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Oblique normal faulting and veining in limestones at the brittle-ductile transition: examples from the Rawil Depression (SW Switzerland)

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We have investigated well-exposed natural examples of transtensional faulting at the brittle-ductile transition in limestones of the Helvetic and Ultrahelvetic nappes in western Switzerland. In the Rawil Depression between the Aar and Mont Blanc massifs, late oblique-normal faults are associated with veins, stylolites, cataclasites and mineralization on fault planes, which cross-cut a thick nappe-stacked basin and platform succession. This detailed field study has established the orientation and distribution of the faults, the fault geometries and kinematics, and the relationship between veining and faulting.
In the Rawil Depression, we distinguish three post-nappe sets of veins and oblique faults on the basis of their strike orientation: (1) NNW/NW, (2) WNW/W, and (3) ENE. Fault set (3) occurs mainly in the Rhône valley, where the fault planes are steep and show a dominant dextral strike-slip component. This set is associated with the Simplon-Rhône Fault, with activity probably throughout much of the Neogene and possibly into the Quaternary.
Fault sets (1) and (2) generally dip at a low to moderate angle to the SW and typically develop domino-like structures. The major faults in the Rawil area are spaced around 1 km and show similar features, whereas small-scale faulting is much more diffuse. Fault sets (1) and (2) are broadly coeval. Nevertheless, there are clear examples (e.g. along the Iffigsee Fault) of set (2) cross-cutting set (1), which establishes, at least locally, a chronological succession of faulting events. In places there is a transition from an initial ductile mylonitic fabric to cataclasite. Since faults of sets (1) and (2) developed across the ductile-brittle transition in limestones, shales and marls, they may represent fossil seismoge¬nic zones in rocks with high pore-fluid pressure, corresponding to the current depth of active seismic activity around 7-12 km under the Rhône valley. At similar depth in the Apennines major earthquakes occur in carbonates, so the exposed fossil fault structures studied here may also be relevant to this important example of active seismicity.
Veins are very common in the Rawil area and developed throughout the deformation history, ranging from pre- to syn-folding to coeval with the later transtensive faulting. A progressive increase in the number and size of veins is observed in the more competent lithologies approaching the main damage zone of oblique fault sets (1) and (2), implying increased fluid circulation toward the fault zones. Pressure-solution, often concentrated on stylolytes, is also active until very late stages of faulting and veining. Veins in the damage zones in limestones are sheared into the initial mylonitic zones and form a major component, together with the mylonites, in the subsequently developed cataclasites. We can distinguish therefore the activity of slow processes (gradual crack-opening, fluid circulation and mineralization, pressure-solution, pre-seismic deformation, progressive vein interconnection) and fast processes (faulting, cataclasis, pulses of pore pressure, crack-propagation). The observed progressive emb-rittlement during fault development may be due to exhumation and cooling during faulting, higher strain rates, or increased pore-fluid pressures. Clasts of cataclasites within cataclasites establish that there have been repeated cycles of faulting resulting in cataclasis and sealing.
Away from the fault damage zones, crosscutting vein relationships and the bending of vein tails indicate a progressive counter-clockwise relative rotation of the stretching direction, from WSW toward S to SSE, which is consistent with the observed change from oblique slip to subsequent dip-slip on faults of sets (1) and (2). Overall, there is an almost 180°, generally (but not exclusively) counter-clockwise change in the stretching direction, from orogen-perpendicular stretching of reclined fold limbs during NW-directed thrusting, to orogen-parallel stretching during the dominant period of veining and oblique, transtensional faulting, to a late period of limited, more orogen-perpendicular extension.