P09

Laboratory Investigation of Shear and Compaction Bands - Compaction and Dilation Identification

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SUMMARY

Shear bands and compaction bands have been obtained in Vosges Sandstone cylinders tested in the laboratory under confining pressures of 30 to160MPa. The specimens have been heavily instrumented under load and subjected to pre- and post-deformation ultrasonic and Xray tomography. The primary purpose of this study is to add a detailed knowledge of the small-scale development of permanent dilational and compactional strains to our understanding of the mechanisms operative in shear/compaction band development and associated mechanical behaviours. This will inform predictions of changed fault zone permeability and lead to better prediction of fault seal or fault leakage under subsurface conditions. Samples were strain gauged and acoustic emissions were also recorded for some samples. Most were subjected to pre- and post-deformation ultrasonic and Xray tomography. Provisional assessment of the shear bands shows that material has densified but the velocities have also decreased. Open fractures are also seen on the processed Xray images. The samples show bulk compaction. The compaction band studies are less advanced, with acoustic emissions showing development of separated discrete bands that may have a shear component. This is an ongoing study and more robust conclusions, including thin section work, are expected by the Meeting.

Knowledge of the micromechanisms of fault zone or shear zone development is a crucial element in the understanding of fault sealing and fault leakage. In terms of sealing or leakage of subsurface faults, what matters is how the permeability of the damaged rock has changed and if (and where) permeability reduction has changed enough to significantly retard or enhance fluid flow under the current saturation and pressure conditions.

Surface observation of fault rocks strongly suggests a complex fabric even in small shear zones and there is abundant subsurface evidence for both fault seal and fault leakage in what otherwise appear to be very similar conditions. Development of dilation and compaction in damaged rock is one of the crucial elements of sealing/leakage. But surface analogues are not a good guide to their occurrence and distribution because of the uplift overprint. Geomechanical simulations can predict distributions of dilational and compactional volumetric strains, including dilation down to 4 or 5 km. But such simulations are difficult to ground-truth. In this study we investigate the evolution of shear and compaction bands in the laboratory under triaxial compression with confining pressure values relevant to typical subsurface conditions. We use a combination of under-load and bench-top investigations in order to link the development of the localised strain features specifically with patterns of dilation and compaction and the lab. conditions under which they occur .

Vosges Sandstone cylinders have been deformed under confining pressures between 30MPa and 160MPa with deviatoric loads sufficient to induce the development of shear bands or compaction bands, depending on the confining pressure used. Figure 1 shows a p-q (mean stress – deviatoric stress) curves for 4 tested specimens that developed shear bands.

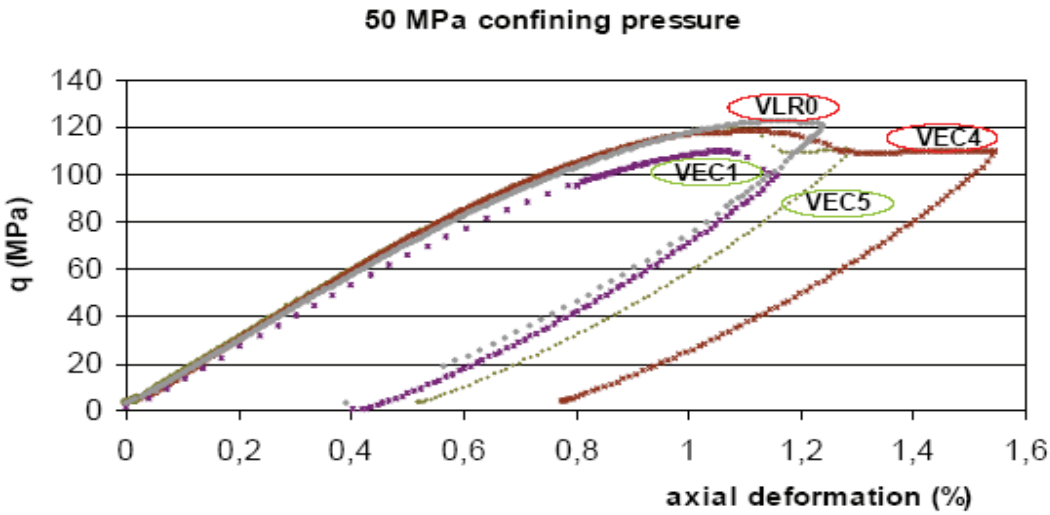

Figure 1 *Mean and deviatoric stress plots for four rock cylinders deformed at a confining pressure of 50MPa under deviatoric loads of approximately 120MPa.*

Two flattened surfaces were cut on each of the cylindrical specimens to facilitate the bench-top ultrasonic velocity measurements, using multi-element ultrasonic transducer arrays, for tomographic reconstruction of velocities. Each specimen was then notched on these flattened surfaces to encourage development of deformation bands (shear or compactional) in a particular plane (fig. 2). Some rock cylinders were instrumented to determine strain states, and acoustic emissions during loading have been recorded.

