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A Case Study on Open-Hole Logging While Tripping LWT Through Drill Pipes, as a New Technology for Risk Mitigation and Cost Optimization in Abu Dhabi Onshore Fields

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Abstract

The ability to measure formation petro physical properties thru drillpipe has always been a challenge. It requires unconventional approaches to remove the effects of metal and borehole fluids on both the transmitted and received logging signals. This paper will present a proven technology executed in more than 1,000 wells all over the world and a first two successful trail case study from ADNOC Onshore wells in the Middle East.

The main objective is to acquire triple combo data (resistivity, density, neutron, gamma ray, spectral gamma ray & caliper) using the LWT conveyance and acquisition technology where there is a high risk of downhole triple combo Logging While Drilling (LWD) and or wireline (WL) tools getting stuck and the risk of losing radioactive sources.

The new patent pending technique was executed by using a slim downhole measurement tools inside specially designed drill collars invisible to the measurement sensors. LWT collars can be used for drilling and reaming as with normal drill collars. Propagation resistivity and neutron measurements are mostly like conventional techniques in tools physics. Density and nuclear caliper are measured by modelling the responses of three detectors short, medium and long distance away from the cesium source.

The measured LWT log data has been validated through back to back comparisons with WL & LWD) logs showing almost one to one correlation considering the effects of mud invasion due to lapsed time between runs, different wellbore condition and different depth of investigations.

Measured caliper, resistivity, density, neutron from LWT showed respectable match with WL or LWD tool. The differences in log responses are explained by differences in tool physics, logging speeds and environmental conditions. Similarly, the computed porosity from LWT tool comparison with WL and LWT porosity has almost the same statistics. The Quality LWT data was acquired in both wells at virtually zero LIH risk and minimum extra drilling rig time.

Introducing the new LWT technique to measure accurate Open Hole formation evaluation data from inside the drill-string is a cost-effective solution in various challenging scenarios,

a. Exploratory/ Appraisal/ Development risky & challenging wells with unknown reservoir pressures or unsystematic depletion scenarios, complex downhole in-situ stress regimes, challenging tectonically faulted or fractured areas & unstable shales and many more, posing challenge to drill stable holes and a threat to LWD/ WL radioactive tool stuck.
b. Unplanned deviated 8-1/2' hole section geo-steered by MWD-GR, where at last minute triple combo is desired.

Introduction

Logging While Tripping (LWT) is a commercially proven, proprietary formation evaluation technique, to acquire quality open hole triple combo data specially in risky wells where chances of losing radioactive source is high. Immediately after drilling has been completed, the LWT tools are deployed (pumped down) and wire-line quality open hole logs are acquired in memory from within LWT collars positioned in the drill string during the trip to surface. The LWT suite of logging tools includes:

- Gamma Ray (GR)
- Spectral Gamma Ray (SGR)
- Compensated Neutron (CN)
- Formation Density (DEN)
- Resistivity – Induction (DUIN)
- Resistivity – Propagation (PRT)

LWT Logging devices are API calibrated and meet all requirements for spectral gammay ray, gamma ray, neutron porosity, formation density and resistivity measurements.

The LWT collars, inserted into the drill string on the last bit trip, see Figure-A, or on the planned reamer run, do not require any change in drilling plans or extra rig time to change to a specialized BHA. The tool is not a replacement to LWD whenever geo-steering is needed. The Technology is an excellent conveyance solution to log challenging and risky wells / reservoirs where the risk of downhole logging tool stuck and losing tools and radioactive sources is high.

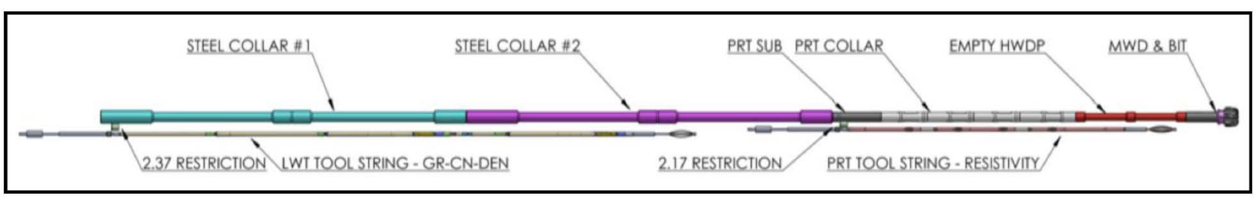


Figure A—Example of typical LWT drill collar configuration.

This paper will discuss the results of two (2) wells in a giant Onshore reservoir of Abu Dhabi, UAE.

LWT Measurement Tools - Theory and Definitions

Formation Resitivity – Propagation. The propagation resistivity tool produces electromagnetic (EM) waves which propagate on the outside of the drill collar. By detecting the attenuation and phase shift of these waves at both 400 kHz and 2 MHz the resistivity of the surrounding formation can be determined at four depths of investigation. These readings are fully compensated against bore hole effects by combining the results from two symmetrically placed transmitters.

Formation Density Tool & Nuclear caliper. The Triple Detector Density tool contains a gamma ray source and three high-sensitivity scintillation detectors. Gamma radiation from the source is back-scattered by the formation and measured by three detectors equipped with proprietary shielding designed to optimize gamma ray collimation. Borehole effects are removed through computed standoff and a mud density measure, which is derived from relative readings of the multi, spaced detectors with reference to calibration and modeled responses. Average caliper, density correction and apparent bulk density are then calculated from borehole-compensated data, see Figure-B.

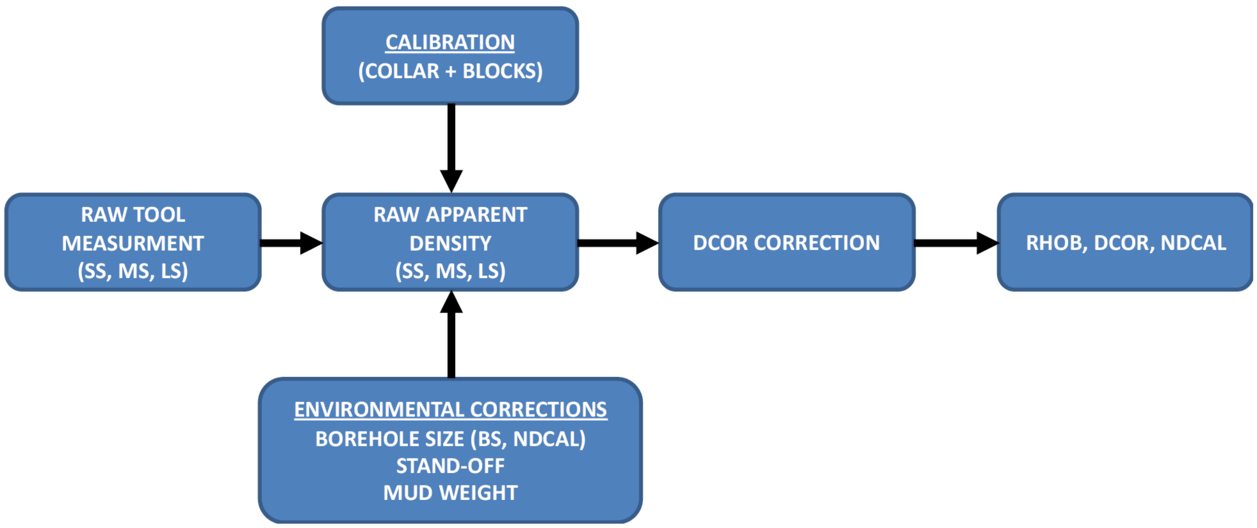


Figure B—Example Formation Density processing workflow.

