Quantitative Formation Evaluation of Hith-Gotnia Evaporites by Integrating Logging-While-Drilling and Cased Hole Wireline Measurements*

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Abstract

The Gotnia and overlying Hith formations are evaporitic deposits with inter beds of limestone. Discovery of hydrocarbon in these carbonates identified them as new exploration targets. During Kimmeridgian and Tithonian times, a hyper-saline setting prevailed; this attributed to the deposition of thick anhydrites, salts, with occasional shales and limestones. These sediments are are the Hith and Gotnia formations in Kuwait. Sharp contrast in the lithology of salt-anhydrite and high-pressured, interbedded limestone layers makes these formations extremely challenging to drill and evaluate. Well data acquisition, namely of well logs and cores, has been a major challenge owing to the gas-kicks conditions encountered while drilling. Hith and Gotnia formations are drilled using mud weights in the range of 18 ppg to 21 ppg to counter the high formation pressure. For obvious safety reasons, casing is set immediately after drilling, limiting open-hole data acquisition. Due to complex lithology and low porosity, a comprehensive acquisition and interpretation methodology is required for carrying out a quantitative formation evaluation to assess the prospectivity. A workflow, using open-hole LWD quad combo measurements acquired in “wash-down” mode, cased-hole wireline measurements and mudlogs, has been devised to optimize formation evaluation in the Gotnia-Hith sequences. Neutron-induced spectroscopy and natural-gamma-ray spectroscopy are acquired behind casing. A thick, homogeneous anhydrite marker is identified on the mudlogs and offsets on the cased-hole spectroscopy measurements are guided to match the lithology across this marker. This is done to eliminate the effect of casing and cement signal on the spectroscopy measurements. Natural-gamma-ray spectroscopy results show that the limestone layers are radioactive, resulting in erroneous shale-volume computation, using open-hole gamma ray. The lithology and matrix properties derived using spectroscopy measurements are combined with other open-hole measurements in a multi mineral model for quantitative formation evaluation. Formation evaluation utilizing the workflow described above was carried-out on multiple exploration wells. The results were first used to optimize the selection of intervals to be tested. The first well tested using the workflow resulted in oil flow, validating the hydrocarbon potential of these reservoirs and opened doors for development of the Hith and Gotnia formations.

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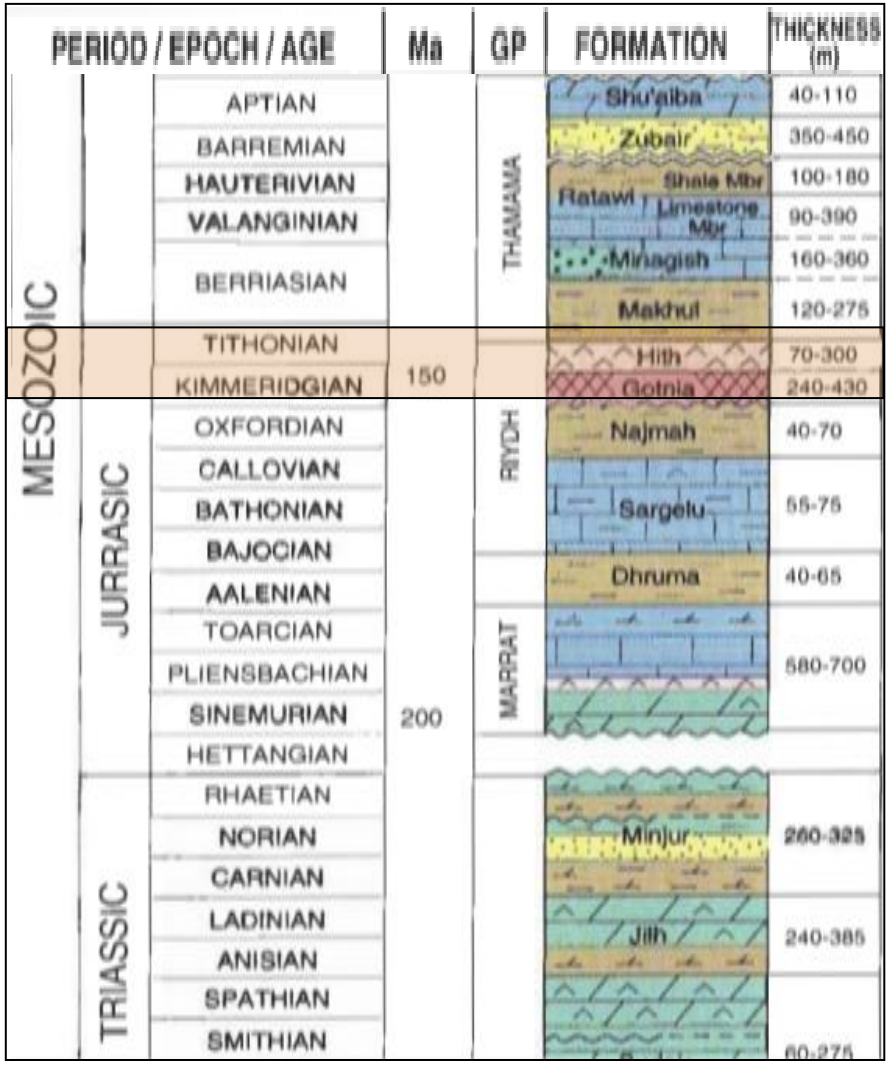
Agenda

- Introduction…
- Reservoir Geology of Hith and Gotnia Formations…
- The Challenges…
- Workflow…
- Results &…
- Conclusions…

Introduction

- Near the top of the Jurassic sequence in Kuwait is the high-pressured Hith Formation, which is mainly anhydrite interbedded with limestone and some shale
- The Gotnia Formation, underlying the Hith, is a massive salt-anhydrite sequence with pore pressure approaching overburden gradient
- Both formations traditionally overlooked as potential reservoirs owing to limited data acquisition in high-pressured environment
- To capture the potential, log data acquisition and petrophysical interpretation is proposed and successfully implemented.

