# The Source of Shallow Slow Earthquakes

## *Insights from field observations and experiments on an exhumed subduction mélange*


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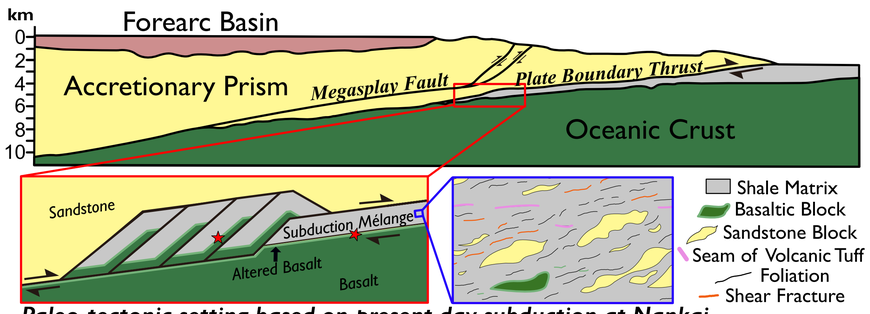
## Geology of the Shallow Slow Earthquake Source

Subduction zones in the up-dip region of the seismogenic zone are low temperature (<300 °C), high pore fluid pressure environments, prone to shallow slow earthquake phenomena (slow slip events and associated LFEs and VLFEs). Here we examine deformation features along the margins of altered basaltic blocks embedded within a shale matrix from an exhumed shallow subduction mélange. Unlike sandstone blocks, which do not have evidence for faulting along their margins, altered basaltic blocks show evidence of localized slip along their margins at high pore-fluid pressure conditions. Faults link basaltic blocks through the shale matrix. We hypothesize that failure of altered basaltic blocks represent LFEs, and that larger magnitude slow earthquake phenomena (e.g. VLFEs) may occur by linking blocks with throughgoing faults.

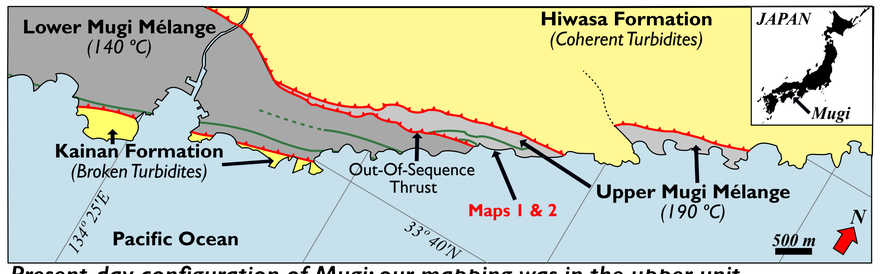
*Our Field Site:* *The Mugi Mélange*

- Ancient analogue for modern day subduction at Nankai
- Active in the late Cretaceous in a warm subduction setting
- Pressures and temperatures are consistent with host environment for shallow slow earthquake phenomena
- Cut by an out-of-sequence thrust: separated into lower and upper units with peak temperatures of 140 and 190°C respectively
- Several examples of paleo-seismicity (pseudotachylyte and fluidized granular flows) within the altered basalt

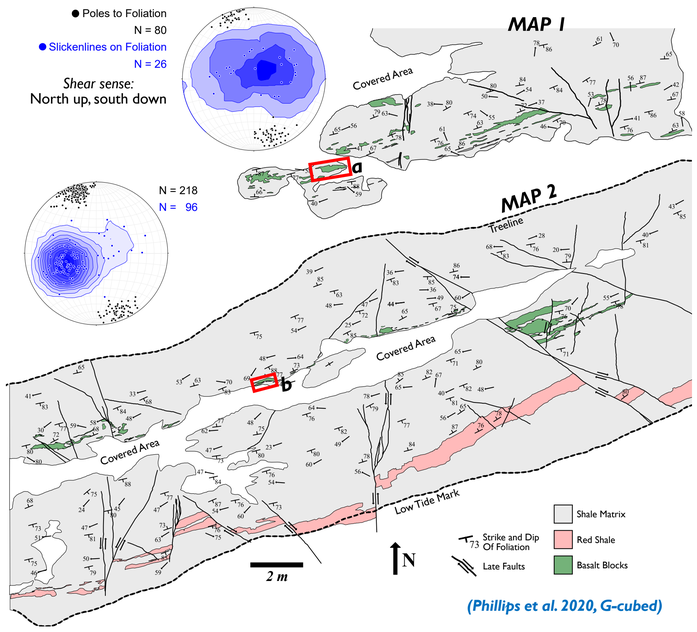
In this poster, we examine the margins of altered basaltic blocks which form 3 distinct, ~2 m wide horizons in the Upper Mugi Mélange, test their frictional properties at *in situ P-T* conditions of deformation for two pore fluid factors, and calculate the critical nucleation lengths for altered basalt based on the frictional properties determined through experimentation.




