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Multiscale pore networks and their effect on deformation and transport property alteration associated with hydraulic fracturing

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Multiple lines of evidence indicate that, during a hydraulic fracture stimulation, the permeability of the unfractured matrix far from the main, induced tensile fracture increases by one to two orders of magnitude. This permeability enhancement is associated with pervasive shear failure in a large region surrounding the main induced fracture. We have performed low-pressure gas sorption, mercury intrusion, and nuclear magnetic resonance measurements along with high-resolution scanning electron microscope imaging on several preserved and unpreserved shale samples from North American basins before and after inducing failure in confined compressive strength tests. We have observed that the pore structure in intact samples exhibits multiscale behavior, with sub-micron-scale pores in organic matter connected in isolated, micron-scale clusters which themselves are connected to each other through a network of microcracks. The organic-hosted pore networks are poorly connected due to a significant number of dead-end pores within the organic matter. Following shear failure, we often observe an increase in pore volume in the sub-micron range, which appears to be related to the formation of microcracks that propagate along grain boundaries and other planes of mechanical strength contrast. This is consistent with other experimental and field evidence. In some cases these microcracks cross or terminate in organic matter, intersecting the organic-hosted pores. The induced microcrack networks typically have low connectivity and do not appreciably increase the connectivity of the overall pore network. However, in other cases the shear deformation results in an overall pore volume decrease; samples which exhibit this behavior tend to have more clay minerals.

Our interpretation of these phenomena is as follows. As organic matter is converted to hydrocarbons, organic-hosted pores develop, and the hydrocarbons contained in these pores are overpressured. The disconnected nature of these clusters of organic-hosted pores prevents the overpressure from dissipating, resulting in localized overpressure at the micron scale. When the rock is subjected to a hydraulic fracture stimulation, the rock surrounding the main induced fracture experiences shear deformation. Those parts of the rock that contain overpressured fluids in the organic-hosted pores will be more likely to experience dilatancy in the form of brittle deformation; the portions of the rock lacking in organic-hosted pores will tend to experience compactive shear failure since the effective normal stresses are larger. The microcrack networks that propagate into the regions of organic-hosted porosity allow the hydrocarbons resident in those pores to migrate to the main induced tensile fractures. The disconnected nature of the microcrack networks causes only a slight increase in permeability, which is consistent with other observations. Our work illustrates how multiscale pore networks in shale interact with in situ stresses to affect the bulk shale rheology.