First ever slim cement map log and production log combination to evaluate horizontal well's performance

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Abstract

To increase the recovery from the Mumbai High field, ONGC has been drilling horizontal and highly deviated wells since 1995. It is essential to log and monitor them so that appropriate action can be taken to maintain productivity of these wells and take better informed decisions while drilling subsequent horizontal and highly deviated wells in the field. Logging these types of wells presents a number of operational and interpretational challenges due to high angle of deviation, complexity of the completions in the well (e.g. intervention friendly completions which have pre-perforated tubings lying in the horizontal section of open drainhole) and corresponding uncertainties induced while interpreting the data due to frequent and drastic changes in flow regime in horizontal section of the wellbore. For the purpose of the first phase of this campaign, two horizontal wells with intervention-friendly completions (or CTU friendly completions) were selected to record production logging data. To address associated operational and interpretational uncertainties, a unique combination of slim cement mapping log and horizontal well production logging suite conveyed on a wireline tractor was used.

The combination used helped in obtaining the production profile in horizontal wells of Mumbai High for the first time. The information obtained provides an insight into the following aspects: flow contribution pattern along the drain hole, location of water/gas entry points, efficiency of clean-up strategies and optimization of the drainhole length to be drilled in future wells. Recommendations were also made to improve the completion design for future wells and review the well clean-up methodology; this would directly translate into an increase in production.

This paper describes the operational and interpretational challenges, tool string used to record data in the CTU friendly type of completions and customized logging program for these wells. The paper also describes the methodology adopted to interpret the data in both the wells and the results achieved.

Introduction

The Mumbai High field of ONGC is located 160 km W-NW offshore from Mumbai in Western Coastal shelf of India at a water depth of ~75m and is the biggest field in India, with an areal extent of 1200 sq km (Fig 1). It was discovered in 1974 and is a multi-layered limestone reservoir with large variations in fluid flow properties both vertically and laterally. In terms of reservoir heterogeneity, it is considered to be the one of the most complex fields worldwide. 90% of the IOIP is contained in the layer L-III, which is sub-divided into more than 15 sub-layers, out of which 10 are hydrocarbon bearing (Fig 2). During the last ten years, ONGC has drilled a number of horizontal and highly deviated wells completed in either one or more of these sub-layers of L-III layer. Also, as a part of the strategy to maximize recovery, ONGC plans to drill only horizontal and highly deviated wells in the future. Therefore, to improve productivity and long-term recovery from the field, it was decided to record production-logging data to gain better understanding of issues such as:

- Prediction of water and/or gas entries in the well: to gain an understanding of water/gas transport mechanism in the reservoir and supply data for planning potential workovers.
- Location of any unproductive sections of the wellbore: indicative of lateral heterogeneity along the drainhole and one of the reasons for low productivity of the well.
- Optimization of length and placement of future horizontal wells.
- Evaluation of Cleanup strategy currently being used for horizontal wells

Completion Type and Associated Challenges

The completion type present in the two wells selected for this campaign is normally referred as intervention friendly (or CTU friendly). It consists of continuous tubing from wellhead to the toe of the drainhole which enables easy access into the drainhole for any intervention purposes. To maintain communication from formation into the tubing, pre-perforated tubings are placed in the horizontal drainhole section. Also, in those sections where shale streaks are present, blank tubings (i.e. not pre-perforated) are placed so that communication on either side of the shale section doesn't break in event of shale sloughing/heaving.

Challenges

Typical problems[1,2,6] encountered in measuring hold-up and velocities in multiphase horizontal wells are (Fig-3):

a) Slight deviations from the horizontal slopes can cause significant changes in the hold-up and fluid velocities. (Fig-4)
b) Segregated flow in which different fluids have different velocities can greatly complicate spinner readings.
c) Water sumps and gas traps can change cross sectional area open to flow.

SPE 49089 and 53249 are a good reference for typical problems and conventional interpretation methodologies in horizontal well production logging,

Determination of flow profile becomes even more difficult in

CTU friendly completions due to the uncertainties introduced by the annulus between perforat ed tubing and openhole. The major uncertainties are:

a) Changing openhole ID due to shale sloughing/borehole collapse introduce difficulty in distinguishing between flow entry from the formation and increase in flow due to reduction in flow area. (Fig-5)
b) Determination of flow in the annulus.

