Issues raised by the vertical deformation pattern of the 2005 giant Sunda megathrust rupture

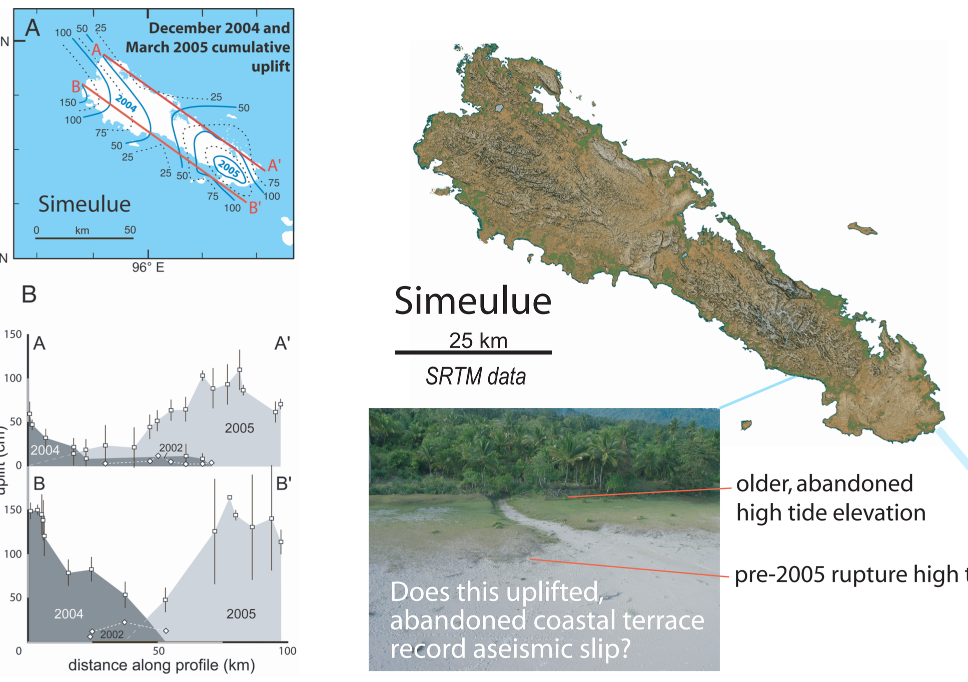
Rich Briggs[1], Kerry Sieh[1], Aron Meltzner[1], Danny Natawidjaja[2], John Galetzka[1], Bambang Suwargadi[2], Ya-ju Hsu[1], Mark Simons[1], Nugroho Hananto[2], Imam Suprihanto[3], Dudi Prayudi[2], Linette Prawirodirdjo[4], Yehuda Bock[4]

[1] Tectonics Observatory, Division of Geological and Planetary Sciences, California Institute of Technology
[2] Research Center for Geotechnology, Indonesian Institute of Sciences (LIPI), Bandung, Indonesia.
[3] Jl. Mahoni, Blok E, Gang I, No. 13, Rt. 002/015, Koja-Jakarta 14270
[4] Scripps Institution of Oceanography, University of California San Diego, San Diego, CA

This poster summarizes our observations of coseismic uplift and subsidence above the 2005 M 8.7 Sunda megathrust rupture and presents a few key questions that emerged from this study.

What is the significance of the Simeulue Saddle?

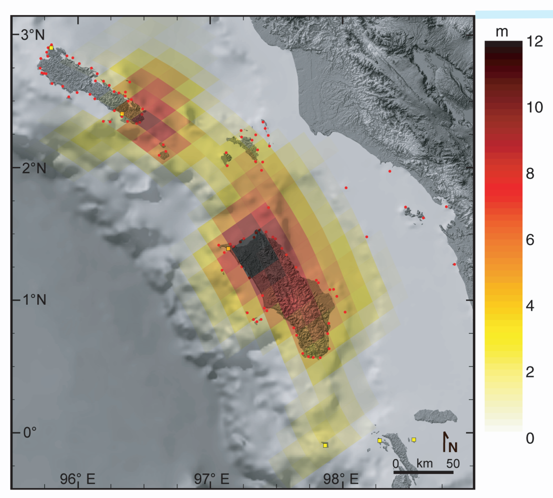
-What controls the length of giant megathrust ruptures?-



