Introduction

The turbidite sandstone reservoir is a hot target of hydrocarbon exploration and development. In this province, the deepwater area of the Niger delta basin has been proven huge recoverable reserves. There are more promising reserves yet to be discovered with new exploration and production technologies.

The study area is located in the deep water area of Nigeria, in front of the large gravity slip in the Niger delta basin (figure 1). The trap is a 4-way closure structure complicated by dense faults. The submarine fan sedimentary system is developed in this area and the petroleum system is confirmed. Two wells were drilled on the structure more than a decade ago and discovered three layers of oil-bearing reservoirs. However, the reserves did not reach the economic threshold, because the oil layer is thin on the structure high, the trap is faulted into too many fault blocks and the oil-water contact is revealed in the main oil layer. In recent years, a lot of research work has been carried out on complex fault recognition (Li et al., 2018; Laake, 2015), reservoir identification and hydrocarbon prediction (Abbey et al., 2018; Olorunniwo et al, 2016; Zhu, 2009) in the Niger delta basin.

With the technology development, the prospect is re-evaluated. The evaluation still face three main G&G challenges. The first one is the complex fault system. Faults are densely developed with complex relationship, which lead to difficulties in fault recognition and interpretation (figure 2). The second challenge is the complex deposits. The periods of sedimentary layers are overlapped and later cut by complex faults (figure 2 and figure 3), which lead to difficulties in reservoir identification. The third challenge is the uncertainty in oil reservoir prediction. In this area, water layer may also generate strong amplitude feature similar to that of oil layer, which often affects the hydrocarbon predication. So it is difficult to discriminate whether the strong amplitude area that below the depth of drilled oil-water contact (OWC) is oil or water layer, as shown in figure 3. In order to solve these problems, an integrated approach is proposed in this paper, which consists of three key techniques: complex fault recognition based on attributes fusion and frequency-divided attribute fusion, complex reservoir identification based on Bayesian lithofacies probabilistic prediction, and hydrocarbon prediction based on AVO attribute and flat point enhancement.

Figure 1 The geological section pass the study area.

Figure 2 Conventional variance attribute along surface, which is not clear enough.

Figure 3 A seismic section pass well X1, showing the complex faults, unevenly distributed reservoirs and ambiguous seismic responses.
Methodology

- **Complex fault recognition based on attributes fusion and frequency-divided attribute fusion**

With the help of fault attribute sliding along depth or horizon, the 3D fault interpretation can be carried out efficiently. However, the conventional variance attribute is not clear enough for fault recognition in the study area (figure 2). Therefore, two methods are evaluated to improve the capability of fault recognition. The first one is the attributes CMY fusion method. First, generate the variance and dip RMS attribute separately; Then, highlight fault details by doing ant-tracking on the dip RMS attribute; Finally, three attributes are fused in the CMY mode. We can see from figure 4 that faults are delineated much more clearly than that of conventional method (figure 2).

**Figure 4** Fault recognition by attributes CMY fusion method. C: Variance; M:Dip RMS; Y: Ant tracking of Dip RMS.

In the study area, controlled by the sealing faults, the oil-water contact changes in different fault blocks. The fault and sealing fault interpretation directly affects the understanding of reserves units. Therefore, the second fault recognition method, frequency divided attribute fusion method, is also used to help the interpretation. Figure 5(a) displays the ant tracking attribute of variance attribute generated from original seismic data. We use the seismic complex spectral decomposition (CSD) and reconstruction method (Han, 2017) to extract frequency dependent data from the original seismic data. This method can broaden the frequency bandwidth in the process of spectral decomposition and obtain reliable frequency-divided seismic data in reconstruction process. Considering the time cost, the general spectral decomposition (GSD) method in Petrel could be an approximated alternative method. Figure 5(b)-(d) show the same fault attribute as figure 5(a) but generated from 15Hz, 30Hz, and 60Hz dominant frequency seismic data respectively. The attribute from low-frequency (15Hz) data is helpful to describe large scale faults, while the attribute from high-frequency (60Hz) data is helpful to describe small faults and fault details. Figure 5(e) shows the CMY fused attributes in figure 5(b)-(d). Comparing of figure 5(a) and figure 5(e), we can see that CMY fusion of attributes from low, medium and high frequency data show fault much clearer than that directly using the original data.

