COMPARING THE PETROPHYSICAL CHARACTERISTICS OF UNCONVENTIONAL CARBONATE RESERVOIRS (VACA MUERTA, MISS LIME, BAKKEN, AND EAGLEFORD)

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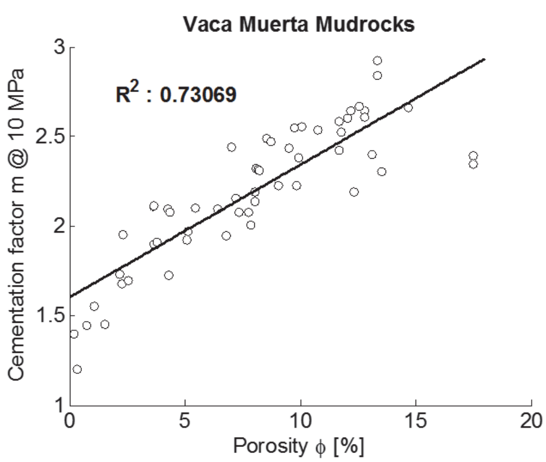
PROJECT OBJECTIVES

- Determine baseline values and the range of petrophysical characteristics (sonic velocity, resistivity, and nuclear magnetic resonance) in different carbonate mudrocks and tie these parameters to pore system architecture and permeability of various carbonate mudrocks.
- Continue to evaluate and characterize the sonic, resistivity and NMR response of the Vaca Muerta and Miss Lime and add samples from the Bakken and Eagleford Shale reservoirs in attempt to establish patterns that can be utilized in these and other mudrock reservoirs.
- Tie rock and mechanical properties to varying facies types and position within a sequence stratigraphic framework to evaluate the potential to maximize predictability of reservoir facies from wireline logs.

PROJECT RATIONALE AND GOALS

Unconventional carbonate reservoirs such as the Vaca Muerta, Miss Lime, Bakken, and Eagleford are characterized by generally low porosity with extremely low permeability values, often in the 0.01 to 0.001MD range (or lower). Due to the small size (micro- to nano-meter scale) and complex spatial distribution of the pores and pore throats in carbonate-rich mudrock reservoirs, evaluating and predicting the controls of pore structure and associated petrophysical properties such as porosity, permeability and fluid saturation is problematic. The goal of this study is to characterize pore types



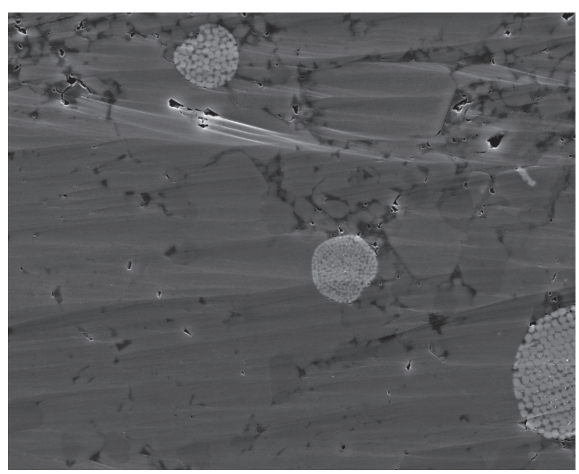


Figure 1. Left: Porosity vs cementation factor (m) cross-plot for 56 mudrock samples from the Vaca Muerta Formation with high correlation coefficient of R^2 = 0.73. Right: BIB-SEM image of Pyrite framboids in sample P03_1A with a low cementation factor of m = 1.27. (modified from Norbisrath, 2017).

and the pore system architecture of carbonate mudrocks and to tie these pore systems to key petrophysical responses to establish baseline characteristics and ranges of values that can be utilized in maximizing production in these unconventional reservoirs.

The systematic comparison of the petrophysical properties of the various mudstones in the above-mentioned reservoirs will likely result in similarities in some properties, while other petrophysical parameters may be different due to compositional, textural and/or diagenetic variations. The proposed study will establish the key controls on varying petrophysical responses and provide insight into how reservoir quality may be better predicted not only in the studied rocks, but also in newly discovered unconventional reservoirs.

