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"Petrography: A Brief History of Rock Imaging and Current Applications to Unconventional Reservoir Characterization"

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Summary

Petrography has long been an important tool for conventional reservoir characterization. Petrographic studies typically involve description and interpretation of standard thin sections and collection of photomicrographs that document both framework and diagenetic components, along with pore types and pore connectivity. Decades of work yielded significant insight into the role of rock-fluid interactions in diagenesis and how porosity is created, enhanced and destroyed by compaction and cementation. Petrographic textures and features that represent the record of various diagenetic processes are well-known and widely applied in conventional reservoir characterization studies.

Petrographic studies are equally important in characterizing unconventional reservoirs; however, higher resolution petrographic tools are generally required to investigate these very fine grained rocks. Most unconventional reservoir characterization studies begin with conventional petrography, perhaps with the addition of epi-fluorescent microscopy to better image very small pores. Micro-CT and scanning electron microscope studies are typically required for fine-grained siltstones and mudstone reservoir characterization. Like conventional petrographic imaging, *digital rock imaging* for unconventional reservoir characterization enables the following observations, except at much smaller scale: 1) determining textures, composition, and grain types for facies analysis and depositional environments; 2) image-based pore characterization and pore throat measurement; and 3) calculating permeability and relative permeability through digital rock physics where conventional laboratory tests fail. Understanding instrument resolution is an important part of unconventional reservoir characterization today, and time and money are saved through understanding what tools and data requirements are appropriate when interrogating fine-grained rocks.

Presentation Outline and Technologies

The inception of petrographic rock imaging dates to the 17th century with the invention of the optical microscope, followed by the construction of the first petrographic microscope, and its 20th century modification to include epifluorescence and confocal fluorescence techniques. A review of basic petrographic textures and features will emphasize framework grain size classification, clay distribution, recognition of primary versus secondary pores, cementation textures, and the role of capillary forces on cement morphologies and distribution. Using standard petrographic examples, rock texture and the importance of determining whether a unit is load-bearing or non-load bearing will be discussed.

The importance of instrument resolution and investigation scale in fine-grained reservoir characterization workflows determines what tool(s) are needed for accurate rock description and interpretation. Newer petrographic tools such as CT and micro-CT and their unique characterization workflows are especially important in evaluating silt- and sand-sized rocks (Figure 1). Mudrock characterization relies heavily on SEM and FIB-SEM imaging and collection of 3-D volumes for advanced petrophysical characterization. After reviewing these technologies, electron micrographs and 3-D volume examples highlight some essential attributes of fine-grained reservoirs. TEM and atomic force microscopy applications are the final technologies mentioned.

Case Histories

This presentation includes example studies of unconventional reservoirs utilizing advanced petrographic imaging techniques and digital rock physics. The first case study involves data and images collected to determine organic matter state (kerogen versus bitumen versus residual oil) utilizing SEM, source rock geochemistry and production data for the Cretaceous Niobrara Chalk, DJ Basin, USA. The second study focuses on the petrographic and petrophysical characterization of the silt-sized Codell Sandstone reservoir in the DJ Basin, Colorado, USA using a nested-scale workflow to accurately image intergranular and clay micro-intercrystalline pore networks.

Conclusions

Petrography remains an essential skill for accurate unconventional reservoir description and characterization. Today's fine-grained reservoirs necessitate the use of multi-scale workflows for proper characterization. Core, conventional petrographic, and microCT investigations are essential first steps in characterization, providing key information about rock texture and competency that higher resolution techniques such as FIB-SEM work lack without this proper context. FIB-SEM work highlights only the nano-to micron-sized grain types and pore networks. Time and money are saved through understanding what tools and data collection are appropriate for meaningful characterization of fine-grained rocks.

