The localized to ductile transition in porous rocks: experimental investigation on Volvic basalt.

Gabriel Meyer, Marie Violay, and Michael Heap

1Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland (gabriel.meyer@epfl.ch)
2Université de Strasbourg, CNRS, Institut Terre et Environnement de Strasbourg, UMR 7063, 5 rue Descartes, Strasbourg F-67084, France

With increasing depth, the rheology of rocks gradually transitions from brittle (localized, fractures) to ductile (homogeneous flow). Recently, it was demonstrated that, in the crust, the transitional zone might extend to shallower depth than previously thought (2km) with a zone where the deformation regime can be both localized and ductile (the LDT). In this regime, both extremely localized (fault slip) and distributed (cataclastic flow and/or plasticity) deformation may occur concurrently. This observation had great importance since the ductile regime is commonly thought to be aseismic and to mark the maximum depth of earthquake nucleation.

However, this observation was made experimentally in non-porous rocks; porous rocks on the other hand display an additional characteristic in that their ductile behaviour may consist in the formation of compactions bands which greatly impact the behaviour of porous reservoirs and systems (e.g., volcanoes). Moreover, ductile rocks are commonly believed to be aseismic, the potential coexistence of both ductile and localized regimes in reservoir rocks might therefore have great implications for induced seismicity mitigation.

Here, we present three conventional triaxial experiments on Volvic basalt (homogeneous, isotropic, fine grain). We deformed cylindrical cores equipped with strain gages at 5MPa and room temperature until a sample-scale fracture nucleated and propagated. Subsequently, we increased confining pressure step wise, loading the sample every step until 0.2% irrecoverable strain was accumulated in the sample. In between confinement steps, the differential stress was unloaded. A pair of Linear Variable Differential Transformers (LVDTs) was used along with the strain gauges to accurately monitor the deformation behaviour of the samples.

We show that Volvic basalt transitions from being purely localized to being purely ductile over a rather narrow pressure range from 40 to 80 MPa. The transition initiates when the frictional strength of the fault equates the yield strength of the bulk and terminates when it becomes greater than the maximum strength of the bulk. In this pressure range, deformation is initially accommodated in the bulk (most likely by compaction bands) until strain hardening eventually leads to fault reactivation. Once both fault sliding and bulk flow are active, the partitioning of strain between the two can be described by the same empirical ratio as that already established for non-porous rocks, i.e. \((\sigma_f - \sigma_y)/(\sigma_{flow} - \sigma_y)\).
We conducted a second experiment at a faster strain rate ($10^4$ s$^{-1}$) and show that faster deformation promotes brittle behaviour which pushes the LDT to greater confinement (i.e., greater depth).

Additionally, we conducted a similar experiment in the presence of water. In this case, the LDT occurs at lower confinement, showing that, fluids, by promoting ductile processes such as stress-corrosion, bring the LDT to shallower depth.

Our results are crucial for the understanding of reservoirs where ductile deformation (compaction bands) and induced earthquake mitigation have to be finely tuned.