The Fault Slip Record From Corals Above the Mentawai Segment of the Sumatran Subduction Zone

B Philibosian (Tectonics Observatory, Caltech); K Sieh (Earth Observatory of Singapore, Nanyang Technological University); J-P Avouac (Tectonics Observatory, Caltech); C-C Shen, H-W Chiang (National Taiwan University); DH Natawidjaja, BW Suwargadi (Indonesian Institute of Sciences [LIPI] Geotechnology)

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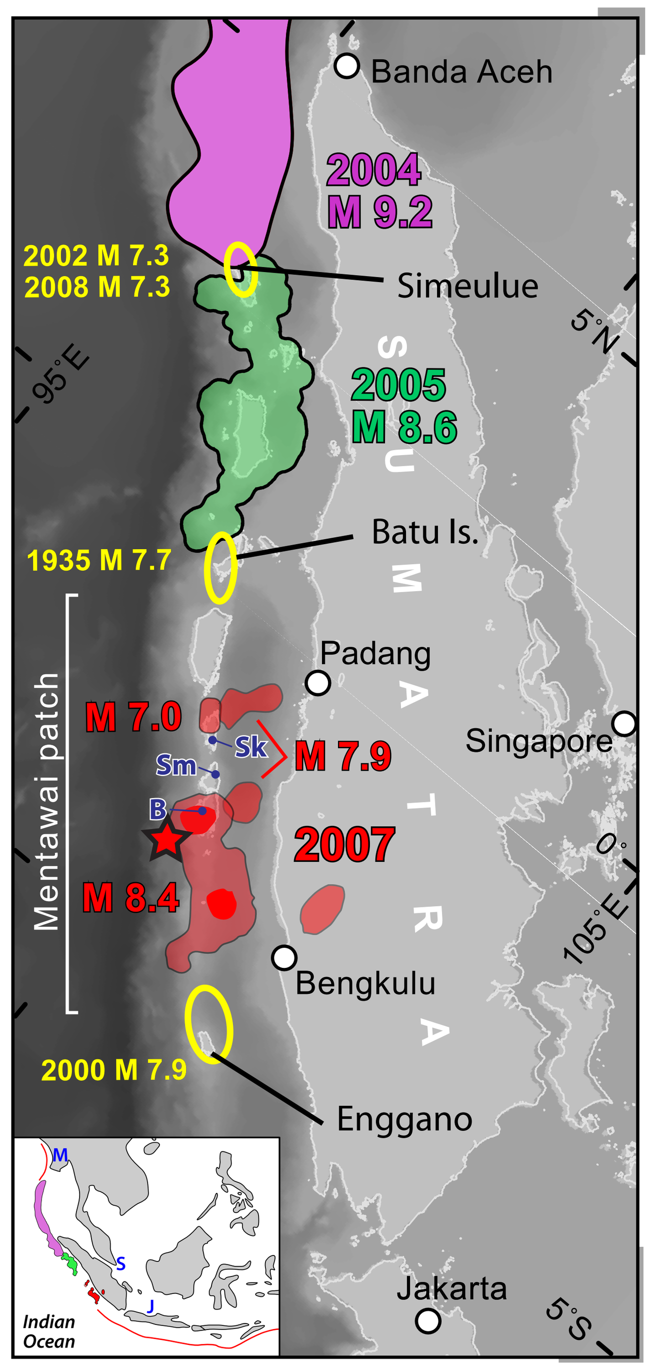
Abstract

Large sections of the Sunda megathrust have failed progressively over the past decade in an extraordinary earthquake sequence. One question of great humanitarian and scientific importance is how the remaining un-ruptured and under-ruptured patches might fail in coming decades. We use annually banded coral microatolls, which preserve precise information about past relative sea levels, to deduce tectonic histories centuries into the past. Our study focuses on the Mentawai segment of the megathrust, which is characterized by internal temporary barriers to rupture and thus provides an opportunity to study the evolution of stress on a fault plane.

