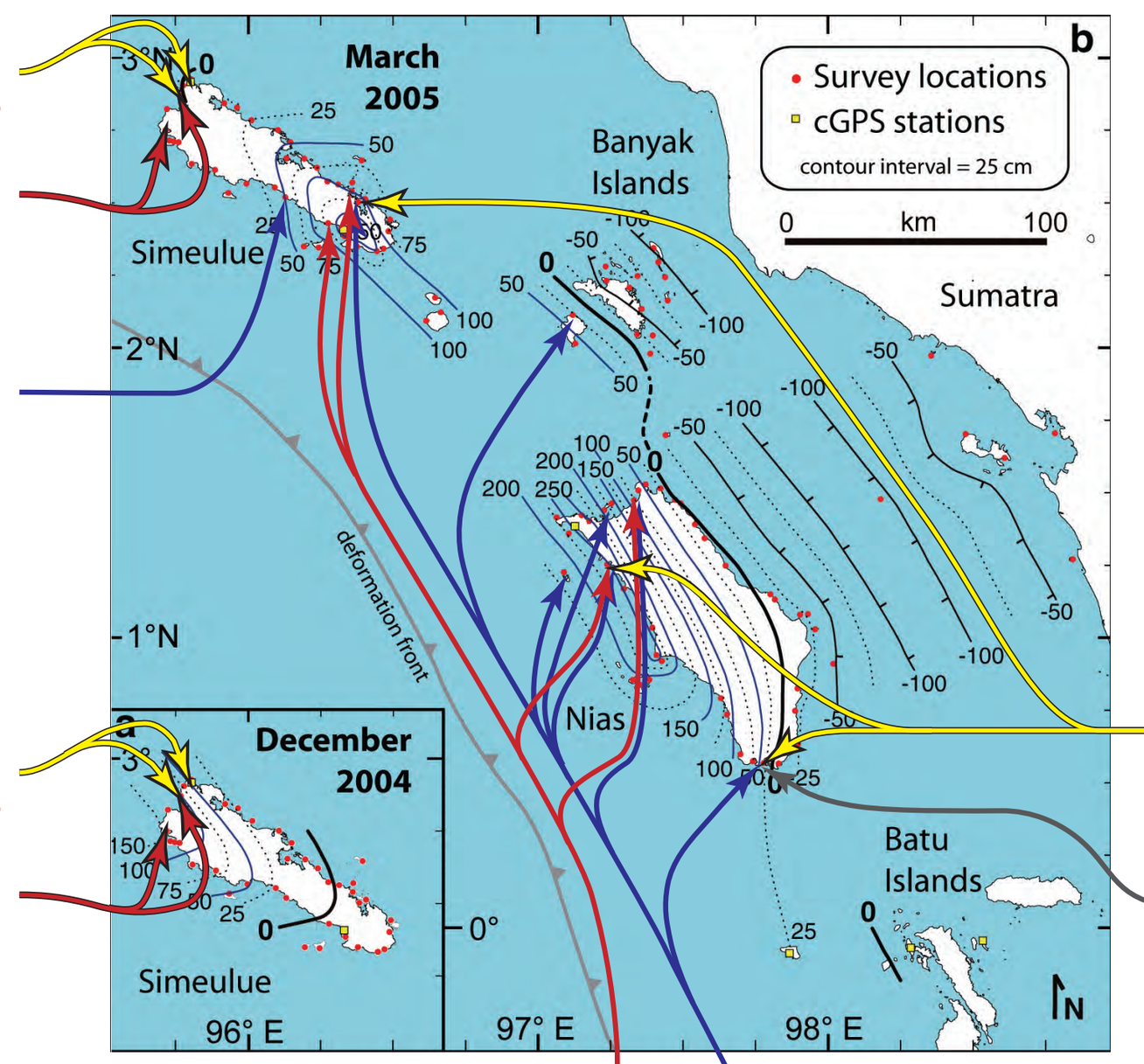


Scenarios for measuring vertical deformation using coral microatolls. (A) Uplift recorded as the difference between pre- and post-earthquake **highest level of survival (HLS)**. (B) Uplift as separation between pre-earthquake HLS **(pre-EQ HLS)** and the post-earthquake annual extreme low tide **(post-EQ ALT)**, determined by (*a*) surveying the water level at any given time; (*b*) noting the exact time of measurement; and (*c*) using a computational tide model and sea-level anomalies to tie the water level measurement to the lowest water level of the year.

