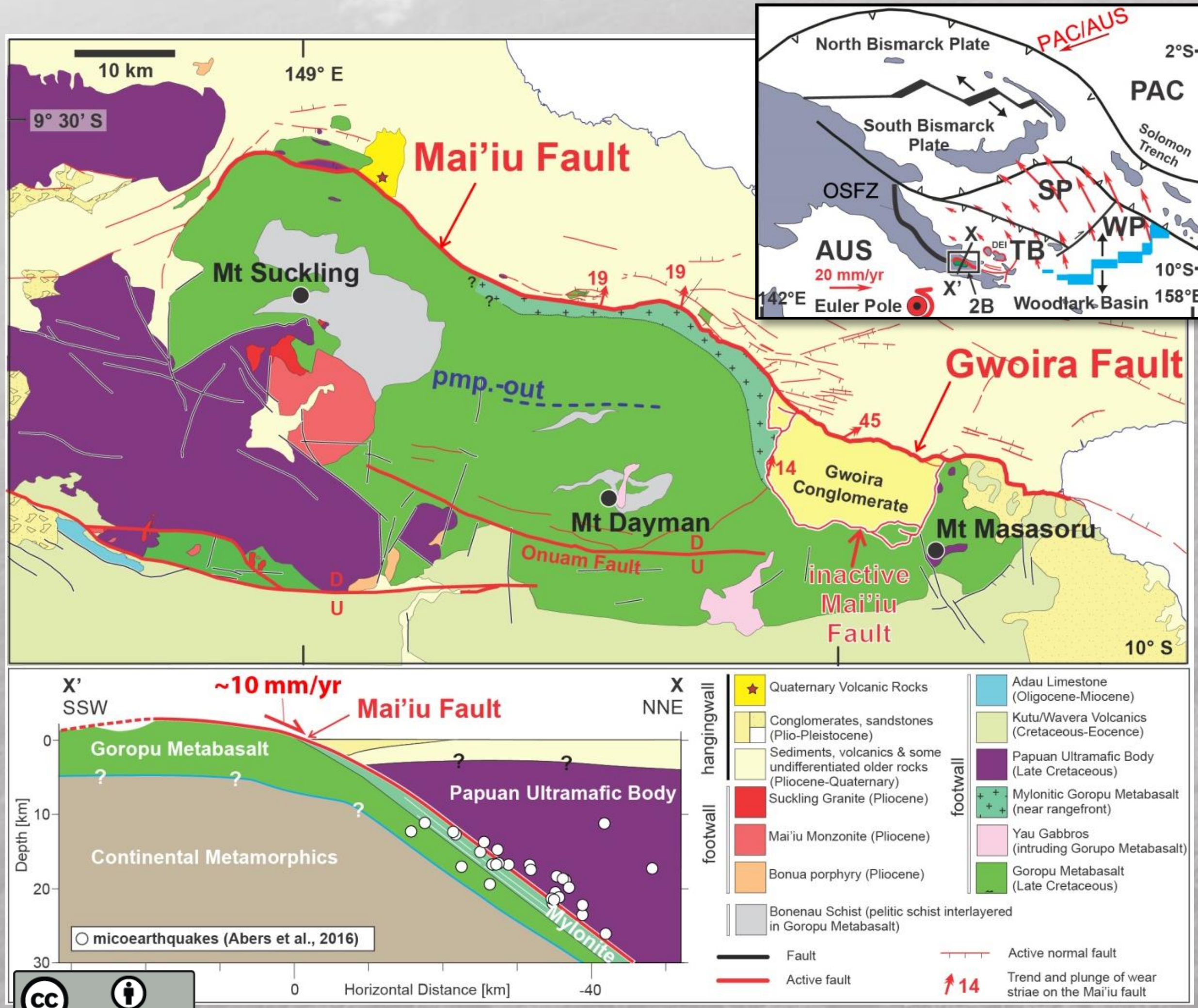
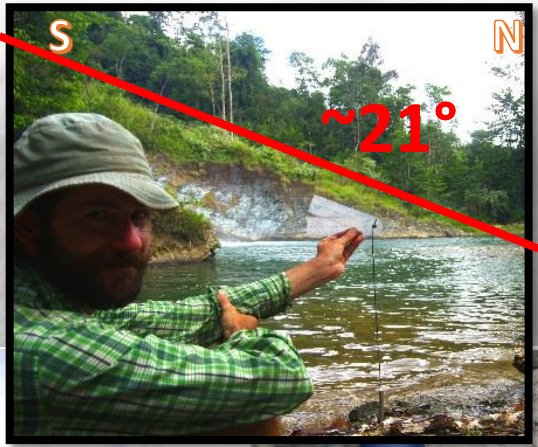
Mixed-mode Slip Behavior and Strength Evolution of an Actively Exhuming Low-Angle Normal Fault, Papua New Guinea

