LWD Pressure Acquisition Learnings and the Application of Real-time Density Image: Case Study, Offshore Niger Delta

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ABSTRACT

Pressure acquisition in some Niger Delta fields can be challenging because of differential pressure behaviors in reservoirs with different flow units, reservoirs composed of interbedded sand-shale sequences and existence of thin, tight zones within formations. Ensuring the identification and selection of good quality reservoir zones with potentially favorable permeability and mobility values is desirable to address reservoir uncertainties, within cost and safety limits. Such reservoir quality necessitates the design of fit-for-purpose pressure data acquisition and formation evaluation logging programs to achieve effective reservoir characterization, and address key uncertainties such as original reservoir pressures, fluid types and contacts penetrated by the well. This paper incorporates lessons learnt from pressure acquisition programs including how to minimize the inaccuracy of depth, choice of acquisition type based on predicted mobility, number of pressure points for each flow unit, selection of best pressure points to avoid tight streaks or shaley intervals. A technique, using LWD density image in real-time to pick the pressure points is proved to be a valuable aide in selecting pressure points and improved success rate. Above learnings and techniques have been applied to two recent drilled wells in shallow water Nigeria, where these challenges were met and dealt with. Acquisition efficiency was significantly improved and objectives were safely met with significant cost savings. For both wells, pressure acquisition has been better planned and pressure data were successfully acquired with 100% success rate.

Keywords:

INTRODUCTION

Selection of good quality reservoir zones in real-time, with potentially favorable permeability and mobility values during a pressure acquisition and formation logging program is typically a challenge, due to the structural and stratigraphic complexity of the reservoirs in the Niger Delta. This is especially so, due to the preponderance of interbedded sand-shale sequences within the reservoirs of the region, and had consequently led to reduced efficiencies in executed pressure data acquisition and formation evaluation logging programs.

With this challenge in mind, and the drive for improved efficiencies and the delivery of cost-effective and reliable data with better success rates, the technique using Logging While Drilling (LWD) density image data in real-time alongside other real-time LWD logs was leveraged and turned out to be particularly useful in these cases. The ability of LWD tools to make azimuthal measurements from around the borehole circumference has changed the way Geologists and petrophysical analysts visualize downhole data. LWD tools acquire linear data along the well, whereas azimuthal tools also acquire data from the full circumference of the wellbore as the tool rotates. Azimuthal data are then presented as borehole images, "painting a picture" of the inside of the wellbore (Brown et al, 2015). Real-time LWD image data helped provide a more holistic picture of the wellbore environment, subsurface structural features and formation geometry, and was therefore harnessed as a valuable means to optimize the selection of pressure points in discretized flow units and heterogeneities within reservoirs, even before achieving well true-depth (TD). Unusable tight streaks and shaley intervals were avoided, depth inaccuracies minimized, and lessons learned from previous pressure acquisition programs were incorporated to inform the choice of pressure acquisition type based on reservoir fluid and predicted mobility.

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Field Overviews

The case study wells for this paper were drilled in the Usari and Oyot fields. These are both shallow water fields, located offshore Niger Delta OML 70, in water depths of approximately 65ft within the Nigeria National Petroleum Corporation (NNPC) and Mobil Producing Nigeria (MPN) Joint-Venture (JV) area, south-west of Qua-Iboe terminal (QIT). They are both operated by ExxonMobil in Nigeria.

The Agbada Formation, a more marine formation is the main objective in the exploration of Oil in southern Nigeria. Almost all hydrocarbon accumulations have been found in the sandstones of the Agbada Formation, mostly trapped in rollover anticlines in growth faults. The reservoirs of the Agbada Formation are typically channel and barrier sandstone bodies, similar to those of the recent delta. Porosity and permeability values are generally high (up to 40% and 1 to 2 darcys, respectively (Short and Stauble, 1967). Regionally, sediment dispersal was controlled by marine transgressive/regressive cycles related to eustatic sea-level changes with varying duration. Differential subsidence locally influenced sediment accumulation. At the high inflection points of the long-term eustatic sea-level curve, flooding took place that resulted in delta-wide shale markers. At the low inflection points, erosional channels were formed that are often associated down dip with turbidites in low-stand sediments. The mega sequences contain regional transgressive claystone units followed by a range of heterogeneous fine-to-coarse progradational or aggradational siliciclastic parasequence sets formed during sea-level high-stand (Reijers., 2011).

