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Relationship Between Pore-scale Characteristics and Petrophysical Properties

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SUMMARY

Fluid flow properties of geomaterials are fundamentally controlled by the characteristics of the pore system and the interaction of different fluid phases occupying complex pore shapes. Both the geometric and topological characteristics of the pore system are important, and each separately influences the flow of fluids. Here, we report a study in which we use network models to assess fluid flow through pore systems extracted from coarse-grained and fine-grained materials. Arbitrary changes to the pore systems, which mimic the effects of compaction, diagenesis, and possibly deformation, produce changes in the multi-phase flow properties, but the roles of pore size and connectivity vary in different materials. Continuing studies aim to identify predictive relationships between readily-obtainable descriptors and the hard-to-determine flow characteristics.

Ultimately, our understanding of sealing must arise from considerations at the pore-scale that seek to explain how rock textures govern the petrophysical properties. When muddy rocks undergo compaction, their pore systems are changed due to porosity loss. When chemical diagenesis occurs, there are effects on the pore system in terms of pore sizes and pore connectivity. When deformation takes place, there can be significant textural changes. These can range from situations with extreme grain-size reduction and porosity loss, to fracturing and dilation. Each of these deformation-caused modifications of textures translates into alterations of the petrophysical characteristics. Thus, an investigation of pore-scale controls is fundamental to underpin any effort to explain how seals form and operate within natural systems.

The work reported here is based on the analysis of pore networks. A pore network is a simple model of nodes and bonds derived from the connected void spaces of the material in question. In practical terms, we need a 3D digital model of the pore space from which to extract the pore network. Such models can be obtained from x-ray computed tomography methods, or from methods that reconstruct the porous medium, such as the PAMs approach (Wu et al 2006). Pore networks have both geometric and topological characteristics, and these need to be preserved in the network representation, as we have described for our PATs algorithms (Jiang et al 2007). Using an appropriate network model as input, it is practical to determine the single-phase permeability, to simulate a mercury-injection experiment, or to calculate the multi-phase flow properties accounting for issues such as wettability and the characteristics of the fluids (e.g. Valvatne and Blunt, 2004; Ryazanov, van Dijke and Sorbie 2009).

Although the methods can be applied to calculate the properties of a specific sample, we contend that it is necessary to use the methods in a different way to gain general understanding about how textural changes control property changes. Here, we illustrate an approach that appears to be promising. The idea is based on using a set of pore networks as a starting point for an investigation that seeks to determine how pore sizes and pore connectivities influence the resulting flow properties. An initial application of this approach was reported in Jiang, Wu and Couples (2009), but here we extend that study to a wider range of materials and continue the analysis into two-phase predictions. In simple terms, the method is summarized as: (1) choose a starting pore system; (2) extract the pore network; (3) calculate the flow properties; (4) alter the starting pore system by adding a film of solid to the inner surfaces of the pore bodies, but do not add material if it changes the connections; (5) re-calculate the flow properties (of the extracted network) based on the changed pore-size distribution; (6) modify the original pore system by randomly deleting a fraction of the pore connection; (7) calculate the flow properties as a function of the new connectivity; (8) repeat (4)-(7) until no more changes are possible.

When this method is applied to different geomaterials (Fig. 1), we obtain some very intriguing results that lead us to suggest that there may be some (as yet not fully identified) fundamental relationships that can be used to predict the petrophysical properties of sealing materials. The sandstone example is a clean, reservoir-quality material. Arbitrary alterations (in this case, reductions) of pore size and connectivity lead to degradation of the single-phase permeability. The relative permeability curves (drainage case is shown) do not reveal major effects from the changes, indicating that the altered pore systems are rather similar to those of the original material. However, there is an impact on the threshold entry pressure as the pore sizes are reduced. The other material is a clean siltstone (actually a loess), which means that there is no significant clay component. Again, the single-phase permeability clearly becomes smaller as the average pore size is reduced. The relative permeabilities and entry pressures are not particularly affected by the changes in pore size, but changes in pore connectivity exert a profound effect. These results suggest a non-trivial relationship between the characteristics of pore systems and the resulting flow properties. We propose that muddy rocks, and deformed rocks, will reveal further interesting relationships that will eventually lead to predictive approaches.

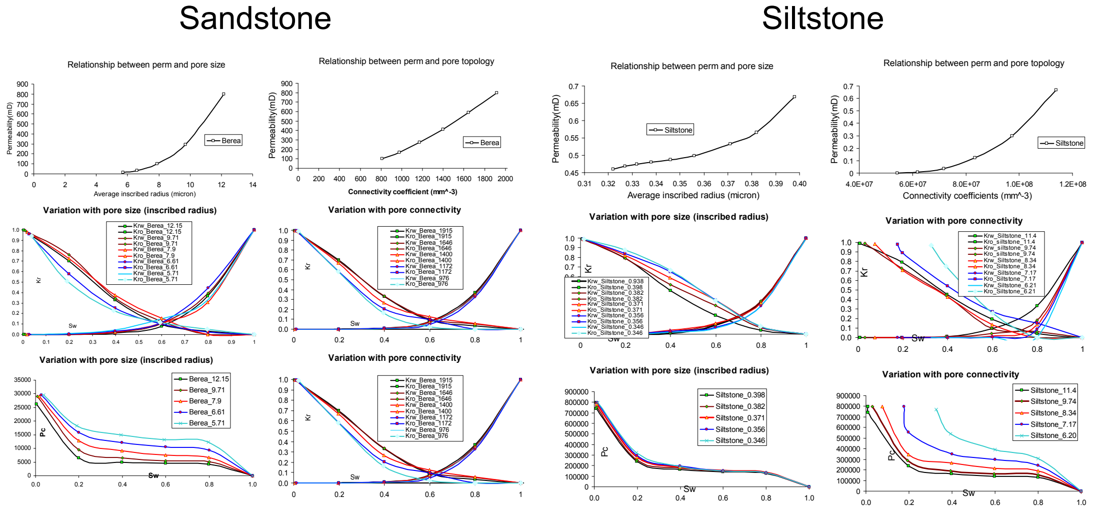

***Figure 1** Calculated petrophysical properties of sandstone and siltstone samples, illustrating effects of alterations to pore sizes and pore connectivities.*

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