Marcel Mizera, Timothy Little, Carolyn Boulton, James Biemiller, and David Prior

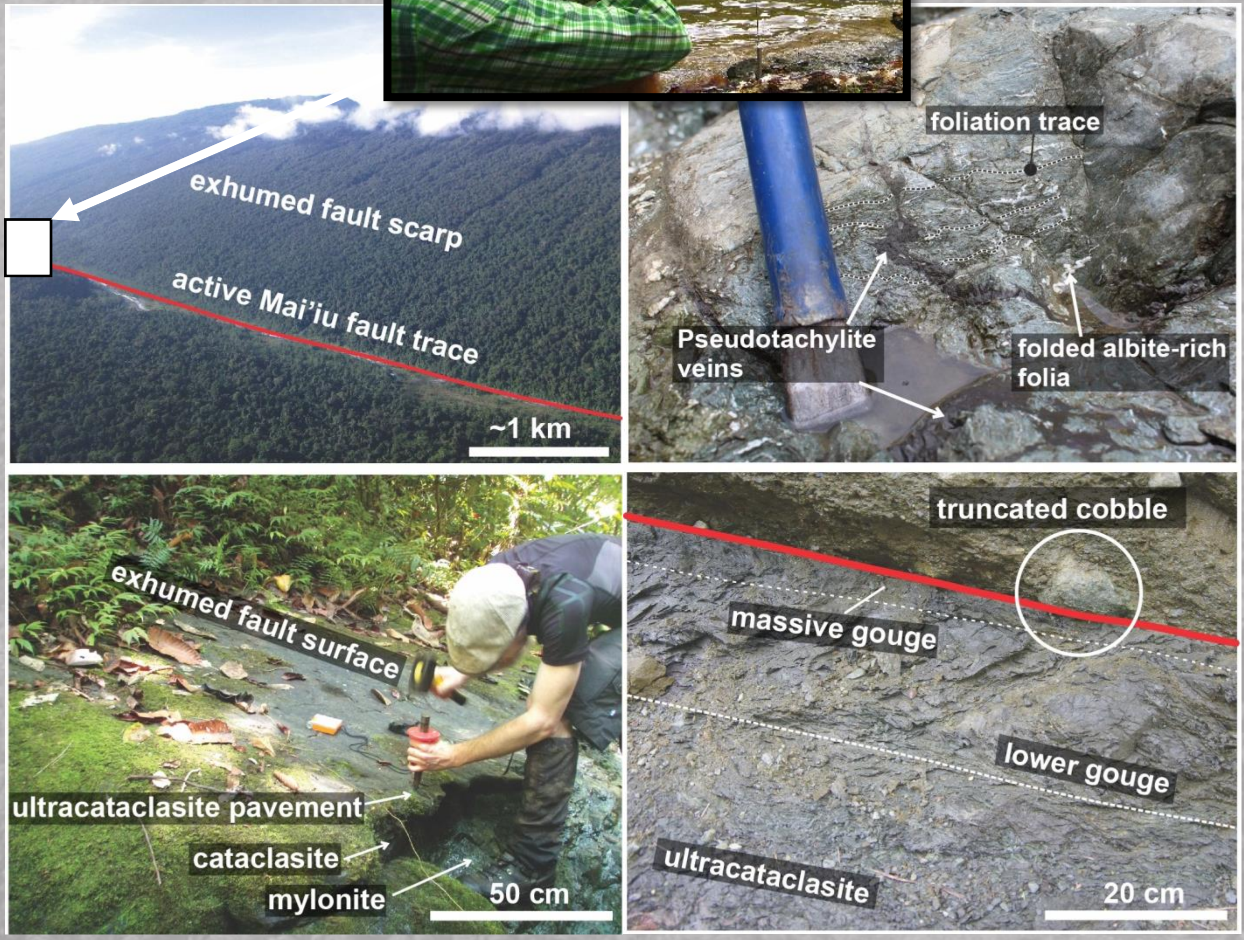
→ See also Mixed-Mode Seismic Slip and Aseismic Creep on a Highly Active Low-Angle Normal Fault System in Papua New Guinea

