DIELECTRIC DISPERSION MEASUREMENTS IN CALIFORNIA HEAVY OIL RESERVOIRS

J.D. Little, Schlumberger; D.R. Julander and L.C. Knauer, Chevron U.S.A. Inc.; J.T. Aultman and J.L. Hemingway, Schlumberger

ABSTRACT

Dielectric measurements have been used over the past thirty years in a variety of reservoirs to determine flushed zone water-filled porosity in formations with fresh or unknown water salinity. This measurement is particularly useful in heavy oil reservoirs because little invasion occurs, making oil saturations of the uninvaded and invaded zones approximately equal. A new dielectric measurement provides dielectric permittivity and conductivity at multiple depths of investigation as a result of multiple frequencies, receiver spacings, and polarizations.

This next-generation dielectric measurement is collected over a large range of operating frequencies using an array of antennas with two separate orientations. A total of nine measurements of attenuation and phase shift are made at four different frequencies, allowing for a true measure of dielectric dispersion. Inversion of these measurements computes a simple water-filled porosity, as was done with older generation dielectric tools based on a single permittivity measurement. By measuring permittivity and conductivity at different frequencies, antenna spacings, and orientations it is possible to construct a water-filled porosity invasion profile.

Inverting all the measurements makes it possible to solve for salinity, invasion depth, and other environmental parameters that led to unpredictable results with previous-generation single-frequency tools. Further processing will make it possible to solve for textural parameters such as saturation and cementation exponents or cation exchange capacity.

Formation evaluation in the oil fields of California has always been challenging. Probably the biggest challenge faced by log analysts years ago was the difficulty of distinguishing oil from fresh formation water. This was further complicated by the inability to distinguish producible oil from oil that was not movable. Recovery factors were often 20% or less, which led to many attempts at enhanced oil recovery, of which steam floods have proved to be the most successful. This paper discusses the application of this new dielectric dispersion measurement in mature heavy oil reservoirs and features examples from California.

INTRODUCTION

Dielectric measurements have been used in California since the mid-1980s to indicate the location of hydrocarbons in fresh water (<20,000 ppm total dissolved solids (TDS)), heavy oil reservoirs. Due to the low salinity of the formation waters in the area, accurate estimates of hydrocarbon in place are difficult to obtain using resistivity measurements and conventional water saturation models. Further complicating the problem is the fact that many of the reservoirs have been under steamflood or waterflood for 45 years or more, and the present water salinity is unknown. To aid in the effort of locating hydrocarbons and quantifying the hydrocarbon saturation, the electromagnetic propagation tool (EPT tool) was added to the standard suite of logs for Chevron U.S.A. Inc. in California. This tool has proved especially useful in heavy oil reservoirs where little invasion by the drilling fluid occurs. The tool measures flushed zone water-filled porosity, and because the invasion effects are minimal, this flushed zone porosity is approximately equal to the uninvaded zone water-filled porosity. Running the EPT tool in conjunction with standard neutron-density logs gives an indication of the oil saturation in the flushed zone by comparing the water-filled porosity from the EPT tool with the crossplot porosity output from the neutron-density logs or preferably a computed total porosity from a petrophysical analysis. This saturation allows Chevron U.S.A. Inc. to locate the hydrocarbon in place and to decide where to complete the well.

While the benefits of using the EPT tool have been readily accepted in heavy oil reservoirs, the tool has its limitations. The tool’s mandrel design makes it quite sensitive to borehole rugosity. Many of the reservoirs in California are unconsolidated sandstones, which are held together by the viscous oil originally contained within. In depleted zones, where the oil has been swept by the advancing steamchest, borehole rugosity is a recurring problem. Of additional interest to Chevron U.S.A. Inc. is the residual oil saturation in the steamchest, but this parameter can be difficult to obtain from the EPT measurements because of borehole conditions. Temperature plays a large part in the EPT...
measurement, and in the steamflooded areas the temperature profile does not follow a linear gradient as assumed for most EPT interpretations. The saturations measured in the heated zones can be in error owing to the lack of temperature corrections applied to the raw data.