Regional Overview

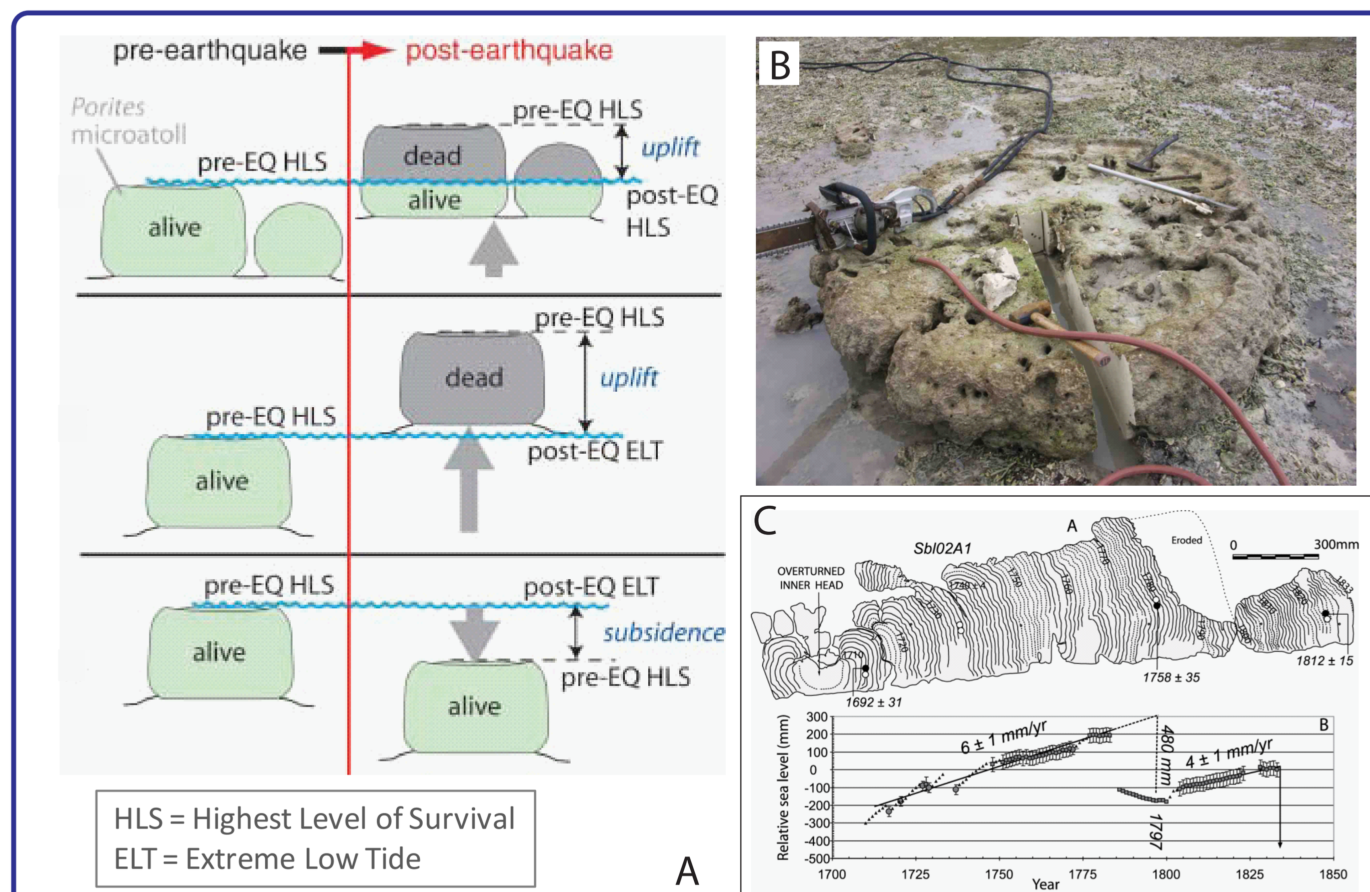


Recent seismic ruptures of the Sunda megathrust, offshore of Sumatra, delineate highly coupled large fault patches. The September 2007 sequence involved partial rupture of the Mentawai patch, which last broke in 1797 and 1833. The red star shows the epicenter of the 25 October 2010 Mw 7.7 earthquake, the latest in the current rupture cycle.