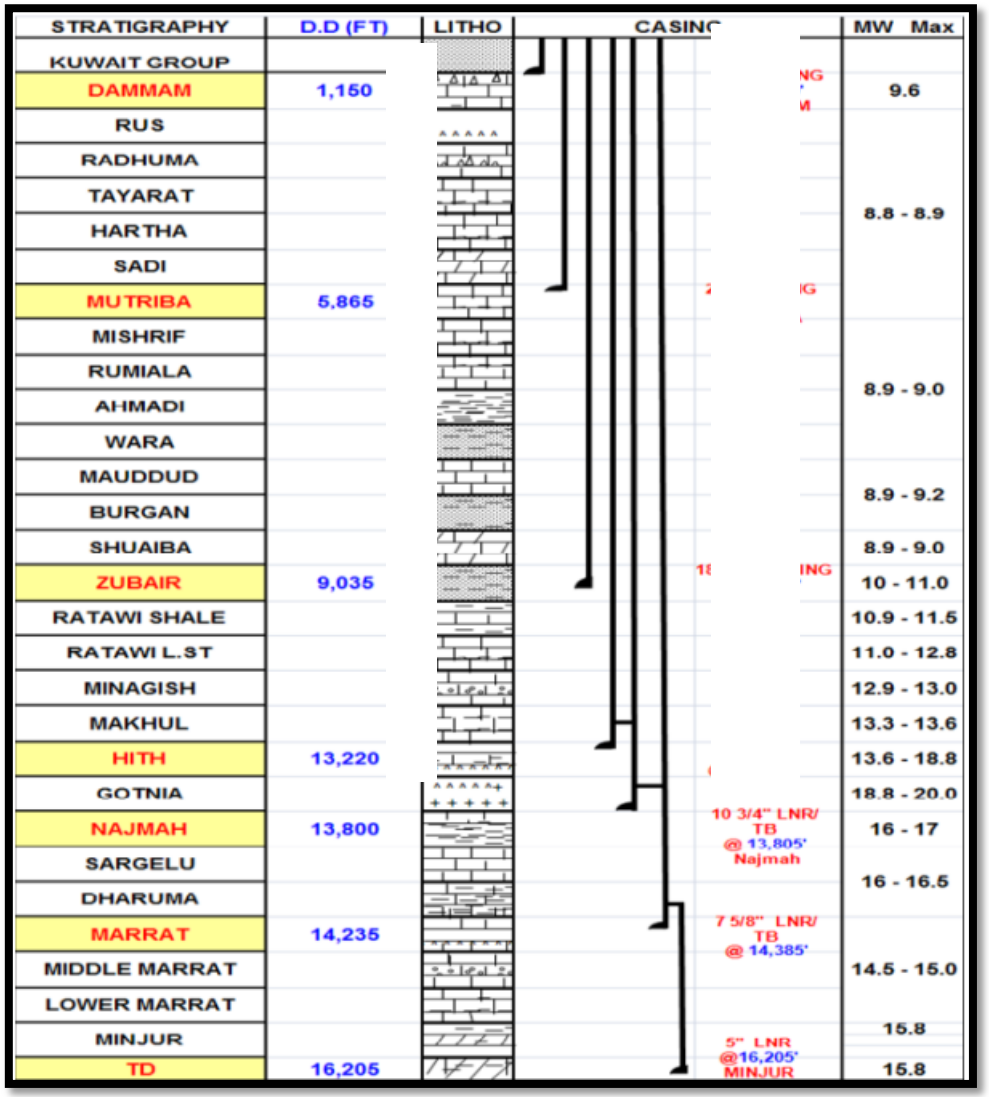


Gross Reservoir Geology

- Hith and Gotnia are the evaporitic sediments, deposited in a supratidal sabkha setting
- Hith Formation consists of anhydrites and limestone beds stacked throughout the section
- Gotnia Formation consists of a series of salt-anhydrite-limestone sequences
- Limestone beds within the anhydrites are the target reservoirs

The Challenges

- High pore pressure requires drilling with high mud weights and avoiding use of any chemical sources while drilling for HSE considerations
- Open-hole logging limited to wash-down logging while drilling (LWD) conventional measurements
- Complex lithology and low porosity require advanced logging measurements for quantitative formation evaluation
- Advanced logging measurements acquired behind casing require corrections
- Uncertainty in the quality of cement job