APPROACH

Previous studies have tied petrophysical properties to pore architectural parameters, i.e., size, shape, and overall geometry, to macroporosity (Anselmetti et al., 1998; Weger et al., 2009) and microporosity in conventional carbonate reservoirs (Norbisrath et al., 2016). The small size (micro- to nano-meter scale) and complexity of the pore types and associated pore throats in unconventional reservoirs, however, are a challenge for correlating sonic velocity, resistivity, and other petrophysical responses to pore structure. Recent studies (Vanden Berg and Grammer, 2016) on carbonate mudrocks have found that expected petrophysical relationships between pore structure and laboratory-measured parameters such as sonic velocity and permeability, which are well-defined in conventional carbonate reservoirs, may not be readily apparent in carbonate mudrocks with predominantly micro- to nano-meter scale pores. Vanden Berg and Grammer (2016) suggest that mixed mineralogical compositions and post-depositional diagenesis such as mineralization along pore throats may be a major process that yields complex pore systems which complicate flow and affects petrophysical response. In addition, the composition (carbonate content, TOC and clay volume) influences the variability of acoustic properties on both log and seismic scale (Singleton, 2015).

Composition of the samples will be evaluated the following way: Carbonate content is determined by crushing part of the sample and dissolving the carbonate portion using 10% hydrochloric acid. The remaining non-carbonate portion is then used to determine %TOC on a Costech Elemental Analyzer coupled to a Delta V Advantage Mass Spectrometer. XRD analysis on crushed bulk materials of the plug established the main mineral constituents of the samples and broad-ion-beam milled SEM images will used to qualitatively determine some of the clay and other components (Fig. 1). Broad-ion-beam milled SEM images will also be used to characterize the micro- and nano-pore structure in the mudrocks.

In addition to continuing the characterization of the samples from the standpoint of the sonic velocity response and the associated complex resistivity parameters associated with these rocks (e.g. Norbisrath et al., 2017), we also plan an analysis of the NMR response in these complex and low permeability systems. Recent work has shown that the NMR response of very low permeability carbonate reservoirs are also variable from conventional carbonate reservoirs. Data from NMR provides crucial information on pore-size distributions, porosity and permeability to saturation and fluid(s) mobility. In combination with petrographic methods, the qualitative analysis of NMR data has also been utilized to infer rock fabric and dominant pore types in carbonate rocks. Successful applications of NMR in unconventional reservoirs include pore network analysis, permeability estimations, and differentiation between mineral- and organic matter-hosted porosity (e.g. Rylander et al. 2013). Incorporating quantitative pore structure data and petrographic descriptions with NMR data will provide a tie between rock fabric, the prevailing pore system, and the petrophysical response in carbonate mudrocks.

Variations in composition, in particular carbonate content and TOC, in any given field are to a large extent related to the position of the sample within the sequence stratigraphic framework. As a result, the petrophysical and mechanical properties of the formation will vary vertically, dividing the succession into zones of different reservoir quality. To address this