Regional geology of the active Mai'iu fault

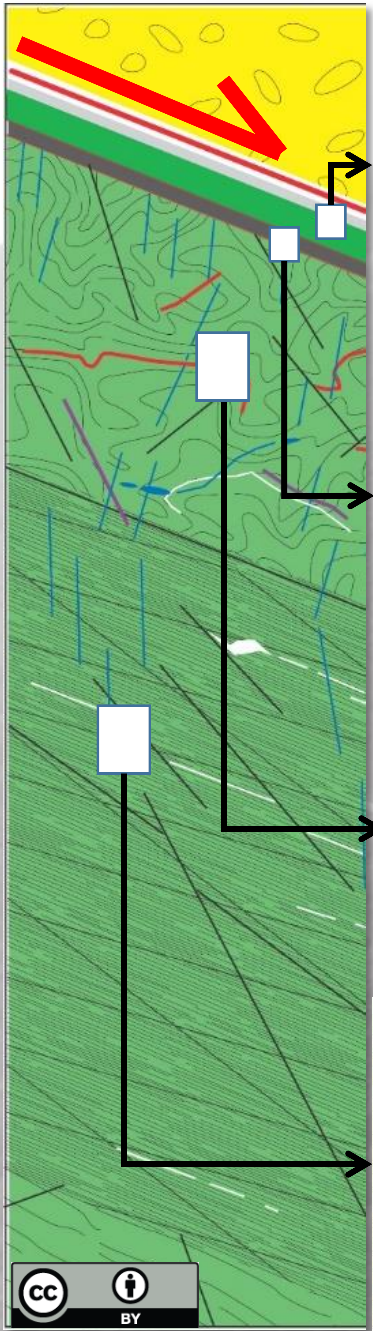


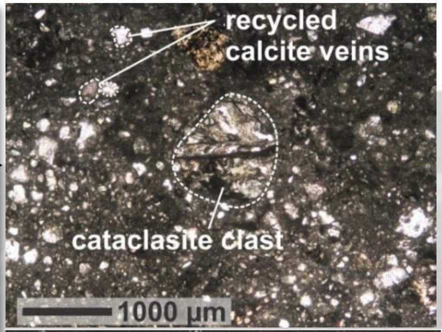


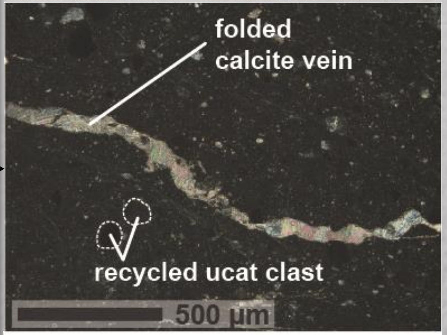
Exhumed fault rocks →

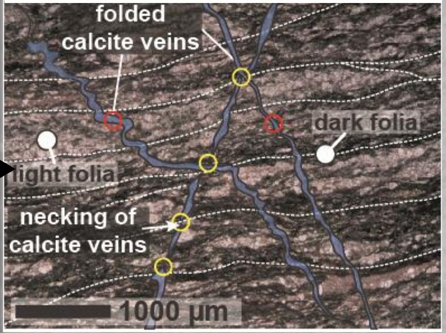


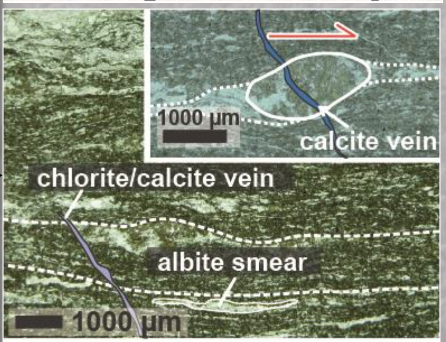
Exhumed Fault Rock Sequence of the Mai'iu fault











Mafic Gouges

~10 cm, massive clay-rich gouges containing abundant saponite (up to 65%); a velocity-strengthening, weak mineral (µ<0.2). Given sufficient areal distribution on the fault plane, saponite gouges may have promoted aseismic slip on the shallowest dipping most poorly oriented part of the Mai'iu fault (dipping ~15–24°)

Ultracataclasites

5-40 cm-thick layer of dark grey or black to brick red, ultracataclasite. Slip in this unit was at least in part accomplished by distributed granular flow of the ultrafine-grained mafic minerals.

