Ancient Shallow Slip and Other Seismic Cycle Variations On the Sunda Megathrust, Sumatra

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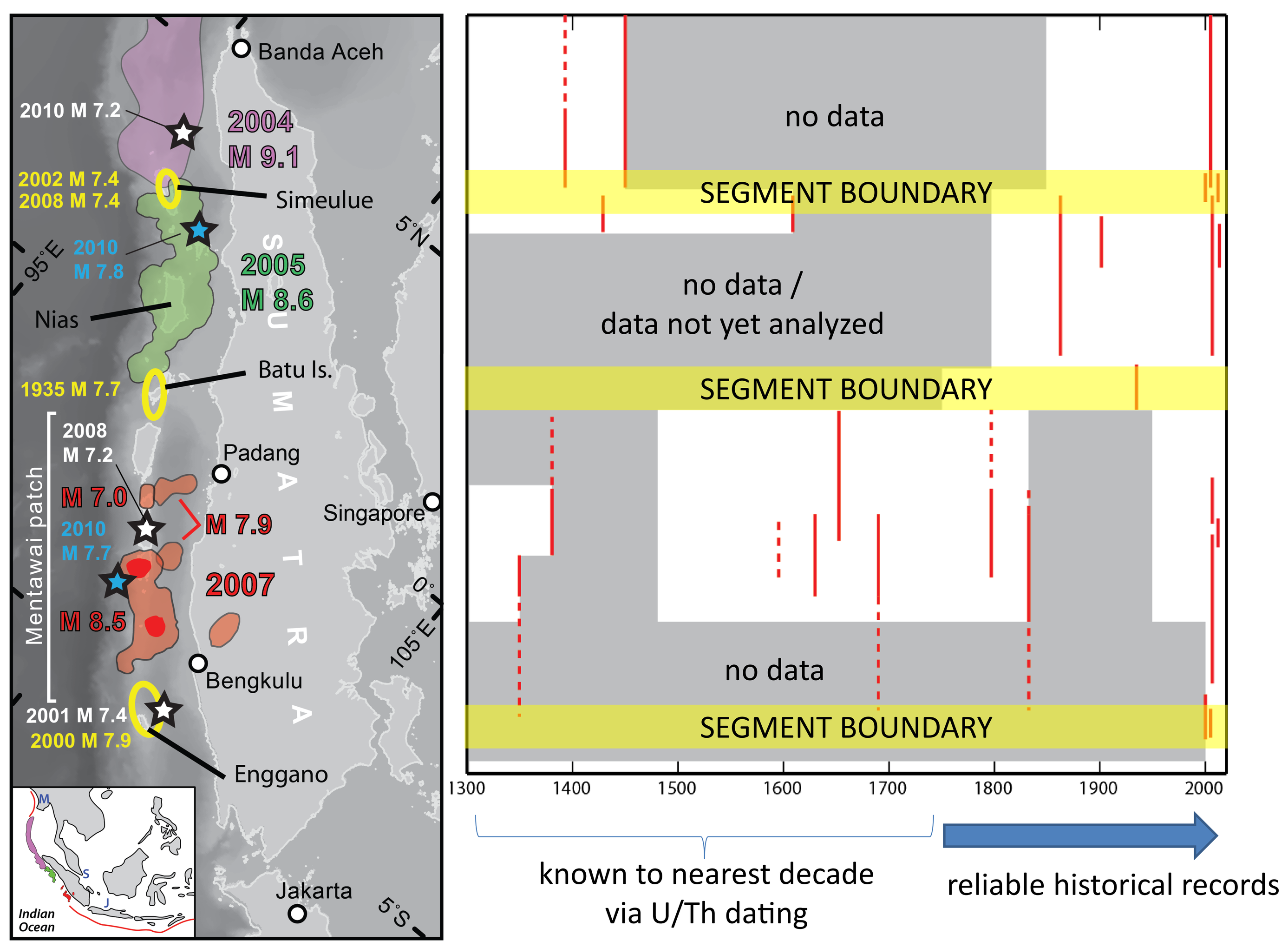
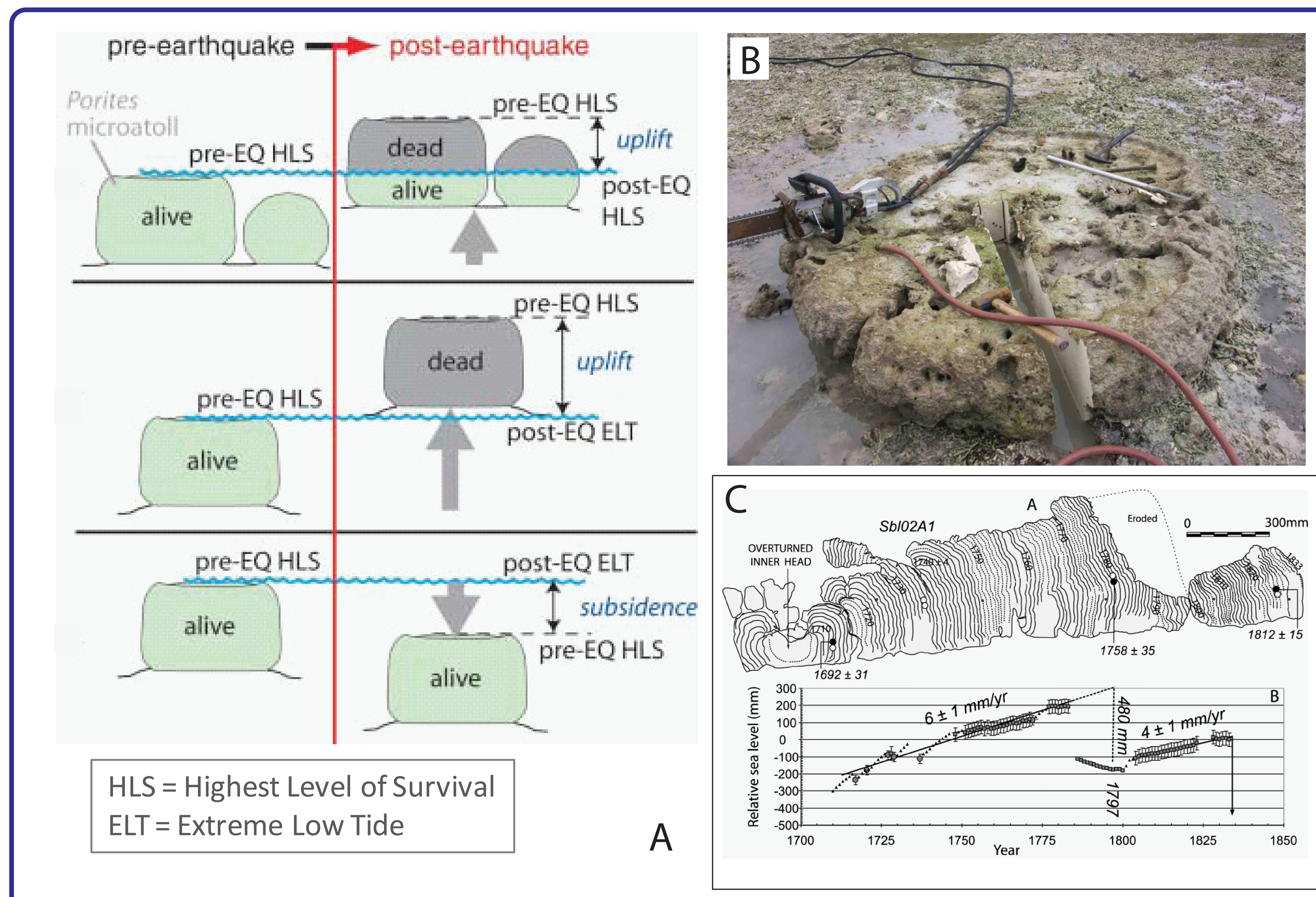
Abstract