B, Sm, and Sk indicate sites with the longest, most complete paleoseismic records in the Mentawai Islands (Bulasat, Simanganya, and Sikici).

(Inset) M, S, and J are Myanmar, Singapore and Java. The red line is the outcrop of the Sunda megathrust on the sea floor.

While Simeulue, the Batu Islands, and Enggano appear to lie above permanent barriers to throughgoing fault rupture, the Mentawai patch is characterized by temporary barriers to rupture. As a result, it breaks in sequences of earthquakes rather than single end-to-end ruptures.

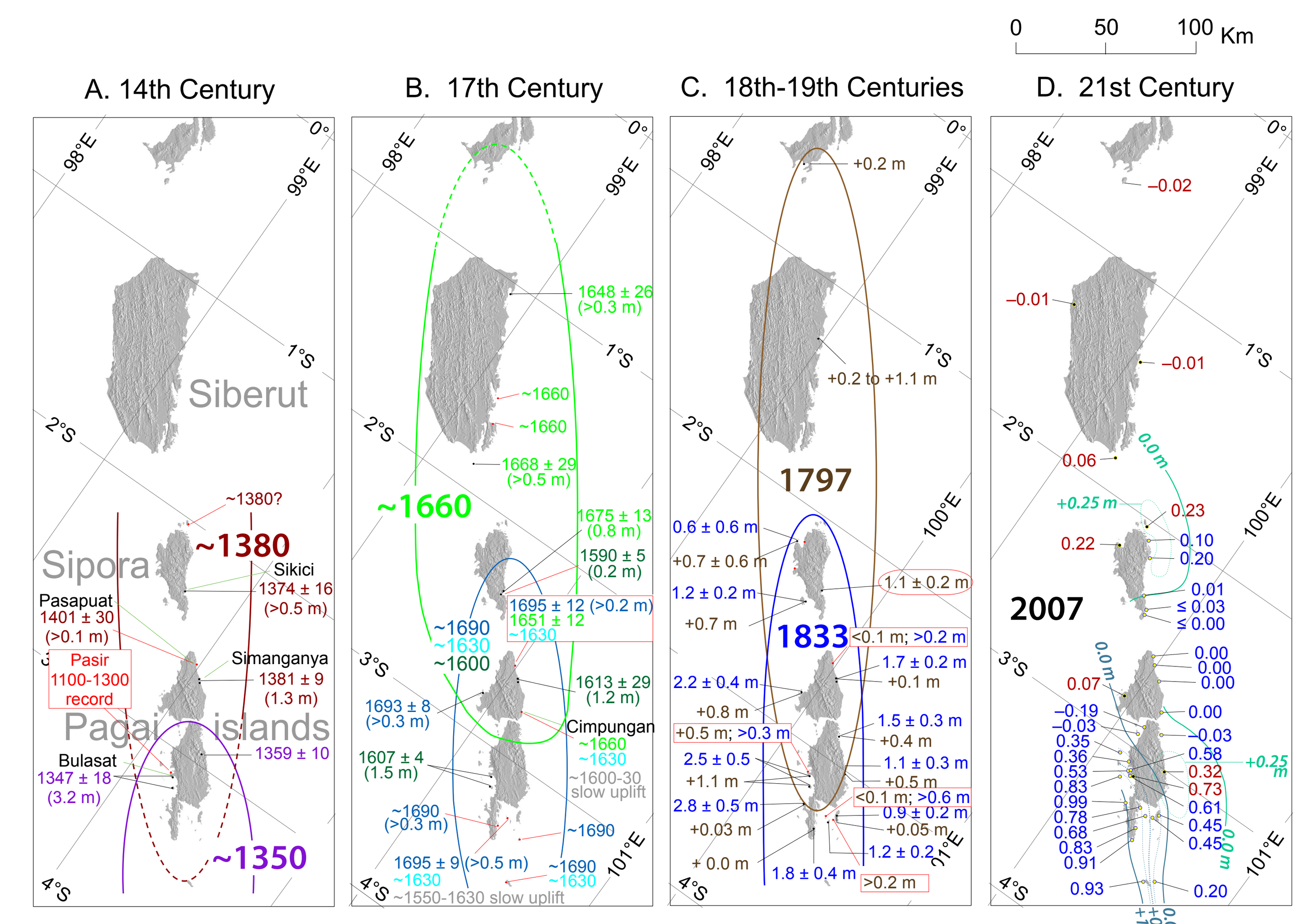


Coral Geodesy and Paleoseismology Techniques

A. Techniques for measuring recent coseismic or postseismic vertical deformation. Net uplift is measured by comparing pre- and post-earthquake HLS (top), while net subsidence can be measured by comparing pre-earthquake HLS to the extreme low tide (bottom). Adapted from Briggs et al. (2006). B. Example of a radial coral slab cut. C. Example of a slab cross-section, showing the annual band growth history and the corresponding relative sea level over time. This coral demonstrates slow interseismic subsidence before and after a coseismic uplift event. From Natawidjaja et al. (2006).

Seismic Supercycles

(right) Four emergence episodes of the past seven centuries. Each episode consists of more than one major event. The 2007 events probably herald the beginning of the next failure sequence.