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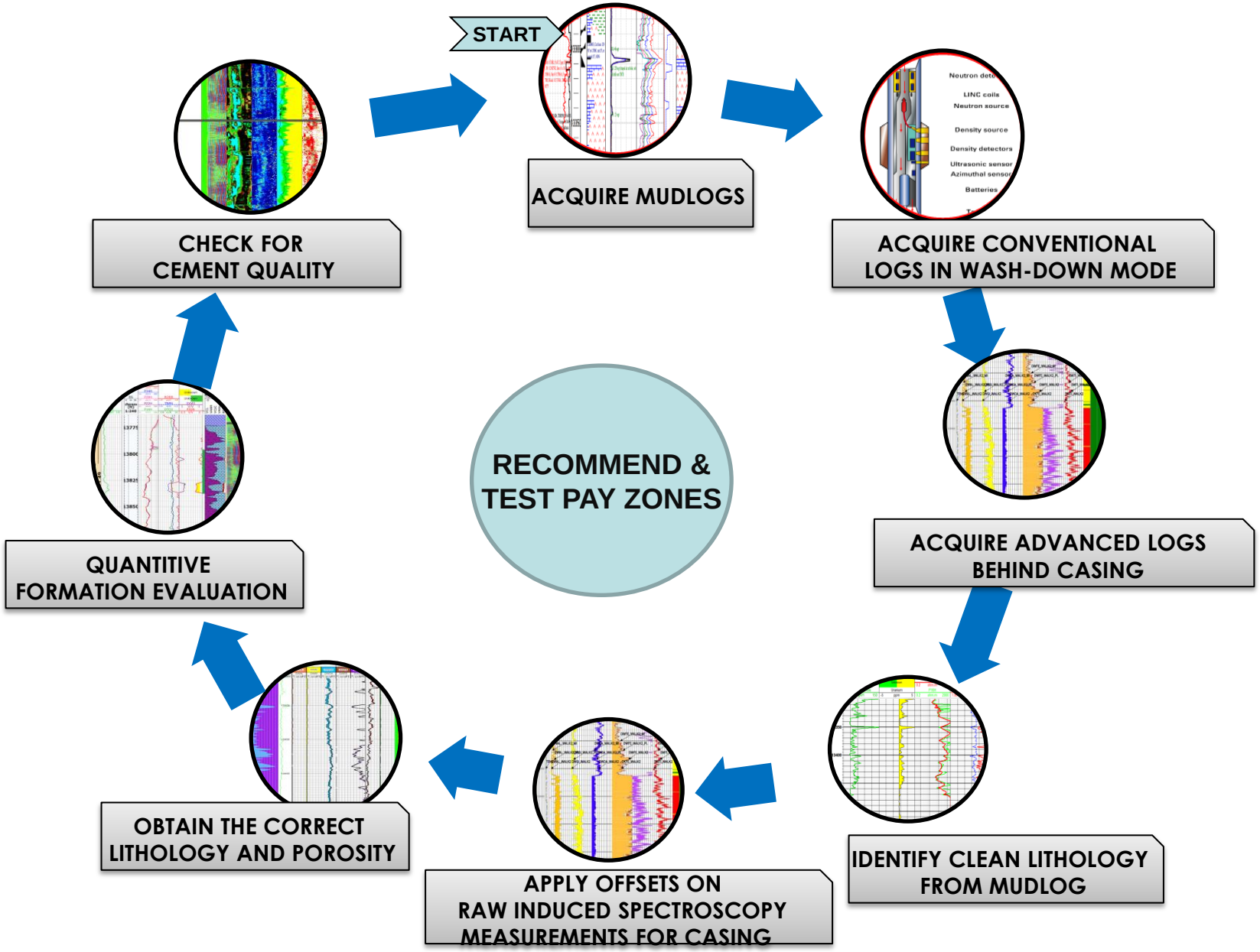
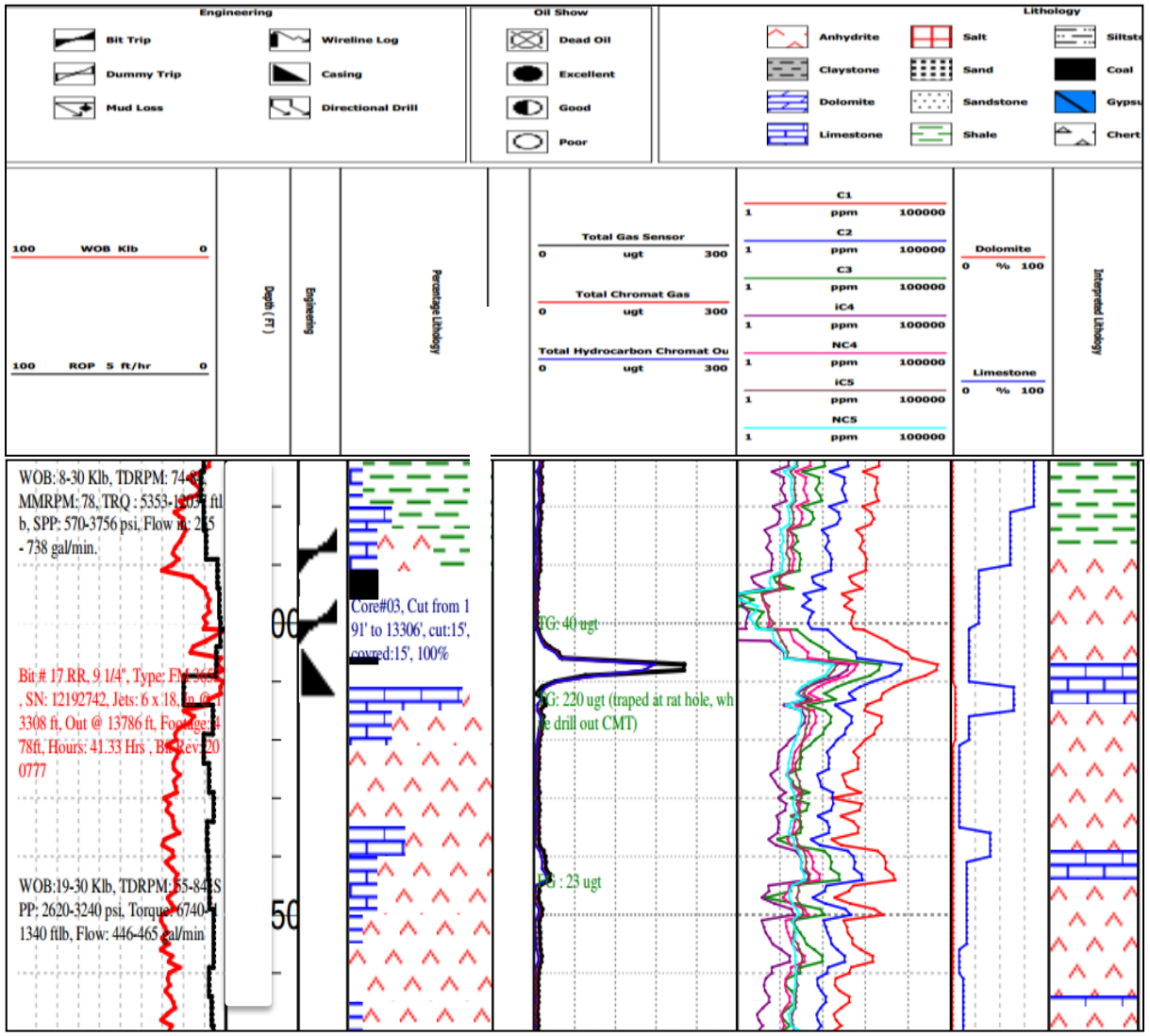
Workflow


