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Borehole Images Play Key Role in Production Enhancement in Samah Field, Libya:

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ABSTRACT

Samah is a brown field with production and water cut problems. Most of the wells in the field have experienced major increase in water cut. This was aggravated by high drawdown pressure in undefined fracture network. Operator decided to revive the field by attempting water shut-off and production enhancement procedures. A study was commissioned to select candidates for stimulation procedures.

The reservoir rock quality plays an important role in fluid distribution along the reservoir layers. Samah field produces from Gergaf tight sandstone formation, where the saturation profile is not uniform due to capillary force variance. Besides the tightness, the productive layers is characterized by natural fractures connecting the reservoir fluid to the wellbore. Therefore, identifying the fracture density and orientation is essential to maximize oil production. Borehole images were used to extract fracture attributes such as orientation and intensity. Borehole images also revealed intervals with fracture swarms that may significantly contribute to fluid flow.

This case study involved 4 producing wells and 2 temporarily shut-down wells. A thorough investigation was performed utilizing available production data, petro-physical logs, and borehole images to qualify the wells potential and nominate candidates for stimulation procedure. A potential candidate well that currently produces from 50 ft interval and delivers at 90 % water-cut was investigated. Integration of borehole image and production data revealed that most of the flow originates from two fractured intervals. The borehole image also showed that fractures are mostly layer-bound, hence vertical permeability is significantly reduced. This suggested that different layers may have been depleted at different rates and that there might be a layer below the assumed OWC that still have bypassed oil. This hypothesis was corroborated by workover performed on the well prior to this investigation. Based on this study, a workover program was developed to revisit the nominated wells, investigate bypassed oil-bearing layers and treat water production using chemical solutions suitable for fracture system.

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EXTENDED ABSTRACT

Introduction

Oil production becomes more challenging as the oil field gets mature. Samah field is a sandstone reservoir with average permeability of 0.8 mD and strong bottom water drive aquifer support. The field is currently experiencing water breakthroughs from high-permeability layers in naturally fractured intervals, leaving hydrocarbons pockets behind. Saturating usually consolidated sandstones with average porosity of 7.6 %.

Samah Field started production in 1967, with original oil in place MMB 1,180. The main reservoirs in Samah Field are Quartizitic Gargaf formation overlaid by coarsely crystalline, vugular dolomite Samah. Natural fractures have or are projected to have a major effect on reservoir fluid flow in the form of (1) enhanced reservoir permeability, (2) enhanced porosity, and/or (3) greater permeability anisotropy in a fractured reservoir,

Impacts of high water cut in mature fields are well known within the oil & gas industry. Samah field, witnessed a sharp increase in water cut over the last 10 years. As a result, the oil production decreased dramatically due to increase in shut-in wells.

