SUB-MICRON DIGITAL IMAGE ANALYSIS (ESEM-DIA), PORE GEOMETRIES AND ELECTRICAL RESISTIVITY IN CARBONATE ROCKS

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PROJECT OBJECTIVES

- Assess the controls of the sub-micron pore structure on electrical resistivity.
- Expand the resistivity dataset to dolomites and combine with existing datasets.
- Develop methods to apply Digital Image Analysis (DIA) to Environmental Scanning Electron Microscopy (ESEM) imagery; combine and compare with Mercury Injection Capillary Pressure (MICP) and/or µ-CT measurements.

PROJECT RATIONALE

Verwer et al. (2011) postulate that electrical resistivity and Archie's cementation factor *m* are directly related to the number of pores and pore throats. This hypothesis is based on digital image analysis (DIA) of thin sections. Successive tests of this hypothesis with a) imaging the pore structure with high-resolution CT scans and subsequent modeling and b) by relating MICP in rocks to electrical resistivity corroborated Verwer's findings (Figure 1). Finite element modeling of resistivity of the µ-CT tomographs, however, revealed the importance of the microporous regions that often lie in the sub-micron range. To understand and predict the effect of the pore structure on the electrical behavior of a rock, it is paramount to analyze both macro- and microstructure of the pore system in both limestones and dolomites.

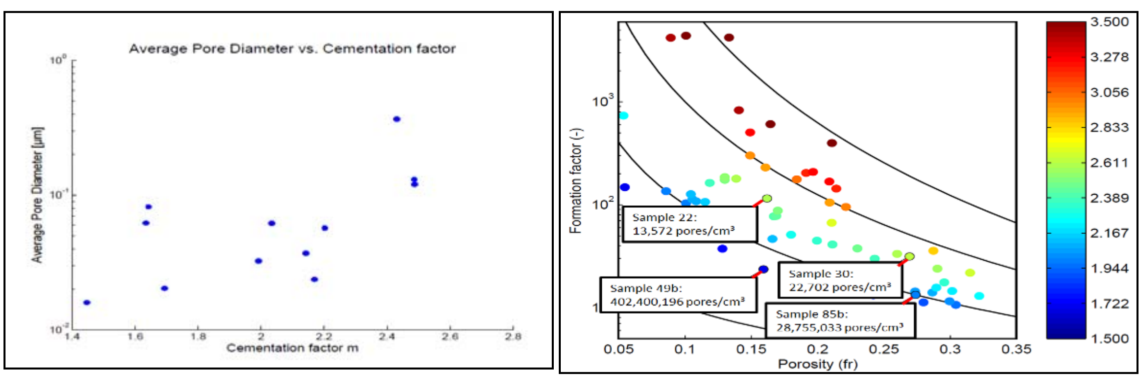

Figure 1. Left: Graph of pore diameter vs. cementation factor based on MICP measurements. The cementation factor increases with average pore size. Right: Number of pores per cm³ (in boxes) derived from µ-CT measurements at equal porosities vs. cementation factor in color. The cementation factor decreases as the amount of pores increases (modified from Norbisrath et al., 2011).

AIM AND APPROACH

This study aims to document that a small and intricate pore network is favorable for the flow of electrical charge due to its increased pore count, whereas simpler networks with larger pores but less pore connections attenuate electrical flow in comparison. To reach this goal, high-resolution 2-D ESEM imagery for DIA and MICP measurements are used to investigate the rock's microstructure and its effects on the rock's electrical behavior.

DIA of thin sections produces quantitative parameters of various aspects of a pore system that can be related to physical properties (Weger et al., 2009). We plan to apply the DIA technique on ESEM images to similarly characterize and quantify the sub-micron pore structure. Combining the results from DIA on OLM (Optical Light Microscopy) imagery and ESEM imagery will quantify the rock's geometrical properties over several orders of magnitude. ESEM images of an extensive array of rock samples with differing petrophysical properties will be acquired and quantitatively analyzed on the geometric parameters of their pore structure. The main difficulty with ESEM-DIA is sample preparation, because a nanometer-scale, perfectly flat 2-dimensional surface is needed for this method to work. Core plugs will get resin-impregnated and their surfaces treated with ultra-fine polishes, in order to get appropriately flat surfaces for truly 2-dimensional images.

