Nanoscale imaging of the Woodford Shale, Oklahoma, USA: Organic matter preservation as clay-organic nanocomposites

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TITLE

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ABSTRACT

Regional and within well variability in hydrocarbon production from organic carbon-rich shales has demonstrated that these unconventional reservoirs are complex and require an in-depth understanding of geological factors to make successful predictions. Variability is apparent in porosity and permeability, mechanical properties governing fracture susceptibility for enhanced hydrocarbon release, and concentrations of organic carbon (OC). The economically successful, though variable Woodford Shale, Oklahoma, USA, shows a $R^2 = 0.72$ correlation between mineral surface area (MSA) and total organic carbon (TOC) consistent with a mineral surface preservative effect on OC extending across a range of samples from multiple cores and with TOC values of <0.5% to 18%. The TOC and MSA data illustrates the systematic stratigraphic co-variant relationship between TOC and MSA showing steps of up to 15% TOC that are matched by similar shifts in MSA. Transmission electron microscope (TEM) imaging performed on ~80 nanometre thick ultramicrotomed thin sections independently confirms quantitative geochemical clay-OC associations at the nanoscopic scale of interaction. Energy Dispersive Spectrometry (EDS) spot analyses reveal that organic carbon is entirely constrained to nanoscale clay laminae within the sample. Grey zones encapsulated by clay aggregates appear homogeneous at low magnifications and are similar to discrete organic matter particles commonly interpreted in recent studies. However, high resolution inspection resolves these zones in to laminated clay particles occurring at tens of nanometres. TEM micrographs of later stage submicron-scale quartz grain growth may also explain how the opposing mechanisms of hydrocarbon leaching and entrapment can co-exist for over 300 million years and provide an insight into shale brittleness, known to increase fracture susceptibility. Determining key modes of how OC is preserved during deposition and early diagenesis in proven gas-shales, such as the Woodford Shale encompasses a more holistic approach to enhancing the prediction of prospective hydrocarbon resources in frontier basins.

Keywords
Organic matter preservation, clay minerals, quartz grain diagenesis, shale, gas storage, TEM, FIB, EGME, TOC variability.

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