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RECONNAISSANCE AVO AND ANISOTROPY PREDICTION, DEEPWATER NIGERIA.

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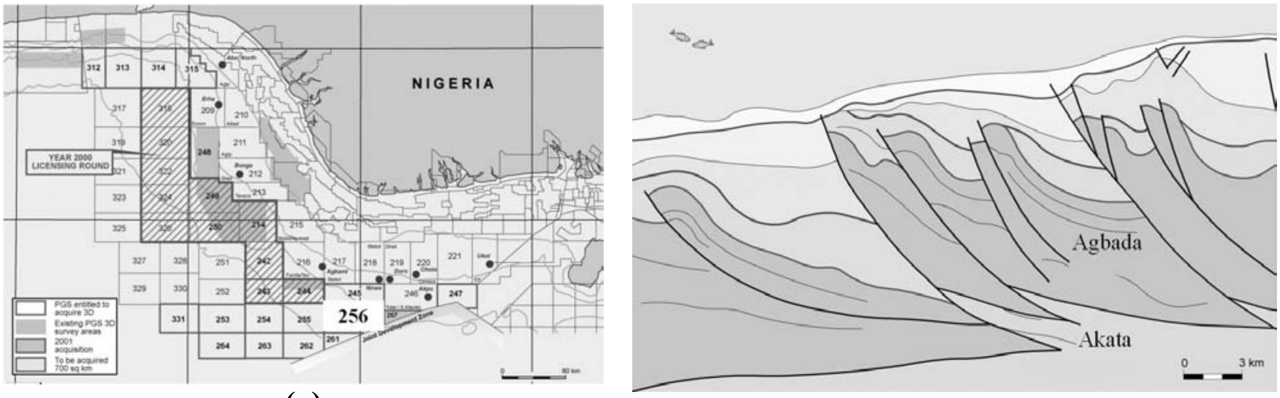
Summary

In 2000 a reconnaissance 3D survey was acquired in deep waters offshore Nigeria. The purpose of this 1850km^2 seismic survey was to image and accurately map tectonic features of the area. In addition to identifying hydrocarbon accumulations, the aim was to obtain high-resolution data for the mapping of the fault systems and deltaic packages.

Two aspects of the seismic data processing are discussed in this paper: i) pore-fluid prediction using AVO analysis, and ii) shale distribution prediction from anisotropy measurements.

Geological setting

The OPL 256 area, offshore Nigeria (Figure 1a) is characterised by a thick Neogene section deposited in a deepwater setting in the outer compressional zone of the Niger Delta. Target structures within the sand/shale Agbada Formation consist primarily of a series of shoreward-dipping toe-thrusts (Figure 1b) that sole out in the over-pressured shale of the Akata formation, together with large turtle-back anticlines. Proven reservoir facies within the Agbada Formation were deposited in channel and turbidite lobe environments.



(a) (b)

Figure 1: (a) Location of OPL 256, in water depths of between 1600m an 2000m.
(b) Shoreward dipping toe-thrusts of the Agbada formation. Target structures lie within this sand/shale formation.

Anisotropy measurements from pre-stack data.

The assumption that the travel time trajectory is hyperbolic is appropriate for data acquired with relatively small offset/depth ratios. At longer offsets the degree of non-hyperbolicity can be considerable, and higher order moveout corrections need to be used. While Taner and Koehler (1969) give the general expression for higher order moveout spectra, Alkhalifah and Tsvankin (1995) cast the higher order moveout in terms in terms of anisotropy. They demonstrate that for transversely isotropic media with vertical symmetry axis (VTI media), just two parameters are sufficient for performing all time-related processing, such as normal moveout (NMO) correction, DMO, and pre- and post- stack migration. These parameters are the zero dip normal moveout velocity V_{nmo} (0) and the effective anisotropy parameter **η.** The higher order moveout equation is given in Equation 1.

$$t^2(X) = t_0^2 + \frac{X^2}{V_{nmo}^2} - \frac{2\eta X^4}{V_{nmo}^2\left[t_0^2 V_{nmo}^2 + (1+2\eta)X^2\right]} \quad , \quad \eta \equiv 0.5\left(\frac{V_h^2}{V_{nmo}^2} - 1\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

V_h is the P-wave velociy in the horizontal direction, and V_{nmo} the zero dip stacking velocity. η contains the ratio of horizontal velocity to the stacking velocity.