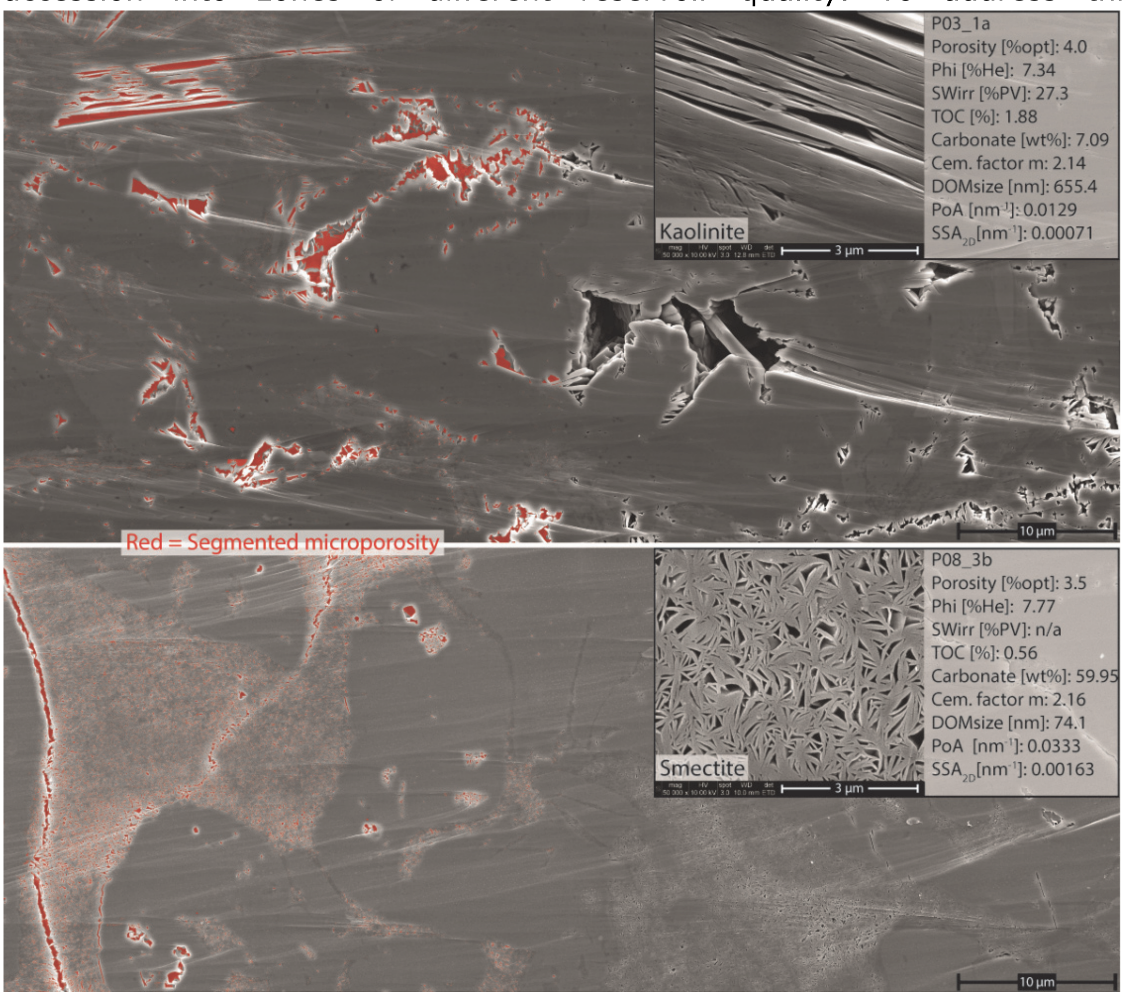


Figure 2. Example of broad-ion-beam milling SEM mosaics consisting of 50 images each at 15,000x magnification and 9.6 nm pixel side length that image the micro and nano-porosity. Segmented microporosity in red. Inserts show petrophysical and mineralogical data and a zoom into different clay pore structures at 50,000x magnification.

stratigraphic compartmentalization, we will place the rock properties into a sequence stratigraphic framework and we will calculate mechanical rock properties using a rock physics model. This analysis will be performed in the Vaca Muerta and the Miss Lime Formations where a sequence stratigraphic analysis has already been made.

SIGNIFICANCE

The assemblage of comprehensive petrophysical data sets from different organic-rich mudrock formations is expected to produce patterns of similarity and differences. The simultaneously assembled geologic information for each plug sample, such as pore structure, composition and TOC content, will aid in explaining the causes for both the similarities and differences. Taken together the results will provide information on which of the rock and mechanical properties are constant in all investigated mudrock formations and which are unique or more local in nature. As such the baseline characteristics and ranges of values can be utilized in maximizing production in these and other unconventional carbonate mudrock reservoirs.

REFERENCES

Anselmetti, F. S., Lüthi, S., and Eberli, G.P., 1998, Quantitative characterization of carbonate porosity by digital image analyses. AAPG Bulletin, v. 82/10, p. 1815-1836.

Norbisrath, J. H., Grammer, M. G., Vanden Berg, B., Tenaglia, M., Eberli, G. P., Weger, R. J., 2017, Nanopore Imaging in Vaca Muerta Mudrocks To Evaluate Controls on Complex Resistivity Spectra in Unconventional Reservoirs. SPE Reservoir Evaluation and Engineering-Formation Evaluation. SPE-185167-PA.

Rylander E., Singer P., Jiang T., Lewis R., and McLin R., 2013, NMR T2 Distributions in the Eagle Ford Shale: Reflections on Pore Size, Society of Petroleum Engineers: 164554.

Singleton, S., 2015, Reservoir characterization for unconventional plays: E&P mag, January 2015, p. 64-67.

Vanden Berg, B. and G. Michael Grammer, 2016, Qualitative and Quantitative Characterization of Carbonate Mudrock Pore Architecture: An example from the Mid-Continent "Mississippian" Limestone, IN T. Olson (ed), AAPG Memoir 112, Imaging Unconventional Reservoir Pore Systems. p. 185-232, doi: 10.1306/13592022M1123698

Weger R. J, Eberli, G.P., Baechle, G. T., Massaferro, J. L., and Sun, Y.F., 2009, Quantification of pore structure and its effect on sonic velocity and permeability in carbonates. AAPG Bulletin, v. 93/10, p. 1-21