We invite resistivity/dielectric/imaging Presentations to be given at our SPWLA Resistivity Special Interest Group 17 June 2025 Meeting. Please email us with your titles and author's names. We encourage you to join this lively group of petrophysicist and electromagnetic specialist. The venue, lite breakfast, lunch, coffee provided by Halliburton. We appreciate Mark Wu and Michael Bittar for their time and resources.

Date: Tuesday, June 17th, 2025

TIME: 8:00 a.m. to around 4:45 p.m.

FEES: All Participants $10.00 registry through SPWLA

LOCATION:

Halliburton North Belt
3000 N Sam Houston Pkwy E, Houston, TX, 77032. Life Center Auditorium (second floor, LC 2220)

Registration Link

READ MORE and REGISTRATION

SCHEDULE:

8:00 AM 8:30 AM Breakfast and Registration

8:30 AM 9:00 AM Officer Introductions, Safety Brief by Halliburton
Nov 7th notes, Budget, and SIG Activities

9:00 AM 9:30AM

"Is UDAR technology ready for 3D environment?"

Michael Rabinovich, BP

9:30 AM 10:00 AM

"Characterizing the Response of a New LWD Micro-Electrical Imager for Oil Based Mud and Large Boreholes in Terms of Formation Wave Impedance and Mud Properties"

Roland Chemali, Well ID SA

10:00 AM 10:30AM

"A Robust Joint Inversion for Improved Structural Mapping in UDAR Applications Using Multiple Measurement Sensitivities and Uncertainties"

Mark Wu, Haliburton

10:30 AM 11:00 AM Coffee Break

11:00 AM 11:30 AM

“Recent Developments and Verifications for the Multi-Dimensional and Data-Adaptive Interpretation of Borehole UDAR Measurements”

Wardana Saputra, The University of Texas at Austin

11:30 AM 12:00 PM

“Geostopping With Ultradeep Electromagnetic Look-Ahead Technology to Mitigate Drilling Risks in Brazilian Presalt Carbonate Reservoir”

Mike Bower, SLB

12:00 PM 1:00 PM Lunch

1:00 PM 1:30 PM

“Electromagnetic Methods for Well Casing Evaluation – A Review of Principles and Applications”

Ahmed Fouda and Junwen Dai, Halliburton

1:30 pm 2:00 PM

“Vendor-Independent Adaptive-Model-Based Inversion of LWD Azimuthal Resistivity Data”,

Jair Sarmiento, ROGII Inc.

2:00 PM 2:30PM

“Geosteering Based on Formation Dielectric Properties Derived From LWD Measurements”

Jun Zhang, Baker Hughes

2:30 PM 3:00 PM Coffee Break

3:00 PM 3:30 PM

"Formation Resistivity Monitoring in CO_2 Reservoirs: Theoretical and Experimental Verification"

Shanjun Li, GeoPrance

3:30 PM 4:00 PM

“UDAR Horizontal Look Ahead Mapping Technology Identifies Fault Ahead of the Bit”

Jin Ma, Haliburton

4:00 PM 4:30 PM

“Time to Revisit Deep Dielectric Measurements? – Interesting Insights from Middle East Carbonate Reservoirs”