Tool String

To address the challenges described above, a combination of Slim Cement Mapping Tool and Integrated Production logging tool string for horizontal wells (hereafter referred as Flagship) was used in the two wells described in this paper to acquire meaningful data (Fig-6). The Flagship tool string is suite of logging tools used for production logging the horizontal wells. It consists of probe hold-up measurement tools (electrical and optical), Reservoir Saturation tool (RST*) apart from basic measurements like pressure, temperature, spinner and caliper. A detailed schematic of the tool string is presented in Fig-8.

Item 1 is PFCS (Flow-Caliper Imaging Tool). The Flow-Caliper Imaging tool includes a directional full-bore spinner, an independent, self-centralizing X-Y caliper with a significant range, and local electrical probes. The electrical probes directly determine water hold-up, and a bubble count measurement yields a simple, robust estimate of hydrocarbon flow rate and accurate identification of fluid entry points.

Item 2 is DEFT/GHOST (Digital Fluid entry tool/ Gas hold-up optical Sensing tool). These tools utilize electrical/optical probe technology to determine water/gas hold-up image in the wellbore.

Item 3 is RST (Reservoir Saturation Tool[3]). The main application of this pulse neutron device is determination of three-phase hold-up in the wellbore in TPHL mode, water flow velocity in WFL mode and formation saturation determination using either carbon oxygen ratio based data or capture cross section (sigma) data.

Item 4 is PBMS (PSP Basic Measurement Sonde). The main outputs from this tool are pressure, temperature, gamma ray and CCL.

Slim Cement Mapping tool (SCMT*) was utilized in an unconventional application to get an idea of the condition of the openhole and flow area available (Fig-7). Shale Sloughing /borehole collapse reduce the flow area in the annulus and is expected to provide compactness outside the perforated tubing. The logic behind using SCMT in such scenario is that SCMT should indicate good bond outside the tubing and thus indicate the section in which sloughing has taken place. (Fig-6)

Also, this information would be crucial to choose intelligent offsets and appropriate model during processing and interpretation of RST-TPHL* data[7].

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Conveyance

The wells discussed in this paper were logged using a wireline tractor which was capable of logging both in up and down direction (Fig-9). Tractor was preferred over coil tubing due to the following reasons:

(a) Coil tubing size available at the time of logging was 1.5”. The tubing size in the completion was 3 ½”. On the basis of past experience, this generally resulted in friction locking of the coil tubing and thus whole of the drainhole could not be logged.
(b) Deck space requirement with tractor is much less than that of coil tubing.
(c) The tractor/wireline combination is generally more accurate than coiled tubing for depth control, which was an important issue for the jobs.

Examples

Two wells completed with CTU-friendly completions were logged in the Mumbai High field. The primary objectives of the logging survey were

a) Determination of water/gas entry points and flow contributing intervals .
b) Identification of cross-flow or recirculation phenomenon, if any.

Well 1

This well is located in the South part of the Mumbai High field. The well was completed with CTU friendly completion of 3 ½” tubing in 6” borehole till 2439m and 7” liner shoe set at 2220m. Open hole logs indicated presence of shale streaks in certain sections of the drainhole. As a completion strategy, blank tubings were placed against the shale sections to maintain communication throughout the drainhole. Flow was achieved by placing the perforated tubings in reservoir section of the drainhole. During planning phase of the job, tool lift forces were predicted for ~800 bbls/day of liquid flow rate in the 3 ½” tubing (2.992” tubing ID with 2.125” tractor OD). Hence, the flow rate was regulated during the logging operations.

During the first run, the well was kept at shut-in condition and SCMT was tractored down on wireline tractor. Despite number of attempts, tool string could not go below 2314m MD. This clearly indicated that drainhole below 2314m is not properly cleaned. SCMT data was recorded in the interval 2050-2305m MD. SCMT log indicated very good bond in all the directions azimuthally in the interval 2238-2258m MD. This section of the borehole has presence of shale streaks. This suggested that shale sloughing in this interval has led to compactness of the tubing and thus, no hydraulic communication is present across the interval 2238-2258m in the annulus. As a result, all the flow in this interval would be through the tubing only. In the second run, Flagship tool string (Wireline Tractor + PSP (Production logging tools) + RST (Reservoir Saturation Tool) + Dual DEFT) was lowered to acquire data during both flowing and shut-in condition.