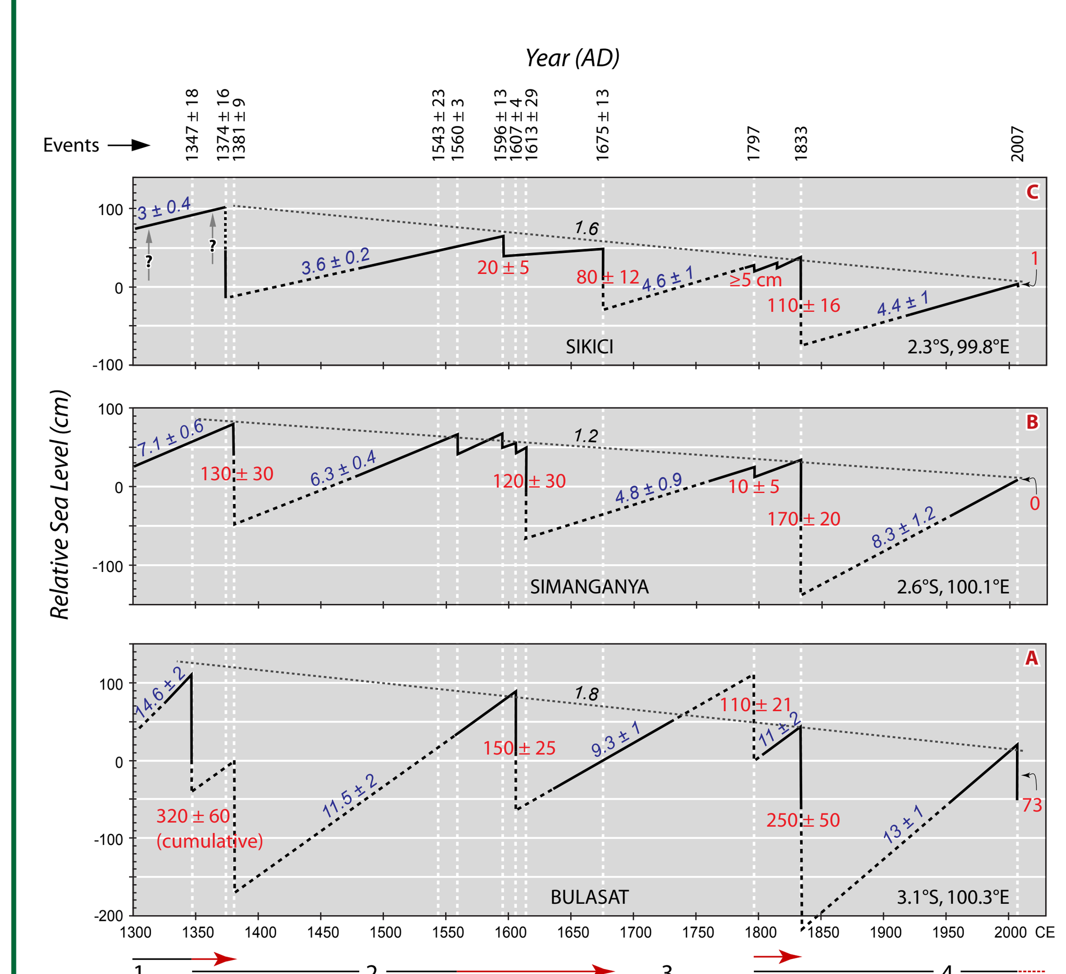


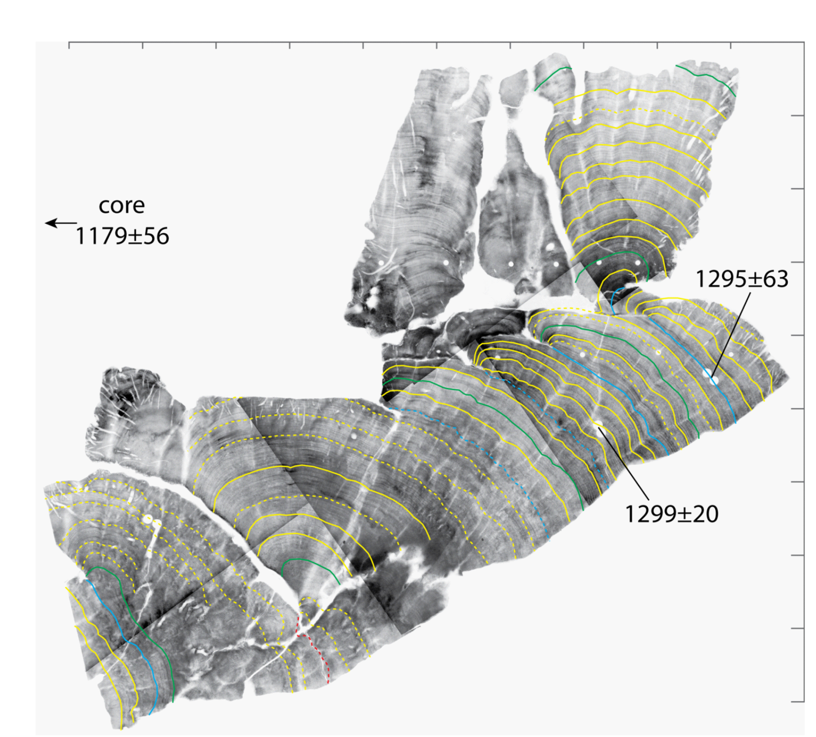
(below) A newly uplifted coral reef, showing the seismic cycle. The dead tree snags represent jungle trees that had grown when their roots were above the sea. Slow subsidence above the locked Mentawai patch lowered them into the sea. Just before the September 2007 earthquakes the shoreline was to their left, at the sandy beach, and their substrate was below lowest tide. Uplift during the earthquake raised their bases once again well above low tide.

New data (collected in 2008 and 2010; shown by red site locations and lines) has allowed us to refine all three of the past known supercycles. Two new sites corroborated the previously hypothesized late-1300s earthquake. The 1600s sequence, previously thought to consist of two earthquakes (in ~1600 and ~1685), was clearly more complex. Our newest data suggests that the northern section ruptured in ~1660, while the southern section had a major rupture in ~1690 and a smaller rupture in ~1630, as well as the ~1600 rupture. Additionally, two sites show evidence of slow uplift in the late 1500s to early 1600s. The 1600s sequence is perhaps a better analog to the ongoing rupture sequence than the relatively simple two-earthquake 18th-19th century rupture sequence. The new data has also provided a few minor refinements to the uplift distributions of the 1797 and 1833 earthquakes.

