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XCT quantified: a multiscale roughness study of fractures and veins in Pomeranian shale on samples collected at 4 km depth

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In low-permeability rocks, such as shale, fractures are an important control on permeability, where the formation permeability will be a combination of matrix permeability plus that of the natural and induced fractures. We obtained shale samples from borehole material, originating at 4 km depth in the Polish Pomeranian basin. They consist of 40-60% illite plus mica, 1-10% organic matter, 10% chlorite, 10% carbonates, plus minor amounts of K-feldspar, plagioclase and kaolinite. There are many bedding-parallel fractures present in the retrieved core material, as well as bedding-parallel carbonate-rich veins. The existence and origin of these fractures at depth is debated, as they could have formed as well during drilling plus exhumation of the borehole samples. However, vein formation occurs at depth, and as such the topography of the vein-rock interface is preserved even upon sample extraction. We have imaged 4 samples in 3D using X-ray microtomography performed on a laboratory tomograph. One sample was also analyzed on the beamline ID19 at the European Synchrotron Radiation Facility, with final voxel spatial sizes ranging between 0.6-26 micrometers, thus allowing a multi-scale analysis of fractures and veins. The shape and aperture of the fractures and veins have been extracted in 3D. Fluid flow is controlled by fracture aperture plus the surface roughness of the fracture wall. Hence, fracture and vein roughness plus their spatial scaling properties are characterized using the Hurst exponent H.

At low resolution (11-26 μm per voxel) there is a small difference in Hurst exponents parallel or perpendicular to the bedding, but on average veins exhibit H = 0.47, and cracks H = 0.35. Thus, veins exhibit more texture than cracks. This may be related to a different aperture mechanism, or to a characteristic ‘grain size’ present in the vein fill material. The sample scanned at multiple resolutions showed that an increase in resolution leads to an increase in the Hurst exponent for the crack. At this high resolution, roughness is the same parallel and perpendicular to the bedding. At the lower resolutions, anomalous patches with irregular spacing of increased aperture are visible, which is most likely the cause of this apparent ‘smoothening’ with increased resolution.

For comparison purposes, open vein surfaces are characterized using white light interferometry. At 10x magnification these surfaces exhibit H = 0.1-0.3, whereas a striated mirror-like slip surface in the same material showed H = 0.4 to H = 0.46 (respectively parallel and perpendicular to slip). This suggests that the open surfaces exhibit relatively little texture, and are thus ‘smooth’, whereas the naturally polished surface, which appears smooth, is actually rich in texture. The mirror surface exhibits approximately the same Hurst exponent as the veins in the XCT scans. This data suggests it is possible to separate fractures and faults formed at depth from fractures formed during sample extraction, based on the analysis of their roughness. This approach provides a new microstructural criterion to separate in-situ fractures from induced ones.