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. Observations over multiple seismic cycles illuminate diverse types of fault rupture behavior, including a separate cycle on the shallow megathrust.

Regional Overview



Map of recent seismic ruptures of the Sunda megathrust, with a space-time diagram of rupture history compiled from our research. (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 fupture, 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

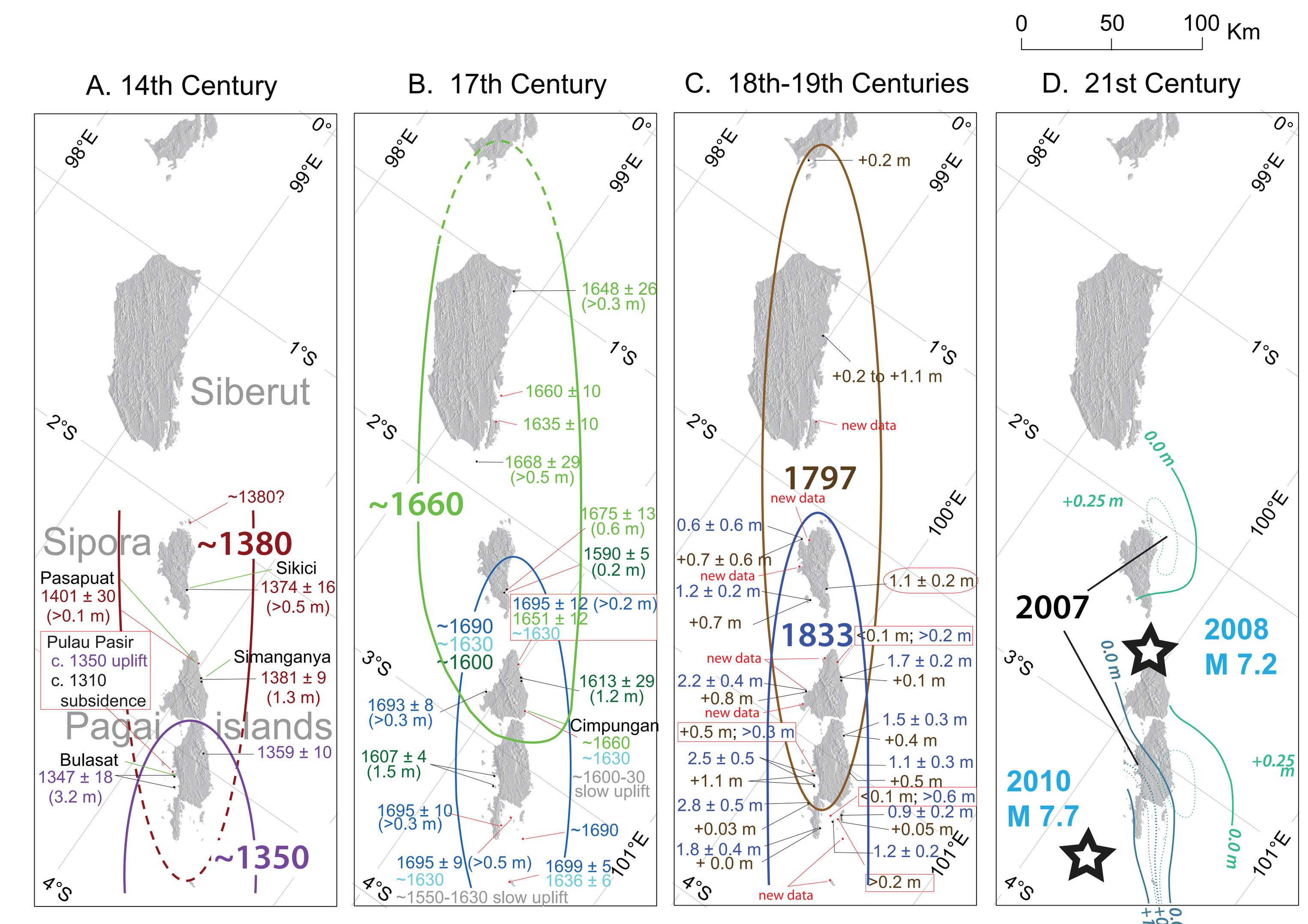
A. Techniques for measuring recent coseismic or postseismic vertical deformation. Net uplift is measured by comparing pre- and post-earthquake HLS (top), while net subsidence can be measured by comparing pre-earthquake HLS to the extreme low tide (bottom). Adapted from Briggs et al. (2006). B. Example 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 Supercycle Variations

(right) Four Mentawai Islands emergence episodes of the past seven centuries. Each episode consists of more than one major event, and each rupture sequence has unique features.

(below) Schematic diagram of interseismic and coseismic vertical deformation.

(below right) 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. The September 2007 earthquake raised their bases once again well above low tide.

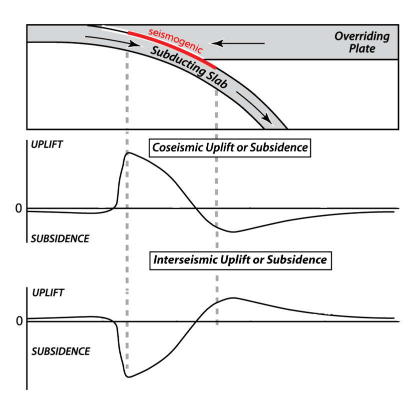


A. At least two "conventional" megathrust ruptures, preceded by a shallow rupture.

B. Approximately four megathrust ruptures, with some slow slip between seismic events. Can possibly be modeled using PCAIM.

