NEW WIRELINE DIELECTRIC DISPERSION LOGGING TOOL RESULT IN FLUVIO-DELTAIC SANDS DRILLED WITH OIL-BASED MUD

Clarke Bean, Scott Cole, Keith Boyle, Chevron Australia
Djisan Kho, Thomas J. Neville, Schlumberger

Abstract

A new dielectric dispersion tool delivers a highly accurate shallow resistivity measurement in a variety of borehole environments. This new-generation dielectric tool differs from previous tools by incorporating a new antenna array on a fully-articulated pad, thus avoiding many of the environmental effects that plagued dielectric logging in the past. A further enhancement is that the new tool makes measurements at multiple frequencies from approximately 20 MHz to 1 GHz with collocated transverse and longitudinal transmitter and receiver arrays.

The new tool was recently used for the first time in Australia in several wells drilled with oil-based muds. Results from the dielectric tool were compared with results from traditional methods in two of these wells. These wells tested Triassic-aged fluvial and deltaic sands and shales on the Northwest Shelf, offshore Australia. In high-resistivity pay zones with resistivity greater than 100 ohm-m, the shallow resistivity measurement from the dielectric tool was superior to standard shallow array induction measurements and, in some places, seemed more representative than even the deep array induction measurements.

Dispersion processing uses the data acquired at multiple frequencies to calculate water-filled porosity. In pay sands, by combining the water-filled porosity from dielectric dispersion measurements with total porosity from density-neutron, water saturation can be calculated that is independent of formation salinity and does not require special core analysis measurements of electrical properties. The salinity of the water in the formation can be determined from conductivity and permittivity dispersion when conditions are favorable. Pre-job planning is essential because not all borehole conditions allow for accurate evaluation of all applications.

Results for water saturation are consistent with conventional calculations from mineral-based log analysis, magnetic resonance data, and Dean-Stark core-plug saturation measurements.

Several other applications were tested, even though pre-job planning indicated only a low-moderate chance of success. Determination of shale porosity, assumed to be water-filled, was tested against two types of core analysis which showed the tight sand and shale porosities to be in the 2 to 5 p.u. range. Dielectric dispersion results in shale intervals were generally close to the core plug porosity in one well and the total magnetic resonance porosity in the other.

In a gas reservoir where significant oil-based filtrate invasion took place, the water-filled porosity was very similar to the bound-fluid volume measured by the magnetic resonance tool. This observation reveals a new application for the tool as an alternative for faster bound-fluid logging.

Another application was formation water salinity determination. Pre-job planning suggested a moderate chance of success only for reservoir-quality sandstones. In clean sands, the dielectric results showed a fair match compared to in-situ salinity measurements from core plugs. However, in shaly sand and shale, the results are possibly affected by the high conductivity of clay-bound water. Further work has been proposed to improve the salinity inversion in shale.

Introduction

Propagation of high-frequency electromagnetic waves is controlled by the conductivity and dielectric permittivity of the medium in which the waves are propagating (Hizem et al., 2008). Dielectric permittivity is a measure of how the medium interacts with the applied electric field through polarization, which can take place through a variety of mechanisms operating at different length scales and over different frequency bands (Figure 1). Several of these mechanisms only operate on water molecules or ions in solution. Therefore, the dielectric permittivity is a strong
function of the volume, properties, and distribution of the water; hence there is interest in using dielectric measurements in formation evaluation.

Dielectric wireline logging based on single frequency measurements was introduced in the late 1970s (Calvert et al., 1977) primarily to determine water-filled porosity independent of resistivity as well as salinity-independent water saturation, and to identify and quantify these properties in thin beds. By the early 1990s, industry interest in this technology waned because of the many wellbore environmental problems, such as borehole rugosity, that caused a lack of robustness in measurements from the first-generation dielectric tools.

A new-generation dielectric tool was introduced in 2007 and has several features designed to overcome the shortcomings of previous tools (Hizem et al., 2008). A new antenna array with collocated transverse and longitudinal transmitters and receivers is set on a fully-articulated pad that is run in contact with the borehole wall, thus avoiding many of the environmental effects that plagued dielectric logging in the past. The new tool makes measurements at multiple frequencies from approximately 20 MHz to 1 GHz, allowing for evaluation of the dielectric dispersion, i.e. the change in dielectric properties as a function of frequency. Analysis of dielectric dispersion allows for the separation and quantification of the different effects influencing the dielectric measurement, such as water volume, water salinity, and rock texture. This also allows for reconstruction of resistivity at the direct current (DC) limit, equivalent to extrapolating frequency to zero.

