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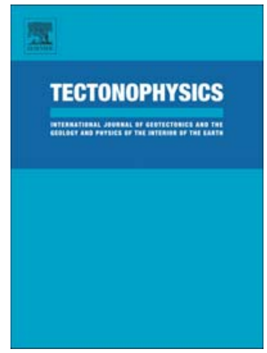

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How Vein Sealing Boosts Fracture Widening Rates – The Buckling-Enhanced Aperture Growth Mechanism for Syn-Tectonic Veins

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Abstract
The paper introduces the mechanism of buckling-enhanced aperture growth for syn-tectonic veins that formed in simple-shear dominated kinematic frameworks in the middle or lower crust. Apart from the well understood concepts of fracture widening driven by effective tensile stresses, buckling-enhanced fracture aperture growth relates widening to active outward buckling of more viscous incipient cement layers precipitated as hydrothermal minerals for the pore fluid on the walls of juvenile syn-tectonic veins, driven by fracture-parallel compressive creep strain in the host rocks. Thus, the mechanism proposed here follows similar principles as tectonic folding, although important differences exist. Inspired by the structural record of low-aspect ratio veins exposed in HP / LT metamorphic rocks cropping out on south Evia island, Greece, generic numerical models are calculated to study development of buckling instabilities in such incompletely cemented veins and their impact on aperture growth rates. The models indicate (1) that aperture growth rates increase with increasing viscosity contrast between the host rocks and the cement layers, (2) an increase in the thickness of the cement layers cause acceleration of aperture growth, (3) that support of restraining forces at the vein tips offered by the host rocks against buckling of the cement layers cause fully compressive states of stress ahead the fracture tips, and (4) that fracture aperture growth is possible against fully compressive fracture-normal stresses. The buckling-enhanced vein aperture growth mechanism yields important implications for the maintenance and decay of fracture-bound permeability and for the mechanical state of the middle and lower crust in seismically active regions.

1. Introduction

Veins are ubiquitous in crustal rocks. The process of vein emplacement comprises initiation, propagation, and arrest of fractures, followed by a single or multiple increments of fracture aperture growth and sealing by deposition of cement layers on the vein walls that precipitate as hydrothermal minerals from the pore fluid percolating through the cavity (Durney & Ramsay, 1973). Veins represent fossilized fluid pathways that controlled transient fluid flow and mass and heat transport in sedimentary (e.g. Hilgers et al., 2006) and metamorphic rocks (e.g. Oliver & Bons, 2001) in the geologic past. Their hydraulic conductivity depends on the fracture length (Olson *et al.*, 2009), and on the effective aperture delineated by the fracture aperture reduced by the thickness of the cement layer, which is controlled by the ratio of the rates of fracture widening and sealing (Lander & Laubach, 2015). Processes involved in sealing, and the resulting microstructures have been subject to numerous detailed studies on natural veins (Durney & Ramsay, 1973), analogous (Hilgers *et al.*, 2004;

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