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Pore-space alteration in source rock (shales) during hydrocarbons generation: X-ray microtomography and pore-scale modelling study

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Hydrocarbons (HC) are generated from solid organic matter (kerogen) due to thermocatalytic reactions. The rate of such reactions shows direct correlation with temperature and depends on the depth of source rock burial. Burial of sedimentary rock is also inevitably accompanied by its structural alteration owing to compaction, dehydration and re-crystallization. Processes of HC generation, primary migration and structural changes are inaccessible for direct observation in nature, but they can be studied in laboratory experiments. Modern technical facilities of laboratories make it possible to carry out experiments on HC generation from the organic-rich rocks at a completely new level (Kobchenko et al., 2011). Some new technologies, including X-ray microtomography and pore-scale modeling, allow us to carry out a step-by-step description of such processes and their development, and to study their reflection in alterations of rock structure.

Experiments were carried out with a clayey-carbonate rock sample of the Domanic Formaition taken at a depth of 1939 m from borehole drilled in the central part of the Melekes depression (West Tatar arch, Russia). The rock chosen fits the very essential requirements for studying HC generation under laboratory conditions - high organic matter content and its low metamorphic grade. Our work aimed such a study in an undisturbed rock sample by heating it in nitrogen atmosphere based on a specified temperature regime in a RockEval6 analyzer and monitoring alterations in the pore space structure. Observations were carried out with a SkyScan-1172 X-ray microtomography scanner (resulting scan resolution of 1 μm). A cylinder, 4 mm in diameter, was prepared from the rock sample for the pyrolitic and microtomographic analyses. Scanning procedures were carried out in 5 runs. Temperature interval for each run had to match the most important stage of HC generation in the source rock, namely: (1) original structure; (2) 100-300° – discharge of free and adsorbed HC and water; (3) 300-400° – initial stage of HC formation owing to high-temperature pyrolysis of the solid organic matter and discharge of the chemically bound water; (4) 400-470° – temperature interval fitting the most intense stage of HC formation; (5) 470-510° – final stage of HC formation. Maximum sample heating in the experiment was determined as temperature of the onset of active decomposition of carbonates, i.e. in essence, irreversible metamorphism of the rock. An additional experiment was accomplished to assess dependence of the thermal expansion and contraction of sample during experiments with the rock structure. After the first microtomographic measurement, the sample was placed into the pyrolyser furnace and heated to 470° in 10 min, which resulted in the cracks' network similar to step-by-step heating structure formation: i.e. rock with cracks along and perpendicular to bedding direction.

To quantify pore space alteration at each stage we use cluster analysis, correlation functions, local porosity analysis and pore-size distributions. Permeability measurements using conventional laboratory techniques are not possible between stepwise heatings. We used pore-scale modeling approach to determine this property numerically based on the 3D pore space information obtained with microtomography. The results of our experiment confirmed the possibility of vertical migration of fluids in the initially impermeable source rocks. They also revealed that pore space of the finely dispersed organic-rich rock changes during its controlled heating for HC generation according to the following scenario: (a) pores in the initial rock are small and isolated; (b) after some heating, pores at first are bound with each other due to the propagation of fractures along bedding, resulting in the formation of isolated filtration intervals; (c) further heating provokes the formation of bedding-perpendicular fractures that connect the isolated filtration intervals into a single system.