Most of the publications on this dielectric dispersion tool have covered applications in water-based mud environments, especially in heavy oil reservoirs (Mosse et al., 2009; Little et al., 2010), thinly-bedded reservoirs (Pirrone et al., 2011), conventional clastic and carbonate reservoirs (Al-Qarshubi et al., 2011; Arora et al., 2010; Decoster et al, 2010; Mude et al., 2010; Schmitt et al., 2011), and oil shale reservoirs (Selezniov et al, 2011). The new-generation dielectric dispersion tool was recently tested in a series of wells drilled with oil-based mud (OBM) in Australia. This paper discusses the tool’s applications in OBM wells.

The dielectric dispersion tool can be run in combination with most standard wireline logging tools and has a higher temperature rating (175 °C) than many standard tools. The combination of high operating frequency and small transmitter/receiver spacing puts the depth-of-investigation approximately 2.5 to 10 cm into the formation, making this a true invaded-zone measurement. This small spacing between antennas in conjunction with the borehole compensation method used to combine different antenna measurements also allows for practical resolution of beds as thin as approximately 6.5 cm in OBM. The conductivity measurement used to output the resistivity curve has the accuracy of ±1% or ±0.5 mS. While wellbore logging conditions and desired applications can affect the logging speed, the tool can commonly be run at speeds up to 1000 m/hr (or 3600 ft/hr). This is much faster than nuclear magnetic resonance (NMR) logging tools, which may be run to achieve similar logging objectives (i.e., bound-fluid measurement in reservoirs at irreducible water saturation and total porosity measurement in shales).

TEST WELLS AND LOGGING OBJECTIVE

This paper shows results from two wells drilled off the Northwest Shelf of Australia, with approximate locations shown in Figure 2. This region is well-known as a prolific gas-prone region where many new gas discoveries have been announced over the past 5 years. The targeted zones of interest in both wells are a series of Triassic-aged fluvial and deltaic sandstones. These sands are typically clean, with kaolinite as the dominant clay mineral, making up to 20% of the mineral volumes. Porosity is typically in the 15- to 25 p.u. range. Sand thicknesses range from beds that are tens of meters thick in the fluvial channels, to beds that are tens of centimeters thick in the deltaic distal distributary system.

Well A is a development well that, while directional, intersected the reservoir vertically. It was targeted to penetrate all major reservoir sands well above the field’s gas/water contact (GWC). The logged interval was drilled with an 8.75-in. bit. Bottomhole temperature (BHT) was 165 °C. In this field, gas sands tend to have very high resistivity; several hundred ohm-m is not uncommon. Since the gas sands are drilled with OBM, one expects that there would be no significant difference between resistivity in the invaded zone and in the uninvaded formation, assuming only gas has been displaced by the OBM filtrate. Well A was conventionally-cored, and all target sands have full core coverage. A comprehensive suite of core analysis was conducted in this well, and the results are compared to the dielectric dispersion tool’s results to help validate the accuracy of the dielectric measurements and processing.

In Well A, the dielectric dispersion tool was run in combination with spectral gamma ray, induction resistivity, litho-density, neutron, and neutron-induced gamma-ray spectroscopy tools. For this toolstring, the
logging speed was controlled by the requirements of the density and neutron tools and chosen to be 550 m/hr (1800 ft/hr). Had NMR been part of this toolstring, logging speed would have been approximately 140 m/hr (450 ft/hr). A subsequent logging run of an OBM imager and dipole sonic supplemented the first toolstring’s measurements. Given this rich dataset, the well was considered the best candidate to test the capability of the new dielectric dispersion tool in OBM.

The objectives for the dielectric dispersion tool in well A were as follows:
- Provide an accurate invaded-zone resistivity.
- Determine water-filled porosity in shales, a necessary parameter to determine effective porosity in the petrophysical models used for this field. The shales are assumed to be 100% wet, and expected to have low porosity in the 3 to 9 p.u. range. This is a parameter that is currently only measured by NMR tools or core-plug tests.
- Independently evaluate water-filled porosity in gas sands. These sands are targeted far enough updip from the GWC that we can safely assume that water-filled porosity is equivalent to bound-fluid porosity. This bound fluid divided by the total porosity gives irreducible water saturation. This can be tested against Dean-Stark measurements on core plugs to determine if the dielectric-based water saturations are accurate.
- Evaluate in-situ formation water salinity. In many fields throughout the world, it is being discovered that formation water salinity in the hydrocarbon leg is different from salinity as measured from water samples taken in the water leg (McCoy, et al., 1997; Clinch, et al, 2010). Ideally, we would like to be able to evaluate salinity in both sands (to enhance water saturation calculations) and shales (to help in estimation of the resistivity of bound water in shales for use in dual-water and other petrophysical models).