The Oyot field is composed of 3rd order low-stand deltaic reservoirs, and the Usari field is characterized by complex rollover anticlinal structures associated with major down-to-the-south growth faults which separates the field into five main reservoir zones: Base Qua-Iboe (BQI), Graben, Shallow, Intermediate and Deep. The reservoir groups are so, based on their geographic locations within the field. Upper Miocene-Lower Pliocene sands are dominant in the BQI and the intermediate and shallow reservoirs are dominated mainly by an interplay of lower and upper shore-face facies and distributary channel facies, with some tidal, estuarine and shelfal deposits coming into play as the environment becomes more distal. The Deltaic environment with upper and lower shore-face as well as distributary channels are the most productive in these areas. An NNPC/MPN JV acreage map is shown in figure 1 below, highlighting the location of the Oyot and Usari fields.

METHODOLOGY

Reservoir Heterogeneities and Density Image Approach

While drilling both wells using Logging While Drilling (LWD) tool assemblies, typical suite of formation evaluation logs were designed to be acquired. These logs; gamma ray, resistivity, neutron and density logs were being used for real-time well surveillance, monitoring and quick-look real-time petrophysical evaluations. The resolution of these logs in two-dimensional space are quite insufficient for delineating interbedded sand-shale sequences (preponderant in both case studies), as the wells cut across several sub-seismic faults and different developed and undeveloped heterogeneous reservoir zones. In order to derive better understanding of the dynamic behavior and 3-Dimensional spatial variations in reservoir quality, detailed pressure data information was required for reservoir/dynamic connectivity analysis, reservoir fluid identification and contact analysis, as well as for reservoir management purposes.

Historically, the execution of a pressure data acquisition and the selection of candidate depth points was done

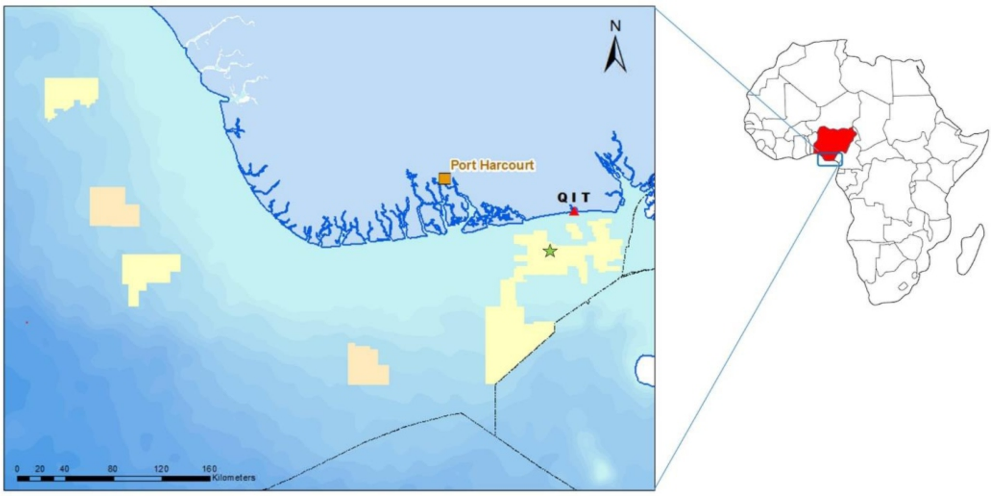

Figure 1: Acreage map of NNPC – MPN JV, highlighting the location of Oyot and Usari Fields (green star) in the Niger Delta (courtesy Mobil Producing Nigeria).

mostly by reliance on "triple combo" logs data alone (Yon et al., 2013). These logs were heavily depended on as these are lithology discrimination logs in the identification of depth points. However, looking back at previous pressure acquisition programs within the JV fields, the efficiencies recorded using these basic suite of LWD "triple combo" logs alone have been far from perfect, often resulting in failed tests obtained from tight, low permeability and mobility streaks, and sometimes pressure depth points were selected in shale laminations that were not easily identified from a combination of the gamma ray, neutron and density logs alone. These had an impact on overall project costs stemming from extended rig-time costs, personnel charges and sometimes attracting extra costs from exceeding the maximum number of points per package as defined in the pressure acquisition service contracts.

