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4D imaging of fluid escape in low permeability shales during heating

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The coupling between thermal effects and deformation is relevant in many natural geological environments (rising magma, primary migration of hydrocarbons, vents) and has many industrial applications (storage of nuclear wastes, enhanced hydrocarbon recovery, coal exploitation, geothermic plants). When thermal effects involve phase transformation in the rock and production of fluids, a strong coupling may emerge between the processes of fluid escape and the ability of the rock to deform and transport fluids. To better understand the mechanisms of fracture pattern development and fluid escape in low permeability rocks, we performed time-resolved in situ X-ray tomography imaging to investigate the processes that occur during the slow heating (from 60° to 400°C) of organic-rich Green River shale. At about 350°C cracks nucleated in the sample, and as the temperature continued to increase, these cracks propagated parallel to shale bedding and coalesced, thus cutting across the sample. Thermogravimetry and gas chromatography revealed that the fracturing occurring at ∼350°C was associated with significant mass loss and release of light hydrocarbons generated by the decomposition of immature organic matter. Kerogen decomposition is thought to cause an internal pressure build up sufficient to form cracks in the shale, thus providing pathways for the outgoing hydrocarbons. We show that a 2D numerical model based on this idea qualitatively reproduces the experimentally observed dynamics of crack nucleation, growth and coalescence, as well as the irregular outlines of the cracks. Our results provide a new description of fracture pattern formation in low permeability shales.