Raghu Ramamoorthy, NoHiddenPay

4:30 PM 4:45 PM

Closing Remarks

Regards,

Dean M. Homan DHoman@slb.com

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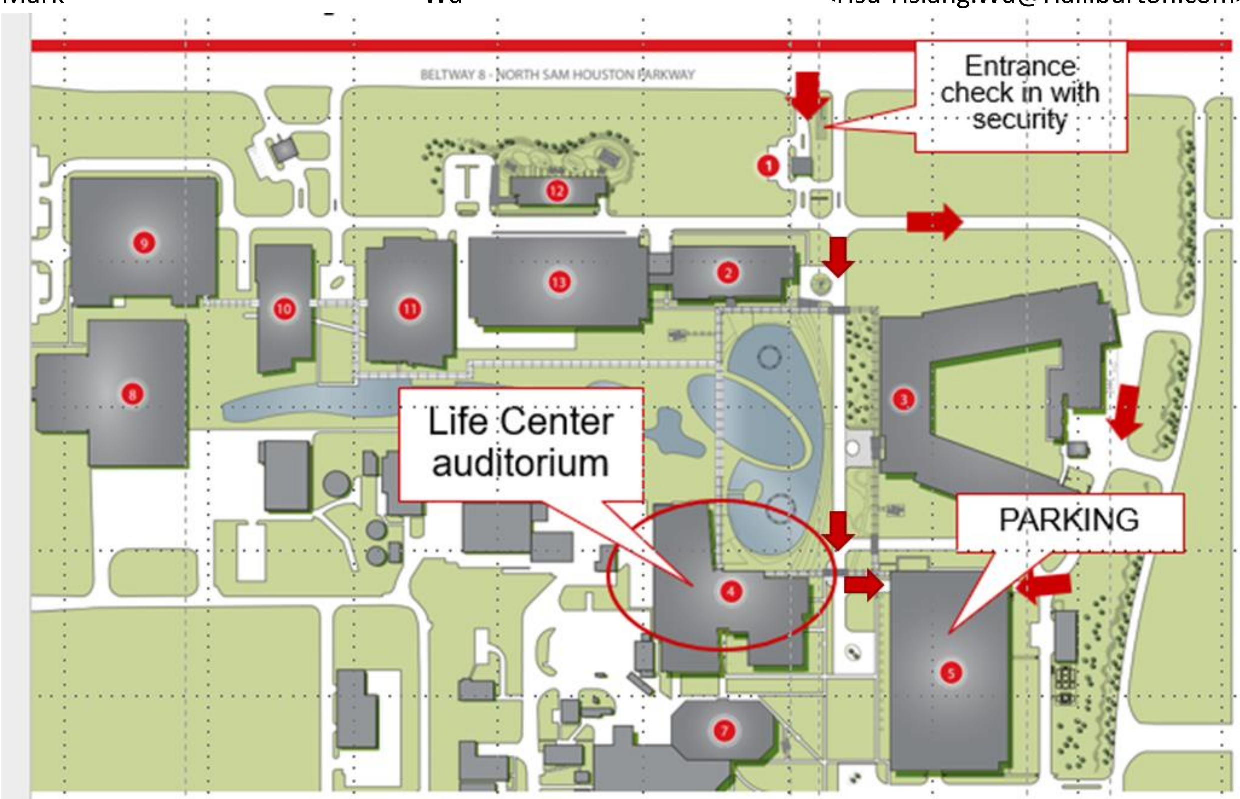
Location instructions:

First, please check in with Halliburton security at location #1 on the map. Then, follow the arrows to drive to the parking garage at location #5, which is right next to the Life Center (#4 on the map). Please note that the speed limit on our campus is 12 miles per hour. After parking, you can walk to the Life Center, take the stairs to the second floor, and you'll see the auditorium immediately upon arrival.

Let me know if you have any questions.

Thanks,

Mark Wu <Hsu-Hsiang.Wu@Halliburton.com>

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SPWLA Resistivity SIG 2025 June 17 Meeting

Abstracts of Presentations

Is UDAR technology ready for 3D environment?

M. Rabinovich, R. Ansari, J. Bergeron, and E. Soza, bp

The Ultra-Deep Azimuthal Resistivity (UDAR) technology has fully proven itself in 1D pan-cake slow changing geology where it is now a reliable and highly valuable service. Fast and accurate workflows for pre-drill studies, real-time interpretation and post-drill analysis based on local 1D modeling & inversion algorithms are established by the service provider and verified by operators in real well applications and in numerical studies using synthetic models. Several academic institutions and geosteering software companies also provide access to UDAR 1D modeling and inversion algorithms.

Infill wells in mature fields are often drilled in 3D environment. For example, operators regularly are looking for cheaper solutions with less environmental footprint by accessing multiple fault blocks with one horizontal well. A local 1D inversion (sometimes called as 1.5D) which is a standard real-time processing for all service providers is inadequate in intervals with 2D/3D effects such as faults with significant throws. It will create major artifacts and blind zones in 1D inversion images in intervals around the faults which, unless properly modeled and understood at the pre-drill study stage, could lead to wrong geosteering decisions. Ideally, applications of the more advanced 2D / 3D inversion algorithms could mitigate these problems, but currently available multi-dimensional inversions are limited in accuracy, resolution, speed and must also be properly examined at the pre-drill study stage.