Nowadays, it is routine processing procedure to perform a two term velocity analysis where the parameters V_{nmo} (0) and η are simultaneously determined. In correcting for this non-hyperbolic moveout, we also determine the anisotropic nature of the subsurface

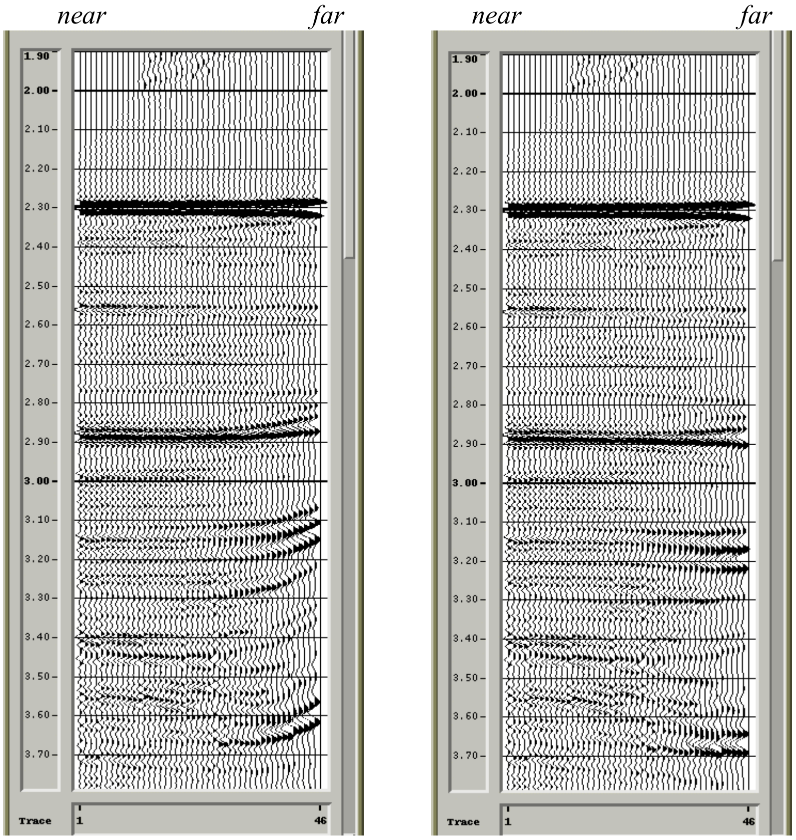
For this data volume, a two term velocity analysis was carried out on a 500m X 500m grid. The method of analysis is summarized as follows:

i) V_{nmo} is determined over that part of the gather where moveout is considered *hyperbolic*. This is done in the usual way by analysing semblance functions generated by applying moveout for a given range of velocity functions.

ii) Using this stacking velocity function chosen in (i) above, a second semblance function is computed using a range of η functions**,** and applying the moveout as expressed in equation 1 to *all* offsets of the gather**.** This is similar to the method described by Gidlow and Fatti (1990) except that here the variation is explicit in the variable **η.**

A typical gather after normal (hyperbolic) moveout correction is shown in Figure 2a. The same data, after two parameter velocity analysis and moveout correction using Equation 1 is shown in Figure 2b. This flattening of the events allows also for a wider aperture to be used in subsequent AVO analysis.

In the same way that stacking velocity volumes are produced and displayed, it is useful to visualize volumes of the effective anisotropic parameter η, which can be a useful qualitative indicator of shale distributions.