Figure 1 shows the inherent interpretation problem when using a single-frequency dielectric measurement to determine an accurate water-filled porosity. To address these shortfalls and expand the capabilities of petrophysical interpretation, a new dielectric dispersion tool has been developed based on modern high-frequency sensors. electronics, which addresses many of the petrophysical challenges of the California heavy oil reservoirs. The new dielectric tool provides information previously not attainable from traditional dielectric tools as well as delivers the highest quality data, even in difficult logging conditions.

The design of the new dielectric tool incorporates an articulated pad, which improves contact with the formation in rugose boreholes. The measurement sensors are on a skid similar to that of the latest generation density tools. Dielectric permittivity is measured at varying frequencies, antenna spacings, and antenna orientations. An inversion incorporating each of these measurements results in a water-filled porosity curve in two radial zones (if invasion is present and within the tool’s sensitivity volume) along with estimated salinities and textural information about the formation. The two water-filled porosity measurements improve the ability of the log interpreter to discern the changes occurring in the flushed zone. Also, because the measurement is made at different frequencies (Figure 1) established relationships between dielectric dispersion and rock textural effects can be investigated. The tool also records pressure, temperature, borehole diameter, mudcake conductivity, and permittivity. These measurements allow for the correction of environmental effects that made interpretation of the data output from previous-generation tools difficult.

A diagram of the new dielectric tool is shown in Figure 2. The design is based on new-generation density tools to optimize pad contact with the borehole. The pad design with two transmitters and eight receivers plus two mudcake probes is also shown. Raw measurements of attenuation and phase shift from the pairs of transmitters (T, T) are made for each receiver (R, R) spacing and at all four frequencies. In addition, these measurements are made in both the transverse and longitudinal orientations. An inversion of all these measurements allows solving for water-filled porosity at different depths of investigation. Water salinity as well as textural parameters such as the cementation exponent m and CEC can also be derived (Hizem et al., 2008).

The new dielectric tool has been run in several wells in the San Joaquin Valley of California to determine the potential applications in the heavy oil reservoirs of the region. This paper discusses the improvements that this tool brings over the previous dielectric tool and the applications that have been found to be of particular importance to Chevron U.S.A. Inc. Data examples will be provided from two San Joaquin Valley oil fields: Cymric Field and Kern River Field.

FIELD OVERVIEW

Kern River heavy oil steamflood - The Kern River Field is located in the southeastern part of the San Joaquin basin on the Bakersfield Arch, where it impinges on the foothills of the Sierra Nevada Mountains (Figure 3). The main producing interval is the Kern River Formation, which is Miocene to Pleistocene in age. The Kern River Formation is the interval used for the EPT and the new dielectric tool comparisons subsequently described in this paper as field examples 1 and 2. The Kern River Formation is mostly unconsolidated fluvial (braided stream and channel) sand...
deposits interrupted vertically by silts and clays. It is overlain by Pleistocene alluvium. The producing sands range from 50 ft to 1,600 ft deep. The reservoir is divided into nine intervals of oil-saturated sand bodies. Average reservoir properties for the Kern River sands are 31% porosity, 3,000-md (500- to 10,000-md) permeability, and 40% to 50% oil saturation. The oil is 12–13 API gravity. Production commenced in 1899 and steamflooding was developed at Kern River in the early 1960s. Production increased to 140,000 bopd in the mid-1980s and is currently 77,000 bopd from 9,600 producing wells. Cumulative production passed 2 billion barrels in 2007.

Fig. 2 - Tool diagram and layout of transmitter and skid for the new dielectric tool.