Based on our experience and growing scope of work in industry, we strongly believe that to facilitate these 1D and 2D/3D pre-drill studies in 3D environments, standardized 2D/3D forward modeling and inversion workflows must be developed, and they should include:

- For pre-drill studies:
  - Streamlined and convenient workflows to populate and extract detailed geoelectrical models and trajectories from subsurface software such as Petrel.
  - User-friendly interfaces to build simplified 2D/3D catalog models.
  - Efficient, parallel, and accurate 3D modeling algorithms for simulating UDAR pseudo-raw data.
  - Detailed validation of vendor's forward modelling software to understand limitations and accuracy or limit usage to pre-validated softwares.
  - Access to vendors' standard 1D inversions to study and understand 1D inversion artifacts in 3D models.
  - Advanced 2D/3D inversion results in synthetic 3D models.
- For real time geosteering:
  - Catalog of 1D inversion results in a predefined set of simplified 2D/3D models.
  - 1D inversion should constantly output a. uncertainties b. misfits c. 3D indicators.
  - Geosteering engineers should be trained to recognize 3D artifacts in 1D images.

- 2D/3D inversion algorithms that have been verified on synthetic data and could be run in real time.

We recognize that developing accurate, fast, reliable and user-friendly 3D modeling workflows is a technically and financially challenging enterprise for each individual company, so we strongly believe that collaboration between operators, service providers and academia in the form of consortia and SIGs is necessary for facilitating these efforts and for creating benchmarks, sharing public domain UDAR information, developing and verifying 3D modeling codes.

“Characterizing the Response of a New LWD Micro-Electrical Imager for Oil Based Mud and Large Boreholes in Terms of Formation Wave Impedance and Mud Properties”

Roland Chemali (Presenter), Lars Oy, Jennifer Market, Well ID SA

A new LWD micro-electrical imager for OBM and large boreholes measures the radar signal reflected off the borehole wall. The new sensor operates at microwave frequencies (3.8GHz). It is important to understand what parameters govern the feasibility of the measurement and how these parameters affect the quality of the signal. Naturally, the characteristics of the borehole fluid, the borehole size, and the electrical properties of the formation each play an important role. In particular, the electromagnetic impedance of the formation and the electrical properties of Oil Based Mud (OBM) emerge as new key parameters. The object of this study is to develop a coherent predictive model to characterize the response of the new electric imaging sensor.

The study integrates theoretical methods, recorded logs, and laboratory measurements and verifies them against each other when possible. Because the reflection of the miniature radar echo is directly related to the impedance contrast between the OBM and the formation, it is natural to compute the wave impedance of the formation in terms of matrix permittivity, water-filled porosity, and water salinity. The traditional Archie’s equation and its variations are known to fail in the microwave range because of the phenomenon of resistivity dispersion, and because of the impact of the dielectric effect. A new formulation is proposed for the formation properties in the microwave range, based on the electromagnetic wave impedance and the Complex Refractive Index Method. The properties of OBM must also be modeled. They play an important role in the attenuation of the wave between the sensor and the borehole wall, and in the reflection coefficient at the borehole wall. Modeling the OBM is accomplished using the Hanai-Bruggeman equation. OBM emulsions lend themselves almost ideally to the Hanai-Bruggeman model, with oil being the continuous phase and the brine the discontinuous phase. The Wave Impedance of the OBM is derived in terms of the Oil/Water ratio for a range of brine salinities.

The results of the modeling of OBM agree with experimental laboratory data. OBM is in fact conductive at microwave frequencies. Furthermore, the amplitude from a recent image log exhibits a strong correlation with the wireline resistivity logs. The characterization of the radar sensor indicates that the range of operation of the miniature radar-based imager is quite large. A weaker signal is observed in tight intervals and in hydrocarbon bearing intervals. A stronger signal is present in high water-filled porosity intervals and in shales. Modelling and field test results show that the new LWD radar-based micro-electrical tool provides accurate and insightful images in OBM in a wide range of hole sizes, including large surface holes.