START
ACQUIRE MUDLOGS
ACQUIRE CONVENTIONAL LOGS IN WASH-DOWN MODE
ACQUIRE ADVANCED LOGS BEHIND CASING
IDENTIFY CLEAN LITHOLOGY FROM MUDLOG
APPLY OFFSETS ON RAW INDUCED SPECTROSCOPY MEASUREMENTS FOR CASING
OBTAIN THE CORRECT LITHOLOGY AND POROSITY
QUANTITIVE FORMATION EVALUATION
CHECK FOR CEMENT QUALITY
RECOMMEND & TEST PAY ZONES

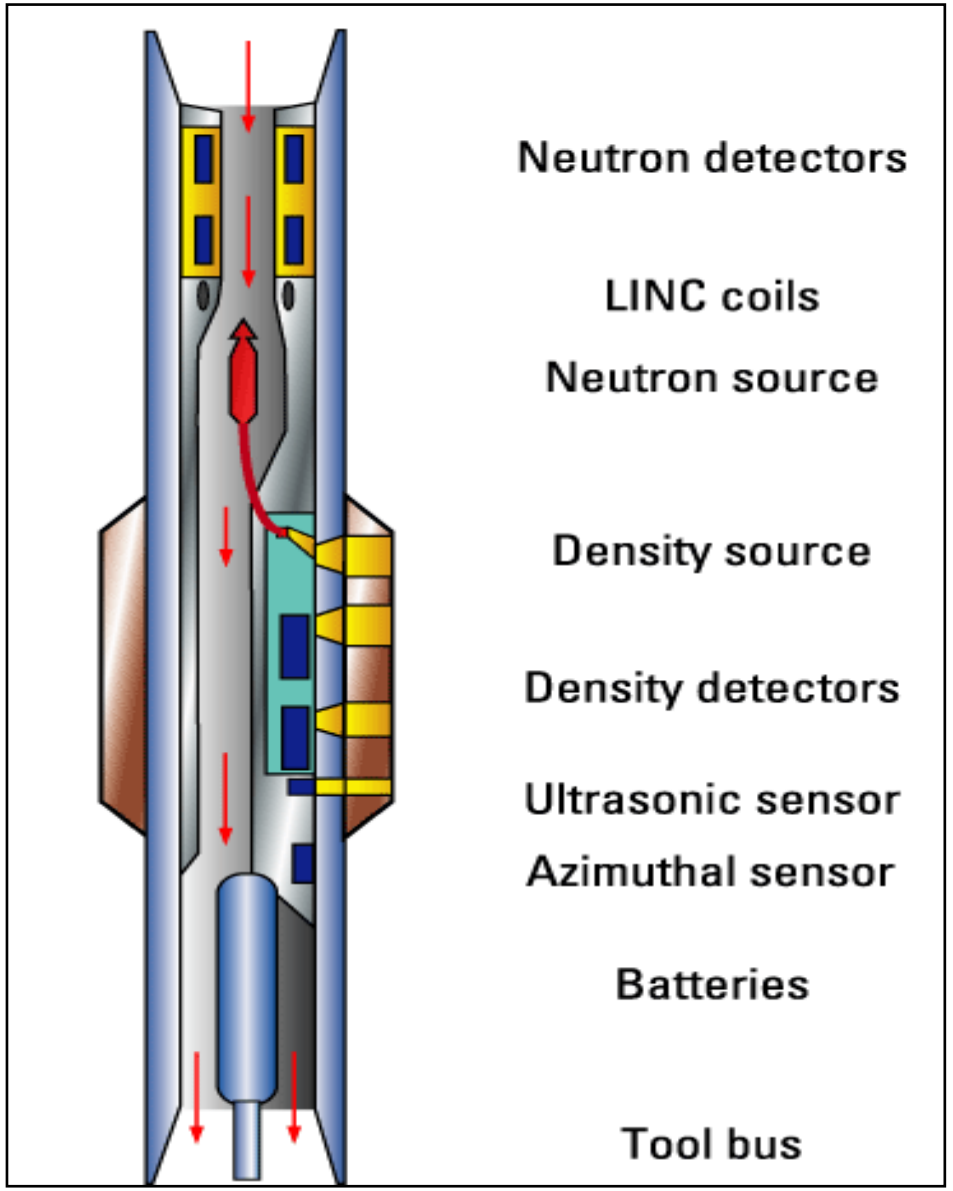
Acquire Mud Logs

- Mud Logs are acquired while drilling
- They provide a qualitative guide about the lithology and possible hydrocarbon bearing zones
- They provide a backup in case no further logs can be acquired due to well related issues
- Care is taken about the depth mismatch between open/cased hole logs and mud logs