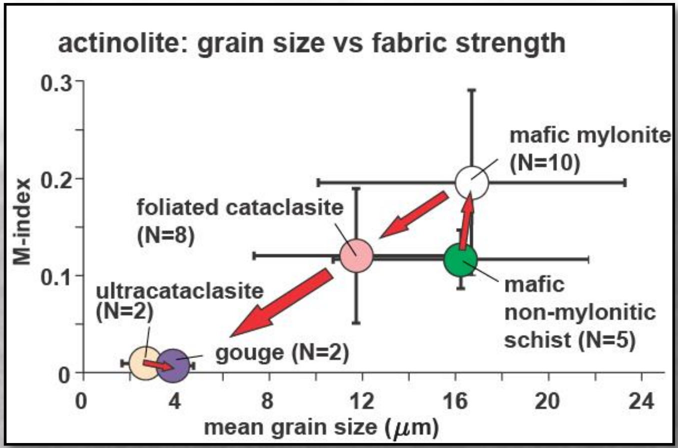
Foliated Cataclasites

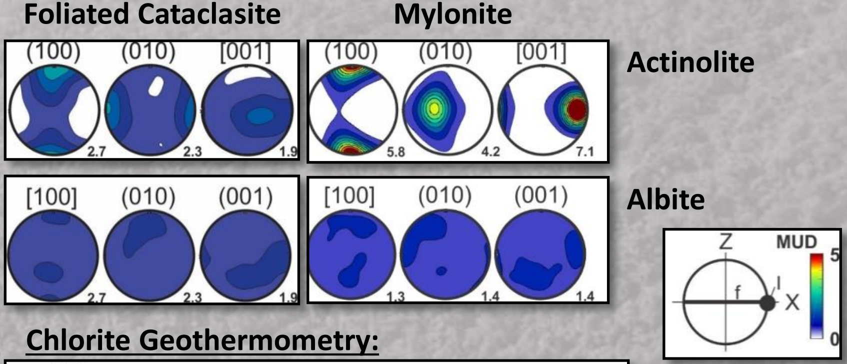
Fluid-assisted mass transfer of albite, quartz and calcite led to mineral transformation reactions with continuous chlorite growth, creating a 1.5-3 m-thick zone of brittlely, faulted foliated cataclasite containing abundant pseudotachylite veins (5-40 mm thick), ultracataclasite seams (cm thick), and late calcite veins (<1 mm thick). All layers are variably folded.

Mafic (Ultra-)Mylonites

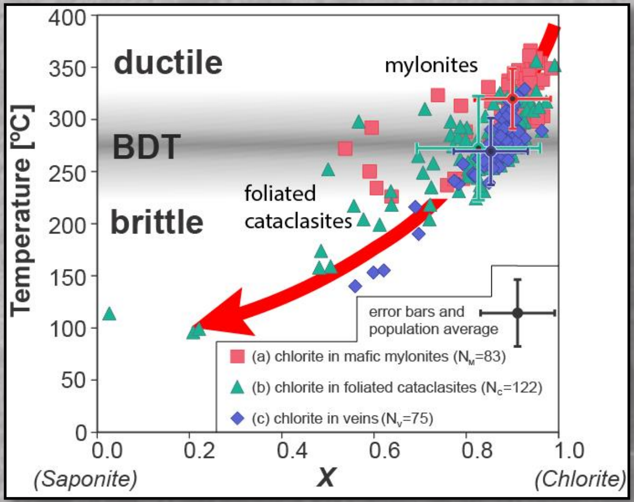
Mylonite zone is at least 60 m thick.
Slip within the mylonites was accomplished by diffusion-accommodated rotation and grain-boundary sliding of pre-existing, fine-grained (6–35 µm in diameter) epidote, actinolite, chlorite, and albite.

Fabric strength (M-index) vs mean grain size in different fault rock units of the Mai'iu fault (N=number of samples analysed):