Cymric heavy oil steamflood - The Cymric Field is located along the southwestern margin of the San Joaquin Valley (Figure 3). One of the main oil-producing intervals in the Cymric Field is the Tulare Formation, which is Pliocene to Pleistocene in age. The Tulare Formation is the target interval for the EPT and new dielectric tool comparison described subsequently in field example 3. The Tulare comprises poorly consolidated, fluviodeltaic sandstones bounded by shales. It is overlain by Pleistocene alluvium. Average reservoir depths are in the 700- to 1,200-ft range. A typical well has anywhere from five to eight sandstone intervals that are oil bearing. Average reservoir properties for the Tulare sandstones are 34% porosity, 2,000- to 3,000-md permeability, and 55% to 65% oil saturation. The oil is 9 to 14 API gravity. The Tulare Formation has produced oil since the early 1900s, but the introduction of steamflooding in the 1970s accelerated exploitation of these reservoirs. The Tulare sandstones continue to be the target of steamflood development.

FIELD EXAMPLES

1 - Water saturation example in a fresh-water clastic environment, Kern River Field, California - Water saturation calculations from resistivity logs in Kern River have been difficult to obtain owing to the extremely fresh formation water. The formation water salinity is typically less than 2,000-ppm chlorides but varies considerably. Injection of steam over the past 45 years has altered the salinity of the original formation water. Techniques for determining water saturation that rely on resistivity are not reliable.

Before dielectric logs were added to Chevron U.S.A. Inc.’s standard logging suite, it was a common practice to take a full core from selected wells to identify formations with oil production potential. It was also common to shoot a suite of sidewall cores in most new wells for immediate identification of fluid contacts and to help with well completion decisions. These practices were expensive and relatively inefficient.
Starting in the 1980s, dielectric measurements such as the EPT tool (1.1 GHz) and a deep-reading dielectric tool (DPT tool) (25 MHz) were employed owing to their ability to measure water-filled porosity with little sensitivity to salinity. In the 1990s, measurements were made in cased hole with carbon/oxygen (C/O) tools because the C/O ratio is sensitive to oil volume rather than water saturation and therefore is not dependent on formation water salinity (Seleznev, 2006).

**Figure 4** shows a sequence of sands and shales at Kern River. There is little variation in the resistivity or porosity of the sands. Comparison of the resistivity response with the lithology track on the right shows that it reads approximately the same in all sands. Only one interval in this section contains significant hydrocarbon saturation: the interval from 1,140 ft to 1,165 ft. Oil saturation is approximately 45% based on water-filled porosity from the new dielectric tool. This is verified by the C/O log, which was run in cased hole a few weeks later. The oil-saturated interval between 1,140 ft and 1,165 ft is indistinguishable on the resistivity log from other intervals above and below that contain close to 100% water (e.g., the underlying sand at 1,195 ft to 1,210 ft). This example is one of the most obvious applications of dielectric logging for calculating water saturation.

Track 2 of Figure 4 compares water saturation calculated from the dielectric log in open hole along with the oil saturation derived from the cased hole C/O log. Differences in response are due primarily to the different vertical resolutions. C/O logs have a vertical resolution of 1.5 ft under the best conditions. Dielectric logs have a vertical resolution of 2 in for the EPT measurements and 1 in for the new dielectric tool measurements. Environmental sensitivity is much improved with the new-generation dielectric tool owing to the use of modern high-frequency sensors, which are contained in an articulated pad. The older EPT tool required the use of microwave wave guides, making it a mandrel type of measurement that was much more sensitive to borehole rugosity.

Track 4 in Figure 4 shows a porosity overlay between total porosity calculated from density-neutron and the dielectric tool water-filled porosity. In wet sands and shales the porosities overlay, while in hydrocarbon-bearing intervals the dielectric-derived water-filled porosity reads lower. The difference in porosities between total porosity (black curve) and water-filled porosity (red curve) can be clearly seen in the hydrocarbon-bearing zone from 1,140 ft to 1,165 ft.