A Robust Joint Inversion for Improved Structural Mapping in UDAR Applications Using Multiple Measurement Sensitivities and Uncertainties

Hsu-Hsiang (Mark) Wu, Dagang Wu, Ting Yan, Jin Ma, Yijing Fan, Clint Lozinsky, and Michael Bittar, Halliburton

Recent advancements in deep and ultra-deep azimuthal resistivity tools (DAR and UDAR) have widened the scope of electromagnetic (EM) measurements available at various depths of investigations. These technologies have successfully enabled geosteering decisions based on a combined assessment of both azimuthal resistivity measurements. UDAR provides valuable insights into formations located farther from the wellbore, whereas DAR excels at identifying complex structures in close proximity. While UDAR and DAR may produce slightly differing resistivity measurements within a transition zone, typically spanning 15 to 30 feet from the wellbore, experienced geosteering engineers can enhance geological decisions by considering the inversion uncertainties and potential detection ranges associated with UDAR and DAR at specific formation profiles. Nonetheless, this approach involves numerous manual steps and can be time-consuming, potentially leading to subjective interpretations if conducted by engineers with limited experience and knowledge in azimuthal measurements and formation geology. Consequently, there is growing interest in automating the inversion process so that both UDAR and DAR measurements can be seamlessly incorporated.

A robust joint inversion technique incorporating both UDAR and DAR measurements has been developed to address the limitations of the traditional human-guided approach. The inversion technique accounts for the significant differences in sensitivity between UDAR and DAR measurements by employing weighted functions tailored to individual measurement types and specific inversion zones. These weighted functions are determined by the sensitivity of individual measurements, individual inversion outcomes, and their associated uncertainties. The joint inversion approach on the basis of different measurements at multiple steps is employed to fine-tune separate inversion zones, at the cost of longer calculation times or increased computational resources.

This paper evaluates various synthetic and field examples where both DAR and UDAR measurements are acquired within the same wellbore. Initially, independent inversion results are obtained using DAR and UDAR measurements separately. Subsequently, a joint inversion is conducted utilizing a multi-layer, multi-transition formation model to integrate both measurement types. Results demonstrate that the proposed joint inversion approach not only enhances the accuracy of formation property characterization but also extends the detection range into deeper formation layers. These improvements are achieved autonomously, without the need for manual intervention.

Recent Developments and Verifications for the Multi-Dimensional and Data-Adaptive Interpretation of Borehole UDAR Measurements Available

Wardana Saputra, Carlos Torres-Verdín, Joaquin Ambia, Bruce G. Klappauf, and Weichen Zhan, The University of Texas at Austin

Ultra-Deep Azimuthal Resistivity (UDAR) measurements provide advanced subsurface imaging capabilities by bridging the gap between traditional well logging and seismic interpretation. However, interpreting UDAR measurements in complex, spatially heterogeneous, or anisotropic formations remains challenging. Traditional 2D and 3D inversion procedures are computationally intensive and unsuitable for real-time applications.

We describe our recent developments in fast modeling and inversion algorithms for UDAR measurements. These algorithms are designed for multi-CPU clusters and tailored for integration with local 3D geological models and arbitrary well trajectories. Modeling employs a finite-volume solution of Maxwell's equations implemented on an adaptive Lebedev grid, effectively handling diverse formation complexities and tool configurations. A new block-based solver computes multi-input multi-output (MIMO) responses efficiently, significantly reducing runtime. Inversion is performed with a gradient-based approach (Occam-type) and incorporates regularization to account for noise and non-uniqueness. Furthermore, inversion complexity grows progressively from 0D to 3D, based on the localized dimensionality of both measurements and spatial distribution of electrical conductivity.

