Novel and Conventional techniques for analyzing the petrophysical properties of deformation bands

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Porosity and permeability changes in deformation bands are commonly quantified using relatively low-resolution techniques, which invite host rock bias in measurement and inevitably underestimate the potential of these structures as fluid barriers. High-resolution petrophysical measurements of these discontinuities in relation to their variable microstructures, reported here, are critical in their incorporation into advanced reservoir simulation models.

Deformation bands are localised but laterally extensive sites of extreme porosity and permeability reduction, particularly in high porosity sandstones (Figure 1). In fact, permeability reductions of up to 3 orders of magnitude have been reported by Antonellini and Aydin, (1994). However, deformation bands in clay-rich sandstones may have a comparable flow barrier potential to certain sedimentary structures. This is because their porosity and permeability is not radically different to the host sandstone, which may have already low depositional porosities and permeabilities (Figure 2a). In the case of cemented deformation bands, cements are particularly effective in structurally tightening deformation bands in high porosity sandstones but have little effect in low porosity sandstones (Figure 2b).

In this study, petrophysical variation between some deformation bands and their host sandstones is investigated using a variety of novel techniques including image analysis porosimetry and pressure decay profile permeametry (PDPK). This latter is useful in the characterisation of deformation band permeability as it is effective in measuring permeabilities as low as 0.001 mD and high resolution (<5 mm) permeability profiles of rock surfaces can be produced.

These results are compared to a suite of conventional measurements; helium porosimetry, mercury injection capillary pressure (MICP) analysis and nitrogen permeametry.

Methodology

Core plugs for helium porosimetry and nitrogen permeametry were taken through zones of deformation bands and cut to separate the host rock from the deformation bands. Plug offcuts were subjected to mercury injection capillary pressure (MICP) analysis and used in the preparation of polished sections.

Thin-sections of deformation bands impregnated with a blue epoxy dye to highlight the pore spaces were prepared for image analysis. Image analysis software was used to separate porous areas represented by blue dye from matrix areas using an intensity cut-off. Porosity values were obtained for 6 regions across the field of view and high-resolution porosity profiles produced. The pressure-decay profile permeameter of Jones (1992) was used in the measurement of permeability anisotropy of slabbed surfaces containing deformation bands. The pressure-decay of nitrogen gas through the rock is used to calculate a slip-corrected (klinkenberg) permeability at a given position and permeability contour maps of 2D surfaces are then plotted (Ogilvie *et al*. 2000).

Results and discussion

Table 1 illustrates that for clay-rich and cataclastic deformation bands, considerable differences are observed in conventional porosity and permeability values relative to the host rock. The MICP technique specifically measures the deformation band porosity hence there is a greater difference in porosity values for the sample pairs than is the case with the helium measurements.

The most significant differences in MICP porosities between sample pairs are for the cataclastic deformation bands relative to the host sandstone, where up to 50% reduction is observed (Table 1). By contrast, the reduction in porosity in clay-rich deformation bands relative to the host sandstone is no greater than 25% (Table 1, Figure. 2a). Furthermore, there is less contrast in irreducible water saturation (S_{wi}) values between clay-rich deformation bands and their host than between cataclastic deformation bands and their host (Table 1). This illustrates a greater difference in fluid storage capacities for the latter samples. There is a 1 order of magnitude reduction in permeability in plugs containing cataclastic deformation bands (relative to the host) compared to those containing clay-rich and cemented deformation bands where the values are very similar to the host (Table 1).

An example of image analysed porosities for a deformation band relative to the host sandstone is shown in a porosity profile in Figure 3. On the accompanying thin-section map, porosity is white and the solid portion of the rock is black. Detailed porosity maps such as these document a 75% reduction in porosity for the cataclastic deformation bands

(Figure. 3, Table 1) and a reduction of 50% into the clay-rich deformation bands from a lower host rock porosity (Table 1).

The PDPK profiles show dark red regions of low permeability coinciding with deformation band zones on the accompanying images (Figure 4). Lighter contours representing higher permeability characterise the host rock. In the highly porous sandstones studied there is a mean reduction of 4 orders of magnitude in PDPK permeability in the deformation band compared with the permeability of the immediate host rock (Figure 4a). In contrast, a mean permeability reduction of up to 3 orders of magnitude characterises the clay-rich deformation bands relative to their host (Figure 4b). In both cases, an increase in grid spacing (and hence the resolution) from 1 cm to 5 mm more accurately constrains the permeability of the deformation band zone and host rock pod. In the highly porous sandstones, the dark red contoured regions coincide with the dark strands on the core image, the regions of most advanced grain communition (Figure 4a). These tightly anastomosing deformation bands enclose a host rock pod, which has slightly higher permeability than the deformation band zones. The increased resolution illustrates that in the clay-rich sandstones, dark, fine-grained laminae have a comparable flow-barrier potential to the deformation bands (Figure 4b). Even in clay-rich sandstones, the novel measurements show a greater difference than the conventional measurements in porosity and permeability values between host rock and deformation band.

