Processes, properties, and microstructures in faults active at retrograde conditions

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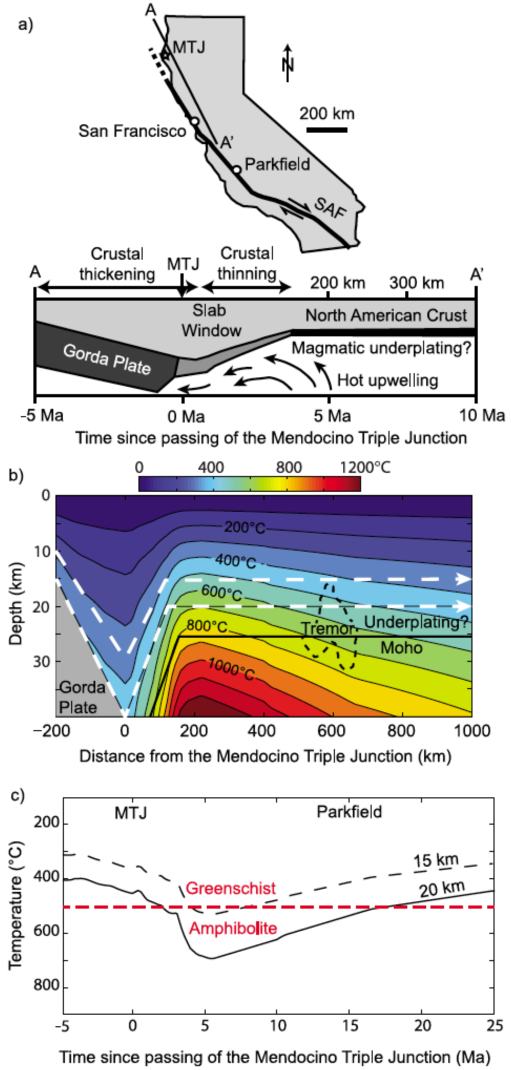


Faults that displace rocks along a cooling *P-T* path will contain metastable, higher metamorphic grade mineral assemblages

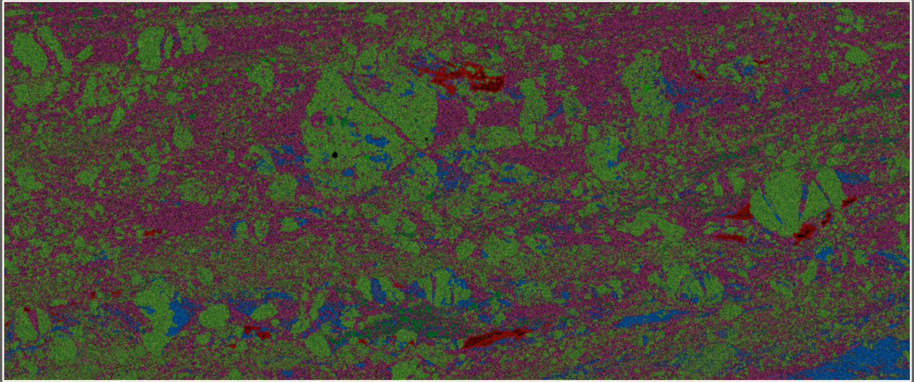
Take for example the San Andreas fault, California, where rocks are translated away from a slab window, and the rocks currently at seismogenic depth have moved from amphibolite to greenschist facies conditions. Hydration of these rocks may be facilitated by fluids from an external source (Fulton et al., EPSL, 2009).

Fagereng and Diener (GRL, 2011)

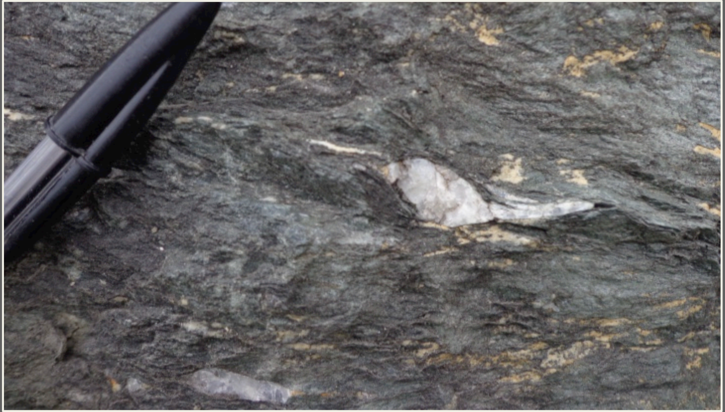
Fluid-consuming reactions lead to growth of relatively weak mineral phases

