MECHANICS OF THE HIKURANGI MEGATHRUST

Long-term strength inferred from wedge dynamics

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Also collaborations with: Dan Barker, Agnes Reyes, Laura Wallace, Demian Saffer, Rob Harris, Stuart Henrys

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Marsden 2013-2016

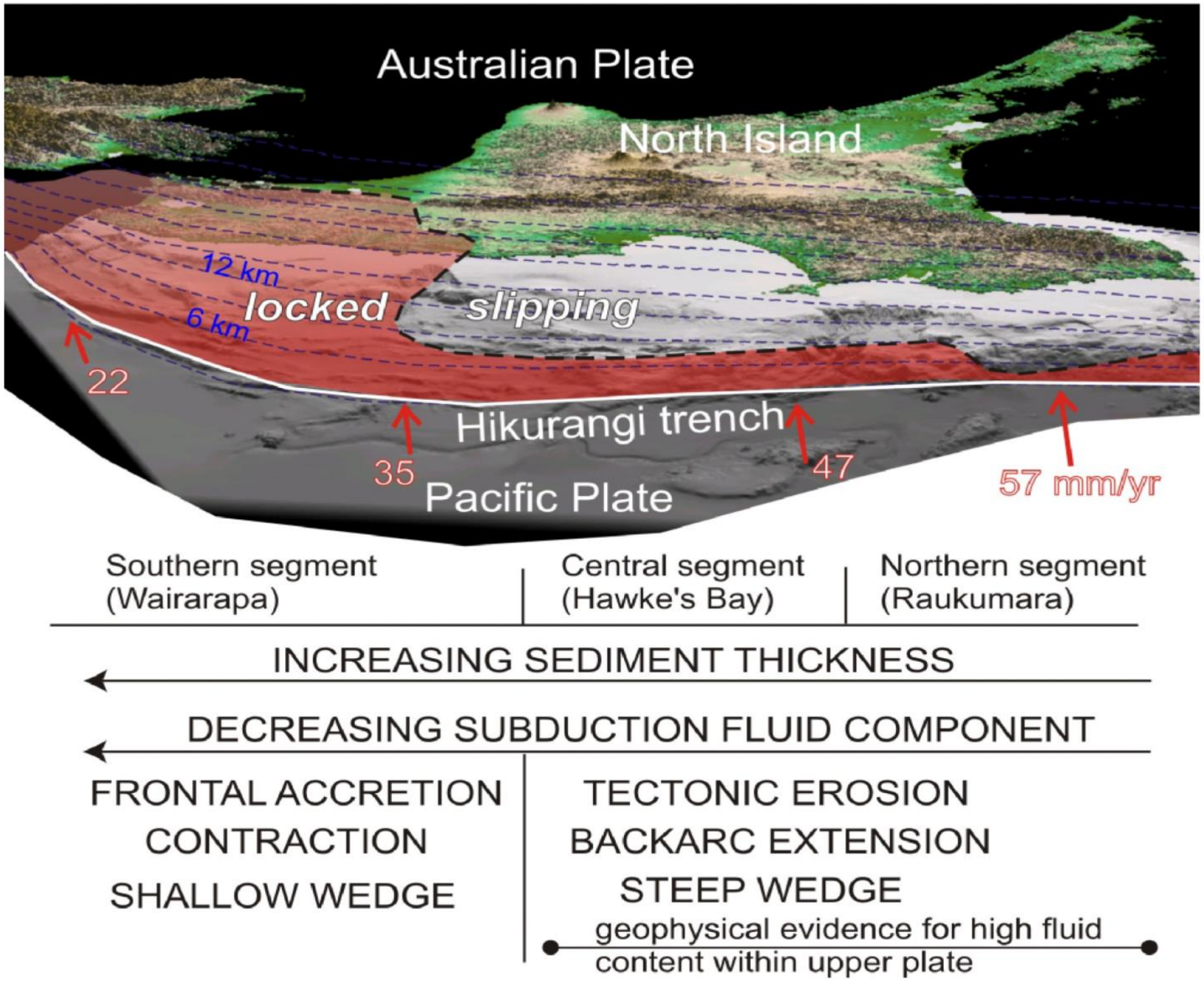


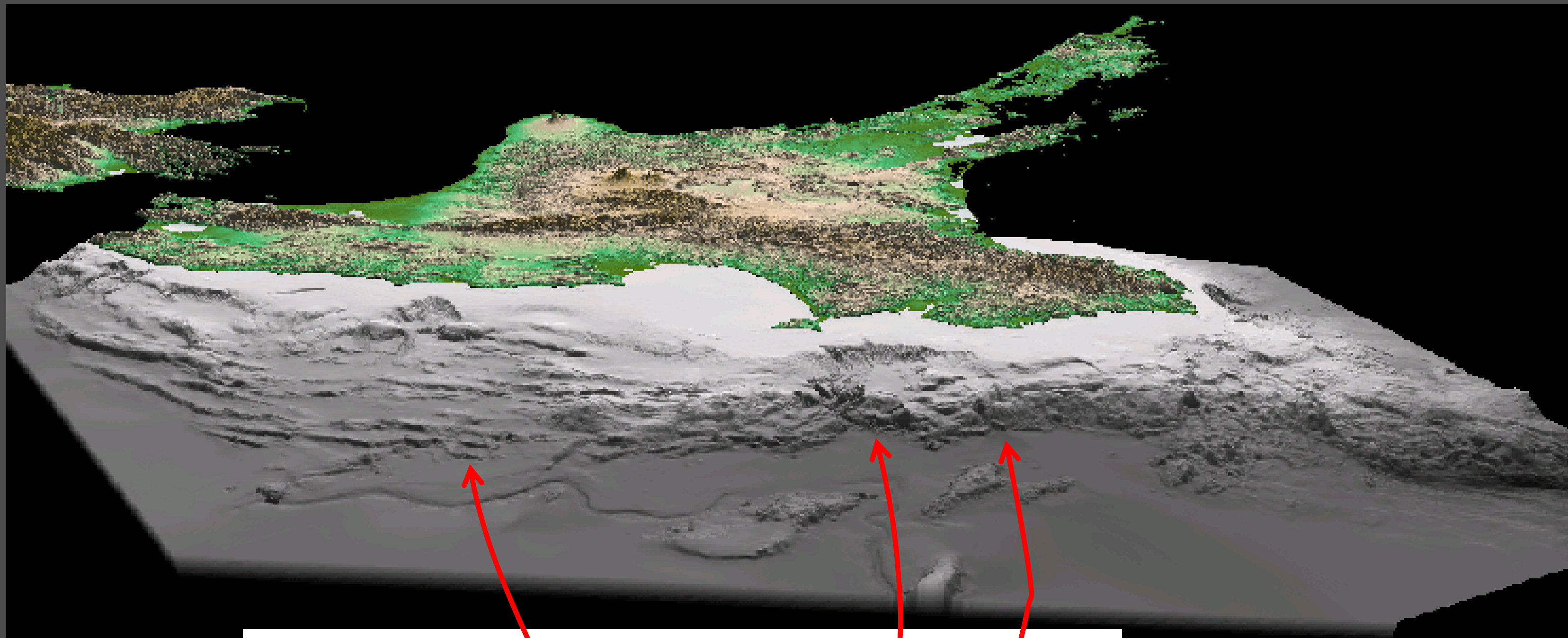
Figure 1: Oblique view of North Island with depth contours of subducting Pacific Plate (blue dashed lines), convergence rates at the Hikurangi Trench (red arrows), and locked (red) vs. slipping interface. Black dashed line marks approximate location of the change from locked to slipping behaviour.

Davy et al., 2009; Barker et al., 2009;

Reyes et al., 2010

e.g., Bell et al., 2009; Wallace and EP, 2013; Heise et al., 2013; Bassett et al., 2014

If the megathrust is overpressured and weak in the north, why are slopes so steep there?



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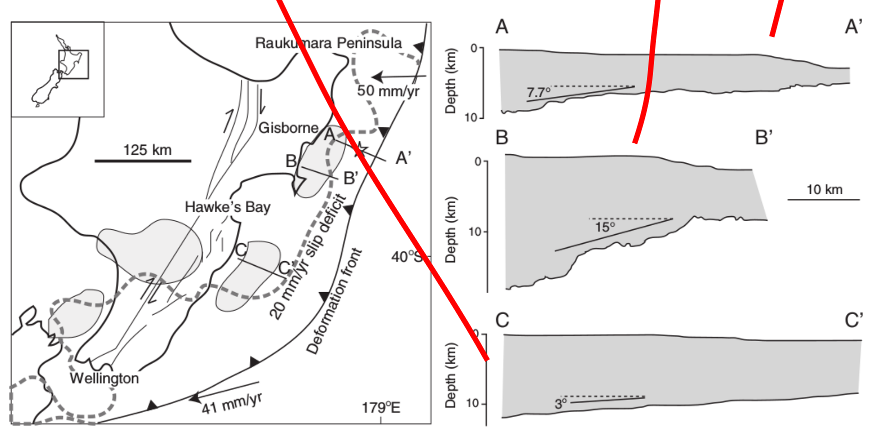
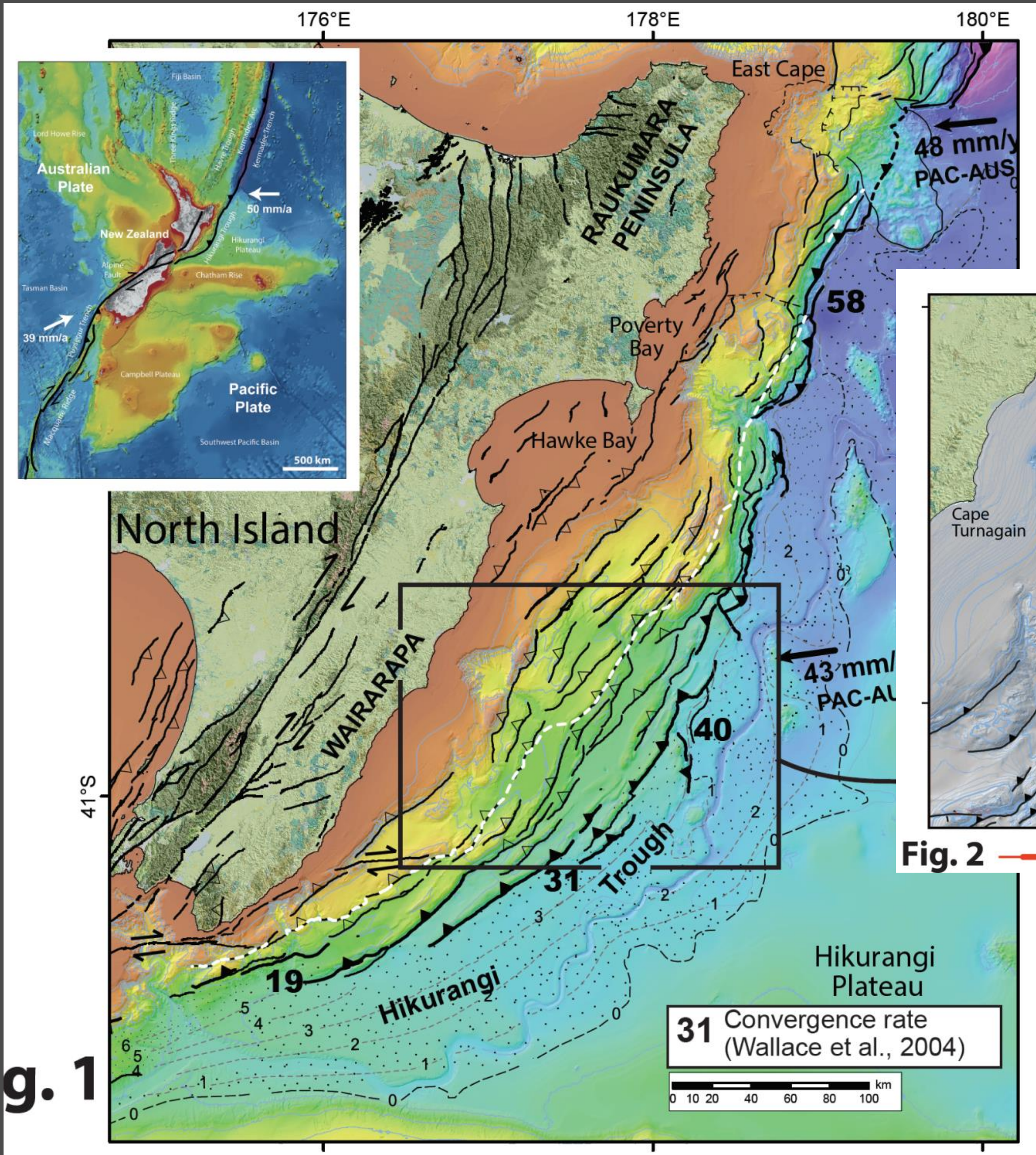


