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A Novel Core Based Methodology for the Evaluation of Unconventional Reservoirs

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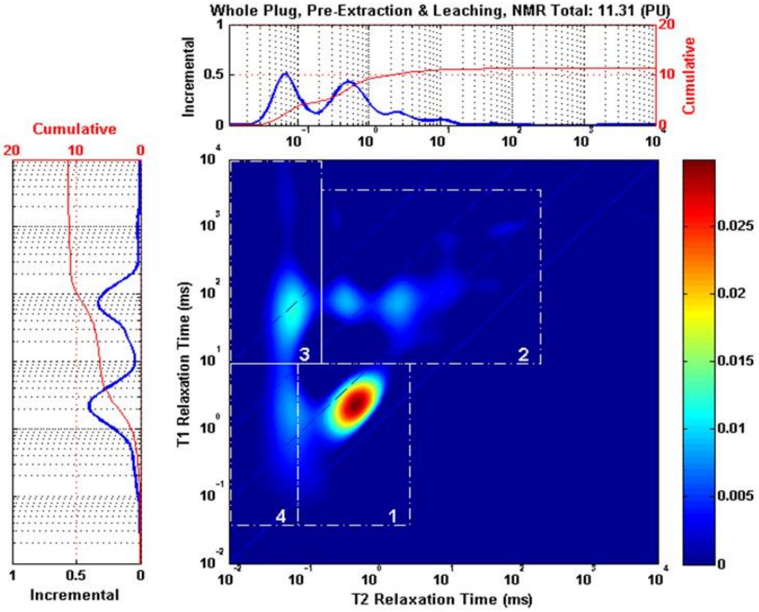
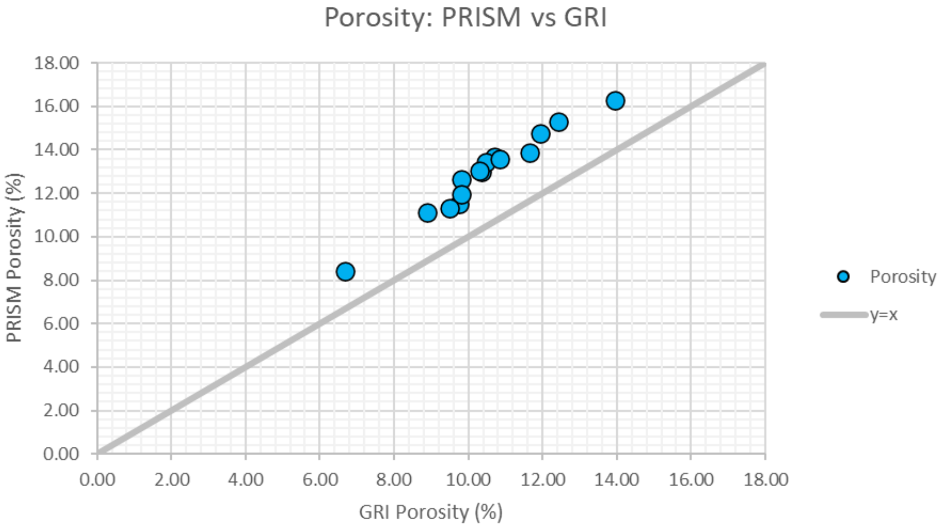
As the demand for greater accuracy in wellbore placement continues to grow, so does the importance of reliable petrophysical models for target identification. Among these models, porosity and saturation are particularly critical for sound reservoir evaluation. The most robust models are derived from those supported by core data. This raises the question: which tests should be conducted, and how should the resulting data be applied to these models? Through our research, we have developed, implemented, and optimized a range of innovative testing methodologies and application practices to maximize the acquisition of critical information. We have consolidated the methodologies into the Silty Sand Protocol, though its application is not exclusively limited to these conditions. The protocol incorporates new testing methodologies, including PRISM, which employs high-frequency NMR mapping both before and after cleaning to account for any lost or residual fluids during CMS and GRI testing. Additionally, electrical measurements are conducted on "as-received" (AR) core samples to determine Resistivity Index (RI), Formation Factor (FF), and other petrophysical properties. This includes the use of RwCore™, which measures equivalent water resistivity (Rw) and reflects the influence of clay content on the measurement. These tests are paired with XRD for clay speciation and mineralogy, along with pyrolysis for volume corrections. By obtaining these measurements, more accurate porosity and water saturation models can be developed, leading to an improved understanding of the targeted reservoirs. Throughout this paper, we will examine the testing methodologies and modeling approaches that comprise this protocol, illustrating how they can enhance wellbore understanding and ultimately increase potential returns.

