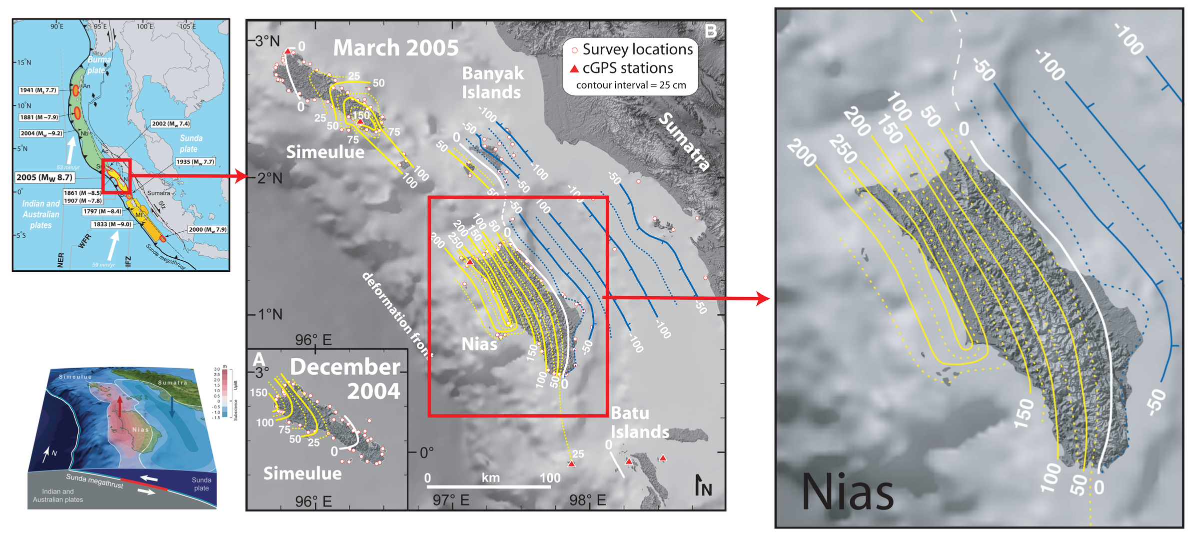
Elastic versus permanent deformation above the Sunda megathrust

Rich Briggs[1], Willy Amidon[1], Kerry Sieh[1], John Galetzka[1], Bambang Suwargadi[2], Danny Natawidjaja[2], Nugraha Sastra[2], Dudi Prayudi[2]

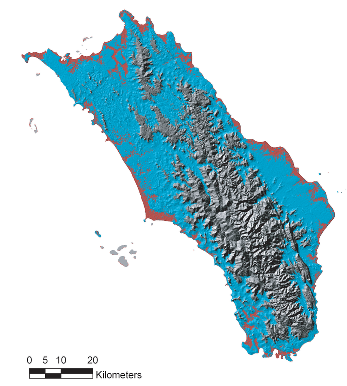
[1]Tectonics Observatory, Division of Geological and Planetary Sciences, California Institute of Technology
[2]Research Center for Geotechnology, Indonesian Institute of Sciences (LIPI), Bandung, Indonesia.

2005 coseismic uplift measurements



Location of study area and contour map of 2005 coseismic uplift. Notice that on Nias island, the welt of maximum uplift -- 2.5 to 3 m -- runs along the NW coast, while the line of zero uplift is nearly aligned along the east coast.

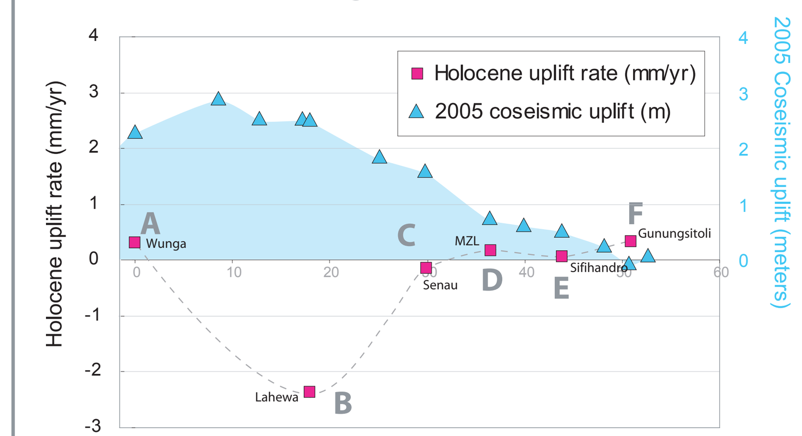
Geomorphic domains on Nias



Areas in red are < 12 m elevation and roughly correspond to Holocene surfaces. These fringe nearly the entire island.

