Microporosity in solid bitumen: The key to unconventional reservoir potential in the Ukrainian Dniepr-Donets Basin

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The evaluation of an unconventional reservoir requires knowledge of commonly accepted parameters like TOC, thickness, thermal maturity, etc., but microstructural features such as organic matter (OM)-hosted porosity are of equal importance for a successful unconventional target. Broad ion beam – scanning electron microscopy (BIB-SEM) offers a great opportunity to investigate relatively large (1-2 mm^2), damage-free specimen surfaces at high resolution. We use this technique on areas large enough to be representative for the quantification of OM- and mineral-hosted porosity and the analysis of pore geometries, resulting in a better understanding of shale diagenesis, primary oil migration and evolution of microporosity. BIB-SEM maps at 312x, 1250x, 10kx and 20kx magnifications were acquired for 17 Upper Visean shale samples from the Ukrainian Dniepr-Donets Basin, covering a broad maturity interval of 0.65 – 2.7 %Rr (vitrinite reflectance) and different mixtures of type II (marine) and III (terrestrial) kerogen.

Results show that SEM-visible (~30 nm of equivalent diameter at 20kx magnification) porosity is less than 2 % in most samples. OM-hosted porosity, restricted to secondary solid bitumen, makes up a significant proportion (10-60 %) of total visible porosity. A good correlation was found between total porosity and OM-hosted porosity (R2 >0.9), and the amount of OM pores furthermore shows a weak correlation with the bulk quartz content (R2 ~0.65). The type of OM pores (pendular/interface vs. spongy) is reflected by the individual size distributions, as spongy pores usually feature smaller sizes (<50 nm), compared to pendular or OM/mineral-interface pores.

We interpret our results so that most porous solid bitumen in oil-prone rocks at peak oil maturity formed after primary oil migration, which accumulated an earlier oil phase in quartz-rich layers, that became nanoporous during secondary cracking. The amount of OM-hosted porosity therefore depends on the availability of intergranular pore space in which the early oil phase is accumulated. The process of progressive transformation into a porous solid bitumen residue is also indicated by elevated saturated/aromatic compound ratios and a high total yield of extractable hydrocarbons, suggesting that OM pores are actually filled with a lighter oil phase. In the terrestrially dominated organofacies, pore generation in pyrobitumen due to gas generation occurs significantly later and less intense. These results are in contrast to conventional models of the evolution of pore space in organic matter of marine shales, which were the starting point of the analysis of our samples. Hence, it is important to combine organic petrography and high-resolution imaging to clearly discriminate different OM types and their individual microstructural properties.

In-situ formation of authigenic clay and carbonate minerals within solid bitumen is likely related to organic acids formed during bitumen decomposition, implying the presence of an aqueous phase even in pores that are apparently filled exclusively with solid bitumen. OM decomposition might furthermore trigger mineral authigenesis (e.g. albite, Fe/Mg carbonates), which we found to have a great influence on porosity characteristics and mechanical properties of a shale.