**Figure 5** is an expanded view of the same hydrocarbon-bearing interval in Figure 4. The thin sand at 1,138 ft appears to have similar properties and oil saturation as the thicker sand below it. However, its thickness of less than 2 ft is too thin to be properly resolved with a C/O measurement, although the C/O measurement is somewhat responsive to this thin sand. Two saturation outputs from the new dielectric tool are shown in Track 2 and two water-filled porosities from the dielectric tool are shown in Track 4. These are from the shallow invaded zone and deep invaded zone measurements using radial-profile processing from all the receiver arrays and frequencies. The interesting feature here is very little invasion in this section. This is common in these heavy oil-saturated formations—especially a formation such as this which has not been heated. Formation temperature in this interval is approximately 100 degF. In heavy oil reservoirs with shallow invasion, computed oil volumes from dielectric measurements compare nicely with oil saturations from C/O logs, which have been demonstrated to be extremely accurate in this environment (Zalan et al., 1995; Harness et al., 1998).

![Figure 4 - Kern River data example.](image)

**Figure 6** shows a section of whole core taken from a nearby well at Kern River. Typically there is very little invasion of drilling mud filtrate owing to the heavy oil. This is not true in the water-productive intervals, where the drilling fluid can easily invade the formation.

This section of core, 14 in. in length, is typical of sands in the Kern River field. The sand itself is unconsolidated and is described as being held together by the viscous oil. The section of core shown is from a sand that is 11 ft thick. The
upper section has been heated with steam and is depleted to a depth of 889 ft. The section shown from 891 ft to 892 ft has been heated somewhat, which has allowed for the slight invasion of 0.25 to 0.5 in., which can be seen along the edges of the core.

2 – Low-salinity heavy oil reservoir, Kern River Field, California - Figure 7 shows the standard triple-combo logs that are commonly acquired in the Kern River Field. Water zones are not easily identified owing to the low formation water salinity. Formation water from this reservoir is in the range of 100 ppm up to 2000 ppm, making the water fresh enough to water nearby crops and livestock. This specific property makes identification of oil from standard log measurements challenging. Track 3 shows a standard deep resistivity (red dashed curve) and a shallow $R_{sh}$ resistivity (green curve). A quick look at the resistivity log response over this interval would lead one to believe that all the sands had the same water saturation. There is no invasion profile evident because the drilling mud and formation water have similar resistivities. Comparing the resistivity response with the lithology displayed on the right shows that the main factor influencing resistivity is the shale content of the formation. Track 4 shows the sigma measurement that was made later in cased hole with a pulsed neutron capture (PNC) tool. PNC tools are very useful in the identification of oil in reservoirs within a more normal formation water salinity range of ~ 40–50 ppm or higher; however, it can be noted that no sensitivity to oil vs. water is seen in the low salinity ranges present at Kern River. As with the resistivity log, sigma responds primarily to lithology in this environment. Presented in Track 5 are oil saturation estimates from the cased hole C/O log (black curve) and the deep measurement from the new dielectric tool (red curve). Based on visual comparison, there is good agreement between these two saturation estimates. Presented in Track 6 is a volumetric representation of formation and fluid volumes based on C/O interpretation. Track 7 shows equivalent formation and fluid volumes based on the new dielectric tool measurements. The results are very similar, providing confidence that the dielectric tool can deliver equivalent information to that provided by the well-accepted pulsed neutron C/O method.

3 – Saturation profiling in heavy oil reservoir, Cymric Field, California - Presented in the composite display of Figure 8 are the results of a full petrophysical interpretation. In this case, the measurements driving this interpretation come from two sources, Platform Express integrated logging system and the new dielectric tool log data. Several tracks are presented for comparison of porosity and saturation, first with core data and also legacy EPT water-filled porosity. A key is provided in the nomenclature appendix that lists the physical meanings of all the curve names. In this display, a water zone is easily identified at the bottom of the interval (below 840 ft). The producing intervals are between 530 ft and 830 ft.