Outer Hebrides Fault Zone, Scotland

Rigid minerals or aggregates wrapped by foliated phyllosilicates



Fractured epidote (green) in chloritic matrix (pink); Moine thrust, Scotland (EDS map)

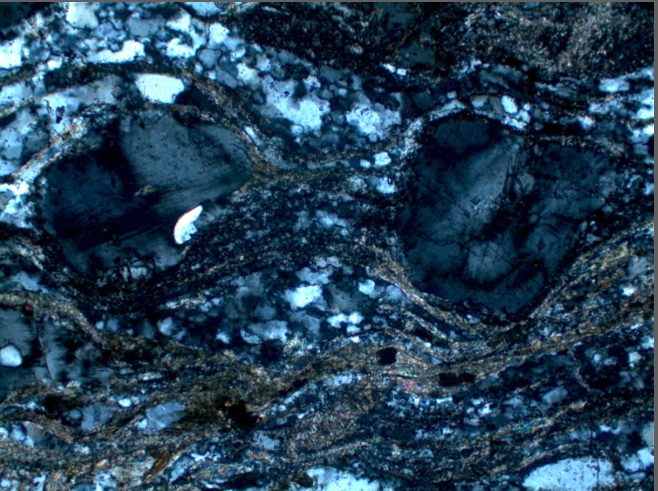


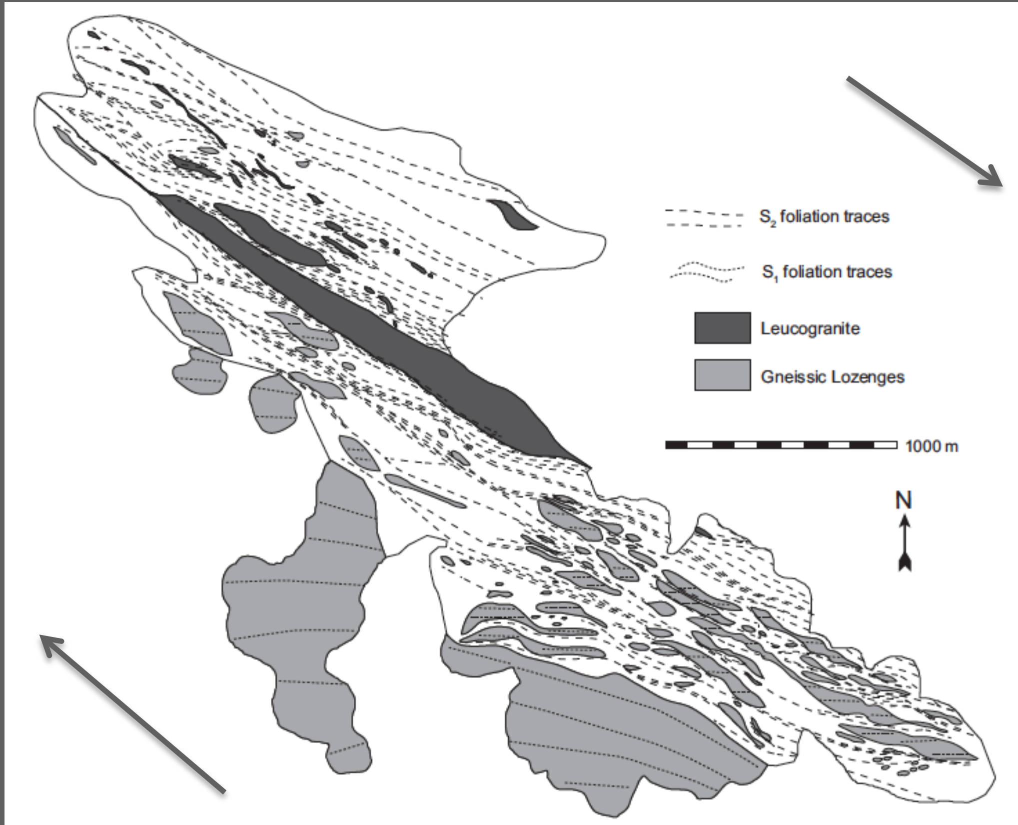
Kalak Nappe, Northern Norway

Discussed, reviewed, and reported by, for example, Wintsch et al. (1995) and Holdsworth et al. (2011) among many others

The Kuckaus Mylonite Zone (KMZ), Namibia, an exhumed greenschist-amphibolite facies dextral shear zone