COMPENSATED DUAL NEUTRON (CN) & Gamma Ray (GR). The Dual-detector Neutron tool uses a chemical nuclear source and two thermal neutron detectors. The source emits neutrons that are slowed down and then captured primarily by hydrogen atoms in the formation fluids. The detectors count the neutrons deflected back to the tool. The ratio of the short-spaced over the long-spaced count rate is processed to calculate the neutron porosity, which relates to the hydrogen content of the formation. Using a scintillation detector, the combined Gamma Ray tool measures the total natural radioactivity of the formation caused by the emission of gamma rays by unstable radioactive isotopes of elements in the formation.

SPECTRAL GAMMA RAY (SGR). The Spectral Gamma Ray tool measures the entire gamma spectrum from 0 to 3,000 keV. All detected gamma rays that exceed threshold-level energy are counted to produce the total gamma ray curve. A spectrum-fitting algorithm uses all the available counts to determine the quantitative content of the three main unstable isotopes—potassium, uranium and thorium—that contribute to natural radiation emissions. Environmental corrections for KCI mud, hole size and casing are applied through software.

LWT Tools Accuracy & Limitations

LWT Tool Accuracy. The following Table 1 summarizes accuracy of LWT triple-combo log measurements;

Table 1—LWT Measurement Accuracy

Tool	Accuracy	Remarks
Resistivity	Max Error is 5%	At 50 Ohm/m
Bulk Density	+/- 0.05 g/cc	
Neutron Porosity	+/- 0.5 PU	0 – 10 PU
	+/- 8 %	10 – 30 PU
	+/- 10%	30 – 60 PU
Gamma Ray	+/- 2%	
Spectral Gamma Ray	+/- 2%	Potassium
	+/- 3%	Thorium & Uranium

LWT Tool Limitations. The following are the limitations to be considered when using LWT technology;

1. Not for while drilling application, no real-time Geo-Steering capability.
2. Memory logging, no real-time QA/QC
3. Formation Density measurement hole size limitation optimal =< 10" and max. < 12.25"
4. LWT tool temperature limitation is < 150 DegC and pressure limitation of < 14.5KPsi.
5. LWT drill collar size is limited to maximum 4 ½" IF

Data and Results

Well #1. Well #1 is a 45-degree deviated oil producer. It was selected to test the LWT technology against conventional open hole wire line logging. The LWT tool was dropped inside the 5-inch drill pipe immediately after reaching the total depth, wireline logging data was acquired 24 hours later.

As shown in the map (Fig. 1) the well is surrounded by LWD logged wells, so, the LWT data is compared with both the back to back wireline data and the nearby offset wells with LWD data.

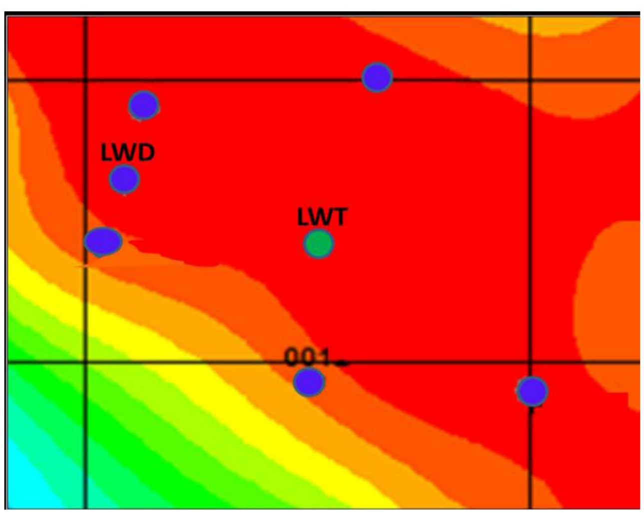


Figure 1—Location map with LWT conveyed Well # 1

Well #1 LWT data versus offset LWD log data

Below Fig. 2 shows a good correlation between basic open hole logs (Rt, Caliper, RHOB, NPHI & Caliper) from Well # 1 LWT and offset well LWD data.

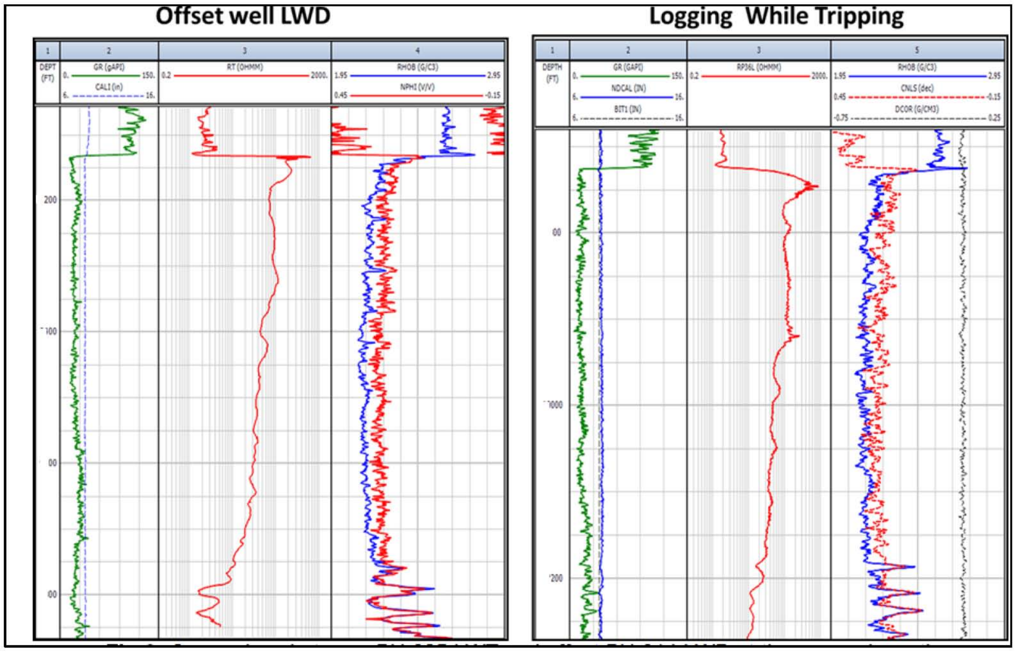


Figure 2—Comparison between complete logged intervals of Well#1 LWT & Offset well LWD data