**Figure 5** Fault recognition by frequency-devided attribute fusion. (a) The ant tracking attribute of variance generated from original seismic data. (b), (c) and (d) show the same attribute but generated from 15Hz, 30Hz, and 60Hz dominant frequency seismic data, respectively. (e) CMY fusion result of the frequency-devided attribute in (b), (c) and (d). C: 15Hz; M: 30Hz; Y: 60Hz.
• **Complex Reservoir identification based on Bayesian lithofacies probabilistic prediction**

The rock physical analysis shows that in the study area, the sandstones cannot be distinguished from mudstones by P-impedance, as shown in figure 6(a). Combining of P-impedance and Vp/Vs can give a better discrimination, as shown in figure 6(b). However, there is still a small overlap. A Bayesian approach (Pendrel et al., 2017; Teixeira et al., 2017) is used after fine pre-stack elastic inversion workflow. Figure 6(c) shows the lithofacies probability prediction result pass the target well. It can be seen from the figure that the three main target layers are all predicted to have continuous reservoirs with a probability above 80%, which is confirmed in the subsequent drilling.

![Figure 6](image)

**Figure 6** Bayesian lithofacies probabilistic analysis and prediction. (a) Probability of P-impedance of sandstones and mudstones. (b) Crossplot of P-impedance and Vp/Vs and their probability density functions. (c) The lithofacies probability prediction result based on Bayesian discrimination.

• **Hydrocarbon prediction based on AVO attribute and flat point enhancement**

We did a lot of analysis work on drilled wells around the study area, including AVO modeling, Rock physics analysis, fluid substitution, porosity substitution, and so on. We get a conclusion in this area that, generally, gas reservoir appears to be class III AVO type, oil reservoir appears to be class II or class III AVO type, and the water reservoir is mainly class I AVO type. AVO anomaly is a necessary condition for the existence of high quality oil reservoirs in this area. We use the AVO fluid factor attribute to look for areas of suspected oil. The AVO fluid factor matches with the drilled wells and predict the target areas to be oil-bearing reservoirs, as shown in figure 7 and figure 8.

![Figure 7](image)

**Figure 7** Oil bearing reservoir prediction result based AVO fluid factor.

![Figure 8](image)

**Figure 8** Plan view of the AVO fluid factor attribute of layer 1.

In order to reduce the uncertainty (Ojo and Sindiku, 2006), we also use other evidence to verify the reliability of the prediction, such as flat point and depth contour. Flat point DHI (Wojcik et al., 2016) plays an important role in hydrocarbon determining and fluid interface prediction, however, the flat point is usually not easy to distinguish. We use optical stacking method to improve the readability of flat points. We can see from figure 9 that the flat point is shown more clearly after optical stacking. Both the AVO anomaly and flat point DHI are consistent with the contour, as shown in figure 8 which further increased the confidence that it’s an oil bearing reservoir in the target area.
Figure 9 Flat point enhancement. (a) Before optical stacking; (b) After optical stacking.

Conclusions

We have proposed an integrated approach for complex faulted reservoir characterization, which includes three main techniques: complex fault recognition, complex reservoir identification, and hydrocarbon prediction. With the integrated approach, an undrilled fault block is found in the south wing of the structure with predicted high-quality reservoir and good superposition in layers. The P-3 well is drilled successfully and high-quality oil bearing reserves are verified below the previous drilled OWC. Proved reserves have been greatly increased and reach the threshold of commercial development. Explorations in the deep-water area become more and more complex and difficult. More efficient techniques and careful works is required to identify and assess the resource potential.

References


Han, L. [2017]. Changeable frequency and phase of seismic data. 79th *EAGE expanded abstracts 2017*.


