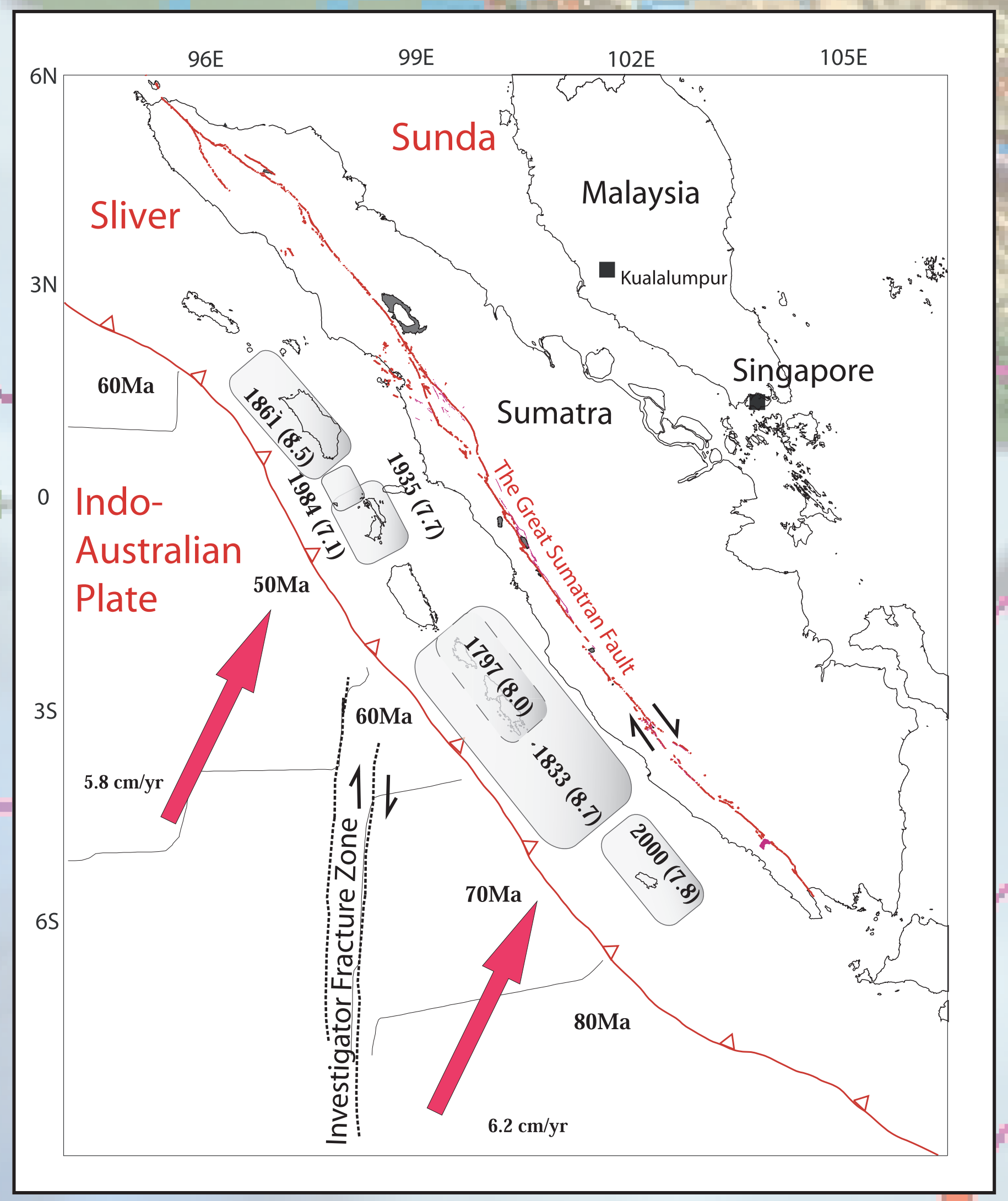
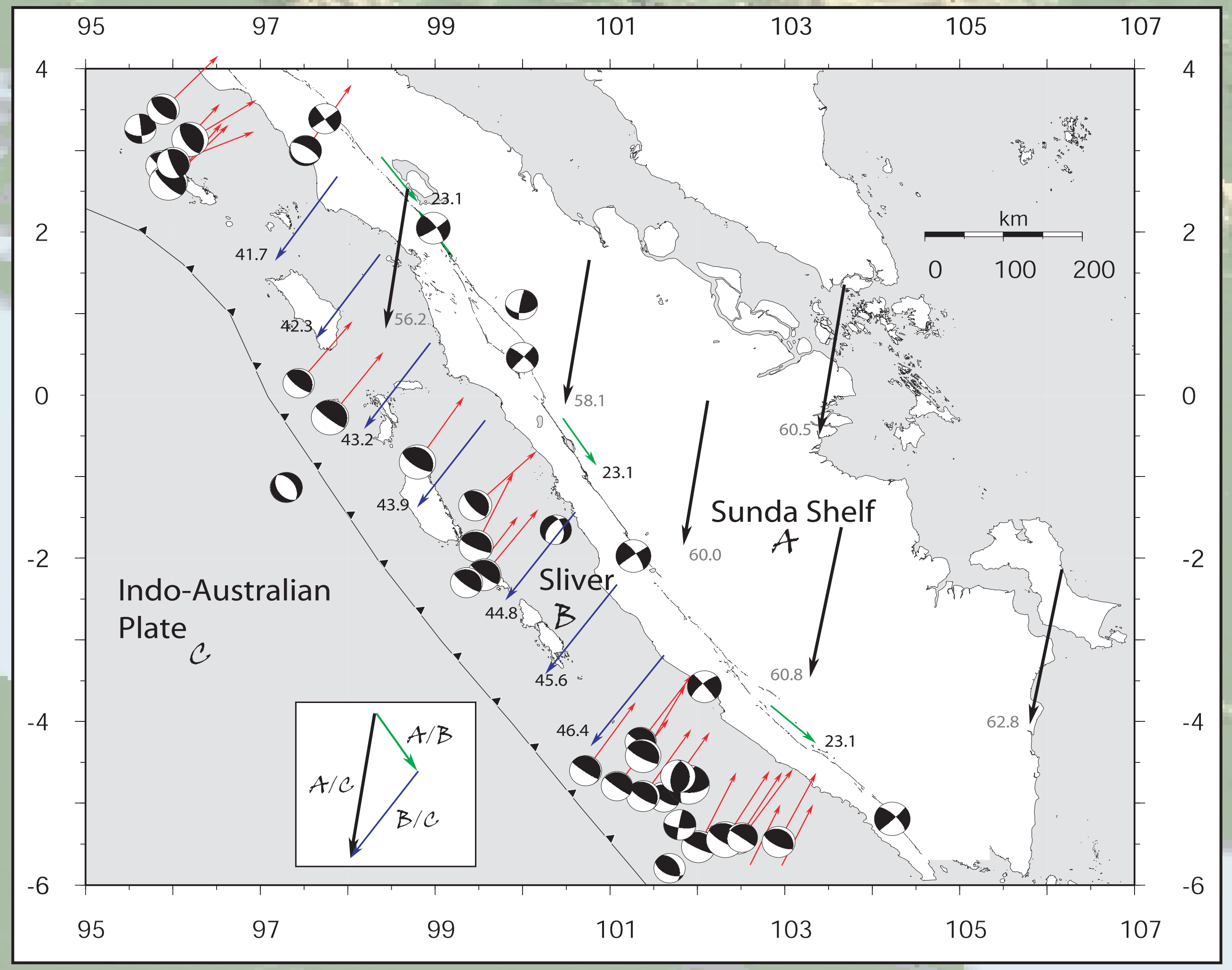
Investigating Lateral Variations of Interseismic Strain along the Sumatran Subduction Zone

Mohamed Chlieh, Jean-Philippe Avouac, Kerry Sieh, Danny H. Natawidjaja, John Galetzka,
Tectonic Observatory, Caltech, Pasadena, CA

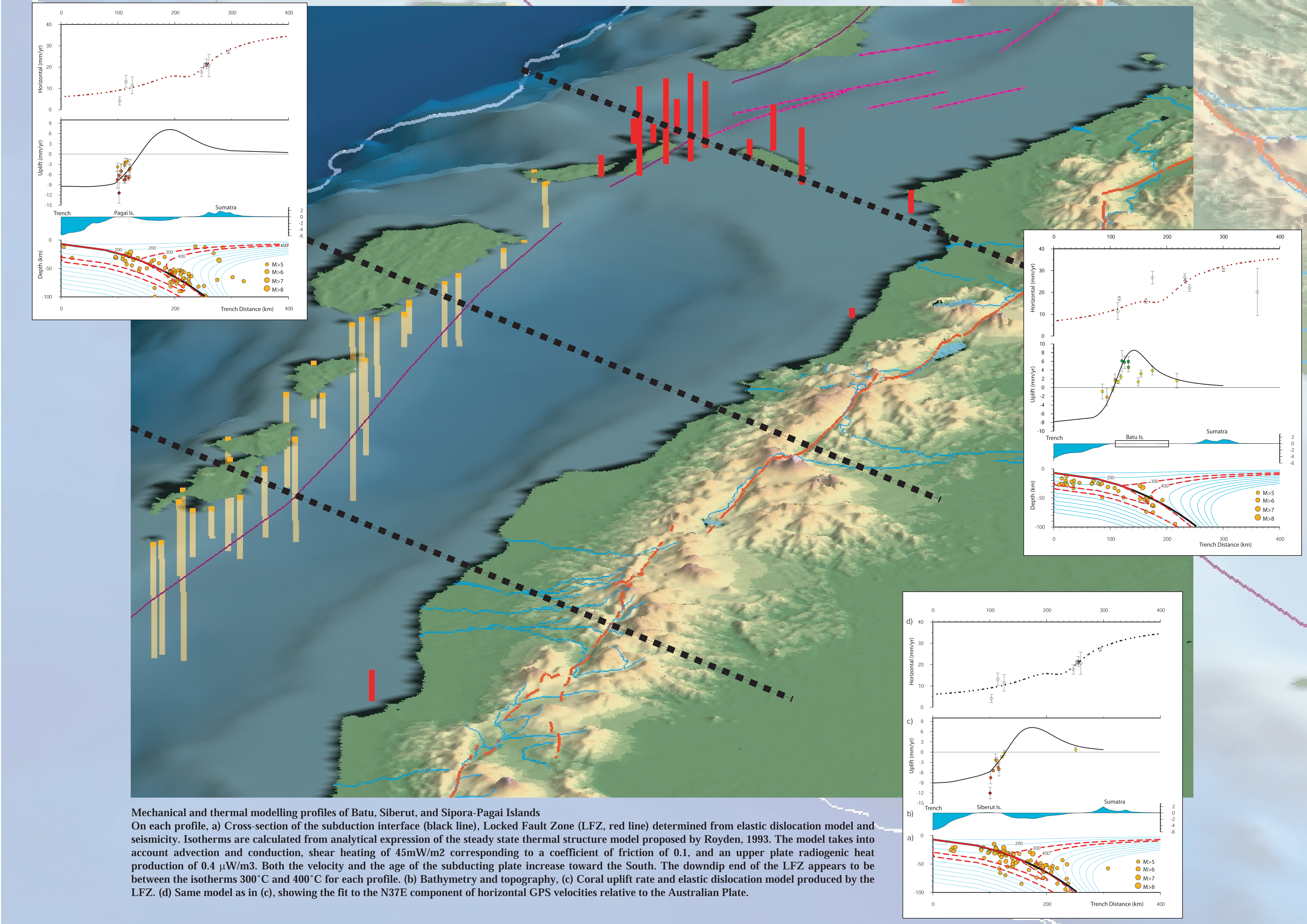
Paleoseismic, paleogeodetic and GPS data from the Sumatran subduction zone provide an unusual opportunity to understand the physical parameters that control the behavior of a subduction interface. Interseismic strains recorded over the last several decades by coral growth rings and GPS instruments allow us to model subduction zone behavior using a three-dimensional dislocation back-slip model. The kinematic model takes into account the partitioning of slip between the subducting Australian plate and Sunda into dominantly dip-slip motion along the subduction interface and strike-slip faulting along the