Well # 1 LWT versus WL data:

Below log plots (Fig. 4 & Fig. 5) and histogram plots (Fig. 6 to Fig. 9) are showing the reasonable similarity between the basic openhole (RT, Caliper, RHOB, and NPHI & Caliper) LWT and wire line (WL) log data. Small differences are due probably to the following reasons including but not limited to:

1. Mud invasion: Wire-line data had been acquired 24 hours after LWT data acquisition so would cause some differences in Neutron, Density and Resistivity logs due to invasion.
2. Density Log Comparison: LWT density tool is reading 360 degree circumferential while WL density tool is a padded tool reading one side of borehole. LWT tool is more representative since it measures more rock volume than WL as shown in Fig. 3 schematic diagram. As per Fig. 4 the difference between LWT & WL density is less in shale (non-reservoir) than reservoir section. The average density difference of 0.027g/cc in reservoir section is within the accuracy of LWT density tool (refer **Table** 1).
3. Neutron Log Comparison: LWT CNL is corrected for collar steel, borehole environments and WL NPHI is corrected for borehole size. The difference between LWT & WL neutron in shale is less than in the reservoir section (refer Fig. 4). The difference in the reservoir section is probably due to the combination of OBM invasion, hydrocarbon and environmental affects, but is close to accuracy of LWT neutron tool specifications.
4. Caliper Log Comparison: As per Fig. 4, the LWT nuclear derived caliper and WL mechanical caliper is similar in the non-reservoir section. In reservoir interval (~ 1000' MD), due to the formation of mud cake the WL caliper recorded 24 hours later is showing lower value than LWT caliper.
5. Gamma Ray Comparison: LWT GR measurement showed a very good overall statistical match and has more signature than WL GR possibly due to difference in log filter resolution.

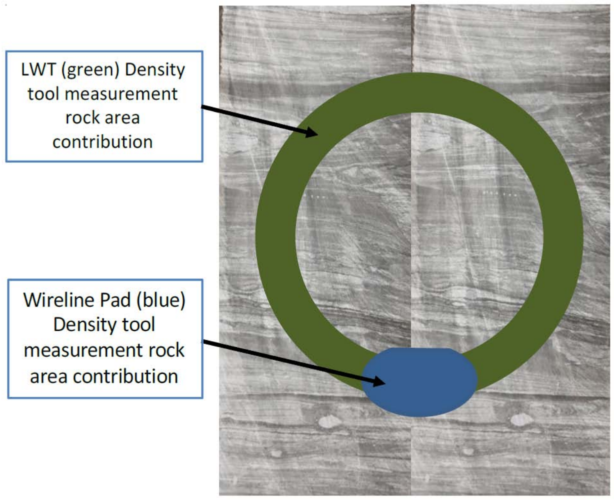


Figure 3—Density measurement in LWT is omnidirectional and in WL by pad towards one side of the borehole

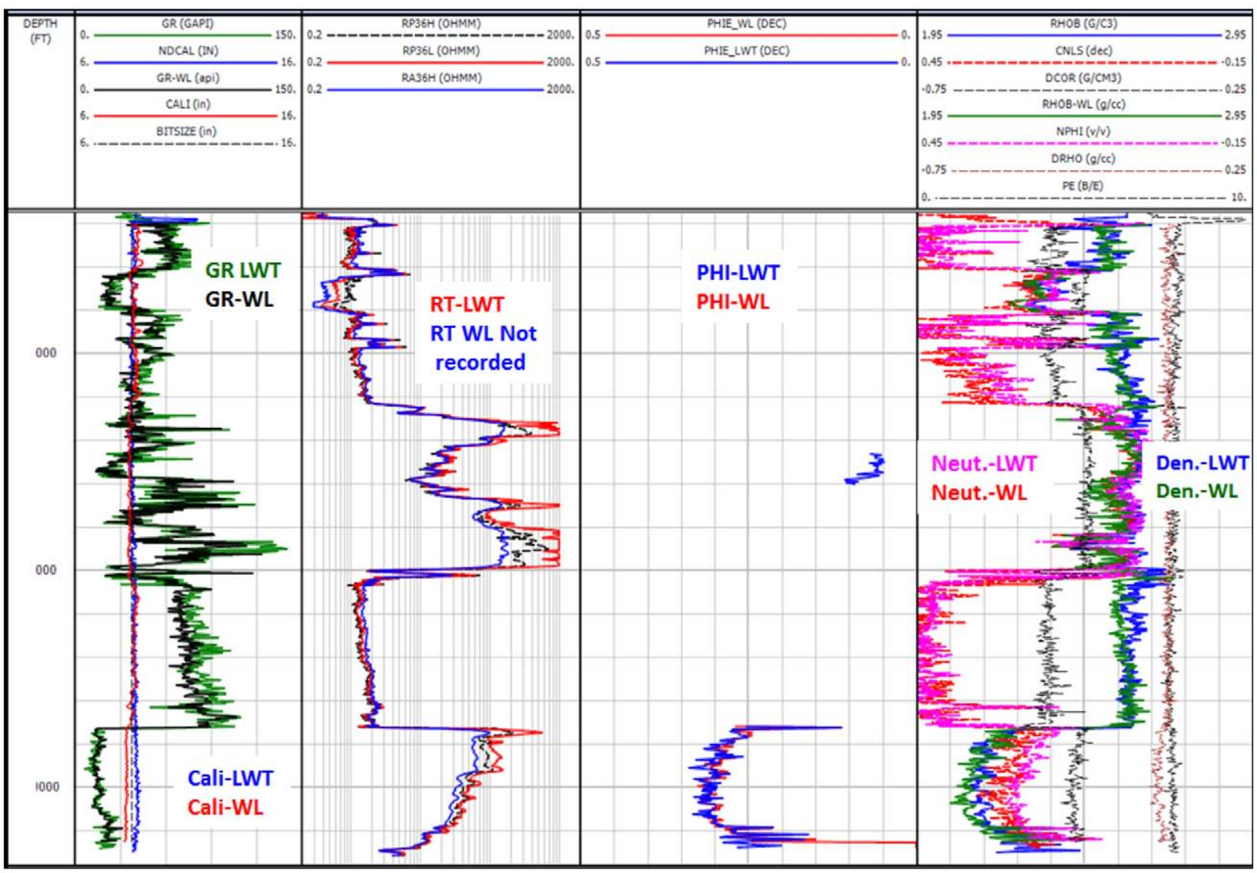


Figure 4—Well # 1 LWT and WL basic open hole log data comparison against reservoir & non-reservoir sections

Below log plots, Fig. 4 in full interval covering reservoir & non-reservoir sections & Fig. 5 in reservoir interval shows a comparison between LWT and WL basic open hole log data. The comparison is showing good correlation both in reservoir and non-reservoir sections.