The blue tint (< 120 m elevation) is at the highest elevation of uplifted reefs on the east coast. Highlighting this elevation illuminates the main geomorphic domains on Nias. The NW corner of the island, nearly all in blue, is low elevation and low relief with relict surfaces and structures, and this area lacks the older uplifted corals observed along the east coast. The southern half of the island in grey is rugged, with high relief associated with active faulting and folding. Note that the southern half of the island has a deeply embayed western coastline.

Anti-correlation of coseismic and long-term uplift?



A comparison of coseismic uplift (blue) to Holocene uplift (pink) along a profile across the north of Nias (left) shows that long-term uplift rates do not scale with 2005 coseismic uplift. Rather, maximum uplift in 2005 corresponds to sites that are apparently subsiding in the longer term.

Summary

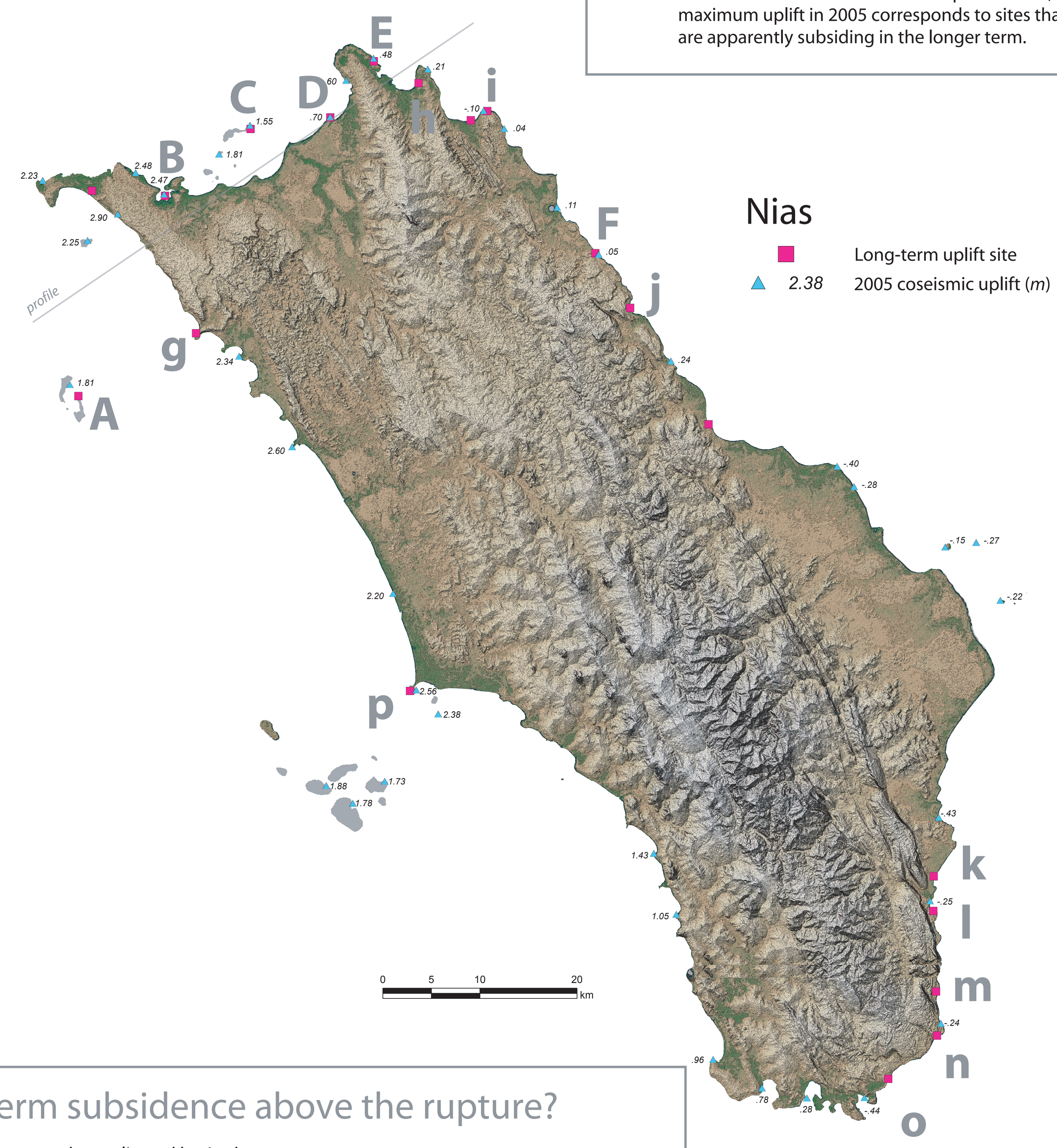
The 2005 Sunda megathrust rupture provides a rare opportunity to explore the relationship between slip on the megathrust and permanent uplift along the outer arc.

