Surface uplift and subsidence of the giant Sunda megathrust rupture of March 2005

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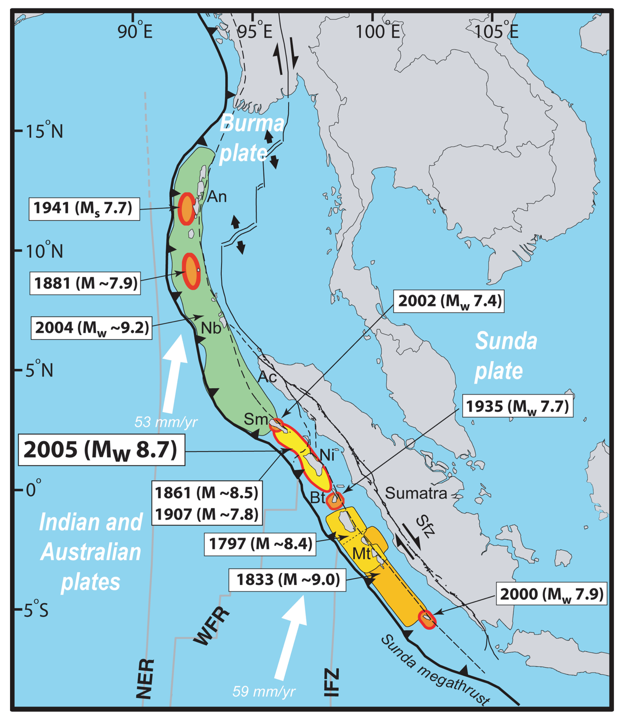
The March 2005 megathrust rupture



Rupture of the Sunda megathrust during the giant (M_W8.7) earthquake of March 28th (*above*) produced spectacular tectonic deformation along a 400-km strip of the western Sumatran archipelago (*below and right*). The pattern of deformation reflects the distribution of slip on the megathrust that produced the earthquake. The uplift pattern also has important implications for the long-term behavior of neighboring portions of the megathrust, the geologic construction of the forearc, and the repetition of large and dangerous seismic ruptures.

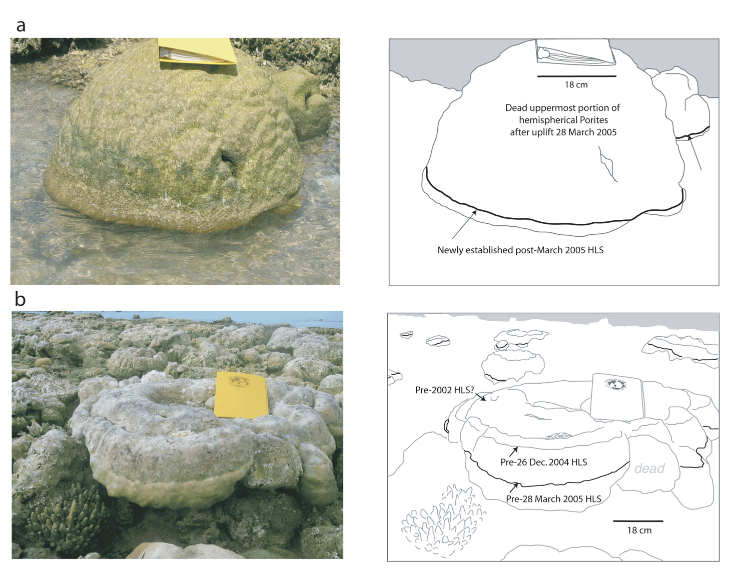
Coseismic uplift

This small island off the west coast of Nias was lifted ~1.9 m during the March rupture, stranding the fringing coral reefs high above sea level (*above*). The children in the inset photo are standing near the former low tide elevation.

Coseismic subsidence

Haloban, a village in the Banyak Islands, subsided ~0.5 m during the March rupture.

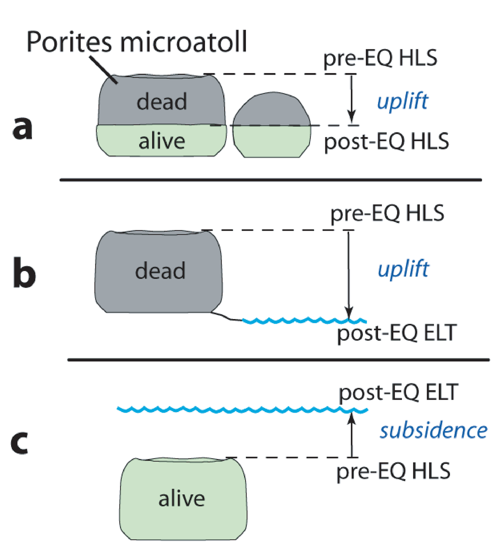
Vertical deformation measurements from corals



The distribution of living and dead tissue on *Porites* coral heads records sea level to within a few centimeters. We take advantage of these natural tide gauges to measure coseismic uplift and subsidence .