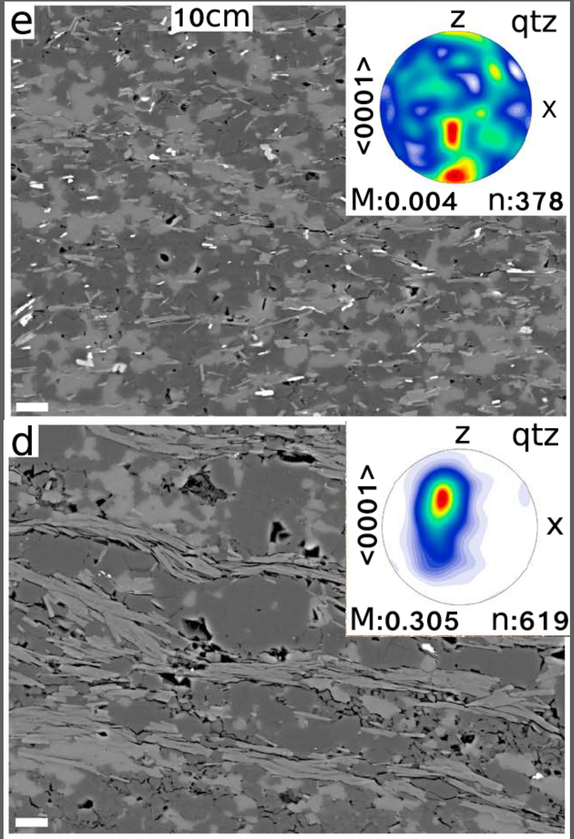
Rigid minerals (feldspar) or coarse gneisses wrapped by schistose phyllosilicates and quartz





Rennie et al., (JSG, 2013)

Strain localization in the KMZ: Grain size reduction, foliation development and destruction

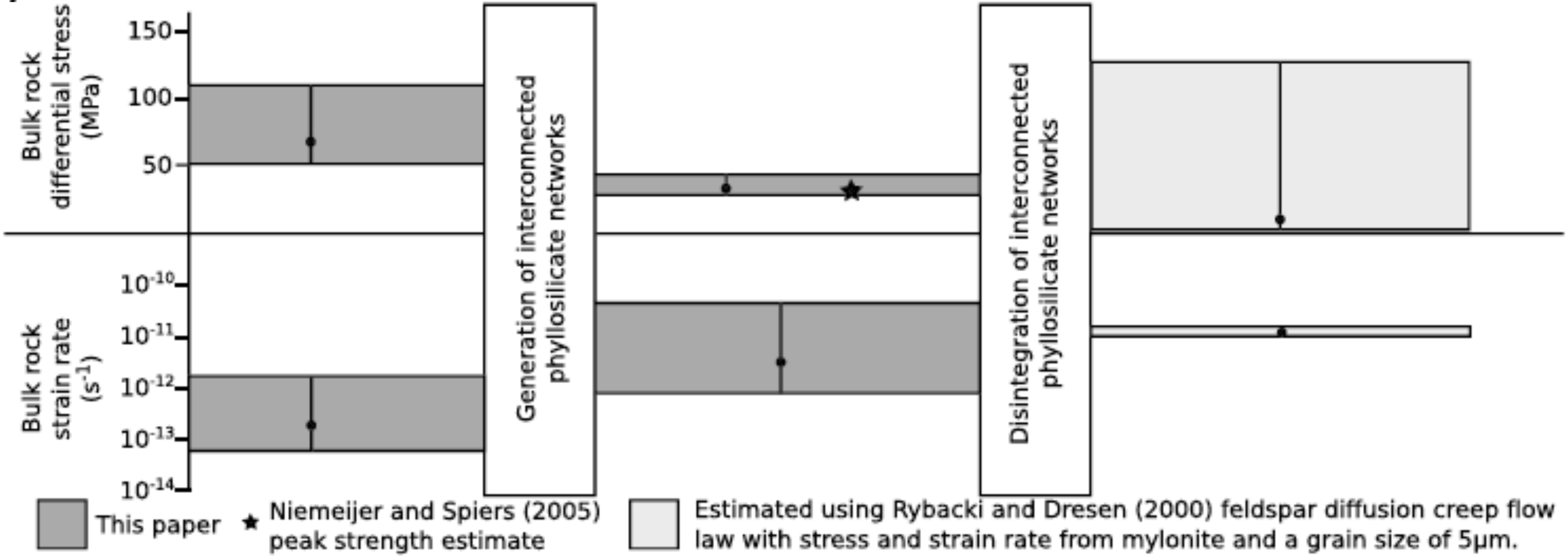


Ultramylonite: Scattered phyllosilicates, finer grain size, poor quartz CPO

Mylonite: Aligned and interconnected phyllosilicates, well-developed quartz CPO

Stenvall et al., (GRL, 2019)

