Survey design and illumination study for complex geology in the Gulf of Suez

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Summary

Neptune Energy has licensed a concession as operator in the North West El Amal in the Gulf of Suez, Egypt (Figure 1). The seismic data available over the block was acquired in 1992 with a narrow azimuth 5 x 3km towed streamer geometry (NAZ), suitable for the shallow target at that time. One of the targets of the project was Nubia sandstones in the deep faulted blocks due to the Red Sea opening at a depth of 4 to 5 km. In order to image these faults, a new set of data was required, with full azimuth for deep target illumination and long offsets to leverage the latest depth imaging technologies, most particularly full waveform inversion (FWI). The presence of surface obstructions such as production platforms, made wide azimuth (WAZ) towed streamer acquisition impossible. Seabed nodes offered the obvious solution. To ensure an optimum illumination of the target and yet economically viable project, it was decided to test and select the optimum acquisition parameters (receiver, shot templates) with a survey design and modelling (SD&M) exercise and compare the results at the target horizons with the illumination generated by the NAZ streamer acquisition of 1992.

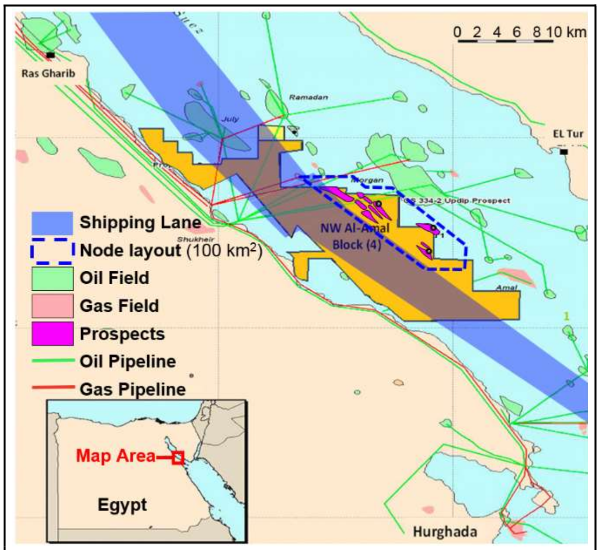

Figure 1: Map of North West El Amal in the Gulf of Suez, Egypt

Introduction

Even though Neptune Energy has been present and active in Egypt for several years, the NW Al-Amal block was the first license awarded to Neptune offshore Gulf of Suez in 2019. The targets are Nubia sandstones in the deep faulted block created by the opening of the Red Sea. In the Gulf of Suez, the main reservoirs are in the pre-salt section, below the Zeit and sometimes close to the basement, as seen on Figure 2.

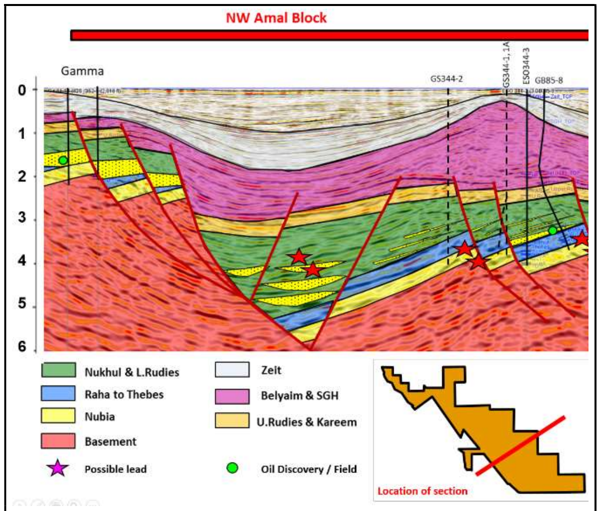

Figure 2: Regional setting

Geophysical challenges in processing Gulf of Suez data are known to practitioners as being amongst the most difficult in the world. In the shallow section, thin beds of high velocity anhydrite cause severe multiple contamination and high attenuation of seismic waves. Combined with the variable thickness of the salt bodies, imaging of the deeper targets is extremely challenging. Over the past decades some ocean bottom cable (OBC) acquisition has been done, but most of the acquisition has been narrow azimuth towed streamer (NAZ). Figures 2 through 4 show the legacy seismic data available, shot in 1992 with a NAZ spread and offsets limited to 3 km. The image from a 3D PreSTM (Figure 3a) highlights the challenges interpreters and imaging specialists face in this area. None of the real dips measured at the well location are visible on the seismic section! A crude, yet sometimes effective method was to apply dip filtering. Although this technique has improved the image by removing non-geological seismic events, we can still observe some events with dips opposite to the real geological trend present in the seismic section (Figure 3b).