*Paleo-tectonic setting based on present day subduction at Nankai* (Phillips et al. 2019, EPSL)



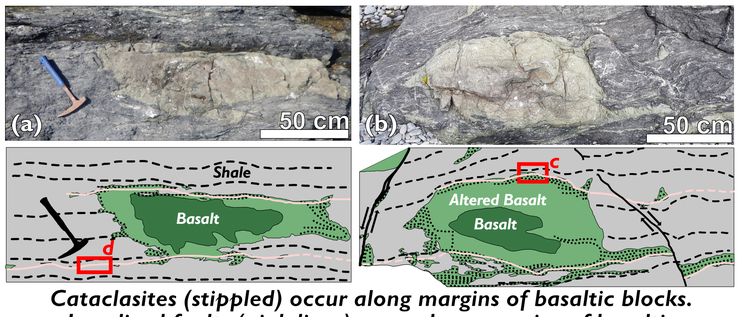

*Present-day configuration of Mugi: our mapping was in the upper unit.* (Phillips et al. 2019, EPSL)



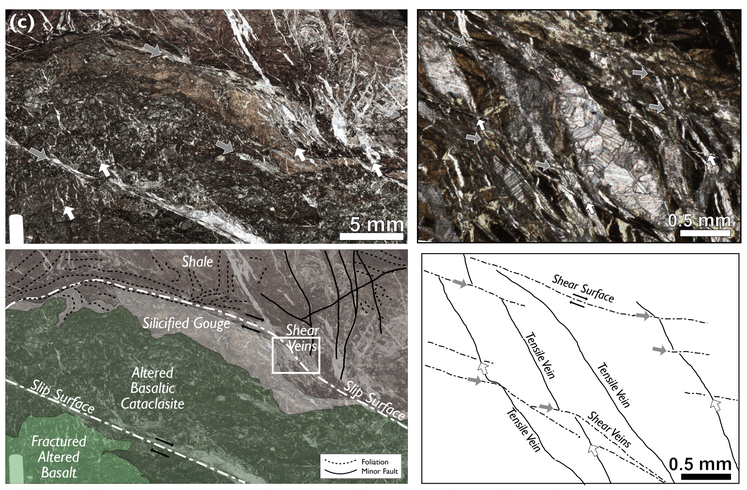

(Phillips et al. 2020, G-cubed)

*Detailed maps highlighting distribution of altered basaltic blocks.*

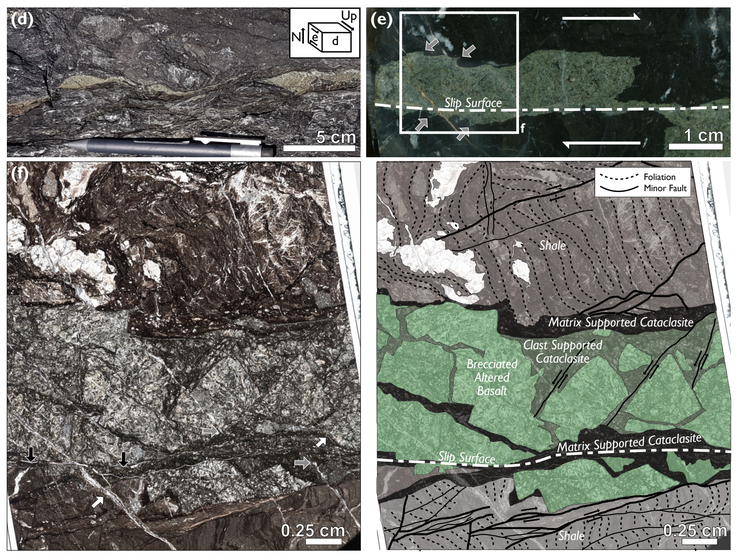
## Localized Low-Displacement Faults Formed at High Pore Fluid Pressures