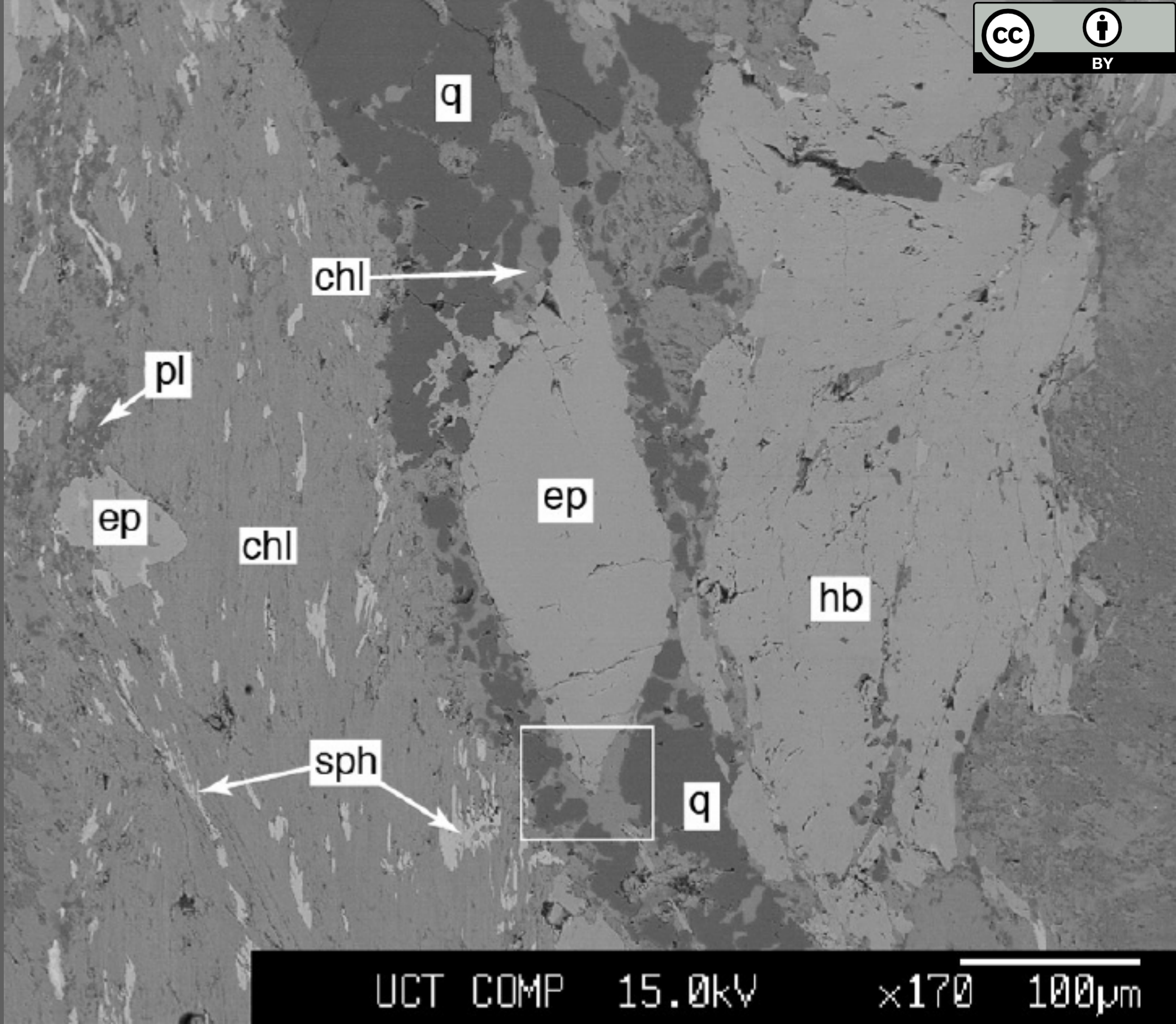
At greenschist facies: generation on phyllosilicates, and a fine grained aggregate, decreases strength and/or increases strain rate



