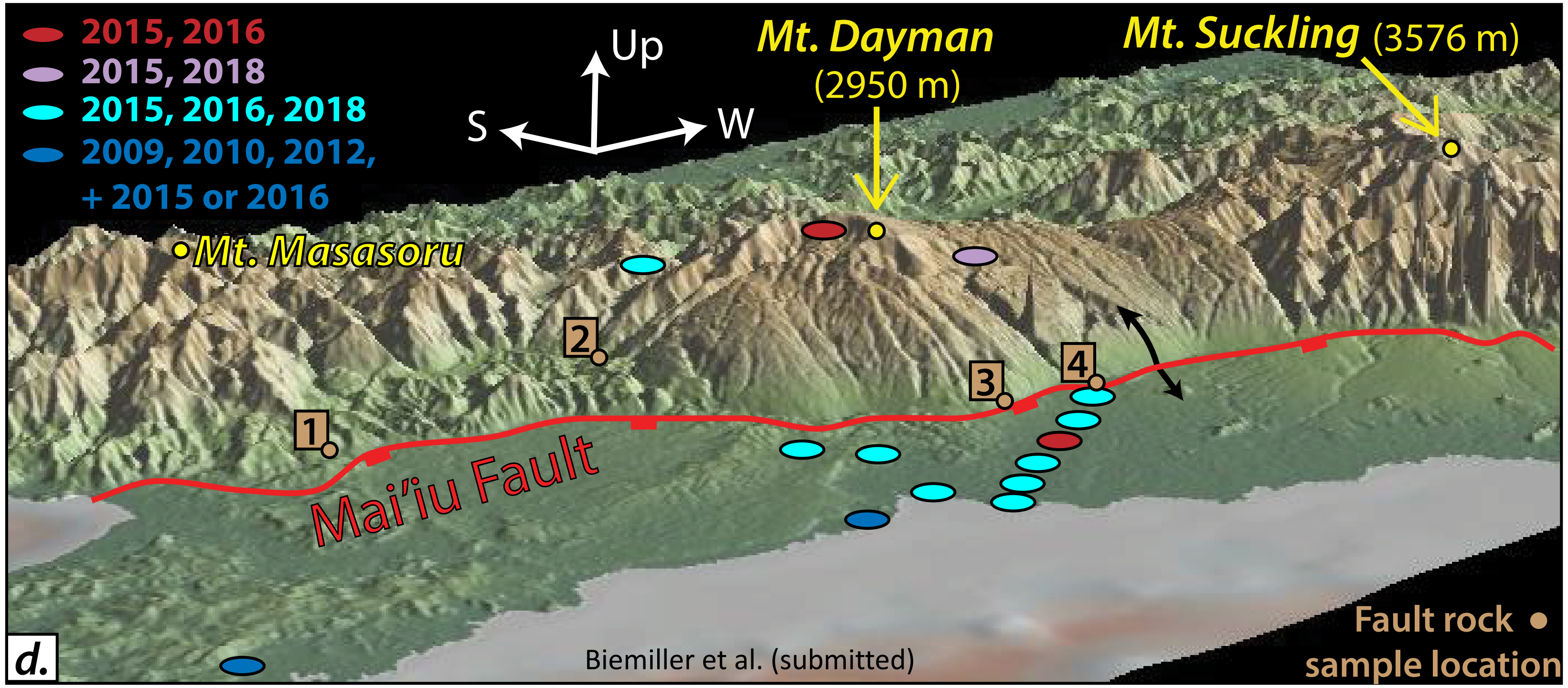
INSTITUTE FOR GEOPHYSICS
JACKSON SCHOOL OF GEOSCIENCES

THE UNIVERSITY OF TEXAS AT AUSTIN

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



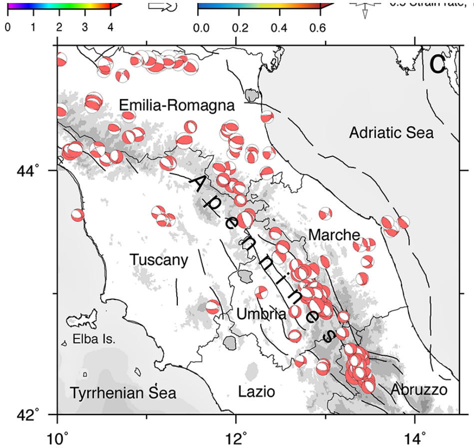
VICTORIA UNIVERSITY OF WELLINGTON TE HERENGA WAKA

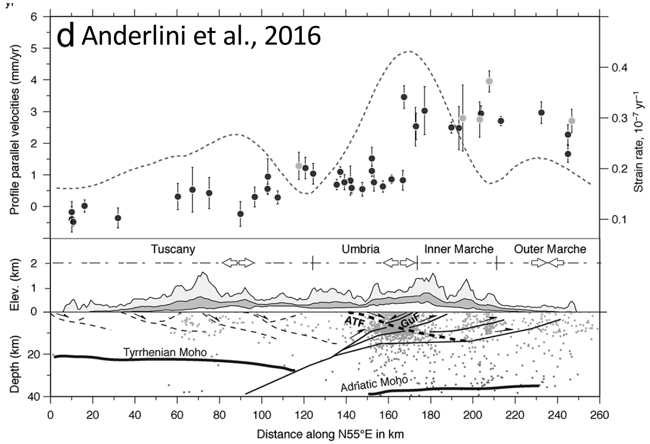
James Biemiller, Carolyn Boulton, Laura Wallace, Susan Ellis, Tim Little, Marcel Mizera, Andre Niemeijer, Luc Lavier

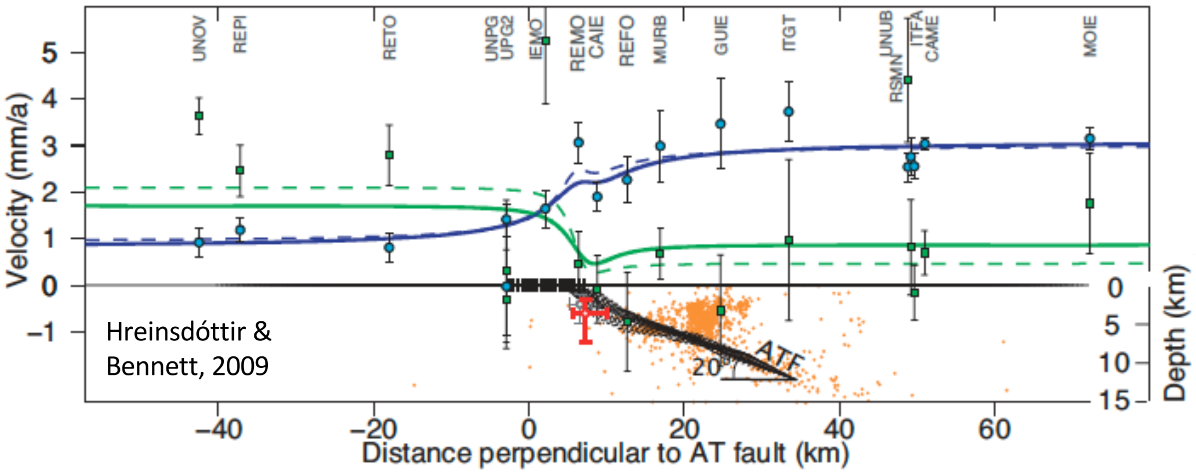
Visit Marcel Mizera's presentation (EGU2020-17399) in this session for microstructural analysis of the Mai'iu fault rocks

Do low-angle normal faults slip in large earthquakes or creep aseismically?