A second independent approach to investigate the microstructure of the rock is with MICP, which is a widely used, reliable methodology for assessing the number and size of pore throats. We plan to measure the cap curves on a variety of lithologies and correlate the measurements with resistivity, velocity and permeability. In addition to various limestones, the lithologies will include a set of pure Mississippian dolomites for which the porosity, velocity and a good analysis of the crystal structure are available (Figure 2). Shen et al. (2000) showed that deviations in velocity at similar porosity can be explained by the occurrence of different rock and pore types but also crystal shapes and crystal size. This data set offers the opportunity to evaluate the influence of the crystal structure on electrical resistivity.

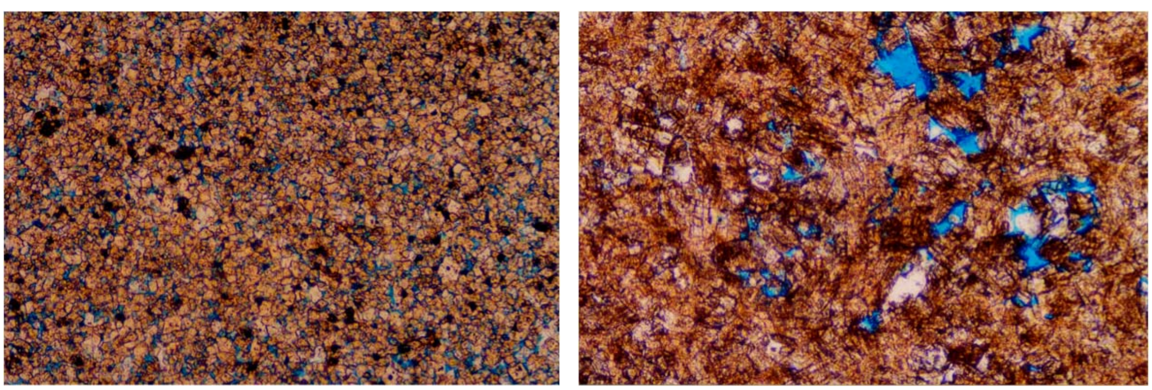

Figure 2. Examples of differences in pore and crystal structure in the Mississippian dolomites. Left: The rock is dominated by intercrystalline porosity and euhedral crystal shape. Right: Moldic porosity and anhedral crystal shapes (modified from Shen et al., 2000).

PROJECT TASKS

- Micro-structural analyses on representative samples from a broad variety of rock facies.
- Perform MICP (Mercury Injection Capillary Pressure) measurements.
- Acquire ESEM (Environmental Scanning Electron Microscopy) imagery and analyze with DIA (Digital Image Analysis).
- Where available, compare to μ-CT imagery and modeled results.
- Evaluate scatter in resistivity measurements as function of pore throat diameters (from MICP), pore size and numbers, and other geometric parameters (from ESEM-DIA).
- Measure electrical resistivity on Mississippian dolomite samples and correlate results with pore and crystal structure.

KEY DELIVERABLES AND EXPECTED RESULTS

This study will add to the comprehensive data set being assembled at the CSL – Center for Carbonate Research that correlates resistivity to porosity, permeability and pore structure, size and number (using MICP and ESEM-DIA). Specifically, the study will address the influence of the sub-micron pore structure on electrical resistivity by means of analyzing both OLM imagery and high-resolution ESEM imagery with DIA, interpreting cap curves from accompanying MICP measurements, and comparing the combined results to measured resistivities of the samples. The results will help to further improve the inversion of carbonate pore structure from down-hole log resistivity data and the thereby improve the calculation of water saturation in carbonate reservoirs, eventually leading to improved oil estimates. Additionally, the outcome will indicate which method of quantification of the pore structure, either with ESEM-DIA or MICP, is the most accurate and/or feasible for following studies of rock microstructures.

REFERENCES

Norbisrath, J.H., Eberli, G.P., Weger, R.J., Knackstedt, M., and Verwer, K., 2011, Modeling electrical resistivity in carbonates using micro-CT scans and assessing the influence of microporosity using MICP. Abstract CSL Annual Review Meeting.

Shen, S., Smith, L.B., Eberli, G.P., McNeill, D.F. and Bracco Gartner, G., 2000, The effects of rock texture and pore type on sonic velocity in dolomite. Abstract CSL Annual Review Meeting.

Verwer, K., Eberli, G.P., and Weger, R.J., 2010, Effect of pore structure on electrical resistivity in carbonates: AAPG Bulletin, no. 20, v. 94, p. 1-16

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, no. 10, v. 93, p. 1297-1317.