

## **In-situ stable isotope tracing of nanoscale deformation processes in earthquake-prone crustal fault materials**

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Localized deformation of carbonate rocks results in granular materials with grain sizes down to 10 nm. It is the physico-chemical behaviour of these materials that determine the rheological behaviour of faults prone to seismic activity. Theories hypothesize that carbonate fault stability in the presence of fluids is dictated by a mixture of superplastic flow and nano-scale dissolution-precipitation processes [1]. However, direct evidence of fluid-assisted deformation mechanisms operating in granular volumes is absent.

For the first time, we have gone beyond classical microstructural analysis to demonstrate that localised dissolution-reprecipitation occurs within a monomineralic calcite fault gouge during deformation. To achieve this we used water enriched in  $^{18}\text{O}$  (97 at%) as a pore fluid for direct shear deformation. Experiments were carried out at sub-seismic velocities ( $0.1 \mu\text{m/s}$ ) at temperatures of 25 or 100 °C and confining pressure of 50 MPa, crossing the boundary between velocity-strengthening and velocity-weakening frictional regimes [2], marking the potential onset of seismic activity. Hyperspectral imaging using Raman spectroscopy showed the presence of  $^{18}\text{O}$ -bearing carbonate isotopologues within newly formed calcite grains. This is consistent with unconfined experiments [3] and demonstrates that a coupled dissolution-reprecipitation mechanism is active during deformation. Focused ion beam - scanning electron microscopy (FIB-SEM) allowed us to excavate nanogranular volumes identified with the Raman analysis to show  $^{18}\text{O}$  enrichment. Subsequently, the direct nanoscale spatial distribution of O-isotopes was mapped using nanoscale-resolved secondary ion mass spectrometry (nano-SIMS).

This multi-scale approach demonstrates that stable O-isotopes are a novel, in-situ tracer of mineral re-equilibration processes during deformation. By combining experimental rock deformation with stable isotope geochemistry, we can gain unparalleled insights into how fault rocks deform at the micro-, and nanoscale to develop multi-scale, rheological models of crustal faults. [1] Niemeijer & Spiers (2007) *J. Geophys. Res.* **112**, B10405. [2] Verberne et al. (2013) *Geology* **41**, no. 8, 863–866. [3] Perdikouri et al. (2011) *Geochim. Cosmochim. Acta* **75**, 6211 – 6224.