Association of Petroleum Geologists. India
Registered under Societies Registration Act,No. 21 of 1860

GEO India 2022

Achieving the anticipated results with Proper Placement of Horizontal Wells under Toe to Heel Air Injection (THAI) Strategy for Enhanced Oil Recovery in the Heavy Oil Field of Cambay Basin, ONGC Mehsana Gujarat India

Praveen Kumar Arasavelli[1], Nikhil Deshmukh, Sanjeev Kawan, Sanjay Deb Barma, S P Trivedi
[1]Email: arasavelli_praveen@ongc.co.in, Oil and Natural Gas Corporation Limited

Abstract

Successful Horizontal Well Placement as per plan is equally important as the Planning of the Well for achieving the desired results. Focussed Real time monitoring plays crucial role in making real-time decisions along with the understanding of the objective of the well, local Geology & Model. The risk and uncertainty factors can be handled with the use of particular well placement techniques during the planning and execution phases.

Study field is part of the heavy oil belt of Cambay basin in India. Due to viscous nature of the Oil, primary recovery of the field is low, to improve the recovery of the field, in the year 1997, In-Situ-Combustion Technique was commercially incorporated. Through this technique, Oil recovery was increased. However, there is a variation in recovery from south to north of the field. In the southern part of this field, the sand thickness is around 6-8m and Oil viscosity is in the range of 150-400CP and average recovery of this part is around 42%, whereas in the northern part of this field, the sand thickness is around 15-20m and Oil viscosity is in the range of 400-1000CP and the average recovery of this part is around 10%.

In the year 2016, Toe to Heel Air injection (THAI) project has been inducted into the North part of the Study Field to improvise the recovery. The strategy is to place Horizontal wells with a combination of two conventional Air Injectors close to the end point (Toe) of drain hole. The Horizontal well placement is designed against the dip direction keeping the total drain hole in the middle part of the sand body.

The Horizontal well placement under this type of scenario requires the use of precise Horizontal well placement techniques and drilling practices to avoid exits from the predefined geological targets. These techniques relied on the use of Logging while Drilling measurements that enabled Real-Time Bed Boundary Mapping.

Since the year 2016, total 6 Horizontal Oil producer wells were drilled in the Study Field under the THAI strategy and results of these wells are very encouraging. The average per well initial Oil rate of these wells is ~20tpd & currently they are producing around 10tpd/well. Whereas the conventional Oil productivity in the Northern part of this field is only 2-3tpd/well.

In the year 2021, Two more wells have been drilled under this strategy in this Study field. This paper presents 3D-Structural Model making, Real Time Monitoring, Decisions, Results & Observations of these two wells and way forward for upcoming Horizontal wells.

Study Area:

Study field, an integral part of heavy oil belt of northern part (Fig-1) of Cambay basin, was discovered in 1971 and put on production in 1985. Areal extent of the field is 13 sq. km. Reservoir characteristics show poor sand consolidation. OIIP of the field is 25.260 MMt. The ultimate reserves are 9.453 MMt with recovery factor of 37.42%. The main Hydrocarbon bearing sands are Sub-Sand, Sand-I & Sand-II of a formation of middle Eocene age. All the sands are hydro dynamically connected and are supported by common Oil Water Contact (OWC). The Crude Oil Viscosity of the field varies from 150-1000cp from South to North at Reservoir Temperature.

Fig-1: Study area representing the dark Green for Heavy Oil fields & light Green for the Light Oil fields in the Study Block.

Geological Setup of Field

This formation of middle Eocene age is the main Hydrocarbon bearing horizon of the field. This formation is capped by extensive Shale layer. Sand-I is deposited in fluvial environment with main channel direction NNE-SSW. The pay thickness of Sand-I in southern part is in the range of 6-8m, whereas in northern, it varies from 15-20m. The porosity of the reservoir is in the range of 28-30% and the permeability varies up to 5-8 Darcy. The Reservoir Pressure is Hydrostatic.

