Exploration Drilling in Mexico through Complex Salt with Seismic While Drilling Technology

Introduction

In 2020 China National Offshore Oil Corporation CNOOC embarked upon an exploration drilling campaign in deepwater offshore Mexico. The prospect is a three-way subsalt closure against an updip, complex, thrust fault system. The reservoir section for the well is interpreted to be stacked deep-water turbidite sandstones, with intraformational and overlying shales as seals. The prospect has been mapped on multiple, uniquely processed seismic volumes. Owing to significant velocity model differences among the various volumes, three distinct structural realizations ("models") are considered viable (Fig. 1).

- The thin salt model derives from a localized seismic imaging (LSI) seismic volume.
- The hybrid salt model derives from a demigrated and remigrated seismic volume and integrates data from an offset well.
- The thick salt model derives from a multiclient seismic volume.

Collectively, the three models introduce significant uncertainty about the thickness of the salt canopy, the geometry of the prospect trap, and the depth to the target interval, among other complexities. Of the three possible interpretations considered in principle, the thick salt model was seen as the least likely, while the hybrid and thin models were seen as equally likely.

Figure 1—Three possible seismic interpretations

The geological uncertainty as a result of the geophysical uncertainty, posed drilling risks to the vertical well design. One of the critical risks identified was the pressure uncertainty and a possible rubble zone at the salt exit. This was made more challenging because of the +/-150 m depth uncertainty of the salt base.

To help mitigate against the pressure uncertainty, the rig was equipped with an MPD system (Chopty, J. 2011) that can monitor and maintain constant downhole pressure during drilling. To help mitigate against the base salt depth uncertainty, seismic while drilling (SWD) lookahead technology was
deployed to image the base of salt ahead of the bit. This would enable the casing shoe to be safely placed close to the base of salt and help alleviate the potential salt exit hazards.

**Method and/or Theory**

SWD technology (Esmersoy, C. 2001) consists of a surface airgun seismic source deployed from a rig crane and a downhole receiver behind the drilling bit in the BHA. Data is recorded during pauses in drilling when the receiver has static conditions and a low noise environment to record seismic data. The seismic waveforms recorded are sent to surface during drilling and allow for real-time (RT) vertical seismic profile (VSP) processing to produce a lookahead seismic image (Kelsall, N.R. 2020).

Prior to drilling, 3D ray trace modelling was performed to give an insight as to what response could be expected from the SWD lookahead and how much lookahead could be achieved to enable proactive decision making. In Figure 2, the expected upgoing reflections from the key horizons are shown. The lookahead image cannot be created instantaneously but requires sufficient data recorded at different depths to be acquired (normally over 200-400 m) to make VSP lookahead processing possible. The modelling showed that to have a lookahead image with the bit at least 200-350 m from the base of salt, 700 ms of waveform needed to be sent in real time via mud pulse telemetry together with other RT logging data. See Figure 2.

![Figure 2 – VSP 3D Ray Trace Modeling and Synthetics](image)

After drilling the 26-in hole section and cementing the 22-in casing shoe inside the top of the first salt body, the assembled 18 1/8-in x 19 ½-in BHA was run in hole containing the SWD tool. See Figure 3.

![Figure 3 – 18 1/8-in x 19 ½-in BHA including Seismic While Drilling Tool](image)

Drilling through the salt body commenced from ~3,048 m until ~3,703 m. Drilling then paused, and pressure was applied to the formation as part of a formation integrity test (FIT). The FIT result confirmed enough formation strength to continue drilling towards the base of salt.
From this point seismic data was acquired after drilling each stand and the RT stacked waveforms, 700 ms in length, could be transmitted to surface while drilling a 40-m stand of drillpipe down to the next connection. VSP processing commenced after 10 waveforms and ~400 m of drilling to produce a lookahead image which could be continuously updated with each new RT data acquisition.

The VSP processing produced an upgoing wavefield that was interpreted for approaching coherent seismic reflectors ahead of the bit. By comparing the time difference between the first energy arrival to the seismic tool and the time of the approaching reflector, a distance ahead of the bit could be calculated. The calculation used the time difference stated above and an assumed velocity ahead of the bit. The velocity used was taken from the salt velocity measured behind the bit +/- 10%.

The upgoing wavefield was partially stacked to produce a corridor stack for a seismic tie with the surface seismic. For the base of salt, the best seismic tie was achieved with high-resolution seismic acquired to help detect shallow hazards. Figure 4 shows the final RT upgoing wavefield where the last measurement was made with the seismic tool approximately 64 m above the actual base of salt and a prediction of 4446 m MD +/- 30 m was made. After the last seismic measurement, another 10 m was drilled to the casing point at 4,405 m MD. The FIT result and homogenous salt provided criteria to set 14-in casing and skip a 16-in contingency liner however the real-time velocity and VSP from SWD, combined with MWD data, provided additional confidence in this drilling decision which saved time and cost. In the next hole section drilling commenced from the casing shoe and the base of salt was logged at 4,434 m MD which was within 12 m of the real-time prediction and well within the uncertainty range.

Figure 4 – Upgoing reflections from VSP processing with BHA (BHA not to scale) (left), corridor stack overlaid on shallow high-res seismic (centre), LWD logs over the interval (current hole section + section ahead) (right).

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Conclusions

The exploration well presented significant challenges due to the subsurface complexity and three different possible models for the position of the base of salt highlighted the depth uncertainties. The drilling risk was increased as hazards were expected at the uncertain base of salt. These hazards could be mitigated as much as possible by having the casing shoe close to the base of salt to have the highest kick tolerance and widest mud weight window.

3D ray trace modelling showed that a VSP could be used to illuminate the base of salt and that SWD technology could be a feasible way to identify the base of salt ahead of the bit during drilling.

In the 18 ½-in x 19 ½-in hole section, SWD technology enabled the operator to safely, reliably and efficiently drill through the salt and set casing close to the base of salt to help mitigate further drilling hazards. The depth uncertainty was reduced from +/- 150 m to +/- 30 m.

References