The method is successfully validated with challenging synthetic and field measurements acquired in the North Sea by various service companies. It is confirmed that the modeling and inversion algorithms are efficient, stable, and reliable for estimating the spatial distributions of anisotropic electrical conductivity around and ahead of the well trajectory. The Jacobian matrix is efficiently calculated and updated by the modeling algorithm, which is as accurate as the traditional perturbation method but five orders of magnitude faster. In addition, we observe that both data misfit and model uncertainty decrease as inversion dimensionality increases. Our adaptive inversion method also significantly reduces computational costs by triggering the expensive 2D and 3D inversions only when necessary. The current modeling algorithm has the potential to be further optimized for hybrid GPU-CPU implementation that enables real-time 2D and 3D inversions.

Geostopping With Ultradeep Electromagnetic Look-Ahead Technology to Mitigate Drilling Risks in Brazilian Presalt Carbonate Reservoir

Mike Bower, SLB (presenter)
Guillermo Marcelo Cuadros, Ligia Naia de Matos and Egor Kovarskiy, SLB

Ultradeep electromagnetic look-ahead technology has proven to be an effective solution for overcoming drilling challenges posed by magnesian clay-rich intervals within the Barra Velha carbonate formation in Brazil's presalt offshore Santos Basin. These intervals, composed primarily of kerolite and interstratified clays rich in smectite, contribute to operational risks such as borehole instability, fluid losses, fishing incidents, redrilling, and completion difficulties. When these magnesian clay-rich zones are encountered, they must be fully cased before drilling the permeable zone in the next phase. Failure to set casing at the optimal depth can result in significant non-productive time.

In this paper, we present how this Ultra-Deep Azimuthal Resistivity (UDAR) look-ahead technology was applied to detect the top of the high-resistivity carbonate reservoir and enable precise geostopping. Previous applications of this technology in the Santos Basin focused on detecting the transition from the extremely highly resistive evaporite section to lower-resistivity formations. However, in this scenario, an opposite conductivity contrast required a different downhole tool configuration and real-time operational workflows to detect the base of this magnesian clay-rich interval up to 15 meters ahead of the bit.

This work presents the technical challenges associated with the presence of magnesian clay-rich carbonates in Barra Velha and the limitations of the conventional geostopping workflow. It also presents technical details of the UDAR look-ahead technology implemented and an overview of the planning that preceded field implementation. It includes the criteria used to enhance detection depth ahead of the bit, such as frequency selection, measures to enhance signal-to-noise ratio, and an additional in-situ receiver antenna calibration.

Two case studies, covering planning, execution, and geostopping decision-making, support the proposed technical solution.

The successful adoption of this technology broadens its application in Santos Basin presalt operations and sets a precedent for applicability in other regions with similar geological challenges.

Electromagnetic Methods for Well Casing Evaluation – A Review of Principles and Applications

Ahmed Fouda and Junwen Dai, Halliburton

Well completions typically incorporate multiple barriers that are essential for supporting production activities and protecting aquifers from contamination. Monitoring the integrity of these barriers is critical to ensuring the reliability of oil and gas production while minimizing environmental risks. Ever since its commercialization a few years ago, electromagnetic multi-tubular inspection technology has become a valuable tool for diagnosing the root causes of metal loss in complex well completions and for enabling proactive remedial planning. In this talk, we provide a brief overview of the operating principles of electromagnetic multi-tubular inspection tools. We compare two excitation methods—frequency-domain and time-domain—and present case studies using full-scale fixtures and field data. These examples demonstrate the capabilities of the multifrequency electromagnetic pipe inspection tool equipped with multiple transmitter and receiver arrays to estimate the individual wall thicknesses of up to seven barriers. We also showcase its application in specialized completions, including dual completions and alloyed tubing.

Vendor-Independent Adaptive-Model-Based Inversion of LWD Azimuthal Resistivity Data

Jair Sarmiento, ROGII Inc. (presenter)
Mikhail Sviridov and Anton Mosin, ROGII Inc.

Deep and ultra-deep azimuthal resistivities are key well logging technologies for proactive reservoir navigation. The use of special inversion algorithms enables the recovering of actual resistivity distribution map around the wellbore from such measurements while drilling. Real-time analysis of this map identifies changes in the formation's structure along the wellbore allowing the drilling direction to be adjusted to reach target formations.

