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Damage, permeability and sealing processes of an exhumed seismic fault zone; The Gole Larghe Fault Zone, Italian Alps

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The Gole Larghe Fault Zone (GLFZ) in the Italian Southern Alps has been extensively studied as a natural laboratory for seismic faulting. Ancient seismicity is attested by the widespread occurrence of cataclasites associated with pseudotachylytes (solidified frictional melts) formed at 9 - 11 km depth in tonalite host rock at ambient temperatures of 250 – 300˚C. Here we sythesise systematic meso- and micro-structural data with permeability and ultrasonic velocity laboratory measurements from samples collected along fault transects, in order to define the damage structure, fluid flow properties and sealing history of a seismogenic source in the crystalline basement.

The GLFZ (∼600m wide) and surrounding tonalite wall rocks have a broadly symmetric damage structure and can be divided in to five distinct zones, distinguished by large variations in fracture density, distribution of pseudotachylyte, volume of fault rock materials, and microfracture sealing characteristics. The ∼80 m wide central zone has pervasive fracture damage in the form of dense cataclastic fault-fracture networks, and is bordered by two unusually (2 m) thick and continuous cataclastic horizons. This central zone is flanked by outer damage zones ∼250 m wide where the fracture density is lower, and individual fault surfaces surround relatively intact blocks of tonalite. In the southern damage zone, macroscopic fracture density (faults + joints) increases gradually from background wall-rock values towards the central zone where it remains relatively high throughout. The boundary between the wall rocks and the southern damage zone is defined by an abrupt transition from joints to cataclasite- and pseudotachylyte-bearing faults. Fracture density drops off sharply within the northern damage zone. Within and immediately surrounding the central zone, the syn-tectonic sealing of both micro- and macro-fractures by epidote, K-feldspar, and chlorite minerals was pervasive, resulting in low permeabilities ($\sim 10^{-21} m^2$). Here the fault-fracture networks were associated with pervasive fluid-rock interaction, defining a c. 200 m wide alteration zone bounded by fluid infiltration fronts with irregular geometry. Fracture density is lower in the damage zones, and partial healing results in higher sample permeabilities ($\sim 10^{-18} m^2$). Laboratory P-wave velocities correlate well with both the architecture and sealing characteristics of the fault zone. P-wave velocities are uniformly high (up to 6km/s) both within and immediately surrounding the central zone, consistent with pervasive sealing of fractures and low sample permeability. In the damage zones P-wave velocities are much lower (3-4km/s) due to the presence of open fractures.

Our field and laboratory measurements highlight the close interplay between fracturing, fluid flow, mineralization, and the strength of large fault zones. Importantly, they demonstrate that seismic wave velocities and permeability depend on both fracture density and the degree of fracture sealing, which has implications for the interpretation of active fault zone structure based on geophysical data.