SEIZE	Collaborative Research: Frictional and Mineralogical Properties of Sediments Entering Subduction Zones: Controls on Stress State and Earthquakes	
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	5/1/2002 – 4/30/2004	OCE 02-03799

This experimental study examines the role that clay minerals play in controlling the frictional properties of subduction plate boundary faults and how, together with regional fluid pressure variations, this controls the state of stress on the subduction thrust. We also address the role that clay digenesis plays in the onset of seismogenic activity. We focus here on the Nankai Trough, SW Japan, because it is representative of sediment-rich subduction zones (including Alaska and Cascadia) that are capable of generating very large earthquakes (~M8 and greater) and it is the proposed site of the IODP NANTROSEIZE drilling project. Two significant, seemingly contradictory attributes of these subduction zone faults are that they appear to be almost fully locked over much of their along-strike length during interseismic periods even though the faults appear to be extremely weak.

Accomplishments:

- Experiments defined a clear relationship between shear strength and total clay content in the Nankai subduction thrust: Working with Mike Underwood (who worked on the mineralogy) we undertook ring and direct shear tests which indicate that shear strengths of materials in subduction thrusts decrease with increasing clay content. Saturated clay phases in the fault possess intrinsically low residual friction coefficients (μ_r) at stress levels between 1 and 30 MPa. These clay phases dominate the Nankai subduction décollement zone. A better correlation between measured shear strength and mineralogy was obtained when the clay data was plotted as total clay rather than the smectite content of the natural Nankai samples. This was because of the dominance of illite in the majority of the samples.
- We determined that the illite (*Il*) phase is already mechanically important/dominant in the altered incoming *Muroto* section (where μ_r should lie between 0.2-0.32) and smectite (*Sm*) contributes to even lower μ_r values of ~0.13 in the older incoming strata off the *Ashizuri* Peninsula (Fig. 1).
- We show that both high clay contents and regional excess fluid pressure contribute to low resolved shear stresses on the Nankai subduction zone plate boundary. Together with elevated fluid pressure, the μ_r values (~0.32) of an *Il*-dominated fault limits shear stresses to below 4 MPa within the frontal ~50 km of the subduction system off *Muroto*. Along strike towards the *Ashizuri* region, increases in wedge taper suggest that fluid pressures fall and basal shear stresses rise slightly. However, the low μ_r values of the clay-rich faults still limit shear stresses to a few 10s Mpa; consistent with other estimates of plate boundary weakness. Thus, we propose that the Nankai and other subduction plate boundaries are weak because of the typical presence of clay-rich faults and moderate fluid overpressures.
- Our data do not support the hypothesis that the smectite to illite reaction directly controls the onset of seismogenic behavior in the Nankai system, because there is already a pre-subduction mechanical dominance of *Il* (rather than smectite) in the incoming section, and because all the clay phases tend to velocity strengthen (Fig.

2).

