

Fluid-rock interaction along the Glarus thrust at Lochseite and its impact on calc-mylonite formation and thrusting.

Josef Mullis*, Torsten Vennemann**, Christian de Capitani* & Leander Franz*

* Institute of Mineralogy and Petrography, University of Basel, Switzerland

** Mineralogical and Geochemical Institute, University of Lausanne, Switzerland

The Glarus thrust is a prominent tectonic feature in the eastern Helvetic Alps that has been investigated by numerous authors. Based on stable isotope measurements (i.e. indirect evidence), it was suggested that fluids played a key role during deformation along the Glarus thrust (e.g. Burkhard and Kerrich, 1990, Burkhard et al., 1992, Badertscher et al. 2002); Abart and Ramseyer, 2002; Abart et al., 2002). Primary fluid inclusions are relicts of the fluid that was present during mineral formation and deformation (i.e. direct evidence). The main aim is to evaluate the importance of high-pressure methane-bearing fluids on the alteration above and below the Glarus thrust, on the formation of the Lochseite calc-mylonite and on thrusting itself.

The Lochseiten calc-mylonite is a fine-grained limestone with abundant 0.1 to 1 mm thick veins of calcite, dolomite, quartz, pyrite and organic material. The footwall infrahelvetic flysch at the Lochseite locality consists of fine marly and silty slates alternating with fine- to coarse-grained sandstone layers. The Verrucano formation in the hanging wall is primarily comprised of massive siltstones and sandstones with intercalated conglomerate horizons. Characteristic features for all three formations are multiple vein generations due to hydrofracturing and dissolution and precipitation of calcite. In addition, the lowermost two meters above the thrust the Verrucano is intensively deformed and has a green colour. In contrast to the overlying reddish Verrucano, ferric iron oxides are replaced by pyrite and more abundant chlorite.

Veining without preferred orientation results in relatively late thrust-related subvertical fissure systems in the footwall flysch. They contain synkinematically formed fibre quartz, prismatic quartz and calcite of different generations. In contrast, subhorizontal en echelon tension gashes in the Verrucano also contain fibre quartz, but they are older and not thrust-related. Small (≤ 1 cm in width) and near vertical SW-NE striking quartz-calcite and calcite veins cut older structures within all formations.

Immiscible methane-bearing water-rich and water-bearing methane-rich fluid inclusions coexist in the foot wall flysch, whereas water-rich fluids without any free gas phase are found in the hanging wall Verrucano. Immiscible high-density methane-rich fluid inclusions indicate the approximate formation conditions.

Detailed investigations of the oxygen isotope compositions of quartz, calcite, whole rock silicates and carbonates, and the carbon isotope compositions of calcite from fissures, veins and host rocks in the Verrucano and the uppermost portion of the foot wall flysch were made.

Preliminary results are:

- Immiscible methane-rich and methane-bearing water-rich fluids were produced by maturation of organic matter within the Infrahelvetic flysch below the Glarus thrust and included within fissure minerals at 228 °C and 2.9 kbar.

- The clay-rich Verrucano thrust sheet with its subhorizontal foliation acted as a classic permeability barrier to the highly pressurized CH₄-bearing fluids.
- The lowermost green Verrucano is the **reaction zone**, where CH₄ was oxidized in the presence of ferric iron oxides and water to CO₂.
- Acidic alteration of feldspars led to massive growth of sericite, chlorite and quartz in the lowermost Verrucano and to a lesser extent in the uppermost Flysch below the Lochseite calc-mylonite.
- Hydrofracturing, acidic alteration, and brecciation of the lowermost Verrucano created porosity and allowed fluid circulation between the uppermost flysch and the lowermost Verrucano.
- Fluid infiltration from the flysch into the Verrucano is confirmed by the oxygen isotope compositions of quartz and calcite and by carbon isotope compositions of calcite from veins of the lowermost Verrucano reaction zone. Here vein minerals change their isotopic compositions towards the compositions of the host flysch when they approach the thrust contact.
- The circulation of acidic fluids into the footwall flysch has dissolved calcite in the flysch matrix and re-deposited it at the flysch/Verrucano interface.
- At more or less close to lithostatic fluid pressure conditions, seismic valving related hydrofracturing caused calcite precipitation and vein mineralization (Etheridge et al, 1984; Sibson, 1990). This led to the formation of the carbonate, which was later transformed to the Lochseiten calc-mylonite. This is confirmed by the carbon isotope compositions of calcite measured in the flysch.
- Supported by high fluid pressures, the Lochseiten calc-mylonite situated between the two more rigid lithologies acted as a “weak” décollement “layer” that accommodated the thrust movements above the Infrahelvetic flysch.
- Episodic escape of highly pressurized fluids is documented by late vertical veins that crosscut all lithologies along the Glarus thrust.

REFERENCES

- Abart, R., Badertscher, N., Burkhard, M. & Povoden, E. (2002): Oxygen, carbon and strontium isotope systematics in two profiles across the Glarus thrust: implications for fluid flow. - *Contrib. Mineral. Petrol.* 143: 192-208.
- Abart, R. & Ramseyer, K. (2002): Deformation induced quartz-fluid oxygen isotope exchange during low-grade metamorphism: an example from the Glarus thrust. - *Schweiz. Mineral. Petrogr. Mitt.* 82: 291-302.
- Badertscher, N.P., Abart, R., Burkhard, M. & McCaig, A. (2002): Fluid flow pathways along the Glarus overthrust derived from stable and Sr-isotope patterns. - *Amer. J. Sci.* 302: 517-547.
- Burkhard, M. & Kerrich, R. (1990): Fluid-rock interaction during thrusting of the Glarus nappe – evidence from geochemical and stable isotope data. - *Schweiz. Mineral. Petrogr. Mitt.* 70: 77-82.
- Burkhard, M., Kerrich, R., Maas, R. & Fyfe, W.S. (1992): Stable and Sr-isotope evidence for fluid advection during thrusting of the Glarus nappe (Swiss Alps). – *Contrib. Mineral. Petrol.* 112: 293-311.
- Etheridge, M.A., Wall, V.J., Cox, S.F. & Vernon, R.H. (1984): High fluid pressures during regional metamorphism and deformation; implications for mass transport and deformation mechanisms. – *J. Geophys. Res.*, 89: 4344-4358.
- Sibson, R.H. (1990): Conditions for fault-valve behaviour. - In: Knipe, R.J. & Rutter, E.H., eds.: *Deformation mechanisms, rheology and tectonics*: Geol. Soc. (London), Spec. Publication 54: 15-28.