Fig. 1. Map of the North Island of New Zealand with tectonic and seismic features. Arrows represent plate convergence vectors and convergence velocities from Anderson and Webb (1994). The dashed contour of 20 mm/year slip deficit is taken from Wallace et al. (2004), and the area of strong interseismic coupling is between this contour and the deformation front. Shaded areas represent areas of slip in slow slip events, after McCaffrey et al. (2008). The star shows the location of the 1947 tsunami earthquakes offshore Gisborne (Doser and Webb, 2003). Vertical cross-sections of accretionary wedge geometry offshore Gisborne, north of Hawke's Bay (both after Bell et al., 2010), and south of Hawke's Bay (after Barnes et al., 2010) are drawn to the right of the map. Profiles A and B are representative for the range of wedge geometries seen north of Hawke's Bay, whereas C is typical of the imbricate wedge developed in the southern, locked segment (Barnes et al., 2010), although C is located at the edge of the transition from the southern locked zone to the weakly coupled northern segments.

Restore and model evolution of low taper in south – determine decollement strength?



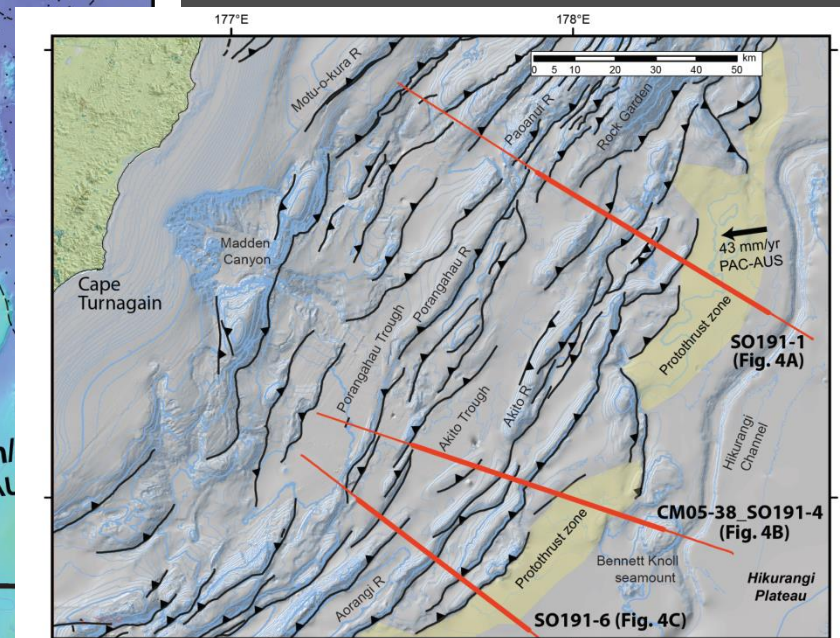
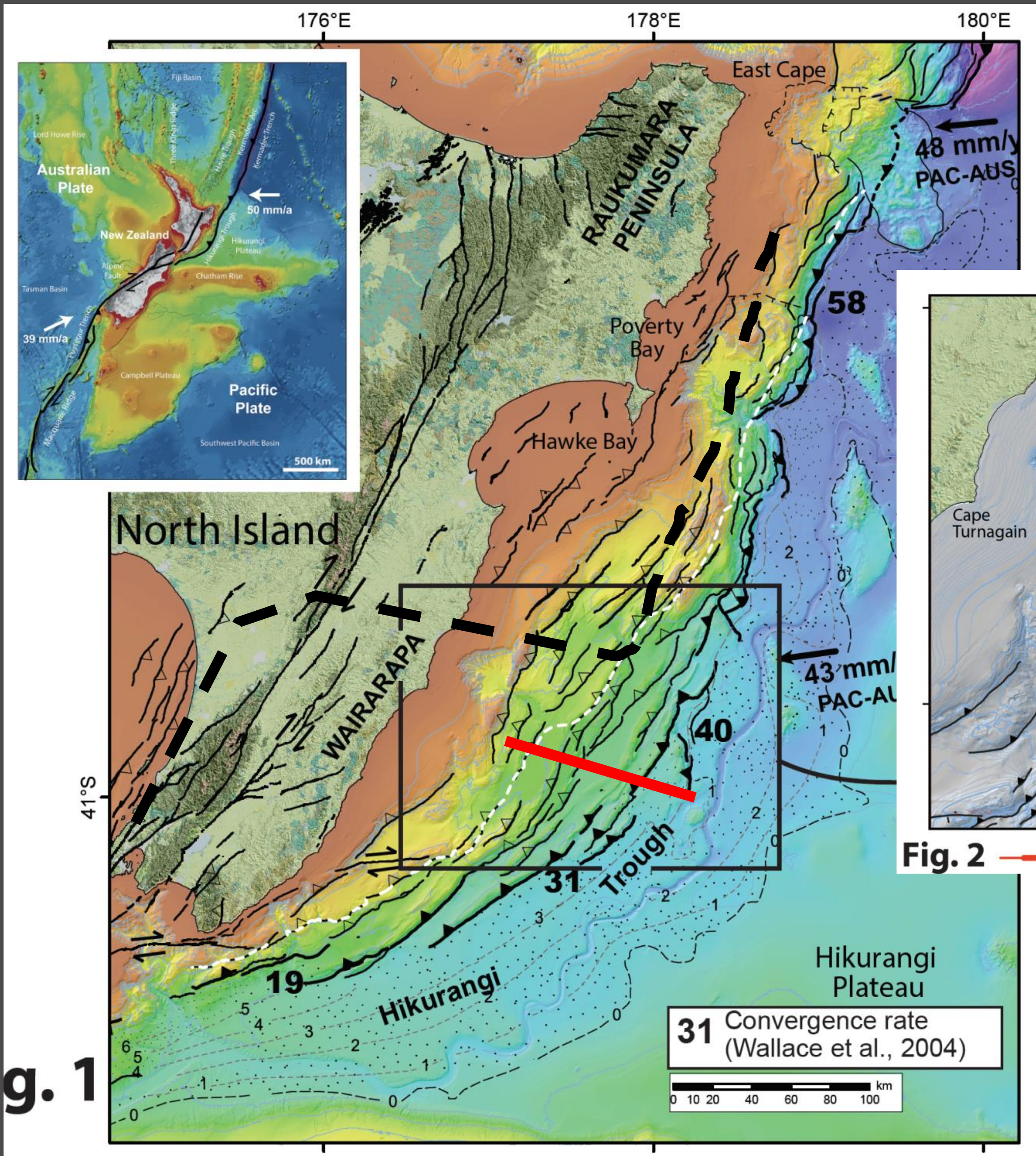


Fig. 2 Restored sections

Restore and model evolution of low taper in south – determine decollement strength?