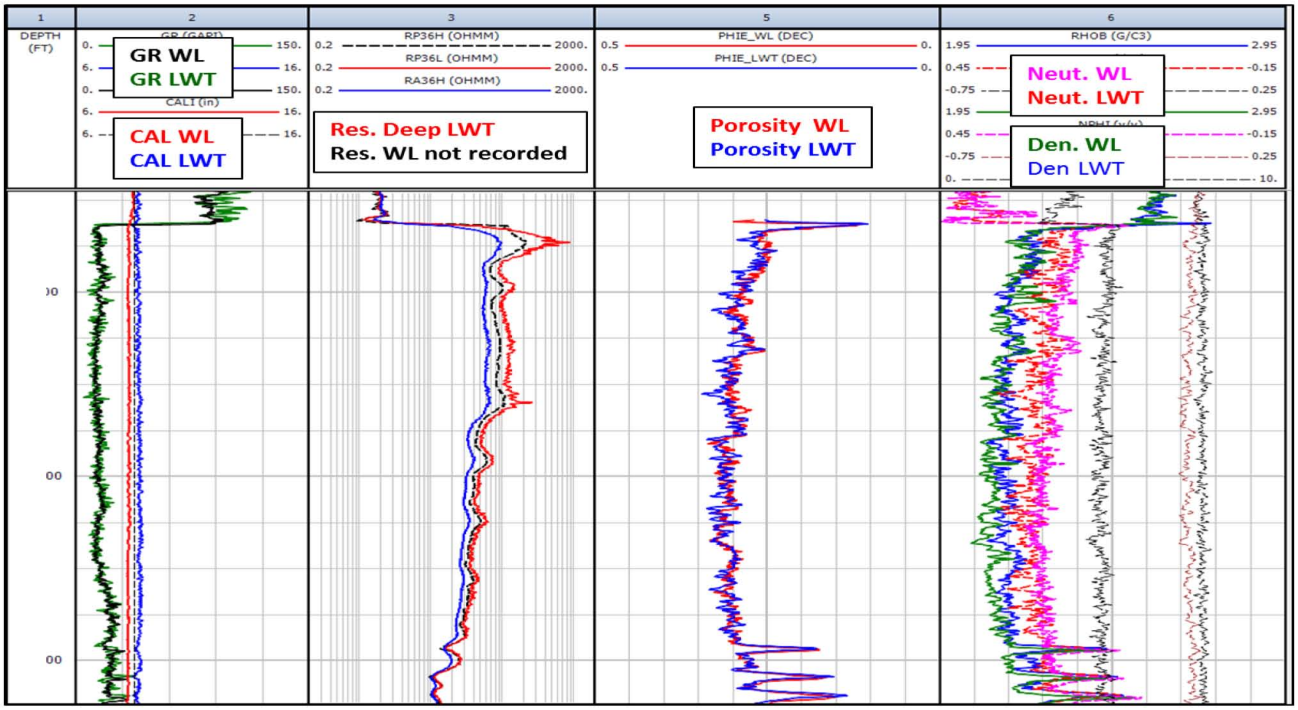
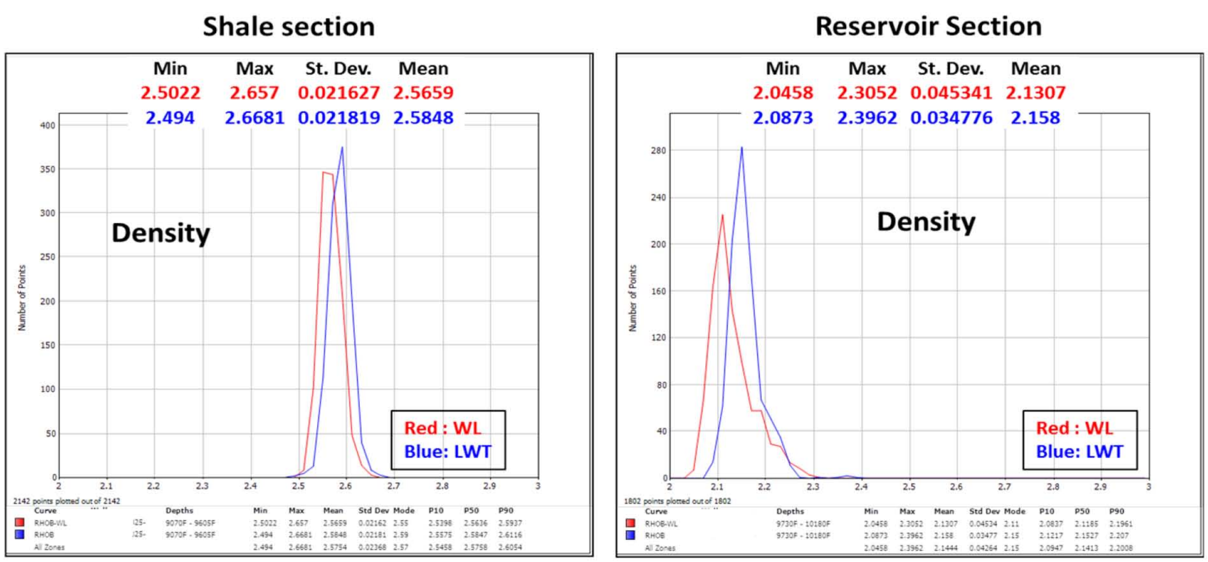


Figure 5—Well#1 basic open whole LWT logs overlays with WL logs in reservoir section



a) In the shale section there is no invasion LWT & WL Density difference are due to different tool physics and rock volume measurement

b) In the Reservoir section LWT & WL Density difference is due to the combined effect of mud invasion, tool physics, different rock volume measurement, hydrocarbon & environmental affects

Figure 6—Density data histogram plots and statistical comparison between LWT and WL data