The northwestern limit of uplift in March 2005 abuts the source region of the **M** 9.2 rupture of December 2004, but with a saddle in uplift values there, precisely where a **M** 7.2 rupture produced uplift in 2002. Does the saddle reflect a permanently weaker section of the megathrust that serves as a barrier to propagation of adjacent ruptures? Does this patch slip mainly aseismically? What causes giant megathrust ruptures to die? Grad student Aron Meltzner is tackling these questions by quantifying the interseismic strain history preserved in coral microatolls along the coast of Simeulue.

Why was slip highest beneath the outer arc islands instead of the forearc basin?

-How is megathrust fault slip related to forearc stucture?-



Inverting coral and GPS measurements for slip on the megathrust yields two main patches of fault slip, with a maximum of 11 m of slip beneath Nias and a pronounced lessening of slip trenchward. Modeling by Ya-ju Hsu.

Along most subduction zones, seismic coupling appears to be maximum beneath forearc basins or, more generally, where trench-parallel gravity anomalies are strongly negative (Song and Simons, Science, 2003; Wells et al., JGR, 2003). During the 2005 Sunda rupture, maximum slip was clearly centered beneath the outer arc high instead of the forearc basin (above). This suggests that the morphology of the overriding plate here may be a response, rather than a control, on megathrust asperities and that a simple correlation between maximum slip and forearc basins is not universal.

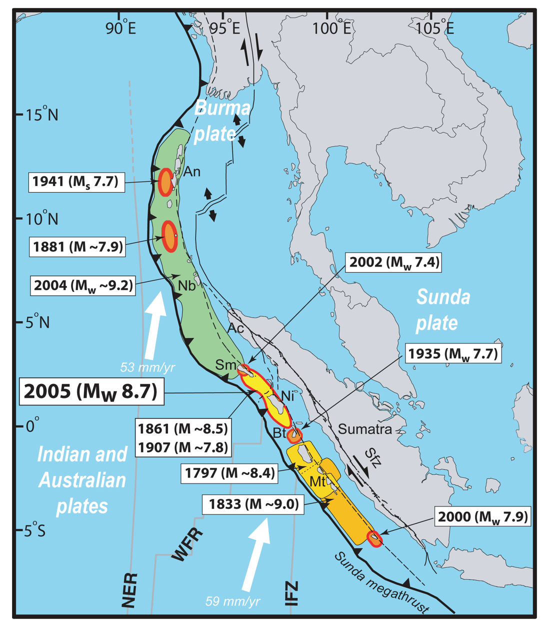
How has uplift and subsidence affected people?

-Should coseismic land level changes be incorporated in disaster planning?-

Elastic strain released during megathrust rupture caused dramatic land level changes over thousands of kilometers of coastline. This uplift and subsidence will likely be recovered nearly in full before the next large rupture. But on the scale of a human lifetime, the elevation changes and their associated costs - disrupted transportation, profound ecological changes, and even sometimes direct destruction of communities (right) - are nearly permanent. The 2005 event provides a sobering reminder that coseismic uplift and subsidence should be explicitly factored into hazard analyses and disaster planning.

The effect of coseismic uplift and subsidence on Indonesians is documented in the article by Richard Stone entitled *The Day the Land Tipped Over* (Science, 20 Oct. 2006)