g. 1

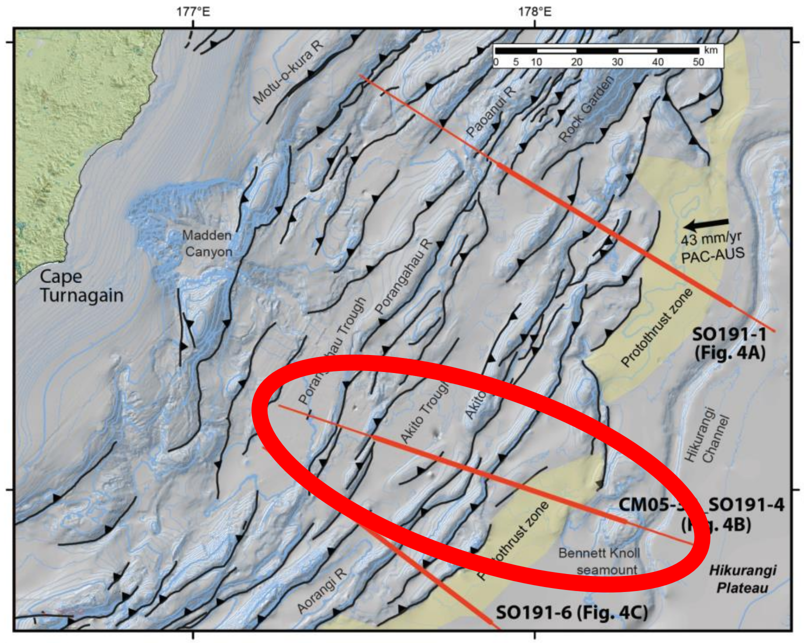
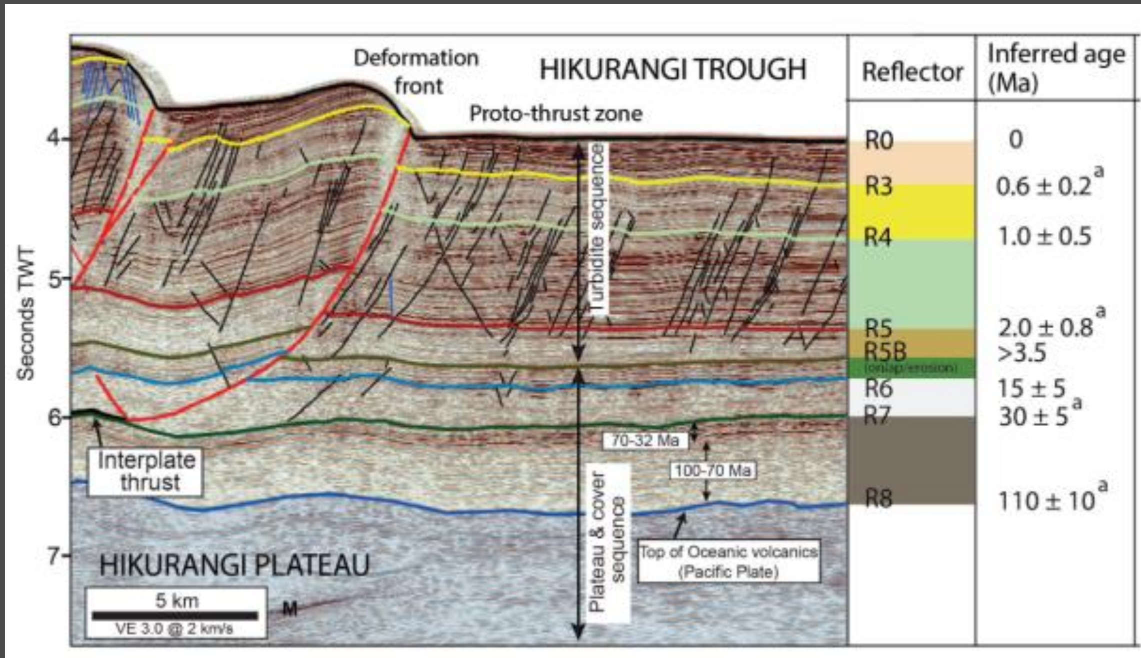


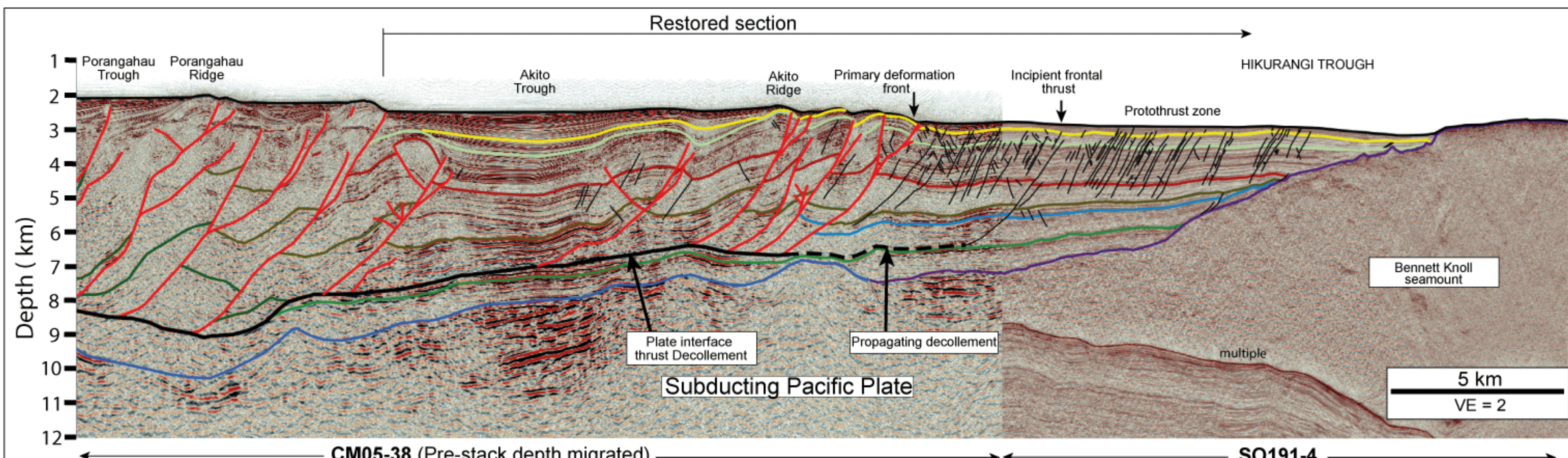
Fig. 2 Restored sections



R7: chalks, clay

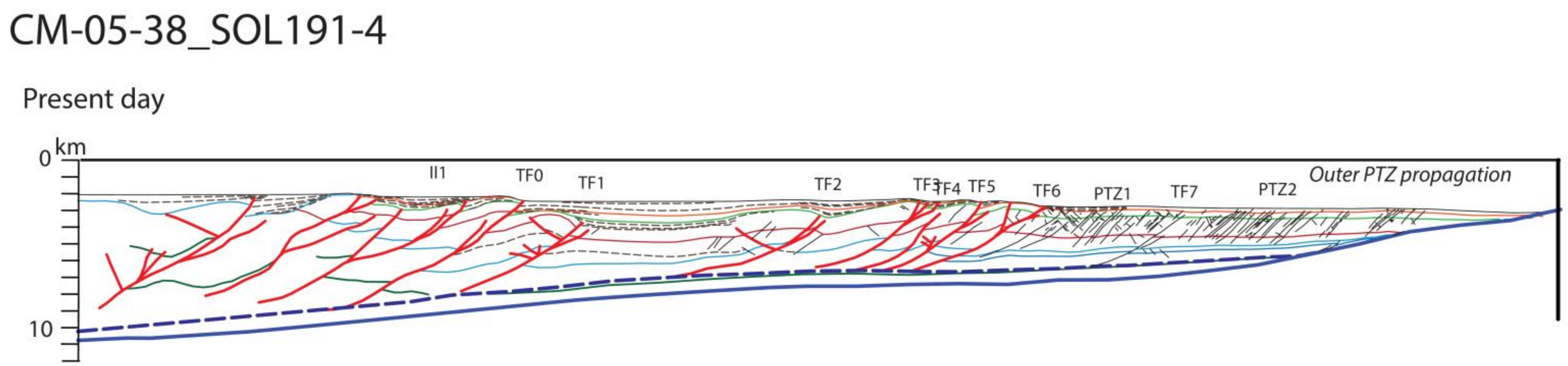
HKB: volcaniclastic sediment, limestone, chert

Basaltic basement



Phil Barnes, Dan Barker, Francis Henrys

Present



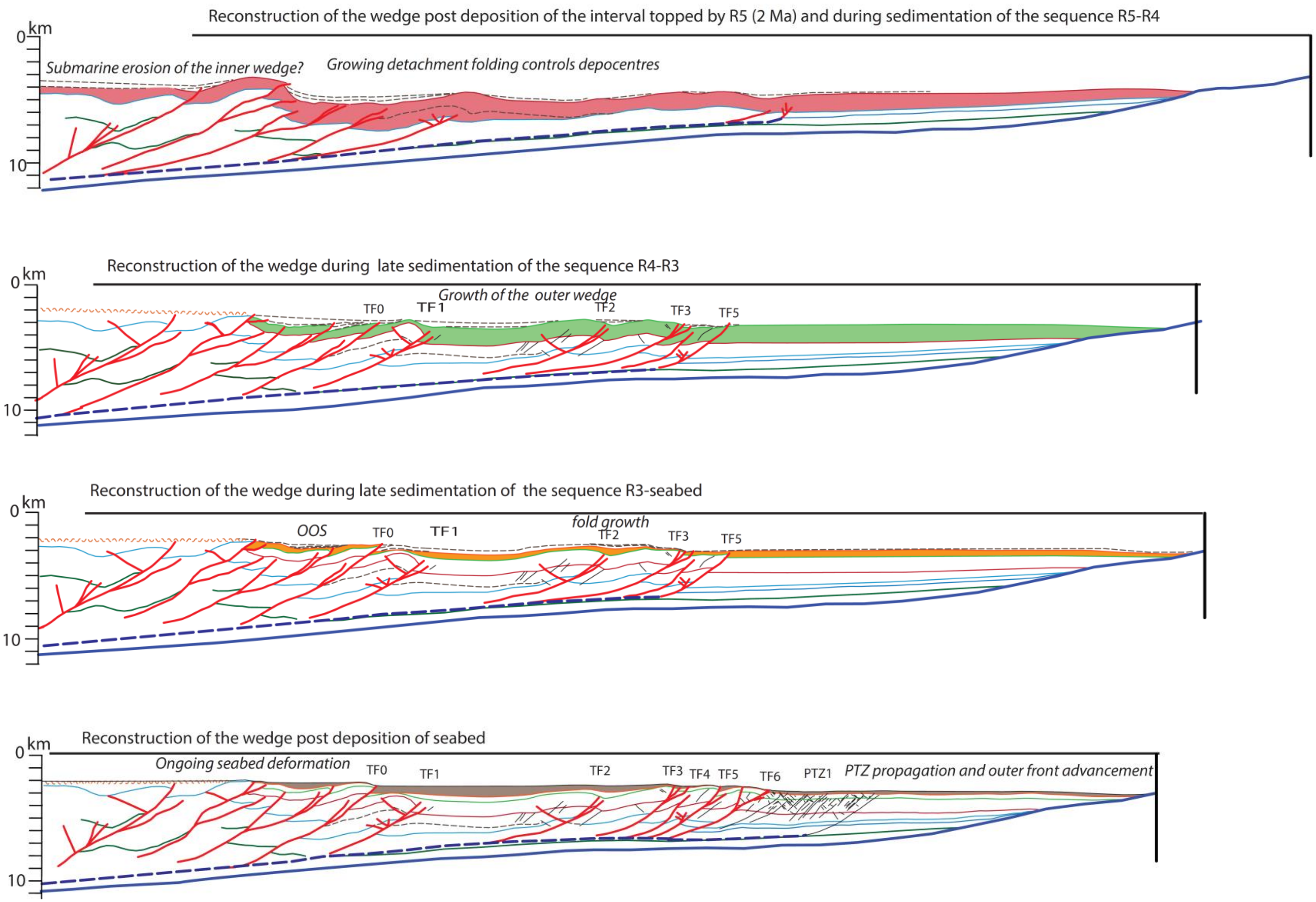
→ Restoration by Francesca Ghisetti (MOVE 4D) of depth section