Stenvall et al., (GRL, 2019)

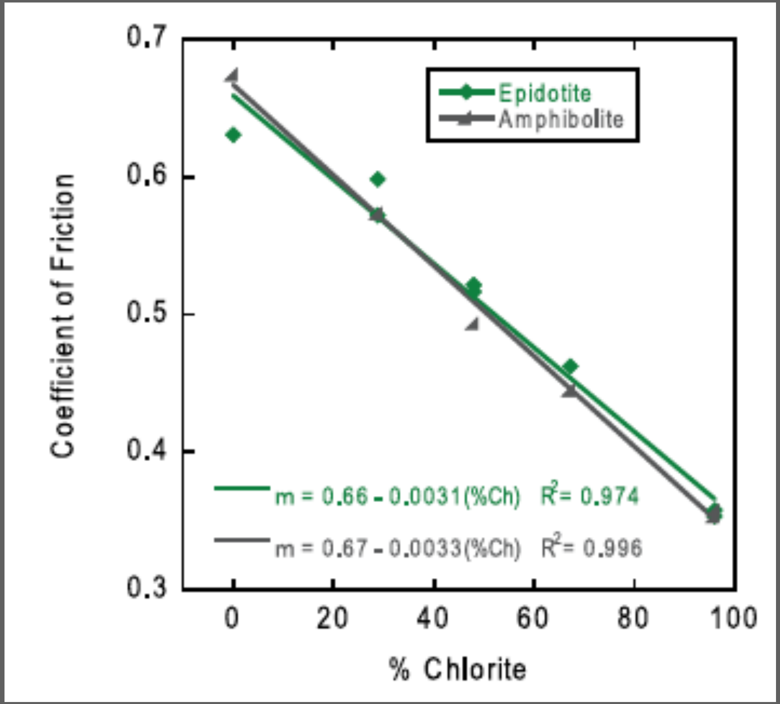
In mafic lenses within the KMZ, greenschist facies hydration (where fluids allowed) led to chlorite growth and reaction weakening during retrograde shearing an amphibolite facies mineral assemblage.

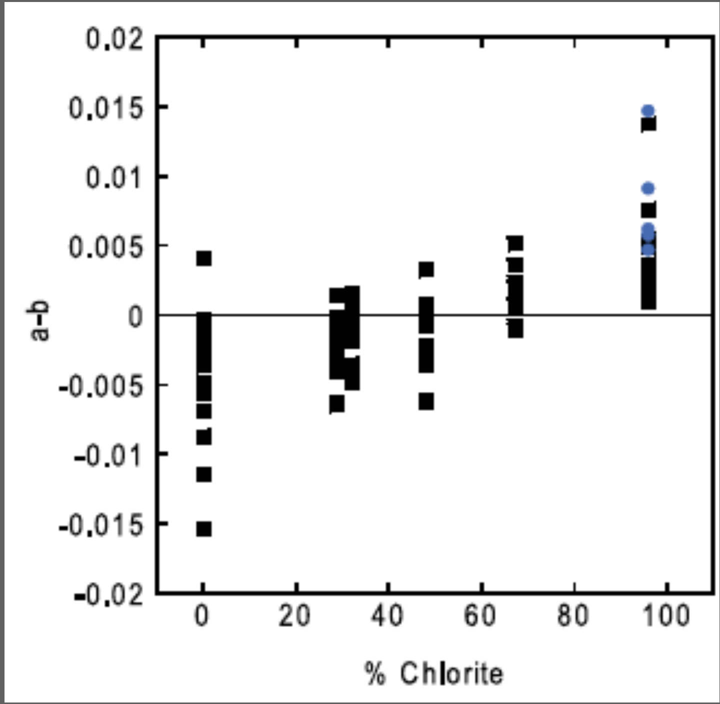
This is a fluid-driven, positive feedback that weakens faults without need for elevated fluid pressure



Diener et al., (Solid Earth, 2016)

At shallower depth and temperature, lab experiments show decreased frictional strength – and change from velocity-weakening to strengthening - with increasing chlorite content





Fagereng and Ikari (JGR, 2020)