Structure

The structure is Homocline dipping towards the east (Fig-2). The area has been tectonically active even during the post Miocene time. Entrapment style is Strati-Structural. The reservoir sandstone is unconsolidated with intermittent discontinuous Shale barriers. These pay sands have a gentle dip of 1-3° from west to east. The field has number of curvilinear faults (NNW-SSE), which segregates the reservoir in to small blocks.

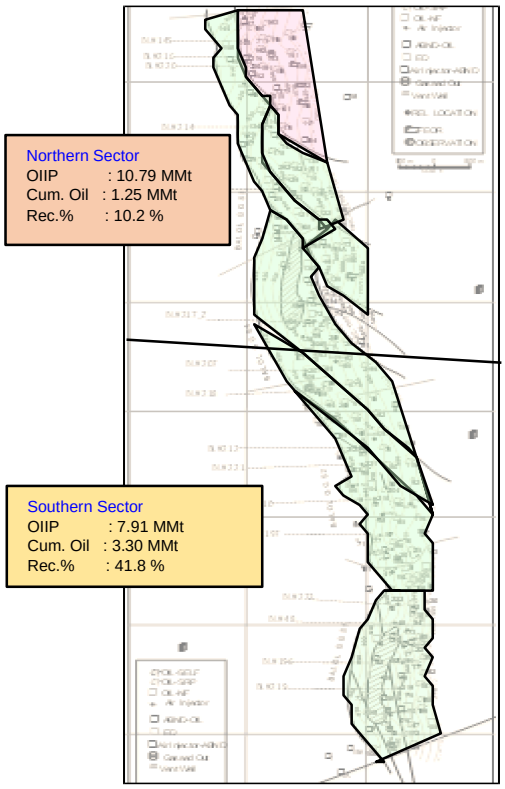

Fig-2: Structural Contour Map of Study Field on Sand-1 top

Technology:

Toe to Heel Air injection (THAI) is an EOR technique helpful in Heavy Oil Fields. The strategy is to place Horizontal wells with a combination of Two conventional Air Injectors close to their Toes in diagonal direction (Fig-3). It is classified into two types viz., 1. Direct Line Drive (DLD) configuration (with only One Air Injector) 2. Staggered Line Drive (SLD) configuration (with Two Air Injectors).

Toe-to-Heel Air Injection (THAI) process are examined 25 years since the start of its laboratory testing and 14 years since the start of its field testing. Comprehensive field testing of THAI was conducted in the Athabasca oil sands in 2006-2011 period (Whitesands Pilot), while it's testing in a conventional heavy oil reservoir with bottom water - Kerrobert reservoir - started in 2009, and is currently under way. These produced success stories and lessons for future.

The Horizontal well placement in the Study field is designed close to E-W direction, (against the dip of the Bed) and to be placed at a distance of 6-8m TVDMSL from the roof.

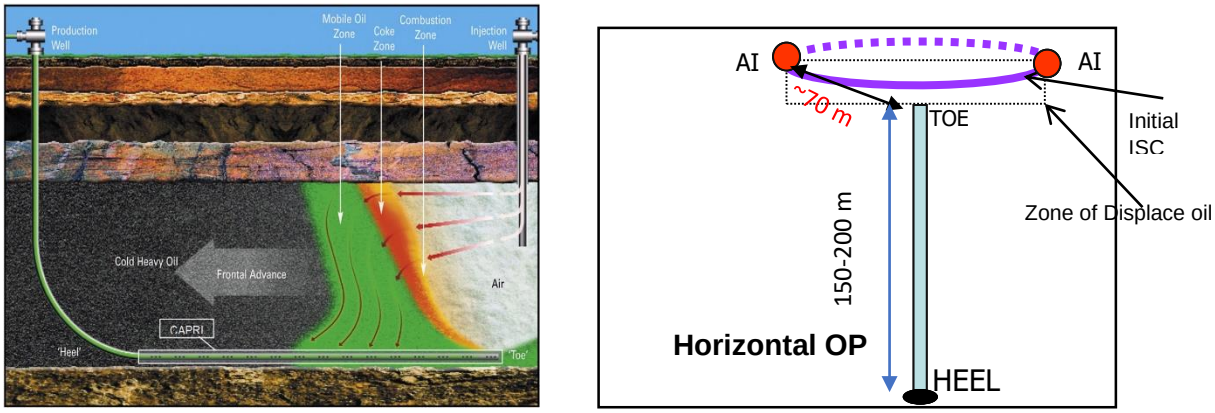

Fig:3 THAI Process
Left: DLD configuration Graphic and Right: SLD Configuration Schematic