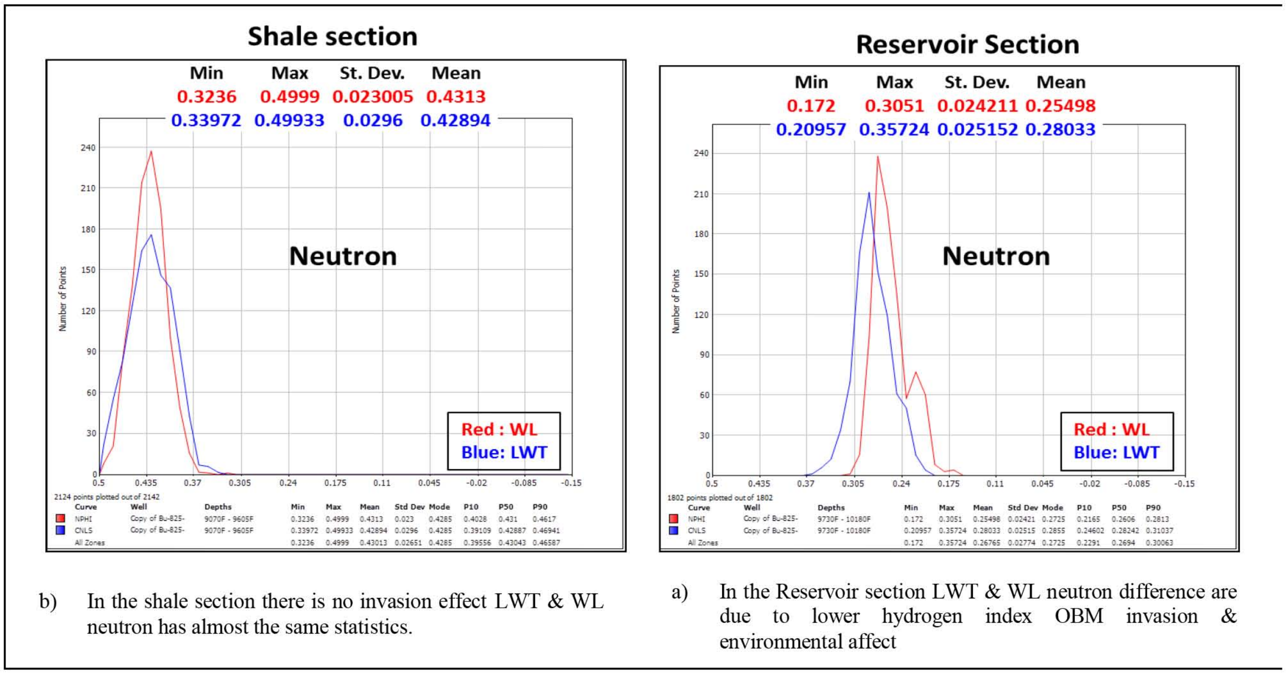


Figure 7—Neutron data histogram plots and statistical comparison between LWT and WL data

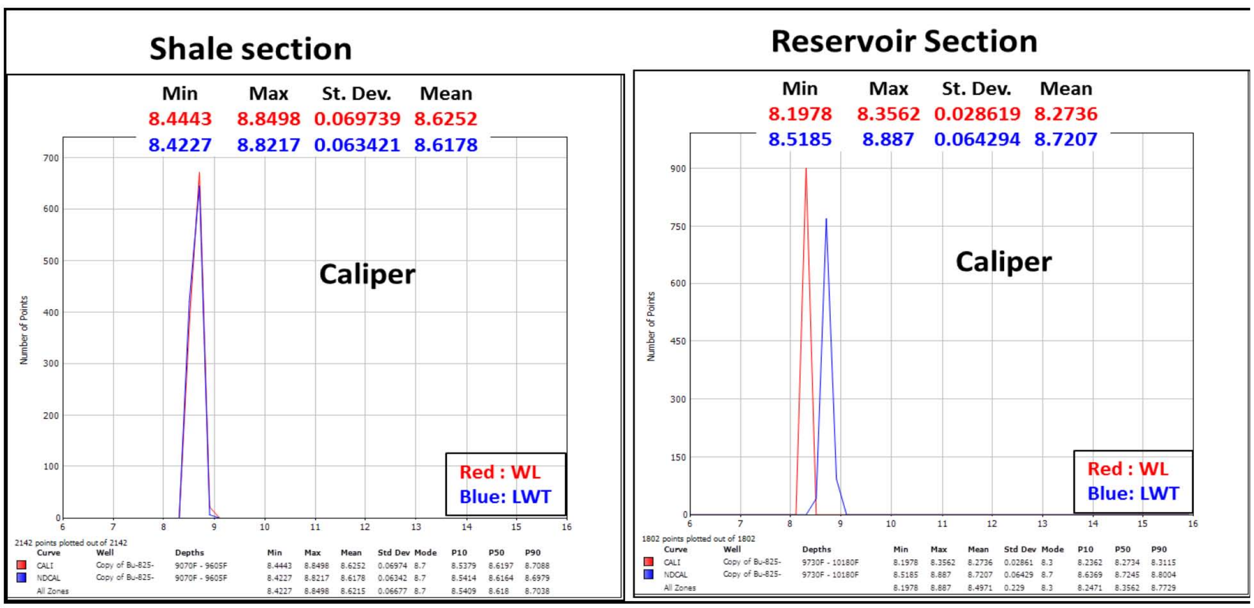


Figure 8—Caliper data histogram plots and statistical comparison between LWT and WL

Further, histogram plots of various sensors of LWT & WL with statistical data in shale and reservoir sections with possible reasons for any differences, is outlined below.

The calculated neutron-density cross plot porosity from both LWT and WL data are nearly at the same mean value as shown in Fig. 9.

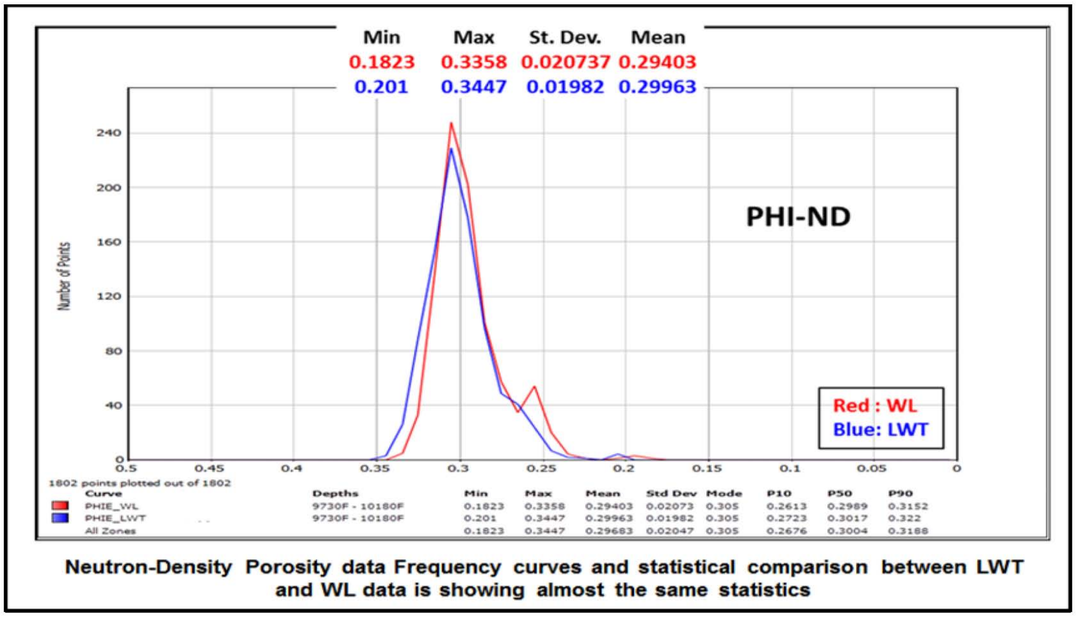


Figure 9—Computed porosity data histogram plot and statistical comparison between LWT and WL

