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Case Studies of Using Far and Ultra-Far Seismic Data in Deep-water Nigeria
Erha North Field: Beauty and the Beast
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Abstract

This paper highlights the complexity and challenges associated with deep-water exploration and development in Nigeria. The Erha North field Reservoir-300 was discovered using the block-wide 2000 seismic survey. A shallow channel severely attenuated the seismic image at the reservoir level. A new 2005 seismic survey was shot perpendicular to the shallow channel and improved the imagability of the reservoirs by undershooting the shallow channel. ExxonMobil’s Pre-migration Spectral Shaping (EM_PreSS) technique further enhanced the data quality. The EM_PreSS ultra-far 38-48° angle stack provided the best well tie in the Erha North Phase I development area. The significantly improved seismic data quality greatly increased interpretation confidence and impacted the business decision to not drill appraisal well Erha Far-East (EFE) and instead to drill the exploration well Erha North-East (ENE).

The Erha NE prospect is located 7 km away from the center of the Erha North field, with the primary target in Reservoir-300. The seismic response at the up-dip of the prospect is similar to the hydrocarbon response observed at the Erha North field, but lacks conformance to structure - an expected DHI element. The original hole (OH) targeted an up-dip location and encountered multiple gas and oil sands, in both primary and secondary reservoirs. However, the primary target Reservoir-300 was penetrated with two separated thin gas-on-oil sands. No water sand was penetrated. A determination was made that such highly compartmentalized reservoir could not be developed economically.

Down-dip from the Erha NE original hole discovery, a strong low-impedance amplitude anomaly was observed on the ultra-far (38-48°) angle stack. No other angle stack showed a similar strong low-impedance response and no other DHI attributes were observed. This amplitude response was neither similar to other known hydrocarbon responses nor to known water leg responses. Geophysical modeling results could not rule out the possibility of down-dip hydrocarbon presence by using reasonable rock properties assumptions. Given the high resource uncertainty, the operator determined it would be beneficial to test the down-dip location before Phase II development starts. The down-dip side-track (ST) well was drilled and penetrated a thick clean water-bearing sand. Post-drill modeling suggested that abnormally high anisotropy in the sand could be the cause of the ultra-far low impedance amplitude anomaly.
Introduction

The study area is in Erha North field which is a Nigeria deep-water block operated by Esso Exploration and Production Nigeria Limited (“Esso”). The block-wide 3D seismic survey was acquired in 2000. It led to the success of exploration wells Erha 7 and Erha 7 side-track and the discovery of the Erha North field. The 2000 survey was shot east-west. A near water bottom shallow channel, trending in the same direction, attenuates a significant portion of the reservoir below the shallow channel. A new seismic survey was acquired in 2005 with shooting direction perpendicular to the shallow channel. The new seismic data enhanced the imaginability at target depths by undershooting the channel and increased the confidence of interpretation for the Phase I development.

Both 2000 and 2005 seismic data has been processed multiple times, including the conventional pre-stack time migration (PSTM), PSTM with generalized wavelet replacement (GWR), and EM_PreSS inversion (Figure 1, Lazaratos and David, 2009).

![Seismic vs. Log Spectra](image)

Figure 1. Comparison of different spectra, including an average seismic spectrum in red, well log impedance spectrum in blue, and well log reflectivity spectrum in pink. The key idea in EM_PreSS inversion technology is to re-shape the seismic spectrum (as shown in green), so that it matches the well log impedance spectrum. It is critical that the re-shaping of the spectrum is performed on un-migrated data.

Among all the datasets, the EM_PreSS 38-48° ultra-far angle stack best defined the reservoir extent in the Erha North field (Figure 2).
Figure 2. A comparison between zero phase and EM_PreSS on 38-48° angle stacks, from the 2000 data. Because EM_PreSS enhances the low frequency content, and the lower frequency is attenuated less than higher frequency, the reservoirs at the southern portion were better on the EM_PreSS data.

