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Anisotropy in the Petrophysical Properties of Deformation Bands

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SUMMARY

Microscopic examination of deformation bands reveals that the internal microstructure of different types of deformation bands varies along the bands at micro-scale. The variation can result in variations in petrophysical properties such as porosity and permeability. We have quantified this variation by utilizing our developed image-processing method and found out that porosity can vary substantialy and permeability by up to two orders of magnitude along a single deformation band.

Introduction

The process of faulting in porous sandstones involves the formation of millimetre-thick strain localization structures, known as deformation bands. They are frequently addressed to perturb the permeability structure of petroleum reservoirs and aquifers. The reported permeability reductions across deformation bands vary from one to several orders of magnitude. The internal permeability structure of deformation bands is difficult to assess by means of classical mini-permeameter and laboratory plug measurements. However, it is possible to capture the microstructural heterogeneity along as well as across deformation bands by means of microscopic and SEM image analysis (Torabi et al. 2008), and this forms the basis for the present results.

Methodology

High-resolution Backscattered electron (BSE) and optical microscope images of thin sections of faulted sandstones have been studied, and grain size distributions have been analysed from binary BSE images using ImageJ software. The gain size distributions are presented as Exceedence Frequency (EF) plots (Torabi et al. 2007), and porosity and permeability have been estimated using our developed image processing method, which utilizes spatial correlation functions and a modified version of Kozney-Carman relation (Torabi et al., 2008). In this method, a binary image is made from a selected BSE image by choosing an appropriate threshold. The binary image $f_{(i,j)}$ is represented by a $M \times N$ matrix, and the one-point correlation function (Eq.1) is applied to the binary image (S_1). This function gives information about the volume fraction of the pore and grain phases, so that the porosity (ϕ) can be estimated through this function:

$$S_1 = \phi =< f_{(i,j)} >= \frac{1}{M \times N} \sum_{ij} f_{(i,j)} \qquad (1) \qquad i = 1,2,...M; \qquad j = 1,2,...N$$

The next step is to calculate the pore–pore two-point correlation function $S_2(x,y)$ for the binary image by using Eq. 2. This function examines the probability that two points with a specified distance apart (a line) are both in pore phase (Berryman, 1998):

$$S_2(x,y) =< f_{(i,j)} f_{(i+x,j+y)} >= \frac{1}{M \times N} \sum f_{(i,j)} f_{i+x,j+y)} \qquad (2)$$

The specific surface area (s, i.e. the total area of the pores divided by total volume of the porous media; Eq. 3) of the pore–grain interface is then calculated from the two-point correlation function (Berryman, 1998):

$$S_2'(0) = -\frac{s}{4} \qquad (3)$$

We calculated permeability by using a modified version of the Kozeny-Carman relation (Eq. 4), where k is permeability, ϕ is porosity and c is a constant related to pore geometry that is equal to 2 for porous materials assuming circular cross section for pores, and F is the formation factor and exponentially relates to porosity (Archie, 1942):

$$k = \phi^2 / cFs^2 \qquad (4)$$

Results

We have quantified the spatial variation of grain size, porosity and permeability within deformation bands through microstructural study of different types of deformation bands associated with different deformation mechanisms. The primary deformation mechanisms are granular flow, cataclasis, dissolution and cementation (Fossen et al. 2007). Figure 1 illustrates an example of a deformation band associated with a mild cataclasis and iron oxide cementation. The sample is from medium-grained and poorly-sorted Nubian Sandstone (Wadi Khaboba, Sinai, Egypt), and the maximum burial depth at the time of faulting was about 1.5 km (Du Bernard et al. 2000; Rotevatn et al. 2008). Two perpendicular thin sections have been prepared from this sample. Microscopic analyses of the thin sections show that microstructure and thickness of the band change along the band. Grain size analysis confirms that this variation is related to variations in cataclasis. Furthermore, our estimated porosity and permeability values vary along the band. This variation can be related to the degree of cataclasis and/or cementation. We found a change in permeability values along the band to be substantial: Permeability values in the xz-plane were up to two orders of magnitude lower than those in the yz-plane.

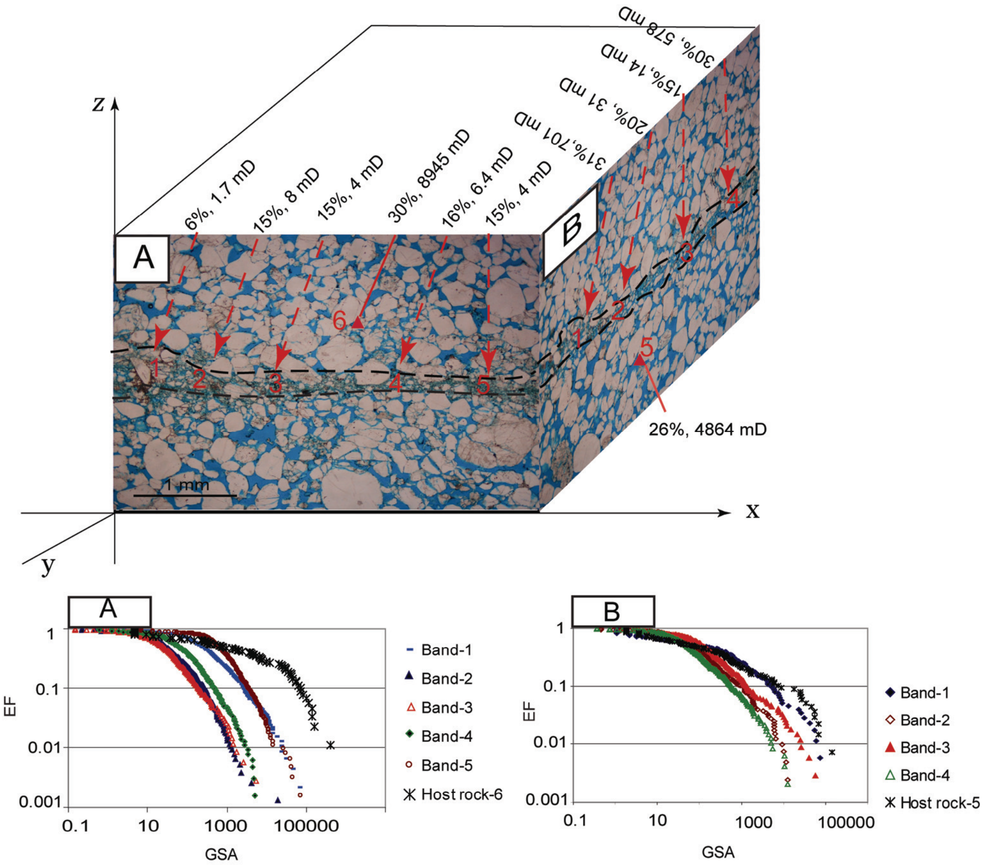

Figure 1 *Two perpendicular thin sections from the same sample that shows a deformation band in the middle. Sample is from faulted Nubian Sandstone, Sinai, Egypt. Note to the variation in grain size, porosity and permeability along the deformation band.*

Similar variations were found in other samples. In summary, we found that:

- Different types of deformation bands show variation in microstructure and petrophysical properties along the bands.
- The widely scattered distribution of previously reported porosity and permeability data for deformation bands can be explained by the observed spatial variations within individual bands.
- Permeability variations along deformation bands may result in restricted contribution of the bands to the sealing properties of faults.

References

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