**Probing pore connectivity of rock cores by PcT2 correlation spectroscopy**

Yiqiao Tang[1], Yi-Qiao Song[1], Stacy Reeder[1], Andre Souza[1,2], Muthusamy Vembusubramanian[1], Kamilla Fellah[1], and Ling Feng[1]

1. Schlumberger-Doll Research
2. Schlumberger Brazil Research and Geoengineering Center

Petroleum reservoirs are complex bodies due to geological processes, such as sedimentation, cementation, dissolution, and dolomitization. These processes lead to complex systems of pore bodies and throats. Consequently, reservoir rocks embody tortuous pore structures with a wide range of pore sizes and connectivity. Characterization of the intricate pore networks are especially important in prolific carbonate systems, where diagenesis and secondary porosity can lead to low-resistivity pay or isolated pore systems with high porosity and low permeability. Properly characterizing these body-throat relationships can also help lead to more characteristic permeability calculations.

Although laboratory methods abound to probe pore body and pore throat sizes independently, it has not been possible to determine their correlations in a bulk sample. Without understanding the connections between the pore bodies and pore throats, it is possible to mis-characterize the complexity of a sample and reduce pore models to simple bundle-of-tubes.

In the oilfield, NMR relaxometry and capillary pressure measurements have been applied for decades in the study of pore configurations: while the NMR relaxation times of proton spins depend on the size of pores and are used to estimate pore size distribution, capillary pressure is a direct measure of pore throats. The two methods provide complementary information about a porous network yet are largely orthogonal techniques and have never been used together in a single experiment.

In this work, we combine the NMR and capillary pressure techniques on a rigorous theoretical footing and name the new method “PcT2 correlation spectroscopy”. This novel 2D approach, mathematically akin to conventional multidimensional NMR methods, provides pore-specific pore throat distribution, a critical insight on pore connectivity that are chiefly responsible for fluid transportation in a porous medium.

We performed PcT2 spectroscopy on several brine-saturated siliciclastic and carbonate samples, revealing a profound richness of their pore connectivity. For rocks that lack post-depositional modification, we observe a linear pore body-pore throat correlation, where pore size distribution reflects the variance of depositional porosity (Fig. 1A, B, C and Fig. 2A, B). However, post-depositional processes can alter the pore space and lead to highly complex pore body-throat dependences (Fig. 1D, E, F and Fig. 2C, D).

PcT2 is the prime example of combining distinctive physics in a single experiment, bringing in insights that neither technique alone nor a numerical combination of their independent probes could provide. It can be a valuable addition to the geoscientists’ toolkit for describing porosity and its classification, visualizing pore connectivity, and modeling multiphase flow and fluid drainage.

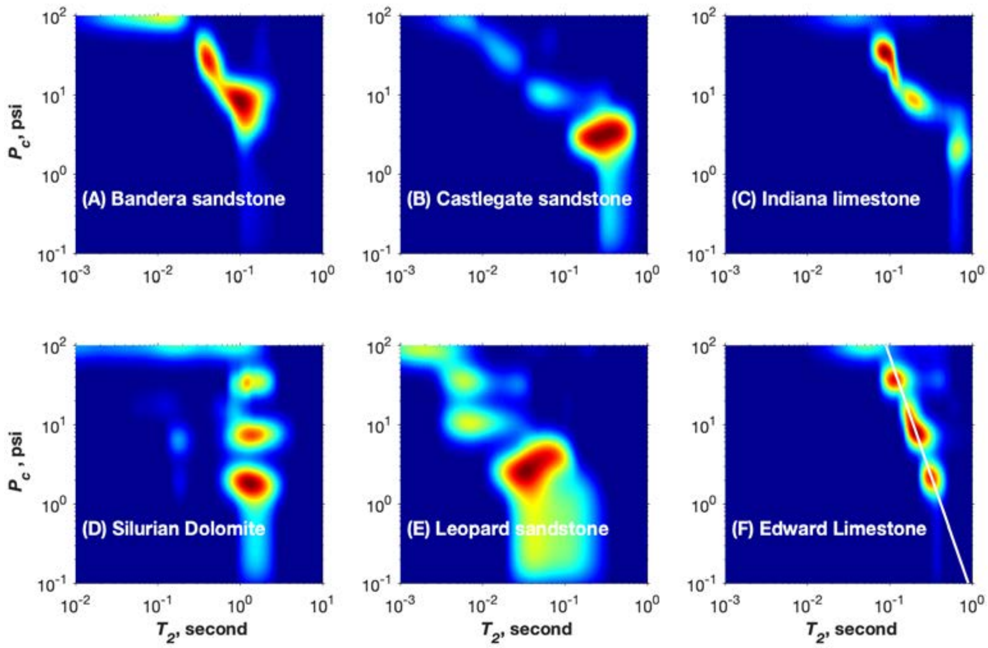


Figure 1. PcT2 maps for several sandstone and carbonate samples. Some sandstones and limestones show a strong PcT2 correlation (A-C), while others exhibit diverse signatures (D, E, F). In F, the white line denotes a correlation of $\alpha$ = 3.

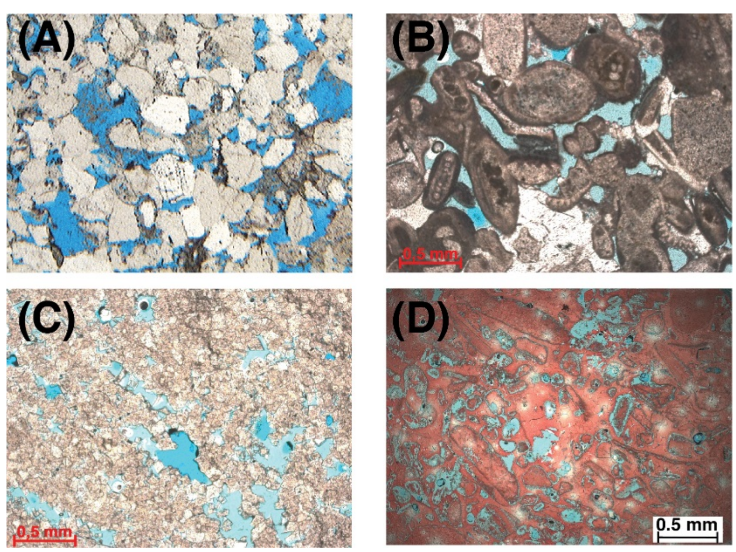


Figure 2. Micrographs of thin-sections of the Berea sandstone (A), Indiana limestone (B), Silurian dolomite (C), and Edwards limestone with red calcite staining (D). Signatures of substantial diagenesis, such as recrystallization, dolomitization and cementation, are observed in (C) and (D).