In heavy oil reservoirs, one of the more interesting aspects of the production can be attributed to API gravity variations. This can often times be seen in terms of hydrocarbon mobility, as indicated in the invasion process. In this particular example, there are no indications on the resistivity
Fig. 7 - Low-salinity heavy oil reservoir. Notice the resistivity, porosity, and sigma responses across this entire interval. The low $S_w$ interval at 1,425 ft looks nearly identical to the 100% $S_w$ intervals above and below in terms of resistivity, porosity, and sigma response. In this plot, DS represents saturation as determined by the new dielectric tool and C/O represents saturation as determined by C/O measurements from the reservoir saturation tool.
Fig. 8 - Saturation profiling in a heavy oil reservoir, Cymric Field, California.
logs that any mobile hydrocarbon has been displaced with mud filtrate. If invasion had occurred, separation would have been observed between the resistivity logs. However, little separation is observed in this example.

Validation of petrophysical work is best achieved through a direct comparison between interpretations from downhole measurements and what can be measured in the laboratory. In this case only sidewall core samples were collected, so only samples that have preserved enough mechanical integrity can be compared. The black dots in Figure 8 show the laboratory measurements of porosity (CPOR in Track 7) and water saturation (CSWM in Track 5) from the core plugs. Both are in reasonable agreement with the petrophysical results.

In non-heavy oil reservoirs, it is normal for core measurements of water saturation to be representative of the flushed zone saturation and, therefore, underestimate oil volume in comparison with uninvasion zone saturations derived from log measurements. In this heavy oil example from Cymric Field, however, the match between core- and log-derived estimates of water saturation is generally quite good, indicating minimal invasion and flushing effects.

The new dielectric tool is designed with a fully articulated short pad that allows optimal contact with the borehole wall even in rugose holes. This is a significant improvement from the legacy EPT tool. This improvement is demonstrated in zones: 690–710 ft and 740–755 ft. These intervals appear to be washed out and nearly filled with mudcake. The environmental effects impact both the flushed-zone resistivity from Platform Express tool (RXOZ) and water-filled porosity from the EPT tool. However, data from the new dielectric tool is generally unaffected by these borehole problems. This is evidenced as follows. First, the RXOZ curve reads significantly less than AHT90 or RXD_AD1 in the washed-out intervals (Track 4 of Figure 8). Above and below these two intervals, the three resistivity logs are in fairly close agreement. Without the data from the new dielectric tool, one could easily misinterpret the difference between RXOZ and AHT90 at about 700 ft and 745 ft as being due to invasion. Second, in the far right-hand track (Figure 8), water-filled porosity from the EPT tool (PHI) and porosity from new dielectric tool (PWXD_AD1) overlay in most intervals. However, in the two washed-out zones, they read quite differently. PHI (EPT tool) should overlap the PWXD_AD1 curve, but it reads too high (by ~10 pu) in these zones. If this were used to estimate water saturation, the calculation would yield an $S_w$ estimate that is too high by 23 SU. That in turn would lead to an estimate of hydrocarbon saturation that is 23 SU too low and might lead an operator to bypass two potential pay zones. However, the data from the new dielectric tool do not suffer from this problem and yield hydrocarbon saturations that match sidewall core saturations quite nicely—even in the washed-out intervals (Track 5, Figure 8). As shown by this example, the new dielectric tool is able to provide a high-quality result—even in rough hole—allowing for a more confident determination of hydrocarbon saturation.

A crossplot of the highest frequency dielectric permittivity and dielectric conductivity shown in Figure 9 also captures the frequency dispersion from this measurement on the z-
axis, with large dispersion shown in blue and low dispersion in red. A clear water point is indicated on the plot, with water-filled porosity increasing from the origin to the water point. Lines of constant salinity can also be drawn, with the lowest salinity on the right side of the data cloud and a second higher salinity bounding the data cloud on the left side.

4 - Comparison of legacy measurement conductivity (from EPT tool) with new dielectric tool measurements: Example in a fresh-water clastic environment, Kern River Field, California - In Track 2 of Figure 10 the legacy EPT-G measurement system is compared with two independent conductivity measurements: shallow conductivity from a microresistivity log (MCFL) and the deepest conductivity from standard 90-in. array induction. In Track 3, similar comparison is made between the deep conductivity measurement from the new dielectric tool and the same two conductivity measurements. Clearly, the legacy EPT-G system is struggling to make a stable measurement of conductivity, whereas the deep inverted conductivity from the new dielectric tool compares very nicely with both traditional measurements. Careful inspection shows that this holds true for the full range of borehole sizes encountered in this well (approximately 8.5 to 10 in.).