With the learnings obtained from historical challenges observed from studies of analog wells across several fields in the Joint-Venture (JV) shallow water area, and the need to optimize project cost-efficiencies in today's business, a unique approach utilizing LWD sixteen-sector azimuthal density image data in real-time was conceived. Bulk density images are a graphical representation of the variation in formation bulk density, around the borehole circumference. Sixteen-sector azimuthal density image data acquired from the full circumference of the well as the tool rotates is quite different from the linearly acquired density log along the well, and is often acquired alongside the density log. It is however not known in Nigeria to be used in real-time for the purpose of identifying good quality formation depth points for pressure data acquisition, while drilling. Unlike the linear density log which only helps to provide inference on reservoir quality and reservoir fluid type, the sixteen-sector azimuthal density image provides a 360-degree orientation of the wellbore environment, including detailed resolution of all reservoir heterogeneities and formation geometry. Image data also provide facies information and are useful in identifying zones of high permeability (Bristow, 2002).

The first process in this approach involved rendering the individual 16 sectors of density image data as delivered by the vendor into a whole image. Utilizing formation evaluation software Geolog's "Scalar to array" workflow in its "log copy" function, the 16 sectors were selected as input data and the density image became the output. Next, the rendered density image output was displayed side-by-side with the common suite of LWD logs; Gamma ray, resistivity, neutron and density porosity, along the depth of the well being drilled. An appropriate colour map and a scale with a range were selected based on the primary lithology grain density (in these Niger Delta cases, sandstone with grain density of 2.65 g/cm3). The rainbow colour map on Geolog was found to be more visually suitable, when used on a scale of 1.6 to 2.4 g/cm3 in these cases. Minor variations to the density scale upper and lower limits could also be applied to better highlight subtle formation heterogeneities as required, especially in the areas around thinly bedded sands and shaley reservoir intervals.

The LWD tool orientation is measured simultaneously as the azimuthal data, as such, the images can be aligned with the geometry of the wellbore (Brown et al, 2015). When all logs are displayed side-by-side to each other along the depth of the well as drilling progresses, any depth mismatches are easily identifiable. The typical lithology responses from the gamma ray log and the neutron and density porosity logs (plotted on the appropriate scale) can be compared and correlated to the corresponding interval on the density image display. If all lithology responses cannot be depth correlated, the density image log data is usually the best to help delineate any subtle offsets relative to lithology or formation fluid type, and the corrections that need to be applied to obtain a match. It is also very useful in providing information about the amount of depth shift required to ensure improved result accuracy in petrophysical evaluations as lithology boundaries (including thin beds) are clearly visible on the density image log. In these case studies however, there were no depth discrepancies in the logs being delivered by the service contractor, and so no depth correction using the density image data was done.

The selection of all planned pressure depth points was done after the rendering of the 16 sectors of the density image data into an image of the wellbore. These were done along the depth of the well in conformance to the objectives of the approved pressure acquisition program for these wells. Emphasis was laid on selecting low grain density, high porosity zones, with potentially favorable permeability (and mobility) values, as observed from the density image log signatures. The density image data was able to clearly resolve low porosity/permeability streaks within seemingly "clean" reservoir sands as depicted by low API value of the gamma ray log. An example of such reservoirs are shown in figures 2a and 2b.

There were also intervals along the path of the well where the gamma ray, neutron and density logs alone depicted shaliness, however on the image log, it was clearly resolvable as low density, good quality intervals. Certain areas were visible on the gamma ray log as hot sands, represented by high API values but equally high resistivity values and neutron-density cross-over. These are shown in figure 3.