No vertical exaggeration

Decollement at R7

2mm/yr sedimentation on average

PTZ = protothrust zone (incipient activation next thrust, decollement)



~ 2 Ma

~ 1 Ma

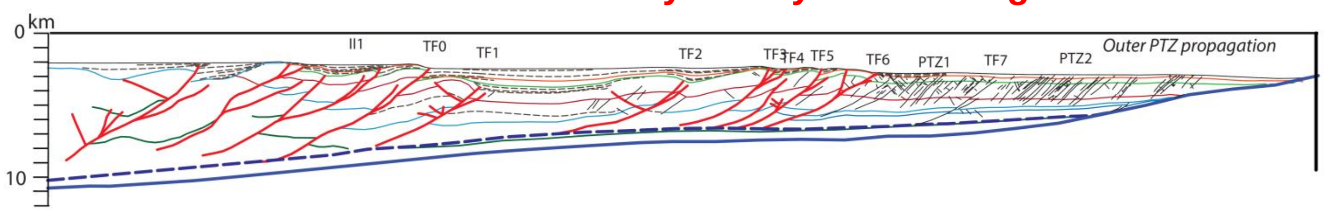
~ 0.6 Ma

~ 0.01 Ma

CM-05-38_SOL191-4

Present day

Restoration accounts for only 6mm/yr shortening across this outer 100km

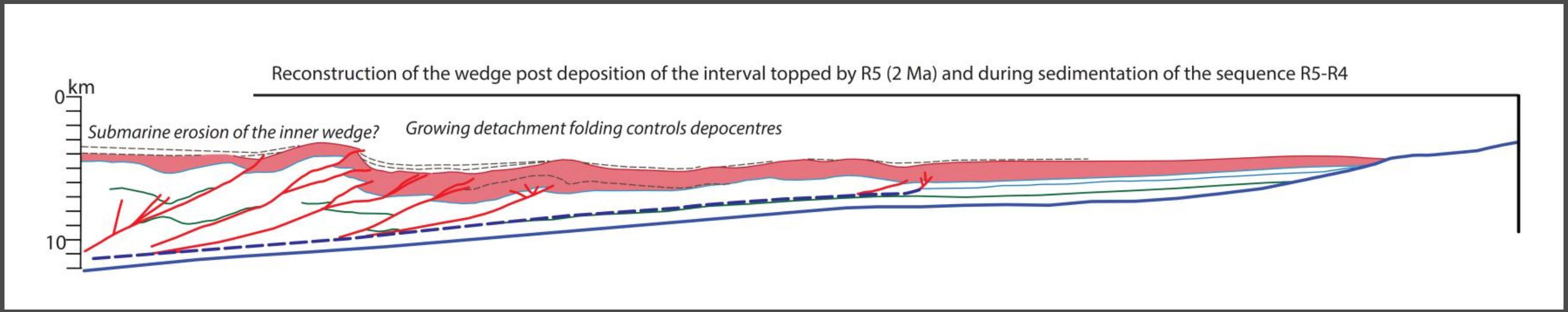


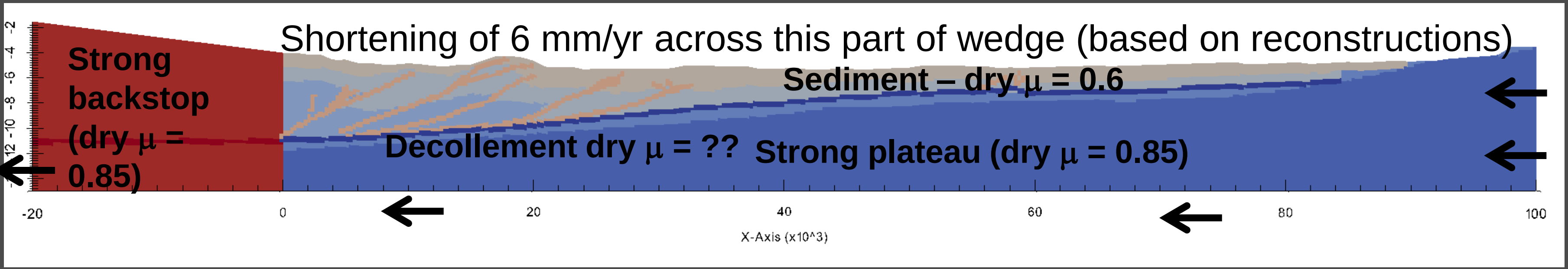
Present

Forward modelling (SULEC): how weak does basal detachment have to be to correctly predict wedge deformation in the last 2 My?

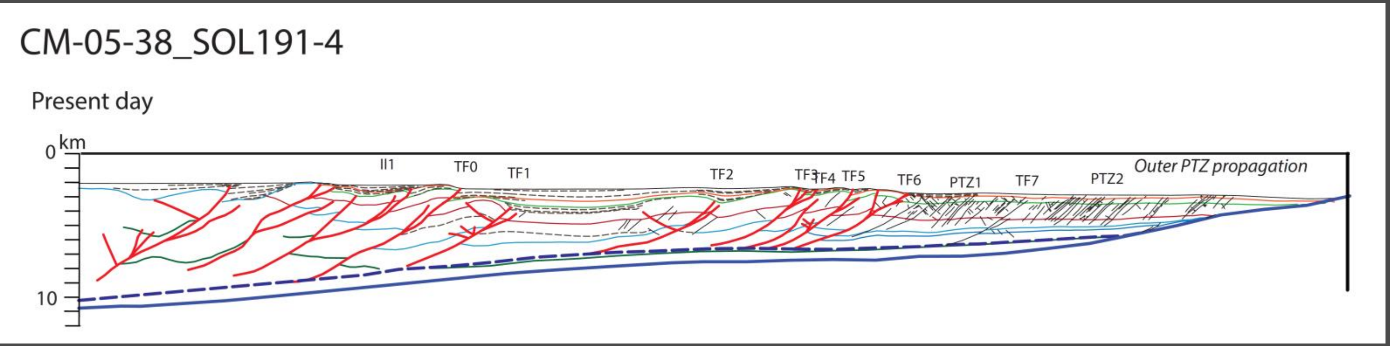
- Start from 2 Ma restoration
- Constant sedimentation proportional to depth bsl (~ 2 mm/yr)
- Coulomb frictional yield strength, initial weak faults
- New faults develop when frictional strains > 20-50%
- Decollement friction modelled separately

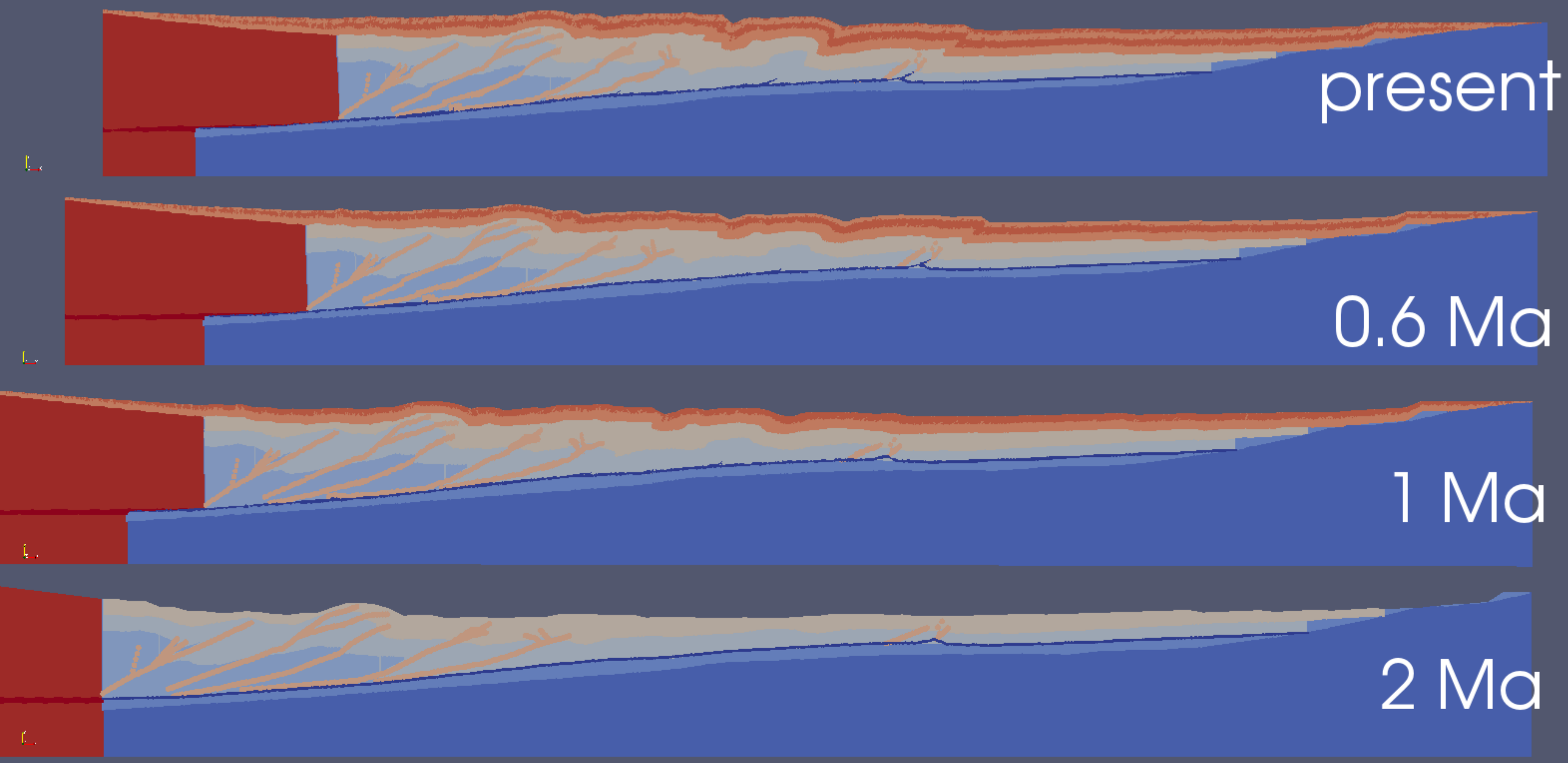
- Transient fluid pressures calculated- fluid sources from porosity changes (where porosity depends on effective stresses). Permeability starts low (10^{-19} m^2) and increases with brittle deformation – 3 orders of magnitude higher in faults and along the decollement.

