Multi-Scale 3-D Quantification of Porosity and Organic Matter Variations in European and U.S. Shale Reservoirs

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ABSTRACT

Microstructural variations, particularly the volumes, geometries and connectivities of pores and organic matter, are critical factors which influence the generation, storage and transport of hydrocarbons in shale reservoirs. The imaging and quantification of macrostructural and microstructural variations is a significant challenge in the characterisation of shale rocks. Combining X-ray tomography and 3D electron microscopy provides a powerful tool for multi-scale imaging and quantification of shale microstructure. With this combined approach, pores, organic matter can be visualized at range of scales over five orders of magnitude (voxel size ~ 44 μm to ~ 0.3 nm). Samples were selected from three shale basins in Europe and the US with variable compositions properties and maturities representing the diversity of shales. Organic matter occurs in two geometries: lamellar masses (length: 1.0-100.0 μm, thickness: 0.5-2.0 μm) and discrete spheroidal particles (large particles: 5.0-20.0 μm, small particles: 0.5-2.0 μm). Interconnectedness of the organic matter network is controlled by TOC concentrations and organic matter geometry. Organic matter forms an interconnected network when TOC concentrations are between 6-18 wt. %, and the lamellar masses contribute more in the network. Pores are classified on the basis of the mineral or organic component with which they are associated. Total pore volumes vary, but in order of decreasing total pore volume are: inter-mineral pores (0.20 μm diameter, elongate), organic interface pores (0.20 μm diameter, elongate), intra-organic pores (0.05 μm diameter, spherical) and intra-mineral pores (0.05 μm diameter, spherical). This indicates that inter-mineral pores, which predominantly occur between clay mineral grains, form the largest pore volume in the studied shales. TOC concentrations directly control the pore capacity of organic matter pore systems, while organic matter types and maturity (time-temperature) controls the formation of intra-organic pores. The use of TEM tomography identifies the presence of pores smaller 10 nm between clay minerals forming an interconnected pore network. This study provides a quantitative 3D dataset of pore and organic matter distributions in shales over a range of scales from diverse locations with variable TOC concentrations, thermal maturities and mineral concentrations. It enables an improved understanding of shale reservoir proprieties and their controls.