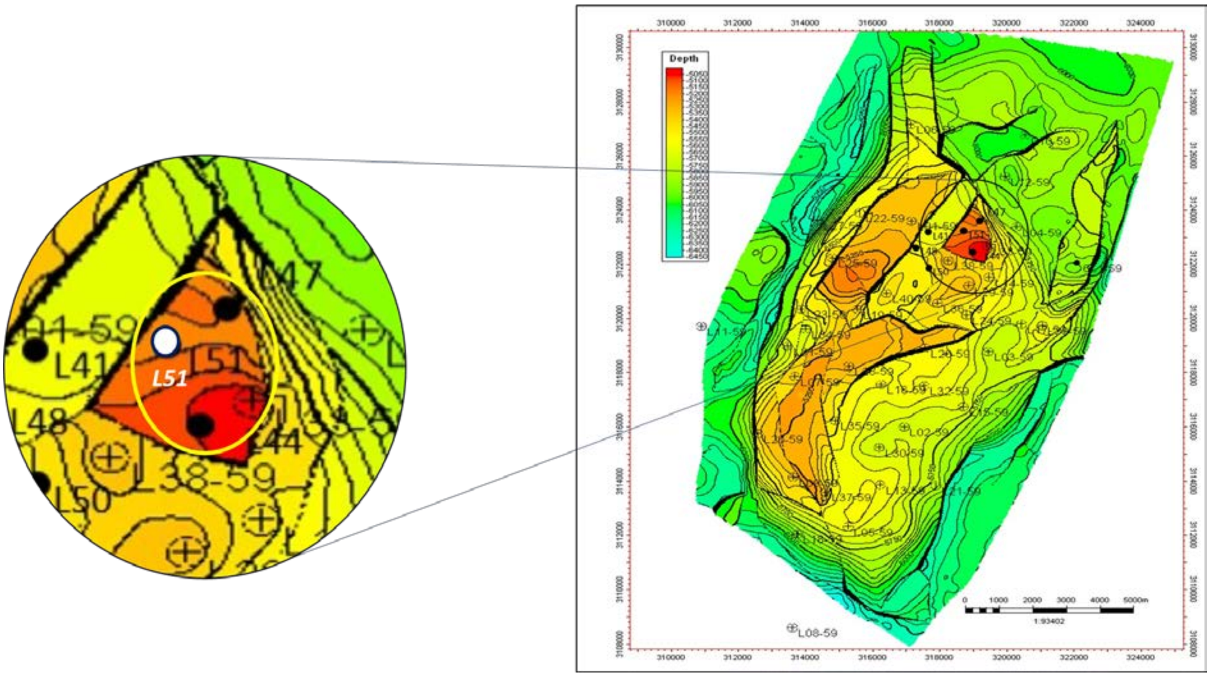

Figure 1. Structure map of the top of the reservoir in Samah Field

An integrated workflow was designed and executed on Samah field in order to spot any potential sources of damage and recommend the best course of action to boost productivity and reactivate shut-in wells.

Reviewing well and production history, production logs, borehole images, and production logging were all part of the integrated workflow. After identifying the fracture network and correlating it to production logging, the oil target zone was then identified.

Target Well History

The candidate well selection is of a crucial importance when an intervention is to be executed in any fields of engineering. In the process of candidate identification, the mechanism of excessive water production and the nature of the problem are evaluated and determined. This entails production history analysis, log interpretations, diagnostic tests and measurements. Due to the significant remaining oil reserve in Well L-51, this well was chosen to be thoroughly evaluated.

Well L-51 was drilled to TD 6400 ft and completed as a vertical open-hole (8.5") oil producer well in Sep-2013 through interval 6,022 ft to 6,400 ft as shown in Figure 2.

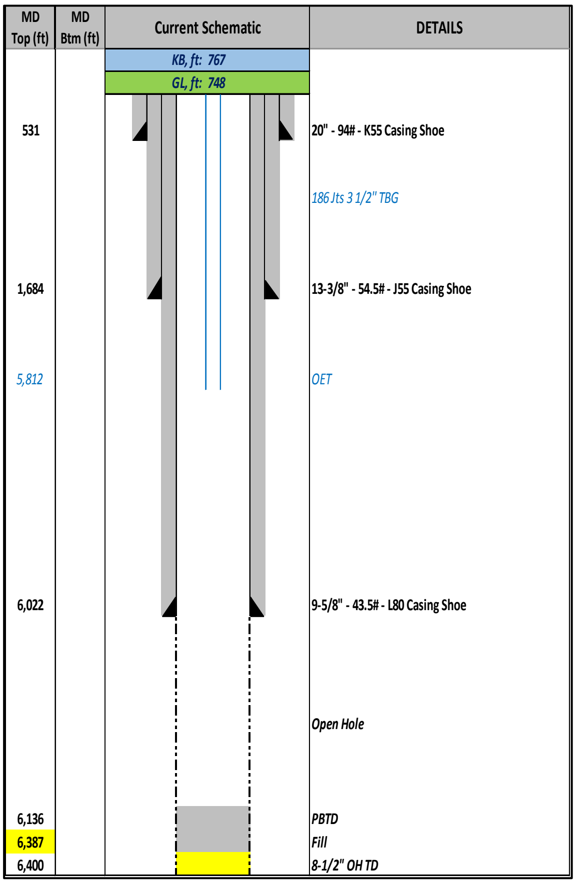

Figure 2. L-51 Well schematic

In February-2014, the well was swabbed for 5 days to remove fluids off the production zone and showed 80% oil & 20% water, however, the well showed low productivity.

