Final Technical Report

Collaborative Research: Evolution of pore structure and permeability of rocks under hydrothermal conditions

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Project Summary

The physical and transport properties of porous rocks can be altered by a variety of diagenetic, metamorphic, and tectonic processes, and the changes that result are of critical importance to such industrial applications as resource recovery, carbon dioxide sequestration, and waste isolation in geologic formations. These inter-relationships between rocks, pore fluids, and deformation are also the key to understanding many natural processes, including: dynamic metamorphism, fault mechanics, fault stability, and pressure solution deformation. Here, we propose work to investigate the changes of permeability and pore geometry owing to inelastic deformation by solution-transfer, brittle fracturing, and dislocation creep. The work would study the relationship of deformation and permeability reduction in fluid-filled quartz and calcite rocks and investigate the effects of loading configuration on the evolution of porosity and permeability under hydrothermal conditions. We would use a combination of techniques, including laboratory experiments, numerical calculations, and observations of rock microstructure. The laboratory experiments provide mechanical and transport data under conditions that isolate each particular mechanism. Our apparatus are designed to provide simultaneous measurements of pore volume, permeability, axial and volumetric strain rates while being loaded under isostatic or conventional triaxial loading. Temperatures up to 1400 K may be obtained, while confining pressures and pore pressures are maintained independently up to 500 MPa. Observations of the structure will be made with standard optical, scanning electron, and laser confocal scanning optical microscopes. The data obtained will be used to quantify changes in surface roughness, porosity, pore dimensions, and their spatial fluctuations. The results of the experiments and the image data are then used in network, finite-difference and other numerical models to verify the

validity of experimentally established relations between permeability and other rock properties.

Final Report (July 2006-June 2007, WHOI): Effect of shear localization on initiation and growth of compaction bands

The pore structure and transport properties of rocks, including fluid permeability and electrical conductivity, can be altered by a wide variety of diagenetic, metamorphic, and tectonic processes. Our goal is to provide better understanding of the interrelationships among permeability, mechanical properties, and the pore shape, under hydrothermal conditions, in mineral aggregates, with and without reactions. The results from July 2006 to June 2007 are summarized below.

Compaction in porous sedimentary rocks involves Hertzian fracture facilitated grain crushing and pore collapse as well as intergranular pressure solution. Recent field and laboratory studies have demonstrated that different modes of strain localization occur in porous sandstones at different stress conditions and that each deformation mode induces significant permeability changes. In particular, shear localization generally provide conduits for pore fluid discharge, whereas compaction bands generally induces significant permeability reduction and provides hydraulic barriers, enabling the development of pore pressure excess.

In many geological settings, different modes of strain localization coexist. Because most natural environments include preexisting heterogeneities that are reactivated during basin evolution or tectonic loading, it is important to determine the type of dynamic hydromechanical behavior expected in a rock that includes a pre-existing fault and is loaded at conditions where an intact porous rock would fail by compaction localization. To address this question, we performed a set of two-step experiments. First, samples of porous Bentheim sandstone samples were deformed at an effective pressure of 5 MPa until shear localization developed in each. Second, each sample was reloaded and deformed at effective pressures of 5-200 MPa. Under 5 MPa confining pressure, the samples showed stable sliding along the pre-existing shear-band. With increasing confining pressure, compaction localization occurred in the pre-faulted rocks. The compaction bands generally initiated at the pre-existing fault and gradually developed into a series of bands that intersect the fault (Figure 1). The experimental data also indicate that the presence of a preexisting shear fault can be very effective in enhancing the local stress and activating various failure modes. The interaction between shear localization and compaction localization significantly alters the pore structure and thus plays an important role in pore pressure excess and earthquake generations in seismogenic zone.

Figure 1 Differential stress (top) and porosity reduction (bottom) versus axial strain for pre-faulted Bentheim sandstone samples deformed at effective pressure of 50, 100, 150 and 200 MPa (from left to right), respectively. Acoustic emission (AE) activity was also measured during deformation (curves in magenta). Micrographs of deformed samples indicate that with increasing confining pressure, multiple compaction localization bands are developed across the pre-existing shear band.

Reference:

Zhu, W., (2007), Faulting Related Initiation and Growth of Compaction Localization in Porous Sedimentary Rocks, *EGU Meeting Abstr.*, Vienna, April 15-19, 2007.