Multi-Scale, Multi-Dimensional Shale Imaging

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ABSTRACT

Shale reservoirs have recently attracted the attention of both industry and academia. Macroscopic and microscopic characterisation of shale is highly challenging due to their fine-grainsize and heterogeneity at different scales. Advances in imaging techniques provide an opportunity to characterise shale components and microstructures at multiple scales. Here we report, using examples from European and US shale plays, the application of 2D, 3D and 4D imaging techniques to the study of shale. 2D imaging techniques can characterize shale microstructures quickly and include optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Additional value can be added through combination with other techniques which measure 2D chemical and physical properties. Automated mineralogy techniques such as QEMSCAN, electron backscatter diffraction (EBSD) and atomic force microscopy (AFM) can be used to map mineral and chemical structure and mechanical properties in samples. 3D imaging techniques including X-ray computed tomography (XCT), 3D SEM (FIB/3View) and TEM tomography, can characterize shale microstructures in 3D from the macroscale to nanoscale (~10-1 - 10-9 m). Core-scale XCT provides information on bedding/laminae and fractures (10-1 - 10-4 m). Micro-CT quantifies granular mineral and organic matter compositions and distributions (10-3- 10-6 m). Nano-CT quantifies fine-grained minerals and organic matter (10-6 - 10-7 m). FIB-SEM/3View and TEM tomography resolve clay mineral grains and nano-pores (10-7 - 10-9 m). Recently, synchrotron-based time-resolved XCT (4D) has become a novel tool for the imaging of in situ shale deformation. Time-lapse heating, indentation fracturing and double torsion fracturing experiments can produce extensive, high-resolution datasets with this approach. Multi-scale and multi-dimensional techniques can image shale features leading to a greater understanding of the microstructural and mechanical properties in these heterogeneous and low-permeability systems. We use our data to demonstrate the combination of imaging datasets over multiple scales, the integration of 2D and 3D techniques, and the application of 4D imaging to identify and quantify the properties of shale and the behaviour of shale during deformation.