Integrating Standard Petrophysical Analysis with Statistical Measures of Petrophysical Heterogeneity to Estimate Petrofacies in Mississippian Limestone, North-Central Oklahoma*

Fnu Suriamin¹ and Matthew J. Pranter¹

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¹ConocoPhillips School of Geology and Geophysics, University of Oklahoma, Norman, OK, USA (fnu.suriamin-1@ou.edu)

Abstract

Mississippian carbonate and chert reservoirs of the mid-continent are extremely complex and exhibit different scales of mineralogical, lithological, and petrophysical heterogeneity. The Mississippian interval consists of four high-frequency cycles that are capped by unconformable surfaces related to subaerial exposure. Key lithologies from core description vary from chert-brecciated limestone, bedded chert-brecciated limestone, bioturbated grainstone and mudstone, and dense, unaltered limestone. Diagenetic products including silicification, dissolution, compaction, fracturing, and brecciation are observed throughout this interval. Relationships of petrophysical methods and statistical measures of heterogeneity are explored to predict petrofacies. Initially, detailed core description, standard petrophysical analysis, and the Multi-Resolution Graph-Based Clustering method are conducted. Statistical measures of heterogeneity, including Lorenz and Dual-Lorenz Coefficient, are calculated on bulk density, neutron porosity, and sonic well logs in the Mississippian interval to evaluate which well logs best capture heterogeneity and define the optimal number of clusters needed to define the petrofacies. The results of core analysis, petrophysical analysis, and numerical measures of petrophysical heterogeneity are integrated to estimate lithofacies in non-cored wells and to identify stratigraphic cycles in order to interpret the sequence-stratigraphic framework.
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Fnu Surirom and Matthew J. Pranter
ConocoPhillips School of Geology and Geophysics, University of Oklahoma, Norman, Oklahoma

1. Abstract
Mississippian Limestone of the mid-continent is an unconventional carbonate reservoir. It is a heterogeneously-complex and -variable depositional environment characterized by thin-bedded limestones, lithofacies, lithological, pore, structure, and petrophysical heterogeneity. The Mississippian interval consists of very low permeability and unconnected surfaces related to subsurface karstification. Key lithofacies are cored from shallower intervals, such as argillaceous, nodular, grainstone, peloidal, laminated packstone-grainstone, skeletal packstone-grainstone, bioturbated packstone-grainstone, and bioturbated middle-wackestones. Diagnostic products including silicification, dolomitization, compaction, fracturing, and brecciation are observed throughout this interval.

2. Research Objectives
Previous work has shown that geostatistical methods for measuring heterogeneity of petrophysical properties in carbonate reservoirs may increase predictability of reservoir compartmentalization or fluid flow zones and improve sampling strategy. This research uses similar methods and applied an unconventional limestone reservoir with objectives to:

1. Accurately characterize petrophysical properties and pore types of the unconventional carbonate reservoir to predict reservoir compartmentalization or fluid flow zones.
2. Investigate if heterogeneity of petrophysical properties of the Mississippian Limestone can be defined and measured using standard techniques.
3. Investigate if measures of heterogeneity of petrophysical properties can be used to improve pore-types and petrofacies prediction.
4. Investigate if heterogeneity of petrophysical properties can be used to predict petrofacies in non-cored wells.
5. Investigate if measures of heterogeneity of petrophysical properties can be used to improve pore-types and petrofacies prediction.

3. Study Area and Geologic Background
Figure 1. Regional base map showing the major sections and formations of Oklahoma and Kansas. The study area of Grant County is marked in the red box. It lies on the southwest edge of the Anadarko Ramp that progrades toward the north. In an ideal stratigraphy section, Meramecian limestones are cored in red; Mississippian limestones are cored in blue. Figure 2. Grant County map showing well locations (data provided by Chevron). The data set consists of 31 wells with core data, and 23 with digital well logs. Four of those wells are cored: Frontier, Dewey, Bowie, and Kirby. Figure 3. Map showing DRTs (Differential Reflectivity Transforms) for the Grant County study area.