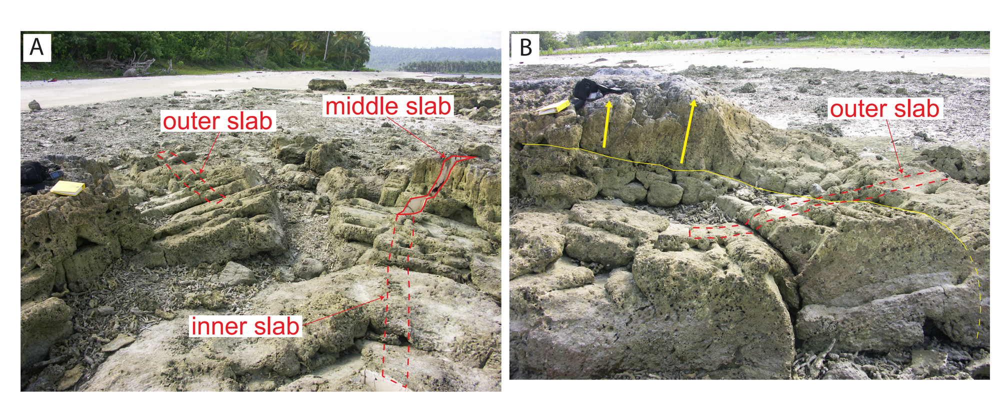
C. No evidence for more than two megathrust ruptures or for significant slow slip. Interseismic and coseismic slip before and during rupture sequence to be modeled using PCAIM.

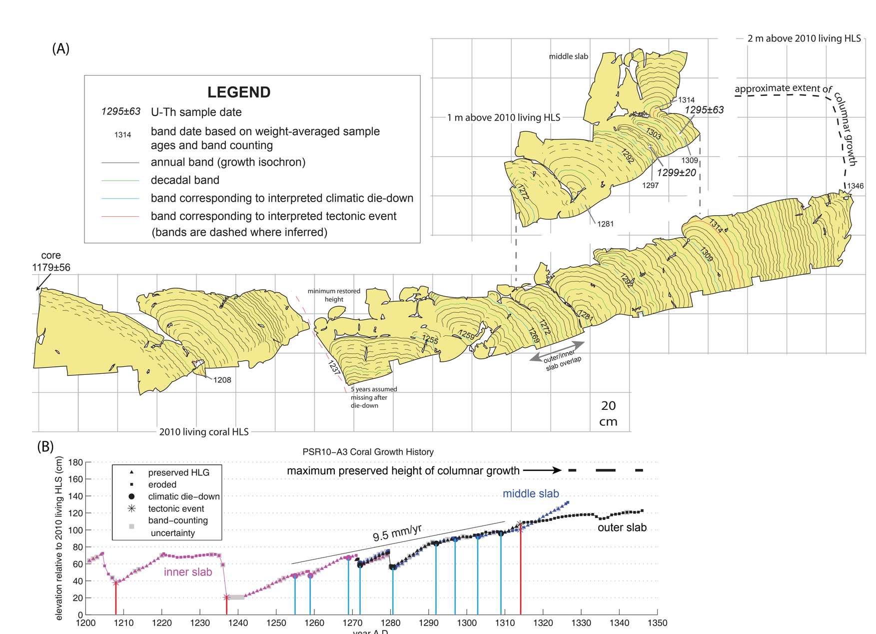
D. Four "conventional" M>7 megathrust ruptures so far, with some slow slip between seismic events. At least one more M>8 rupture is expected. October 2010 shallow rupture is likely the first of its kind since the early 1300s.



