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A review of porosity-generating mechanisms in crustal shear zones

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Knowledge of the spatiotemporal characteristics of permeability is critical for the understanding of fluid migration in rocks. In diagenetic and metamorphic rocks different porosity-generating mechanisms contribute to permeability and so influence fluid migration and fluid/rock interaction. However, little is known about their relative contributions to the porosity architecture of a rock in a tectono-metamorphic environment. This presentation reviews porosity-generating mechanisms that affect fluid migration in shear zones, the most important crustal fluid conduits, in the context of the tectonometamorphic evolution of rocks.

Mechanisms that generate porosity can be classified in a) those that involve the direct action of a fluid, b) processes in which a fluid partakes or that are supported by a fluid or c) mechanism that do not involve a fluid.

a) Hydraulic fracturing, where it happens through the formation of tensile fractures, occurs where pore fluid pressures equalize the combined lithostatic pressure and strength of the rock (Etheridge et al., 1984, Cox & Etheridge, 1989, Oliver, 1996). Here an internally released (devolatilisation reactions, e.g., Rumble, 1994, Hacker, 1997, Yardley, 1997 and references therein) or externally derived (infiltrating from metamorphic, magmatic or meteoric sources, Baumgartner et al., 1997, Jamtveit et al., 1997, Thompson, 1997, Gleeson et al., 2003) fluid directly causes the mechanical failure of a rock.

Where a fluid is in chemical disequilibrium with a rock (undersaturated with regard to a chemical species) minerals will be dissolved, generating dissolution porosity. Rocks ‘leached’ by the removal of chemical components by vast amounts of fluid are reported to lose up to 60% of their original volume (e.g., Kerrich et al., 1984, McCaig 1988). Dissolution porosity is probably an underrated porosity-generating mechanism. It can be expected along the entire metamorphic evolution, including diagenesis (Higgs et al., 2007) and weathering (e.g., Holdren & Berner, 1979, Berner & Holdren, 1979).

b) Fluids contribute to replacement porosity by acting as agents providing chemical components for replacement reactions (e.g. cation exchange in feldspars). Porosity results from changes in molar volume between reactants and products and dissolution (Walker et al., 1995, Putnis, 2002, Putnis et al., 2007). Porosity generated this way is restricted to individual mineral grains, however, these may make up significant proportions of a rock.

Where a fluid is involved in metamorphic reactions volume changes arise (Hacker et al., 1997). During devolatilisation reactions these are negative; porosity is generated directly as the reaction progresses (Rumble et al., 1982, Oliver et al., 1990, Rumble 1994). During rehydration or recarbonation the volume changes are positive, which creates stresses on the grain scale which potentially cause fracturing of individual grains (Jamtveit et al., 2007).

A mechanical process generating porosity is creep cavitation, which is associated with viscous grain boundary sliding. Cavities form at stress concentrations in crystals and along their boundaries as well as at triple junctions in grain aggregates essentially by diffusion, which is supported by the presence of a fluid (Dyson et al., 1976, Kassner & Hayes, 2003, Rybacki et al., 2008, Fusseis et al., in review).

c) Where rocks are subjected to temperature changes (e.g., during burial, contact metamorphism or exhumation) individual minerals expand or contract heterogeneously (e.g., Fei, 1995). Anisotropic thermal expansion creates stresses on the grain scale resulting in cracks, which form porosity without the evolvement of a fluid (e.g., Sprunt & Brace, 1974, Kranz, 1983).

Despite these mechanisms have been described in the literature, they were rarely discussed in the context of their potential to affect permeability (with the exception of hydraulic fracturing). However, all of them commonly occur in crustal shear zones. It seems reasonable to assume that the total porosity in shear zones is the sum of porosities generated by all of these mechanisms, and that the individual porosities have different effects on permeability. We propose that a fundamental understanding of the porosity evolution in a shear zone can be derived from

an assessment of the stress-temperature-fluid/rock chemistry-time path during the tectonometamorphic history of a rock. In this contribution we present a first evaluation of typical porosity-permeability evolutions. We furthermore present a new generation of numerical experiments that allows the quantitative assessment of the roles of the thermal, chemical and mechanical generation of porosity and their feedbacks on the evolution of shear zones.

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