Well Placements:

Well-1:

The planning of well placement started with making of a 3D-Structural Model of the sub-surface location with the help of nearby wells (Fig-4) Logs, Deviation surveys, References & Co-ordinates and the Planned Trajectory of Well-1 was incorporated in the Model. A Log correlation profile has been made as shown in Fig-5. A 3-D Structural Model has been made as shown in Fig-6 out of this Correlation.

It is understood that the thickness of the bed is in the range of 15-25m & Depth (TVDMSL) of Sand-I top in the range of XX83.5m-XY13.4m. The target sand body is dipping towards East. The initial plan was to drill the drain hole of 170m, from the Landing point at XY05.2m TVDMSL with an angle of 90.73deg to achieve a depth of XY03.21 m TVDMSL at End Point and to keep the well trajectory within 6-7m TVDMSL from the roof.

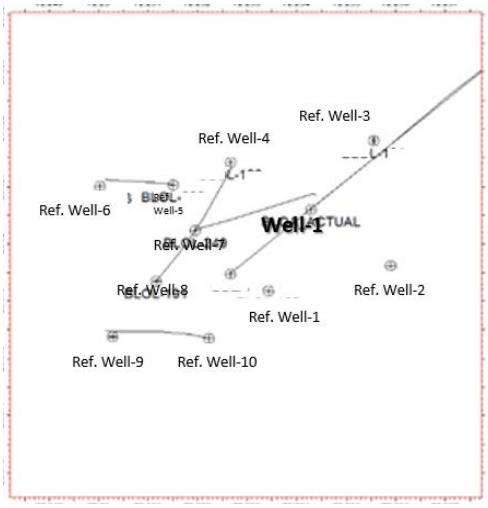

Figure-4: Location map of Well-1 and Near-by reference wells

In reality, the well entered in the sand body at XY03.5m TVDMSL and as the well is being drilled against the dip direction the Sand-I top at Landing point was envisaged at ~XY00m TVDMSL and the landing was planned ~5m below the sand top at XY04.71m TVDMSL.