The use of the density image log proved an invaluable tool in confirming these as hot sands. Following the use of this approach, a combined total of fifty-nine (59) pressure

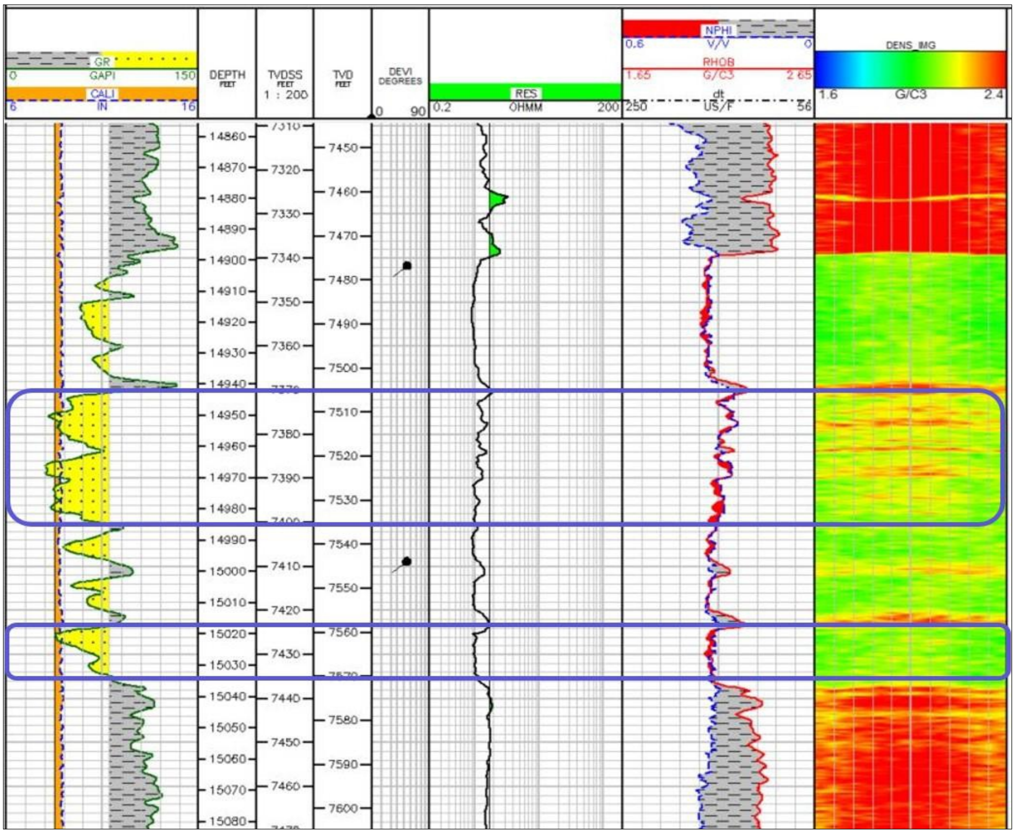

Figure 2a: Low porosity/permeability streaks visible on image data in seemingly "clean" reservoirs.