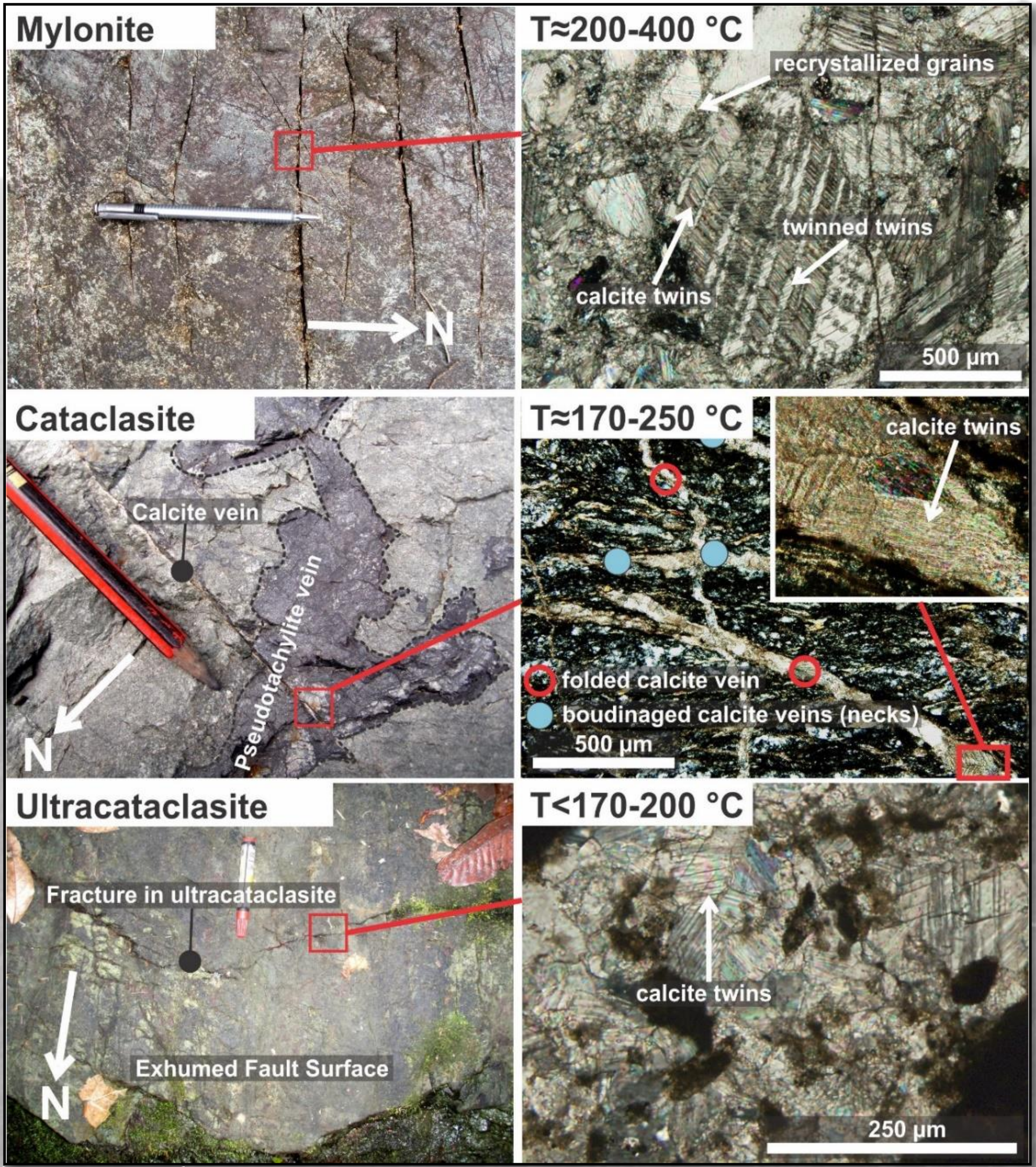


Chlorite Geothermometry:



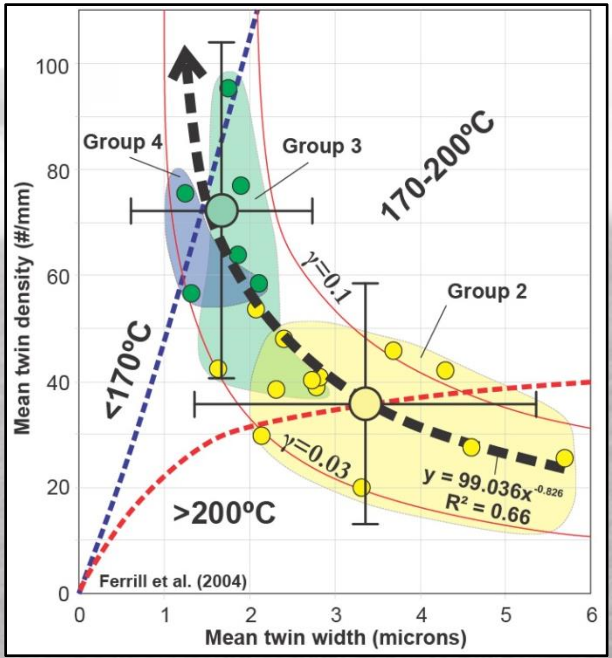
Calcite-Twin Geothermometry and Paleopiezometry

