Faculty of Geosciences
Department of Earth Sciences
High Pressure and Temperature Laboratory

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# Frictional Behaviour of Carbonates: Defining the Seismogenic Zone in Dolomite

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## Motivation

Natural and induced earthquakes frequently occur in carbonate formations across tectonically active regions, often resulting in fatalities and economic loss. Investigating the frictional strength of thermally sensitive rocks like dolomite is critical as temperature, stress and the presence of (pressurized) fluids can affect both strength and deformational behaviour. Therefore, constraining the seismogenic depth by investigating the frictional behaviour and active deformation mechanisms at various depth conditions will enhance our knowledge of the frictional-viscous transition and, with that, our understanding of fault slip nucleation and, by extension, earthquake occurrence.

## Objectives

- Constrain the temperature range in which earthquakes can migrate in dolomite.
- Investigate the deformation mechanisms operative on a laboratory scale (mm to cm).
- Using laboratory results, to model seismic sequences more realistically, facilitating a shift from empirical to physics-based approaches.
- Combining experimental results, microstructural observations and physics-based models to provide insights into fault behaviour at regional scales (hundreds of m).

## Approach

- Friction (evolution) experiments in the hydrothermal Rotary Shear Apparatus (RSA) on simulated dolomite gouge at temperatures ranging from RT – 600 ℃ and velocities ranging from 3 $^{nm}/_{s}$ - 300 $^{\mu m}/_{s}$.
- Analyses of velocity stepping test using the Rate and State Friction (RSF) law (Eq. 1).
- Microstructural and microchemical analyses to identify deformation mechanisms.

$$\tau = [\mu_0 + (a-b)\ln(^{v}/_{v_0})]\sigma$$
$$(a-b) = {}^{\Delta\mu}/_{\Delta\ln(v)}$$

**Eq. 1.** Steady state RSF law where τ is shear stress , σ effective normal stress, v slip velocity, $v_0$ reference velocity, $\mu_0$ steady state friction and a and b are material properties.