After the flow stabilization, three up and down passes were recorded. These passes would now be referred as “flowing passes”. During down passes, only PLT data was recorded while logging up passes, RST data (TPHL, WFL and sigma mode respectively) along with the PLT data was recorded. The stabilized surface flowrates with 32/64" choke was 600 bwpd, 200 bopd and 5570 scmd of gas. During second up pass, 14 WFL stations were recorded at depths decided on the basis of the trajectory and data recorded during first down and up passes. After 7 hrs of shut-in, passes were recorded from 2100-2290m. These passes would now be referred as "shut-in passes". While coming up, 14 shut-in WFL stations were recorded from 2290m.

The results of the flowing and shut-in pass are presented in the Fig 10 and 11 respectively. During the flowing pass, following were the main observations:

a) Spinner and water velocity from RST Water flow log (WFL) indicate flow below the blank tubing, i.e., below 2268 m. Hold-up from RST*, TPHL*, and DEFT* indicates the presence of both oil and water below 2268 m, suggesting influx of both oil and water.
b) At 2268m, Spinner and water velocity from WFL increase; DEFT starts seeing small quantity (~14%) of hydrocarbon hold-up. This is due to reduction in flow diameter from 6" drainhole to 2.992" inside the tubing at 2268m. RST-TPHL also indicates ~15% oil hold-up above 2268m inside the tubing.
c) Due to increase in flow diameter from 2.992" inside the tubing to 6" drainhole at 2213m, spinner and water velocity from RST water flow log (WFL) decrease above the blank tubing i.e. above 2213m.
d) Above 2202m, TPHL and DEFT show an increase in hydrocarbon hold-up and spinner reading. Also, WFL Water velocity at 2194m is more than that at 2204m. The increase in hydrocarbon hold-up, spinner and water velocity could be attributed to either or both of the following factors:
    i) Production inflow from the reservoir.
    ii) Change in trajectory from flat to downhill(Fig-4)
e) In the interval 2185-2192m, spinner stalls to zero, temperature decreases at 2192m, DEFT shows almost 100% hydrocarbon hold-up, DEFT bubble count increases, TPHL shows an increase of hydrocarbon hold-up, and borehole sigma (SIBF) decreases to ~5 (typical of gas). The responses of all these sensors conclude a gas entry in the drainhole in this interval.

During Shut-in passes (Fig-11), the pressure increased during different passes taken over a period of time indicating that pressure was not stabilized. Spinner and temperature indicated a cross flow from 2195m to 2130m. Also, DEFT indicated hydrocarbon accumulation in the interval 2233m -2268m.

SCMT indicated total hydraulic isolation in the annulus in the interval 2268-2232m due to shale sloughing, thus confirming that all the flow in this section is through tubing only. Therefore, quantification of flow could be done at four different points in the interval 2232-2268m using Stratflow Model[4]. Water hold-up from TPHL, Water flow velocity from WFL readings and deviation at those points were input into the Stratflow Model to get oil and water flowrates at various points. The rates calculated at the four points were around 88 bopd and 398 bwpd indicating contribution from the lower section i.e. 2268-2295m MD. Rest of the production i.e. (161 bopd and 238 bwpd) is coming from the section above blank pipe section.

To summarize, following conclusion were made:

a) SCMT clearly indicated shale sloughing in the annulus and thus the hydraulic isolation in the annulus against the shale section.
b) The drainhole below 2314m is not properly cleaned and thus not contributing to its potential.
c) 66% of total water production and 33% of total oil production is from lower section. This indicated that flow contribution is from both sections of borehole with majority of water being produced from the lower section.
d) A gas entry is taking place in the borehole at around 2190m.

Well 2

This well is located in the North part of the Mumbai high field. The well was completed with CTU friendly completion of 3.5" tubing in 6" borehole till 2365m. Open-hole logs indicated clean limestone in the reservoir section; therefore no blank tubings were placed in this well.

The objectives of logging in this well were similar to well 1. Therefore, tool string used in this well was similar to well 1 except that GHOST was also added in this well since gas production in this well was quite high. Though this well did not have any shale streaks, it was decided to run SCMT in order to ascertain any wellbore collapsing or reduction in flow area in the annulus. Well was flowed at a choke of 72/64" and surface flow rates were 258 bwpd, 578 bopd and 56400 scmd of formation gas with a water cut of 30% and GOR of 613 v/v. The logging program was also similar to that in well 1.