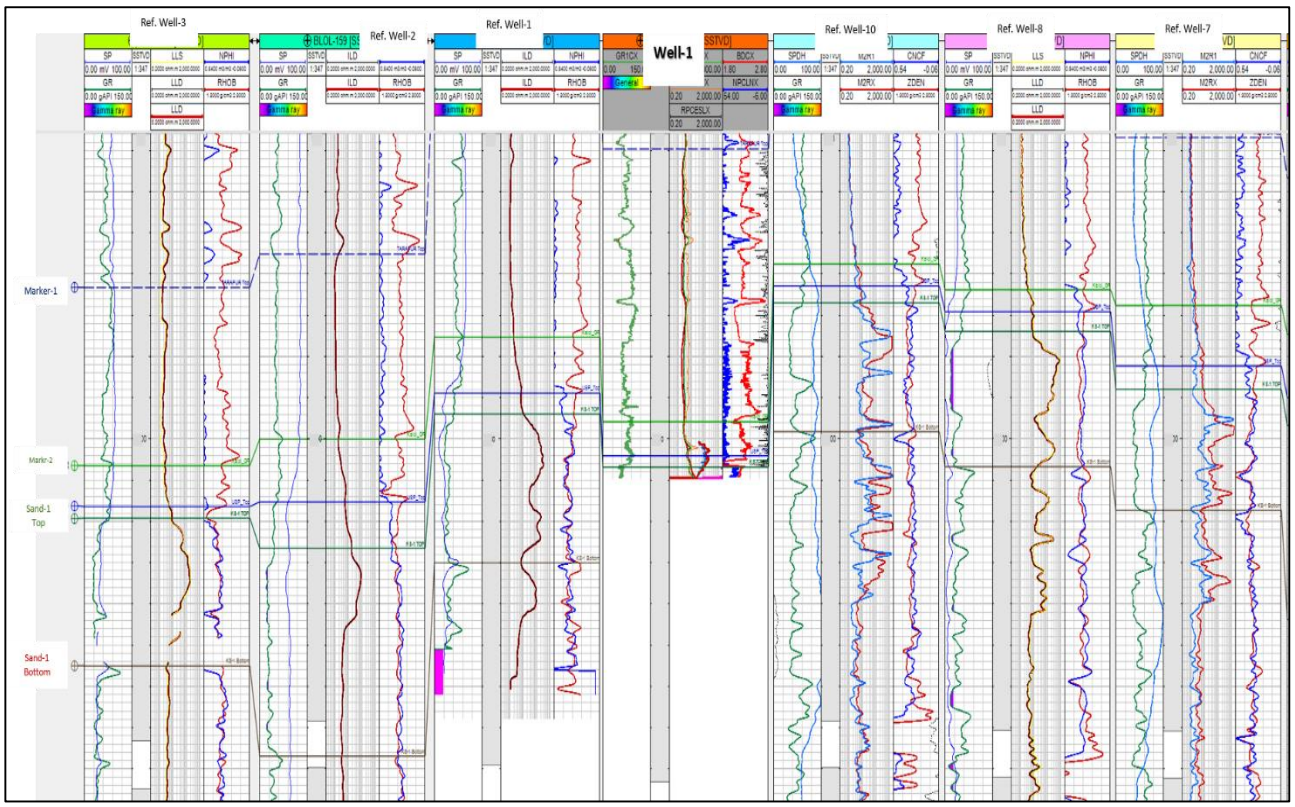

Fig-5: Log correlation of Well-1 with nearby wells.

However, it was analysed in real time that with this profile, the well would be steered in away from the roof by around 10m (TVDMSL) deeper at end point against the envisage target of 6m (TVDMSL) below sand top. In view of this, the trajectory was reviewed and angle has been advised to be built up to 92°, which was eventually been followed so as the well was completed within 6-7m depth from the Roof in TVDMSL.