In the same workover, an injectivity test was performed prior matrix acidizing job to optimize mud acid recipe. An acid wash (200 bbl, 15%HCL) was spot to clean the wellbore, then followed by main treatment of mud acid (9000 gal, 13.5% HCL & 1.5% HF). After that the spent acid was lifted by swabbing.
After 4 days of swabbing, the well productivity improved with slight increment of water cut from 20% to 30%. ESP pump was run in hole and the well was put on production. Figure 3 shows injectivity before and after acid job that reveals significant improvement in the well injectivity.

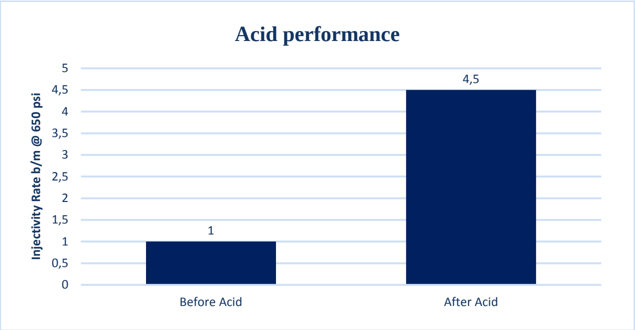

Figure 3. Injectivity results before and after acid job.

The well started producing in August 2016 with 2,200 bopd and 20% WC (Water cut) for one year. During the first year of production, the well was tested once before it shut down due to force majeure. After three months of SI period, the production resumed with decline in liquid from 2,200 to 1500 due to pump downgrade.

During this period, the WC was increasing sharply until it reached 90 % accompanied with decline in oil to 160 bopd as shown in Figure 4.

In Feb-2019, a water shut-off was performed to isolate the lower part of the open hole interval by spotting cement over stages. Initially, the cement was spot up to depth 6282 ft, then swabbed for 5 days. Last day the well showed 93% WC.