Outcrop photographs of the Mai'iu fault rock units and photomicrographs of calcite-filled veins that cross-cut them:

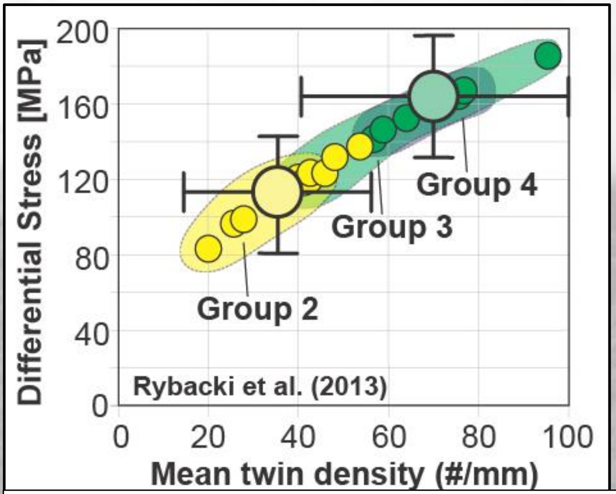


 Mizera, 2019

Estimated deformation temperatures based on deformation twinning in calcite:

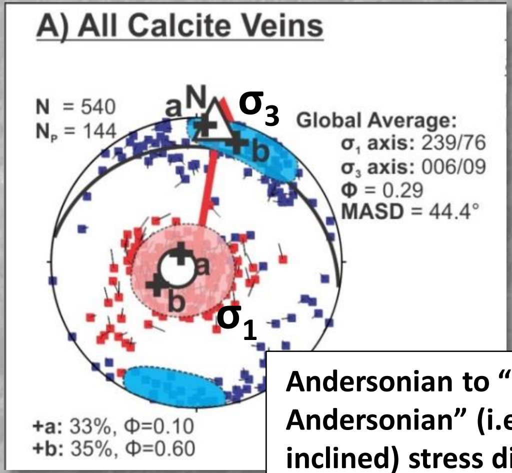


Graph of differential stress versus mean twin density based on calcite:



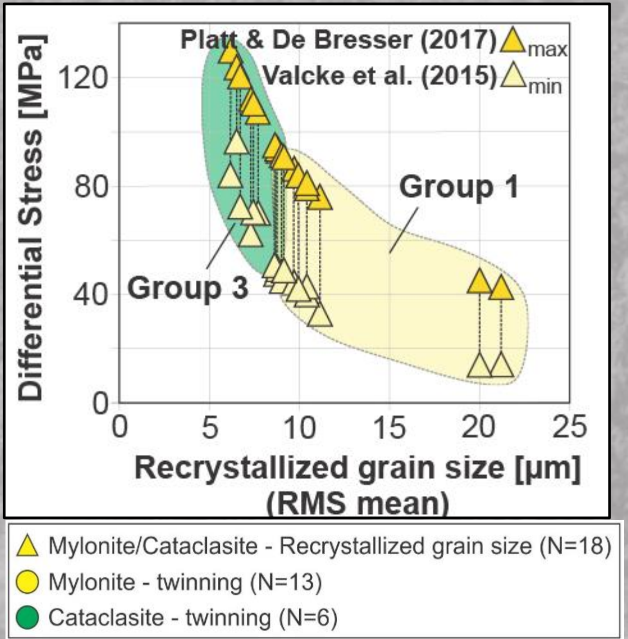
peak differential stresses of ~140–185 MPa in the foliated cataclasites

Reconstructed principal stress directions (lower hemisphere, equal-area stereograms) based on observed calcite-twin pairs as analysed by the MIM-method (Yamaji, 2000):