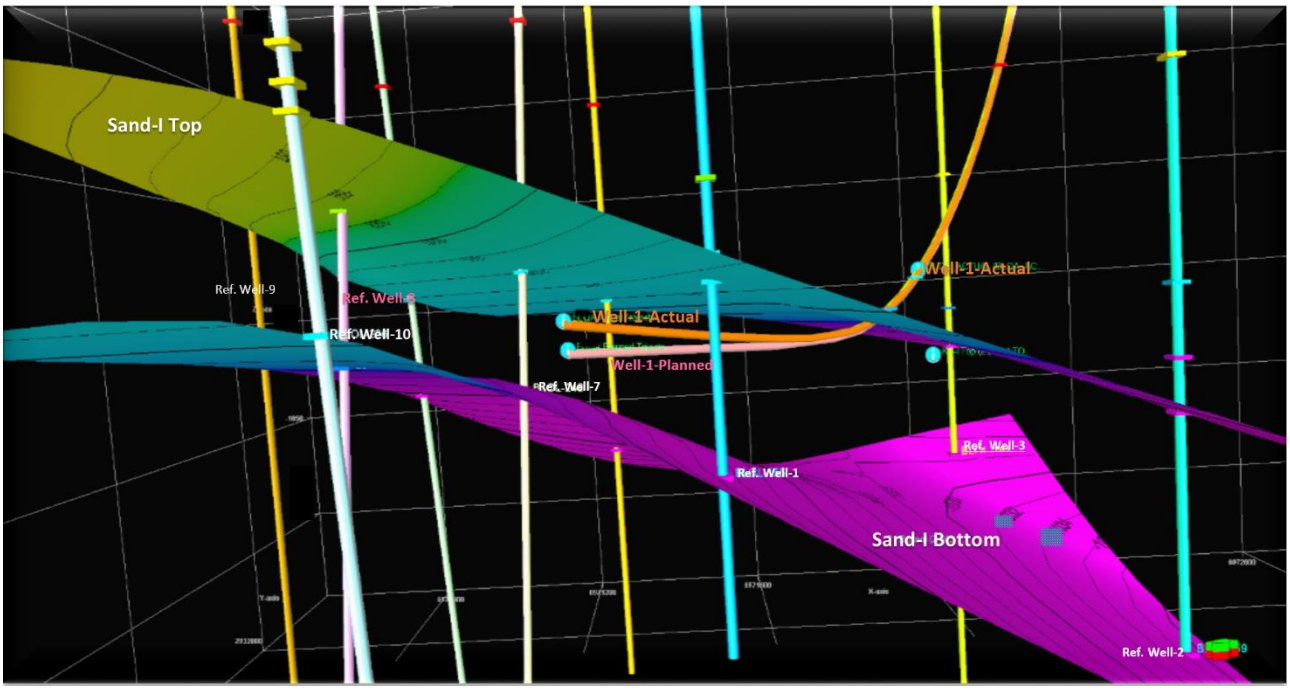

Fig-6: 3d-Structural Model of Sand-1 Top & Sand-1Bottom with Well-1 & nearby wells.
Well-1 Planned well Trajectory and Actual Trajectory

Within this TVDMSL the Air Injection is active from two staggered Air Injectors Ref.Well-8 and Ref.Well-10. The Well-1 was activated and produced good amount of Oil. The initial rates were Q_L:33m3/d, W/C:62%, Q_O:12TPD.

Well-2:

This well is planned with a target of placing a drain hole of 140m in the TVDMSL of X92.96m at Landing Point and X87.16m at End Point within the Sand-I by maintaining an inclination of 93.51°. 8 numbers of nearby wells (Fig-7) have been taken for preparation and a Correlation profile using their Logs, Deviation surveys, References & Co-ordinates. Through this process, a 3D- Structural Model (Fig-9) has been derived incorporating Planned Trajectory of Well-2. It is understood that the thickness of the bed is varying in the range of 16-20m & TVDMSL of Sand-I top in the depth range of XX78.0m-XX98.0m TVDMSL and dipping upwards in E-W direction. Model predicted the top of Sand-I TVDMSL of ~XX89.0m at Landing Point and XX83.0m TVDMSL at End point. The initial plan was to drill the drain hole to keep the well trajectory within 6-7m (TVDMSL) from the roof, which is dipping up-wards in the drain-hole direction. In reality, in the landing section of the well, the Top of Sand-I is identified at XX89.3m TVDMSL. The landing was done at XX92.0m TVDMSL. To achieve the objective, the well has to be steered with-in the TVDMSL of XX87m at end Point.

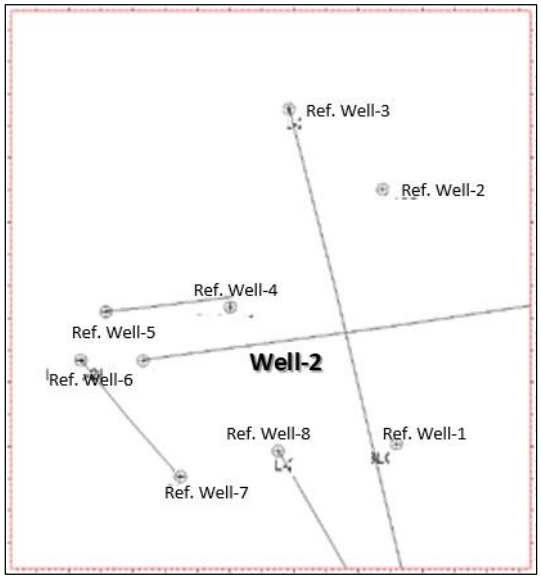

Figure-7: Location map of Well-2 along with nearby Reference Wells.