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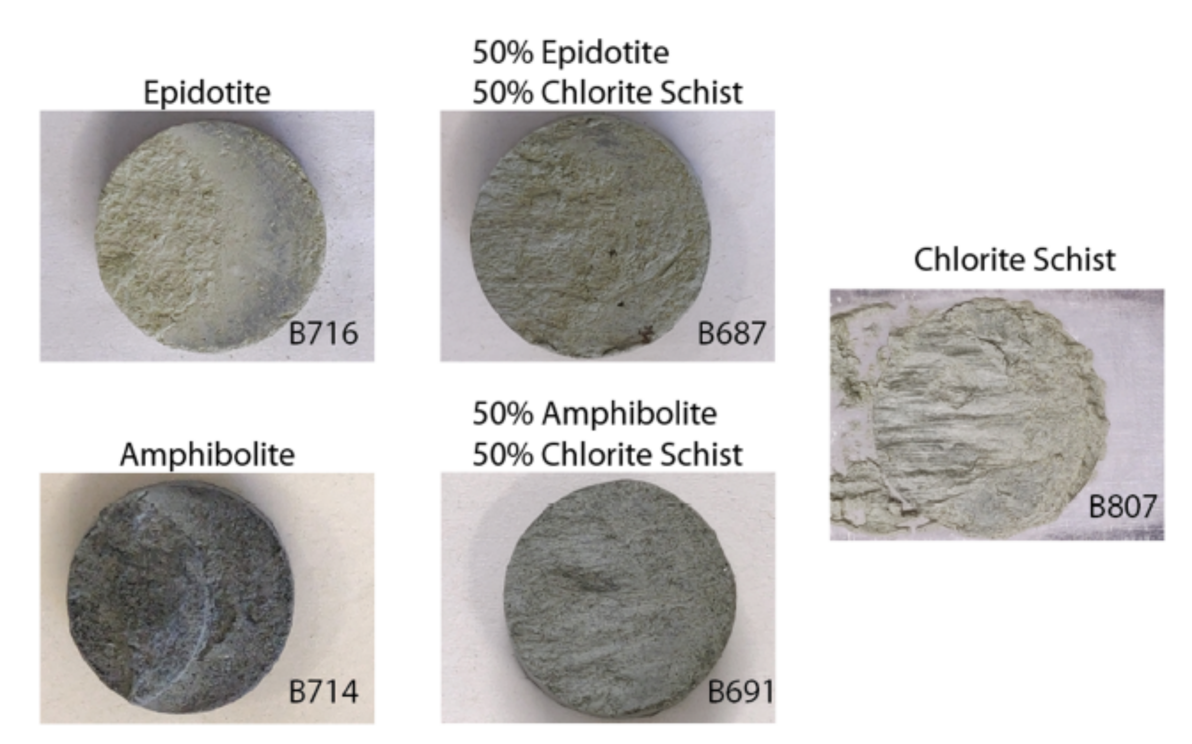
At shallower depth and temperature, frictionally weak and velocity-strengthening samples develop a striation, not seen in frictionally strong and velocity-weakening amphibole and epidote