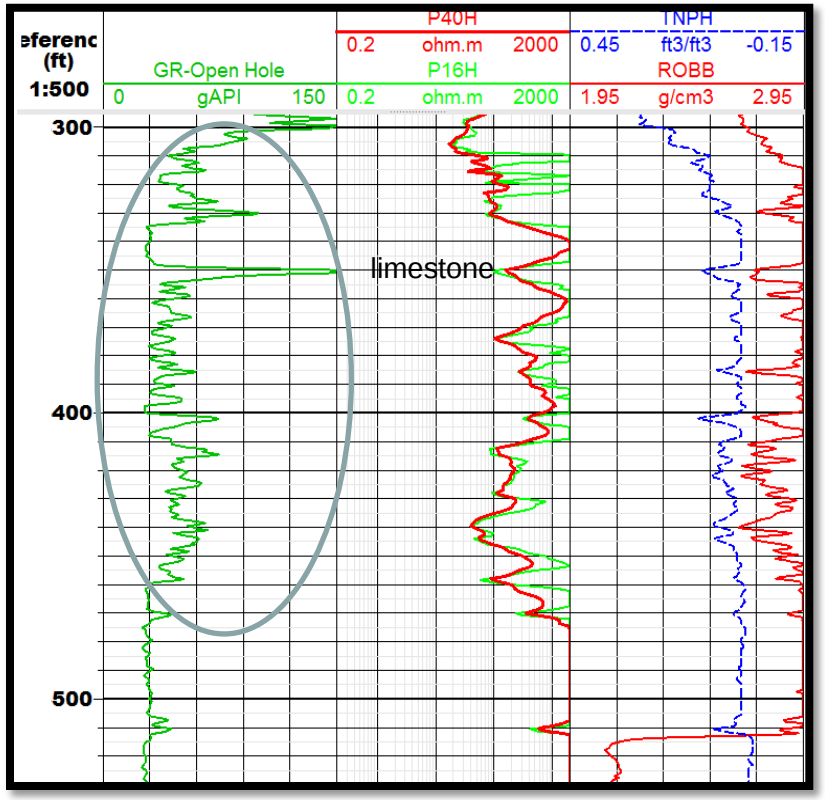


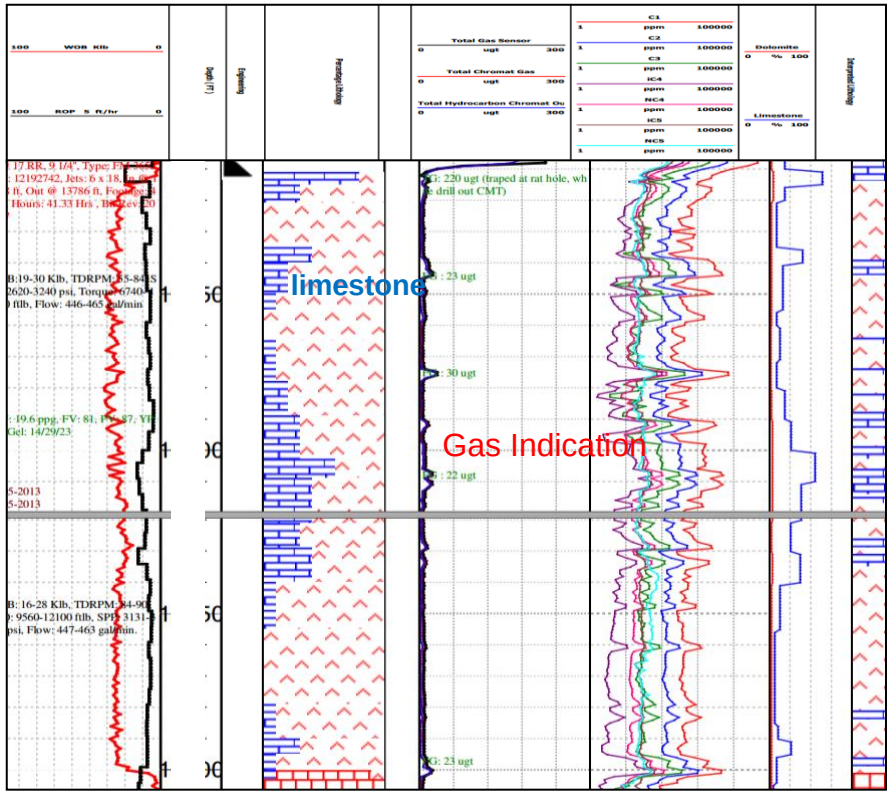
LWD Logs- Wash-Down Mode

- Porosity logs (neutron and density) both have radioactive sources
- Owing to the high pressure, it was advised not to go down with radioactive sources while drilling
- LWD logs were acquired on a drill-pipe-post drilling (wash-down mode)
- Tools used have provision of retrieving source in case of stuck tools



Conventional Logs vs Mud Logs

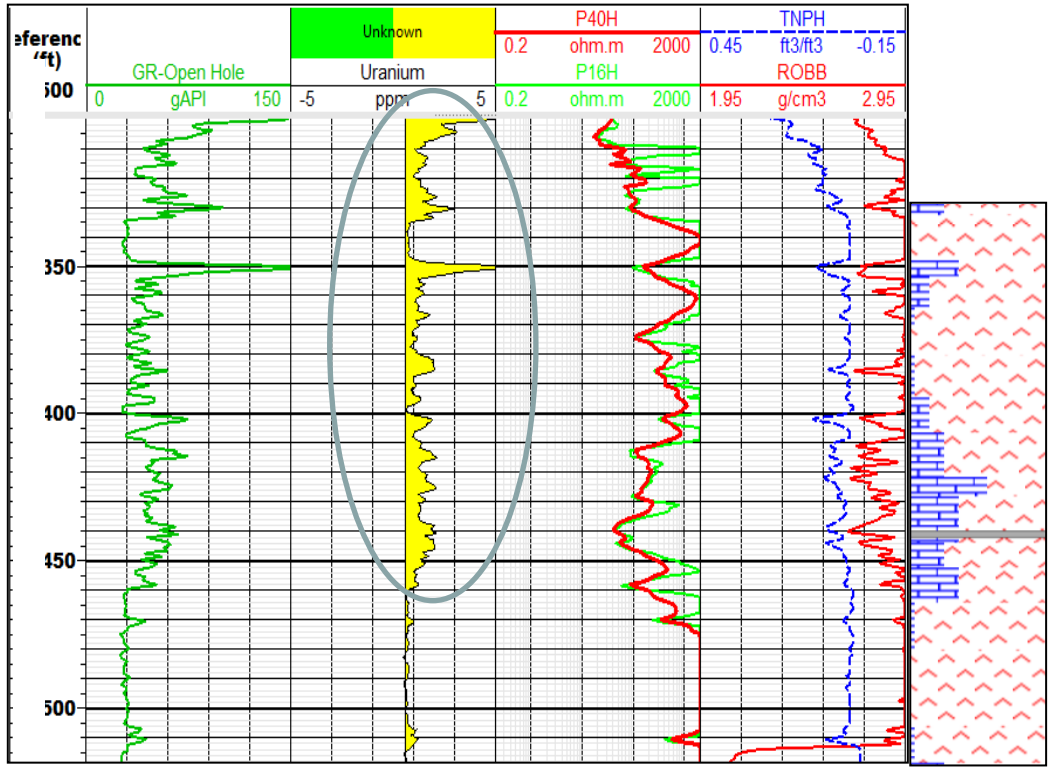




☞ High Gamma-Ray readings correspond to limestone layers, and not shale as confirmed from mud logs