Altotiberina fault, Italy (2-3 mm/yr extension)



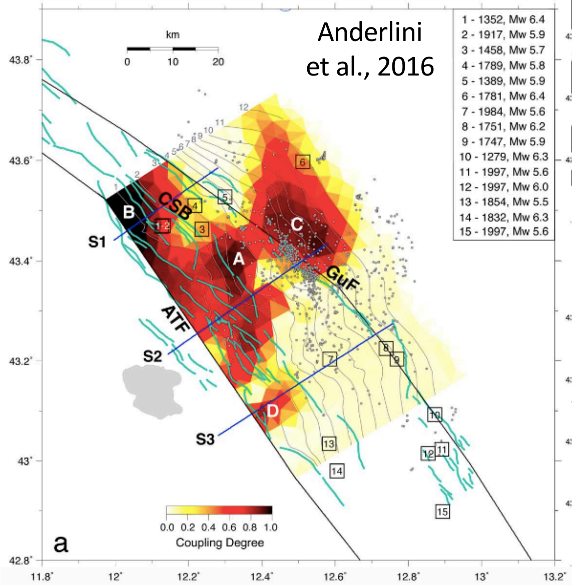




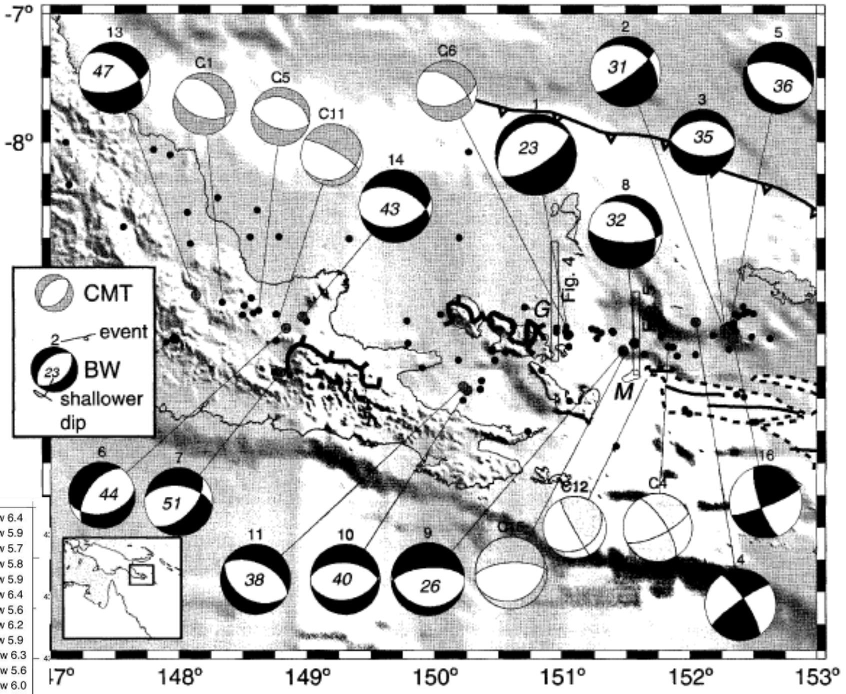
Here, we use campaign **GPS measurements** and **laboratory friction experiments** to investigate the (a)seismic slip behavior of one of the world's fastest-slipping low-angle normal faults, the **Mai'iu fault** in southeastern Papua New Guinea

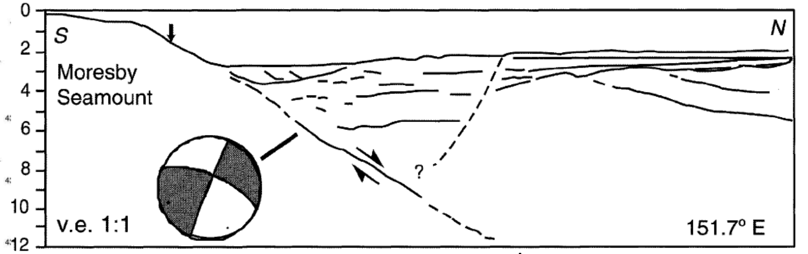
Active low-angle normal faults are rare, and typically slip < 3 mm/yr

Evidence for seismicity (Woodlark, Corinth) up to M_w 6.8, and for significant aseismic creep (Altotiberina)