(a) **(b)**

Figure 2: (a) CDP gather after application of normal (hyperbolic) moveout correction (b). Application of higher order moveout correction using Equation 1

The η volume (sampled at 500mX500m) ,was loaded on a visualization system and a selected inline is shown in Figure 3.

Anisotropy parameter η

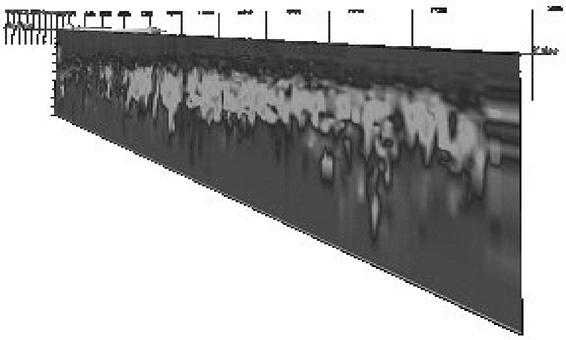


Figure 3: Perspective inline image of the anisotropy parameter η.

Fluid Factor

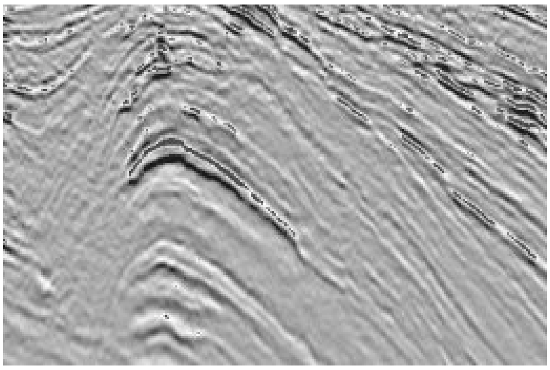


Figure 4: A inline section of the AVO attribute Fluid Factor. High amplitudes indicate higher probabilities of hydrocarbons.

AVO Analysis

AVO analysis was performed over the entire survey. From each migrated CDP gather the compressional reflectivity (ΔI/I) and shear reflectivity (ΔJ/J) were computed using the normal

$$R(\theta) = \frac{\Delta I}{2I}\left(1+\tan^2\theta\right) - 8\frac{J^2}{I^2}\frac{\Delta J}{2J}\sin^2\theta \quad \dots\dots\dots\dots(2)$$

At spatial intervals of 2km, and temporal intervals of 1 second (beneath the ocean bottom) a background compressional/shear reflectivity trend was computed. This background trend, representing the shales and water sands of the Agbada formation, was then removed from the data. Deviations from this background trend are then displayed, and this is known as the fluid factor. In a clastic formation, e.g. the Agbada, higher amplitude fluid factor events correspond to greater likelihood for the presence of hydrocarbon filled reservoirs, Smith and Gidlow (1987). In other words, the fluid factor gives a measure the prospectivity of a reservoir rock of interest.

By performing a two term anisotropic velocity analyses, it was possible to flatten the gathers over a greater offset range, allowing a wider aperture of data into the AVO analysis, and therefore giving more robust results.

The entire 3D AVO volume was loaded onto a visualization system. This allowed for the the immediate recognition of high amplitude AVO events. An inline section showing a fluid factor anomaly attribute is shown in Figure 4. As discussed above, this high amplitude anticlinal structure would be interpreted as having a high potential of being a hydrocarbon reservoir.

Conclusions

Performing a two term velocity analysis provides two advantages. Firstly, CDP gathers are flattened over a wider offset range, providing a wider aperture over which to perform subsequent AVO analysis. Secondly, the effective anisotropy parameter **η,** derived from the analysis can be used to predict areal shale distributions. AVO analysis is a routine process nowadays. The generation of large volume AVO indicators and subsequent interpretation on 3D visualization systems, hastens the exploration cycle.

Acknowledgement

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