## Mechanical results

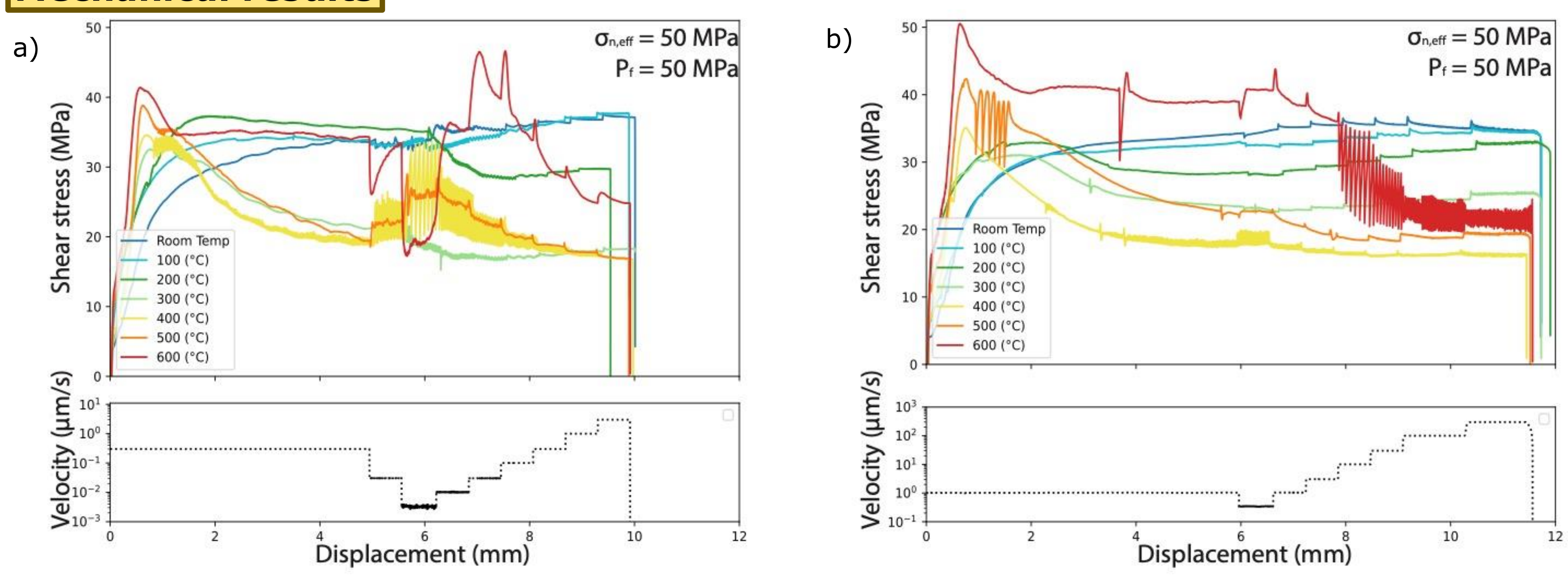


**Fig. 1.** Shear stress vs. displacement plots for dolomite gouge sheared at a) v = 0.003 – 3 $^{\mu m}/_{s}$ and b) 0.3 – 300 $^{\mu m}/_{s}$. All experiments were conducted at constant $\sigma_n$, $P_f$ and T as indicated in the plots. RSF (a-b) values were only analysed for velocity upsteps.

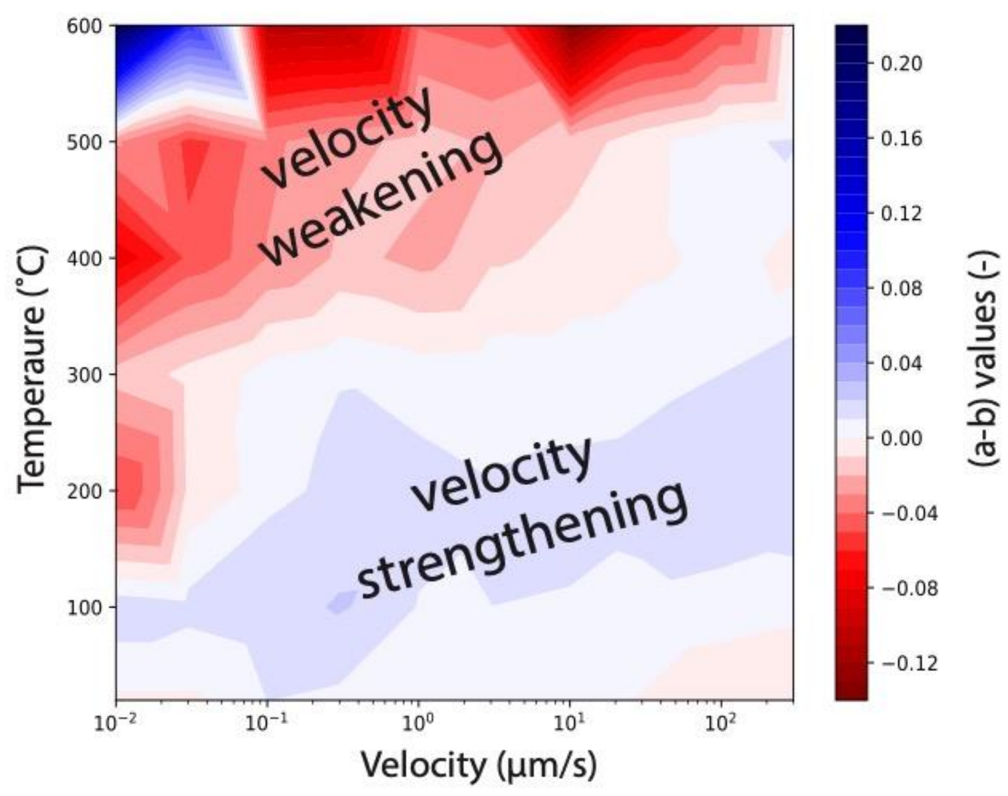


**Fig. 2.** Contour plot of (a-b) variations with temperature and velocity, where bluish colours represent stable and reddish colours unstable zones.

## Microstructural observations

Observations made on experimental samples include scanning electron microscope (SEM): Back Scattered Electron (BSE) imaging, Energy Dispersive X-ray Spectroscopy (EDX) and Raman microscopy.