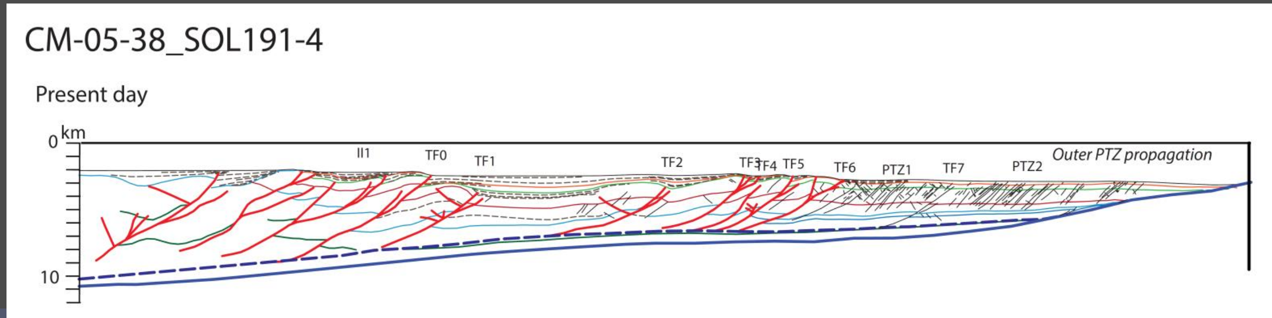


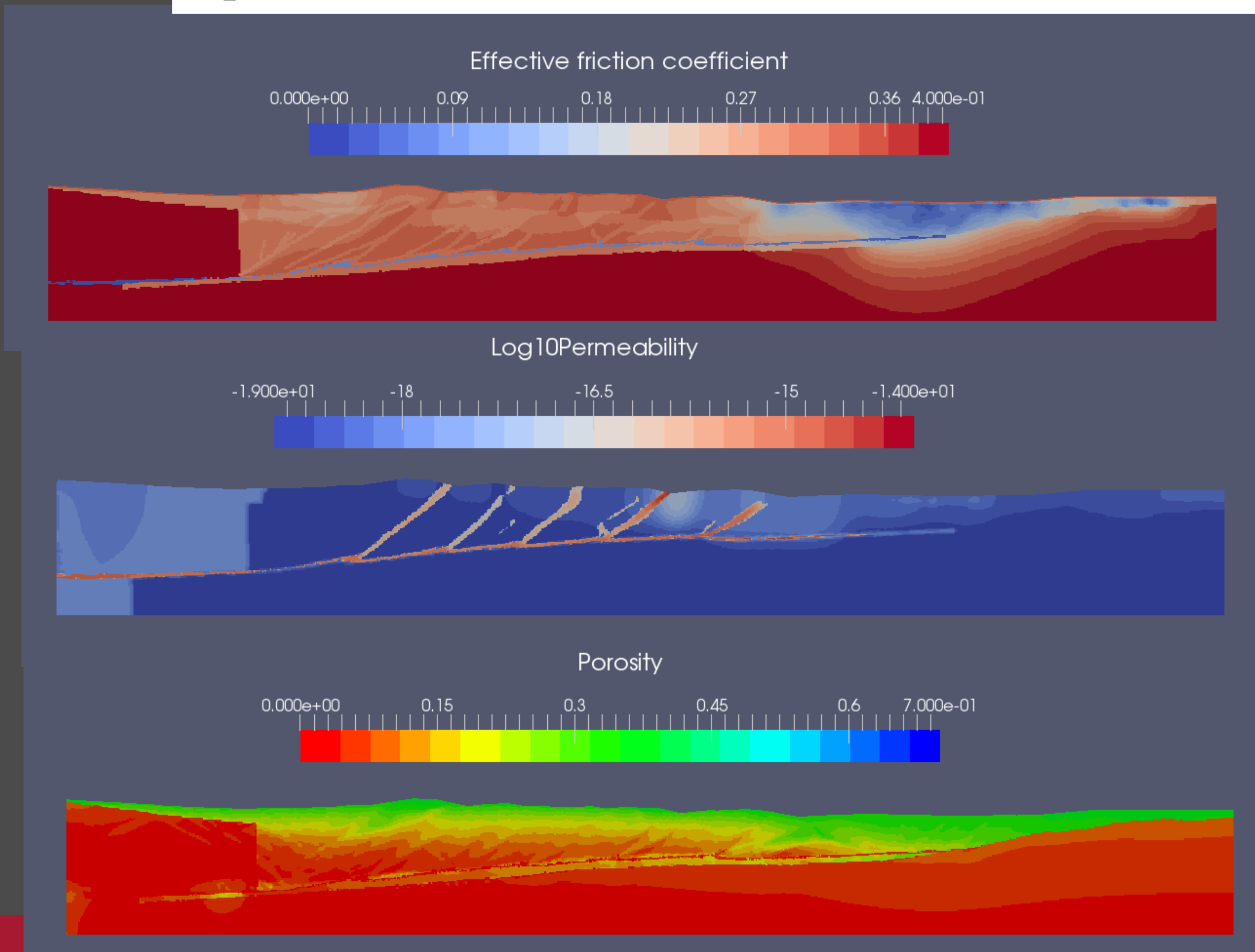


Requires dry décollement friction coefficient ≤ 0.15, with fluid pressure ratio between 0.4 and 0.6







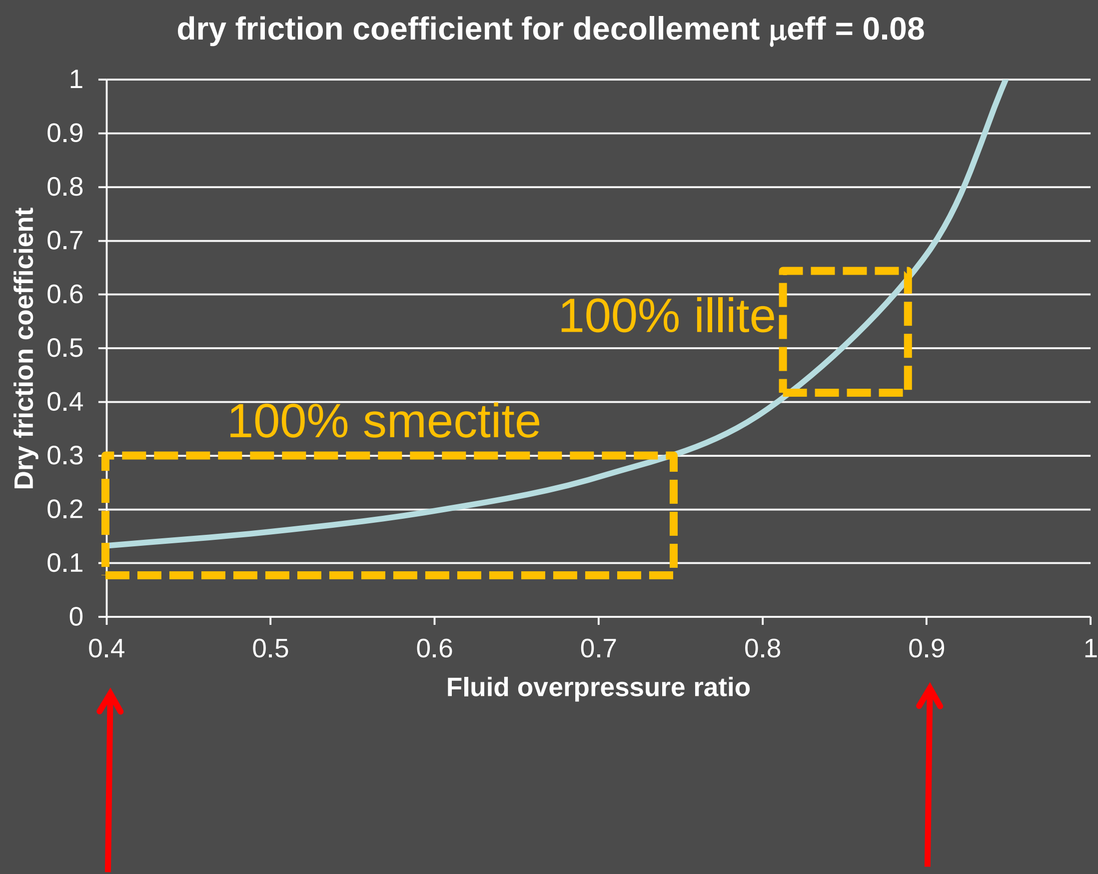


λ only approaches 1 in protothrust region.

Faults become permeable with deformation, limiting fluid overpressures along decollement and wedge

Higher porosity is maintained in channel beneath detachment

Permissible “effective” decollement friction coefficients to produce low taper are < 0.08



Note that these are coefficients averaged over seismic cycle (not dynamic)