Woodlark Rift, Papua New Guinea

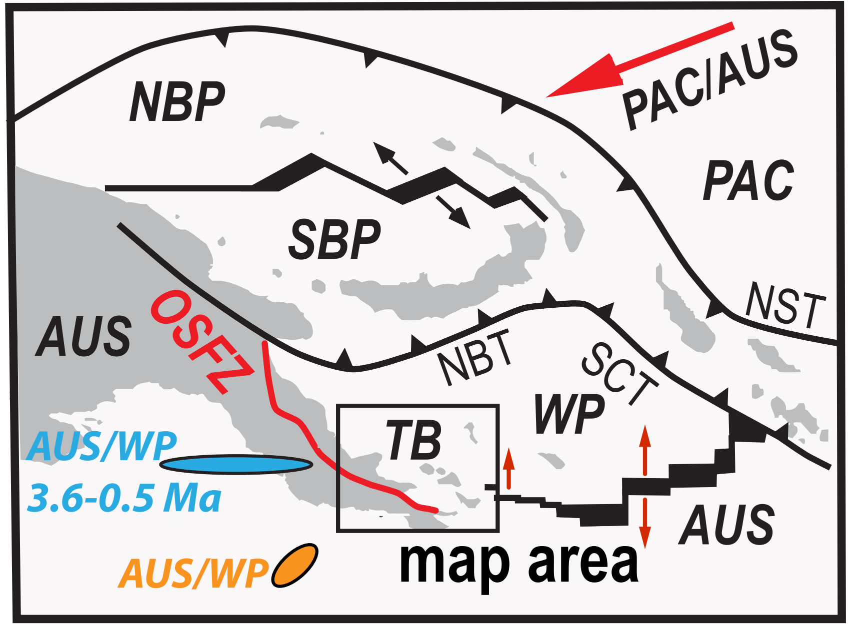


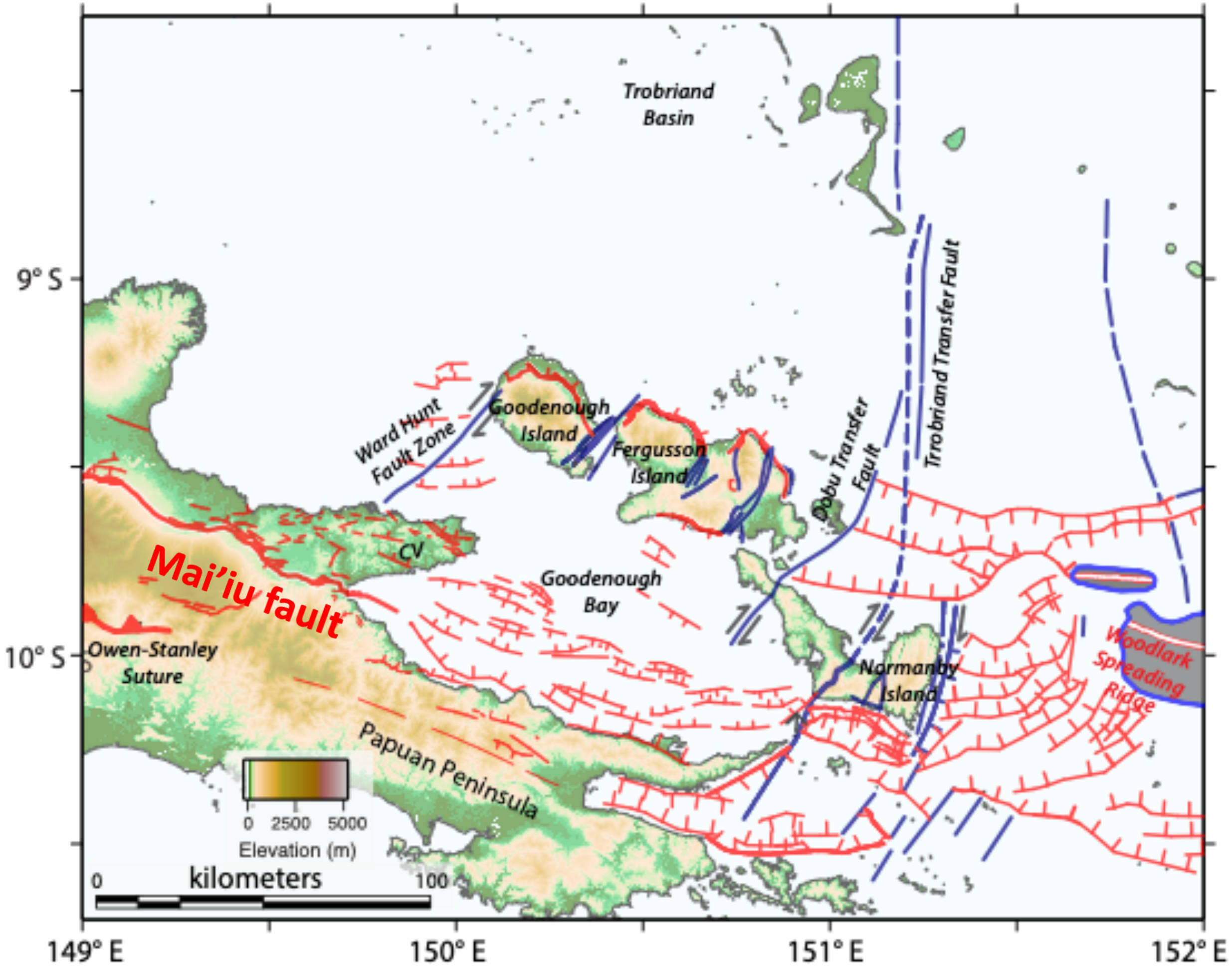


Abers, 2001

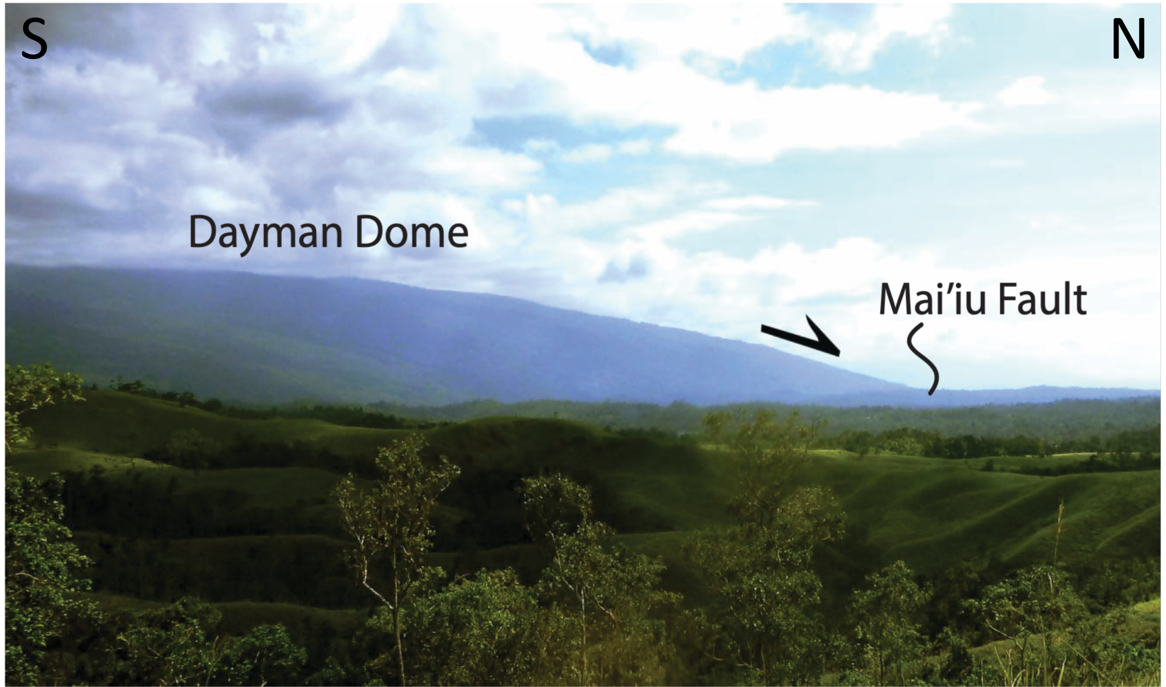
The Mai'iu low-angle normal fault

- Dips 16-24° at the surface (Little et al., 2019; Mizera et al., 2019)
- Geodetic slip rate up to 1 cm/yr (Wallace et al., 2014)
- Be^{10} exposure -> slip rate of 11.7 ± 3.5 mm/yr (Webber et al., 2018)
- Main structure exhuming the Dayman-Suckling core complex

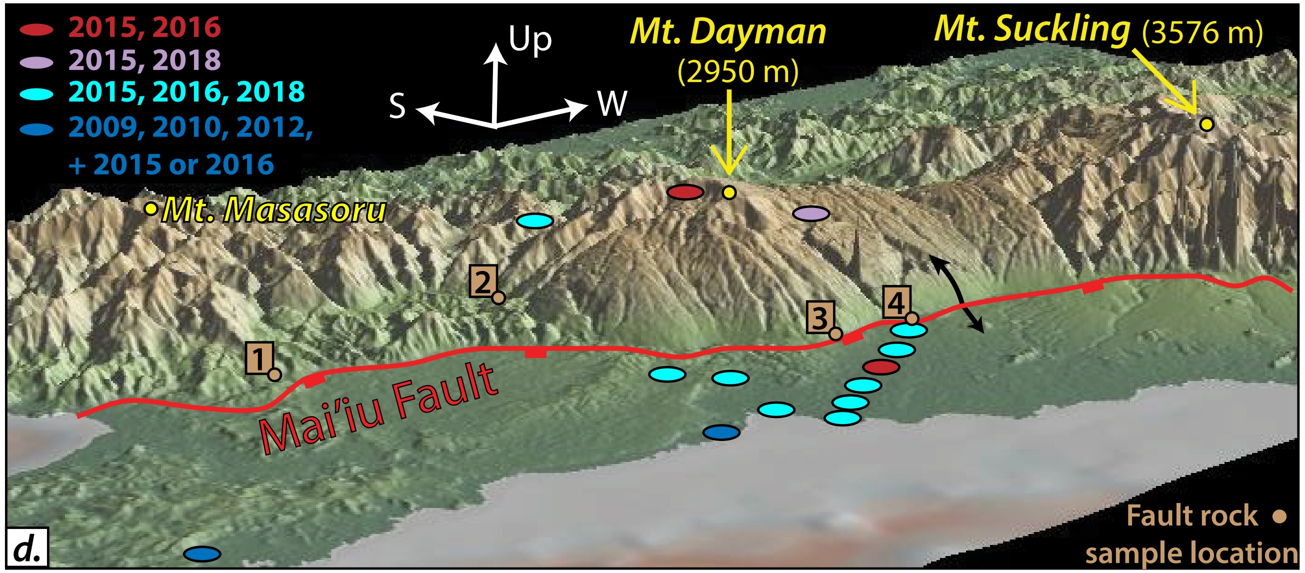




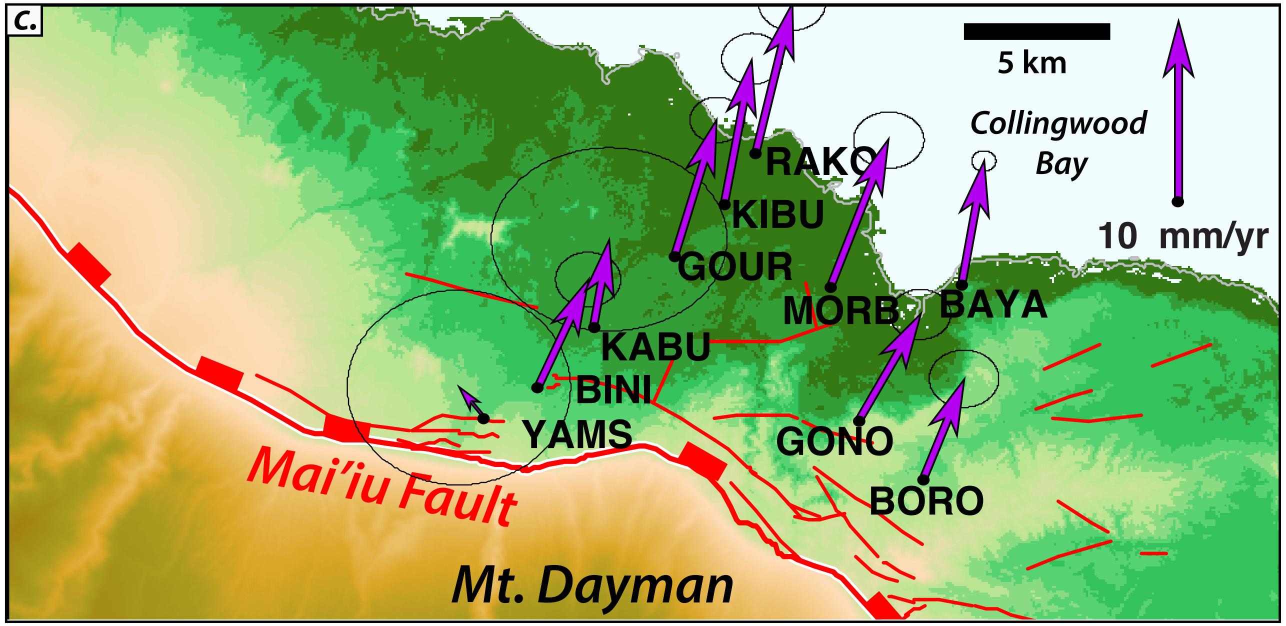
Modified from Webber (2017)