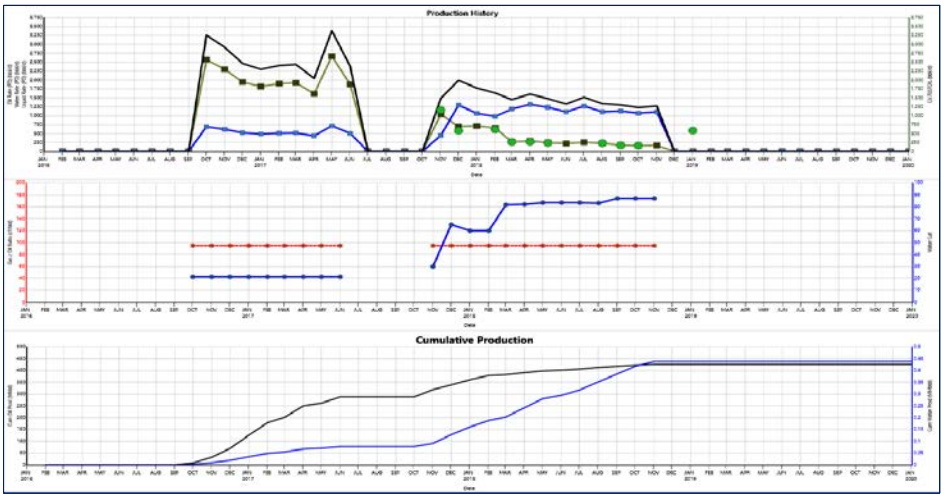

Figure 4. Well L-51 Production History

The second cement spot was performed and covered the interval 6,136 to 6282 ft, however the water cut increased to 97%, which may indicate that an oil-contributing interval could have been isolated by cement.
Lately, in Oct-2019 due to high water cut, a production logging tool was run to identify the zonal contribution and water bearing zones.
Production Logging survey (PLT) has been performed via Y-tool (bypass system provides access to the reservoir below the ESP, enabling logging with wireline without the need to retrieve the completion) during October 2019, in both flowing and shut-in conditions.

Study Workflow
The study workflow consists of three main stages, (1) well correlation to identify the corresponding patterns between the target well and offset wells. (2) Borehole images to pinpoint the fracture density and orientation that may significantly contribute to fluid flow. (3) Production Logging to identify the contributing zones and the correlation to fracture density, which was identified by borehole images.

(1) Well correlation
The integration of subsurface data for petrophysical characterization of reservoirs is a major aspect in formation evaluation in the oil and gas industries [1]. In order to evaluate the petrophysical properties and determine the hydrocarbon in place of potential reservoirs in Samah field, a well log data from the field was collected and interpreted. The petrophysical parameters showed isolated sand bodies with porosity ranges from 7 to 11 % with low matrix permeability of 0.8 mD. A cross section was established between the target well and the offset wells to correlate the petrophysical characteristics. Gamma Ray (GR) and porosity were the key logs used for the correlation. Figure 5 reveals that the Gargaf formation's GR log signature, which consists of clear sandstone portions split by shale streaks, appeared to be quite consistent throughout all of the wells. Regarding porosity, all the wells share a

comparable attribute of low porosity with no discernible trend, although there are occasional peaks of porosity caused by the emergence of fractures at certain intervals.