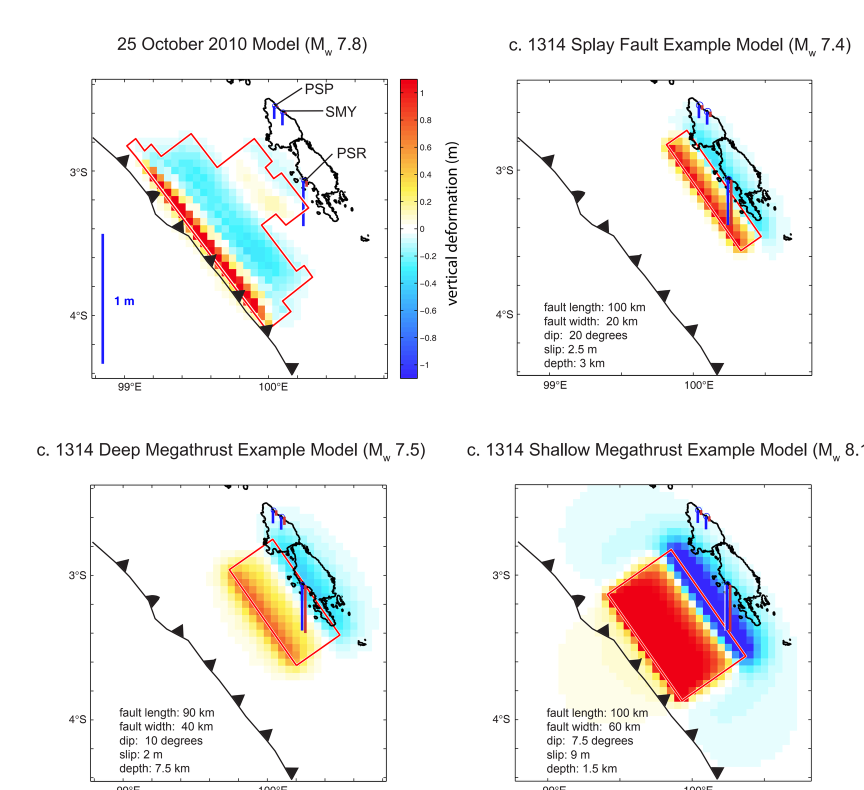
Shallow Slip, Ancient and Modern

A coral record from South Pagai island suggests that a shallow megathrust rupture occured c. A.D. 1314. This rupture must have been larger or deeper than the October 2010 shallow rupture. Elevations of coral microatolls over the past three millennia show evidence that the shallow megathrust has a distinct seismic cycle with a ~1000 year recurrence interval.

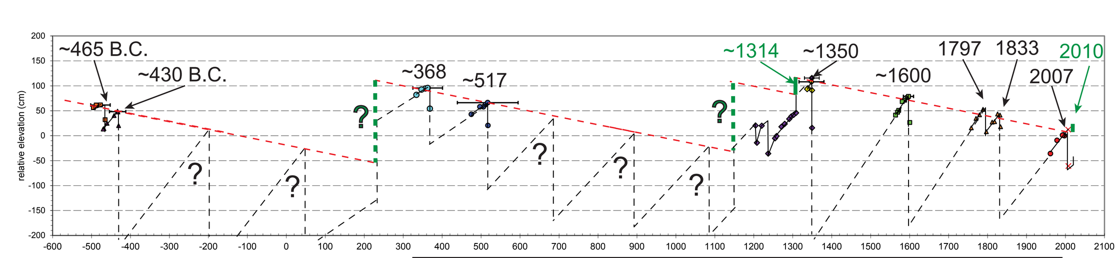


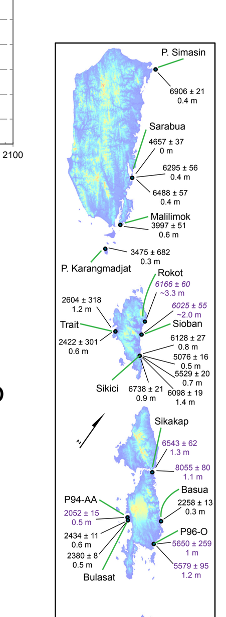


Photographs of a huge microatoll show sudden inception of columnar growth (indicatign subsidence) around A.D. 1314. A radial slab shows the coral growth history prior to its death in about 1350 (likely due to uplift in a previously-identified "conventional" megathrust rupture).



There are a large suite of fault rupture models which could reproduce the observed coral paleogeodetic data, but in essence the rupture must have been larger than the 2010 event, and/or deeper on the plate interface.