Fully automatic data-driven inversion methods allow obtaining unbiased formation models from the tool measurements only. However, if the measurement sensitivity is insufficient, these methods cannot reliably resolve formation parameters within the tool investigation area and may produce uncertain and unrealistic results. This paper presents a new deterministic inversion approach that is applicable to most azimuthal resistivity tools available on the market and overcomes the above limitation by adaptive incorporating a prior reservoir model into the inversion process.

The proposed approach uses 1D anisotropic layer-cake formation models and is based on finding the minimum of specially constructed cost function. The function is configurable by the users and may include 3-5 items, e.g. misfit (describing the difference between simulated and measured tool responses), penalty (preventing model parameters from leaving considered parameter domain), and 1-3 regularization items (improving the smoothness and consistency of inversion results, as well as their closeness to the prior model). The approach adaptively weights regularization items relative to other terms to provide the most reliable model both explaining the data and satisfying prior assumptions as much as possible.

The prior reservoir model can be either taken as a squared curve from the offset well, or constructed by the users from scratch, or taken directly from the geosteering cross-section with automatic launching the inversion in case of any changes done while the logging data correlation.

Unlike many existing techniques, the presented approach does not require the user to be deeply immersed in the inversion process and provide guidance for each model parameter. Since the model-based regularization terms are computed as an "integral" deviation between the prior and recovered models, the approach does not require any assumptions about the number of layers in the models. The approach can handle inadequate prior models provided as an input, returning almost data-driven results in such cases.

Two fast gradient-based algorithms are employed for local optimization: either a quite popular Levenberg-Marquardt or less common adaptive secant, that usually requires less iterations to find a minimum in case of significantly nonlinear tasks or working in zones with high values of the cost function. To prevent sticking in local minima, the method utilizes an advanced method of parameter domain exploration that generates preliminary models randomly, selects the most promising ones in terms of misfit and parameters' diversity for further analysis, and remembers already explored zones within the domain to make the process computationally effective.

The developed approach is high-performance because it is adapted for running on multicore computers through the parallelization over different inversion intervals, exploring points, and local optimizations corresponding to various combinations of regularizers' weights.

The approach enables statistical estimation of model parameters' uncertainty. For that, it collects all intermediate models which are evaluated while local optimizations and generates a sampling. This sampling is analyzed statistically, and the results are represented as predefined P10/P50/P90 percentiles describing possible scenarios of resistivity distribution around the well.

Application of the proposed approach is demonstrated on a series of synthetic scenarios and field cases from the Australian continental shelf, where ultra-deep azimuthal resistivity tools were used to penetrate multiple hydrocarbon-saturated targets located in complex geological environments with high structural uncertainty.

Employing prior reservoir model, the approach helps to resolve structural uncertainties, increase the reliability of inversion results and enable field operators to make more confident steering decisions.

Geosteering Based on Formation Dielectric Properties Derived from LWD Measurements

Jun Zhang, Baker Hughes

Recently, studying formation dielectric permittivity from LWD electromagnetic (EM) measurements has been an area of special interest. Beyond our previous efforts in comparing and validating derived LWD dielectric permittivity from various extracting methodologies, in this study, we report our latest progress in developing an innovative algorithm for utilizing the resulting LWD dielectric permittivity as a real-time geosteering indicator. Such breakthrough serves the purpose especially when other logging modalities do not provide enough facts for geosteering such as during underbalanced coil tubing drilling.

As well known, various polarization mechanisms give rise to the dielectric effect at LWD frequencies and make the dielectric permittivity especially dispersive at this frequency range. In addition, formation porosities may be derived from wireline (WL) dielectric measurements at multi-frequencies from 100 MHz to above 1 GHz. Therefore, we believe there must be a better usage of the dielectric constants derived from low MHz frequencies LWD, e.g. as a qualitative indicator related to formation porosities. In this study, our algorithm by analyzing the dielectric dispersion from the 400 kHz and 2 MHz frequencies concludes a new parameter that has the potential to be a real-time indicator for geosteering. Examples containing both