Petrophysical Reservoir Integrated Saturation Measurement (PRISM)

PRISM is a multi-disciplinary integrated workflow designed to mitigate core saturation loss, more accurately quantify carrying capacity, evaluate bitumen dissolution, and more concisely understand hydrocarbon mobility. This methodology utilizes purpose-built instrumentation to evaluate unconventional reservoirs and tight reservoirs that straddle the boundary regarding using more conventional approaches for analysis. The workflow employs the use of a Higher-Frequency 23 MHz NMR system with 2D T1/T2 mapping for reservoir fluid evaluation and quantification. This unique tool enables the investigation of fluids left behind post-extraction to correct both porosity and grain density calculations. This component of the PRISM evaluation will serve as one of the primary inputs to the core to log model discussed in this presentation.



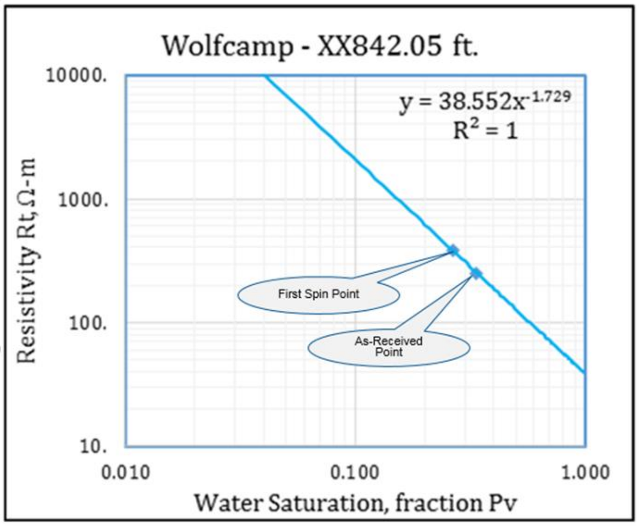
HF-NMR 2D T1/T2 Map defining the liquid system present in the core sample. The map has been zonated into four distinct regions quantitatively defining the reservoir fluids present. These maps can be generated on intact or crushed samples. Post-extraction and drying maps can additionally be generated to evaluate fluids left behind that can impact the porosity and grain density determination.



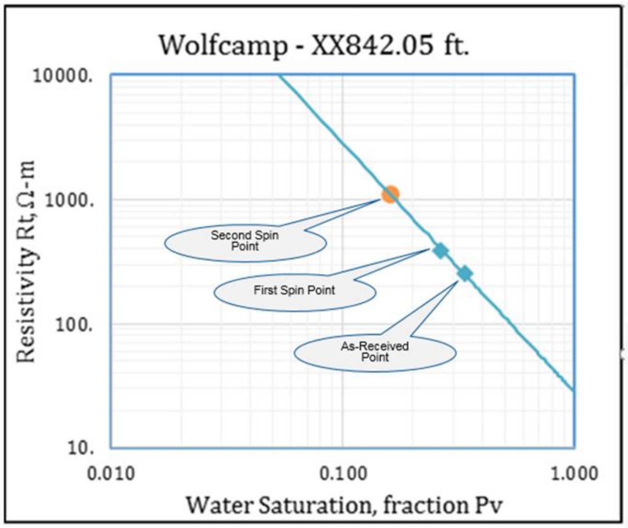
The cross plot illustrates the quantitative power that the 23 MHz HF-NMR brings to the equation in evaluating fluids left behind in tight rocks. Both rock quality and fluid properties can impact the amount of fluid that can be left behind, leading to erroneously low pore volume values measured with calibrated instrumentation. This technique provides more realistic values of storage capacity and is an important input into the petrophysical model and the evaluation of reserves.

As-Received Core Electrical Properties

As-received core electrical properties represent a new core analysis workflow designed to determine Resistivity Index (RI), Formation Factor (FF), and other petrophysical properties directly from as-received (AR) core samples. Unlike conventional methods that involve time-intensive core cleaning and wettability restoration, this workflow bypasses these steps. Shale and ultra-tight lithologies, which are significantly permeability-challenged, are particularly unsuitable for traditional plug-based cleaning and drying processes. These limitations often prevent the successful application of conventional electrical property measurements on such samples. With this new workflow, the need for cleaning, drying, and re-saturating the samples is eliminated, enabling efficient and accurate analysis of these complex lithologies without further alteration of wettability and clay structure. The workflow employs the use of RwCore™ a patented resistivity-base method that provides rapid Rw determinations on fresh preserved core samples.