Well B is a vertical exploration well. This well penetrated a series of variable quality fluvial channel sands, with a mixture of gas, low-saturation “fizz” gas, and wet sands. The intermediate and total-depth sections were drilled with 12.25-in. and 8.5-in. bits, respectively, with a BHT of 135 ºC. An interval of well B was conventionally cored, and rotary sidewall samples were obtained as well. NMR was also acquired, so direct comparisons can be made of the measurement of water-filled porosity against NMR bound-fluid volumes.

In well B, the dielectric dispersion tool was run in combination with NMR, neutron-induced gamma-ray spectroscopy, and a formation pressure test tool. This toolstring was run at a logging speed of approximately 140 m/hr (450 ft/hr), in order to acquire good NMR data.

The objectives for the dielectric dispersion tool in well B were as follows:
- Evaluate water-filled porosity in gas sands. Conventional and sidewall core were taken in the target reservoirs to obtain both conventional core analysis measurements and Dean-Stark water saturation. The dielectric dispersion measurement could be tested against the core measurements as well as the bound-fluid volume computed from NMR.
- Evaluate in-situ water salinity. Well B penetrated several reservoirs with expected variations in water salinity between 14 ppk and 20 ppk.

Job planning is essential to ensure that downhole conditions are suitable for the tool to deliver quality results. The input parameters are the expected formation resistivity and the expected oil/water ratio in the OBM. Figure 3 shows that the water-filled porosity objective can be achieved in the reservoir sections in both wells. However, meeting this objective is less likely in the shale zones, especially in well A.

RESULTS

Older generation dielectric tools were very sensitive to borehole rugosity, so we were interested how the new tool performed. The new dielectric dispersion tool is run eccentered, with the antenna array mounted on a fully-articulated pad, which was predicted to have greater stability in the face of rugosity. Figure 4 shows several intervals where the caliper indicates some washout, yet the invaded-zone resistivity in track 2 and the water-filled porosity in track 4 seem reasonable and stable. This degree of washout would have caused older generation tools to read a combination of formation and borehole, yielding invalid results.

Reservoir units in the Northwest Shelf commonly have clean sands with resistivity values above 100 ohm-m. Under such conditions, the raw conductivity measured by standard array induction logging tools is so small that the error associated with the measurements can be greater than the actual measurement. This error affects the shallow arrays more than the deep arrays (Barber and Shray, 2001). Figure 5, track 2, shows a typical high- resistivity induction response in a well drilled through gas sands using OBM. Note in track 3 that the invaded-zone resistivity from the dielectric dispersion tool matches the deep induction curve, as would be expected. Any petrophysical application that uses invaded-zone water saturation as a basis for calculation
would benefit from this more accurate invaded-zone resistivity measurement. In places, such as depth x980 m in Figure 5, even the deep induction seems to have some noisy zones of unrealistically-high resistivity. In these zones, the dielectric dispersion measurement of resistivity has a lower uncertainty than conventional induction measurements.

The short antenna spacing of the dielectric dispersion tool permits better bed resolution than standard wireline induction or LWD propagation resistivity tools. We have observed that the vertical resolution of the dielectric dispersion measurement is almost the same as an OBM imager, but the signal is stable. Even in thick channel sands, shoulder bed effects on deep resistivity measurements causes the measured response to be pessimistic for 1 to 2 m over the bed boundary. This in turn biases water saturation calculations. Figure 5, track 3 compares resistivity from the dielectric dispersion tool to a standard wireline induction. Track 4 compares with resistivity extracted from an OBM imager. Note the many noise spikes throughout the interval in the image resistivity data. Depth x993 m is an example where the dielectric bed resolution is particularly sharp. In these bed boundary zones, water saturation calculated using standard equations with the dielectric-based resistivity will prove to be more accurate.