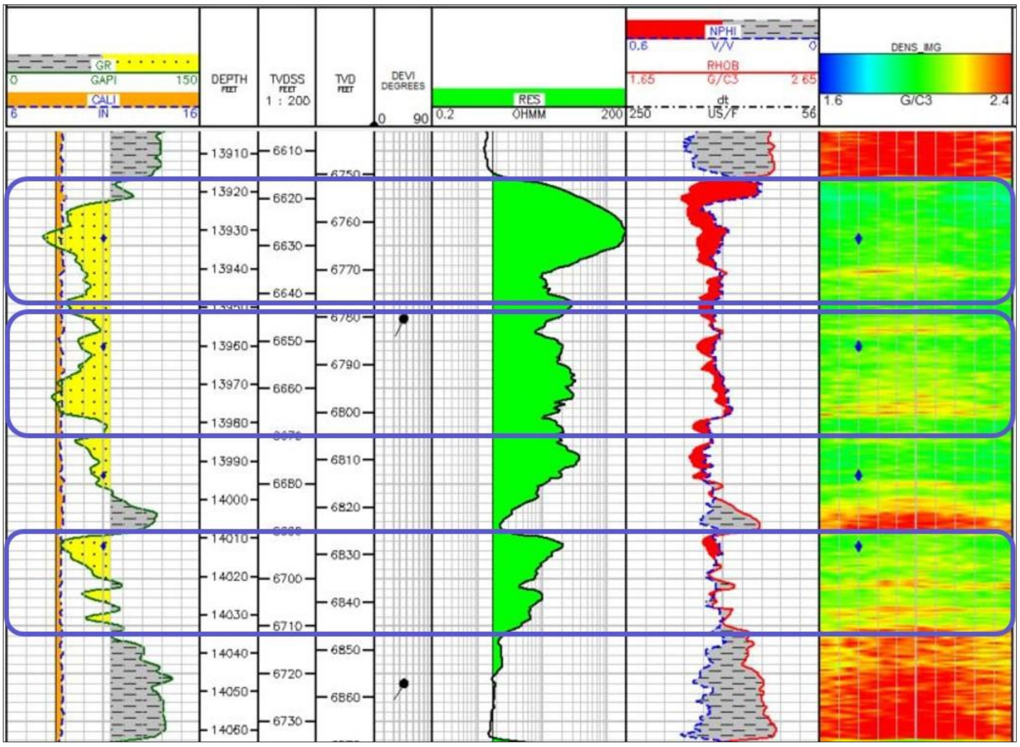

Figure 2b: Low porosity/permeability streaks visible on image data in seemingly "clean" reservoirs. (Blue diamonds represent selected pressure depth points).

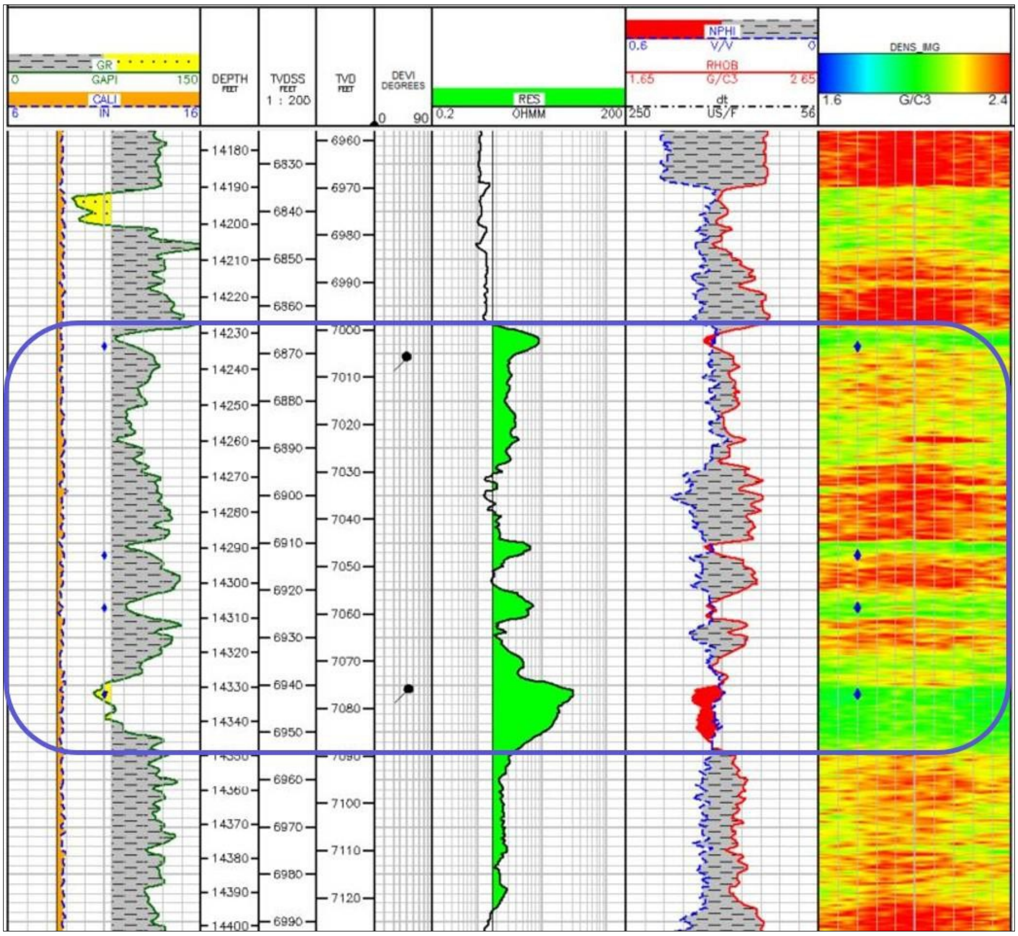

Figure 3: High gamma ray API sands ("hot sands") discernable on density image log.
(Blue diamonds represent selected pressure depth points)