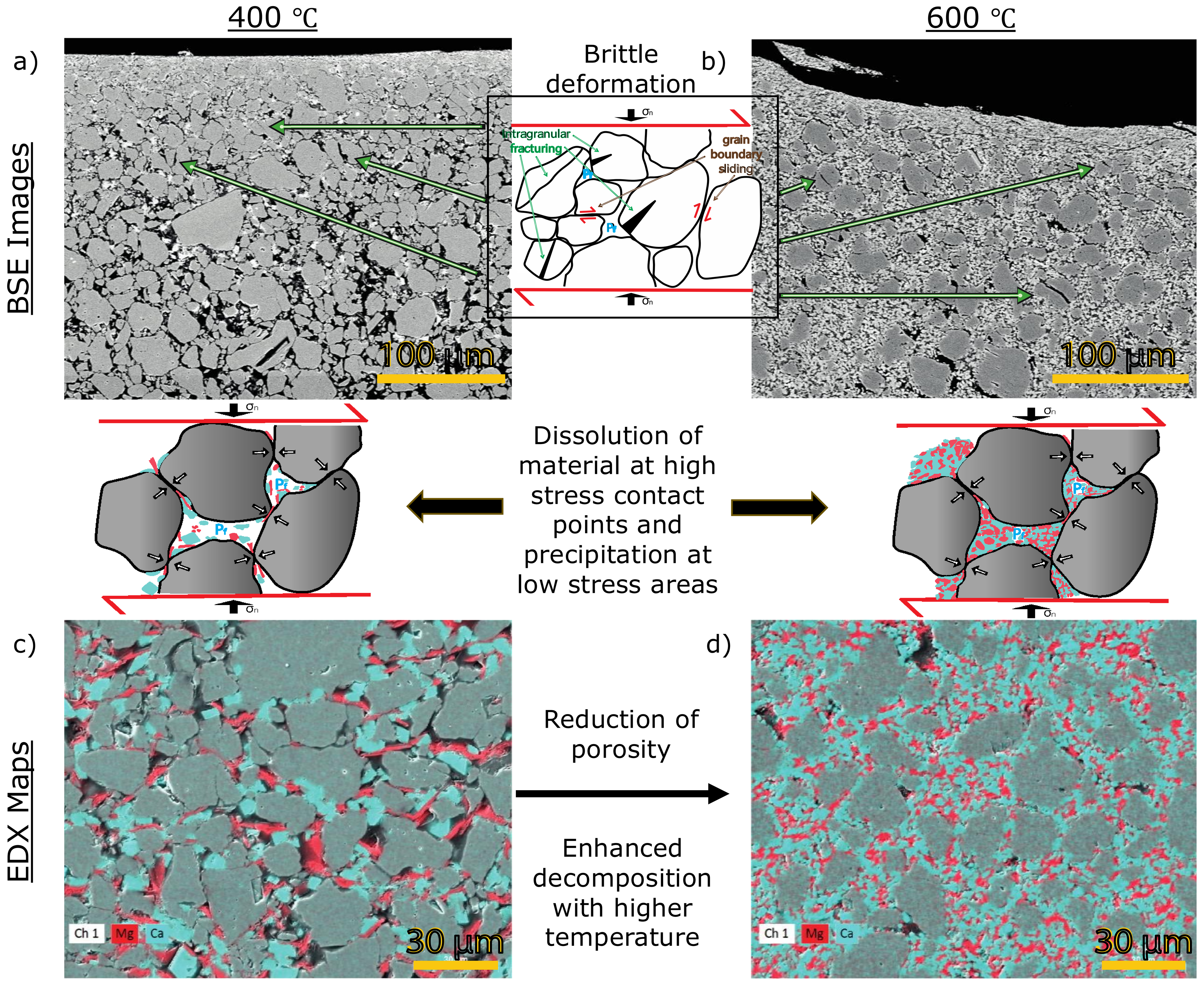


**Fig. 3.** BSE-SEM a), b) and EDX c), d) images of two post-experimental samples: dolomite gouge sheared at a), c) 400 ℃ and b), d) 600 ℃ at otherwise same conditions and velocity protocols (t ≈ 90 h, v = 0.003 - 3 $^{\mu m}/_{s}$). EDX images show the formation of fibrous Mg-rich minerals (red) at grain boundaries at 400 ℃ which becomes more rounded at 600 ℃.