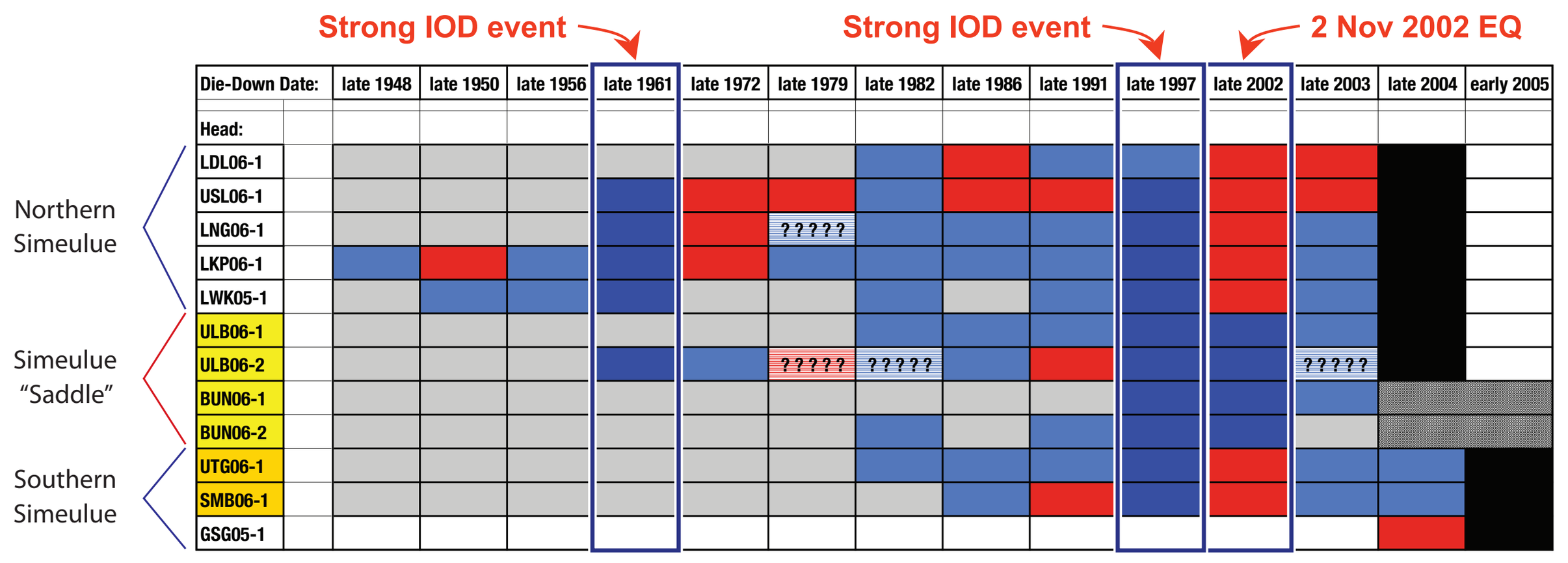


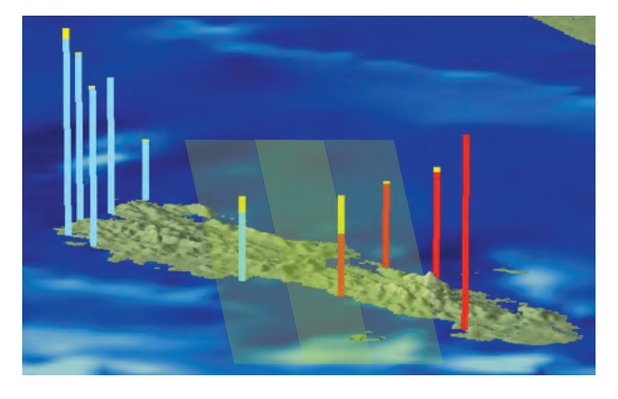
And spatio-temporal patterns of fossil coral die-downs lack any evidence for rupture propagation across the Simeulue Saddle: the Saddle acted as a barrier to rupture in 1394, 1428, 1454, 1861, 2004 & 2005, and likely in other events.