Well#2. The second trial well has been carefully selected to be in a high risk well, the LWT data acquisition was planned to be acquired after the conventional logging while drilling. As shown in the below map the well was surrounded by other offset LWD and cored wells to widen the scope of comparison.

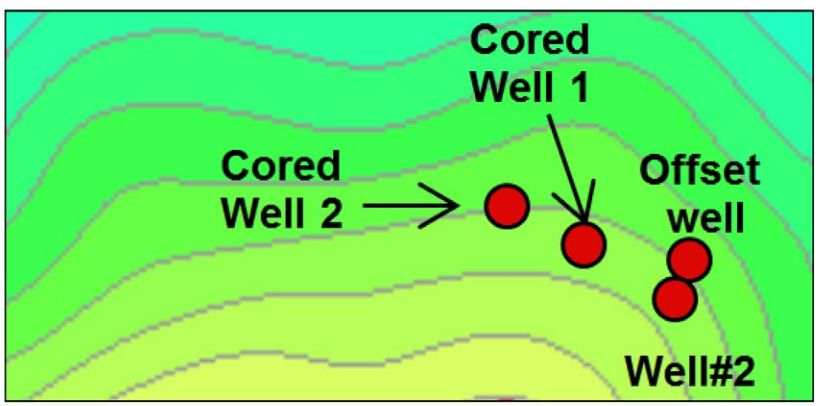
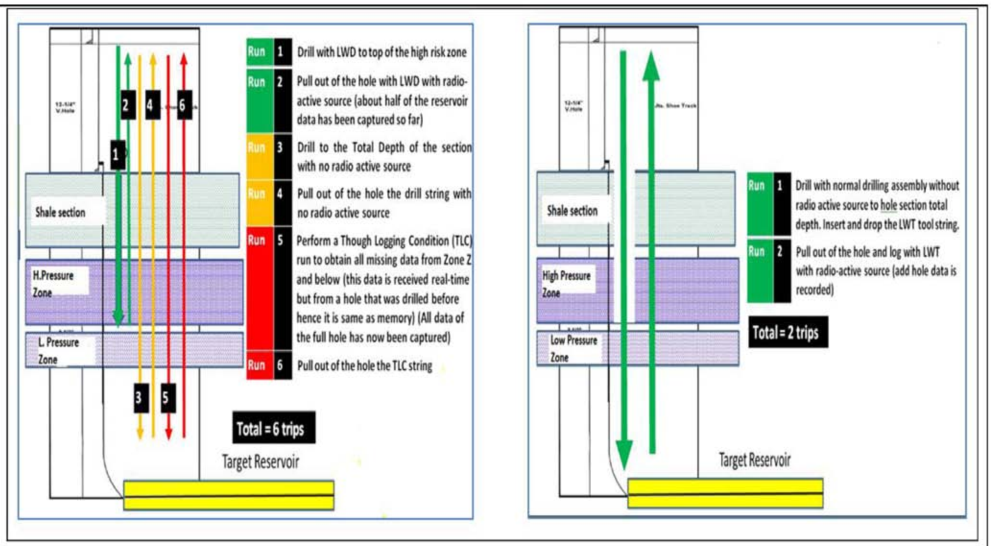


Figure 10—Location map with LWT conveyed Well # 2 & nearby cored wells for log comparison

Well # 2 schematic diagram (Fig. 11) is showing that the drilling team had to pull out and remove LWD tools to avoid the possibility of getting stuck & losing the radioactive sources while drilling through such a complex scenario of high pressure reservoir immediately followed by depleted reservoir and the presence of very thick shale section above both reservoirs. Using LWT did avoid doing 4 bit trips, saving almost 2 rig days as shown in the diagram.



a) Normal drilling practice with LWD & TLC combination but w/o LWT conveyance

b) New approach using LWT – Saving 4 bit trips (2 Rig days)

Figure 11—Well#2 schematic diagram showing added value of LWT conveyance saving 4 bit trips as against LWD & TLC combination

Well # 2 LWT log versus Offset Well LWD log data:
Below Log plots, are showing the comparison between Well#2 LWT and offset LWD data both in the reservoir & non-reservoir sections.

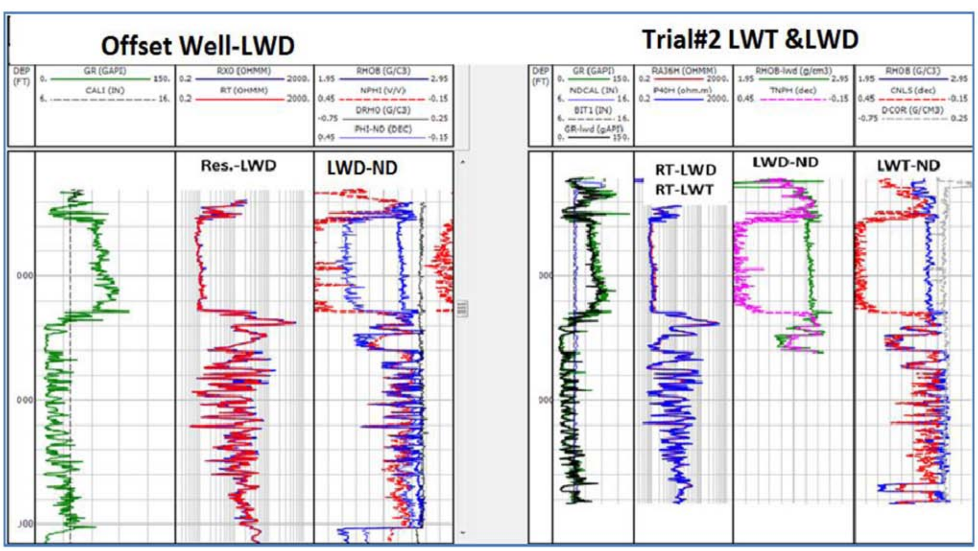


Figure 12—LWT Well#2 and offset well LWD log data comparison

In Well#2, the LWT neutron & density data is affected by 5 days of mud invasion; LWD & LWT deep resistivity data are matching; LWT & LWD density shows a similar trend; LWT CNL & LWD TNPH has different environmental corrections causing their differences. In the offset well with LWD data, the reservoir section shows an increase in the deep resistivity and decrease in neutron as compared to Well#2, suggesting possible presence of different HC (gas? with oil) and its saturation.