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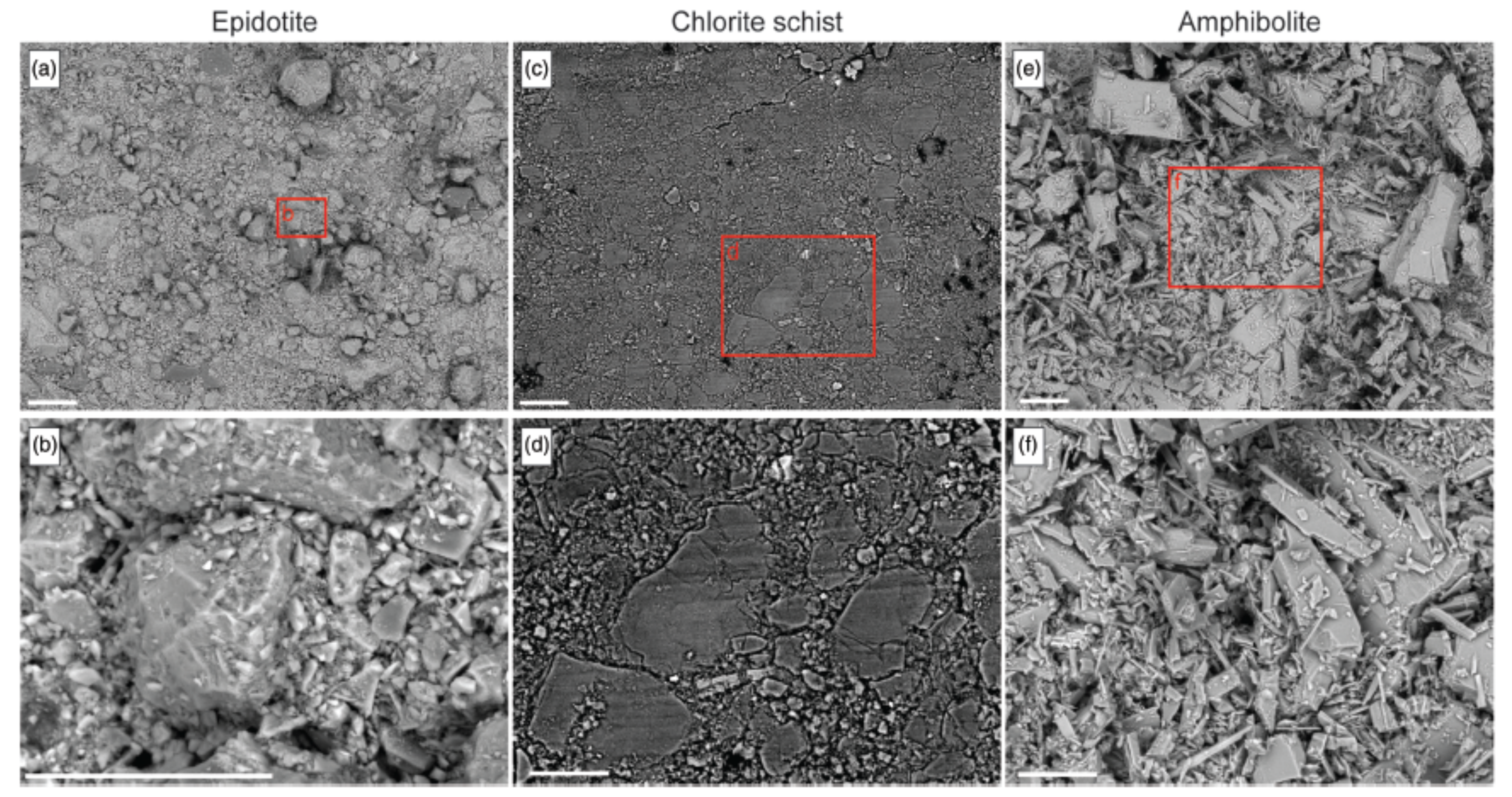
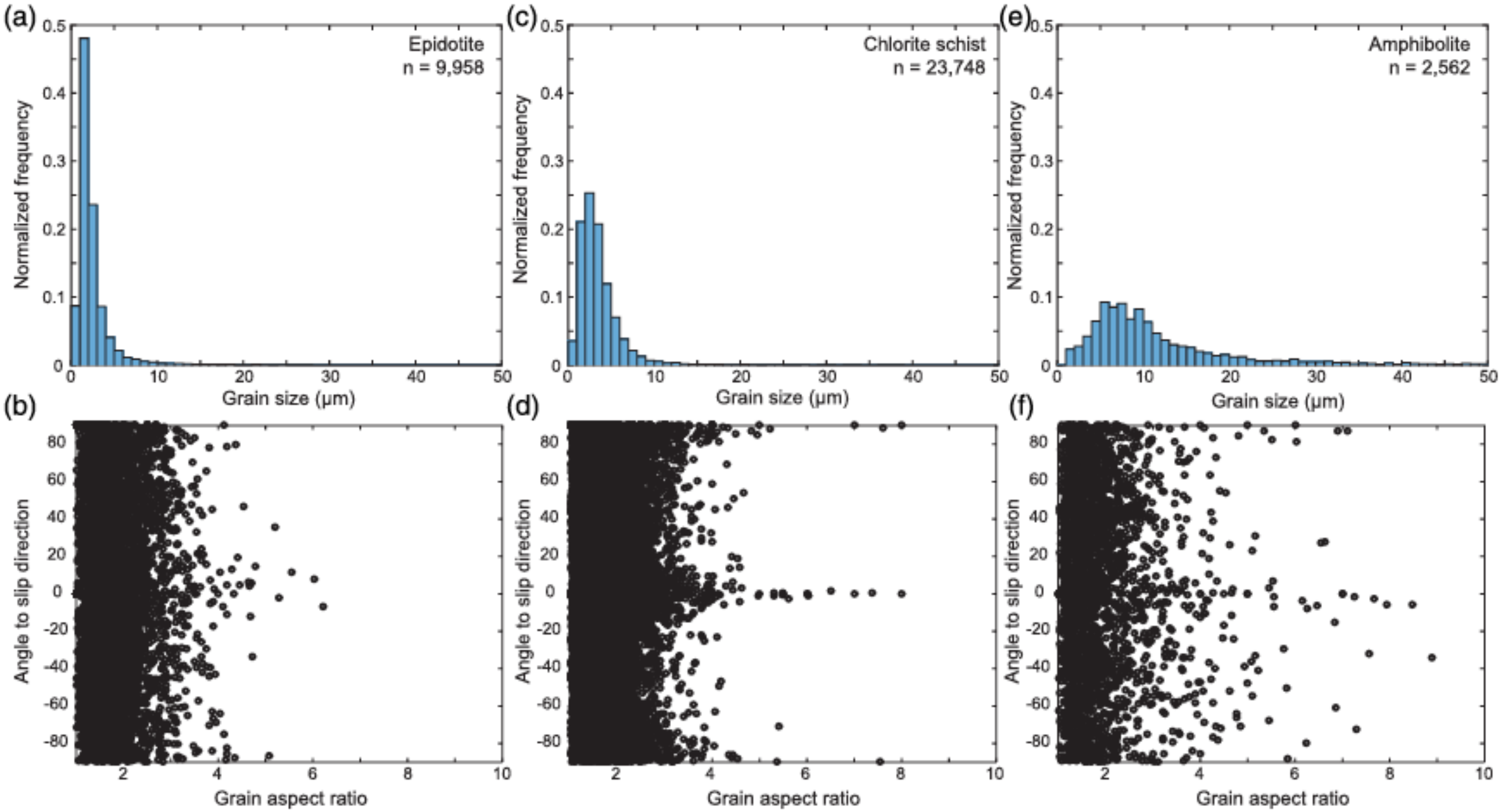