Ro estimation from the AR and first centrifuge spin RT and Sw results. The initial centrifuge spin is equivalent to about 600 psi. The saturation exponent, n, is equivalent to the exponent of the power fit solution of the line of the desaturation series.

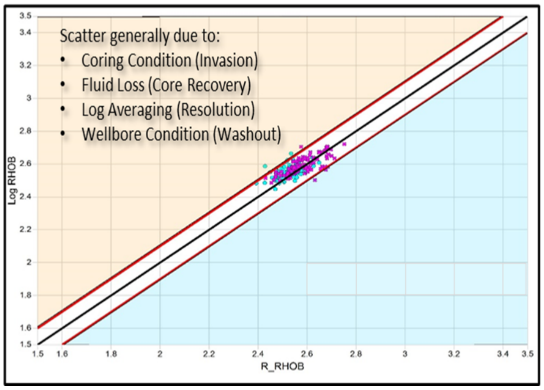


Ro estimation from the AR and first centrifuge spin Rt and Sw. The second spin results are represented as the orange circle. The second centrifuge spin is equivalent to about 1200 psi. Note that the second spin falls on the power fit trend line of the desaturation series.

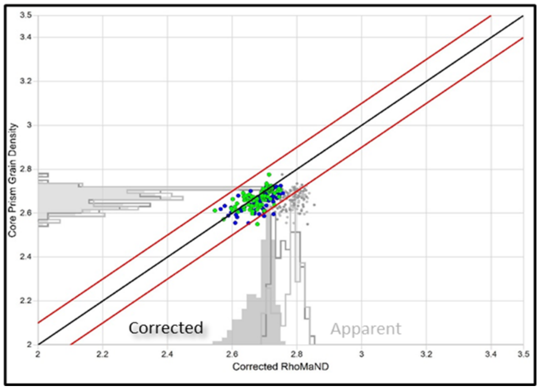
Log Application Workflow

Once the data has been obtained, the initial quality control is established by comparing the shifted core bulk densities from PRISM to the log to confirm a match between the core and log densities (+/- 0.1g/cc tolerance). Porosity modeling is conducted by utilizing the PRISM data and logging values as inputs into a series of multivariant models. An apparent grain density from the neutron and density log measurements (RhoMaND) is conducted to form an initiation point for the grain density model. RhoMaND is then corrected for the effects of TOC and clay on the respective logging measurements.

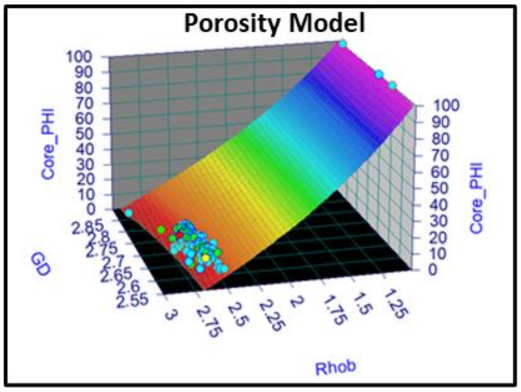
QC Cross-plot

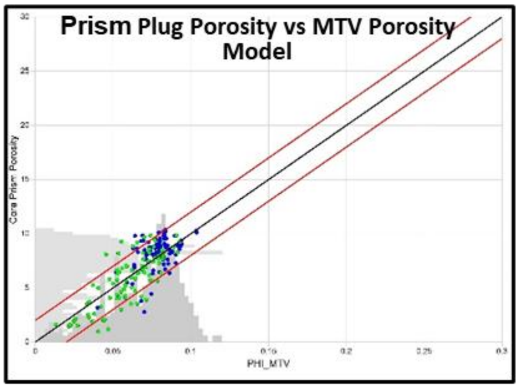

Scatter generally due to:
- Coring Condition (Invasion)
- Fluid Loss (Core Recovery)
- Log Averaging (Resolution)
- Wellbore Condition (Washout)

VAR_GD vs. PRISM Grain Density



The corrected grain density is then used as an input into the porosity model to upscale the core-based model to logs. Using the measured PRISM grain density and log bulk density as the independent variables and PRISM porosity as the dependent variable. This method allows for the model to remove the need for establishing a fluid density.