4. Methods and Proposed Workflow
Figure 4. The workflows on the left are modified from Chevron Patent application for carbonate petrophysical rock typing. The original workflow consists of eight (8) steps including data scenario, depositional rock typing (DRT), petrophysical rock typing (PRT), and core data analysis (CDA). CDA provides input to the modeling laboratory (MLL), and the geostatistical workflow is shown in steps (data inputs integrating heterogeneity logs to PRT definitions is a multi-step workflow and quality control). The workflow also integrates electrofacies analysis using Multi-Resolution Graph-based Clustering and Neural Network techniques.
ed packstone-grainstone or chert-brecciated limestone. With bioturbated mudstone-wackestone, bioturbated packstone, and capped by bioturbated grainstone or skeletal grainstone. Occasionally, the top section is characterized by nodular granules or peloidal laminated packstone-grainstone or chert-brecciated limestone. The deepest lithofacies is characterized by glauconitic sandstone. Shoaling-upward cycle is typically started with bioturbated mudstones-wackestone, bioturbated packstone, and capped by bioturbated grainstones or skeletal grainstone. Occasionally, the top section is characterized by nodular granules or peloidal laminated packstone-grainstone or chert-brecciated limestone. Following the core description, Figure 9 (Figure 9) shows the sequence throughout the Mississippian interval in Frieouf 1-7 SWD well and was analyzed using transmitted light microscope and Scanning Electron Microscope (SEM) for determining pore-types, pore sizes, permeability, and mineral composition. The result will be integrated with routine core analysis and X-Ray Diffraction (XRD) data.

Petrophysical analysis will include:

a. Velocity - density log and separation of sonic and density - neutron porosities method - pore types.

b. Nuclear Magnetic Resonance (NMR) - hard, grain supported, sedimentary structures.

c. Silton wave analysis - permeability estimation

d. Multifrequency analysis - volume of minerals.

e. Heterogeneity log - fluid flow units, track typing.

In summary, the complementary attitude of each log and techniques will be used to evaluate this complex unconventional carbonate reservoir. Previous work has proven that heterogeneity logs can be used to identify fluid flow zones in carbonate reservoir. Therefore, applications of heterogeneity logs to better constrain fluid flow units and to improve rock typing are expected to better illuminate issues related to reservoir characterization of unconventional carbonate reservoirs.

6. Future Works

Enhanced reservoir characterization is critical for continuous development of Mississippian limestone reservoirs of the Mid- continent. These reservoirs provide a great opportunity to test the concept of statistical measures of petrophysical heterogeneity for rock typing in an unconventional carbonate reservoir.

This research is in the early stages of designing the investigation, allowing a statistical analysis of data to test the hypotheses. Preliminary result of core description suggests that the Mississippian limestone in the study area consists of six (6) lithofacies including chert-brecciated limestone, nodular granules, peloidal laminated packstone-grainstone, skeletal packstone-grainstone, bioturbated packstone-grainstone, and bioturbated mudstones-wackestone. Shoaling-upward cycle is typically started with bioturbated mudstones-wackestone, bioturbated packstone, and capped by bioturbated grainstones or skeletal grainstone. Occasionally, the top section is characterized by nodular granules or peloidal laminated packstone-grainstone or chert-brecciated limestone. Following the core description, Figure 9 (Figure 9) shows the sequence throughout the Mississippian interval in Frieouf 1-7 SWD well and was analyzed using transmitted light microscope and Scanning Electron Microscope (SEM) for determining pore-types, pore sizes, permeability, and mineral composition. The result will be integrated with routine core analysis and X-Ray Diffraction (XRD) data.

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References


Mazzullo, B. J., 2011, Monotachitic of limestone in the section: evaluation criteria for a future reservoir objective, Search and Discovery Article 102705.


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