Heterogeneous stresses and deformation mechanisms at shallow crustal conditions, Hikurangi Subduction Margin, New Zealand

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Large-displacement (~4–10 km) thrust fault active during early Miocene (~25–20 Mybp).

Formed primarily in Eocene calcareous mudstones; other lithologies include ribbon sands, siltstones, and marls.

Sediments have 27–58% phyllosilicates (smectite > white mica > kaolinite), 7–56% calcite, and 15–30% quartz.

Sediments exhumed from ≤4–5 km depth based on apatite FT and mineralogy.

Case Study: Hungaroa Fault Zone
Mixed-Mode Viscous Flow and Brittle Fracture

- Foliated gouge
- Sheared calcareous mst
- Calcite shear veins
- Foliation boudinage structure
- Slickenfibre shear veins
- Calcareous mudstone
- Massive gouge
- Dark solution seams
- Limestone layer

Textural analyses next slide
Textural Analyses of Calcite Veins

EBSD-based misorientation map of calcite shear veins

Evidence for grain boundary migration, subgrain formation and high dislocation density! But at what temperatures?

mean grain size of recrystallized grains = 7.2±4.2 µm

EBSD -based calcite orientation map

TEM sample location

STEM – dark field image

strongly deformed clast

free dislocation
tangled dislocation

subgrain boundaries

100 µm
Clumped isotope measurements give independent estimates of the growth temperature and $\delta^{18}O$ of carbonate minerals, enabling the $\delta^{18}O$ of diagenetic waters from which the minerals grew to be calculated.
Our results indicate that:

1. stresses are spatiotemporally heterogeneous in crustal fault zones containing mixtures of competent and incompetent minerals;
2. heterogeneous deformation mechanisms, including frictional sliding, pressure solution, intracrystalline plasticity, and mixed-mode fracturing accommodate slip in shallow crustal fault zones;
3. brittle fractures play a pivotal role in fault zone deformation by providing fluid pathways that promote fluid-enhanced recovery and dynamic recrystallisation in the deforming calcite at remarkably low temperatures (~60-140°C).

Together, field geology, microscopy, and clumped isotope geothermometry provide a powerful method for constraining the multiscale slip behavior of large-displacement fault zones.