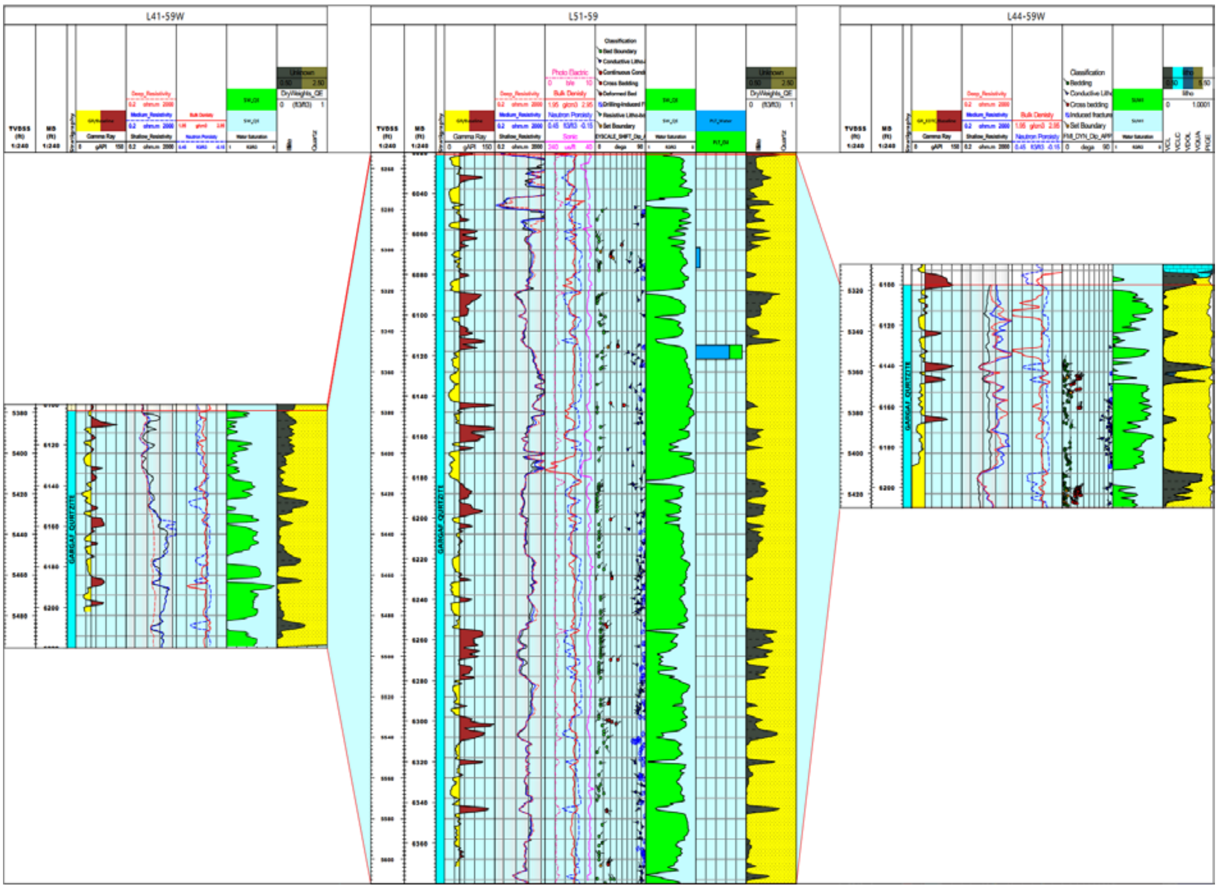

Figure 5. Open-Hole log well correlation in TVD (Subsea). Well L-51 track 4 shows dip interpretation, track 6 shows PLT logs. Well L-44 track 4 shows dip interpretation.

(2) Borehole images

Borehole images in the target well were processed and depth matched to the depth reference log. Geologic features including bedding and fractures were traced on borehole image to get the feature orientation. Each feature traced on the borehole image is assigned a color-coded symbol that illustrates the dip class, true dip inclination and true dip azimuth. Once all features are traced, dip feature counting is performed on fractures to compute the fracture density per unit of depth (In this case, one foot). Fractures are also assessed based on the trace continuity around the borehole to understand if the fractures are extending across multiple bedding planes or are often observed as litho-bound. The behavior of fractures across bedding planes could indicate how fractures act as fluid conduits vertically. Fracture relationship to local structure and nearby faults is also assessed. Fractures associated with a fault tend to be more connected than other types of fractures

Fracture density and fracture types are correlated to production logging that are logged in the same borehole to indicate which of the fracture clusters has potential to flow and the kind of fluid contributed in these zones.

(3) Production Logging Results

A production logging tool was performed via Y-tool (bypass system provides access to the reservoir below the ESP, enabling logging with wireline without the need to retrieve the completion) to the target well L-51 in both flowing and shut-in conditions. The logging was run to establish detailed downhole flow profile as well as determine any necessary remedial actions.

Observation and Results

Borehole micro-resistivity image was utilized to identify fractures and their attributes within sandstone formation. The thorough analysis of borehole image revealed the abondance of litho-bound fractures within the tight, “glass-like”, formation (figure 1). It was observed that the litho-bound fractures density varied within the logged interval and concentrated at certain depths (figure 6). High number of fractures was observed over most of the logged interval. All the fractures were classified as conductive which means they are potentially open fractures. Major strike orientation for the fracture is NNE-SSW. The fracture density is distributed into 3 main zones separated by thin shale layers.

- Zone 1: Lower interval from (6380 – 6319) ft
- Zone 2: Middle interval from (6297 – 6280) ft
- Zone 3: Upper interval from (6250 – 6113) ft

The fact that most fractures observed on the borehole image is litho-bound suggests that vertical permeability is degraded. This is suggesting that each high fracture density unit in which all fractures are litho-bound could be a discrete flow unit. When producing such reservoir in an openhole completion, it is suggested that upper layers may have been depleted at higher rates that some of the layers in the lower part of the completed sections.

