geoconvention
Virtual Event
September 21-23
2020
CSPG • CSEG • CWLS • GAC • MAC • IAH

Core Calibration of Log Derived Petrophysical Models for the Characterization of Source-Rock Reservoirs

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Summary

Unconventional reservoir systems (source rocks and/or the adjacent carrier beds) often consist of finely laminated and heterogeneous mudstones and/or siltstones. These fine-grained beds can contain highly variable matrix densities which frequently complicate porosity estimates. They can often be classified as non-Archie rocks wherein water resistivity and clay corrected Archie parameters are unknown. Typically, these sediments also contain non-Darcy transport mechanisms (i.e. slip flow and Knudsen diffusion) and complex storage mechanisms (adsorbed gas and absorbed liquids) that are rarely encountered in conventional reservoir settings. Furthermore, unconventional reservoir systems usually possess extremely low permeability which requires aggressive, costly, hydraulic fracturing as part of their completions process to facilitate economic levels of production. The cumulative effects of these unique reservoir characteristics result in the following key features:

- Highly productive wells are generally limited to basin/field “fairways” with marginal to poor production in the larger, regionally massive areas of the basin.
- On average, recovery factors for unconventional gas plays range from 20-30% of OGIP and unconventional oil plays range from 3-7% of OOIP.[1] Furthermore, initial production rates will typically decline by 70-80% within a year. As a result, continuous drilling of new wells is usually required to sustain target cumulative production volumes.
- A “blind” statistical drilling, completions, and production approach which ignores formation and fluid heterogeneities can result in a net loss of Cap-Ex.

Accurate calibration of log based petrophysical models is essential for successful assessment of the risks, economics, and potential success of an unconventional resource. It is therefore in an operator’s best interest to obtain enough rock and fluid data to effectively evaluate the resource potential. In this technique, traces are derived that enable characterization of key reservoir properties (porosity, fluid saturations, lithology, and rock mechanics) and hydrocarbons-in-place over the entire logged interval (at the same resolution of the log depth-step) from a discrete set of rock and fluid data. Calibrated petrophysical models are critical for unconventional reservoirs because standard petrophysical modeling techniques are frequently unsuitable.

Log-based cluster analysis allows one to partition a large stratigraphic interval into similar or dissimilar rock types. The coupling of log-based cluster analysis to calibrated petrophysical models adds value to resource assessment in that each electro-facies, determined from cluster typing, can be characterized based upon its associated rock properties as determined by the petrophysical models.

Methods and Workflow

We introduce the different approaches (stochastic versus deterministic and global versus local) available to petrophysical log analysis. We then present a workflow for the development of local deterministic core-calibrated petrophysical log models for use in the characterization and evaluation of source rock reservoirs.[2] The 10-step workflow is as follows:

1. Load, QC, edit, and apply environmental corrections to the log data as required.[3]
2. Merge, import and depth shift core data to align with the logs.
3. Compare as-received core bulk density to log measured bulk density.
4. Calibrate the lithology model by solving for weight fraction TOC and all inorganic minerals.[4, 5, 6]
5. Convert each lithological component (including kerogen) to volume fractions, adjusting each end member density until a match to the core measured grain density is achieved.
6. Compute a kerogen corrected total porosity.[5, 6]
7. Convert all end member grain volumes to bulk volumes to account for porosity and complete the lithology model.
8. Compute water saturations, calibrating to measured core data.[7, 8]
9. Compute hydrocarbons-in-place.
    a. If a gas play, compute adsorbed gas as a function of TOC, solve for corrected free gas, and calculate a total gas-in-place.[9, 10, 11]
    b. If an oil play, compute oil-in-place.[11]
10. If core geomechanical data is available, compute a static Young's Modulus and Poisson's Ratio by calibrating sonic logs to the core data.