Conductivity data from the legacy EPT-G tool (Track 2, Figure 10) suffer from two effects: (1) the data show MSFL and array induction tool, and (2) there is a persistent offset between EPT conductivity and the other two conductivities. Neither of these effects is apparent in the deep conductivity curve from the new dielectric tool (Track 3, Figure 10) in the same conductivity comparison. The reasons for the EPT conductivity behavior are the lack of dispersion corrections, because the primary measurement is made at only one frequency (1.1 GHz), and the effects of small borehole defects for which there is no applicable correction. If one were to incorporate the EPT conductivity data from Figure 10 into a petrophysical interpretation, the end result would be an erratic model with false indications that there is significant invasion into the formation.

Historically speaking, when a separate measurement of conductivity was required for a petrophysical analysis, the EPT tool was unable to deliver a reliable conductivity estimate. Consequently, other conductivity logs (e.g., MSFL) were commonly used. Such measurements were not always optimal, because the depth of investigation of the measurement varies as a function of the measured resistivity. This resulted in an increase in the uncertainty of the interpretation, which then cascaded through to some of the other parameters that were estimated (e.g., cementation exponent m).

Fig. 10 - Comparison of legacy EPT and new dielectric tool measurements with two conductivity logs.
Unlike the conductivity curve from the EPT tool, the new dielectric tool outputs two conductivity curves (shallow and deep), and both are stable and reliable. This is because the variation in depth of investigation has been corrected through inversion of the 72 raw conductivity measurements that are collected by the new tool. With a stable conductivity output, the new dielectric tool data can now be incorporated more confidently into petrophysical interpretations.

CONCLUSIONS

From the San Joaquin Valley examples presented in this paper comparing and contrasting the two dielectric logging tools, the legacy EPT tool and new dielectric dispersion tool, it can be seen that the dielectric dispersion measurement brings valuable information for reservoir evaluation and management decisions. This new high-resolution measurement has been shown to provide equivalent saturation information to that provided by the well-accepted pulsed neutron C/O measurement of oil saturation when formation water is fresh or salinity is unknown. Additionally, porosity and saturation from the interpreted results are shown to be in very good agreement with laboratory measurements from sidewall core samples. It has also been shown that the improved transmitter receiver array and borehole compensation of the new dielectric tool design do a better job of successfully navigating significant rugosity and mudcake than the EPT tool, providing a much improved answer. Finally, the advantages provided by application of dispersion corrections to the multifrequency data of the new dielectric tool results in several significant advantages over single-frequency EPT measurement: the delivery of two measurements of water-filled porosity at different depths of investigation, which enables a much more definitive invasion analysis, and the delivery of stable, reliable conductivity measurements that can be used for more advanced applications, such as textural analysis.

ACKNOWLEDGMENTS

The authors would like to thank Chevron U.S.A. Inc. for its support during the field test of this new technology and for allowing these examples to be published. We would like to thank Mehdi Hizem, Ollivier Faivre, Laurent Mossé, and Martin Luling of the Schlumberger-Riboud Product Center, Clamart, France, for their efforts in developing the new dielectric dispersion technology. Finally, we would like to thank Anthony Lucas, Schlumberger, Denver, Colorado, USA, for providing the reservoir saturation tool interpretation results shown in this paper.

REFERENCES


ABOUT THE AUTHORS

Jeffrey Little Principle Petrophysicist and department head, Petrophysics Data and Consulting services, Schlumberger Bakersfield California. Jeff has 29 years of industry experience. Starting as a field engineer Jeff worked in various field assignments including California land and offshore operation, deep desert operations Syria, and as high pressure and temperature specialist in the North Sea. Jeff has been working in the area of log interpretation and application development since 1995. He earned his BS degree in physics from CSU Durango in 1981.