Porosity Model

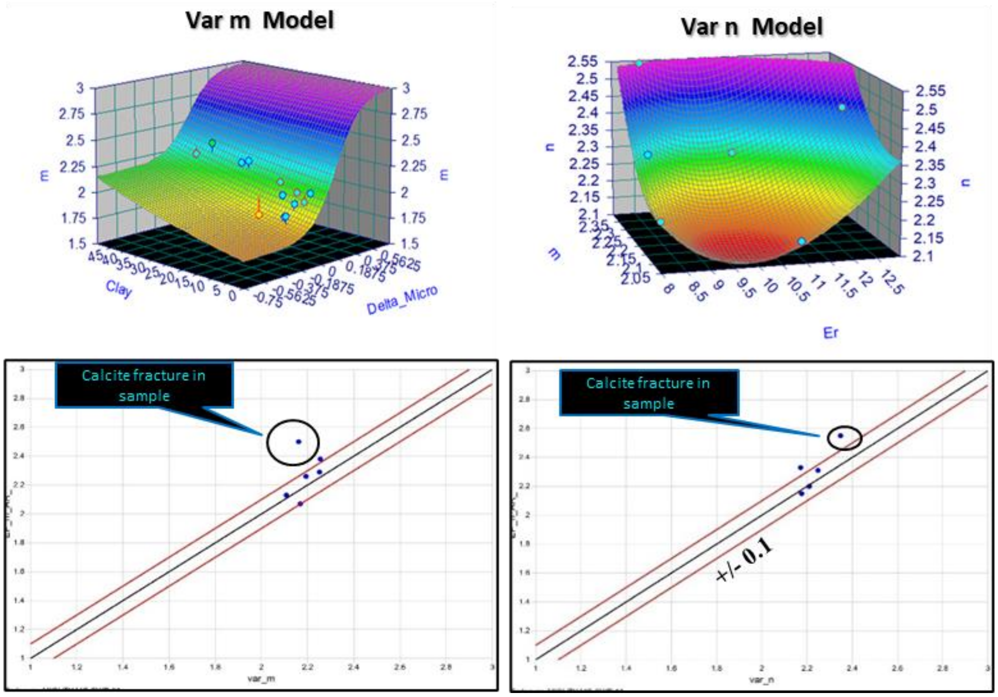

Prism Plug Porosity vs MTV Porosity Model

Saturation modeling has typically been conducted in block or zonal fashion, relying on single Archie parameter inputs for each identified zone. Analytical data supports that as reservoirs become more complex and heterolithic the zone style approach needs to be modified to accommodate. Our current workflow first evaluates indicators of changing clay speciation. Some examples of indicator references are spectral wireline data (for changes in thorium and potassium ratios), multifrequency dielectric measurements (changes in the delta between the lower frequency measurements shows potential change in clay type), and Gamma Ray intensity paired with changes in triple combo measurements. These relative indicators are coupled with measured XRD from core to determine their validity. Once clay speciation has been identified by zone a continuous effective water resistivity can be determined based on the RwCore™ measurements combined with total clay volume and parsed out by zones of variations in clay speciation. With this method, the modeled equivalent water resistivity (Rwe) can be used as a substitute for Rw in the Archie Saturation Equation. By doing so the Archie equation now considers a correction for the clay effect on the resistivity measurements making its functionality characteristic of a Modified Simandoux Saturation Model.

The remaining as-received electrical properties can be integrated in a variety of ways. A popular choice is through Pickett analysis by zone with comparison to the core measured values. This method, although expectable, runs into the previously stated issue of modern targeted reservoirs being more heterolithic in nature. An adaptation we have implemented is to utilize two different approaches for the cementation exponent “m.” The first approach is that of a multivariant method that takes the delta of micro-resistivity measurements and clay volume as the order pairs and the measured as-received “m” parament as the dependent variable. The secondary model is to solve for “m” by rearranging the apparent water resistance calculation. This requires the previously developed Rwe model as an input along with total porosity. By comparing the calculated “m” versus that of the measured, confidence in the modeled output and input variables is achieved when strong agreement exists. When available it is recommended to run both methods for validation purposes.

$$R_{wa} = \frac{R_t \times \phi^m}{a} \quad \Rightarrow \quad \frac{\log_{(10)}\left(\frac{R_{we} \times a}{R_t}\right)}{\log_{(10)}(\phi - \phi_{CBw})} = m$$

For the saturation exponent “n” we have found success in modeling it directly from the high frequency dielectric measurement. This method primarily works for tight reservoirs due to the shallow depth of investigation. The dielectric measurement is primarily controlled by the tortuosity of the water phase in the near wellbore environment, giving rise to the idea that the effects of “m” and “n” are combined and related to the recorded permittivity. That said we use the core calibrated continuous and variable modeled “m” as an input into a multivariant model along with the permittivity to solve for “n.”