Updip Slip Circa A.D.1300: Ancient Analog of the 25 Oct 2010 EQ?

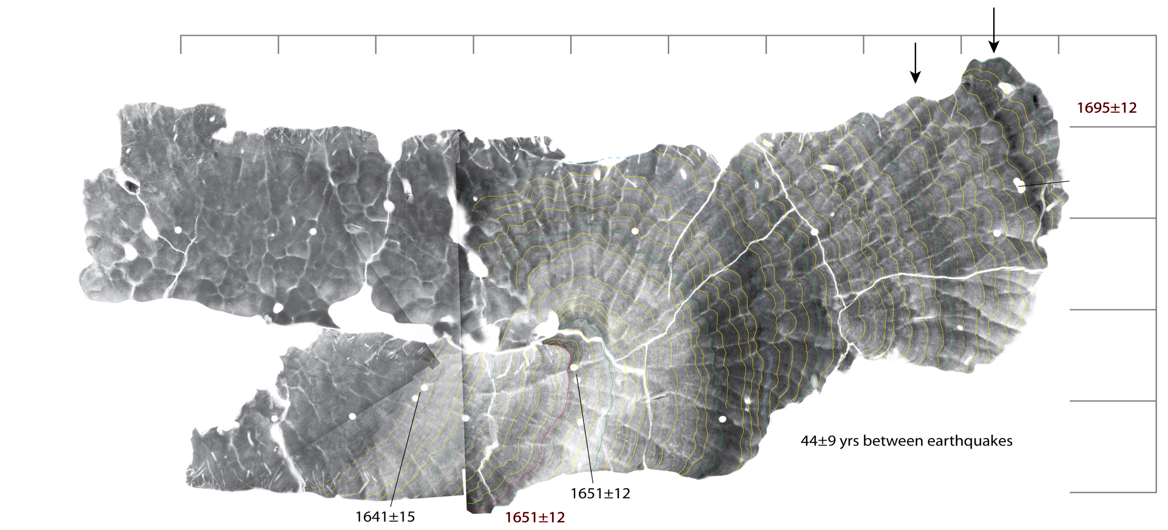
Long-term deformation histories (below) suggest slow net uplift. This uplift may be balanced by subsidence during more infrequent updip slip events. A 4-meter-radius coral (right) from Pulau Pasir (near the Bulasat site) supports this hypothesis: gradual interseismic subsidence is observed leading up to unfettered upward growth of the top of the coral in c.1300. This suggests a sudden subsidence event occurred at that time. The recent Mw 7.7 earthquake may also have been an updip event, which has probably caused the islands to subside. We will continue to study and compare the ~200-year growth history of this coral head and deformation resulting from the recent earthquake.



