WS9-C01

Joint CSEM–seismic Evaluation of Risky Drilling Task

Z.X. He (BGP, Inc.) & G. Yu* (BGP, Inc.)

SUMMARY

Due to the complex surface and subsurface exploration conditions, hydrocarbon reservoir distribution is controlled by many unknown factors, such as structure reservoir, lithologic trap reservoir, stratigraphic trap reservoir, and changes of exploration target, etc., any single geophysical exploration method has higher risk to predict and evaluate the hydrocarbon reservoir. Explorationists have high expectation to identify hydrocarbon target using CSEM method, but its wide applications have been limited due to its low resolution and poor accuracy. Recent years, CSEM and seismic constrained or joint inversion has achieved higher accuracy for electrical anomaly target exploration. Based on this trend, we have developed a new exploration method of the joint TFEM (Time and Frequency domain EM) – Seismic evaluation of risky drilling task. When an exploration area not only has confirmed seismic structure trap and reliable AVO anomaly, but also has matched induced polarization (IP) and resistivity anomaly (R) on the potential exploration target, it will have much lower drilling risk. The wide application of this new exploration method in the west of China has significantly improved the drilling success rate through the using the joint TFEM – Seismic method to predict and evaluate the potential hydrocarbon target.

Introduction

Due to the complex surface and subsurface exploration conditions, hydrocarbon reservoir distribution is controlled by many unknown factors, such as structure reservoir, lithologic trap reservoir, stratigraphic trap reservoir, and changes of exploration target, etc., any single geophysical exploration method has higher risk to predict and evaluate the hydrocarbon reservoir. Explorationists have high expectation to identify hydrocarbon target using CSEM method, but its wide applications have been limited due to its low resolution and poor accuracy. Recent years, CSEM and seismic constrained or joint inversion has achieved higher accuracy for electrical anomaly target exploration (He and Wang, 2002). Based on this trend, we have developed a new exploration method of the joint TFEM (Time and Frequency domain EM) – Seismic evaluation of risky drilling task. When an exploration area not only has confirmed seismic structure trap and reliable AVO anomaly, but also has matched induced polarization (IP) and resistivity anomaly (R) on the potential exploration target, it will have much lower drilling risk. The wide application of this new exploration method in the west of China has significantly improved the drilling success rate through the using the joint TFEM – Seismic method to predict and evaluate the potential hydrocarbon target.

Theory

The TFEM method is based on the Long Offset Transient Electromagnetic (LOTEM) and Control Source Audio Magnetotelluric (CSAMT) methods. The TFEM method has the advantages of the above two methods: LOTEM has high vertical resolution and sensitive to conductive layer; CSAMT has high lateral resolution and sensitive to resistive layer. Therefore, the TFEM method is an efficient way to detect resistivity feature for various depth by changing wave length and frequency magnitude.

The theory and practice have shown that there exists strong IP and resistivity anomaly above the known hydrocarbon reservoir. Therefore, in an exploration area with good structure trap and strong AVO anomaly as well as matched IP and resistivity anomaly (IPR), the drilling success rate will be significantly improved in the confirmed TFEM – Seismic anomaly combined area.

Application examples

In an initial exploration area, it may only have 2D seismic data. The joint TFEM – Seismic method is used to evaluate the hydrocarbon potential within 2D seismic confirmed trap target, and provides basis for 3D seismic survey layout and exploration drilling target. In an area with higher degree of exploration activities such as 3D seismic survey, the joint TFEM – Seismic method is used to optimize drilling target within the 3D structure trap and improve drilling success rate. In a mature oilfield with many wells and high resolution seismic data available, we use the joint TFEM – Seismic method to look for bypassed or residual oil, delineate oil-water boundary and improve recovery rate (He, 2005).