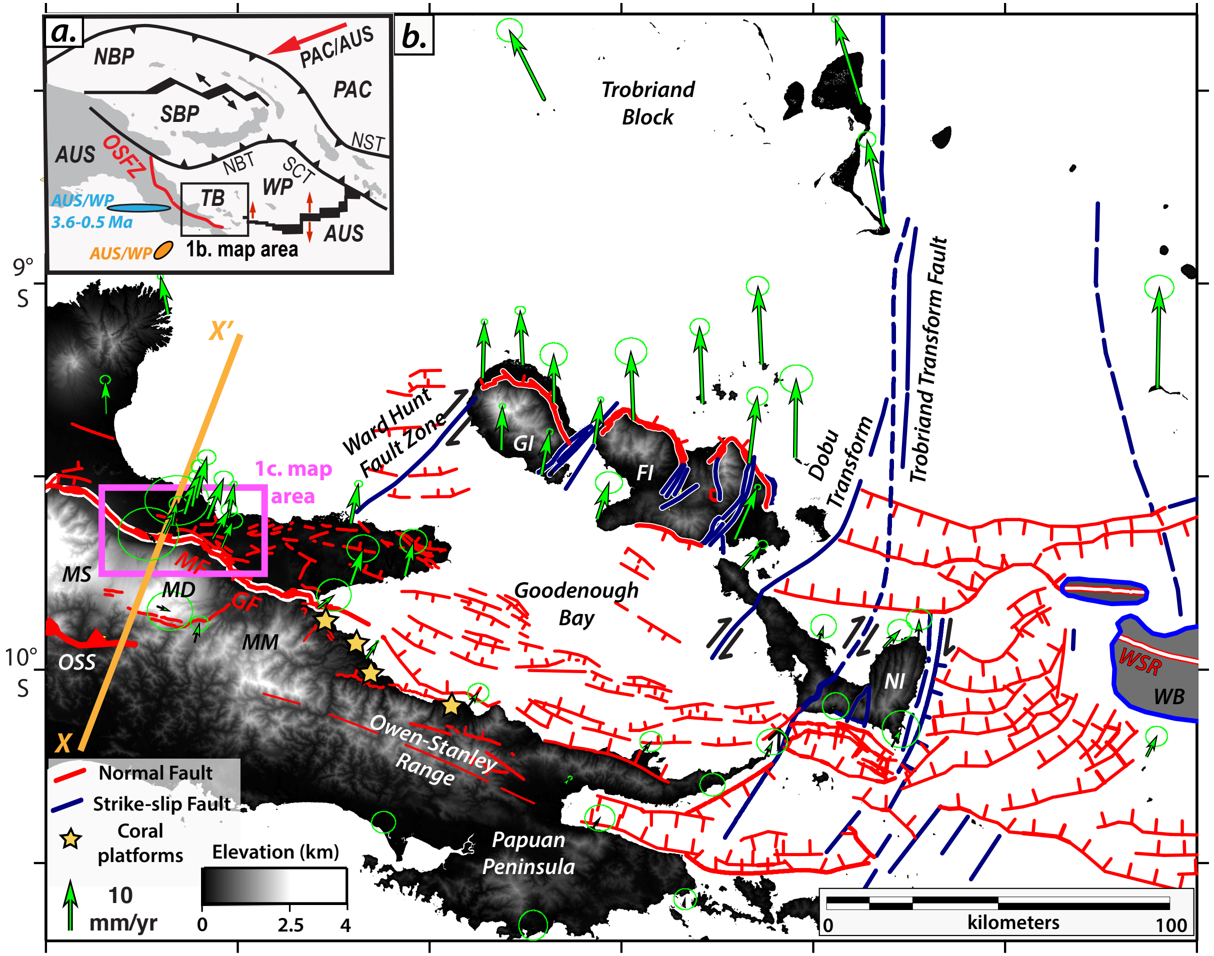
Campaign GPS experiment across the Mai'iu fault



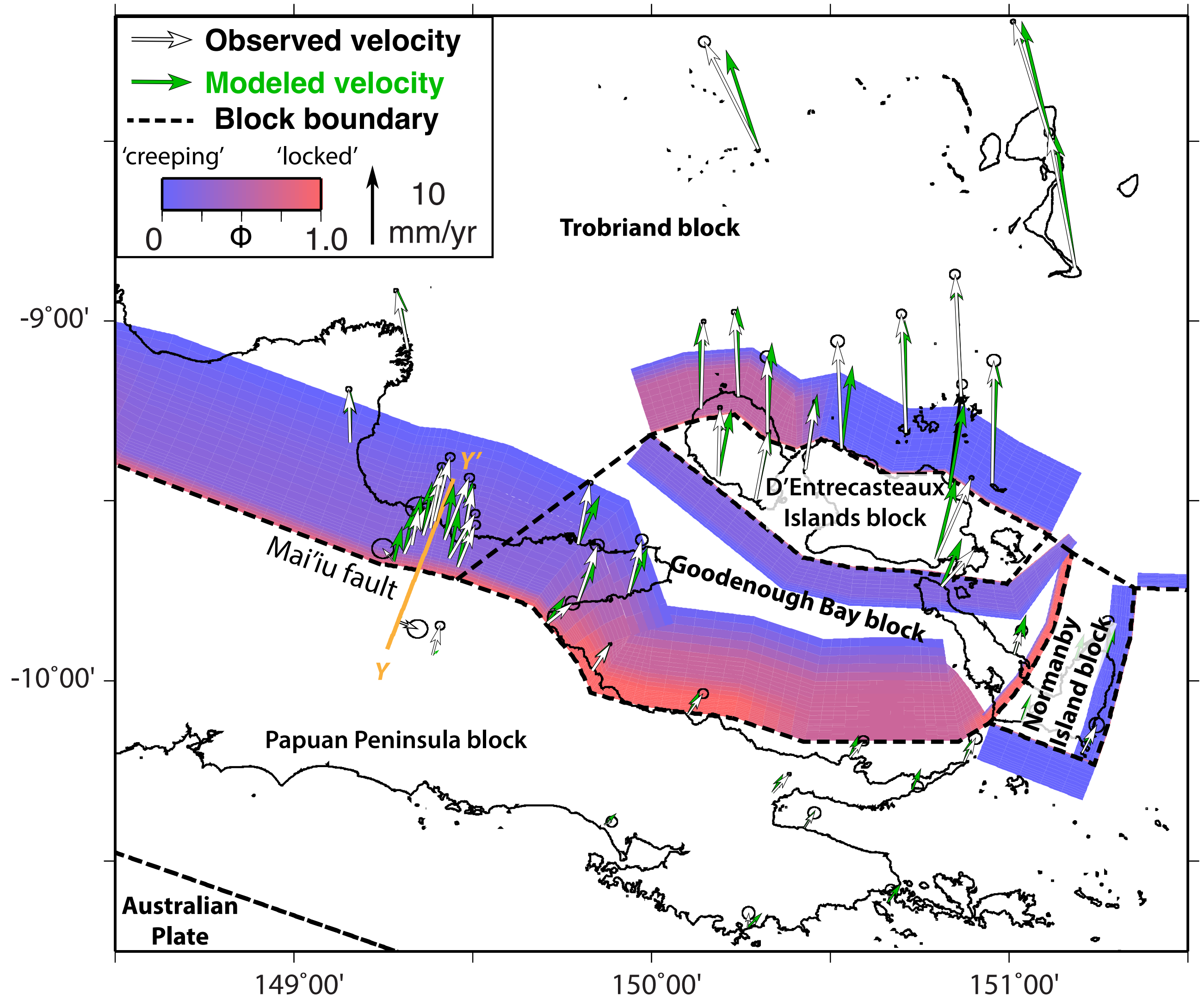
- Dense (3-5 km) station spacing in the hanging wall to resolve any elastic strain accumulation related to fault locking
- ≥ 3 years of 2-4 day observations
- Horizontal extension of 8.3±1.2 mm/yr (~8-11 mm/yr dip-slip) across the Mai'iu fault