Evidence for Paleo-Earthquakes inferred from Uplifted Microatolls

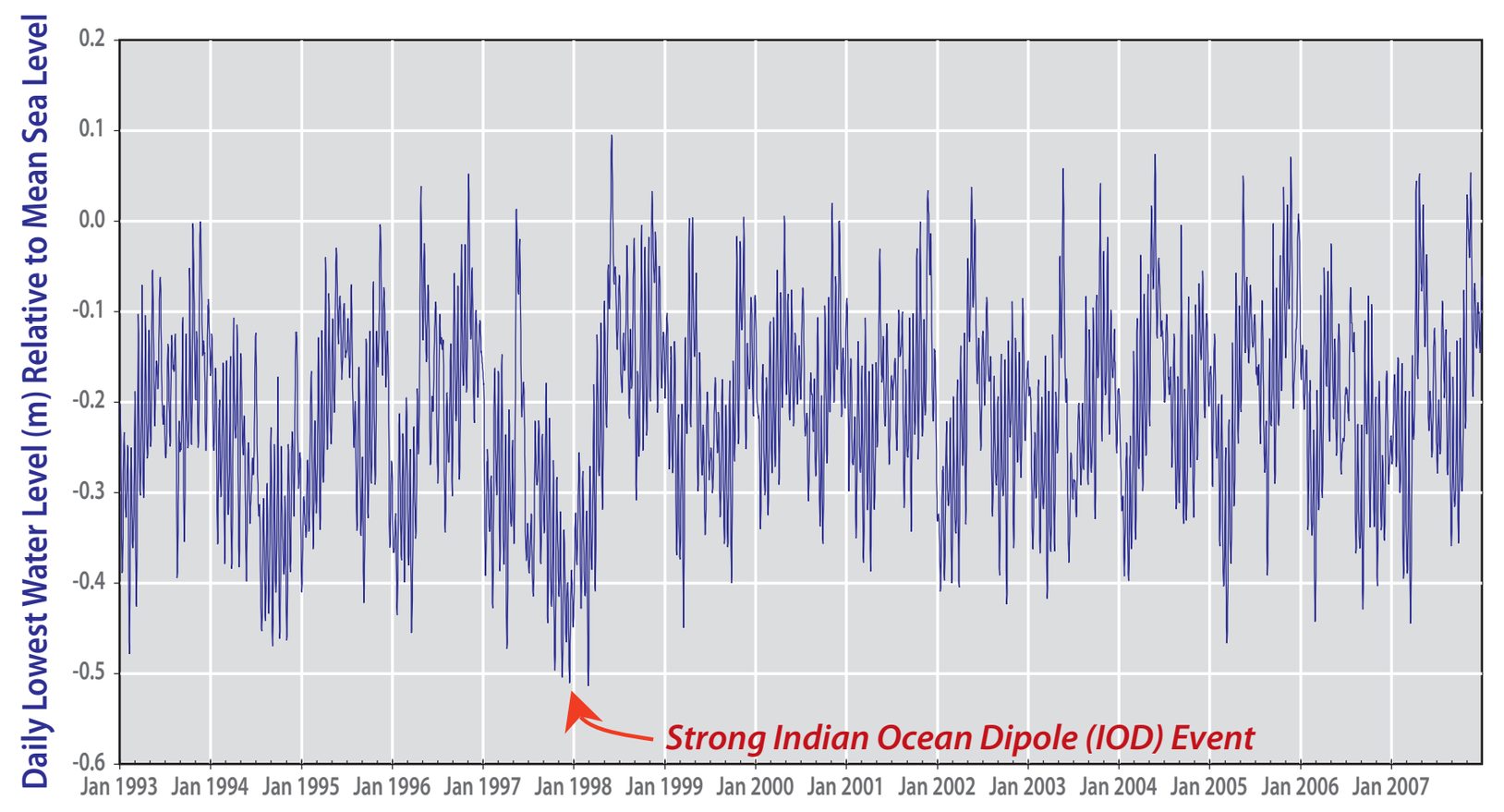


Spatio-Temporal Correlations of Microatoll Die-Downs on Simeulue