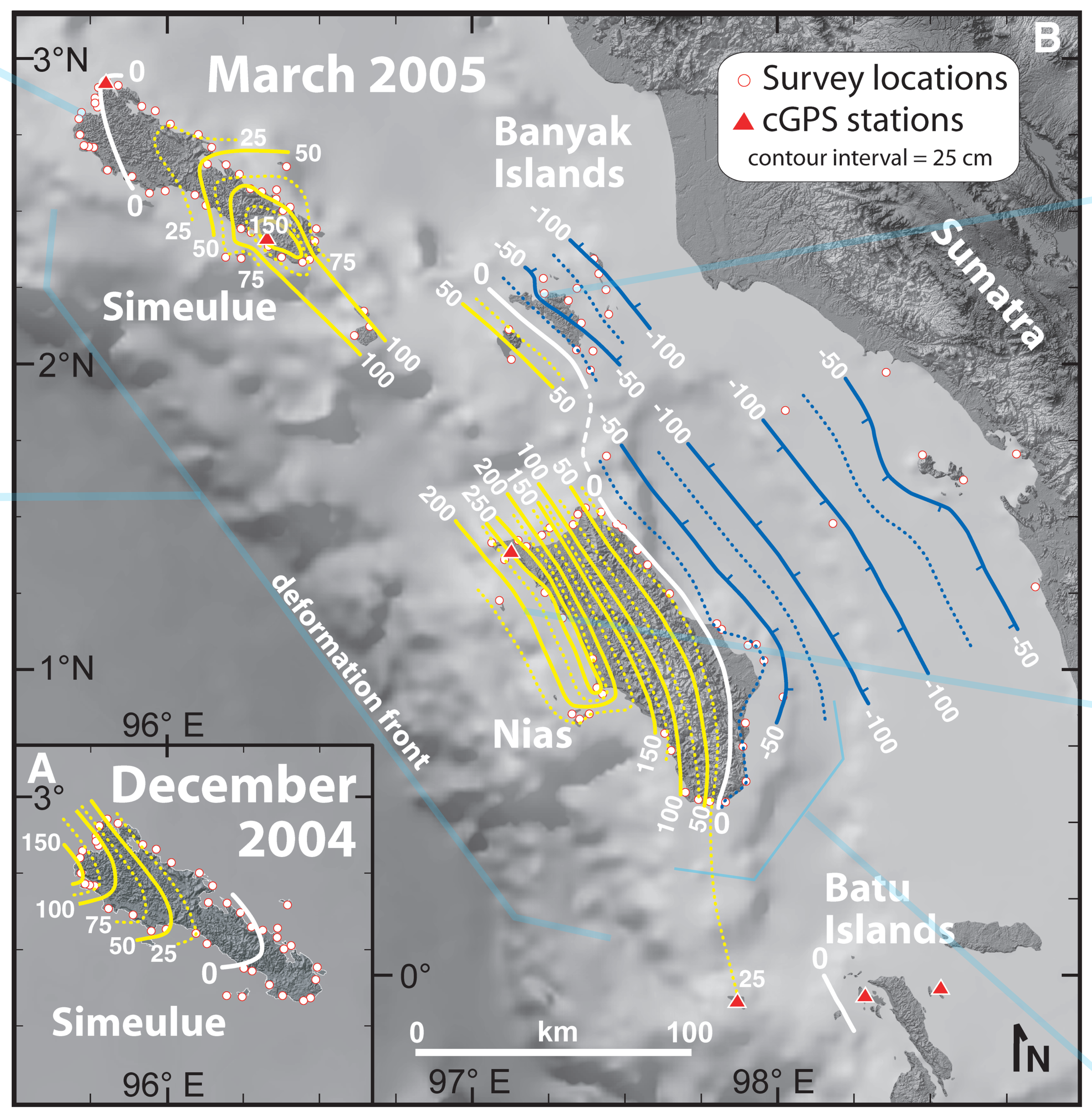
Location of the 2005 Sunda megathrust rupture



We combined nearly a hundred measurements of uplifted coral and several continuous GPS records from the SuGAR network to produce a contour map of coseismic vertical deformation (Briggs et al., Science, 2006).