*Cataclasites (stippled) occur along margins of basaltic blocks. Localized faults (pink lines)occur along margins of basaltic blocks and link blocks.*

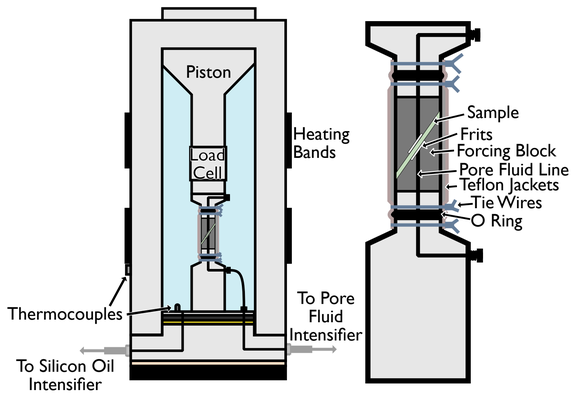


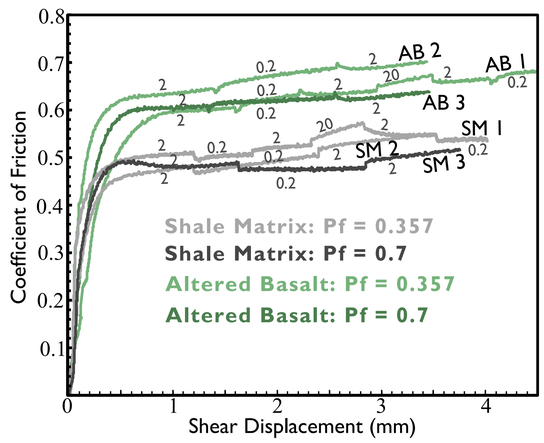

*Mutually cross-cutting shear surfaces and tensile veins occur along block margins and are evidence of slip at high pore fluid pressures.*

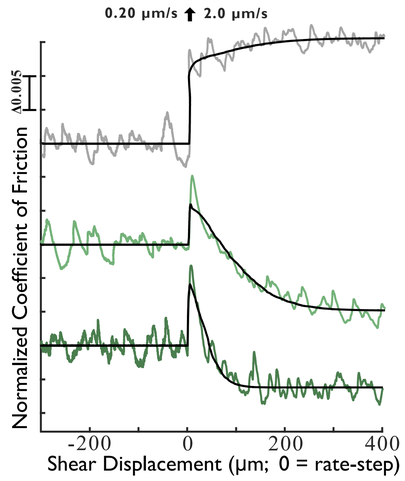



*Faults which link blocks contain smeared altered basaltic cataclasite.* (Phillips et al. 2020, G-cubed)