The Vosges Sandstone cylinders were also imaged using X-ray tomography before and after deformation (fig. 3). Provisional results show that, for the lower confining pressure (50 MPa) experiments where shear bands developed, densification occurs in the shear band region and velocities across that region are decreased. This does not appear to be a character of the pre-deformed rock because thin sections taken from rock adjacent to the cylinders show no obvious textural or mineralogical changes in density in the shear band. Later in the study thin

sections of the deformed samples will be used to identify what role grain breakage, sliding and rotation play in the development of the shear band and potentially how this is manifest as a distribution of dilation and compaction – and so also as changes in permeability

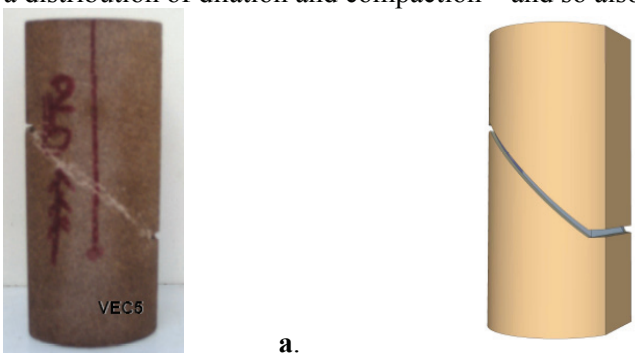

Figure 2 *(a) Photograph of Vosges Sandstone deformed at a confining pressure of 50MPa and a deviatoric load of 120MPa. Photo also shows geometry of two parallel planed-off vertical slices and notches to encourage planarity in the resulting shear band. (b) Schematic of cylinder geometry with notches and schematic shear band.*

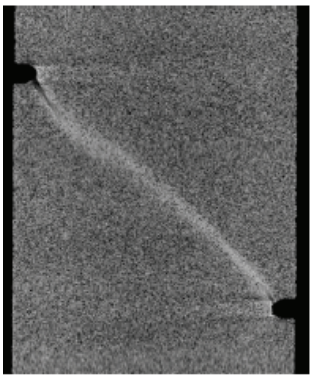

Figure 3 *High-resolution (voxel size29 microns,) Xray reconstruction from 65 vertical slices showing the central region of sample VEC5. Note lighter appearance (densification) of the main shear band plus darker regions extending from each notch that correspond to open fractures. Note also that the shear band could be two separate slightly en-echelon band.*

The 120 and 160 MPa confining pressure experiments developed low-angle compaction bands, possibly with a small component of shear. Provisional results show a dominance of compaction from the initial strain calculations but the X-ray and ultrasonic tomography results are still to be assessed. Combined with the shear band experiments they should help provide a better geometric and mechanistic understanding of the nature and distribution compactional and dilational strains for subsequent use in estimating regions of enhanced and degraded permeability if fault zones.

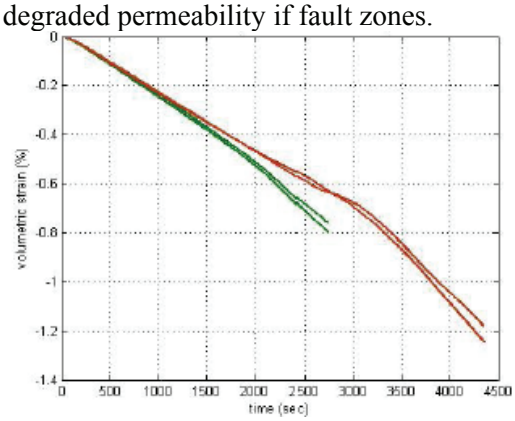

Figure 4 *Volumetric strain for cylinder deformed at 160MPa.*