points were selected through both wells, paying close attention to all subtle laminations that could potentially pose permeability barriers and result in failed tests.

Lessons Learnt, Pressure Acquisition and Test Types

After the wells were drilled to true-depth (TD), depth calibrations were performed to properly station the drilling bottom-hole assembly (BHA) at the starting depth point and the actual pressure data acquisition commenced using Schlumberger's Stethoscope tool in both case studies. Pressure was acquired from bottom upwards (i.e. from true-depth towards surface) in both cases, to ensure minimum discrepancies in depth due to pipe buckling, while keeping tension and torque in check. Prior to drilling the wells, analog wells in the shallow-water area with similar reservoir characteristics were studied, and the observations from these wells served as a guide to the selection of the pressure-while-drilling tool type deployed, as well as the more reliable test type that provides high results accuracy. Based on these learnings, the decisions were tailored to suit the reservoir fluid types and reservoir characteristics expected to be encountered in each interval, and the pressure acquisition type was optimized to suit the peculiarities of each depth point. The choice of test type is based on predicted formation mobility and utilizes fixed volume and rate for pressure investigation and measurement.

An overview of different test types available for the Schlumberger Stethoscope tool fixed pretests is shown in table 1.

Overall, the 2C test type was used in oil-and-water-bearing reservoir zones and 0D(define pls) test type in gas-bearing reservoir zones. The 2C test adjusts rate, volume and build-up period to fit the conditions encountered in each interval, and allows stabilized pressures in heterogeneous formations or where in-situ formation mobility is unknown. One major lesson carried forward during the execution of the pressure data acquisition was the need to provide room for flexibility to switch between test types, based on the formation (and inherent reservoir fluid) characteristics encountered. This came in valuable in the acquisition of pressure at the very first station of the well in the Oyot field. Measured

Table 1: Schlumberger Stethoscope Tool Test Types (Blanco et al, 2013).

Test Type Mobility Range (mD/cP) λ	Pretest 1 (Nominal)			Pretest 2/Final (Nominal)		Total Test Time (sec)
	Volume (cc)	Rate (cc/s)	Buildup Time (sec)	Volume (cc)	Rate (cc/s)	
0-A:λ > 0.1	4.5	0.2	600	0.5	0.2	1200
0-B: λ > 1	5	0.3	116	6	0.3	300
0-C: λ > 10	9.5	0.5	119	14.5	1	300
0-D: λ > 100	9.5	1.0	69	14.5	2	180
Intelligent Pretest	Pretest 1, Investigation Phase			Pretests 2, 3, …Measurement Phase		
1-A	as needed	0.5	as needed	computed	computed	300
1-B	as needed	0.3	as needed	computed	computed	300
2-C	as needed	0.5	as needed	computed	computed	300
2-D	as needed	0.3	as needed	computed	computed	300

permeability and mobility came in much higher than predicted for that interval, and resulted in an inability to capture a drawdown profile using the 2C test type, as should be the case in a typical test signature plot. This is shown in Figure 4 below:

The decision was therefore made to switch to the 0D test type for subsequent stations, as the 0D test type is capable of accurate pressure data acquisition in formations with greater mobility than 100mD/cp, as shown in table 1 above. A better stabilized pretest plot using the 0D test type for the high permeability/ mobility formation is shown in figure 5 below:

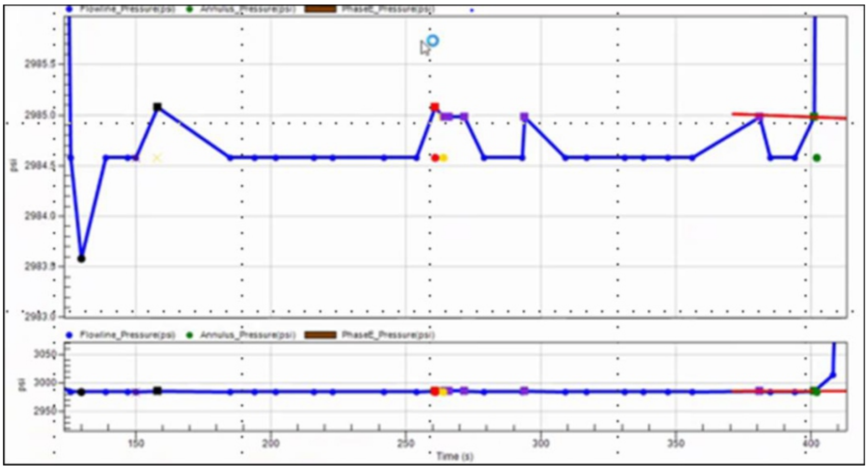

Figure 4: Pretest plot highlighting the inability of the 2C test type to effectively capture drawdowns due to high formation mobility

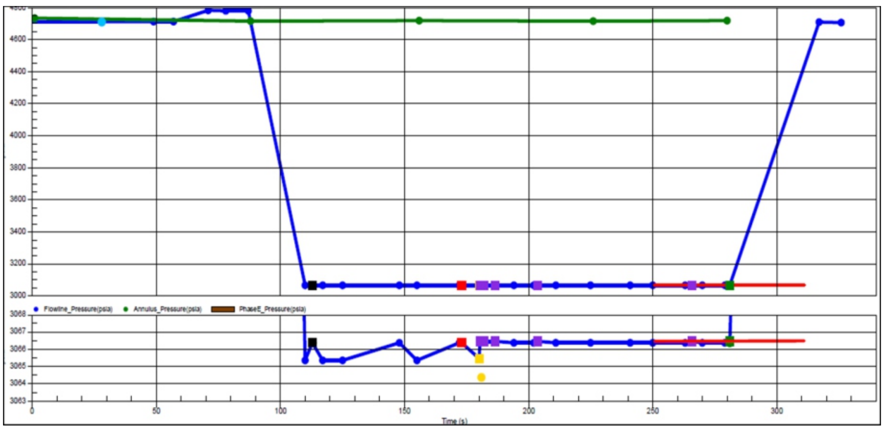

Figure 5: Pretest plot after switching to the 0D test type which effectively captures drawdowns in high mobility formation.

DISCUSSION AND CONCLUSION

Utilizing all previous lessons learned from past logging programs and pressure data acquisitions, and using these as a basis for improved efficiencies and project cost savings, the unique approach of incorporating azimuthal bulk density image data in real-time proved invaluable. Bulk density images are a graphical representation of the variation in formation bulk density, around the borehole circumference. The sixteen-sector azimuthal density image data acquired from the full circumference of the well provided a 360-degree orientation of the wellbore environment, including detailed resolution of all reservoir heterogeneities and formation geometry. This was in contrast to relying solely on linear “triple combo” logs as historically done, which were observed to have been insufficient in efficiently executing pressure data acquisitions. The result of incorporating real-time azimuthal bulk density image was the ability to visualize the best candidate points for the pressure data acquisition programs within the heterogeneous reservoirs penetrated by both wells in the case study.

With no tight spots, leaky or lost seals and a 100% success rate recorded for all 59 pressure tests that were acquired from two Niger Delta wells, there was significant cost savings from rig time and personnel charges, as well as from keeping the number of pressure points designed and planned for within budget limits. Results obtained from all selected depth points were usable and lined up as expected for all gradients, and in the undeveloped reservoirs provided expected reservoir pressures that were within expected ranges and reliable. The approach also contributed to more detailed and accurate formation evaluation by adequately guiding the interpreter in discernment of net reservoir, by including pay intervals that would have otherwise been excluded and not considered, if reliance was solely on the basic suite of gamma ray, neutron and density logs.

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