## Frictional Properties of Altered Basalt and Shale

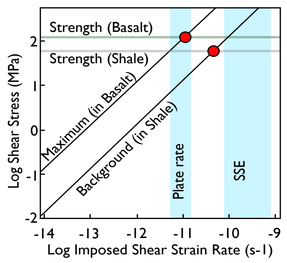


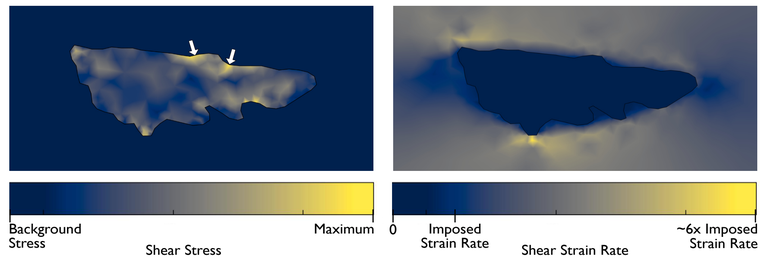



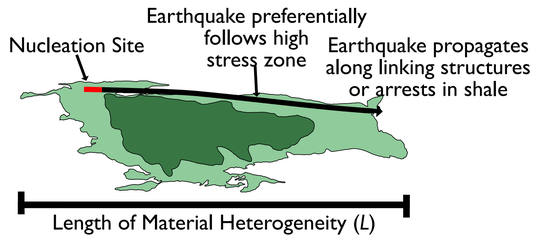




*Experiments were performed at ~in situ conditions (P = 120 MPa , T = 150°C) for 2 pore fluid factors (0.36, 0.7) with rate-steps between 0.2 and 20 µm/s.*
*Shale exhibits velocity strengthening behavior and is frictionally weaker than altered basalt.*
*Altered basalt exhibits velocity weakening behavior and is frictionally stronger than shale.*
*Increasing pore fluid pressure led to a decrease in critical slip distance (Dc) in altered basalt.* (Phillips et al. 2020, JGR)

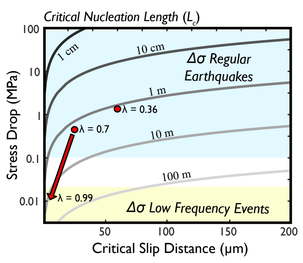
## Failure of the Blocks

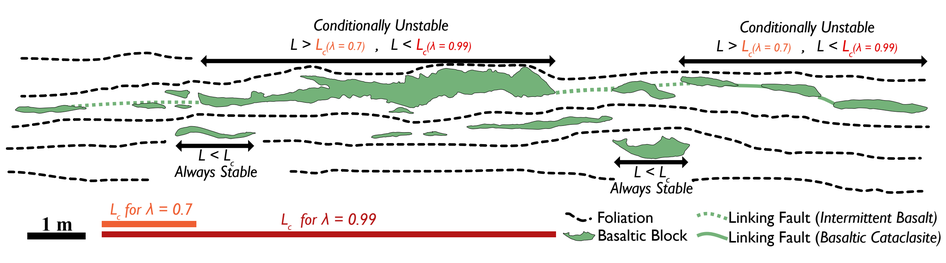


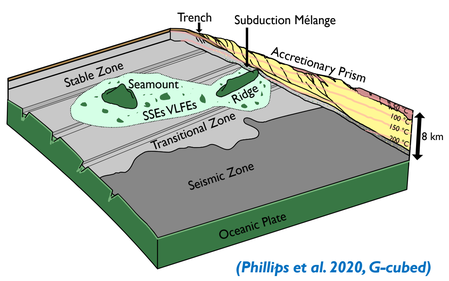




*Models of stresses in basaltic blocks during distributed shear in the shale (through pressure-solution creep) indicate that altered basalt would fail frictionally at a lower imposed strain-rate than shale, consistent with fault development along altered margins of basaltic blocks*




(Phillips et al. 2020, G-cubed)

*Calculations of critical nucleation lengths for the blocks show they would fail dynamically (i.e. block lengths are greater than critical nucleation length) at hydrostatic pore fluid pressures, producing microearthquakes.*
*At near lithostatic pore fluid pressures, block lengths are below the critical nucleation length for dynamic failure and may produce slow earthquake phenomena (i.e. low-frequency earthquakes).*
*Linking faults through the velocity strengthening shale may facilitate larger magnitude slow earthquake phenomena (i.e. very low-frequency earthquakes).*
*Slow earthquake phenomena may preferentially occur when altered basalt is more easily incorporated into the shale matrix; this could be during subduction of seamounts, ridges, topography (horst-and-grabens), or young (hotter and more buoyant) oceanic crust.*


Phillips, N.J., Motohashi, G., Ujiie, K. & Rowe, C.D. 2020 Evidence of localized failure along altered basaltic blocks in tectonic mélange at the updip limit of the seismogenic zone: Implications for the shallow slow earthquake source, *G-cubed, 21, 7, 1-17*
Phillips, N.J., Belzer, B., French, M.E., Rowe, C.D. & Ujiie, K. 2020 Frictional strengths of subduction thrust rocks in the region of shallow slow earthquakes, *Journal of Geophysical Research: Solid Earth, 125, 3, 1-20*
Phillips, N.J., Rowe, C.D. & Ujiie, K. 2019 For how long are pseudotachylytes strong? Rapid alteration of basalt hosted pseudotachylytes from a shallow subduction complex, *Earth and Planetary Science Letters, 518, 108-115*