The results of the flowing and shut-in passes are presented in the Fig 12 and 13 respectively. During the flowing passes, following were the main observations:

a) Spinner and water velocity (from RST-WFL) indicate flow near the toe of the drainhole. Hold-up from RST-TPHL and DEFT+GHOST indicates presence of oil, water and gas towards the toe. This suggests flow of all the three phases (predominantly gas) in the interval 2340-2260m MD.
b) A Steady increase in velocity (from spinner) and oil hold-up (RST-TPHL indicates entry of oil in the drainhole from the interval 2250m to 2185m MD.
c) Little or no contribution is observed from the interval 2250-2280m. This interval corresponds to lower porosity (~24%) than rest of the drainhole (~30%). This indicates correspondence of, inflow pattern with lateral heterogeneity along the drainhole.
d) Reduction in fluid velocities in the interval 2185m to 2150m MD, as indicated by spinner and WFL suggests a possible enlargement of drainhole.

During Shut-in passes, a cross flow within the drainhole from 2195m to 2250m MD was observed. Due to presence of gas in most of the drainhole during shut-in condition, SCMT data was affected in most of the places (Fig 12). However, in the 4 intervals (troughs), which were mostly filled with liquid (oil /water), SCMT data was reliable. SCMT data against the bottom most trough indicated the tubing to be more free when compared to the intervals against the other three troughs. This suggested that though the formation is shale free, formation has lost its strength at different places along the drainhole trajectory.

To summarize, following conclusions were made:

a) Formation collapse is observed in non-shaly zones.
b) The toe and heel of the drainhole are producing mainly gas.
c) Major oil entry in the borehole is from the interval 2195-2250m MD.
d) Flow contribution pattern corresponds to lateral heterogeneity along the drainhole.

Conclusions

This campaign was completed successfully by recording and interpreting the production log data in ONGC's horizontal wells for the first time. The combination of Flagship and SCMT conveyed on wireline tractor proved successful in CTU friendly type of completions. Information from SCMT has been very valuable in obtaining downhole flow profile in both the wells and in Well 1; rates could even be quantified against shale section. The log recorded in Well 1 also provided insights into the efficiency of cleanup methodology currently in use.

Finally, to summarize the most important results from this project:

a) Downhole production profile suggests that most of the drainhole is contributing to the flow in both the wells. Water is being produced along with the oil and distributed pretty homogenously.
b) Flow contribution pattern corresponds to the lateral heterogeneity along the drainhole as seen in the well 2.
c) Drainholes in Mumbai high asset are not very stable and susceptible to collapse even in non-shaly zones. Thus, it is recommended to use 4.5" tubing instead of 3.5" so as to achieve maximum flow area.
d) Cleanup methodology currently in use needs to be reviewed. Well 1 should be cleaned up in order to achieve its optimum production.

Acknowledgments

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Figures:

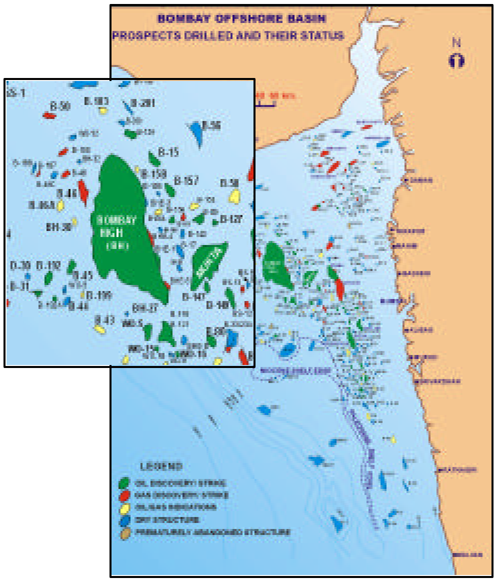

Figure-1 Location of Mumbai High

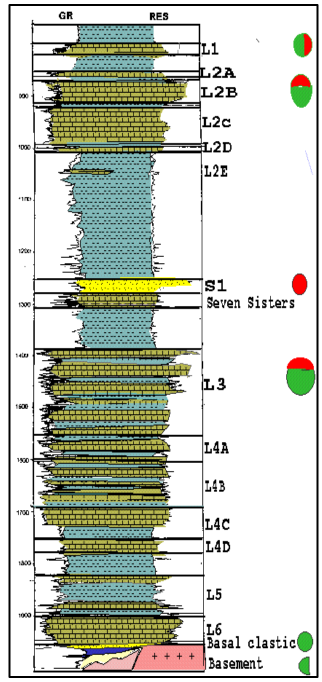

Figure-2: Mumbai High Stratigraphy

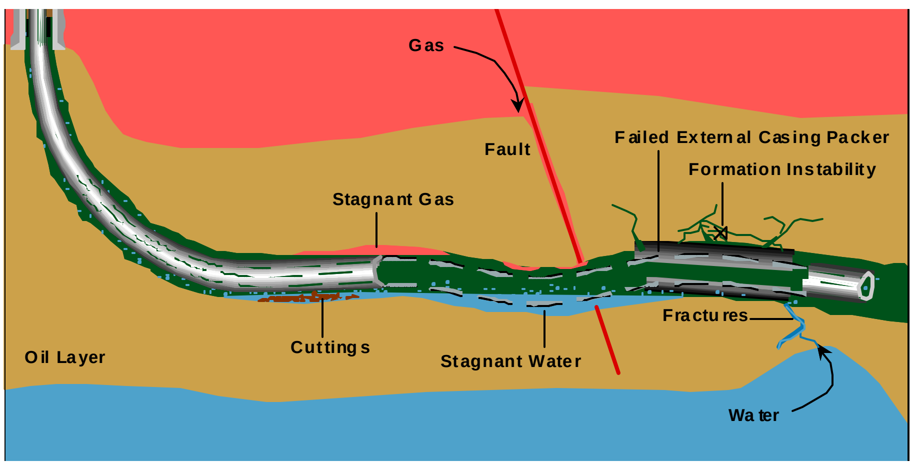

Figure-3: Potential problems in horizontal wells

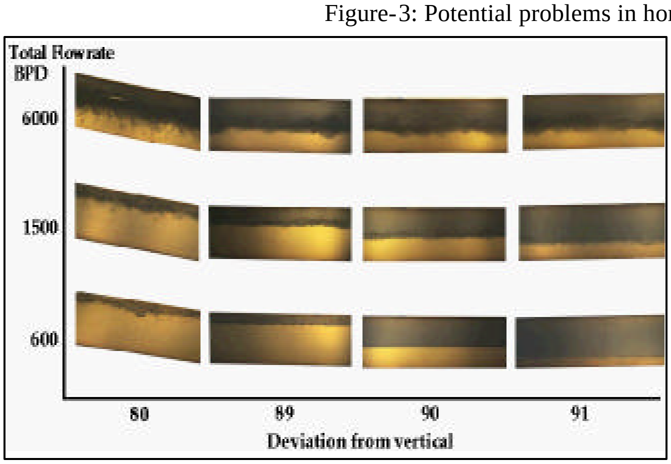

Fig-4: Effect of change in deviation on hold-up and fluid velocities; Water-Oil Stratified Flows in 5.5 in. Casing, Water Cut is 50%