In Well B, accurate invaded-zone resistivity from the dielectric dispersion tool shows effects of OBM filtrate invasion. Figure 6 shows a sand occurring in a transition zone, relatively near a GWC. The resistivity in track 2 from the conventional induction tool shows little separation between shallow and deep induction curves. Comparing the invaded-zone resistivity measurement from the dielectric dispersion tool to the uninvaded-zone resistivity measurement from the induction tool showed that, in the sand, the very near wellbore volume was being extensively flushed by OBM filtrate, even though this was not seen on the induction log. Track 3 density and neutron logs show that the sand is very low porosity, and inferred to be low permeability, thus susceptible to filtrate invasion. Track 4 shows the differences of calculated invaded zone water saturation when the shallow induction log or the dielectric invaded-resistivity ($R_{inv}$) curve is used. The dielectric tool is showing that significant amounts of OBM filtrate have invaded this sand.

One of the outputs of the dispersion processing is a calculated water-filled porosity. In sands that are hydrocarbon-filled, if one divides the water-filled porosity by the total porosity (as determined by conventional methods such as density/neutron), the ensuing calculated water saturation does not require knowledge of water salinity, nor any of the electrical “Archie” parameters that otherwise require measurement on core samples. In both test wells, the water saturations from dielectric dispersion measurements in gas sands were very consistent with calculations from the resistivity-based methods. Results from well A are seen in Figure 7a. Track 2 compares the wireline deep induction to the dielectric-based resistivity. Track 3 shows that in the pay sand, saturation from dielectric dispersion measurements matches the saturation calculated from standard log calculations and the Dean-Stark core measurements. Similar kinds of results are seen in Figure 7b taken from exploration well B. Well B combines both conventional and sidewall core data, as well as NMR and conventional density, neutron, resistivity and sonic logs. Track 3 shows that the water volume from dielectric dispersion measurements is very similar to the bound fluid from NMR and the Dean-Stark core measurements.

An application that was less certain from the pre-job planning was whether the total porosity of shales could be accurately determined. In these test wells, the shale porosity is assumed to be 100% water-filled. In Well A, the shale porosity was expected to be in the 3 to 7 p.u. range, while Well B is shallower, and shale porosity was expected to be in the 6 to 9 p.u. range. Since many petrophysical models use shale porosity to calculate effective porosity, the dielectric dispersion tool’s ability to deliver accurate results is important. Figure 8a shows how the dielectric measurement of shale porosity matches core plug measurements in well A. There were two different methods employed to measure core porosity in shales: standard routine core analysis with high temperature drying and a bulk volume mercury immersion technique (details in API RP40). The two methods yielded very similar porosity results. Recall that, as shown in Figure 3, pre-job planning predicted that interpretation of the dielectric dispersion data would be challenging in shale zones in the 2 to 5 ohm-m range. In Figure 8a, track 2, the depth range x185 m to x192 m shows shales which have this lower resistivity. Track 6 indicates a poor match between core porosity and dielectric-based water-filled porosity in these low resistivity shales. Slightly deeper, from x192 m to x206 m, the shale resistivity increases into the range where pre-job planning indicated a 50/50 chance of getting good data. Here we note that the dielectric-based water-filled porosity is consistently about 2 to 3 p.u. greater than core porosity. For many applications, this may be “good enough” accuracy. From x206 m to x213 m, the lower gamma ray in track 1 combined with the clear change in sediment color from the core photos in track 4 suggest this to be a silty-sand formation. Even though the porosity and
permeability of this zone are very low, the neutron curve in track 3 and the systematically low dielectric-based water-filled porosity suggest that this zone is gas-charged. There are higher resistivity siltstones and shales in zones x213 m to x218 m and x227 m to x230 m where the dielectric-based water-filled porosity matches the core data nicely. Pre-job planning (Figure 3) would predict good quality data in this zone.

Figure 8b is a comparison of water-filled porosity in shale derived from the dielectric dispersion tool and from NMR in well B. Because of controversy about the accuracy of core porosity measurements in shales, some petrophysicists consider NMR porosity in shale to be the accepted standard. The comparison in Figure 8b shows a very close match between the two methods. Zones xx85 m to xx90 m, xx30 m to xx37 m, and xx67 m to xx71 m are good examples of this match. So, while the match between porosity in shales derived from dielectric dispersion measurements and core porosity was not always perfect, the accuracy of the dielectric water-filled porosity in shale becomes good when compared to NMR porosity, a reference for many standard applications.