Velocity-weakening epidote is associated with development of very fine particles while retaining large clasts; velocity-strengthening chlorite has long, elongate asperities

Fagereng and Ikari (JGR, 2020)



Velocity-weakening epidote is associated with development of very fine particles while retaining large clasts; velocity-strengthening chlorite has long, elongate asperities

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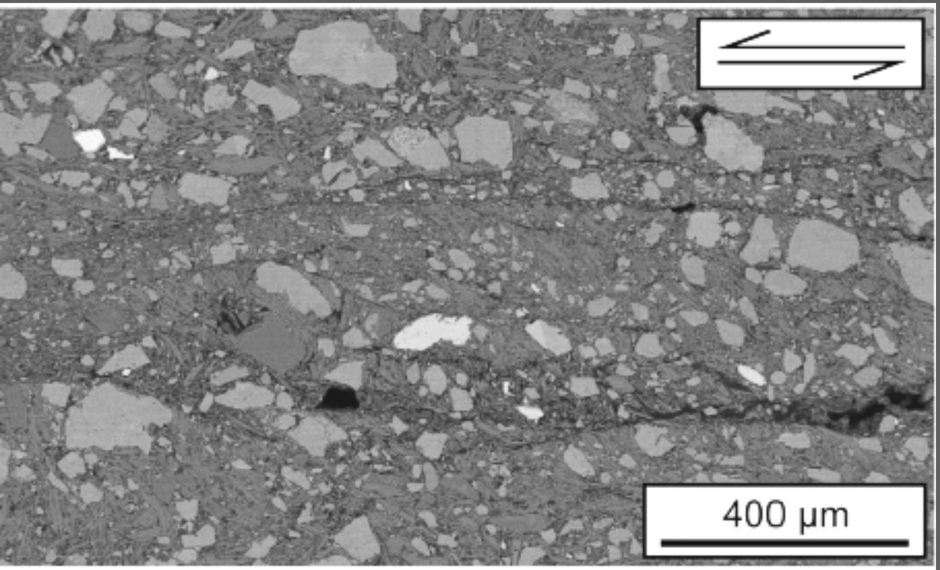
Greenschist, seismogenic depths:

retrograde growth of phyllosilicates and fine-grained new phases leads to profound weakening



Near-surface conditions:

retrograde growth of phyllosilicates leads to frictional weakening and velocity-strengthening

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Conclusions

- Retrograde mineral growth: leads to decrease in strength in both the deep (450˚C) and near-surface conditions we investigated – and velocity-strengthening in near-surface experiments and switch to diffusion creep in the KMZ
- External fluids: are required for retrograde reactions in otherwise dry host rocks, as inferred for several active faults (incl. San Andreas and Alpine faults)
- Variable hydration: represents a potential source for variable strength and slip behaviour, reflected in variable microstructures in nature and experiment