Biemiller et al. (submitted)

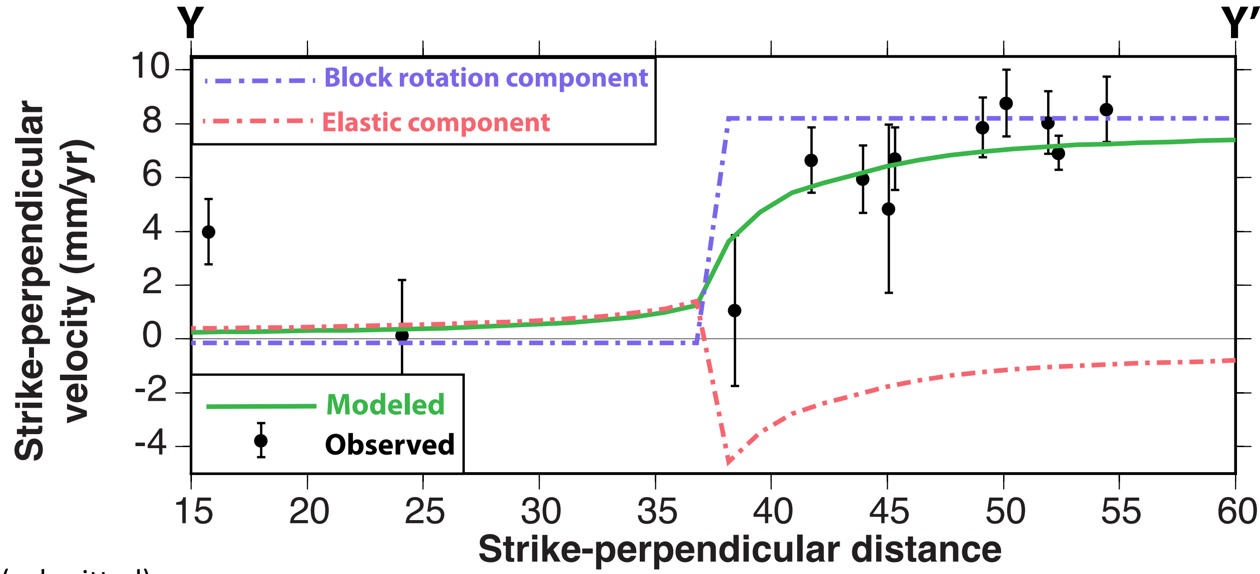


Elastic block modeling



Modeled with TDEFNODE (McCaffrey, 2013)

- Joint inversion of local and regional GPS velocities for block poles of rotation and fault kinematic coupling prefers very shallow locking (**surface to ~2 km depth**) with creep downdip of this zone



Biemiller et al. (submitted)

2D elastic dislocation modeling

- Simple models of strike-perpendicular velocities help focus on local fault properties & locking of the Mai'iu fault
- Inversions that assume locking from the surface to some depth prefer shallow locking (Model 1)
- But allowing for a locked zone at depth and shallow splay fault creep, Model 2 fits the data similarly well

Modeled with equations for surface displacements due to shear dislocations in an elastic half-space from Okada (1985)

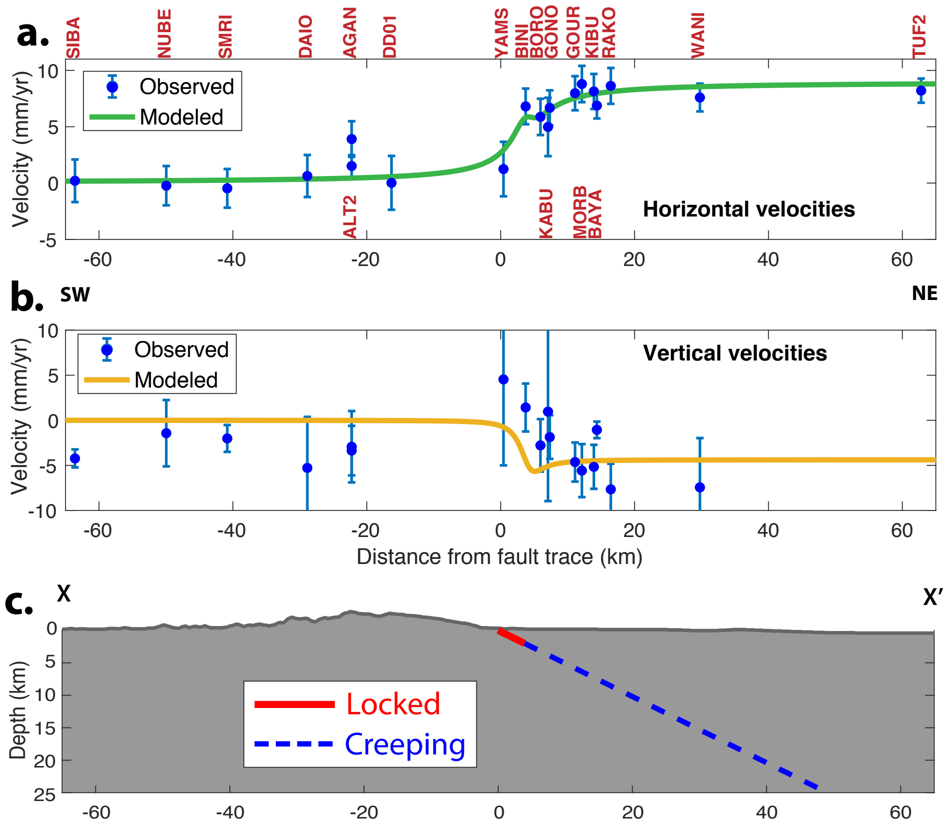
Model 1 $\chi_n^2 = 0.94$

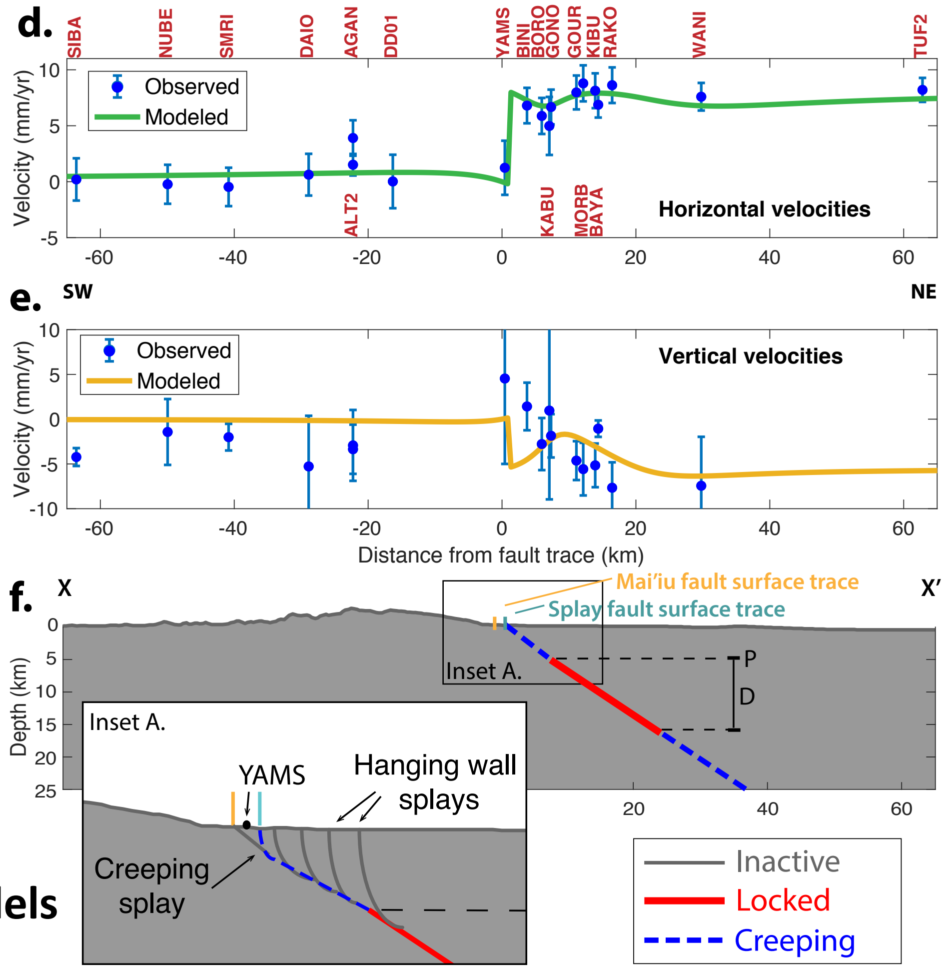
26° dip; dip-slip rate of 10 mm/yr; locked from surface to 2 km depth