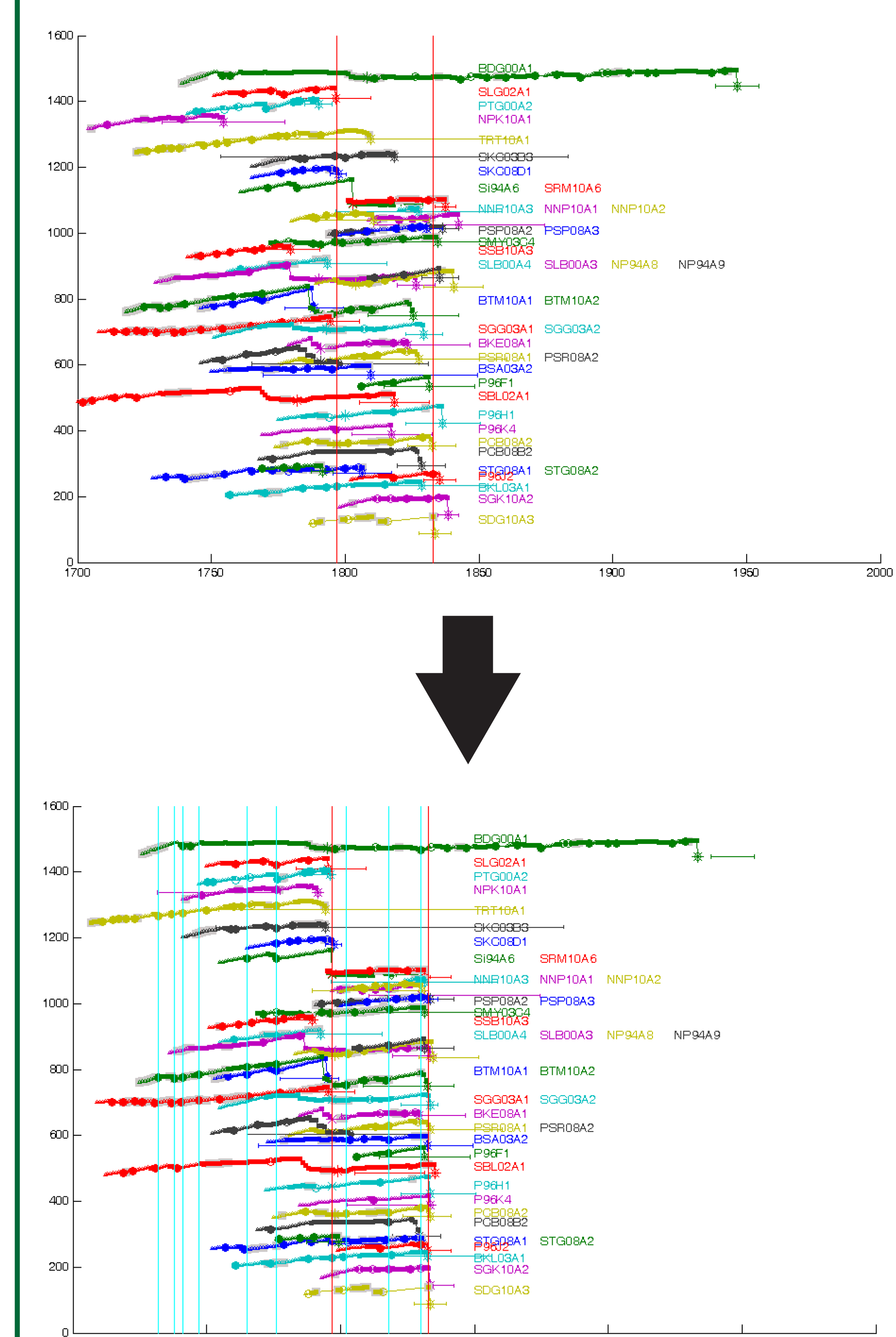


(above) Comparing elevations of microatolls at a nearby locality from the past 700 years suggests a long-term uplift rate of 1.8 mm/yr. However, the elevations of older microatolls indicate that this trend cannot be extrapolated farther into the past. Subsidence events must have balanced this uplift trend. According to our interpretation, the red and green sawtooth curve represents tectonic stress buildup and seismic release on the shallow megathrust, a signal which is superimposed on the higher-frequency "conventional" megathrust seismic cycle.

(left) The presence of microatolls between 2000 and 8000 years old still within the intertidal zone indicates that little to no permanent uplift has occurred in the Mentawai Islands since the mid-Holocene. Therefore, apparent long-term uplift observed at other sites is also probably an expression of the shallow seismic cycle.

Correlating Coral Records Using Climatic Events

In preparation for modeling, coral records must be correlated more precisely than radiometric dating uncertainties allow. This can be accomplished by lining up temporary oceanographic lowerings in sea level (which, like tectonic uplifts, kill the top of the coral.)



Future Work

* Perform PCAIM inversion for interseismic and coseismic slip leading up to and during 1797/1833 rupture sequence.

* Correlate 16th- and 17th-century coral records using climatic coral die-downs.

* If data are sufficient, perform PCAIM inversion for 16th-and 17th-century rupture sequence.

* Compare ancient rupture sequences to the modern coral and GPS data.

Postseismic slip following the 2007 Mentawai earthquake (Kositsky and Avouac, in preparation), inverted using PCAIM.