However, dip filtering does nothing to address the fundamental limitation of the 1990's NAZ acquisition technique: the lack of illumination, in particular below the salt bodies. As a result, faults known to be present are not visible on the seismic sections or are very poorly imaged.

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Moreover, this poor illumination results in an unreliable velocity model that puts high uncertainties on all structural elements: structure relief, fault imaging and spatial positioning.

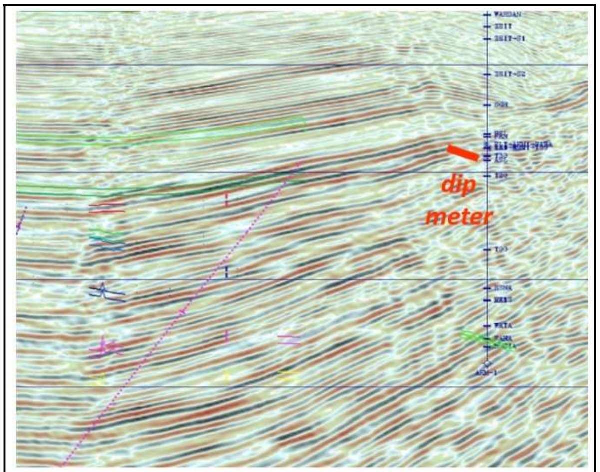

Figure 3 (a) Without dip filtering

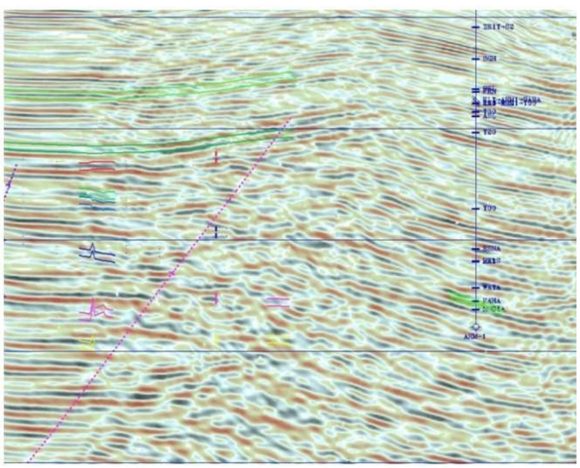

Figure 3b: With dip filtering

The latest reprocessing done on the original field data, in 2017 (Figure 4), used more advanced imaging techniques, but the imaging of the faults still offers great challenges for the interpreter. A thorough review of all the seismic data available on the license has led us to the following list of shortcomings:

- Imaging: fair to poor due to interbed multiples and significant energy attenuation from Zeit & Gharib
- Structural: sub-salt imaging very poor (faults, resolution) due to acquisition parameters (limited offset, narrow azimuth)
- Seismic velocities: poor control due to above issues

The mitigation of these shortcomings was clearly leading us towards acquiring a new seismic dataset allowing for optimum imaging of the deep targets. To leverage all the recent technologies, we wanted to have both full azimuth for a better, more regular illumination of the pre-salt section and long offsets to be able to use Full Waveform Inversion (FWI) to improve the imaging via a more accurate and robust velocity model.

Operational constraints including production infrastructure, shallow water and a major shipping lane (shown on Figure 1) make the acquisition of wide azimuth, long offset towed streamer data inconceivable in this area. The obvious solution was then to use seismic node acquisition. With the appropriate parameters such as node spacing (density) and shooting template (spacing and maximum offset), it should be possible to address most, if not all the issues found in the current datasets.

- Imaging: Dual geophone and hydrophone sensor data allows the best water-layer demultiple techniques to be implemented thanks to UP/DOWN wavefield separation, improved resolution and higher S/N with broadband processing.
- Structural: subsalt imaging should greatly benefit from higher illumination and fold, denser acquisition allows the use of the latest imaging tools (WEM, RTM) providing better focusing and improved S/N.
- Seismic velocities: long offsets, greater than 6 km, and full azimuth will allow the use of the latest velocity model building tools (FWI, R-FWI) which in turns allow for the use of the advanced imaging algorithms mentioned above.

