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Invasion-percolation fracturing controlled primary migration of hydrocarbons during heating of organic-rich shales

Maya Kobchenko (1), Hamed Panahi (1,2), Francois Renard (1,3), Dag K. Dysthe (1), Anders Malthe-Sorenssen (1), Adriano Mazzini (1), Julien Scheibert (1), Bjorn Jamtveit (1), Paul Meakin (1,4,5)

(1) Physics of Geological Processes, University of Oslo, Norway, (2) Statoil ASA, Oslo, Norway, (3) Institut des Sciences de la Terre, University Joseph Fourier and CNRS, Grenoble, France, (4) Idaho National Laboratory, Idaho Falls, USA, (5) Institute for Energy Technology, Kjeller, Norway

Primary migration, i.e. the transport of hydrocarbon fluids from extremely low permeability source rocks in which they are generated to more permeable rocks through which they migrate to a trap (reservoir) or to the surface is an example of both economic and fundamental interest. As the organic-rich fine grained sediment from which the source rock is formed is buried, the organic material is transformed into complex high molecular weight/cross-linked organic oil and gas precursors (kerogen). On continued burial, the temperature and pressure rise, and kerogen decomposes into low molecular weight hydrocarbon fluids (gas and oil) which have a much lower viscosity than the kerogen. Part of the generated hydrocarbon fluids escape from the shale into secondary migration pathways, by processes that remain enigmatic, in spite of decades of investigation. The rest is retained in the source rock explaining why shales are becoming an important source of unconventional hydrocarbon fuels. Fracturing is commonly cited as the most likely mechanism to increase the permeability of source rocks and provide pathways for the generated hydrocarbons. Here we present the first time-resolved in situ 3D experimental investigation of crack formation in organic-rich shale during kerogen decomposition [Kobchenko et al.].

A series of samples were obtained from an outcrop of the organic-rich R-8 unit, in the Green River Formation of the Piceance Basin in northwestern Colorado, USA. It contains organic matter (total organic content 9.92 wt%) present in the form of patches of kerogen, distributed preferentially along lamination planes. Before the experiment, this shale had not been exposed to temperatures that would cause significant thermal maturation.

High resolution synchrotron x-ray tomography was performed at ID19 ESRF, Grenoble, France. Time-resolved three-dimensional in situ imaging was used to investigate the effects of slowly heating of one of the shale samples from 60° to 400°C, in air without confinement. Cracks are found to nucleate in the interior of the sample at a temperature around 350°C. As the temperature increases, these cracks grow and coalesce along lamination planes to form bigger cracks. These results provide the first 3D monitoring of an invasion percolation-like fracturing process in organic-rich shale. This process increases the permeability of the sample and provides pathways for fluid expulsion - an effect that might also be relevant for primary migration under natural conditions. As a matter of fact, we find that fracturing is accompanied by a release of light hydrocarbons generated by decomposition of the initially immature organic matter, as determined by thermogravimetry and gas chromatography. We propose a 2D fracture model that reproduces both the observed non-linear crack growth in a lamination plane and the irregular geometry of the crack fronts.

1. Fracturing controlled primary migration of hydrocarbon fluids during heating of organic-rich shales, M. Kobchenko, H. Panahi, F. Renard, D. K. Dysthe, A. Malthe-Sørenssen, A. Mazzini, J. Scheibert, B. Jamtveit and P. Meakin, preprint hal-00554879.