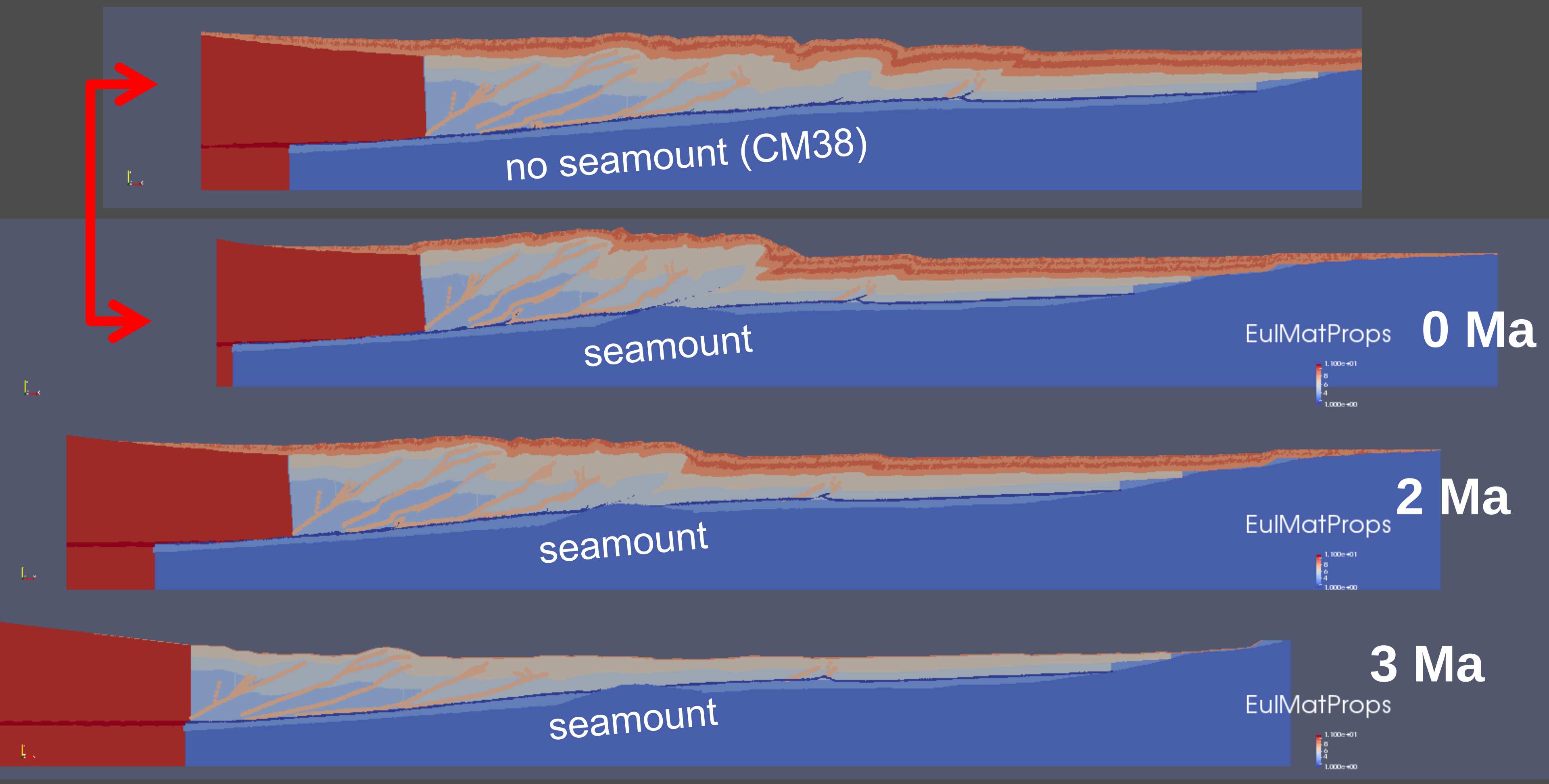
(clay friction coefficients from Saffer and Marone, 2003)

Hydrostatic fluid pressure: (dry coefficient ~ 0.15)

Near-lithostatic fluid pressure: Byerlee friction (dry coefficient = 0.68)

Effect of seamount subduction:

- increased taper
- narrow wedge
- Wedge is NOT critical: slope evolves as seamount passes through



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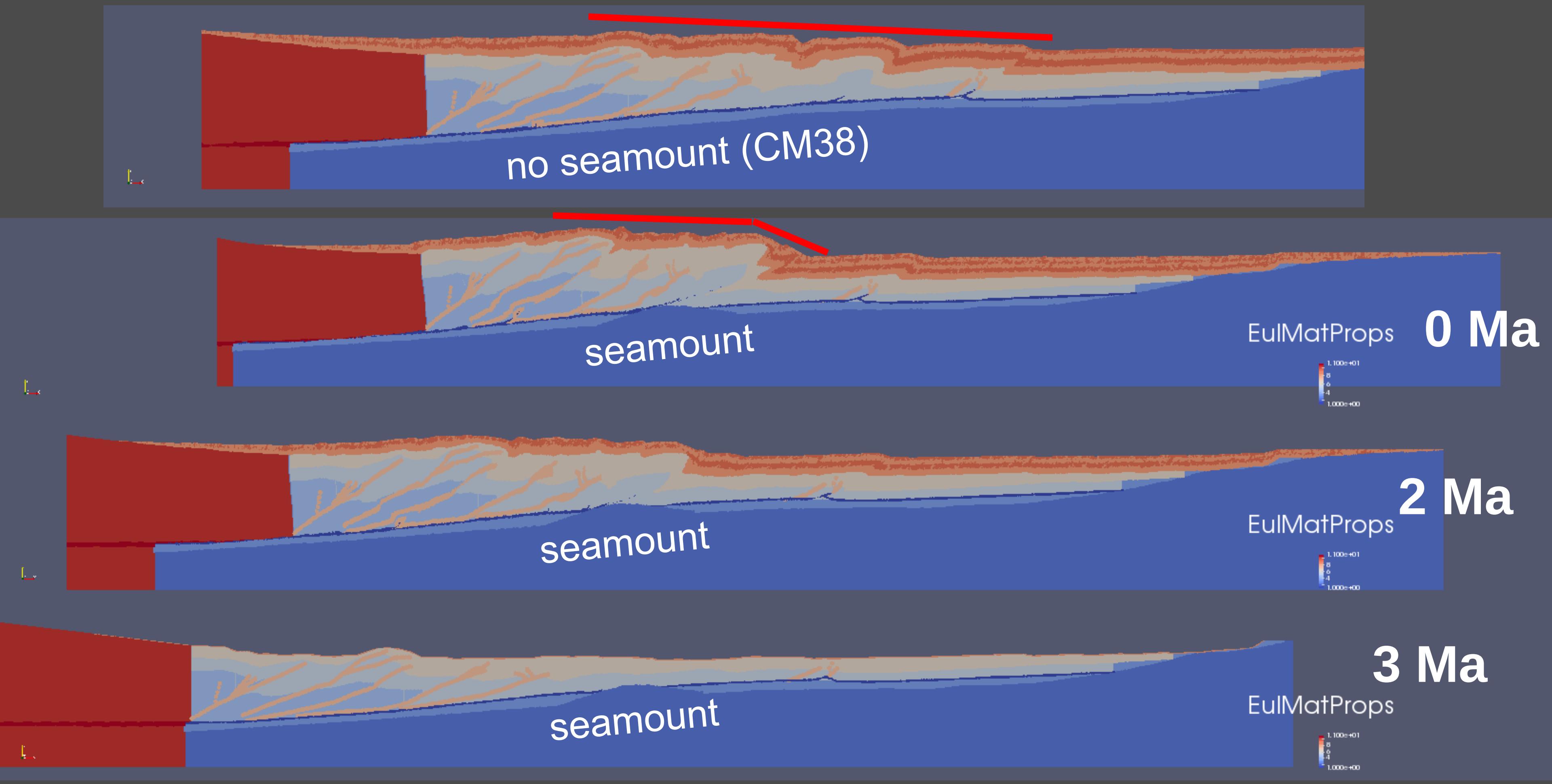
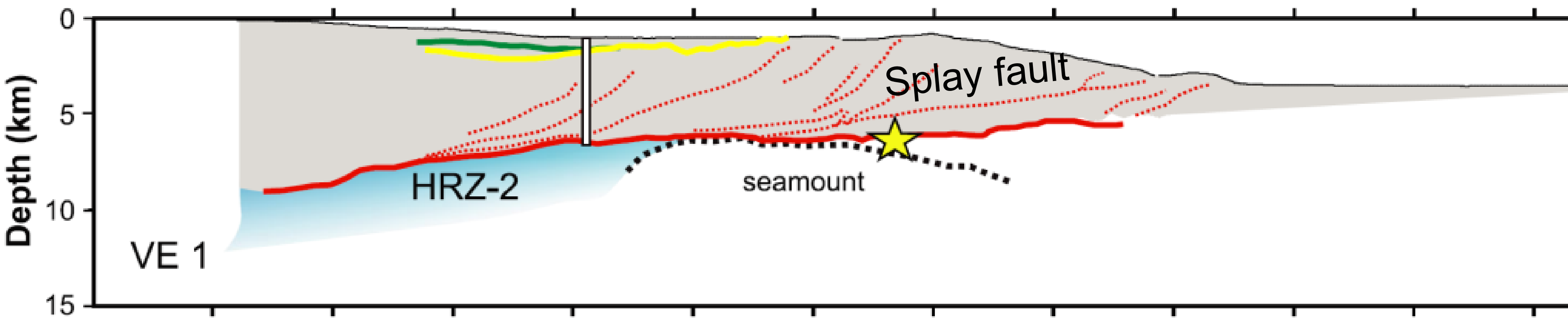
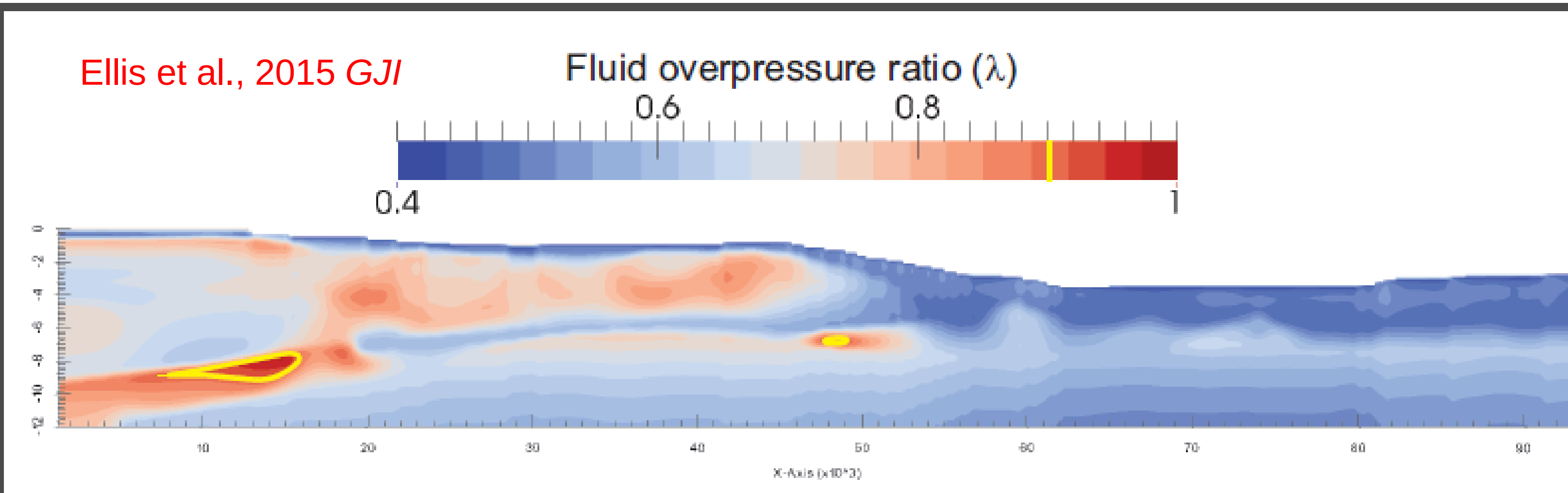