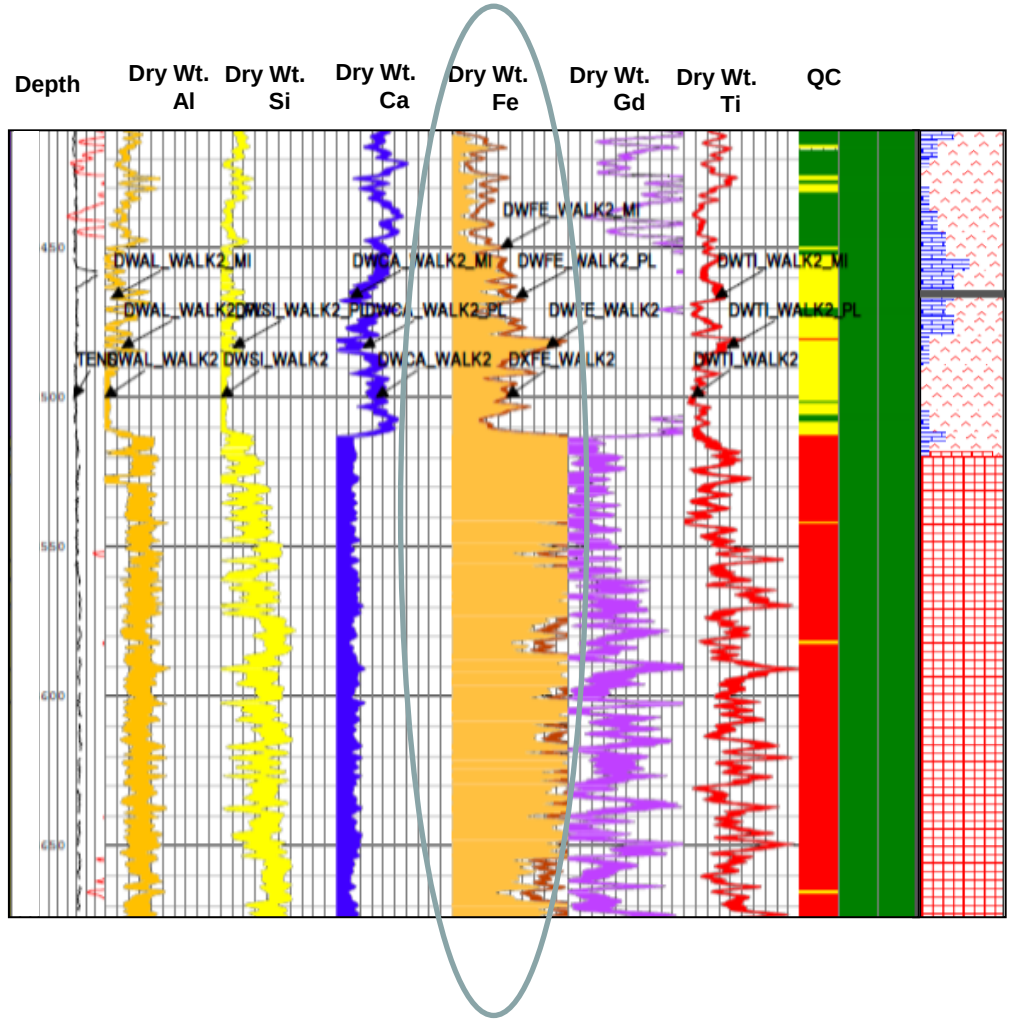
Natural-Gamma-Ray Spectroscopy Logs

- Natural-Gamma-Spectroscopy logs identify presence of radioactive material across low shale content layers.
- This would make shale volume computation using conventional Gamma Ray misleading.
- Advanced measurements are thus required for quantitative formation evaluation



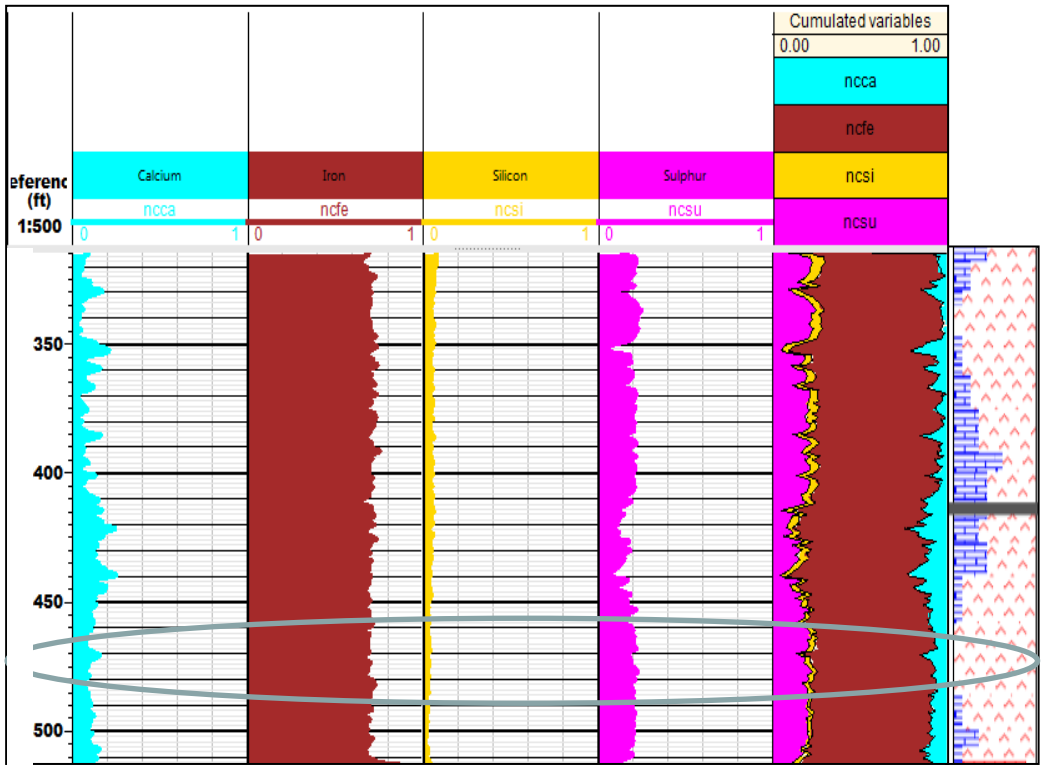
Raw Cased-Hole Neutron-Induced Spectroscopy