Well # 2 LWT versus LWD Data
Knowing that LWT had been logged 5 days after LWD then it is expected to see invasion effects only in the reservoir sections and good comparison over non-reservoir sections. Also, the difference in logging speeds, 100 ft. /hour for LWD and 900ft/hour for LWT will affect the log response and its resolution.

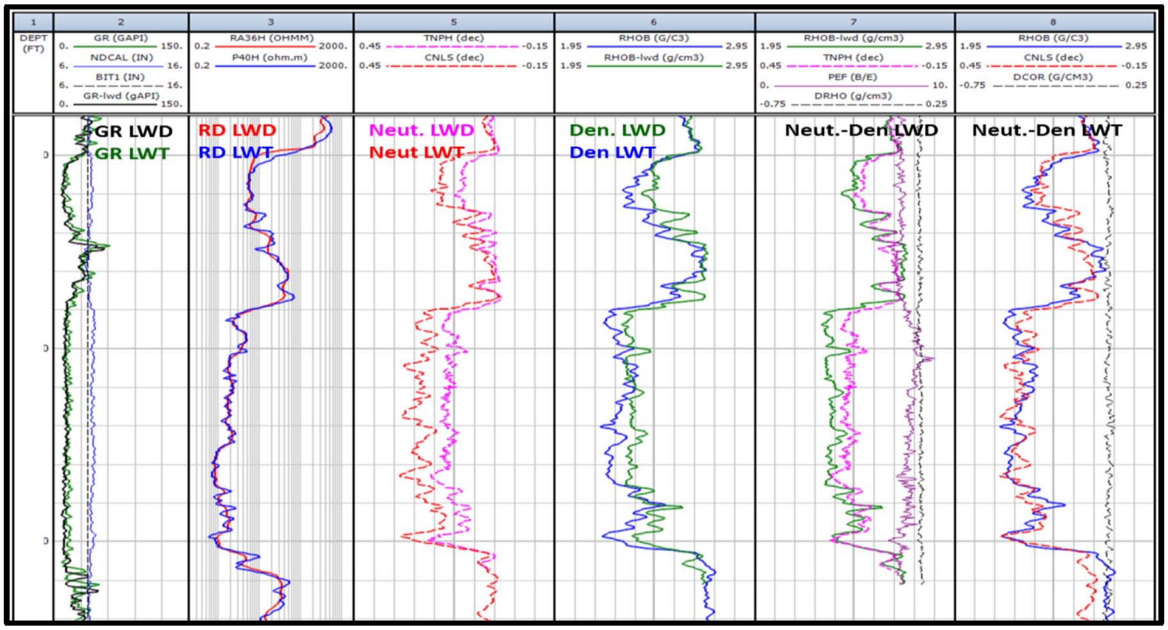
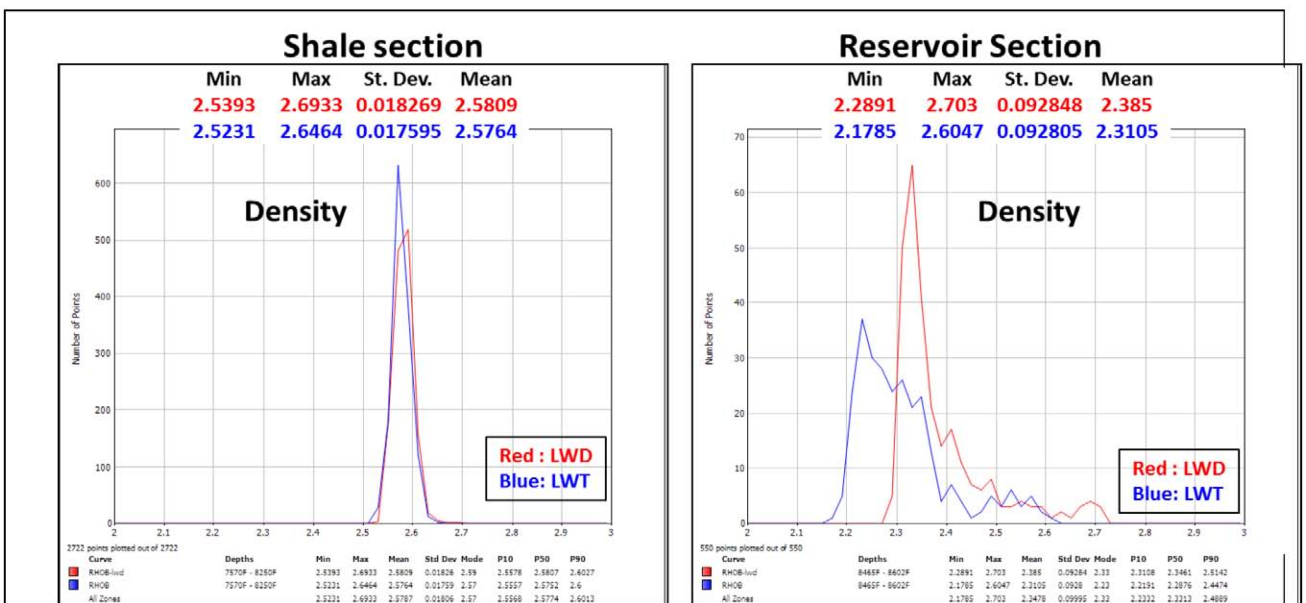


Figure 13—Comparison overlay between Well#2 LWT and LWD in the reservoir section: See the effect of invasion on LWT density, neutron data against reservoir sections. Both LWD & LWT deep resistivity data are matching, both are too deep to be affected by invasion