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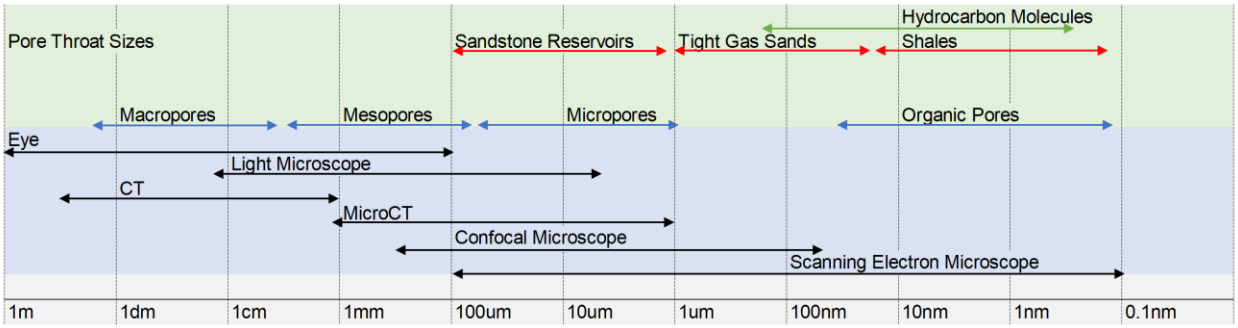

Figure 1. Comparison of select imaging methods (in blue area), to pore, pore throat, and hydrocarbon molecule sizes (in green area). Modified from Nelson, 2009, Choquette and Pray, 1970, Pommer and Milliken, 2015 and the AIM GeoAnalytics website.

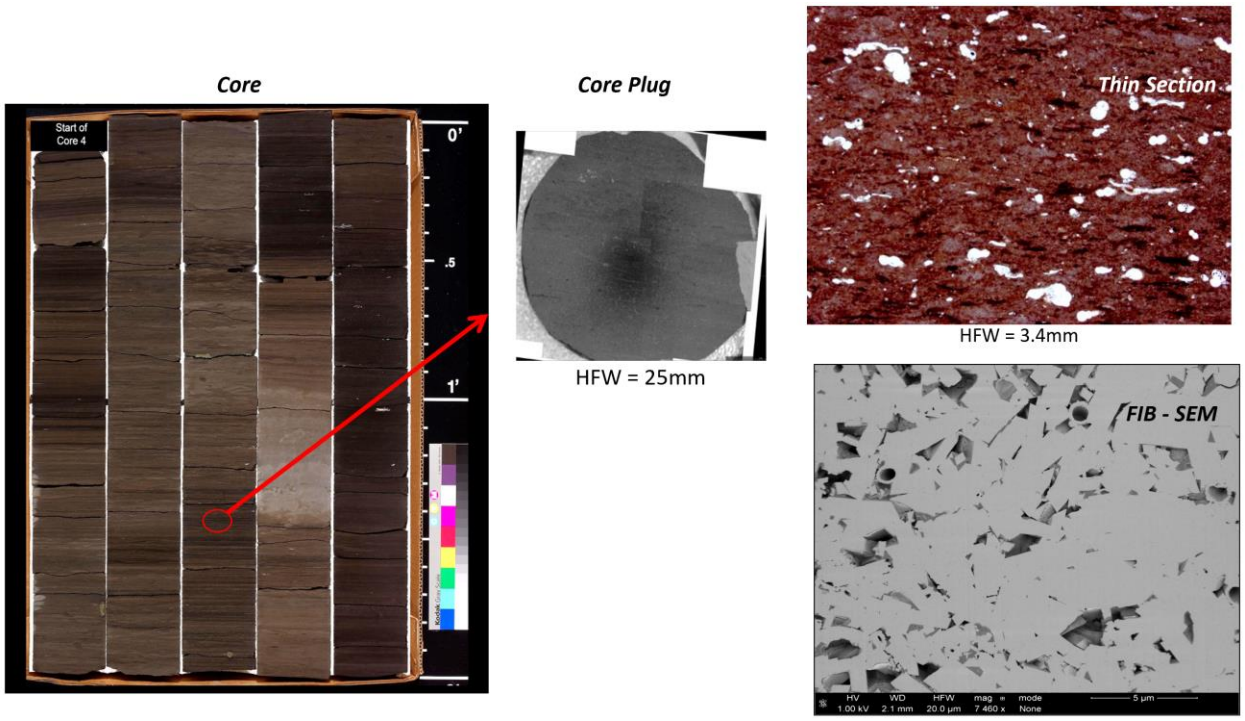

Figure 2. Comparison of scales of investigation: from slabbed conventional core (subsurface depths in feet), to 1" plug sample (horizontal field width - HFW) of 25mm, to thin section (HFW – 3.4mm) to FIB-SEM cross section (HFW – 20um) illustrating the type of information that is visible at each scale. Note that all grains and pores present in this chalk example can only be determined from SEM investigation.