Fossil head at Sifihandro (site E to right)

We compare our measurements of 2005 coseismic uplift (above) to longer term deformation as recorded by Holocene fossil coral reefs on the outer arc island of Nias (right). A reasonable hypothesis might be that long-term deformation mimics the 2005 coseismic signal, such that recent uplift is concentrated along the island's northwest coast. This is not the case, and instead a transect across northern Nias (right) shows that Holocene deformation appears to be nearly anti-correlated with the 2005 uplift pattern. In fact, the region of maximum uplift -- nearly 3 m in 2005 -- appears to have been subsiding during most of the Holocene. And surprisingly, long-term uplift rates are highest on the east coast of the island, where uplift in 2005 was nearly zero.

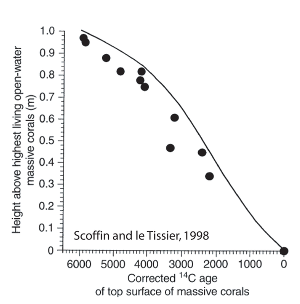
A survey of Holocene surfaces around the remainder of the island, for which U/Th dates of fossil corals are in progress, confirms that Holocene uplift is concentrated along the east coast of the island, with differential offsets apparent across active upper plate faults. Thus it appears that recent deformation of Nias occurs in two distinct domains. Elastic strain accumulation and release due to 2005-type megathrust ruptures causes very little net uplift, and even subsidence, of the northwest coast. Along the east coast, active faults in the upper plate appear to be responsible for the highest rates of permanent uplift. The partitioning of deformation modes between the northwest (megathrust dominated) and east/southeast (upper plate dominated) is reflected in the gross geomorphology of the island.

Nug measuring and chopping at La'aya (site h to right)



SRTM data courtesy JPL

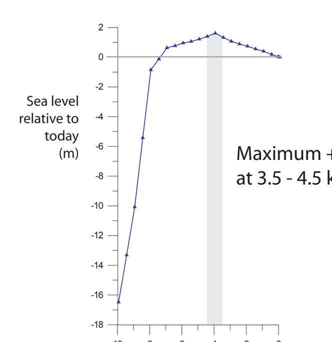
A complication: the mid-Holocene sea level high



Example of Holocene sea level curve for the Malaysian peninsula

In general, sea level has risen worldwide since ~21 ka due to the melting of glacial ice. But glacial unloading also caused global isostatic adjustments, resulting in a spatially and temporally variable mid-Holocene sea level transgression at lower latitudes.

The timing and magnitude of this sea level high is not well determined for Nias. At present we use model data (right) to apply a correction for the mid-Holocene sea level rise. Our observations so far suggest that the magnitude of the model rise is reasonable, but the timing of the model maximum seems several thousand years too late. At present this is the largest source of uncertainty (at worst, up to 1 m but more typically tens of centimeters) in our uplift measurements.

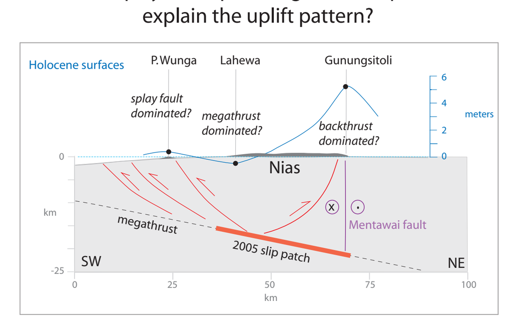


ICE-5G v1.2 with earth-viscosity model VM2 and a lithospheric thickness of 90Km (Peltier, personal communication)

Why long-term subsidence above the rupture?

A correlation between megathrust slip and basins has long been noted (e.g. Mogi, 1969 and more recently Wells et al., 2003 and Song and Simons, 2003) but the causal explanation for this correlation is unclear. It may be that during the long interseismic period of subsidence above the future megathrust rupture, strain accumulation is not entirely elastic and a significant portion of plastic, non-recoverable deformation takes place. This might be through a bulk mechanism such as regional pressure solution. Alternatively, some type of basal erosion may take place coseismically (e.g. von Heune and Scholl, 1991). At right we schematically show the possible interplay of shortening along brittle upper fault structures and subsidence controlled by the earthquake cycle on the megathrust.

Do splay faults plus megathrust ruptre explain the uplift pattern?



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

Topographic profiles of uplifted Holocene surfaces

We compare uplifted fossil coral heads, which are reliable recorders of paleo-low tide, to present-day low tide to determine total apparent uplift. From this raw number we subtract 2005 coseismic uplift, and also the appropriate mid-Holocene sea level transgression to calculate net tectonic uplift. U/Th dates of the uplifted corals allow us to calculate uplift rates. All profiles below show raw uplift values. Locations on Nias are shown on the map at left.