The production logging results showed estimated total water production of ~ 1358 STB/d and 92 STB/d of oil.
The interpretation has revealed that water was coming from 2 main entries at 6067 – 6077 ft and 6115 – 6122.5 ft, where the bottom zone is contributing the majority ~ 88% from the total water production. The apparent drop in velocity across 6020-6045 ft is due to the washout across that interval as indicated by OH caliper.
The small amount of oil ~ 92 STB/d production was coming from the bottom contribution interval as shown in Figure 6 below.

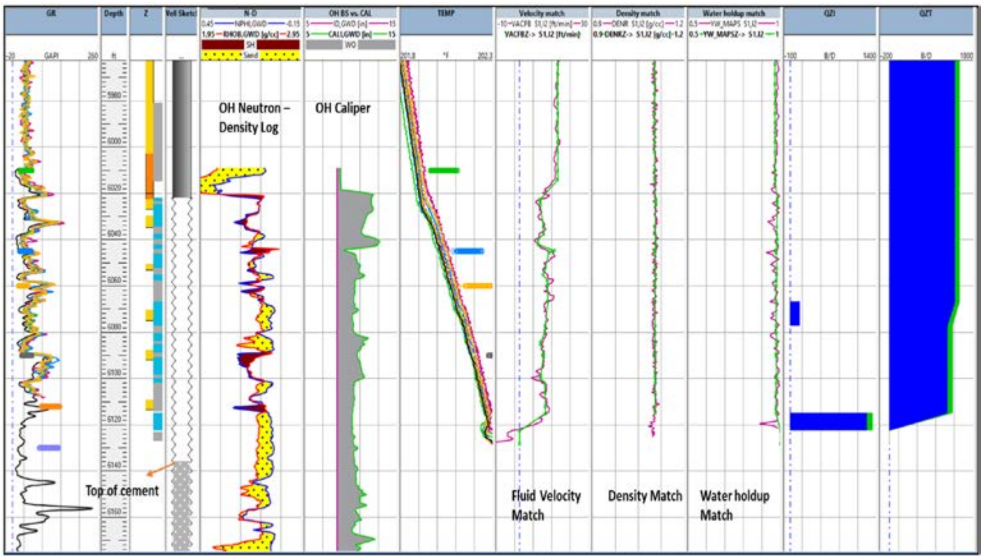

Figure 6. Production Logging Results

It is important to note that the oil came from the lower part of the OH interval, whereas the top interval just produced water. Such a behavior can be a sign of uneven layers depletion.

Due this phenomenon, the previously considered as a one connected reservoir was revealed to be a compartment reservoir due to the peaks of GR and the vertical discontinuity of fractures limiting vertical fluids flow. Such phenomenon leads to ununiform saturation profile due to the capillary force variance. Therefore, the depletion of each sand interval was different; were showed water at the top and oil at the bottom.

Considering the results of the cement workover operation in February 2019, where the water cut increased while isolating the lower interval, this confirmed the presence of oil at the lower interval as compared to the higher interval. This hypothesis was supported by production logging results that indicated solely water produced from the top versus water with some oil at the bottom.

In light of the presence of vertical flow barrier, it appears that the upper layer is significantly more depleted than the lower interval. Figure 7 shows the integration between open-hole logs and micro-resistivity image suggested that the abundance of shale within different intervals acted as a soft mechanical barrier, hence limiting the vertical extension of these fractures, making them concentrated at different zones.

