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Hydraulically-induced earthquake swarms: Geological evidence from the Adamello Batholith in the Southern Italian Alps.

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Earthquake swarms are often characterised by clusters of seismic events with highly variable earthquake focal mechanisms, irrespective of whether or not they are associated with a main shock event. Our current understanding of how such events manifest themselves in the geological record is based largely on the Hill (1977) and Sibson (1996) 'fracture mesh' models. Whilst these simple models are theoretically sound for homogeneous isotropic rock masses, they do not account for the effects of variably oriented pre-existing mechanical anisotropies and how these may lead to a more complex fracture evolution and geologic strain.

Interconnected networks of faults and veins filled with zeolites and other hydrothermal minerals are widespread in many orogenic terrains, including deformed granitic plutons and regions of metamorphic basement. Typically the fracture fills formed late in the tectonic history, at relatively low temperatures (e.g. < 200°) and depths (< 7 km), and appear to represent a late phase of fluid flow and mineralisation developed during the final stages of exhumation.

Here we focus on zeolite-bearing mineralised fractures associated with the Gole Larghe Fault Zone in the Southern Italian Alps. These mineralized veins, faults and fracture meshes are consistently found associated with variably orientated pre-existing structures and display strong evidence of elevated pore-fluid pressures. They initially formed as tensile/hybrid fractures and, once local rock cohesion was lost, accommodated small magnitude (<a few cm) shear displacements. The cyclic reactivation of these structures leads to a complex sequence of stress loading and reactivation of widely distributed pre-existing structures (contacts, joints, shear zone fabrics, faults). The differing orientations of the pre-existing structures relative to the far-field and near-field stresses lead to the simultaneous development of interlinked reverse, strike-slip and extensional faults. The kinematic complexity and cyclic nature of the hydraulically-induced fracturing provides compelling evidence that the mineralised fracture systems represent a geologic manifestation of foreshock-aftershock swarm development. Our proposal highlights the key role of crustal fluids during earthquake swarm development and the inherent geometrical complexities that may result from the reactivation of pre-existing anisotropies in rocks.