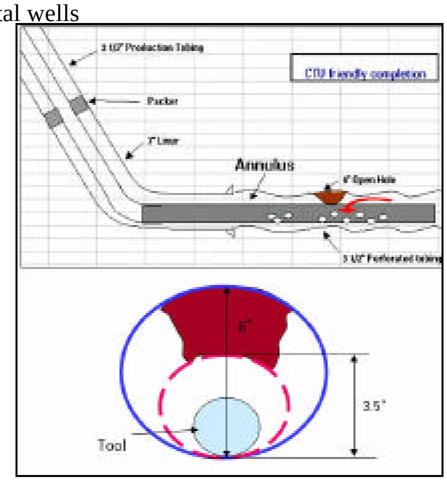

Fig-5: Changing flow ID due to shale sloughing / borehole collapse

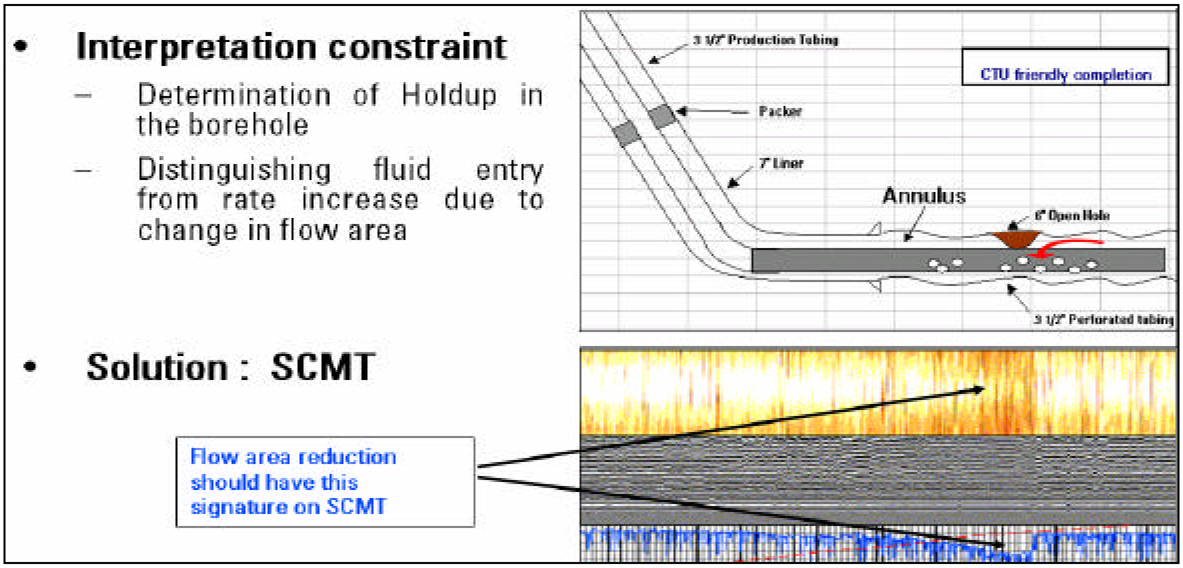

Fig-6: SCMT's response to shale sloughing /borehole collapse

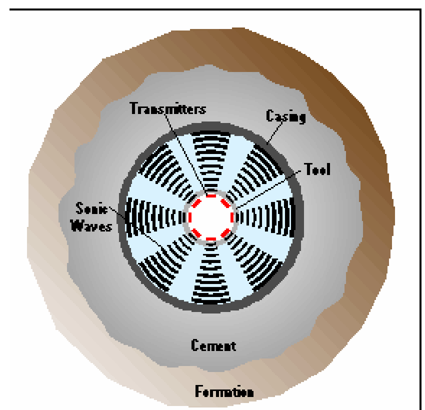

Fig-7 : Slim Cement Mapping Tool ; OD=1.875"; suitable for through tubing operations, Outputs standard 3ft CBL and 5ft VDL measurement in addition to radial continuous cement image (right)

Measurement Principle: 8 Radial sonic image sensors (high resolution transducers)