Biemiller et al. (submitted)

Model 2 $\chi_n^2 = 0.89$

35° dip; dip-slip rate of 10.5 mm/yr; locked from 5 to 16 km depth

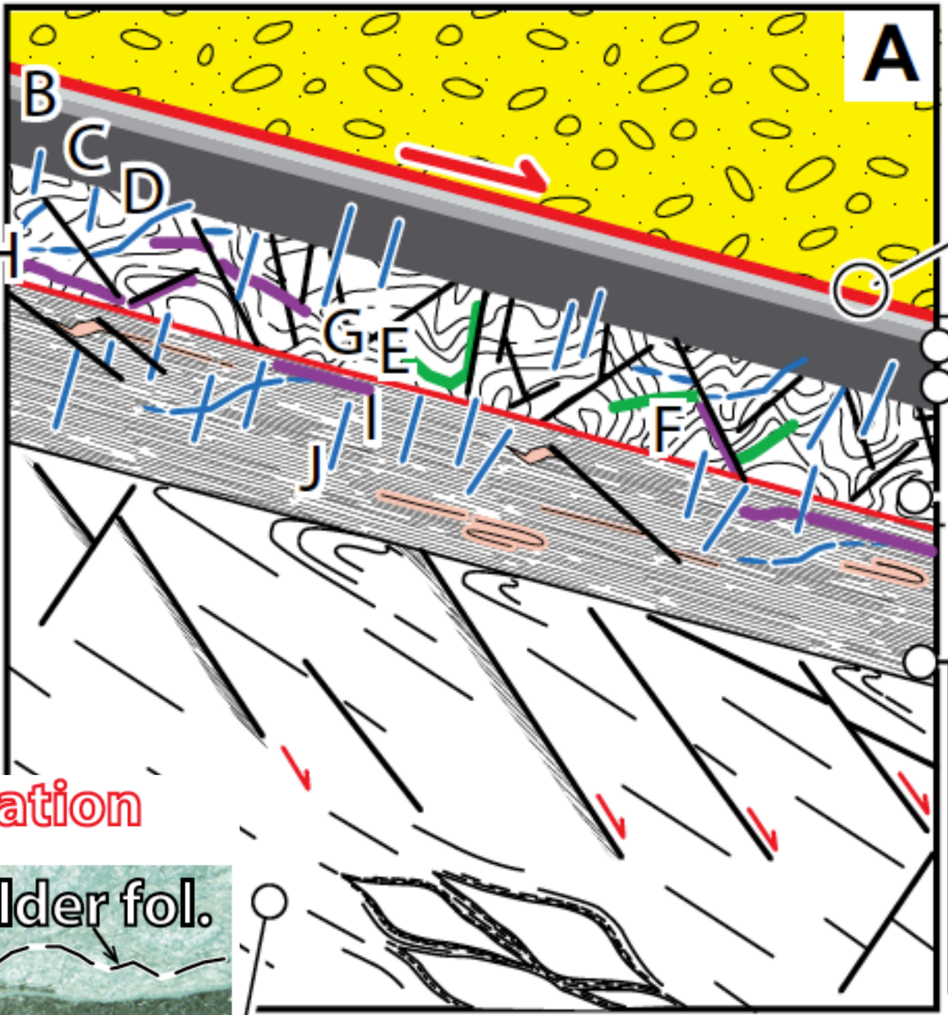




Lab and field evidence can help constrain and evaluate these locking models

Mutually cross-cutting veins, faults, and folds of diffusion-creep formed foliations -> **mixed frictional-viscous slip** in foliated cataclasites

See Marcel Mizera's presentation (EGU2020-17399) in this session for more microstructural results



Mai'iu Fault Rocks

Little et al., 2019

Gwoira Conglomerate
(pebbles mirror-faceted against **PDS**)

Mai'iu Fault (**PDS:** sharp, planar)

Mafic Gouges (<20 cm thick).

Ultracataclasite (<1–40 cm thick).

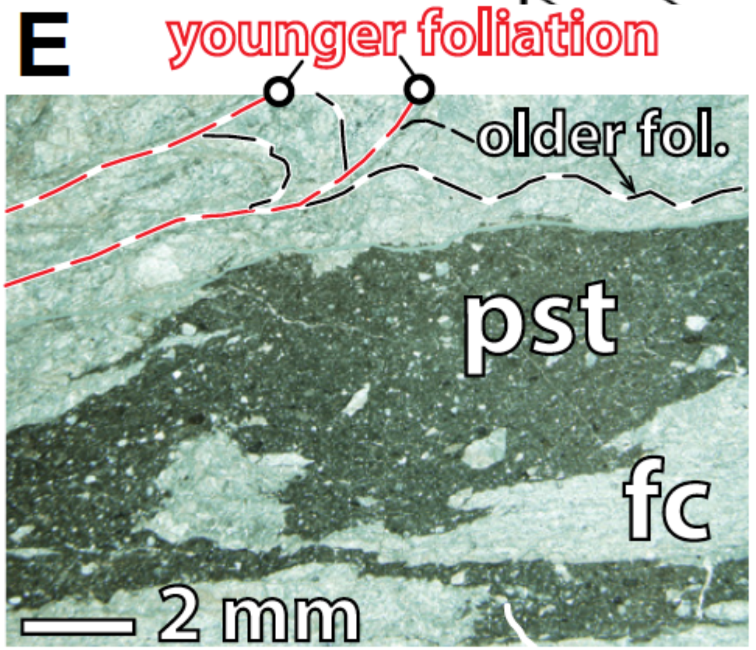
+ saponitic gouges

fault (minidetachment truncates overlying faults)

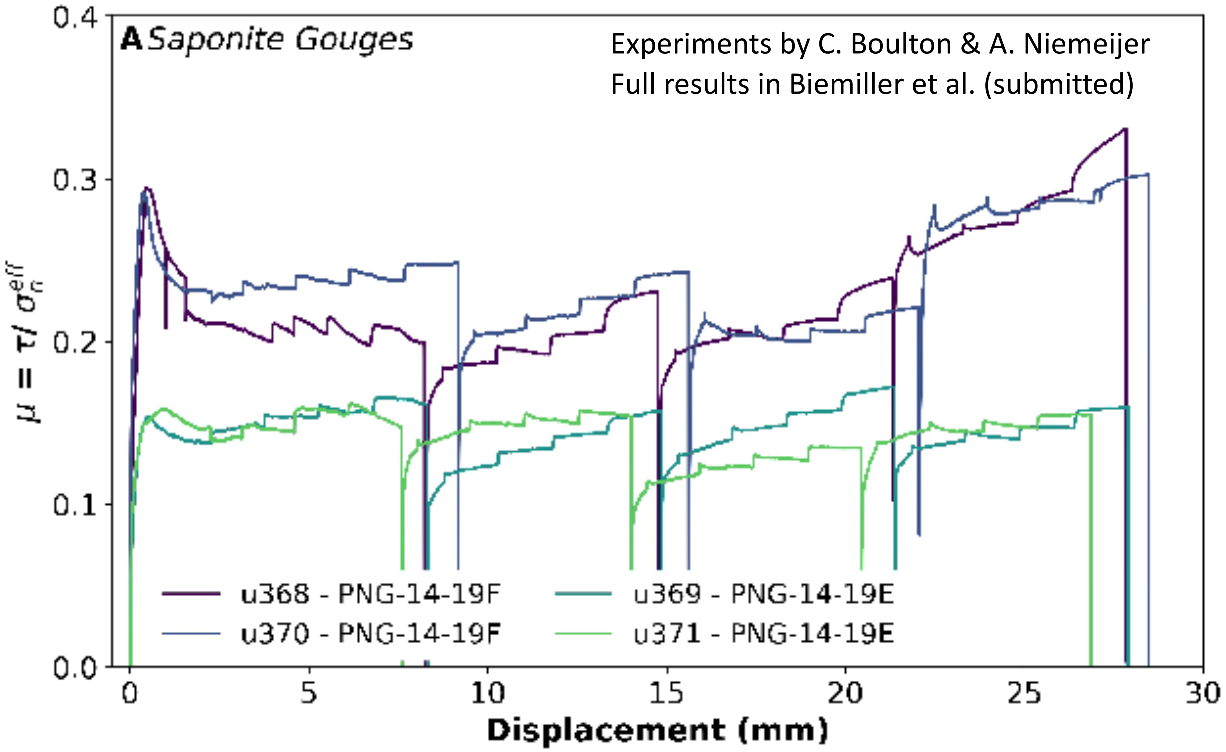
Foliated Cataclasite-Breccia
(~1.5 m thick). Faulted and cataclastically deformed. Spaced foliation, **pseudotachylyte veins** (5-40 mm thick), **ultracataclasite & ultramylonite** seams (cm-thick), and late (<1 mm thick) **calcite veins.** All layers are variably folded.