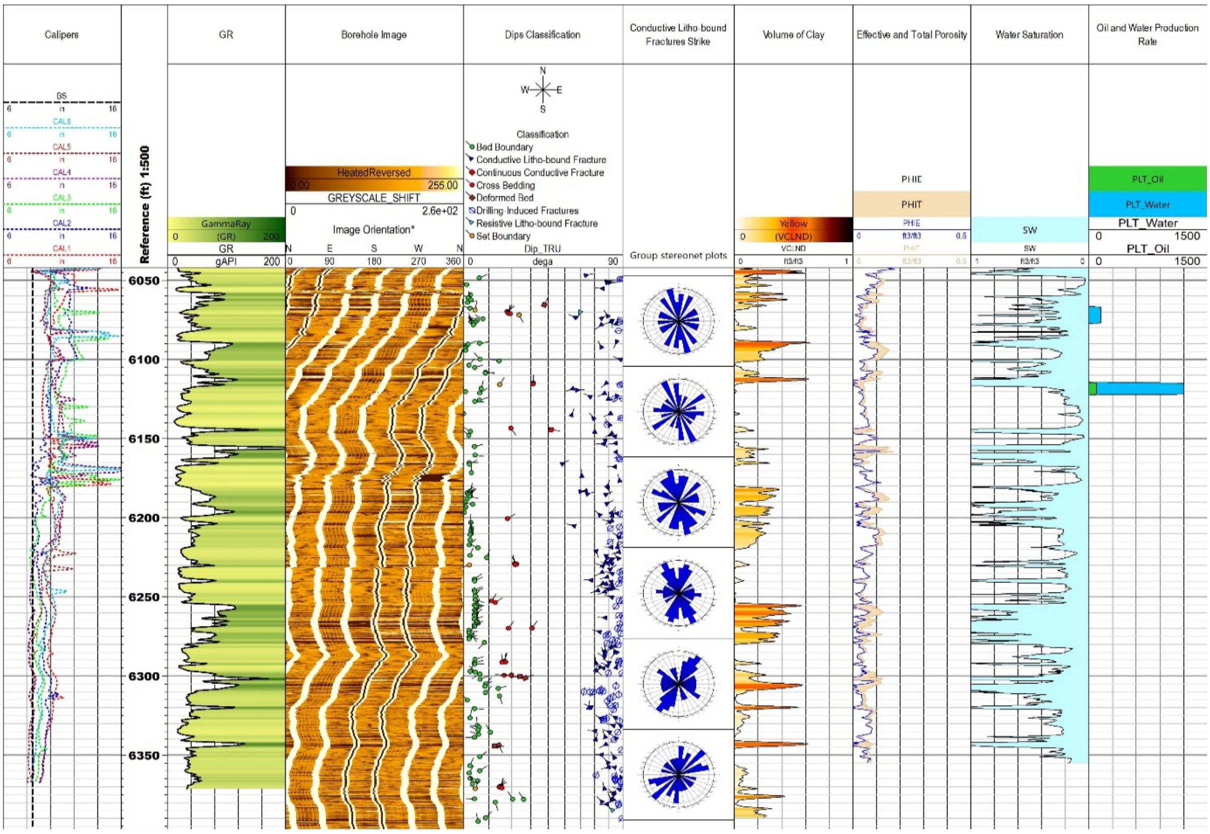

Figure 7. Integrated OH and Production logs.

Conclusion and Way forward

The coordinated efforts of several disciplines have demonstrated their capacity to characterize reservoir layering and its relationship to fractures and how that may have affected production behavior in this well. It is anticipated that the latest cement operation could have isolated a portion of the oil zone and left some potential behind.

In order to unblock the flow pathway of the oil zone interval, the study advised drilling out the cement, perforating, and executing an acid wash to clean the well. Afterward, it is recommended to run the production logging tool to verify the zone contribution and depleted zones. An additional recommendation for a chemical shut-off will be made in light of the production logging's findings.

It is believed that proper understanding the reservoir and the fracture distribution could have led to more suitable workover operation. Example is litho-bound fracture creating discrete flow unit that may not be communicating vertically which may have caused variable depletion of different flow units. A more optimal way to combine image log interpretation, petrophysical logging and production logging to understand the potential and contribution of each flow unit and design a workover accordingly.