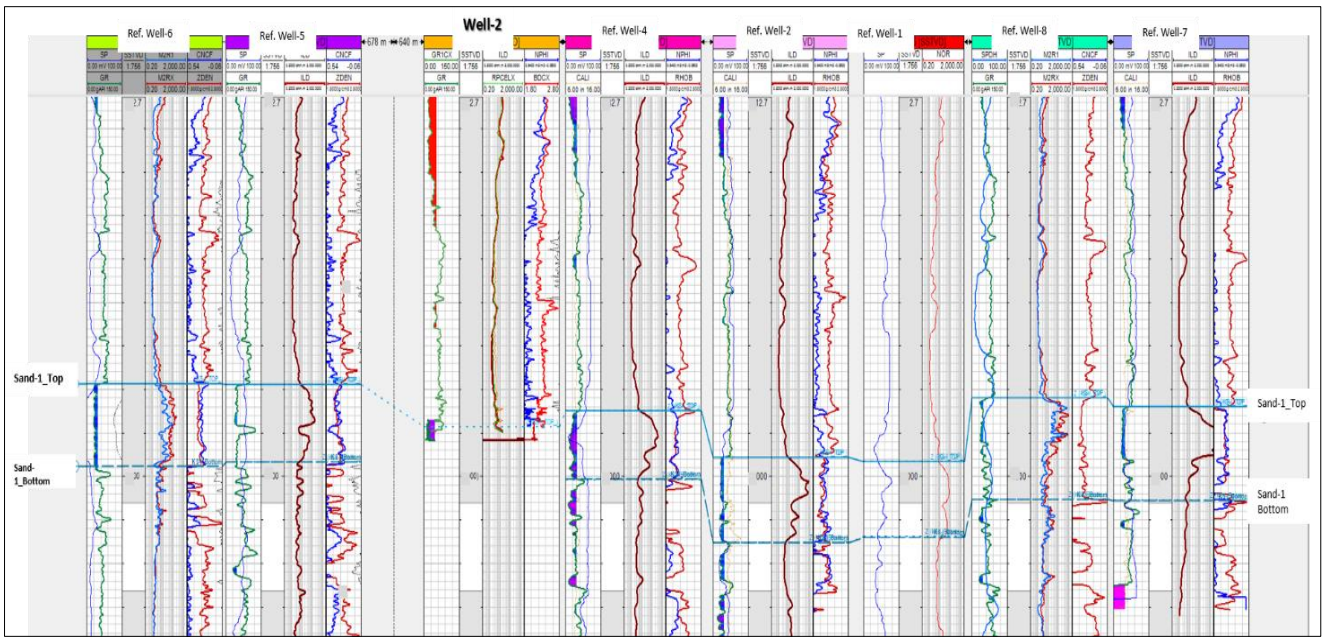

Fig-8: Log correlation of Well-2 with nearby Reference wells.

After the well being Drilled till depth at the Landing Point, the model (Fig-9) was reviewed and updated with the actual profile of the well. The Logs have been matched with nearby reference wells. The local spatial undulations in the bed have been understood. And to keep the well trajectory in geologic target, Planned Trajectory was reviewed and advised to change in the angle to 92.0^{o}, eventually, the same has been followed and the Drain-hole was drilled within XX92.0m TVDMSL at Landing point & XX86.77m TVDMSL at End Point. Within this TVDMSL, Air Injection has been happening from one of the nearby well Ref.Well-6 (Fig-9).