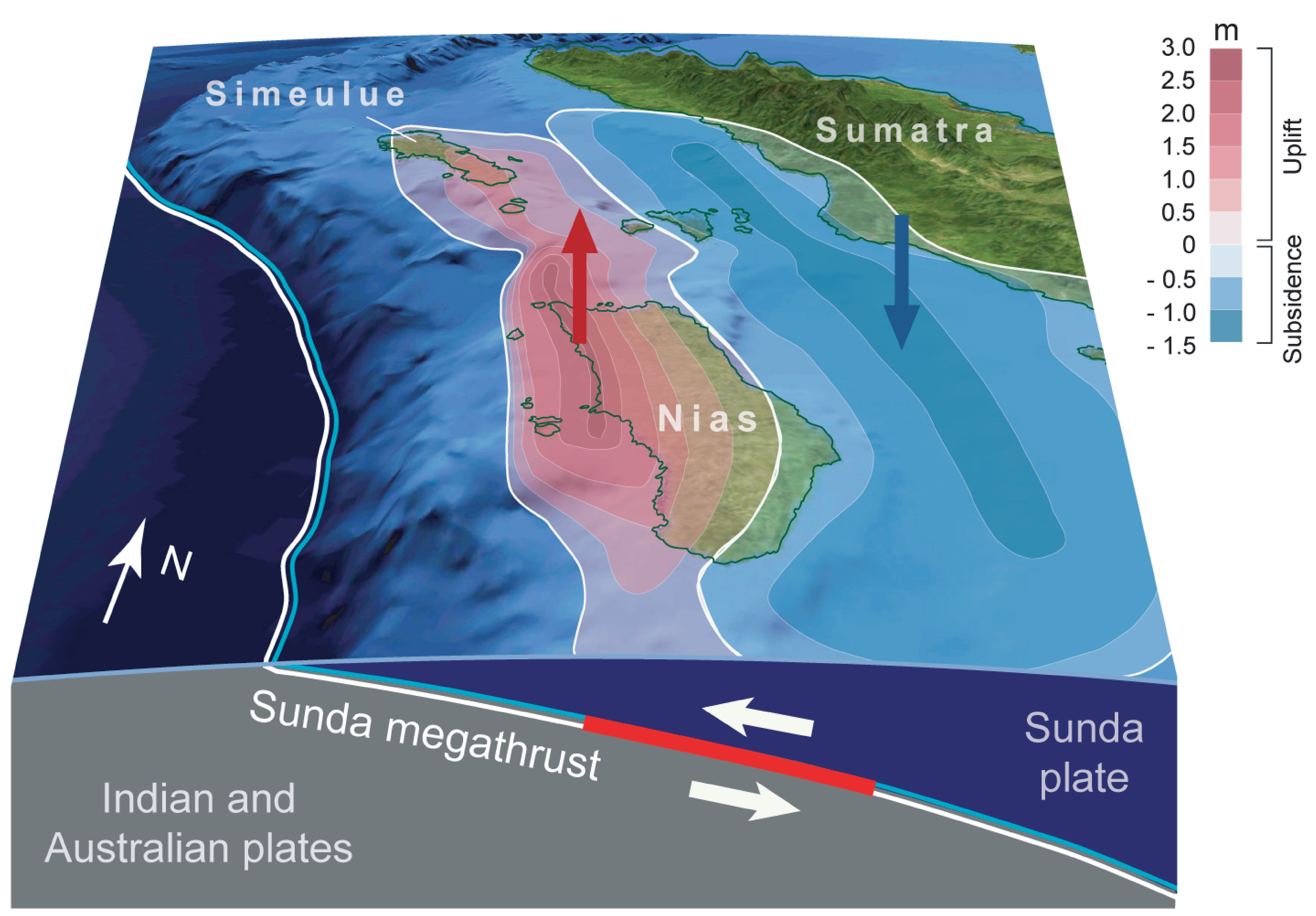
The March 2005 rupture (left) produced arc-parallel belts of uplift as high as 2.9 m on the two largest islands above the rupture and a 1.1-m-deep subsidence trough between the islands and the mainland Sumatran coast (below). The corals also record the decay of slip at the southern end of the December 2004 rupture (inset below).

Contour map of coseismic uplift and subsidence



yellow = uplift
blue = subsidence

Oblique view of coseismic uplift and subsidence



How do the Banyak islands persist in the middle of the forearc basin?