Detail …

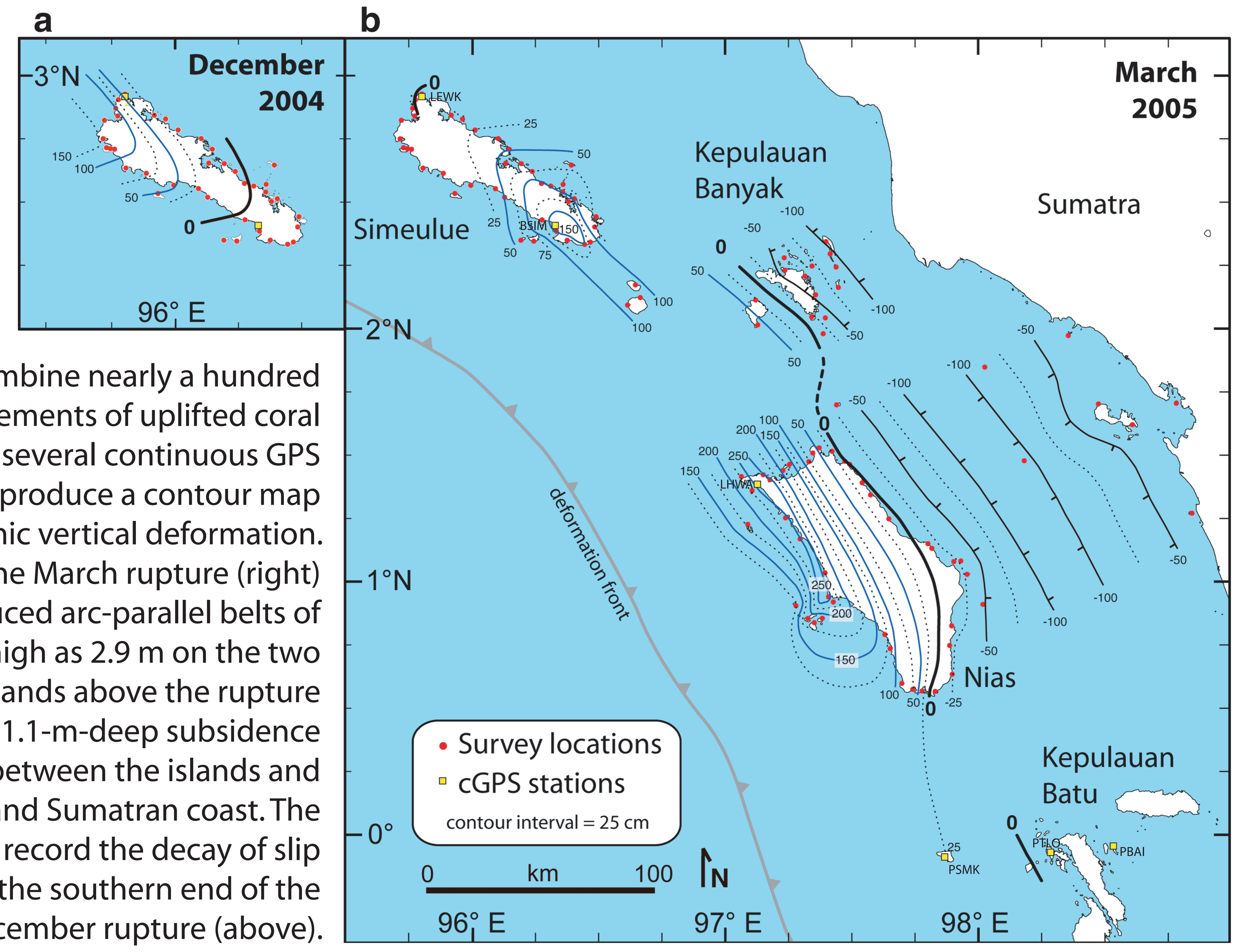
Photographs and corresponding line drawings of uplifted *Porites* coral heads. Panel A shows an uplifted hemispherical coral head that records the new, post-earthquake highest level of survival (HLS) as a thin living strip at its base. The uppermost, exposed portion of the coral head is dead and covered with algae. Panel B shows a *Porites* microatoll that records multiple uplift events. 11 cm of uplift during the December rupture resulted in the elevation difference between the uppermost living coral before (labeled 'pre-26 December 2004 HLS) and after ('Pre-28 March 2005 HLS) the earthquake. The more brightly colored area beneath the pre-28 March HLS is 3-5 mm of outward growth during the period between the December and March earthquakes. During the 28 March earthquake the coral was uplifted another 80 cm, causing it to be entirely out of the water and too high to record post-28 March HLS. An older uplift event of a few cm, possibly in 2002, is evident on the top of the microatoll.