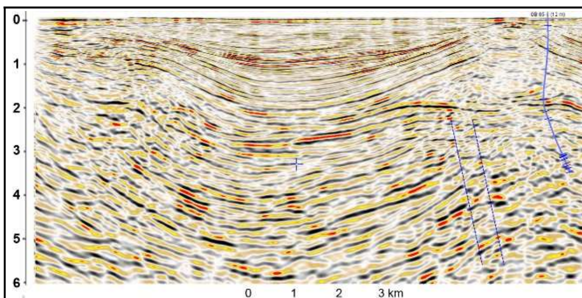

Figure 4: 2017 Reprocessing : Kirchoff pre-stack depth migration. Velocity model building with 6 tomography iterations.

Initial Survey design

A number of basic survey designs were considered, and it was quickly determined that the most cost-effective solution would be a sparse node geometry in which the spatial sampling was determined by a 25m x 25m grid of shots.

The receiver grid was then constrained to ensure a minimum of 6 km offsets at all azimuths over the area of interest. In practice, the actual in-line offsets acquired will be

considerably larger. The density of the receiver node grid then governs two critical imaging properties : (i) the trace density and (ii) minimum continuous near trace offset which is critical for adequate imaging of the shallow Zeit horizon. It quickly became apparent that the node density required over the shallowest portion of the Zeit horizon was significantly higher than that required towards the edges of the imaged area. Many variable density options were considered, though only 2 are illustrated here. In the "Dense" geometry, the receiver grid is 200m x 100m throughout. In the "Variable" geometry the receiver density is reduced to 200m x 200m away from the shallow Zeit horizon.
Figure 5 illustrates that all the OBN options considered provided massively higher trace density and azimuth diversity than the vintage streamer survey. Interestingly, since in all OBN cases the time (and thus cost) to acquire the survey was driven by the shooting time rather than the time to recover and deploy nodes, the cost was only a weak function of node density.

Figure 5: Active receivers for a single shot

It is worth noting that trace densities for the OBN survey are higher for all offsets greater than 1,000m, but at short offsets, trace densities are comparable. Consideration was given to the use of a short streamer towed behind the source vessel.
Dual and triple sources were considered, with particular regard to the direct arrival times relative to both P and S wave reflections from the target horizons.

Illumination study: Method

The time harmonic wave equation,

$$\frac{\partial^2 u}{\partial t^2} - v^2\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) = 0$$

$$u(t) = e^{i\omega t}$$

can be solved using downward continuation to obtain the wave field for a single frequency.
The solution,

$$u(x, y, z, t) = f(x, y, z)e^{i\omega t}$$

can be thought of as a representation of the wave field generated by a monofrequency source (e.g. vibrator truck) at a fixed location vibrating at a single frequency. This solution has built into it all of the physics of wave propagation – constructive and destructive interference, spherical divergence, etc. With this solution we can form several types of illumination volumes: source illumination, receiver illumination, and total illumination.
These correspond to:

- Source illumination – The total energy that is injected into the subsurface (e.g. the total energy that reaches a particular horizon).

$$I_S(x, y, z) = \sum_{s=sources} |f(x, y, z; s)|$$

- Receiver illumination – The total energy that will be collected by the receivers from the subsurface if the subsurface is uniformly illuminated (e.g. from an "exploding" horizon).

$$I_R(x, y, z) = \sum_{r=receiver} |f(x, y, z; r)|$$

- Total illumination – The total energy that will be collected by the receivers from the energy that is injected by the sources. This take into account both the energy loss in reaching the reflectors and the energy loss in going back up to the receivers.

$$I_T(x, y, z) = \sum_{s=source} \left| f(x, y, z; s) \sum_{r=receivers} f(x, y, z; r) \right|$$

Figure 6 shows a cross-section through the velocity model that was used for the illumination study with the lightly shaded area highlighting the downgoing energy from a single shotpoint.

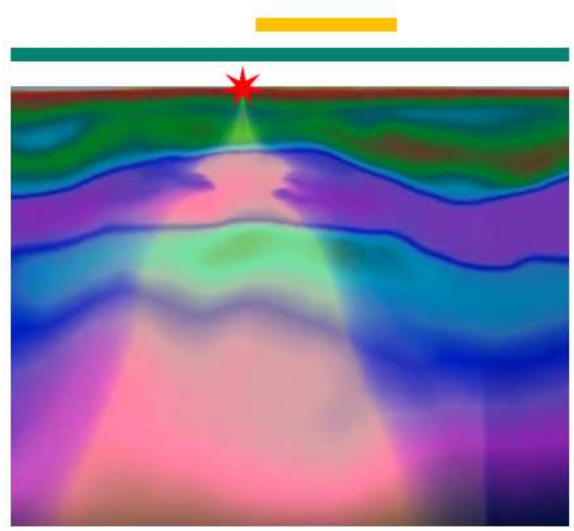

Figure 6: Velocity model used for wave equation modelling with down going shot energy for a single shot.