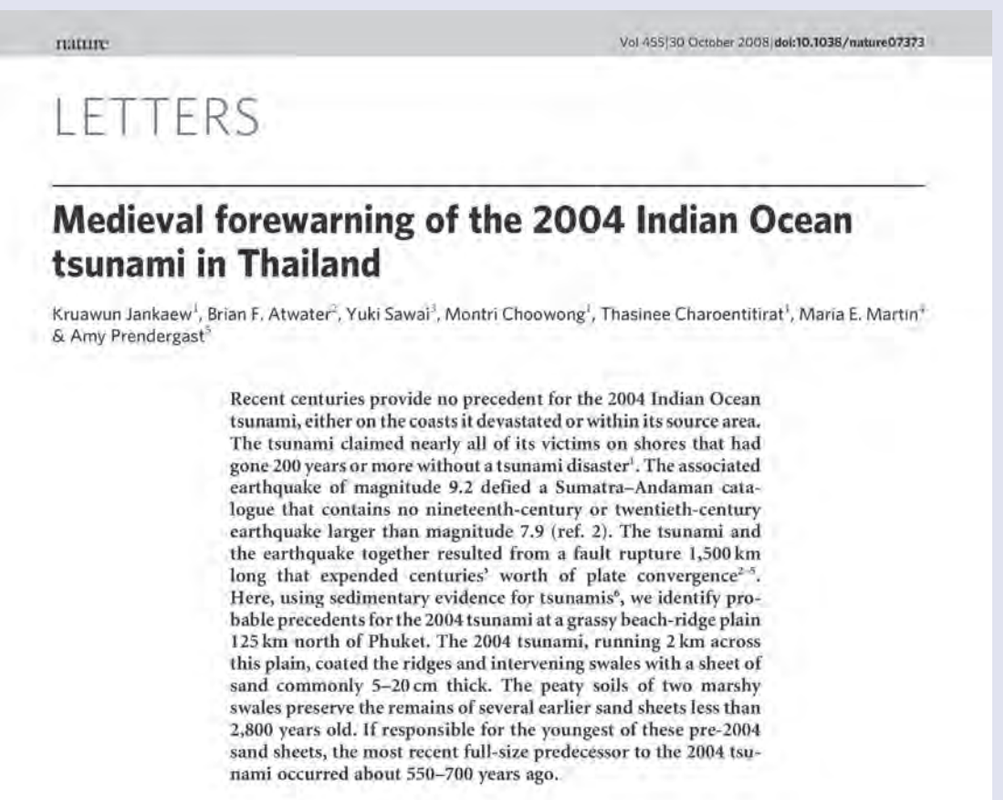




Central Simeulue Low Water Variations



An Emerging Story of the Predecessors of 2004....