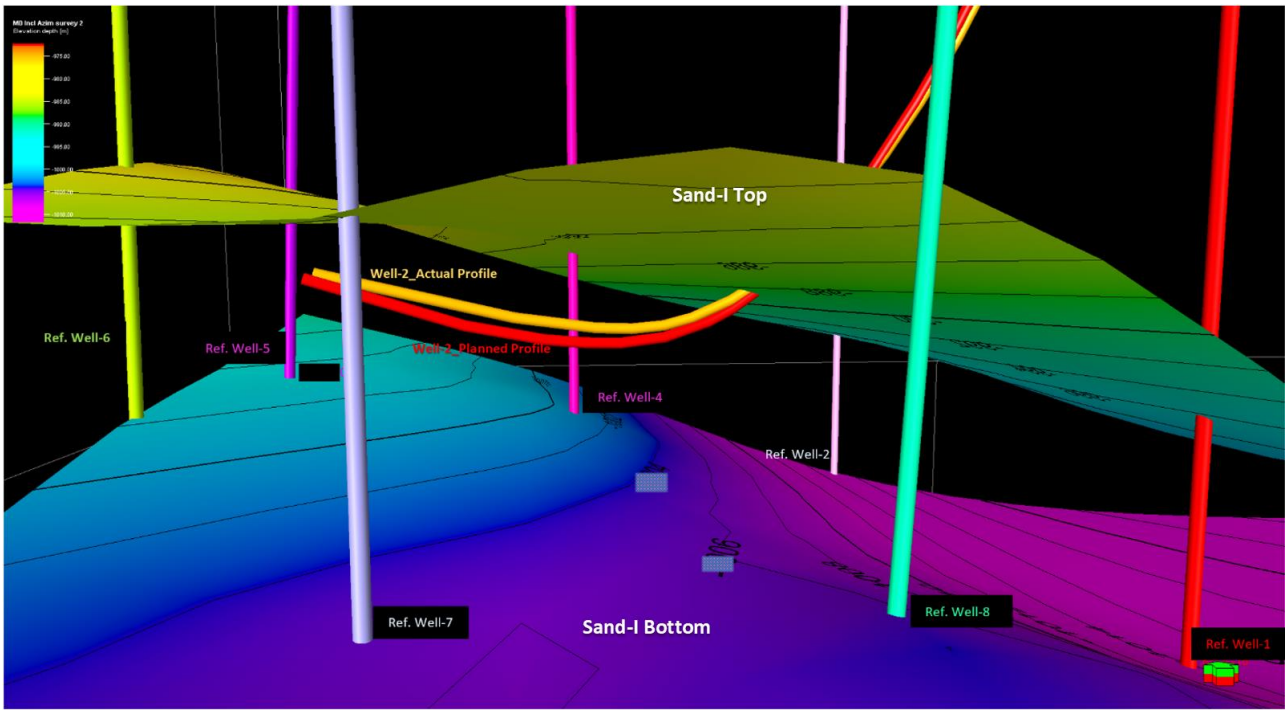

Fig-9: 3D-Structural Model of Sand-1 Top & Sand-I Bottom with Well-2 & nearby wells.
Well-2 Planned well Trajectory and Actual Trajectory

The well was activated and produced good amount of Oil with rates Q_L: 32m3/d, W/C:33%, Q_O:21TPD, which is significantly good result comparing to conventional wells in this Heavy Oil field.

Discussions:

3D-Structural Models & Real Time Monitoring of LWD data with Drill-Cutting Sample Analysis helps to understand the Log Correlations in 3-Dimensional and Spatial Undulations in the Target Reservoir Top and Bottom profiles, which are helpful to place the wells in objective geological targets (TVDMSL depths) which are crucial for successful execution of THAI Strategy in Heavy Oil fields. The distance from the roof plays crucial role in achieving the anticipated productivity from THAI wells.

Way forward:

- More wells have been planned under THAI project to achieve higher recovery in Northern part of Study field.
- 3D Structural Models to be prepared prior to drilling of well to presume/avoid any geological surprises.
- LWD to be used for Real Time monitoring and Bed Boundary mapping.
- Drain-hole section to be kept in the middle of the sand body for better results.
- Maximum angle to be kept around 92^{o} according to completion strategies.

Acknowledgments:

Authors express their gratitude to ED-Asset Manager, ONGC, Mehsana Asset for the Opportunity & Guidance.

Authors express their gratitude to CGM (Wells)-Head, Logging Services, ONGC, Mehsana Asset for continuous guidance and valuable discussions.

Authors express their gratitude to CGM (Res)-SSM, Sub-Surface Team, ONGC, Mehsana Asset for encouragement and valuable inputs while well placements.

Thanks are also goes to all the team members of the Interpretation Group, Logging Services, Mehsana Asset for authentic inputs and intensive discussions.

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