Great Sumatran fault (GSF). The sliver between the trench and the GSF is assumed to behave, in the long term, as a rigid microplate. Given the northward secular motion of the Sumatra forearc, the normal convergence across the subduction zone is 40-46 mm/yr. Our modeling shows that the GPS and coral data are well fit by a simple model that assumes full locking of the subduction interface with lateral variations in the depth of the downdip end of the locked interface. The width of the locked interface is at a minimum value of ~135 km near the Equator and increases to about ~190 km farther south (This corresponds to a variation in depth from ~35 to 55 km). We note that over the past 250 years the subduction interface near the Equator has produced smaller earthquakes (Mw = 7.7 in 1935 7.2 in 1984) than the area farther south, which has produced giant earthquakes in 1797 and 1833 (Mw = 8.4 to 8.7+). This difference in both the seismic behavior and width of the locked fault zone may be related to the structural irregularities associated with subduction of the Investigator Fracture Zone or to lateral variations in the age of the subducting plate and/or the rate of convergence. We investigate these possibilities by modeling the effect of thermal structure on the behavior of the subduction zone.



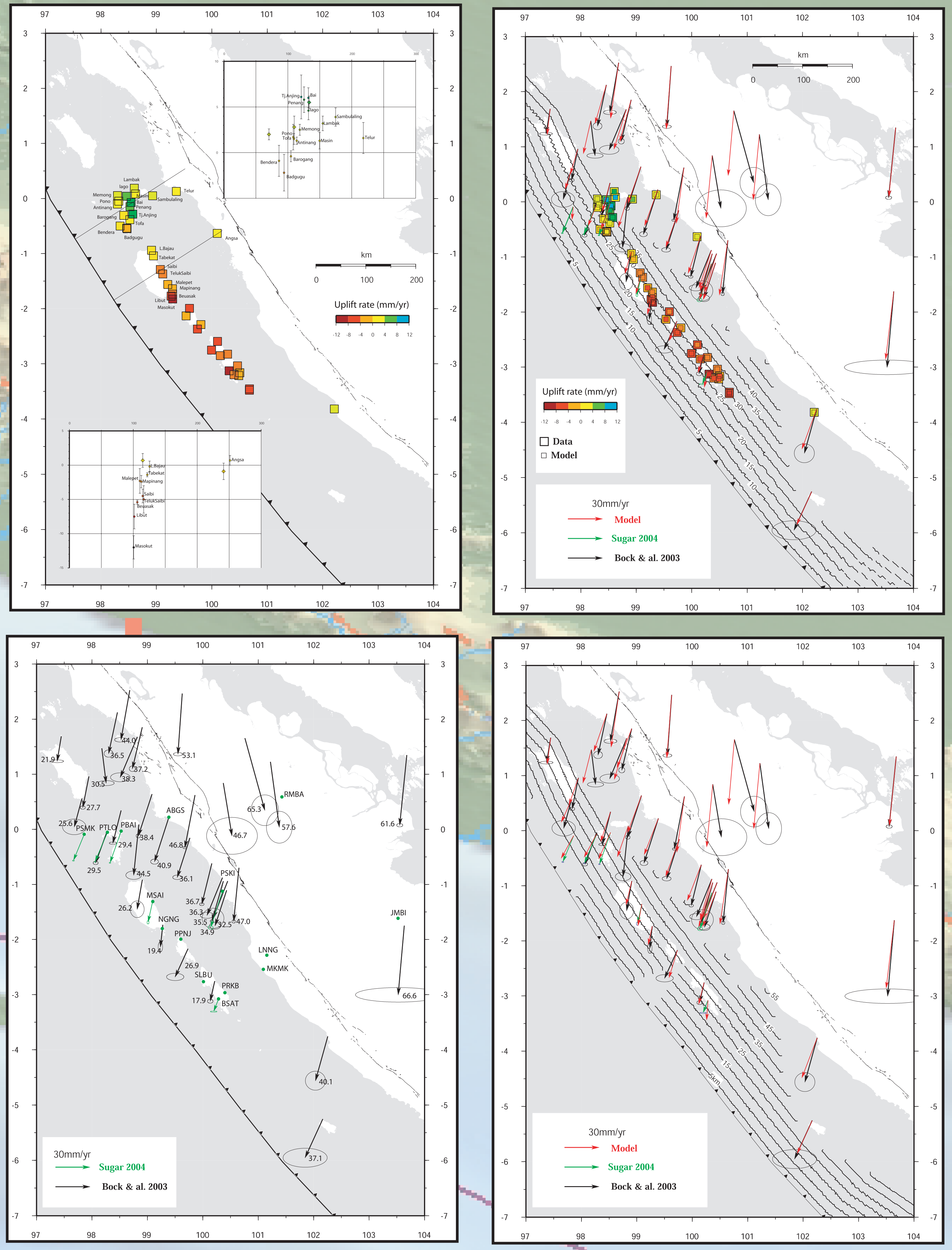
Geodynamic setting of the Sumatran plate boundary.
Oblique subduction of the Indo-Australian plate beneath Sumatra is accomodated principally by dip-slip on the Sumatran Subduction Interface and by right-lateral slip on the Sumatran Fault. Arrows show Australian plate motion relative to the Sunda Shelf. Large historical seismic ruptures on the subduction interface are represented by grey rectangles.



Slip-partioning model and Harvard CMT of M>6 earthquakes.