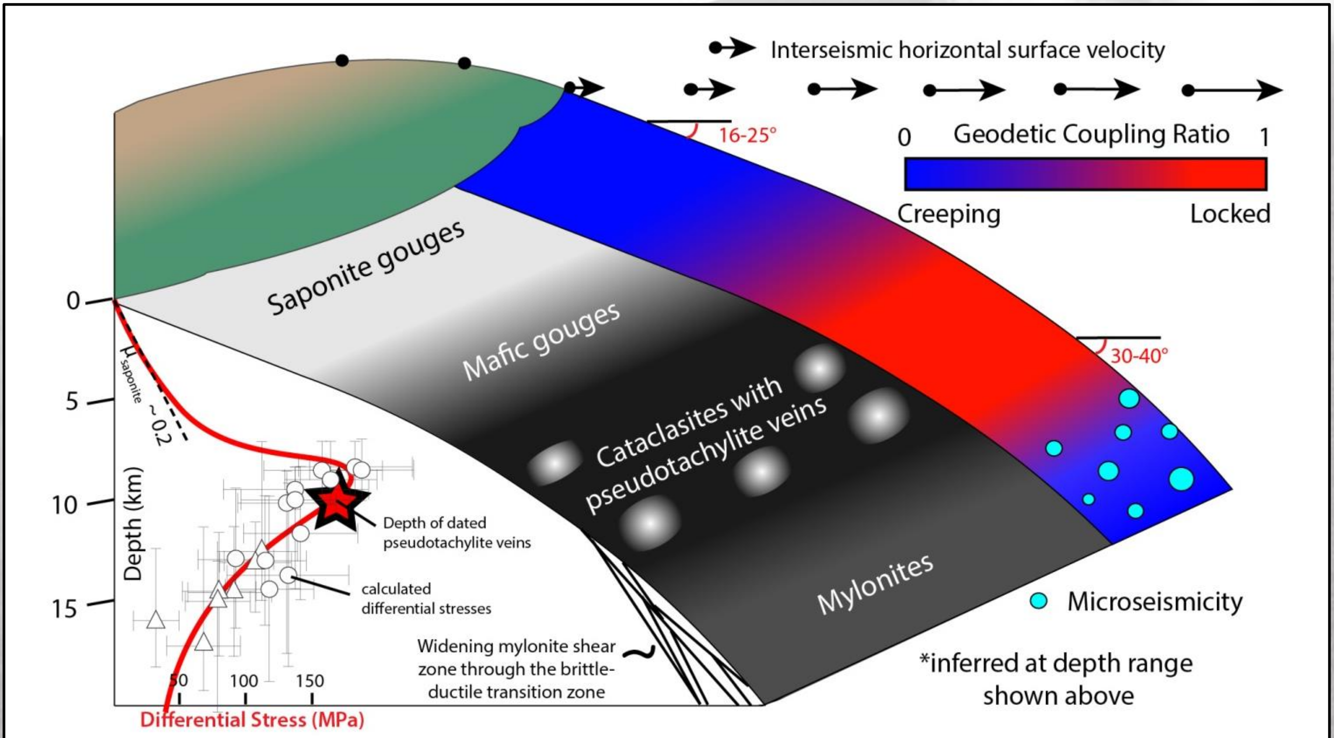
Andersonian to "near-Andersonian" (i.e., slightly inclined) stress directions

Differential stress versus dynamically recrystallized calcite grain size plot:



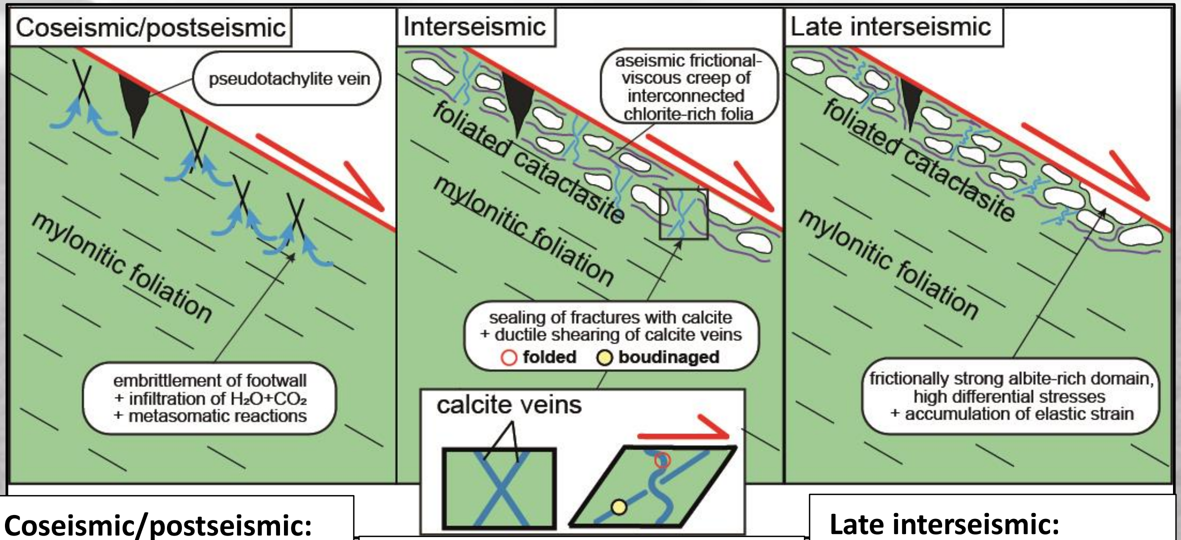
Slip Behavior and Strength Evolution of the active Mai'iu fault