Mafic Mylonite zone (post late Neogene).
(1.5 m thick, but thickening to North). Includes **ultramylonite** bands near top contact. Also deformed **albite** & **calcite** veins.

onitic zone
foliation)

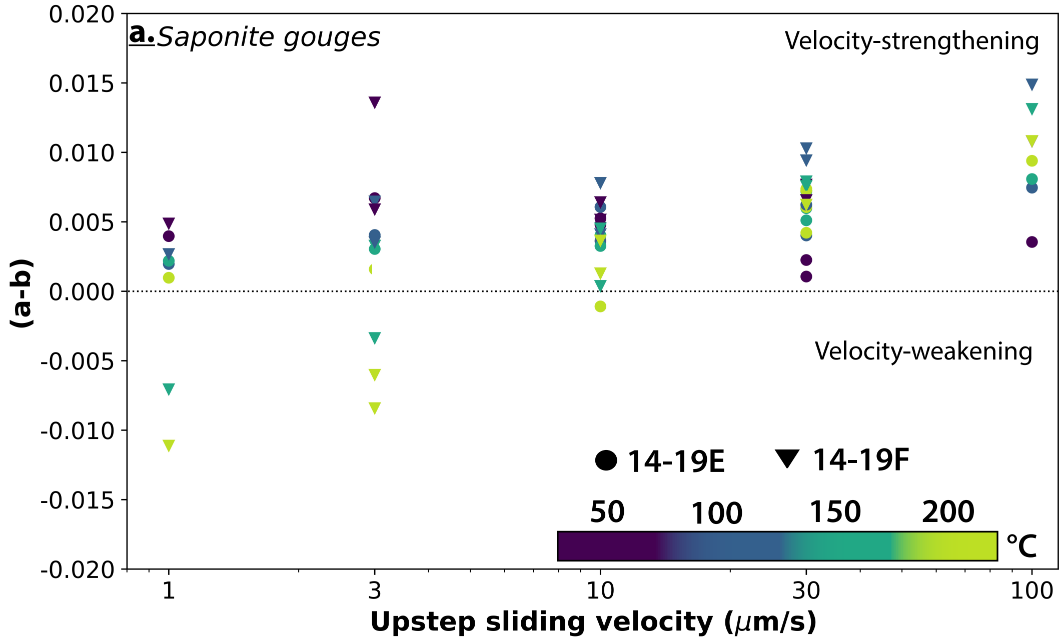


- Pseudotachylite -> **earthquake slip**
- $^{40}Ar/^{39}Ar$ age of 2.2 Mya -> formed at **~10-12 km depth**



Frictional behavior of Mai'iu fault rocks: velocity-stepping experiments

Fault Rock Unit	Friction Coefficient	Frictional Stability
Saponite gouges	0.11 - 0.28	Velocity-strengthening
Mafic gouges	0.22 - 0.57	Velocity-weakening to velocity-strengthening
Cataclasites with pseudotachylite veins	0.44 - 0.80	Both velocity-weakening and velocity-strengthening



3 frictional stability regimes:

- T ≤ 150 °C, v-strengthening (stable)
- 150 °C < T < 400 °C, v-weakening (unstable)
- T ≥ 400 °C, v-strengthening (stable)

Revisiting the geodetic locking models

Slip behavior

- Paleoseismic slip at 10-12 km depth
- Mixed frictional-viscous slip in cataclastic units
- Creep from ~15-25 km depth
- Friction stability transitions (VS-VW-VS) at T = ~150 °C and T = ~400 °C

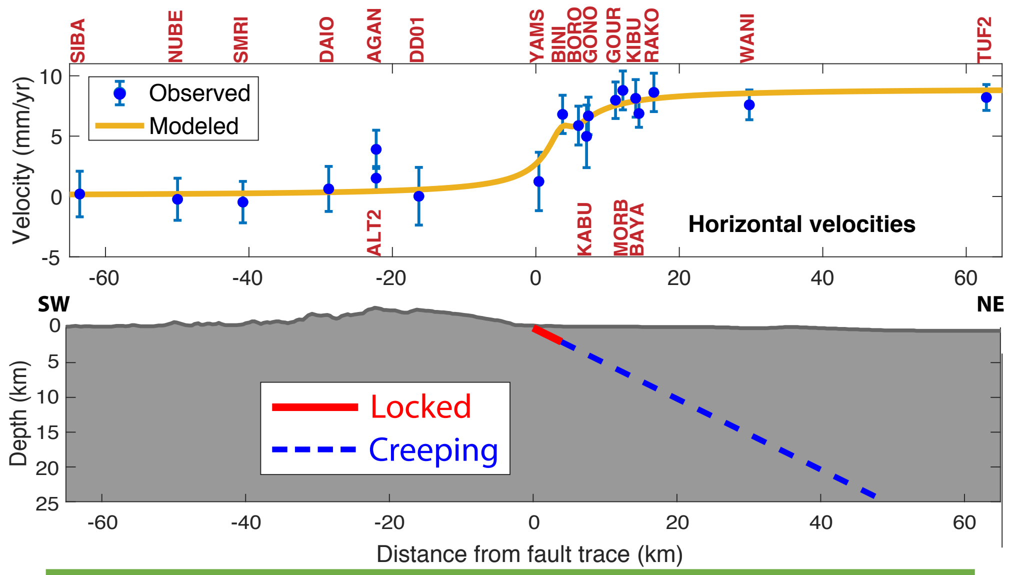
Observation

- Pseudotachylites (Little et al., 2019)
- Mutually cross-cutting brittle/ductile microstructures (Little et al., 2019; Mizera et al., submitted)
- Planar microseismicity zone downdip of Mai'iu fault trace (Abers et al., 2016)
- Velocity-stepping laboratory friction experiments (Biemiller et al., submitted)

Geologic, experimental, and seismological evidence point to **stronger locking at depth (~5-16 km), with interseismic creep updip and downdip** of this zone