Similarly, we observed that the dielectric-based water-filled porosity shows a good match with volume of bound fluid from NMR in sands, both gas-filled and wet. Referring again to Figure 8b, in the pay sands in the depth range xx08 m to xx28 m as well as xx60 m to xx68 m, the comparison to NMR bound-fluid volume is quite good. The implication here is that under certain circumstances the dielectric dispersion tool will deliver an equivalent bound-fluid volume measurement at faster logging speeds and at higher temperatures than NMR tools in gas sands and shales.

Another application that was evaluated is the estimation of formation water salinity. Ideally, one would like an answer that would be accurate enough if salinity in the reservoir’s hydrocarbon leg is the same as or different than what can be measured from water samples in the water leg. Well A was selected because there were some pre-existing water samples taken from wet sands in previously-drilled wells, and the newly-acquired conventional core allowed for some “crush and leach” plug tests to measure in-situ water salinity. Details about the crush and leach techniques can be found in API RP40, Pan (2005), and Clinch et al. (2010). Table 1 shows the results of the core plug tests, evaluated in both sandstones and shales. Table 2 shows the results of water salinity measured from previous fluid samples taken from other wells in the field. The measured water sample salinities are about 10,000 to 15,000 ppm lower than what was measured by dielectric dispersion measurements and core tests. However, these differences do not lead to a significant change in calculated water saturation, given the very high formation resistivity.

Figure 9, from the pre-job planning, is to confirm that the formation salinity can be inverted properly for in clean sandstone zones. The parameters needed are the expected formation salinity and the BHT. Figure 9 shows that calculating accurate formation salinity in well A would be difficult because of the high temperature of the well. Figure 10a shows salinity evaluation from the dielectric dispersion tool measurements in well A. In the gas sands, the salinity predicted by dielectric dispersion is reasonably close to the in-situ values determined from the core plugs in the clean sands near x900 and x260. Given the uncertainties of both sets of measurements, one could argue that this is mere coincidence, but similarities between the two sets of results is striking, and both sets are yielding results that are approximately in the same range as the measured water samples from Table 2.

Figure 10b is an example of salinity evaluations from two zones in well B: a clean sand containing a gas-water contact (GWC) at depth x77 and a clean wet sand at the base of a shalier wet sand. Track 3 shows the dielectric dispersion results plotted against apparent water resistivity from standard log calculations, and the salinity obtained from a formation tester water sample. Even though pre-job planning predicted that salinity predictions in this zone would be of good quality, we see that the dielectric dispersion salinity is noisy in the water legs, and above the GWC it is significantly higher than the measured water samples.

In the shaly sands and shales of both wells, the dielectric dispersion tool is predicting salinities that are significantly greater than measured values. Dielectric dispersion is a reflection of a number of rock properties, including water volume, water salinity, rock texture, and, in clay-rich rocks, phenomena associated with the electrical double layer. Although models have been developed to separate these different effects (Han et al., 2012), they rely on the higher sensitivity of the lowermost frequency dielectric measurements to interfacial effects. It is also these lower frequency data that are more sensitive to environmental effects in wells drilled with OBM. For this reason, a simplified model was used that treats the additional dispersion inherent in clay-rich rocks in terms of an effective equivalent salinity. This salinity is significantly higher than that obtained from salt extraction from core samples in the shales; however it may be representative of the overall electrical effect of the clay-water system.
CONCLUSIONS

The new dielectric dispersion tool performs as anticipated for several applications in wells drilled with OBM.

- The performance of the invaded-zone resistivity from the dielectric dispersion tool is equivalent to that of standard induction measurements in the 2 to 100 ohm-m range, and superior to induction where resistivity is greater than 100 ohm-m.
- Vertical resolution appears similar to OBM imagers, but with a more stable resistivity measurement.
- With adequate pre-job planning, the dielectric dispersion processing yields highly accurate answers for water-filled porosity in clean sands and reasonably accurate porosity in shales.
- Accurate determination of formation water salinity in OBM may be possible, but was not demonstrated in this study. Pre-job planning showed that environmental factors resulted in a very low chance of getting accurate formation salinity predictions in well A, but that we should expect accurate results in well B. Neither well showed dielectric dispersion salinity values that seemed particularly successful.

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REFERENCES


ABOUT THE AUTHORS

Clarke Bean is a Technical Lead Petrophysicist working for Chevron in Perth, Australia. He received a B.A. degree in geology from Albion College in 1978, and a Master’s degree in geology from Indiana University in 1981. Starting with Chevron in 1981 as a Development Geologist, he spent almost 10 years in various geological assignments before moving into petrophysics permanently. Since then, he has worked on a variety of projects in the Gulf of Mexico, Kuwait’s Greater Burgan sandstones, and Australia’s Northwest Shelf.

