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Geochemical mapping of fault architecture and permeability structure of a detachment fault system

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The Tasna nappe in the Alps of eastern Switzerland is an ideal natural laboratory to attempt correlation of the geochemical fingerprints of multistage fluid flow with the evolving architecture of a major fault system. This system includes the Upper (UTD) and Lower (LTD) Tasna Detachments and represents a Jurassic ocean-continent transition (OCT) which is thought to have facilitated mantle exhumation during magma-poor continental break-up and opening of Tethys.

In this study we compare geochemical profiles (δ^{18}O, major- and trace elements) with the mapped fault architecture (Engström and Manatschal, in prep) and permeability structure of Caine et al. (1996). The profiles were measured normal to the detachment surface which is at z=0m and structurally downwards, into the mantle.

The UTD and LTD are late shallow structures which were active at greenschist to seafloor conditions and were accompanied by serpentinization of the mantle. The deformation related to the detachment faults in the OCT formed in the brittle field, although, on the scale of the fault zone, deformation was localized and behaved in a ductile manner. Low-temperature structures include fractures, serpentine and calcite veins, serpentinite cataclasites, foliated serpentinites, foliated serpentinite cataclasites and serpentine gouges. The distribution of these structures in the fault zone demonstrates that high strain was localized to a narrow "core", a zone approximately 1m thick beneath the fault surface (z=0-1m). Beneath the "core" a wide "damage zone" was found in which strain varies considerably but overall decreases with depth. "Protolith" or undeformed protolith rock was not found. However, after z=40-70m deformation decreases significantly and larger areas of undeformed rock increases considerably.

Oxygen isotope variation with depth and therefore distance from the LTD and the UTD can be correlated with fault architecture. In the fault "core" values are shifted towards

low δ^{18}O in the profiles. The "core" is also very well defined by variations in major- and trace elements, although its width varies from 1m to 5m between profiles. Thereafter there is an abrupt change in element concentration defining the boundary with the "damage zone". Enrichments of Al_2O_3, Fe_2O_3, Na_2O, Sc, V, Y and Yb occurs at z$\sim$0m at the upper "core" boundary on both LTD and UTD and might indicate upwards mechanical transportation of more aluminous material and/or mechanical mixing with the hanging wall. This zone is not visible in the field and can only be seen geochemically.

Compared with the "core", the "damage zone" shows both lower and higher δ^{18}O values in the UTD, where the pattern is irregular. The "damage zone" in the LTD-profile is, on the other hand, characterized by higher and constant values close to 8 ‰. The data fits very well with observations in the field. Whereas the "damage zone" associated with the UTD contains several high-strain cataclastic zones, the "damage zone" beneath the LTD is generally less deformed. Consequently, the strain distribution in the "damage zone" across the UTD is more varied and fluid flow channels or other local fluid pathways therefore existed. The "damage zone" may act as both a conduit and seal. The low δ^{18}O in the fault "core", on the other hand could either indicate fluid flow or (partial) preservation of peridotite signature due to low permeability and isolation from fluid, i.e. this zone was either very permeable or impermeable. However, it is clear that the oxygen isotope and element data show a clear permeability contrast between the fault "core" and "damage zone" at z=1-5m. From z=5-160m in the LTD-profile there is no significant change in geochemistry. Therefore we interpret the entire exposed mantle section $>$5m as a "damage zone". In the UTD-profile the extent of "damage" decreases with depth which correlates with a gradual decrease in δ^{18}O.

Studies from Tasna show that the fault architecture is well distinguished with both structural and geochemical methods. However geochemistry outlines the fault architecture in more detail than structural studies. Therefore a combination of structural and geochemical studies can successfully recognize and characterize the interaction between fluid flow and deformation in a fault zone.

References: Caine, J.S., Evans, J.P., Forster, C.B., 1996. Fault zone architecture and permeability structure. Geology 24, 1025-1028. Engström, A., Manatschal, G. What is the strain record of continental break-up? Insights from the Tasna and Iberia Ocean-Continent-Transitions. To be submitted to Journal of Structural Geology.