Our results combined with fault dislocation models of GPS velocities from campaign stations in this region suggest a combination of brittle frictional and viscous flow processes within the Mai'iu fault zone.



Fault Rock Unit	Friction Coefficient	Frictional Stability*	Deformation Mechanism*
Saponite gouges	0.11 - 0.28	Velocity-strengthening	Aseismic frictional creep
Mafic gouges	0.22 - 0.57	Velocity-weakening to velocity-strengthening	Mixed diffusion creep, frictional-viscous creep & seismic slip ('partial locking')
Cataclasites with pseudotachylite veins	0.44 - 0.80	Both velocity-weakening and velocity-strengthening	
Mylonites	0.6 - 0.8	Both velocity-weakening and velocity-strengthening	Diffusion creep, grain-boundary sliding, small frictional failures

Schematic evolution of the rheology in the foliated cataclasites, active at a depth range corresponding to T=150 to 270°C, approximately 8 to 15 km:



Coseismic/postseismic: Brittle fracturing of the mafic mylonites and/or foliated cataclasites increases the permeability of the fault core, leading to the infiltration of H2O + CO2-rich fluids.

Interseismic: Time-dependent and stress-dependent diffusive mass transfer processes within the foliated cataclasites ultimately lead to the development of interconnected chlorite-rich folia, promoting creep by stable frictional sliding in the chlorite-rich folia. Open fractures are sealed with hydrothermal calcite, and the calcite veins are ductilely sheared during interseismic periods.

Late interseismic: Gradually, precipitation of albite, calcite and quartz from an intergranular fluid phase in fractures and pores cement and strengthen the foliated cataclasites, thus promoting elastic strain accumulation (Late interseismic).

Modified after Biemiller et al., submitted

→ See also Mixed-Mode Seismic Slip and Aseismic Creep on a Highly Active Low-Angle Normal Fault System in Papua New Guinea

References:

Abers, G. A., Eilon, Z., Gaherty, J. B., Jin, G., Kim, Y. H., Obrebski, M., & Dieck, C. (2016). Southeast Papuan crustal tectonics: Imaging extension and buoyancy of an active rift. Journal of Geophysical Research: Solid Earth, 121(2), 951-971.

Little, T. A., Webber, S. M., Mizera, M., Boulton, C., Oesterle, J., Ellis, S., Boles, A., van der Pluijm, B., Norton, K., Seward, D., Biemiller, J., and Wallace, L. (2019): Evolution of a rapidly slipping, active low-angle normal fault, Suckling-Dayman Metamorphic Core Complex, SE Papua New Guinea.

Mizera, M. (2019). Deformational Processes Accommodating Slip on an Active Low-Angle Normal Fault, Suckling-Dayman Metamorphic Core Complex, Papua New Guinea. (http://hdl.handle.net/10063/8666)

Platt, J. P., & De Bresser, J. H. P. (2017). Stress dependence of microstructures in experimentally deformed calcite. *Journal of Structural Geology*, *105*, 80-87.

Rybacki, E., Evans, B., Janssen, C., Wirth, R., & Dresen, G. (2013). Influence of stress, temperature, and strain on calcite twins constrained by deformation experiments. *Tectonophysics*, *601*, 20-36.

Smith, I. E. & Davies, H. L. (1976). Geology of the Southeast Papuan Mainland. Bureau of mineral resources, geology and geophysics, Bulletin 165.

Valcke, S. L. A., De Bresser, J. H. P., Pennock, G. M., & Drury, M. R. (2015). Influence of deformation conditions on the development of heterogeneous recrystallization microstructures in experimentally deformed Carrara marble. *Geological Society, London, Special Publications*, *409*(1), 175-200.

Yamaji, A. (2000). The multiple inverse method: a new technique to separate stresses from heterogeneous fault-slip data. *Journal of Structural Geology*, *22*(4), 441-452.