LWD and WL logs are shown to demonstrate the consistent correlation between LWD dielectric dispersion and formation porosities.
To study the dielectric dispersion relationship, LWD and WL dielectric constants are first plotted together vs frequencies across both ranges. It is observed that the slopes of the dispersion, especially at lower frequencies, are very different. Then a new log based on a unitless parameter defined by this dispersion relationship is generated. It has been validated that the new parameter correlated very well with the pay zones interpreted by WL logs, such as in a typical low resistivity pay (LRP) formation, where the LWD resistivities are constantly below 10 ohm.m. The new LWD dielectric dispersion log exhibits a stable pay zone interval whose values are below a threshold, e.g., 170. Thus, it can independently indicate the pay zone (<170) and has a great potential to become a real-time geosteering indicator, especially in such LRP formation, when other conventional logging parameters do not provide sufficient references.
In this study, an innovative algorithm deriving an indicator for geosteering from LWD dielectric constants is revealed and validated for the first time. It is one step closer to ultimately utilizing the dielectric properties estimated from LWD measurements for geosteering.

Formation Resistivity Monitoring in CO_2 Reservoirs: Theoretical and Experimental Verification
Shanjun Li, Weishan Han, Geoprance

To enable real-time monitoring of resistivity changes in CO_2 reservoirs, we propose an Underground Reservoir Resistivity Monitoring System that utilizes toroidal coils mounted outside the casing, functioning as both transmitters and receivers. To assess the feasibility of this approach, we conducted a series of studies:
1. A two-dimensional finite element method (2D FEM) code was developed to simulate the distribution of induced currents density around the transmitter toroidal coil and along the casing. Analysis of the simulation results led to the following conclusions:
 Induced current decay, phase shift, and flow velocity are effective indicators of changes in formation resistivity.
 Conversion charts between formation resistivity and current decay, as well as between formation resistivity and current phase shift, were generated.
 The depth of investigation (DOI) can exceed 30 meters.
2. A prototype tool was built, and experiments were conducted. The experimental results closely align with the trends observed in the simulations, confirming the viability of the proposed methodology.

UDAR Horizontal Look Ahead Mapping Technology Identifies Fault Ahead of the Bit Available
Jin Ma, Nigel Clegg, Arthur Walmsley, Nelson Suarez Arcano, Halliburton

Ultra-deep azimuthal resistivity (UDAR) technologies have been successfully deployed to identify resistivity changes ahead of the bit in near-vertical wells. To date, this has not been possible in horizontal wells due to 3D changes in resistivity, invalidating the 1D assumption. Instead, look-around inversions are used to identify boundaries in the vertical and lateral planes. Interpreted structure can be projected ahead, but only by assuming continuous boundaries. Many geological hazards cannot be predicted by this technique and require inversion with sensitivity ahead of the bit.

In a clastic reservoir a fault predicted from seismic data terminated a hydrocarbon-filled sand, resulting in a direct transition to unstable shale. In a horizontal well, drilling needed to stop prior to the bit entering the shale.

Look-ahead UDAR inversions deployed in near-vertical wells work by modelling the EM field for the formations already intersected, assuming that the bedding is perpendicular to the wellbore. This allows for the contribution of formations and fluids ahead of the tool to be isolated from the whole electromagnetic field and inverted for separately. This approach is unreliable in horizontal wells where the bedding is not perpendicular to the wellbore. Therefore, an inversion technology that resolves changes in three dimensions simultaneously is a better fit for horizontal wells. The 3D inversion is applied in an unbiased fashion to avoid false positives for fault detection. Nine tensor components are used from tool measurements to maximize sensitivity around and ahead of the tool. The position of the UDAR transmitter is critical, identifying a hazard after it has been penetrated is of limited use. Placing the transmitter 3 m from the bit and developing an inversion sensitive to a volume ahead of the transmitter makes this a viable geostopping tool.