- Excess iron signal seen throughout the log due to the presence of casing
- Poor spectroscopy results across salt zone due to the presence of chlorine (neutron absorber)
- Need a reference formation with known lithology (possibly clean anhydrite) to identify the offsets needed to be applied on raw data
- Clean Anhydrite zones identified from mud logs were used to ascertain the offsets needed to obtain accurate lithology



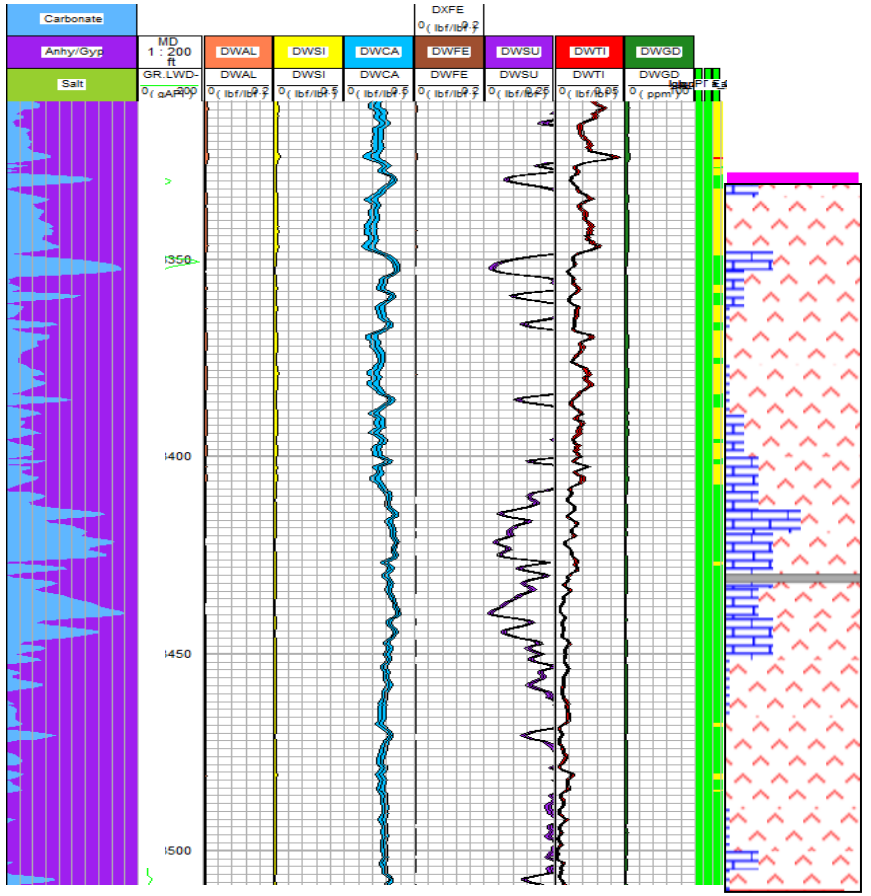
Reference Formation Selection

- Figure shows the relative contribution of main elements to the total signal
- Iron comprises more than 60% of the total signal
- The offsets on various elements are decided across clean anhydrite formations (identified from mud logs and conventional logs) where there should be no contribution from the iron signal