### Raman microscopy

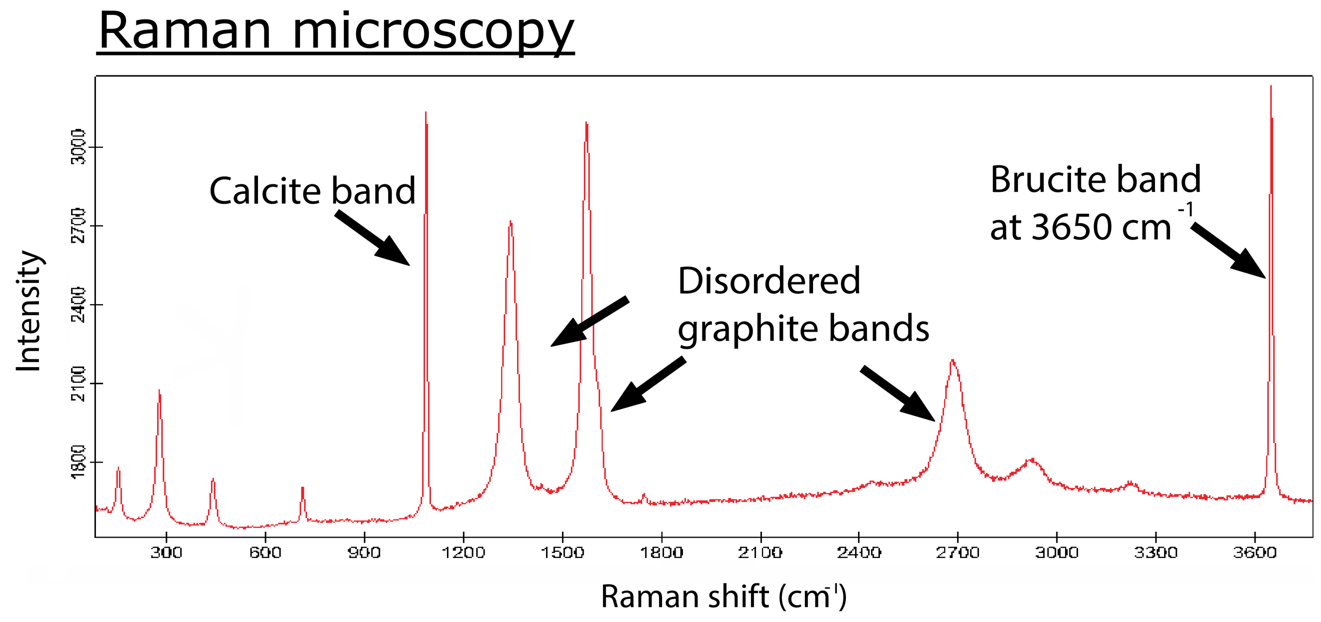


**Fig. 4.** Typical Raman spectrum for a pore space in samples that showed separation of Magnesium and Calcium in EDX measurement.

**Decarbonization of dolomite:**

$$CaMg(CO_3)_2 \rightarrow CaCO_3 + MgO + CO_2$$

**Reaction of periclase with water:**

$$MgO + H_2O \rightarrow Mg(OH)_2$$

## Main findings

- Friction shows a dependence on both velocity and temperature, where cooler temperatures (< 300 ℃) are mostly velocity strengthening and therefore conditionally stable, while higher temperatures (400 – 600 ℃) result in mostly velocity weakening, potentially unstable outcomes.
- All investigated samples showed signs of brittle deformation; samples sheared at T > 300 ℃ also showed ductile pressure solution creep.
- Displacement weakening at higher T can be associated with decomposition of dolomite to rel. weak brucite and rel. strong calcite. Additionally, minor graphite is observed.
- At T = 600 ℃ high shear stress values are interpreted to be due to the formation of frictionally strong periclase.

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