Conclusions

Deformation bands are particularly effective baffles to flow in high porosity reservoir sandstones. Pressure Decay Profile Permeametry (PDPK) and image analysis porosity techniques used in this study have the advantage of providing high resolution deformation band- specific values and not a mean of deformation band and host rock properties as is commonly the case with conventional measurement techniques. In tandem with mercury injection analysis, novel results such as these are crucial in reducing the uncertainty regarding the role of deformation bands in fault sealing, and such data integrated with macro-scale fault properties is important input into advanced reservoir models.

References

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Table 1. Petrophysical data for a range of deformation bands and their host sandstones using conventional core analysis.

Deformation band type	S_{wi} (%)	Porosity (%)			Nitrogen-technique permeability (mD)
	MICP	Helium	MICP	Image analysis	
Cataclastic	65	14.1	10.3	4-10	1324
Host rock	12.2	20.7	19.5	10-21	45.74
Clay – rich	62.7	10.6	11.1	5-9	0.49
Host rock	46.9	10.8	14.9	9-16	0.94

Figure 1: (a) A compound zone of deformation bands (centre, left to right) in highly porous sandstones. (b) Compartmentalisation of porous sandstones by barite cemented deformation bands.

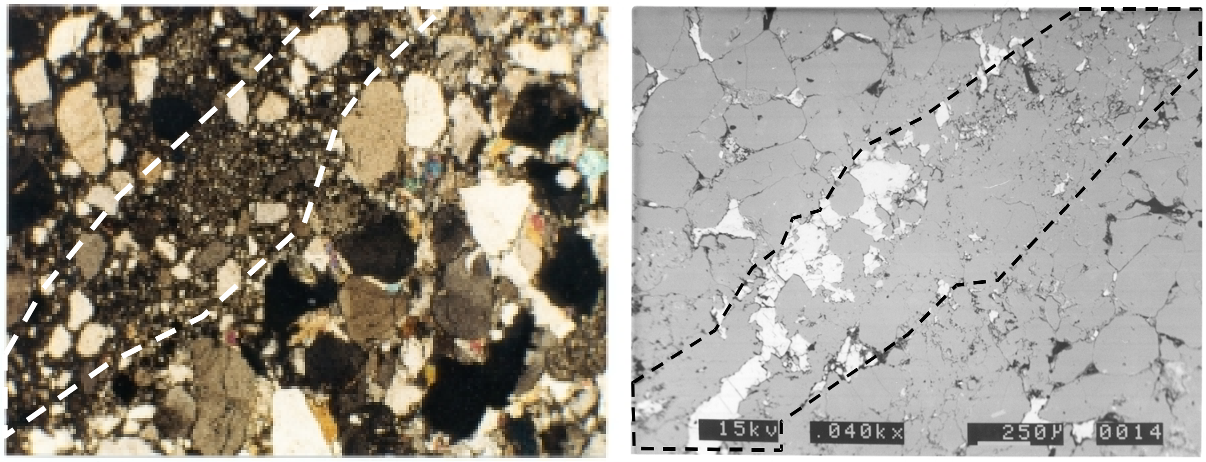

Figure 2: Images of clay-rich (a) and cemented (b) deformation bands in sandstones.