Oblique convergence of the Sunda Shelf (A) relative to the Indo-Australian plate (C) is a typical example of slip partitioning along a subduction zone. During slip partitioning, the convergence between A and C occurs on two parallel Faults: the Great Sumatra Fault and the Sumatran Subduction Interface. The sliver (B) behaves as a rigid micro-plate moving toward the northwest relative to A. We determine a pole of rotation for B constrained by the velocity of the Sumatran Fault and the slip vectors (red arrows) of significant earthquakes on the thrust interface. In this model the dextral Great Sumatran Fault accomodated 1/3 of the convergence between A and C.



Mechanical and thermal modelling profiles of Batu, Siberut, and Sipora-Pagai Islands
On each profile, a) Cross-section of the subduction interface (black line), Locked Fault Zone (LFZ, red line) determined from elastic dislocation model and seismicity. Isotherms are calculated from analytical expression of the steady state thermal structure model proposed by Royden, 1993. The model takes into account advection and conduction, shear heating of 45mW/m2 corresponding to a coefficient of friction of 0.1, and an upper plate radiogenic heat production of 0.4 µW/m3. Both the velocity and the age of the subducting plate increase toward the South. The downdip end of the LFZ appears to be between the isotherms 300°C and 400°C for each profile. (b) Bathymetry and topography, (c) Coral uplift rate and elastic dislocation model produced by the LFZ. (d) Same model as in (c), showing the fit to the N37E component of horizontal GPS velocities relative to the Australian Plate.



Top Left: Coral uplift rate of the last 50 years (from Natawidjaja et al., 2004). Right: Best 3D elastic dislocation model, based on coral data and predicted GPS. Subsurface contours of the Locked Fault Zone are each 5km. Bottom Left: GPS data relative to the Australian plate (Bock et al., 2003). The Sugar Network is in green. Right: Best GPS elastic dislocation model.