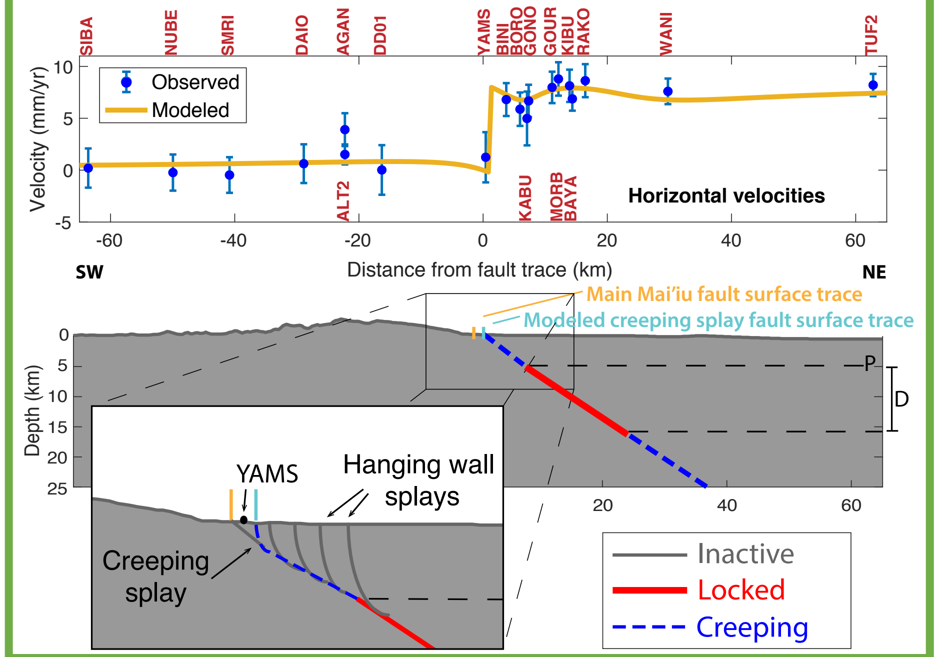
Model 1

26° dip; dip-slip rate of 10 mm/yr; locked from surface to 2 km depth



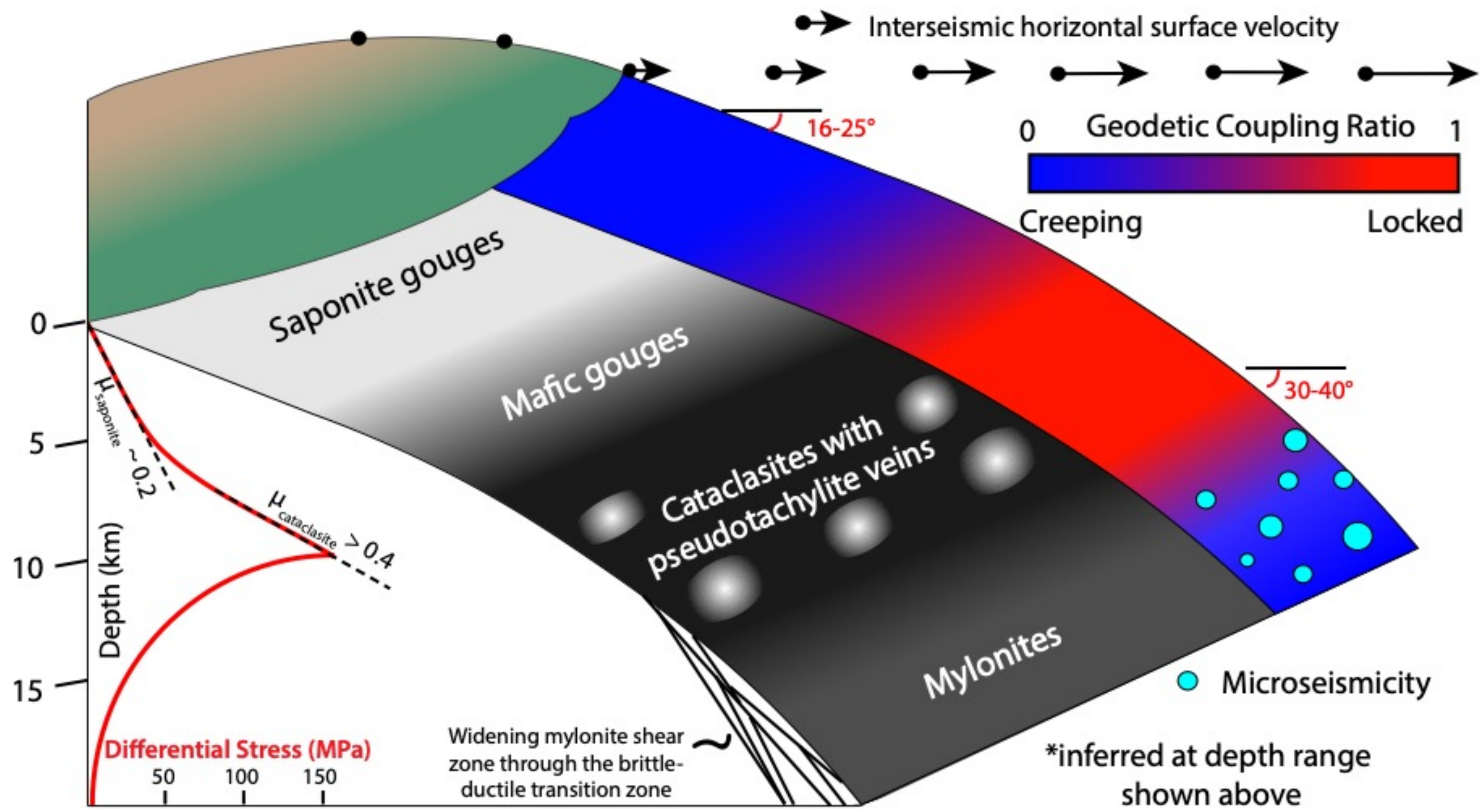
Model 2

35° dip; dip-slip rate of 10.5 mm/yr; locked from 5 to 16 km depth



Conclusions

- Low-angle normal faults are not necessarily aseismic
- Horizontal extension of 8.3± 1.2 mm/yr across the Mai'iu fault (~8-11 mm/yr dip-slip)
- Shallow frictional creep (< 5 km) updip of more strongly locked zone (~5-16 km) updip of creeping mylonitic shear zone
- Low-angle normal faults could generate M_w 7+ earthquakes



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

Visit Marcel Mizera's presentation (EGU2020-17399) in this session for microstructural analysis of the Mai'iu fault rocks

And keep an eye out for Biemiller et. al. and Mizera et al., recently submitted to JGR and G3

References

- Abers, G. A. (2001). Evidence for seismogenic normal faults at shallow dips in continental rifts. *Geological Society, London, Special Publications*, *187*(1), 305–318. https://doi.org/10.1144/GSL.SP.2001.187.01.15
- Abers, G. A., Eilon, Z., Gaherty, J. B., Jin, G., Kim, Y., 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. https://doi.org/10.1002/2015JB012621
- Anderlini, L., Serpelloni, E., & Belardinelli, M. E. (2016). Creep and locking of a low-angle normal fault: Insights from the Altotiberina fault in the Northern Apennines (Italy). *Geophysical Research Letters*, *43*(9), 4321–4329. https://doi.org/10.1002/2016GL068604
- (submitted), Biemiller, J., Boulton, C., Wallace, L., Ellis, S., Little, T., Mizera, M., Niemeijer, A., Lavier, L., Mechanical implications of creep and partial coupling on the world's fastest slipping low-angle normal fault in Southeastern Papua New Guinea. To Journal of Geophysical Research: Solid Earth.
- Hreinsdóttir, S., & Bennett, R. A. (2009). Active aseismic creep on the Alto Tiberina low-angle normal fault, Italy. *Geology*, *37*(8), 683–686. https://doi.org/10.1130/G30194A.1
- Little, T. A., Webber, S. M., Mizera, M., Boulton, C., Oesterle, J., Ellis, S., … Wallace, L. (2019). Evolution of a rapidly slipping, active low-angle normal fault, Suckling-Dayman metamorphic core complex, SE Papua New Guinea. GSA Bulletin. https://doi.org/10.1130/B35051.1
- McCaffrey, R. (2013). Crustal Block Rotations and Plate Coupling (pp. 101–122). American Geophysical Union (AGU). https://doi.org/10.1029/gd030p0101
- (submitted), Mizera, M., Little, T., Boulton, C., Prior, D., Watson, E., Biemiller, J., Niemeijer, A., Slow-to-fast slip deformation of mafic rocks on an actively exhuming low-angle normal fault, Woodlark Rift, SE Papua New Guinea. To *Geochemistry, Geophysics, Geosystems*.
- Mizera, M., Little, T. A., Biemiller, J., Ellis, S., Webber, S., & Norton, K. P. (2019). Structural and Geomorphic Evidence for Rolling-Hinge Style Deformation of an Active Continental Low-Angle Normal Fault, SE Papua New Guinea. *Tectonics*, *38*(5), 1556–1583. https://doi.org/10.1029/2018TC005167
- Okada, Y. (1985). Surface deformation due to shear and tensile faults in a half-space. *Bulletin of the Seismological Society of America*, *75*(4), 1135–1154.
- Wallace, L. M., Ellis, S., Little, T., Tregoning, P., Palmer, N., Rosa, R., … Kwazi, J. (2014). Continental breakup and UHP rock exhumation in action: GPS results from the Woodlark Rift, Papua New Guinea. *Geochemistry, Geophysics, Geosystems*, *15*(11), 4267–4290. https://doi.org/10.1002/2014GC005458
- Webber, S., Norton, K. P., Little, T. A., Wallace, L. M., & Ellis, S. (2018). How fast can low-angle normal faults slip? Insights from cosmogenic exposure dating of the active Mai'iu fault, Papua New Guinea. *Geology*, *46*(3), 227–230. https://doi.org/10.1130/G39736.1