**Case Studies**

The Phase I development in Erha North field used 2000 seismic data in the planning stage. The amplitude response was weak and patchy over the eastern half of the field due to the attenuation of the shallow channel. The appraisal well Erha Far-East (EFE) was planned as the last well in the phase I development plan to better define reservoir presence and developable reserves before starting the Phase II development. After the EM_PreSS processing, the 2005 data showed a more continuous channel geometry and consistent amplitude response at the appraisal well location. Based on the reprocessed seismic data, it was concluded that good reservoirs were present and well connected. Thus a business decision was made not to drill the Erha FE well and to use the rig slot to drill an exploration prospect in the Erha North East area instead.

The Erha North East prospect was interpreted in the same depositional channel system on the low-side of a major fault, separating it from the Erha North field. It had the advantage of being only 7 km away and could be tied back to the Erha North field if the well were a success.

Reservoir-300 in the Erha NE prospect is a channel complex comprised of four single-cycle reservoir sands. The first sand, Sand A, has the strongest amplitude response and carried most of the volumes in the assessment. The amplitude shows weak low impedance signature at near- (8-18°) to mid- (18-28°) angle stacks, stronger low impedance at far- (28-38°) to ultra-far (38-48°) angle stacks, consistent with a hydrocarbon response. However, the water leg was not clearly observed. The conformance to structure was poor. Reservoir-300 amplitude could be mapped continually to the syncline without a clear termination. The NE prospect original hole was designed to penetrate the Reservoir-300 below the structural spill point, expecting to reach the water leg.

The well successfully penetrated hydrocarbons in both primary and secondary targets. However, vertical connectivity in the penetrated Reservoir-300 was not as expected as two gas-on-oil sand packages were penetrated within the single cycle A Sand, both thin. Such thin oil columns and highly compartmentalized reservoirs would not be economically developable.
The well did not penetrate any water sands. A low-impedance amplitude anomaly was observed down-dip of the discovery location on the ultra-far 38-48° angle stack. The amplitude response was neither the same to the penetrated hydrocarbons nor to known water penetrations in the Erha North field (Figure 3). Geophysical modeling for the down-dip seismic response showed irreducible uncertainty using parameters from the near-by discoveries. The chance of success for finding hydrocarbons was assessed below 20%. Even with this high risk, Esso determined it was critical to know the fluid type at the down-dip location before the Phase II development starts. The side-track well was drilled and penetrated a 40-meter thick clean, wet sand. Post-drill modeling suggested that abnormal anisotropy in the thick sand could be the reason for the strong low impedance response seen only on the ultra-far angle stack.

Figure 3. Reservoir-300 amplitude extraction from the EM_PreSS data, from 18-28, 28-38, and 38-48 angle.

Conclusions

These three case studies illustrate the complexity and challenges associated with exploration and development activity in the deep-water Nigeria. The same aged reservoirs could vary dramatically in terms of rock quality, fluid type and level of connectivity, within only a few kilometers distance. Near-surface geologic features, such as the shallow channel, affected seismic image quality and brought another level of difficulty to the interpretation. A good seismic data is essential to explore for and develop these reservoirs with confidence.

In the development case, the new seismic data, especially EM_PreSS inversion helped improve image quality and better define reservoir extent under the attenuated zone. This resulted in cost savings by not having to drill the appraisal well Erha Far-East.

However, the same data used in the exploration setting led to mixed drilling results in Erha North-East.

Far- to ultra-far offset seismic data can be an effective analysis tool to help identify deep hydrocarbon accumulations when used consistently with other DHI attributes and relevant geologic concepts, especially characterization of environment of deposition (EOD) and lithology.

Risk of false anomalies increases with increasing offset. This is due to critical angle, normal move-out (NMO), anisotropy, lithology, overburden effects, and processing artifacts. Wet sands encountered in the ENE down-dip sidetrack highlighted the risks of targeting anomalies on ultra-far angle stack data that are not supported by other DHI attributes.

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