Figures and Captions

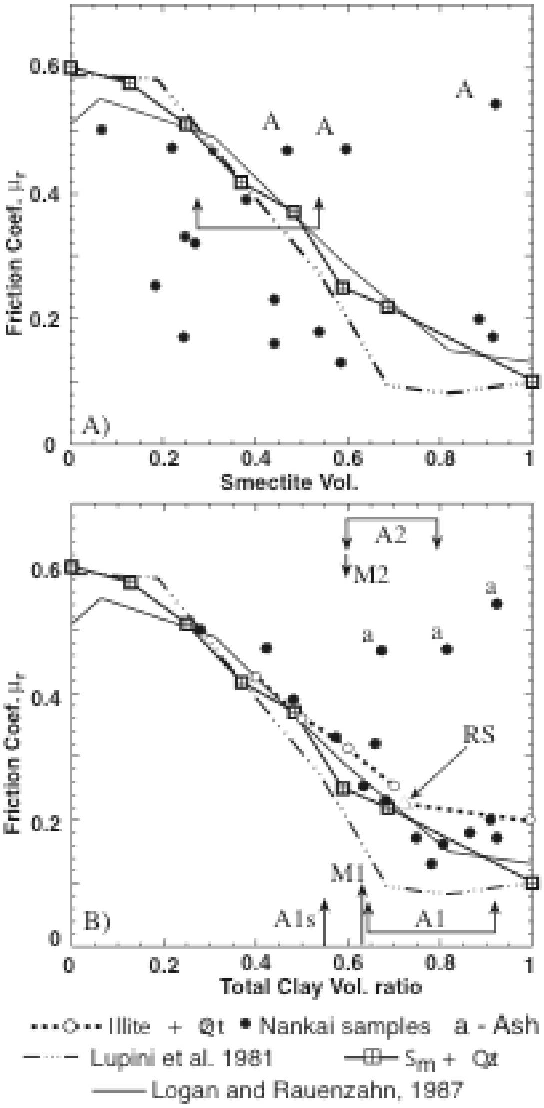

Figure 1: Results of ring shear tests conducted on natural Nankai samples (black dots) and artificial mineral mixtures of *Sm* with *Qtz*. Data for tests we conducted on *Il* and *Qtz* mixtures are also shown. The residual friction (μ_r) data are plotted against the volumetric ratio of (A) smectite (V_S) and (B) total clay (V_{S+I+Ch}) within the solid fraction. *A2* and *M2* denote estimated altered deep décollement property ranges (based on altered mineralogy), *A1* and *AS1* are unaltered *Ashizuri* shallow décollement ranges and *M1* is the estimated shallow Muroto value. (a - Vitric ash containing samples).