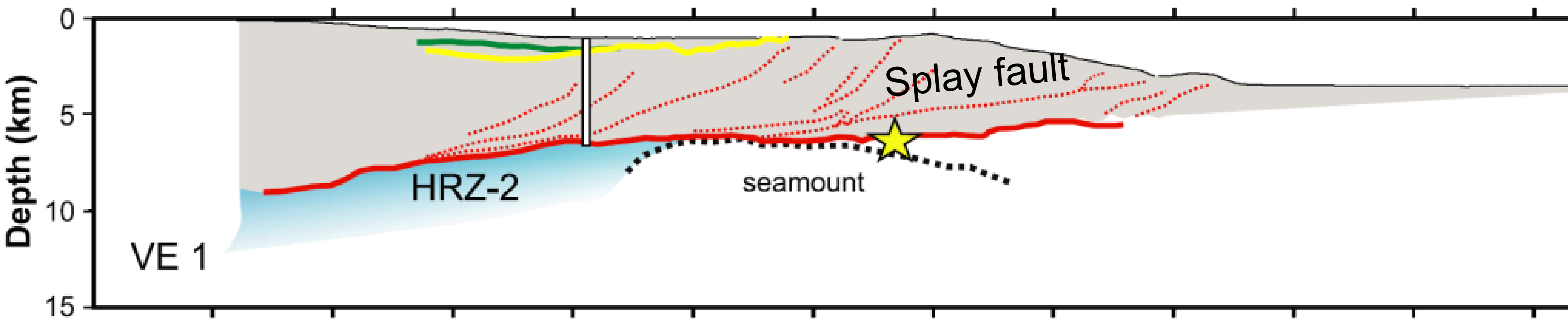
Effect of seamount subduction: line CM05-04

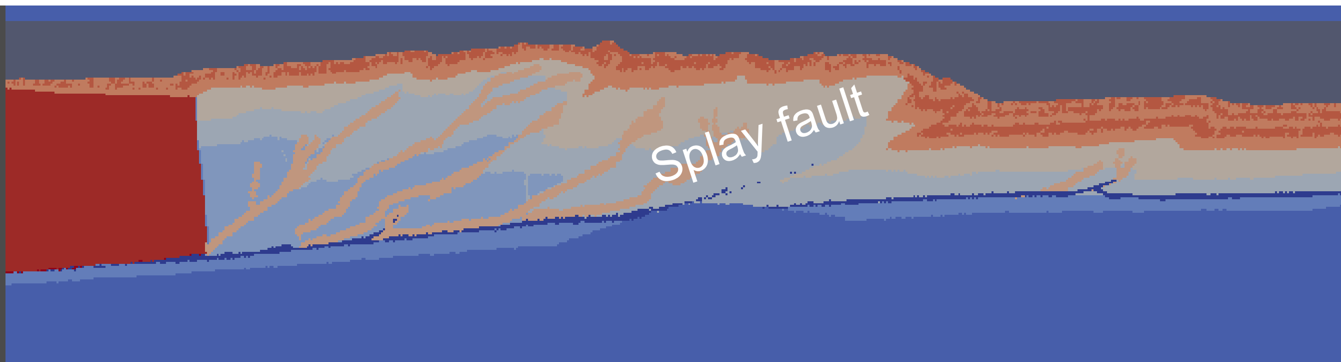


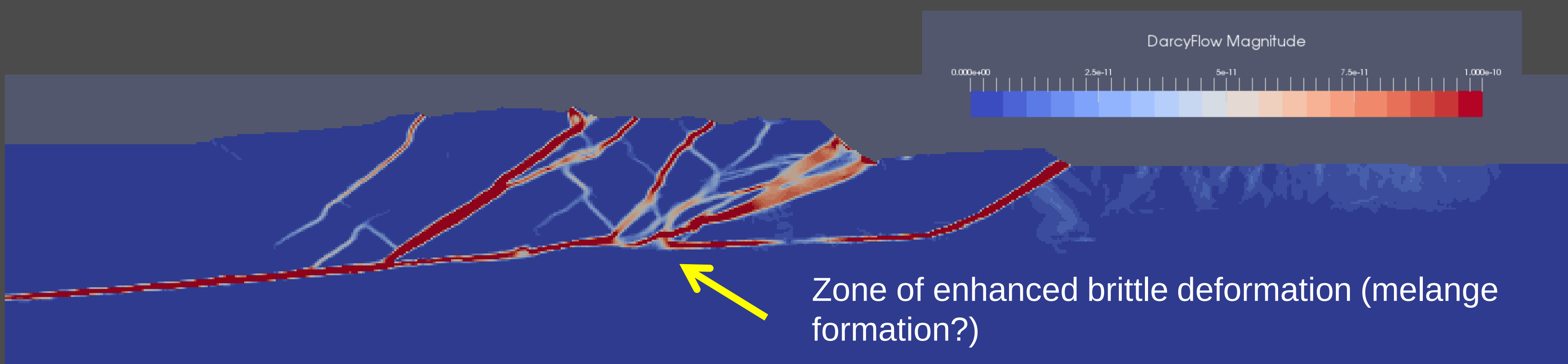
End-member where decollement permeability is reduced for T > 80°C



Effect of seamount subduction: cf. line CM05-04







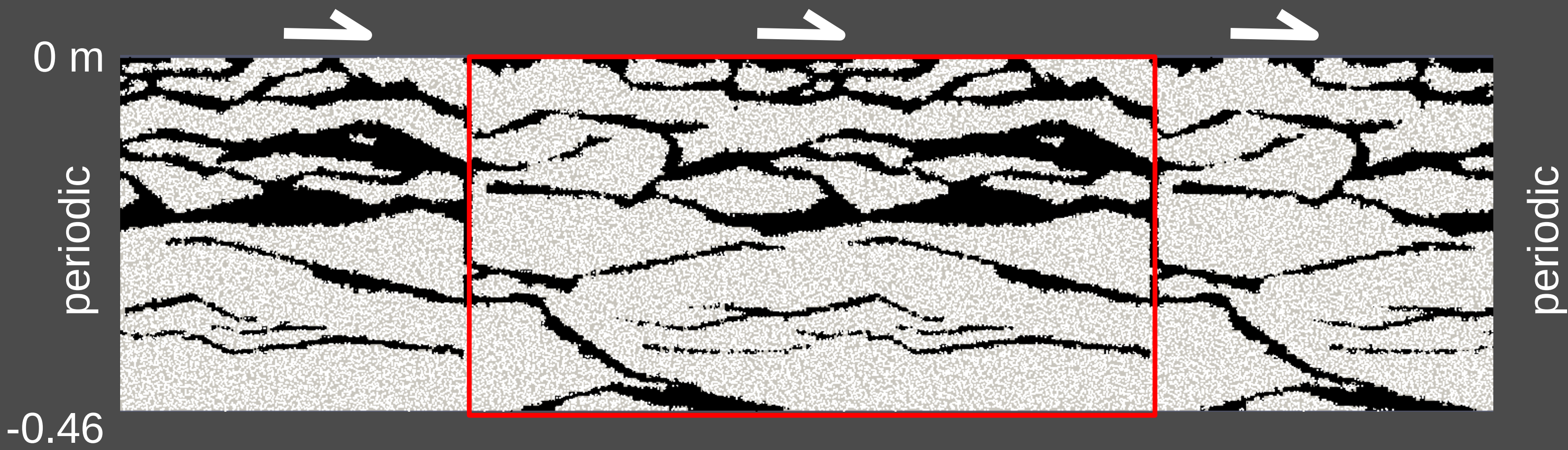
eg Dominguez et al., 1998; Wang and Bilek, 2011

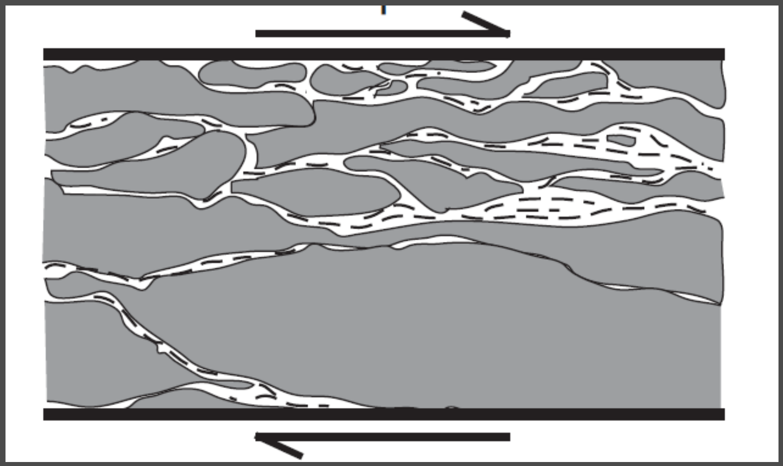
“Virtual shear box experiments” of deforming melange:

Matrix: phyllosilicate flow law (Kronenberg et al., 1990)
Clasts: quartz flow-law, friction coefficient = 0.6
Fluid pressure ratio λ = 0.67 (moderate overpressure)
20 km overburden pressure added

Impose constant velocity boundary condition on top

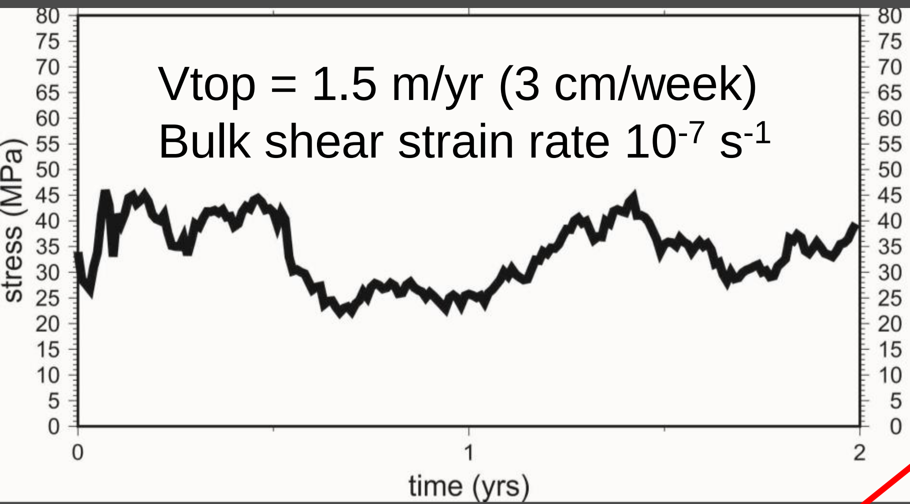
Measure shear force to deform box over time