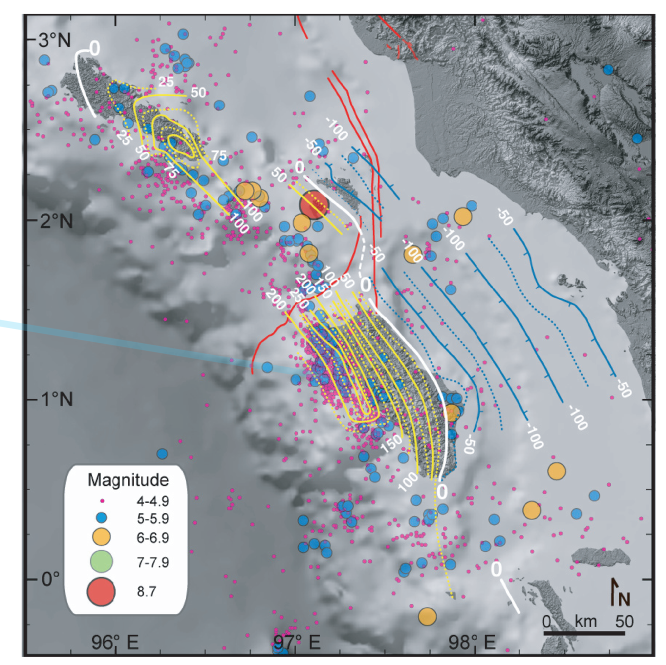
-How and when does the upper plate deform?-

Haloban, a village in the Banyak Islands, subsided ~0.6 m during the March rupture.

The anticlinal crest and the pivot line marking the transition from coseismic emergence to submergence are predominantly arc-parallel, but have a pronounced misalignment near the Banyak Islands between Nias and Simeulue (*see left and below*). This suggests that a major structural feature divides the March rupture area into two main patches - an observation supported by seismic- and geodetic-based models of coseismic slip distribution. This transverse structure, or set of structures, may also be responsible for the intraplate deformation that keeps the Banyaks above water in the long term. Marine geology cruises in this region by several international teams are focused on deriving a record of upper plate deformation from seismic and bathymetric data.

Why are aftershocks clustered along the western edge of Nias?

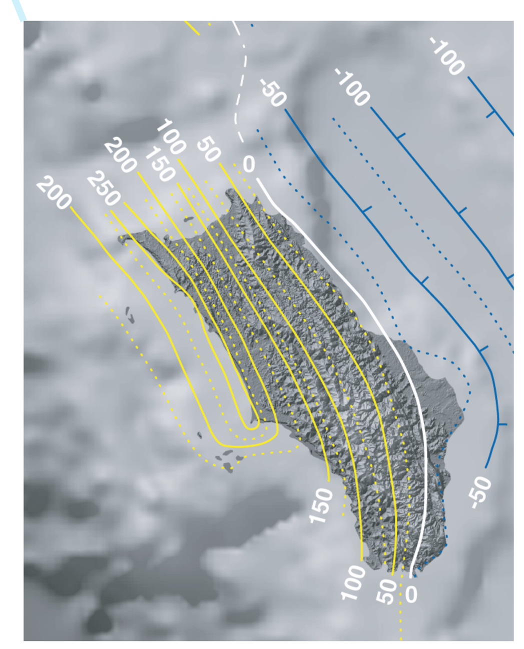
-What is the nature of postseimic slip on the megathrust?-



Upon our return from the field in the summer of 2005, we noticed dense bands of aftershocks just trenchward of the belts of maximum uplift, beneath the descending limb of the uplift antiform. This suggested high concentrations of stress just updip from the coseismic rupture. Hsu et al. modeled postseismic slip in the region using SuGAR GPS data (Hsu et al., Science, 2006). They quantified the temporal evolution of postseismic slip and found that this aftershock distribution and rate of decay is consistent with a large amount (= **M** 8.2) of afterslip, mostly concentrated on the updip portion of the megathrust.

How will the 2005 uplift pattern contribute to permanent construction of the islands?

-What is the relationship between elastic and anelastic strain in the forearc?-



The uplift pattern in 2005 broadly mimics the shape and location of Nias island: the welt of maximum uplift is along the west coast and the line of zero uplift approximately follows the east coast. Will some increment of 2005 uplift be preserved as permanent deformation? With the support of the Tectonics Observatory and NSF, we are currently studying uplifted fossil coral reefs around the margin of Nias to address this question.

Funded by the National Science Foundation and a grant from The Gordon and Betty Moore Foundation to the Tectonics Observatory, California Institute of Technology