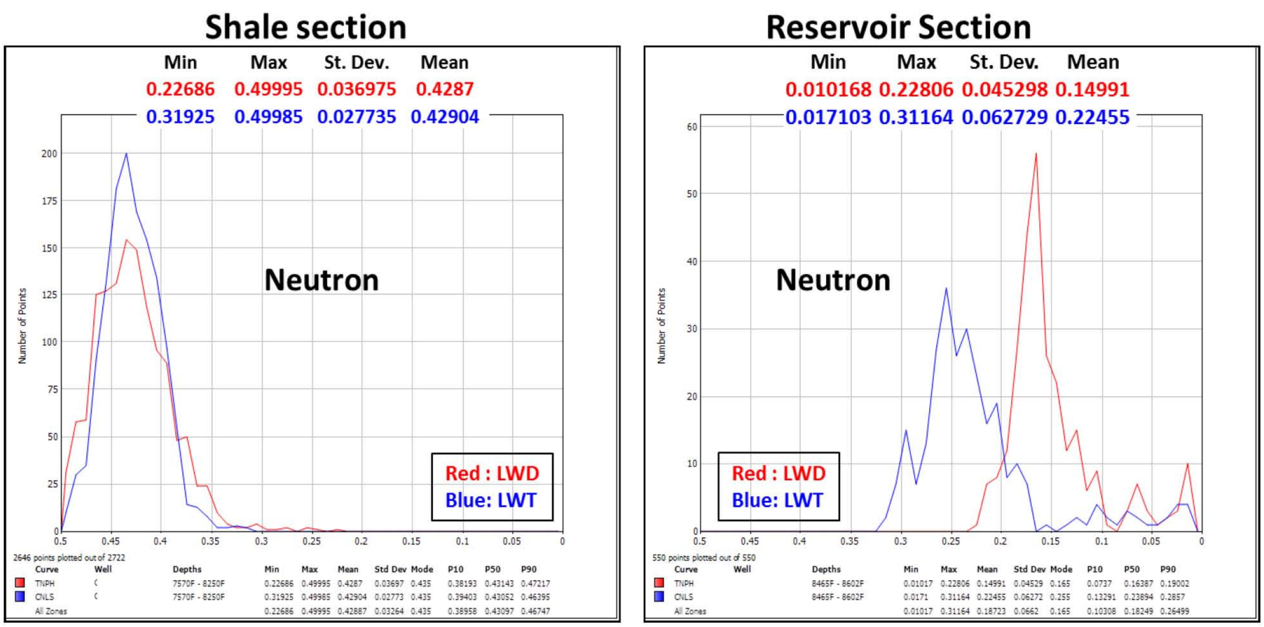
The following comparison of histogram plots between shale and reservoir sections is clearly explaining the logical responses of LWT tools in both rock types due to complicated invasion process (oil base mud invading reservoir oil and formation water in a transition zone).



a) In the shale section there is no invasion effect. LWT & LWD density are almost at the same mean value

b) In the reservoir section LWT & LWD density difference are due to the complex OBM invasion. LWT reads more PHID.

Figure 14—Density data histogram plots and statistical comparison between LWT and LWD



a) In the shale section there is no invasion effect. LWT & LWD Neutron have almost the same Mean Value.

b) In the reservoir section LWT & LWD neutron difference are due to complex OBM invasion & environmental corrections. Offset core data reconciled better with LWT density-neutron porosity

Figure 15—Neutron data histogram plots and statistical comparison between LWT and LWD

Porosity Reconciliation: Since density & neutron response between LWD & LWT in Well # 2 are different across reservoir sections, it calls for reviewing these logs with offset wells. As per that the histogram plot (refer Fig. 16) comparison between computed density-neutron cross-plot from LWD, LWT and core porosity from nearby offset wells shows that LWT computed porosity is closer to core porosity than LWD computed porosity and suggests that LWT logs are reliable over LWD logs in this case.

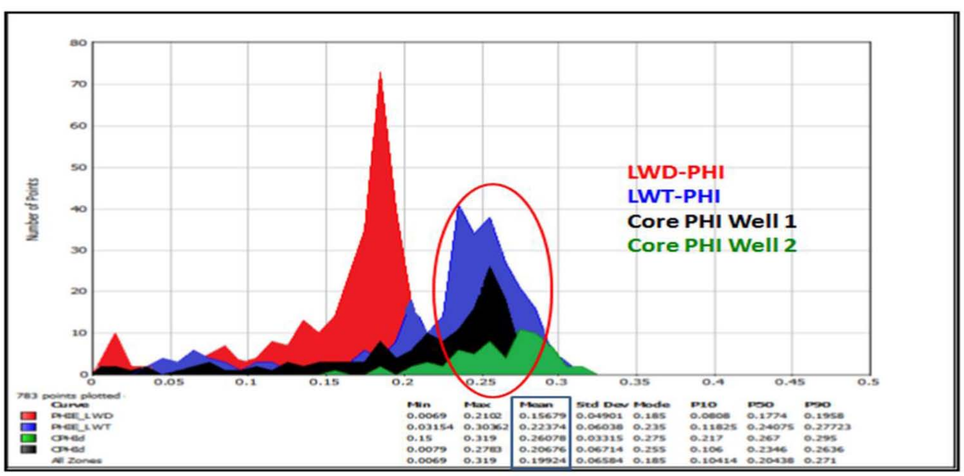


Figure 16—Histogram plot comparison between computed density-neutron cross-plot porosity of LWD & LWT logs of Well#2 and core porosity from nearby offset wells

Conclusions

From the case studies following conclusions can be drawn:

1. LWT logs matches back to back the WL & LWD logs, differences in log responses are explained by differences in tool physics, logging speeds and environmental conditions.
2. In Well # 1, the LWT calculated Neutron-Density Porosity is matching WL Neutron –Density Porosity.
3. In Well # 2, the LWT provided reliable porosity matching core porosity from offset wells.
4. LWT propagation resistivity is in good match with LWD resistivity and could be used for further resistivity inversions (e.g. anisotropy analysis).
5. LWT nuclear caliper (derived from density data) is matching with WL mechanical caliper and thus infers more confidence in LWT behind pipes density & caliper measurements.
6. Quality data has been acquired in both Well # 1 and Well # 2 with minimal risk and virtually no extra rig time.

Recommendations

It is highly recommended using LWT conveyance and acquisition technology to acquire triple combo open hole formation evaluation data to reduce overall data acquisition costs and lower the operation risk profile. In challenging down hole conditions, LWT technology will provide the useful desired formation evaluation data in cost and time efficient manner at a low risk.

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Nomenclatures

ADNOC = Abu Dhabi National Oil Company
BHA = Bottom Hole Assembly
CN = Compensated Neutron
CNL = Compensated Neutron Log
DEN = Density
DUIN = Dual Induction
GR = Gamma Ray
LWD = Logging While Drilling
LWT = Logging While Tripping
MWD = Measurement While Drilling
NPHI = Thermal Neutron Porosity corrected only for borehole size
QA = Quality Assurance
QC = Quality Control
RHOB = Bulk density
Rt = True Resistivity
SGR = Spectral Gamma Ray
TNPH = Thermal Neutron Porosity
UAE = United Arab Emirates
WL = Wireline
LIH =Lost in Hole

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