Dale Julander Currently Senior Staff Petrophysicist for Chevron U.S.A. Inc.’s San Joaquin Valley Business Unit, Bakersfield, California. Dale has 27 years of industry experience—all of it based in California. Dale earned his BS degree in geology from the University of Puget Sound, Tacoma, WA, in 1980. He earned his MS degree in geophysics from the University of Utah in Salt Lake City, UT, in 1982.

Larry Knauer Currently senior geologist with Chevron U.S.A. Inc. Kern River Technical Team, Bakersfield, California; Project Manager Kern River Reservoir Monitoring Program. Earned a BS in geology from Whittier College 1976 and an MS in geology from UCLA in 1982.
Jason Aultman Currently represents Schlumberger as Wireline Sales representative for the Chevron U.S.A. Inc. account in Bakersfield, CA. Jason has 5 years of industry experience, which began as a field engineer in Midland, TX. He earned his BS degree in chemical engineering from the University of Florida in 2005.

Jim Hemingway started with Schlumberger in 1980 and has held various log analyst and engineering positions with Schlumberger since 1982. James received a BS degree in chemistry from Emporia State University in 1978 and a BS degree in chemical engineering from Texas A&M University in 1979. He has worked extensively on pulsed neutron spectroscopy interpretation techniques. He moved to Paris in 2001 as a new technology advisor responsible for developing applications of new technology for formation evaluation. He has been based in Houston since 2010 as a Petrophysics Advisor.

APPENDIX: NOMENCLATURE

ADTPRO – processing software for the new dielectric tool
API Gravity – relative measure of hydrocarbon density
AT90 – 90-inch induction resistivity
AT60 – 60-inch induction resistivity
AT30 – 30-inch induction resistivity
AT20 – 20-inch induction resistivity
AT10 – 10-inch induction resistivity
ADT – new dielectric tool
Carbonate – volume representation for calcite or dolomite
CXO, CXOZ – conductivity measurement in flushed zone
Dispersion - phenomenon in which the phase velocity of a wave depends on its frequency
CXO – EPT – conductivity measurement form EPT and EPT-G tools
C/O – carbon/oxygen ratio, reservoir saturation tool
CPOR – core porosity measurement
CSWM – core measurement of water saturation
Caliper – measurement of the inside diameter of an oil well
Carbonate – volume representation of calcite and/or dolomite
CEC – quantity of positively charged ions (cations)
Conductivity - reciprocal (inverse) of electrical resistivity, $\rho$
Crossplot – specialized chart comparing multiple measurements
CXO – conductivity measurement in flushed zone
Dielectric - electrical insulator that may be polarized by the action of an applied electric field.
ELAN – petrophysical interpretation software
EPT, EPTG – electromagnetic propagation logging tool
EPSI $f_0$ – dielectric permittivity at angular frequency $f_0$
EPSI $f_1$ – dielectric permittivity at angular frequency $f_1$
EPSI $f_2$ – dielectric permittivity at angular frequency $f_2$
EPSI $f_3$ – dielectric permittivity at angular frequency $f_3$
EPSI_MA – matrix permittivity
NPOR – environmentally corrected neutron porosity

MCFL – shallow resistivity device of Platform Express system
Permittivity – resistance against electric field in a vacuum
PEX – Platform Express logging system
PHIT – total porosity
PNC – pulsed neutron capture
PWXD_AD$T$ – water-filled porosity from deep array combination of the new dielectric tool
QFM – volume representation of a quartz + feldspar + mica fraction
RHOZ – bulk density log measurement from Platform Express system
RXOZ – shallow resistivity measurement from Platform Express system, MCFL
RXS_AD$T$ – resistivity AD$T$ shallow array combination
RXD_AD$T$ – resistivity AD$T$ deep array combination
SIGM – capture cross section from reservoir saturation tool
cased hole logging system
TPL – propagation time log from EPT logging tool
VCL – volume of clay
VXBW – volume of clay-bound water
VXIW – volume of irreducible water