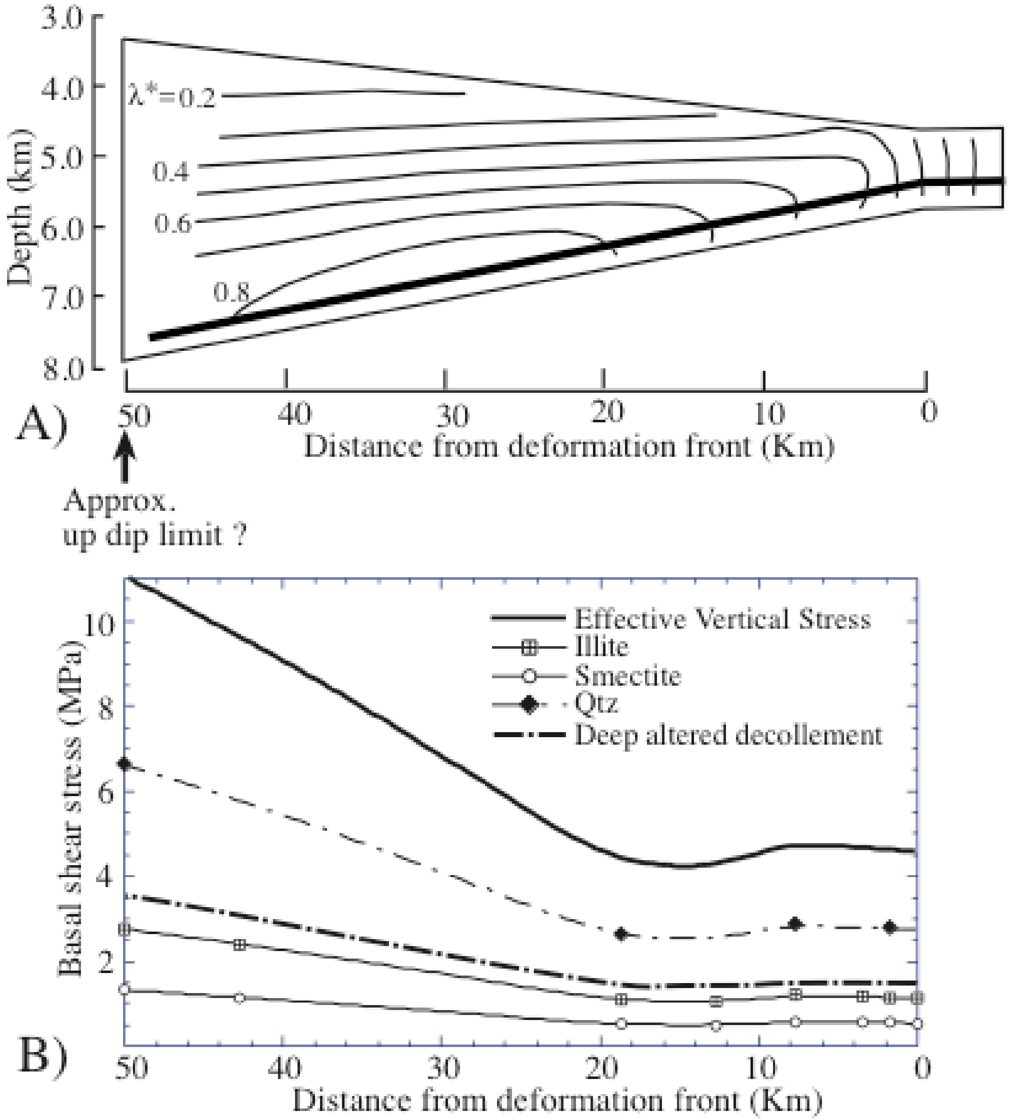

Figure 2. (A) numerically estimated [Saffer and B.A. Bekins, 1998] fluid pressure distribution in the frontal 50km of the wedge (B) Estimated shear stress on the Nankai subduction thrust off *Muroto* derived from the fluid pressure distribution shown in Figure 2A and the frictional properties of the purified clay minerals (*Sm* and *Il*) and Qtz. The estimated frictional resistance for the diagenetically altered *Muroto* décollement lithologies are also shown (M2, Fig. 1).

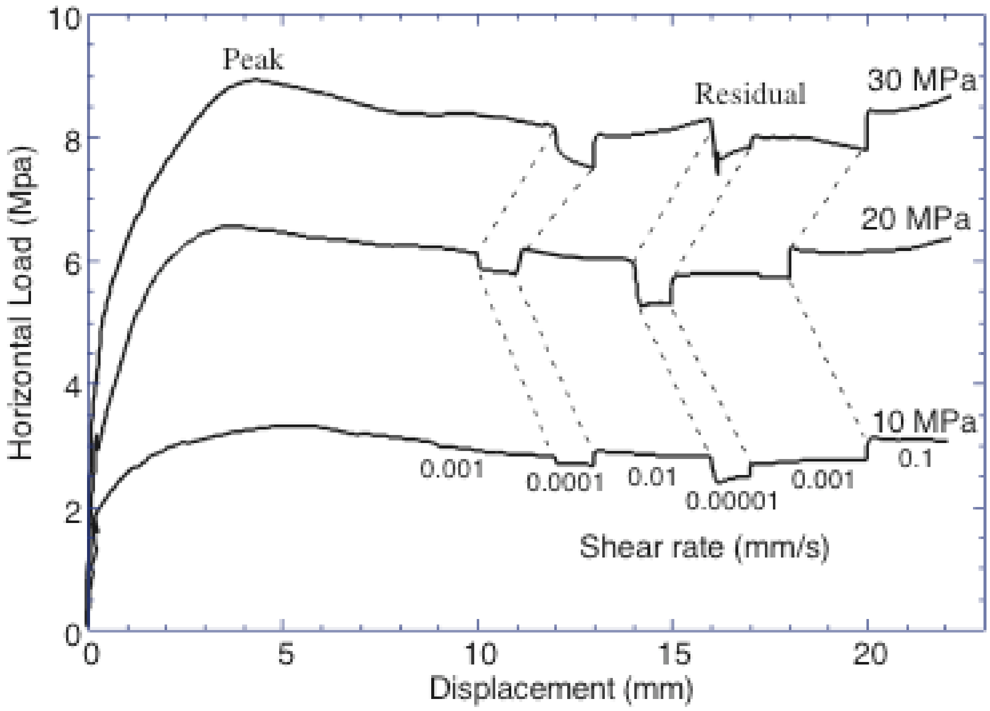

Figure 3: Example of direct shear results for saturated illite at stress levels of 10, 20, and 30 MPa. Rates of velocity stepping tests are shown. Typically, a velocity rate change is followed by a direct initial change in the frictional resistance (*a*-value), which then subsequently comes to a steady state value at the new slip velocity (*b*-value). The magnitude of the decay to a steady state friction is typically reported as, $a \square b = \square\square_r / \square \ln Vel$, where $\square\square_r$ is the change in steady state frictional strength and Vel is the sliding velocity. We consistently report positive values of $a \square b$ for a velocity increase, implying a velocity strengthening or stable sliding mechanism is operating for illite.