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Architecture of a dolostone-hosted brittle-ductile fault: effects of the interplay between weakening and strain localization mechanisms

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Carbonates can remain mechanically strong under most upper crustal conditions, which is testified by the considerable number of moderate to large earthquakes associated with slip on carbonate-hosted faults. Yet, under certain environmental conditions carbonates decompose into mechanically weak minerals, with major consequences for a fault's rheological behavior. We combine structural analysis with petrography, geochemistry and K-Ar dating of synkinematic illite to investigate the processes that control the initial weakening of dolostone and the subsequent strain localization within brittle-ductile faults, aiming at better understanding why some faults remain strong and seismogenic, while others evolve into weak, creeping systems.

The Kvenklubben fault (KF) is exposed in the Repparfjord Tectonic Window, northern Norway and is part of a compressional imbricate stack formed during Caledonian SE-directed nappe emplacement. It dips c. 40° to the NW and juxtaposes greenschist facies metabasalts in the hanging wall against chert-bearing meta-dolostones. The fault core is about 2.5 m thick and is composed of talc-bearing calc-phyllonites at the base and chlorite phyllonites at the top. Kinematic indicators show top-to-the SE thrusting, but also late localized top-to-the NNW extensional reactivation. The complex internal architecture of the fault results from multiple faulting episodes. K-Ar ages document that slip initiated in the lower part of the fault core and propagated upwards. The uppermost part of the fault was reactivated as a normal fault in the Mesozoic. Chlorite geothermometery shows that initial localization at the base of the fault core took place at 180-250 °C, whereas later peak Caledonian deformation occurred under higher temperatures (300-350 °C). This is also supported by sub-grain rotation recrystallization of quartz. Within the footwall dolostones an intraformational thrust fault developed sub-parallel to the main KF strand. Its fault core is significantly thinner (<10 cm) than the KF and is formed by cataclasite and discrete, thin (< 1mm) talc slip planes. Associated with this fault are sub-vertical stylolites and calcite and quartz-calcite veinlets, all of which are cross-cut by the discrete slip planes.

We conclude that during the early stages of compression strain was accommodated mainly by pressure-solution of the host dolostone, cataclasis localized along geometric irregularities of the fault plane and by formation of optimally oriented tensional fractures. During ongoing deformation fluids caused dolomite to start reacting with quartz and decomposing into calcite and talc. Phyllosilicate-rich levels imparted a pervasive mechanical anisotropy to the rock and thereby accommodated viscous creep along distinct shear planes. The intraformational fault locked before developing a significant foliated fault core, whereas the KF core became progressively thicker with increasing shear strain. Continued localization and weakening of the KF reflects the progressive juxtaposition of metabasalts in the hanging wall. The combined effect of dolomite decarbonation in the footwall and hydration reactions in the hanging wall formed synkinematic, authigenic chlorite and illite within the phyllonitic fault core. The upward-decreasing ages of deformation indicate that the fault zone thickened upward as an effect of strain hardening at the base and continued fluid-rock interaction-induced weakening at the top.