…and more detail

Three scenarios for measuring vertical deformation using *Porites* coral microatolls. Panel a shows uplift recorded as the difference between pre- and post-earthquake highest level of survival (HLS). Panel b shows uplift as separation between pre-earthquake HLS and the model elevation of post-earthquake extreme low tide (ELT). Panel c illustrates subsidence measured upward from pre-earthquake HLS to post-earthquake ELT.

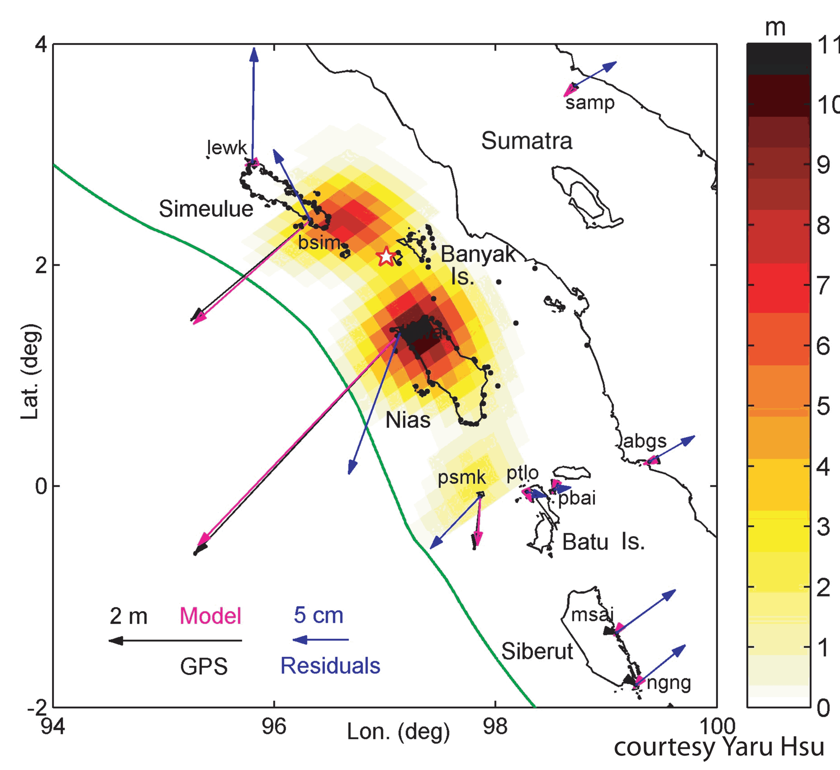
Contour map of coseismic uplift and subsidence



We combine nearly a hundred measurements of uplifted coral and several continuous GPS records to produce a contour map of coseismic vertical deformation. The March rupture (right) produced arc-parallel belts of uplift as high as 2.9 m on the two largest islands above the rupture and a 1.1-m-deep subsidence trough between the islands and the mainland Sumatran coast. The corals also record the decay of slip at the southern end of the December rupture (above).

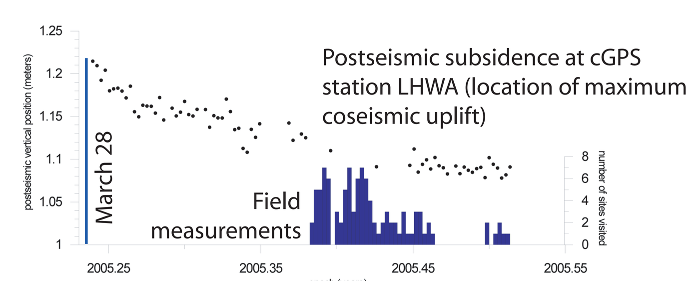
The anticlinal crest and the pivot line marking the transition from emergence to submergence are predominantly arc-parallel, but have a pronounced misalignment near the Banyak Islands between Nias and Simeulue (*above*). This suggests that a major structural feature - possibly the Batee fault (*right*) - divides the March rupture area into a Nias and a Simeulue patch.

