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Correlative multi-scale 3D imaging of shales: An example from the Haynesville-Bossier Shale, southeast USA

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Shale and shale reservoirs have attracted the attention of both industry and scholars. However, the strong heterogeneity at different scales and the extremely fine-grained nature of shales makes macroscopic and microscopic characterisation highly challenging. Recent advances in imaging techniques have provided many novel characterisation opportunities of shale components and microstructures at multiple scales. Correlative 3D imaging, where multiple techniques are combined, is playing an increasingly important role in the imaging and quantification of shale microstructures. In this study, combined utilization of X-ray computed tomography (XCT) and 3D electron microscopy (3D-EM) characterized the heterogeneity of shale microstructures over a large range of scales, from macro-scale to nano-scale (∼100 - 10-9 m). Specifically, core-scale XCT provides bedding/lamination/fractures information at macroscale; Micro-CT quantifies granular minerals and large piece of organic matter at meso-scale; Nano-CT gives fine-grain minerals and small pieces of organic matter at micro-scale; FIB-SEM and TEM tomography provide nano-scale images, and clay mineral and nano-pores can be resolved at this scale. Other chemical and physical measurements correlated to imaging techniques can provide complementary information for minerals, organic matter and pores. The application of these techniques can be used more widely for imaging particular features in different shales and further lead to a greater understanding of properties in the heterogeneous and low-permeability systems.