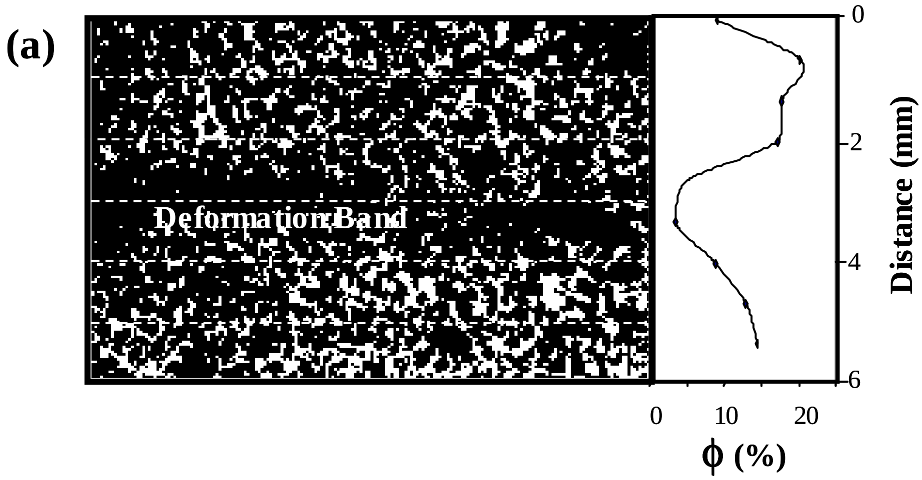

Figure 3. Thin-section image analysis porosity of deformation band and host rock

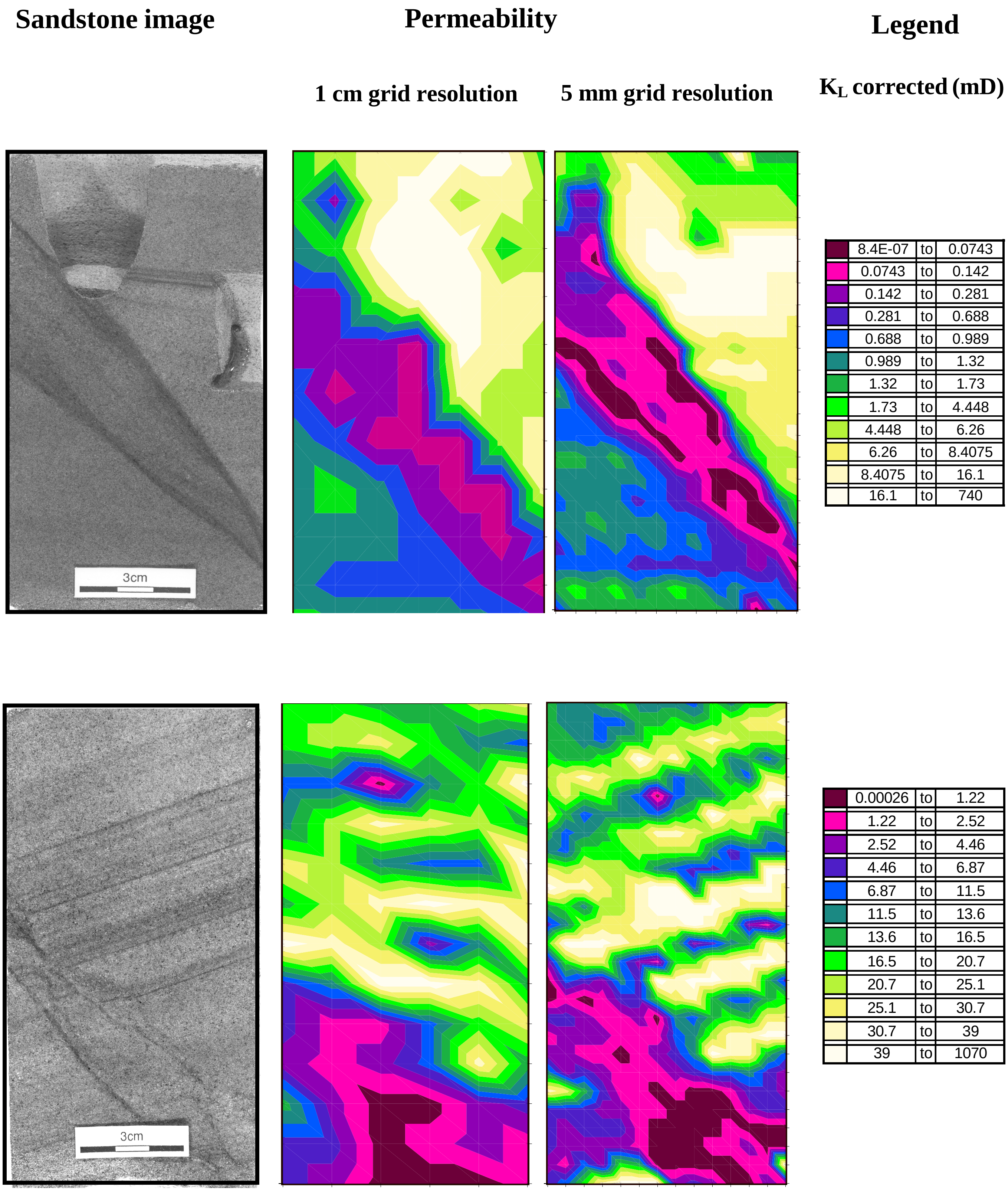

Figure 4: Pressure decay profile permeametry (PDPK) maps of cataclastic (a) and clay-rich (b) deformation bands