Scott Cole is a Senior Petrophysicist with the Chevron Australia Exploration Asset. After completing a B.Eng from the University of Western Australia, he joined Schlumberger from 1990 to 2001 where he worked as a Wireline Field Engineer and Service Delivery and Field Service Manager. In 2001 he joined Crocker Data Processing in Perth, Australia as a petrophysicist and Petrophysical Software Development Manager. In 2008 he joined Saros as Director of Petroleum Services and in July 2012 he accepted a full-time position with Chevron.

Djisan Kho is the Principal Petrophysicist working as Petrophysics Domain Champion for Schlumberger, overseeing the wireline logging operation in the Western Australia region. He received his engineering degree (Hons) from Bandung Institute of Technology and joined Schlumberger as wireline field engineer in 1994. He was assigned in different countries in the Far East and the Middle East of Asia, before attending Schlumberger Log Analyst Training in Houston in 2000. He has held several positions including marketing staff, senior petrophysicist, technical team leader, and project manager. He was the formation evaluation advisor for Schlumberger-KOC North Kuwait Jurassic Gas Development project before moving to Perth.

Tom Neville is Asia/Australasia Petrophysics Advisor for Schlumberger, based in Kuala Lumpur, Malaysia. Tom joined Schlumberger in 1996 and since that time has held a variety of technical and managerial positions in operations, engineering, and research, primarily in North America and Asia/Australasia. Prior to joining Schlumberger, Tom worked for 6 years as a geologist and petrophysicist with a number of independent operators in Australia. He has a BSc (Hons) in geology and mineralogy from the University of Queensland, Brisbane, Australia.
Fig 1 Polarization mechanisms influencing dielectric permittivity in rocks (after Hizem et al., 2008).
**Fig 2** Well locations on the Northwest Shelf of Australia.

**Fig 3** Operational range of the dielectric dispersion tool in OBM with test well conditions. Green shows the best conditions for tool operation; yellow, moderate tool operation; red, conditions out of operational range.
**Fig 4** Dielectric tool dispersion measurements in rugose borehole. Caliper in track 1 shows up to 2 in. of washout. Dielectric curves (red) in track 2 and track 4 are not affected.

**Fig 5** Dielectric dispersion-based invaded-zone resistivity compared to shallow conventional induction (track 3) and OBM imager measurements (track 4).
**Fig 6** Transition zone sand drilled with OBM. The induction response in track 2 shows no hints of invasion; however, elevated invaded-zone resistivity from the dielectric dispersion tool indicates OBM filtration displacing water. Track 4 shows water saturation ($S_w$) calculated for the uninvaded zone (pink) and $S_w$ calculated from the invaded zone using dielectric invaded-zone resistivity ($R_w$) curve (olive).
Fig 7a Data from Well A. Track 3 is a comparison between water saturation from the dielectric dispersion tool, standard calculations from wireline logs, and Dean-Stark core measurements.

Fig 7b Data from Well B. Track 3 is a comparison between water saturation from the dielectric dispersion tool, Dean-Stark core tests, and NMR bound-fluid volume.
Fig 8a Data from Well A. Track 4 displays core photos in plain light. Track 5 shows results from dielectric-based water-filled porosity in shales. PWXO is water-filled porosity of the invaded zone. Note two different methods of measuring core porosity of shales, both yielding similar results.

Fig 8b Data from Well B. Comparison between dielectric water-filled porosity, NMR bound-fluid and total porosity from density-neutron. Log-based results are compared to core total porosity and Dean-Stark wet porosity.
Table 1 Well A results of in-situ water salinity measured using the residual salts crush and leach technique on conventional core plugs.

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<th>Sample Depth (meters)</th>
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Table 2 Data from wells near Well A. Salinity results of water samples recovered from drill stem testing.

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<th>Salinity (ppm NaCl)</th>
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**Fig 9** Formation salinity inversion limit for clean sandstones.
Fig 10a Track 3 shows a comparison of dielectric-based water salinity and the residual salts analysis from core plugs in Well A. FSXO is formation salinity of the invaded-zone.

Fig 10b Water samples (indicated by blue dots) taken from two wet sands with a comparison between the calculated dielectric water salinity and the Archie apparent water resistivity in track 3.