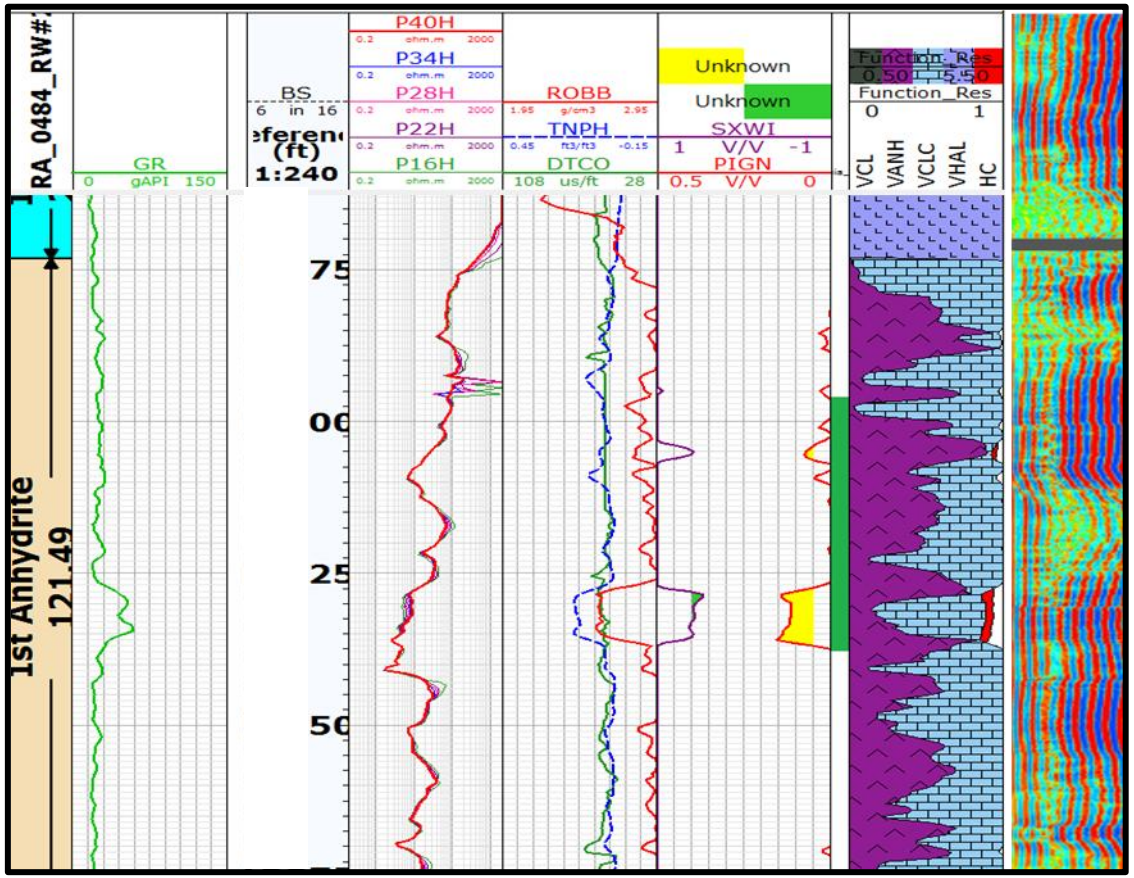
Results after Corrections

- Figure shows the improvement in the spectroscopy results after applying the iron offset
- It is clear that mud logs are more qualitative and the spectroscopy are at much higher resolution and can be used quantitatively
- The spectroscopy results were then combined with open-hole logs for quantitative formation evaluation



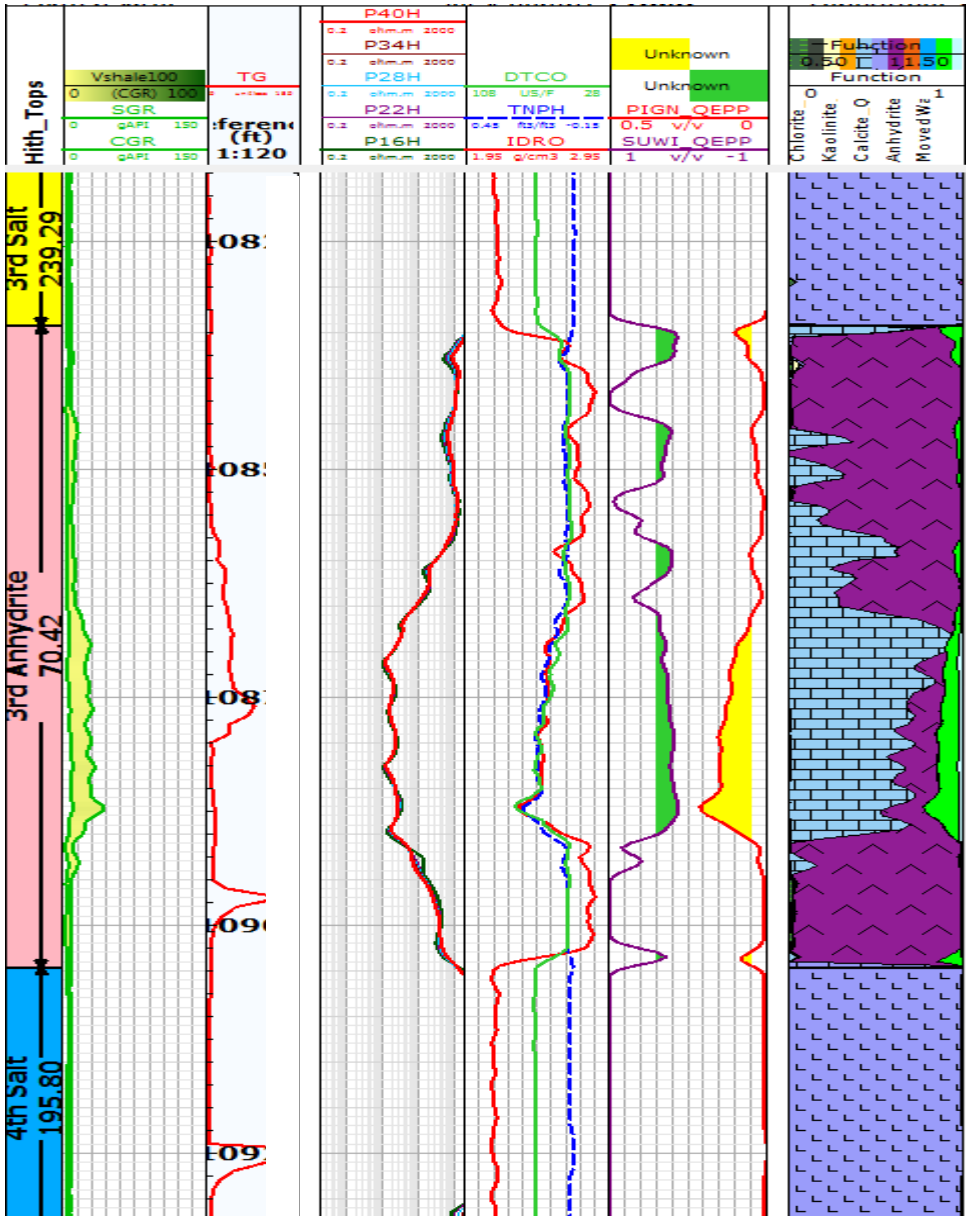
Formation Evaluation

- Formation evaluation identified the best zones in the logged interval
- Cement bond logs identified good cement across the zone of interest
- Testing this zone confirmed the presence of movable hydrocarbon for the first time in this reservoir



Integrated Formation Evaluation- Case Study II

- Formation evaluation performed, combining open-hole logs, cased-hole logs and mud logs with total gas count
- Integrated formation evaluation allows identification of pay zones
- Optimization of zones to be tested done, based on the results



Conclusions

- LWD logs in wash-down mode have been successfully recorded in these formations.
- Cased-Hole logs have been acquired for integrated formation evaluation
- Require reference formation identification based on mud logs to remove casing signal on cased-hole logs
- Cased-hole offsets on spectroscopy measurements derived across reference formation
- It is important to validate for poor cement before going forward with well test
- The first well tested using the workflow resulted in oil production across the selected formations

THANK YOU