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LETTERS

Medieval forewarning of the 2004 Indian Ocean tsunami in Thailand

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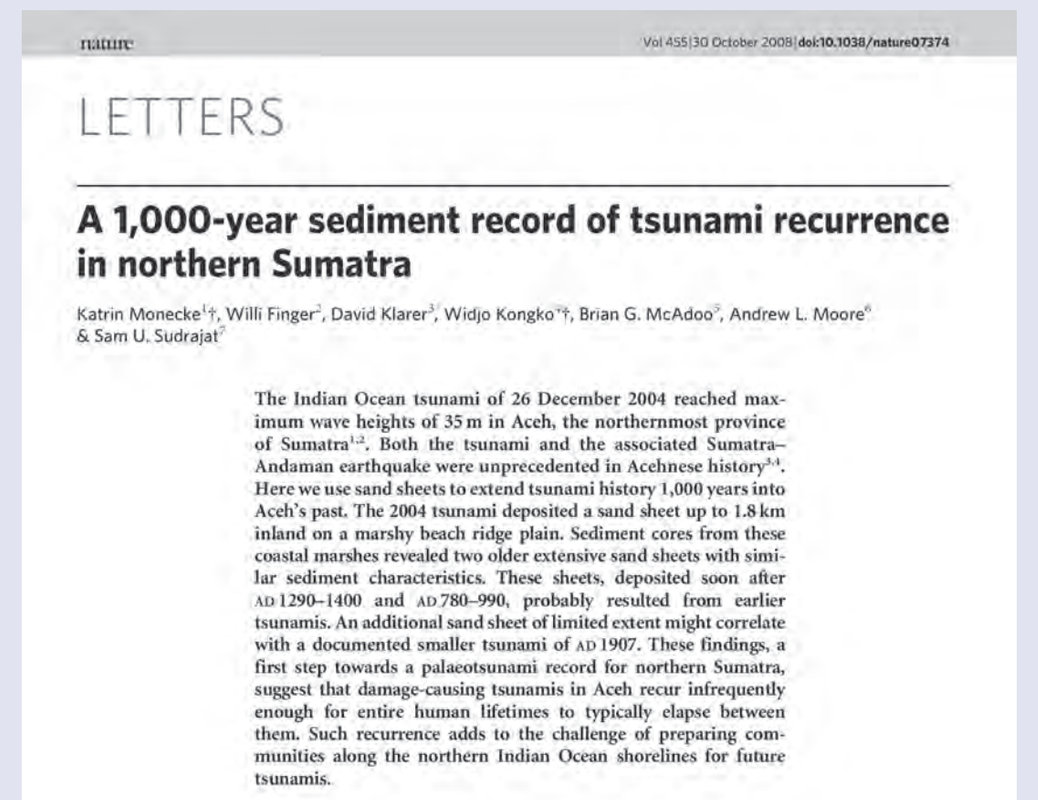
Recent centuries provide no precedent for the 2004 Indian Ocean tsunami, either on the coasts it devastated or within its source area. The tsunami claimed nearly all of its victims on shores that had gone 200 years or more without a tsunami disaster[1]. The associated earthquake of magnitude 9.2 defied a Sumatra–Andaman catalogue that contains no nineteenth-century or twentieth-century earthquake larger than magnitude 7.9 (ref. 2). The tsunami and the earthquake together resulted from a fault rupture 1,500 km long that expended centuries' worth of plate convergence[2–5]. Here, using sedimentary evidence for tsunamis[6], we identify probable precedents for the 2004 tsunami at a grassy beach-ridge plain 125 km north of Phuket. The 2004 tsunami, running 2 km across this plain, coated the ridges and intervening swales with a sheet of sand commonly 5–20 cm thick. The peaty soils of two marshy swales preserve the remains of several earlier sand sheets less than 2,800 years old. If responsible for the youngest of these pre-2004 sand sheets, the most recent full-size predecessor to the 2004 tsunami occurred about 550–700 years ago.



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LETTERS

A 1,000-year sediment record of tsunami recurrence in northern Sumatra

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The Indian Ocean tsunami of 26 December 2004 reached maximum wave heights of 35 m in Aceh, the northernmost province of Sumatra[1,2]. Both the tsunami and the associated Sumatra–Andaman earthquake were unprecedented in Acehnese history[3,4]. Here we use sand sheets to extend tsunami history 1,000 years into Aceh's past. The 2004 tsunami deposited a sand sheet up to 1.8 km inland on a marshy beach ridge plain. Sediment cores from these coastal marshes revealed two older extensive sand sheets with similar sediment characteristics. These sheets, deposited soon after AD 1290–1400 and AD 780–990, probably resulted from earlier tsunamis. An additional sand sheet of limited extent might correlate with a documented smaller tsunami of AD 1907. These findings, a first step towards a palaeotsunami record for northern Sumatra, suggest that damage-causing tsunamis in Aceh recur infrequently enough for entire human lifetimes to typically elapse between them. Such recurrence adds to the challenge of preparing communities along the northern Indian Ocean shorelines for future tsunamis.