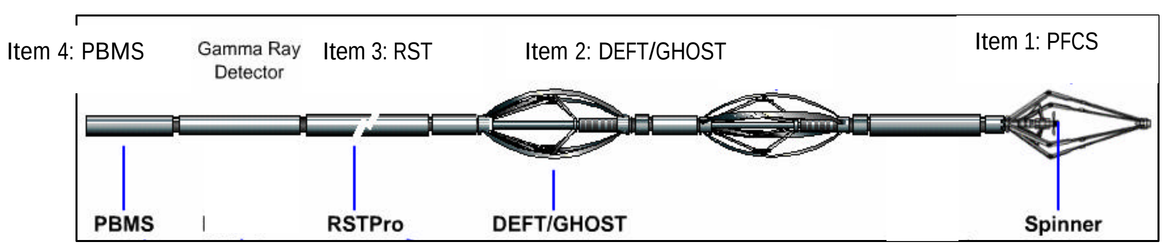

Fig-8: Schematic of Integrated Production logging tool string

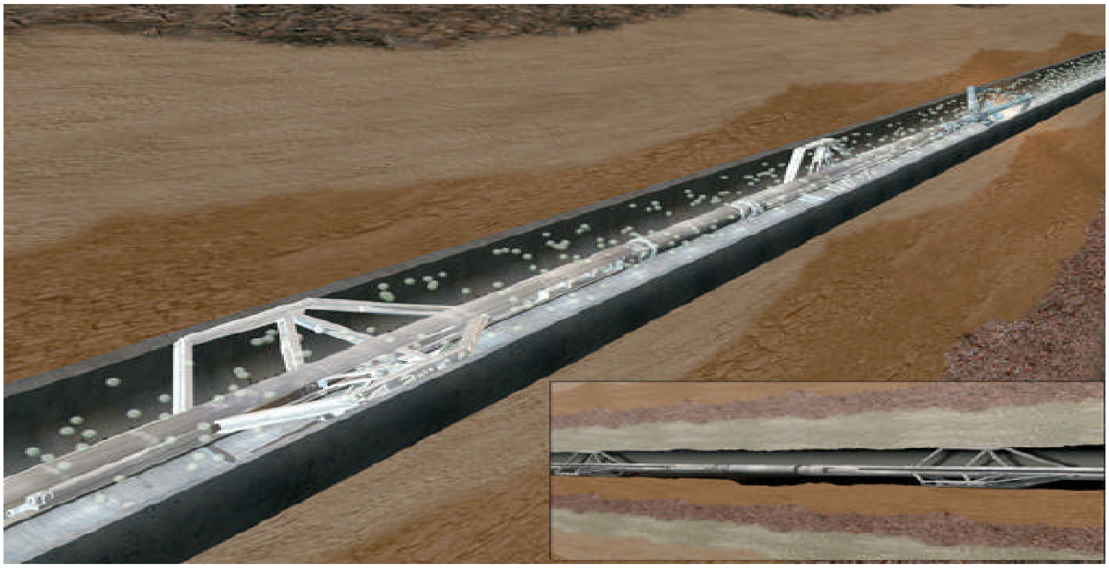

Fig-9: Wireline Tractor Schematic during Production logging and in Open hole (inset)