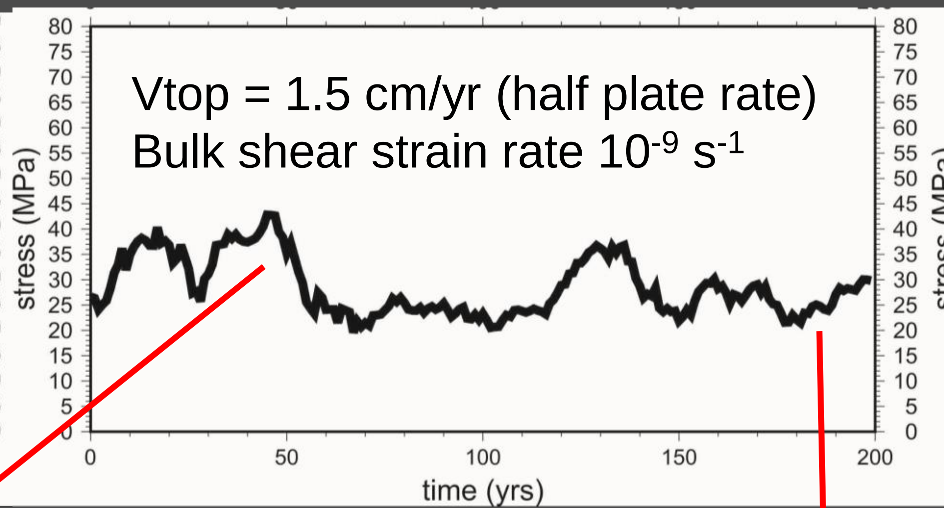


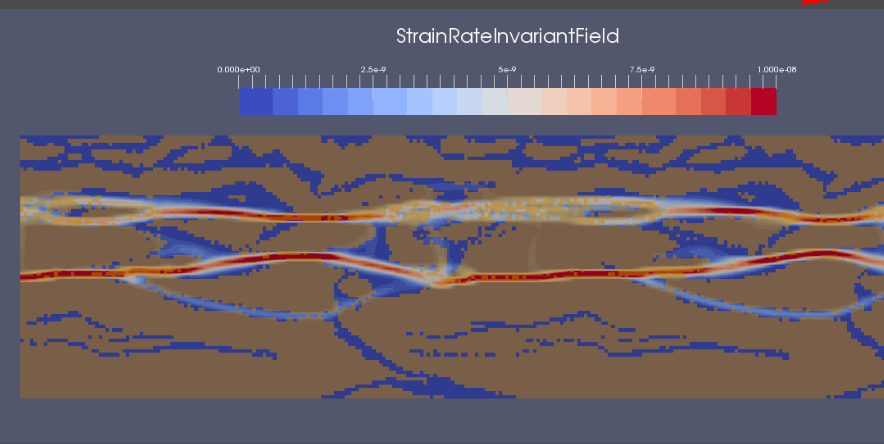


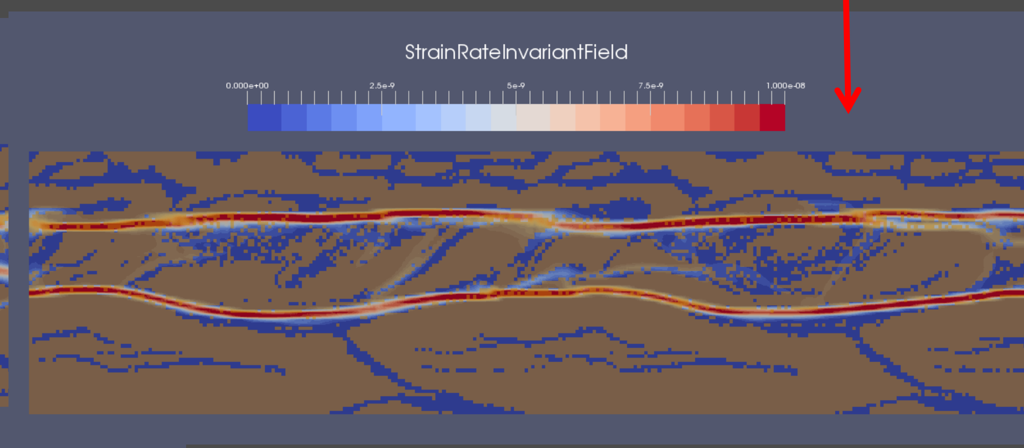
Geometry based on Fagereng and Sibson, 2010 (Chrystalls Beach Complex)

- No fluid cycling in these simple models (since ratio is prescribed)
- Oscillations up to 30% occur as a result of force chains breaking and linking during finite deformation of the melange
- Oscillation timescale depends inversely on slip velocity, and/or on width of shear zone

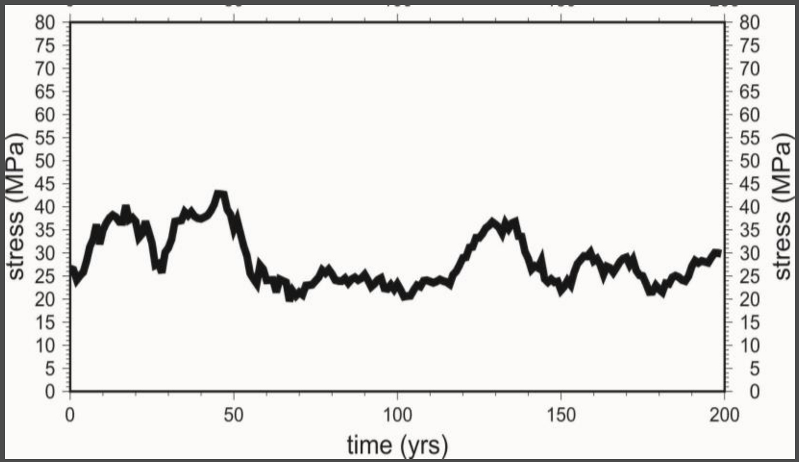




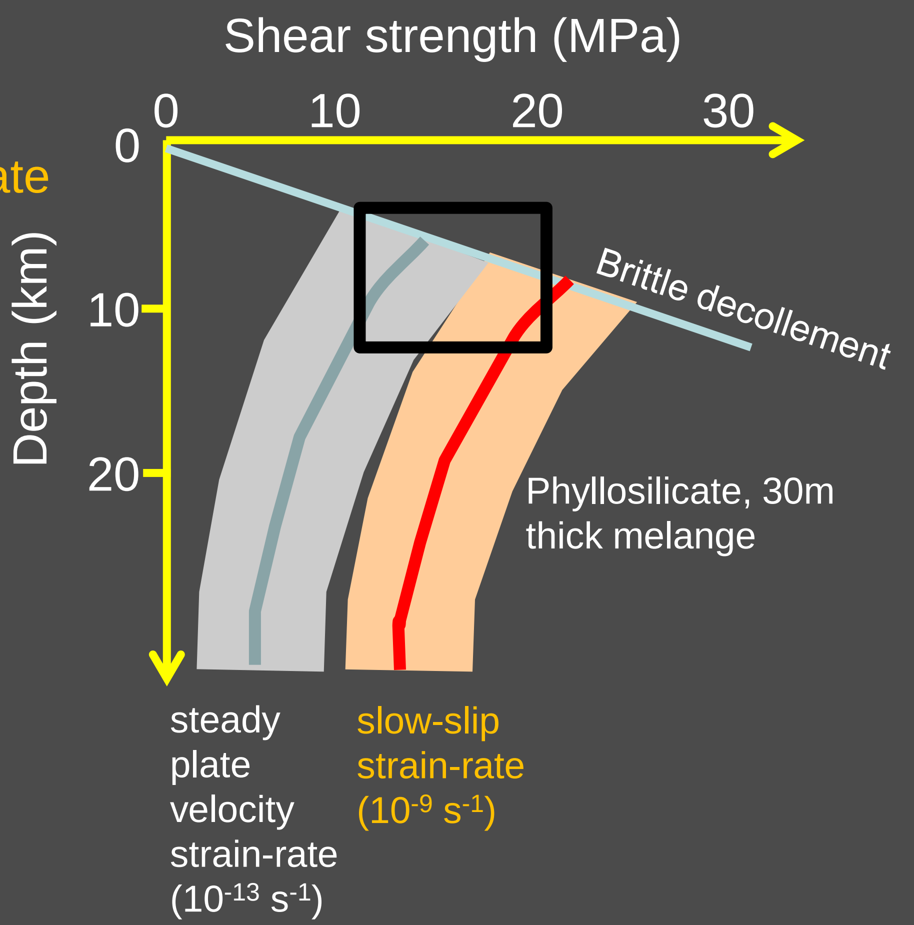




Stress cycling at constant imposed slip rate

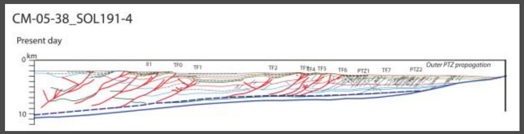


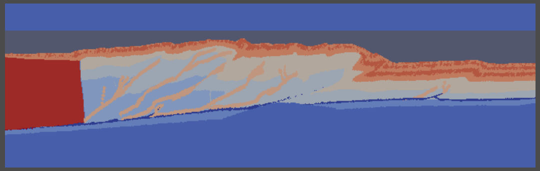
Slip cycling+stress cycling, brittle/viscous



Main points

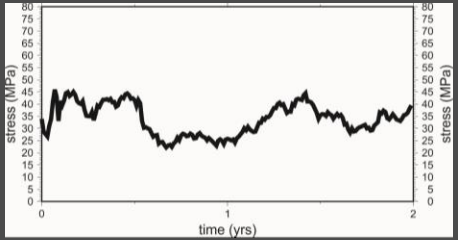
Southern Hikurangi's outermost 100 km wedge has a weak decollement





By adding a "seamount" the shallow southern taper can be turned into the steep northern taper- meaning they could potentially have similar megathrust strength away from the seamount

Disruption of a smooth, thin decollement by seamount subduction may lead to melange tectonics. The faster the melange strains, the faster force chains form and break, leading to stress cycling



The stress cycling timescale depends on strain-rate. Its amplitude depends on relative strengths of blocks vs. matrix. This cycling may also occur in melange permeabilities and fluid pressures (though not modelled yet)