Illumination study : Results

Figure 7 shows the illumination intensity achieved using the streamer, variable density OBN and dense OBN on the

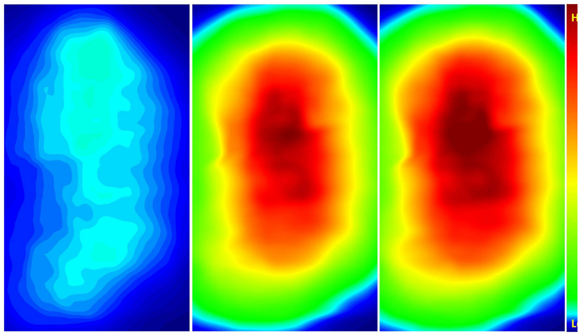

Figure 7: Illumination intensity Nubia : (a) 1992 streamer, (b) variable density OBN (c) Dense OBN

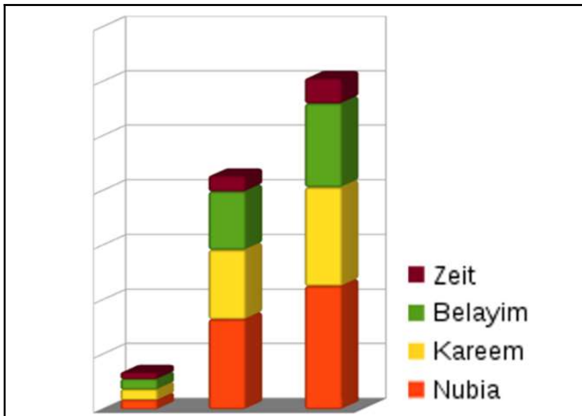

Figure 9 : Illumination intensity summary for all horizons : (a) 1992 streamer, (b) variable density OBN (c) Dense OBN

deepest (Nubia) horizon. As expected, there is a strong uplift in illumination strength for the OBN geometries.

Figure 8 shows similar displays for the shallow Zeit horizon, indicating the challenges of the shallow target. This is further explained in Figure 9.

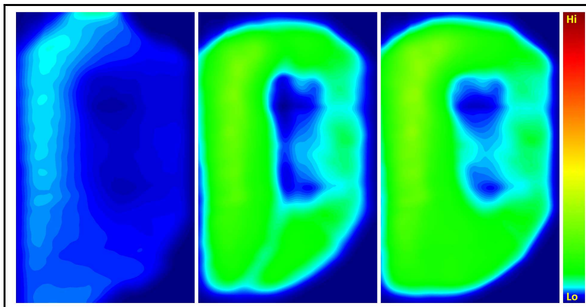

Figure 8: Illumination intensity Zeit : (a) 1992 streamer, (b) variable density OBN (c) Dense OBN

In Figure 9 there is a summary of the overall illumination energy for the four horizons that were modeled. It is clear that for the three deeper horizons there is a significant increase in the illumination energy with either of the OBN designs in comparison with the 1992 streamer acquisition. This is due to the fact that the trace density for the wide azimuth acquisition is proportional to the square of the offsets under consideration while for the narrow azimuth streamer acquisition the increase in trace density is more linear.

Conclusions and Recommendations

A preliminary analysis of CMP fold indicated that the originally specified 100 km^2 node boundary was not adequate to provide good coverage of the prospects that were close to the original boundary. For this reason the node deployment area was increased by 63% to improve the area of coverage.

From a simple analysis of CMP fold and trace density for the different geometries it would be clear that we should expect improved data quality with a wide azimuth nodal acquisition geometry in comparison with a narrow azimuth streamer survey. However, the imaging issues caused by the anhydrites, multiple interference, etc., could still have resulted in less than optimum interpretation data volumes.
The use of a wave-equation consistent illumination study requires the best depth-velocity model possible. In this case, even though the 1992 narrow azimuth 3D survey had many issues related to the velocities and imaging, the additional information from wells (formation depths, dip meter values, sonic velocity measurements, etc.) greatly improved the model. The study clearly showed that excellent illumination of the target objectives can be achieved with either of the OBN geometries.
In addition, the time/motion/cost analysis of the survey designs showed that both of the OBN geometries are source vessel limited and therefore very similar in cost.
Because of the similarity in trace density at the short offsets (<1000m) between the 1992 streamer acquisition and the OBN geometries, it is recommended that short streamers be deployed on the source vessel to increase the trace density in the short offset ranges and thereby improve the illumination of the shallowest (Zeit) reservoir interval.

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REFERENCES