The juxtaposition, across a fault, of a high-resistivity hydrocarbon-bearing sand with a low-resistivity shale is a structure with major impact on the electromagnetic field. It results in a large change in the measured components of the EM field prior to its penetration and provides the ideal environment to identify changes of resistivity ahead of the drilling assembly in a horizontal well. Sensitivity ahead of UDAR tools has been demonstrated previously in vertical wells and for casing detection in horizontal wells. Raw data analysis alone showed sensitivity to resistivity boundaries ahead of the bit, but 3D inversion is required to convert the measurements into an easily understandable geological model. The use of such novel technology in a horizontal well in the Norwegian North Sea resulted in sensitivity to the fault 23-25 m ahead of the bit. Drilling continued for a further 21 m, at which point the fault was clearly mapped immediately in front of the bit. Although the new horizontal look-ahead technology was not used in the decision to stop drilling, the progress made on UDAR technology takes the industry a step closer to identifying geological changes before they are penetrated and drive safer and more efficient well-placement operations.

Time to Revisit Deep Dielectric Measurements? – Interesting Insights from Middle East Carbonate Reservoirs

Raghu Ramamoorthy and Martin G. Lüling, NoHiddenPay LLC

Industry interest in deep dielectric measurements dates back to the 1960s and 1970s, when several oil operators and service providers developed wireline tools to measure the formation dielectric permittivity away from the borehole. Simultaneously, both academic and industry research explored interpretation methods to derive water saturation from the measured quantity. Water saturation derived from dielectric permittivity has been shown to be far less affected by salinity variations, which is an attractive feature/advantage in formations with mixed or unknown salinity. Several Middle East carbonate reservoirs have high salinity connate waters (180 - 220 kppm) and are subject to active water flooding with sea water (35 - 40 kppm). This mix of salinities makes the estimation of fluid saturations within the flood zone from resistivity or neutron capture logs very challenging due to uncertainty in the water salinity. Resistivity-based saturation estimates assuming either connate water or sea water can differ by more than 40%. At the same time, the water saturation estimate from dielectric permittivity is minimally affected by rock texture and wettability variations (Rasmus and Kenyon, 1985; Focke and Munn, 1987), both of which are known to greatly affect resistivity interpretation. However, deep dielectric measurements in saline boreholes or very conductive formations proved technically challenging when performed with conventional wireline logging devices. Hence, these measurements fell out of favor and virtually disappeared from the industry by the mid-1980s. However, recent enhancements in the processing of Logging While Drilling (LWD) propagation-resistivity logs have provided a quantitative estimate of formation dielectric permittivity in the undisturbed formation (Anderson et al., 2007; Luling, 2015).

We adopt this innovative method to process the LWD logs, which respects the fundamental physics of electromagnetic propagation and determines both conductivity and dielectric permittivity from the measured data. Before the introduction of this method the industry ignored permittivity information as an independent petrophysical parameter. Instead, they opted to empirically estimate permittivity as a function of conductivity which is then used to derive two independent conductivities. Our method allows rigorous model comparisons, which demonstrate a more accurate and numerically reliable and stable conductivity and permittivity output.

The dielectric permittivity is related to fluid saturation using well established mixing laws while applying a new interpretation of published laboratory data, which is applied to the frequency range of LWD logs. The present study offers "what if" computation results assuming different water salinities to substantiate the reduction in saturation uncertainty from the dielectric measurement compared to the uncertainty from only the resistivity measurements. Results are demonstrated both on simulated and actual logs of wells drilled into Middle East Carbonate reservoirs.

The results establish the advantage of dielectric permittivity for formation water-saturation computation in mixed-salinity formations. Our findings show that the estimated water saturation from permittivity is insensitive to the assumed water salinity. The method is vendor agnostic and has been applied to LWD EM propagation tools from several vendors that are described in the SPWLA Resistivity SIG database. The interpretation method is based on published algorithms and a new analysis of data from published laboratory studies. It is easily incorporated into existing petrophysical interpretation platforms and workflows.

The method can be applied to existing "legacy" logs as well as to newly acquired data. This feature provides an excellent cost-effective opportunity to use data acquired on in-fill wells to map saturation variations caused by water flood. The method can be simultaneously applied to data from multiple vendors, thereby substantially increasing the applicability across the history of the reservoir development. Dielectric permittivity from LWD propagation measurements represents a powerful new tool for reservoir characterization and management in carbonate reservoirs.