Elastic model of slip on the megathrust



Inverting the uplift data for slip on the megathrust yields the highest slips under the islands - up to 8 m beneath one and 11 m beneath the other. Repetition of 2005-like ruptures would have to occur about every 160 to 335 years to keep up with rates of strain accumulation.

Postseismic motion



Postseismic deformation was only a few centimeters at most of our survey sites, and we've chosen not to include these small corrections in our map of coseismic uplift.

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Main observations *and interpretations*

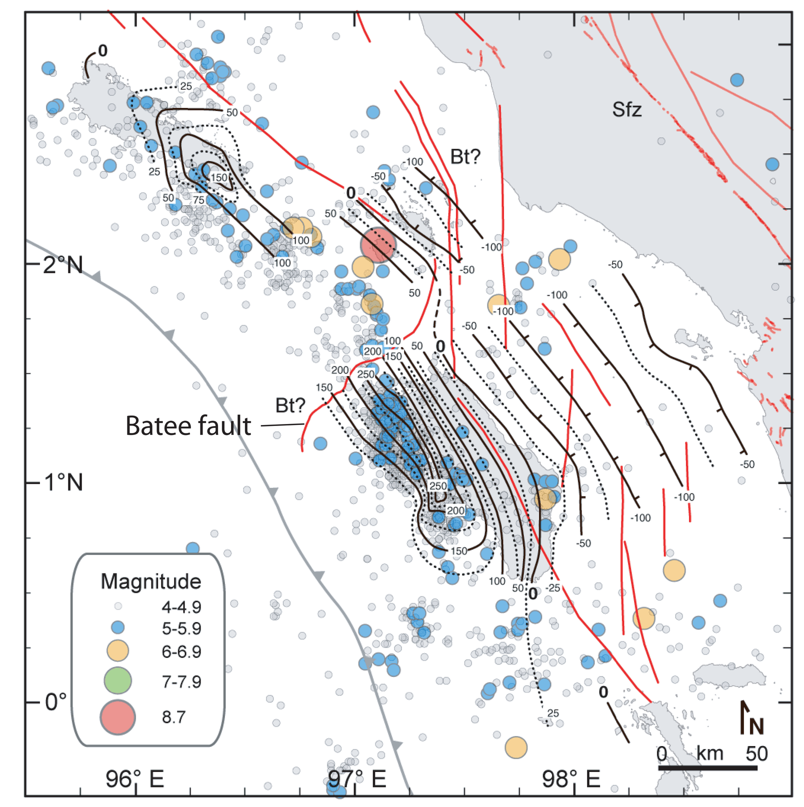
The distribution of uplift and subsidence is consistent with elastic strain release due to slip on the underlying megathrust - *the data do not require slip on splay faults within the overriding plate*

A pronounced deflection in the uplift contours occurs between Nias and the Banyak islands - *this suggests that two main slip patches are separated by a major discontinuity, perhaps a tear in the forearc along the Batee fault*

A saddle in cumulative Dec. 2004 - March 2005 displacement occurs where the ruptures overlap on Simeulue island - *this may correspond to a permanently weaker section of the megathrust*

The pattern of coseismic uplift is similar to the structural form of the outer arc islands - *and the presence of older, uplifted coral terraces suggests that slip on the megathrust results in some increment of permanent uplift*

Coseismic vertical deformation, aftershocks, and faults of the overriding plate



Dense bands of aftershocks just trenchward of the belts of maximum slip suggest high concentrations of stress just updip from the coseismic rupture. The clear trenchward diminishment of uplift and slip may demonstrate that significant interseismic slip - either seismic or aseismic - occurs on that portion of the megathrust between the islands and the trench. However, the fact that the pattern of coseismic uplift is similar to the structural form of the islands suggests that slip on the megathrust has resulted in an increment of permanent uplift of the outer-arc ridge.

The Simeulue Saddle

The northwestern limit of uplift in March abuts the source region of the Mw9.2 rupture of December 2004, but with a modest saddle in uplift values there, precisely where a Mw7.2 rupture produced uplift in 2002. This saddle may reflect a permanently weaker section of the megathrust, which serves as a barrier to propagation of adjacent ruptures. The southern limit of uplift also abuts a weaker section of the megathrust, characterized by a high degree of aseismic slip and a Mw7.7 rupture in 1935.