The joint TFEM – Seismic method has been used in more than 70 hydrocarbon targets within China, and nearly 30 targets in Oman, Saudi, Chad, and Niger. The target trap types include structural trap, lithologic trap, stratigraphic trap and composite trap. The hydrocarbon reservoirs have clastic hydrocarbon target, carbonate hydrocarbon target and unconventional shale gas reservoir. All the applications have achieved excellent results.

According to application statistics on more than 50 clastic reservoir targets, joint TFEM – Seismic method achieved more than 80% drilling success rate (He, et al., 2007). For example in the NRER region, the 18 exploratory wells with hydrocarbon discovery have excellent matching EM – Seismic anomaly. Based on the matched EM – Seismic anomaly, 5 planned and drilled exploratory wells have encountered commercial oil flow in 4 wells (He, 2011). One well has hydrocarbon show from logging data interpretation but no commercial

production. According to the application statistics of more than 40 carbonate reservoir targets, more than 70% drilling success rate have been achieved through the application of the joint TFEM – Seismic method (Figure 1). For example, 45 wells have been planned and drilled in the YM area based on the matched joint TFEM – Seismic anomaly (Figure 2). Some wells are located within 1 km of the TFEM survey line. A total of 30 hydrocarbon discovery wells matched the TFEM anomaly prediction perfectly, 9 wells matched the TFEM anomaly but their hydrocarbon production is not stable due to their location at the edge of the TFEM anomaly. A total of 6 wells did not match the predicted results (Wang and He, 2006).

Due to the complexity of reservoir type, especially in the carbonate reservoir, the reservoir heterogeneity is very significantly. Reservoir lateral distribution change dramatically. Sometimes the closely spaced 2 wells may have completely different drilling results. The joint TFEM – Seismic method may have limited application for the requirements of fine reservoir description of the carbonate reservoir.

Conclusions

Because of the complexity of the hydrocarbon exploration and the uncertainty and non-uniqueness of geophysical exploration methods, the joint TFEM – Seismic method can combine their respective advantages and make the full use of both techniques. It can be used to reduce the risk of exploration and drilling. The application examples show that this joint method has effectively developed the optimized direction of hydrocarbon exploration and development. At present, the joint TFEM – Seismic method has been tested and applied on many hydrocarbon target evaluation, but this technique is still in continuous development, especially the joint inversion of both data sets and wider applications are needed. Reasonable and flexible use of the joint TFEM – Seismic method are bound to achieve a higher return benefits in the hydrocarbon exploration.

Figure 1 This is the IP anomaly characteristics from different type of reservoirs. (a). Thin layer or thick layer IP anomaly from porosity type reservoir; (b). Fracture controlled cluster shape IP anomaly from fracture type reservoir; (c1). The bead-like IP anomaly from bulk or block type reservoir; (c2). The bead-like seismic amplitude anomaly for comparison with IP anomaly in (c1).

Figure 2 Exploratory well planning and evaluation. Top: resistivity profile; Middle: IP anomaly profile; Bottom: IP anomaly overlays on the seismic profile. The red arrow is the well location and this well has commercial oil production.

References

- He, Z. X. and Wang X. B., 2002, Artificial source time-frequency electromagnetic sounding system, CSEG Annual Meeting, Abstracts (in Chinese), 599
- He, Z. X., 2005, Mapping reservoir boundary by borehole-surface TFEM: Two case study, The Leading Edge, 2005, 896-900.
- He, Z. X., Dong, W. B. and Lei, Y. H., 2007, Joint processing and integrated interpretation of EM and seismic data—an effective method for detecting complicated reservoir targets, *TLE*, 336-340.
- He, Z. X., 2011, BSEM for Mapping the Boundary of Reservoir and a Case Study of Well-S7 Borehole Geophysics Workshop - Emphasis on 3D VSP, 16-19 January 2011, Istanbul, Turkey, 1-4.
- Wang, C. F. and He, Z. X., 2006, Lithology study using TFEM technique in western Qaidam Basin, SEG 2006 Annual Meeting, *Expanded Abstracts*, 825-829.