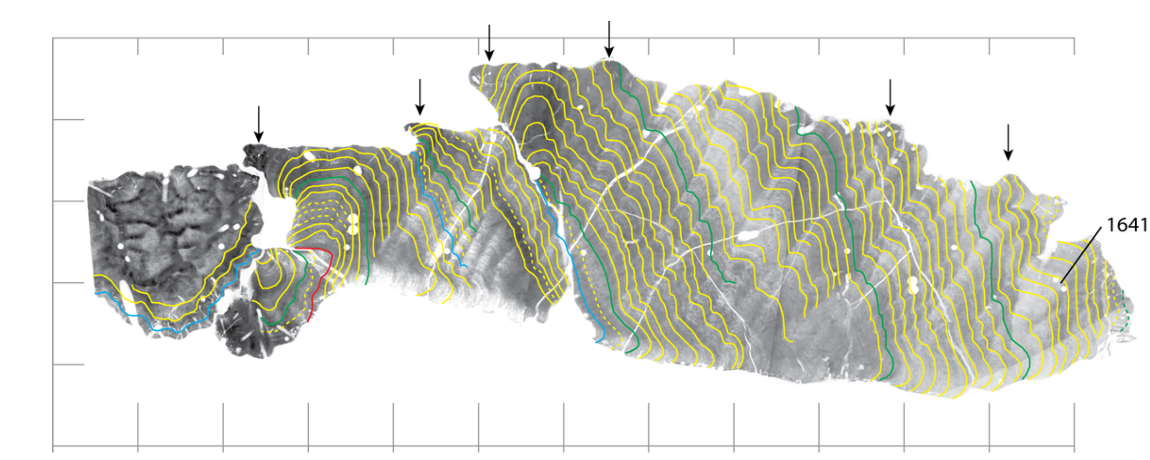


The 17th Century: 4 Earthquakes Interspersed With Slow Uplift

Recent results from corals dating to the 17th century suggest that the Mentawai patch ruptured in a complicated sequence involving as many as 4 separate earthquakes (in ~1600, 1630, 1660, and 1690). There is also evidence that slow uplift occurred during this period, perhaps a manifestation of aseismic slip. This rupture sequence may be analogous to the ongoing sequence, which has so far involved three separate earthquakes and significant postseismic motion.



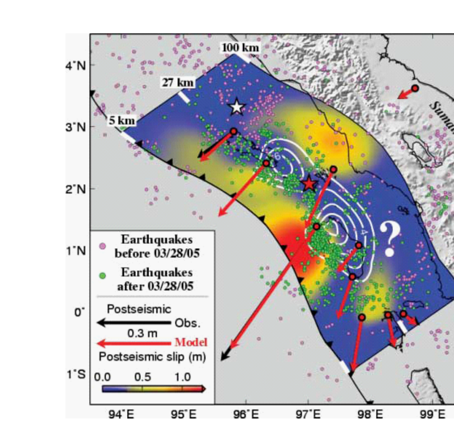
Coral from the Pasapuat site showing evidence for two earthquakes. The head was overturned in about 1660, probably by a tsunami, and then continued growing until about 1690 when it was uplifted and killed.



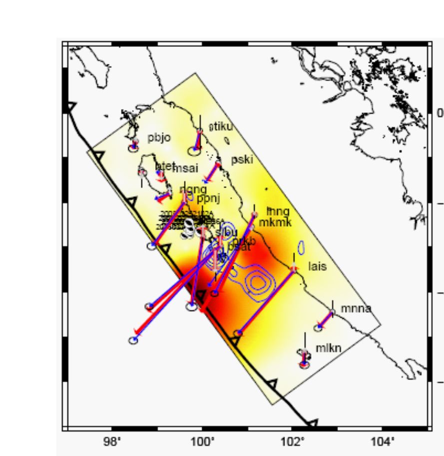
Coral from the Cimpungan site showing evidence for slow uplift. Black arrows indicate concentric rings observed in the field, indicating that the surface was not significantly eroded.

The 21st Century: Combining Corals With GPS

The beginning of a modern Mentawai rupture sequence in 2007 provides the opportunity to study the nature of temporary barriers to rupture. Modeling recent GPS and coral data will illuminate aseismic fault slip that may be responsible for stress transfer between highly coupled fault patches (asperities) which rupture seismically. We plan to construct a kinematic model of fault slip along the southern Sunda megathrust from 2004 to the present, updating and connecting the piecemeal models which have been done previously. Comparing the current behavior with the ancient supercycles, particularly in the 17th century, may provide insight into the process of fault plane stress evolution and suggest how the current rupture sequence is likely to unfold.



Postseismic slip following the 2005 Nias earthquake (Hsu et al. 2006)



Postseismic slip following the 2007 Mentawai earthquake (Kositsky and Avouac, in preparation)