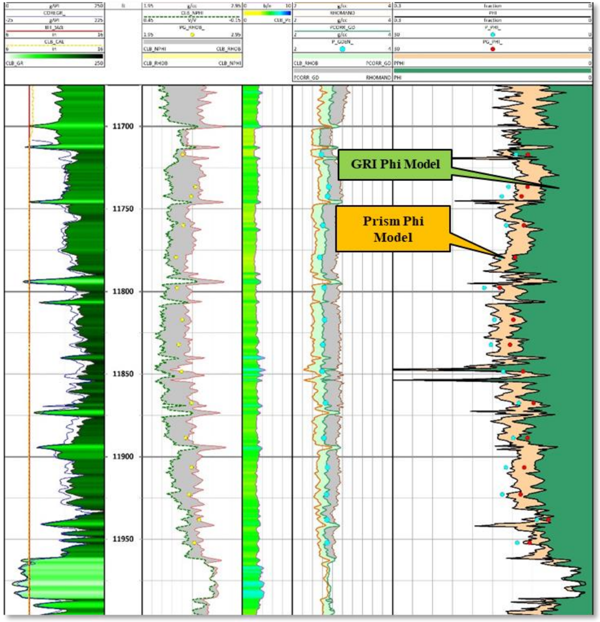
Calcite fracture in sample

Calcite fracture in sample

The resulting outputs from the various methods outlined above allow for continuous archie parameters that vary over sections based on changes in clay speciation, lithology, tortuosity, and fluid.

Conclusions

On average the PRISM protocol results in grain density measurements that 1.5 to 2.5% higher than that of standard GRI measurements. With a resulting increase of porosity from PRISM in the range of 5 to 20%. The increase is a direct result of the identification of fluids lost and or remaining in the samples during and after standard cleaning and preparation methodology.



The addition of as-received electrical property testing has led to a stronger understanding of clays' effect on the resistivity measurements. Through the acquisition of RwCore™ in various formations throughout the world we have had the privilege to see the effects of clay composition, volume percentage and dispersant effects on the resistivity logging signatures. Through these observations we have been able to identify the outlined protocol to correct for these effects via direct measurements that can be readily applied to the logs for refined saturation modeling. Also, the as-received measurements allow for Resistivity Index (RI), Formation Factor (FF), and other petrophysical properties to be obtained in rocks that do not allow conventional methods to be applied. By obtaining these measurements, more accurate porosity and water saturation models have been developed, which has given way to improvements in the modeling methods and understanding of the targeted reservoirs.

Novel/Additive Information

In addition to employing novel proprietary and patented technologies and analytical processes for the formation evaluation of unconventional and tight rock formations, a comprehensive petrophysical workflow has been developed to fully leverage these advancements. The approach outlined in this paper has been successfully implemented across numerous basins in North America and the Middle East.

Acknowledgements

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References

Newsham, K., Hanna, R., Lee, R., Whitney, C. (2018). As-Received Core Electrical Properties Test for Determining Formation Factor FF and Resistivity index RI. Society of petroleum Engineers. Paper 191476, ATCE, Dallas, TX, Sept. 24-26, 2018.

Ransom, R. C. (n.d.). *Dual-Water Archie, and the Importance of Water Geometry. A Model and a Discussion*. https://archieparameters.com

Reffell, O., Xie, Z.H., Carvajal-Ortiz, H., and Ramoin, J., 2022a, A Multidisciplinary Approach to Unconventional Petrophysical Reservoir Integrated Saturation Measurements, Paper 83, *Transactions*, *SPWLA 63rd Annual Logging Symposium*, Stavanger, Norway, 11–15 June. DOI: 10.30632/ SPWLA-2022-0083.

Reffell, O., Xie, Z.H., Davidson J., and Markell, J., 2022b, Evaluation of Shale Oil and Gas Formation Reservoir Quality Using a Multidisciplinary Workflow of Crushed Rock Core Analysis, Paper URTEC-3724027-MS presented at the Unconventional Resources Technology Conference, Houston, Texas, USA, 20–22 June. DOI: 10.15530/urtec-2022-3724027.

Xie, Z. Harry, and Omar Reffell. "Applications of Two-Dimensional Laboratory Higher-Frequency NMR in Unconventional Shale Characterization." *Petrophysics* 64 (2023): 848–863.