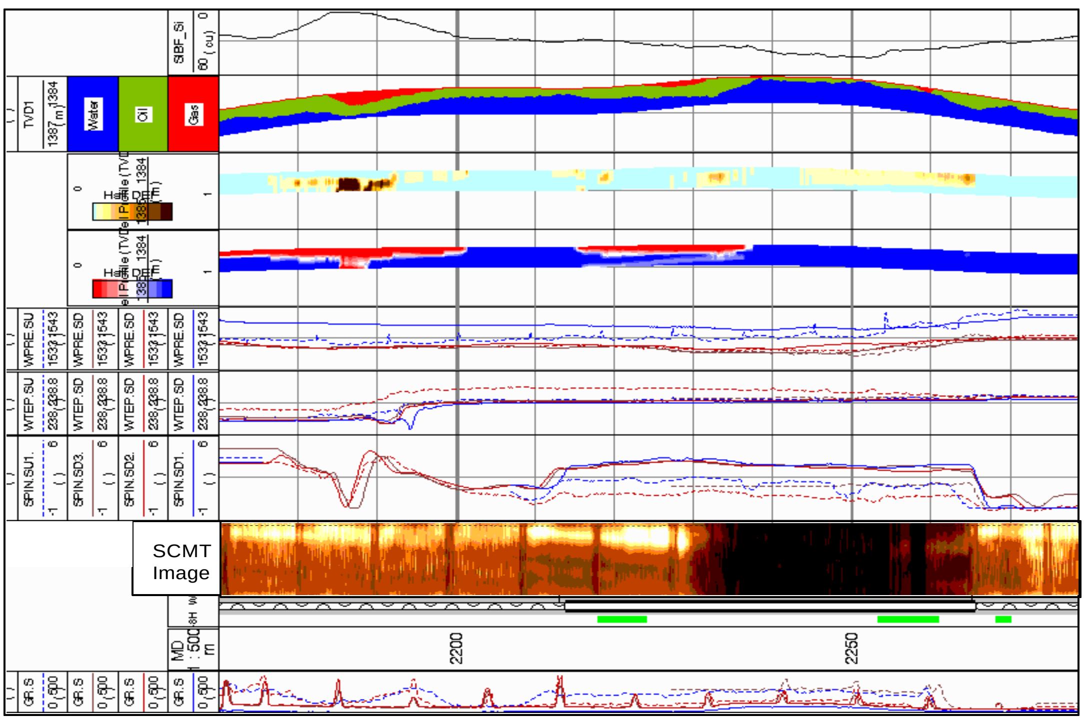

Figure 10: SCMT* and Flowing Survey Data from Flagship* tool string in Well 1

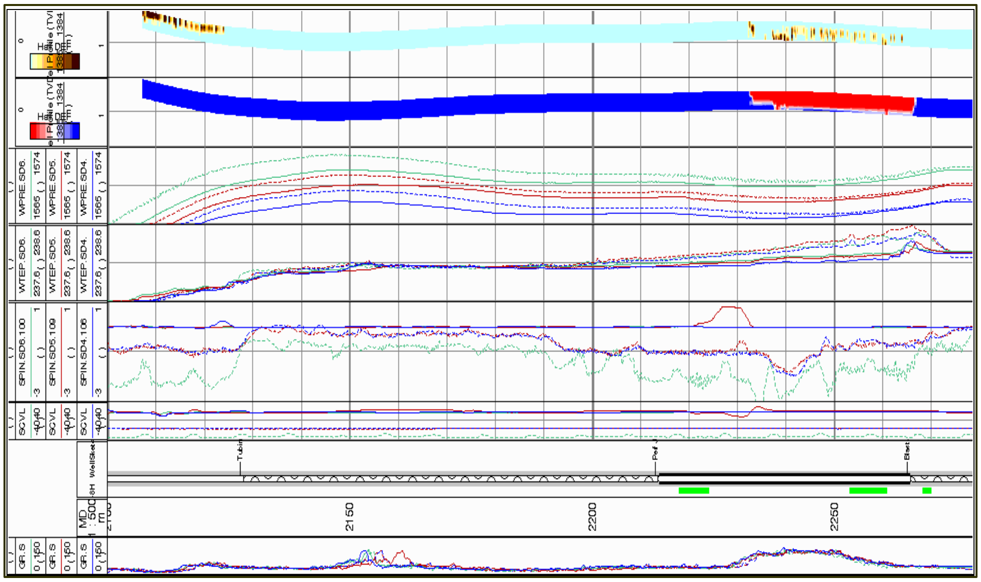

Figure 11: Shut-in Survey Data from Flagship* tool string in Well 1

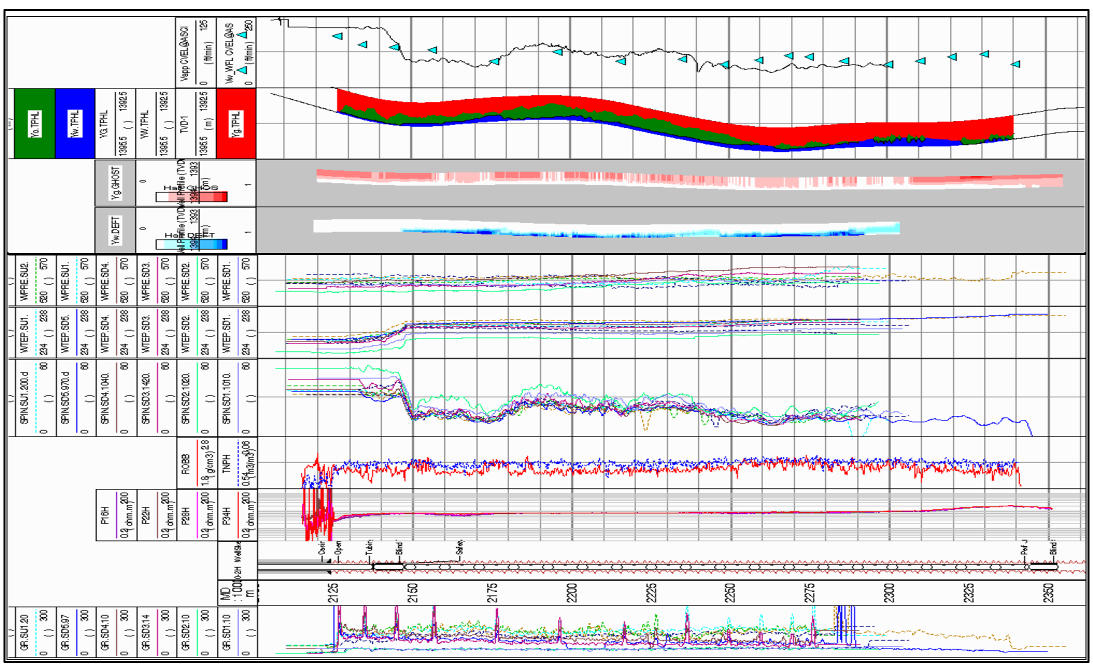

Figure 12: Flowing Survey Data from Flagship* tool string in Well 2

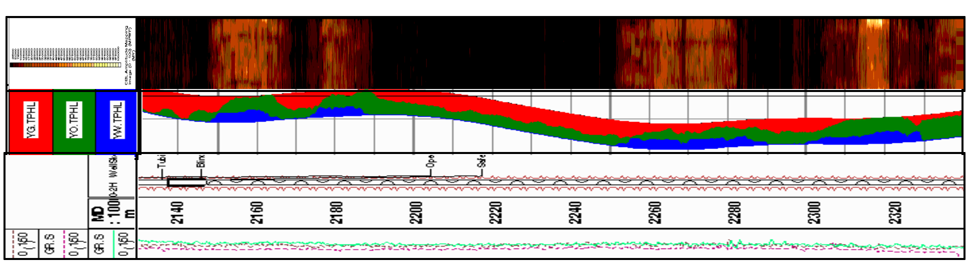

Figure 13: Shut-in SCMT* and Flagship* data in the Well 2