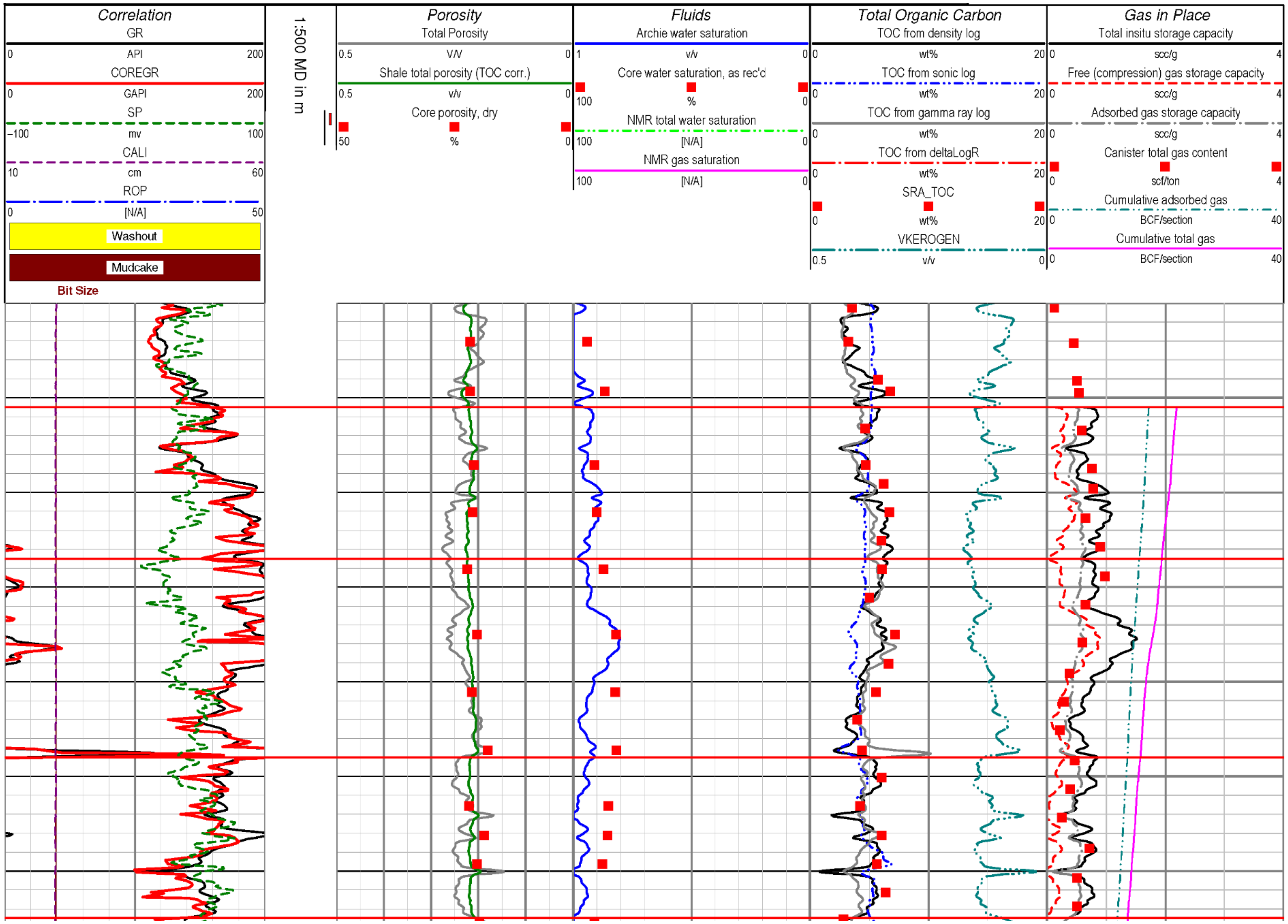
Case Study - Colorado Shale Group, Southern Alberta, Canada

A three well case study involving an appraisal of the Colorado Shale Group in Southern Alberta will be presented and discussed to illustrate the application of our workflow. The scope of work for this study included the following:

- Three locations were selected and wells were drilled. Minimum of 200 meters of core were acquired from each well.
- A comprehensive core and gas analytical program was conducted on each well.
- Each well was logged with a complete modern log suite.
- Local deterministic petrophysical log modeling was conducted for each well.

Core and log data used to calibrate each individual well were then merged and used to develop a common log model. Although there was some loss of accuracy in the property predictions within each individual well, this maximized the applicability of the final model over a much larger acreage position.

Figure 1. Calculated porosity, water saturation, TOC, and gas storage capacity log with core points shown in red



Acknowledgements

We wish to recognize and express our deep gratitude to the late Mr. Bob Cluff and to Perpetual Energy Inc. for their significant contribution to the contents of this presentation.

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