Using MT data to find velocity traps in middle and shallow layers

Weibin Sun¹, Yong Li², Yanbin Feng¹, Zuzhi Hu¹, and Ximing Sun¹

¹ BGP Inc., China National Petroleum Corporation
² Tarim Oilfield Company of CNPC

Abstract. In the complex piedmont oil and gas exploration, due to the large change of lithology in the middle and shallow strata, the vertical and horizontal changes of velocity in the middle and shallow strata are more intense. It is difficult to identify some strata with obvious changes in velocity on the seismic section, which leads to the inaccuracy of velocity model or obvious velocity trap in the seismic prestack depth migration processing. This will further cause the incorrect deep structure and target layer solution. MT method are mainly characterized by deep sounding depth, high sensitivity to high conductivity geological bodies in high resistivity layers. This makes it very effective to study the deep structures of basements and lithology distribution. We here analyze the technical advantages of MT method in tracing in middle and shallow layers by MT modeling geoelectric model of mountainous areas, and demonstrate that MT method can play an important role in oil and gas exploration in complex areas, especially in finding velocity traps for seismic processing by analyzing some cases.

1. Introduction

BD area in western China is a typical geologically complex piedmont area, where salt rocks are richly developed in deep layers and gravels are richly developed in its middle and shallow layers. Gravels with 3100m thickness are encountered in well BD6, which hasn’t been predicted in seismic sections before well-drilling. So the errors of interpreting deep-seated target layers are relatively large and the costs in drilling are increased.

The BD area in West China is a piedmont complex area with middle and shallow conglomerate layers well developed. The same set of 3D seismic data in this area is processed and interpreted by two different companies, but the structural characteristics of the same target layer obtained are quite different (Figure 1), which makes it difficult for oil companies to decide the next drilling deployment. Further analysis shows that the main reason for the difference in interpretation of the main target layer is that the velocity models applied by the two companies are completely different. The formation resistivity logging and acoustic logging data show that there are obvious resistivity differences between sandstone and conglomerate layers, but the acoustic logging data is not particularly sensitive to such lithology differences. This lithological feature lays an important foundation for the deployment of MT exploration to trace the distribution of high-speed and high resistance conglomerate.

In order to decrease exploration risk and improve precision of seismic data, high density 3DMT survey are deployed with grid of 500×500m² in this area. The purposed 3DMT exploration are: 1) to trace distribution of Quaternary and Tertiary gravels, providing information on lithology of middle-shallow-seated layers for seismic velocity modeling for pre-stack depth migration; 2) to trace deep-seated subsalt structures. Figure 2 shows 3D MT survey sites distribution map BD area, in which well
BD3 and well BD6 are explored wells. Quaternary gravels have been encountered in well BD3 and Tertiary gravels in well BD6 respectively. The north part of the work area is mainly mountainous area.

![Figure 1](image1.png)

**Figure 1.** The same target layer structure interpreted by two companies with same 3D seismic data.

![Figure 2](image2.png)

**Figure 2.** 3D MT survey sites distribution map in BD area.

2. Physical properties of gravels and analysis of its modeling

Figure 3 shows the resistivity logging curve, sonic logging velocity curve and density curve of well BD3 and BD6 respectively. Among these curves, density curves are converted from velocities. We can conclude from these curves that, whatever well BD3 where Quaternary gravels have been encountered or well BD6 where Tertiary gravels have been encountered, lithology contrast between gravels and arenaceous mudstones are mainly reflected in resistivity curves with relative variation rate reaching 100%. However, the difference of their densities or velocities is not obvious. It is can be concluded that the MT exploration which takes resistivity contrast as its basis can easily distinguish gravels in this area.

![Figure 3](image3.png)

**Figure 3.** Logging curves of well BD3 and well BD6.
In order to further prove the feasibility of tracing gravels with MT exploration in this area, a 1D geoelectric model and a 3D geoelectric model is calculated for analysis. The target layer has a thickness of 50m, 100m, 200m, 500m, 1000m, 2000m and its resistivity is 500Ωm. Figure 4 shows MT curves of forward modeling for 1D geoelectric model.

Apparent resistivity responses corresponding to high frequencies show obviously high value with the increasing of gravel thickness when its thickness is more than 200m, which means gravel with thickness of more than 200m in this area can be detected with MT survey.

Since gravels are developed locally in lateral direction and with uneven grain in vertical direction, feasibility test of 3D MT survey is conducted with a 3D geoelectric model shown in Figure 5. Figure 5 is a 3D geoelectric model slice traversing gravel sediments center. Its first layer is designed as eluvial soil which is 100m in thick and 50Ωm in resistivity. The second layer of the model is 500Ωm in resistivity and 500m—1400m in thickness, representing coarse gravel of Quaternary and upper Tertiary. The third layer is of 70Ωm in resistivity and 1900m—2500m in thickness, representing gravels of upper Tertiary. The forth layer is 5Ωm in resistivity and 2000m—4000m in thickness, representing arenaceous mudstones of lower Tertiary of the work area.

Figure 4. Apparent resistivity and phase curves of 1D forward modeling.

Figure 5. Slice of 3D geoelectric model traversing gravel sediment center.

Figure 6. Slice of 3D inversion resistivity of TE response of the geoelectric model (Fig.5)
The response of geoelectric model mentioned above is calculated using finite element difference method[1]. Some noises are added to the TE response to conduct pseudo 3D inversion[2,3]. Figure 6 is the resistivity slice after pseudo 3D inversion of TE response of the geoelectric model, which shows inverted resistivity distribution agrees well with that of designed geoelectric model from the shallow layer to the deep layer. So we get the conclusion that inverted resistivity with 3D MT data can reflect lithology variation of shallow to middle layers.

3. Inverted resistivity features of the work area and their calibration

Figure 7a and b shows overlay sections of logging curves of well BD3 and well DB6 on 3D inverted resistivity slices of two main MT survey lines traversing the two wells respectively.

The Figure 7a shows that resistivity close to well BD6 laterally varies obviously at shallow to middle depth corresponding to survey sites 18-28. There exists a developed local high resistivity anomaly body with resistivity of 60-300Ω.m and thickness of 3000m below 1000m depth. We take logging data of well BD6 to calibrate the slice to get to know this local high resistivity anomaly is the reflection of locally developed coarse gravels of Tertiary, which has not previously been detected with seismic data. The Figure 7b shows that there exists an obvious high resistivity layer at shallow depth with thickness of about 1100m and resistivity of 300-800Ω.m, forming a distinct interface with its underlying layer (its resistivity is lower than 10Ω.m). We take logging data of well BD3 to calibrate the section to get to know shallow layer’s high resistivity corresponds to gravel of Quaternary, and the underlying low resistivity layer corresponds to arenaceous mudstones of upper Tertiary. So we get the conclusion that MT data can effectively reflect resistivity contrast between gravels and arenaceous mudstones.

3D inverted resistivity slices at elevation of 750m and -1300m are obtained to further define distribution of Quaternary and Tertiary gravels. Figure 8a shows the inverted resistivity slice at elevation of 750m. The zone has a resistivity value of more than 60Ω.m (the red color zone) which qualitatively reflects the Quaternary gravels distribution; Figure 8b is the inverted resistivity slice at elevation of -1300m. This zone has a resistivity value of more than 60Ω.m (the red color zone—NEE-oriented ) mainly reflects upper Tertiary gravels distribution. We take logging data of well BD6 and
well BD3 to calibrate 3D inverted resistivity against depth data to get thickness map of Quaternary and upper Tertiary (Figure 9a and 9b).

From Figure 8a we find that Quaternary gravels are mainly developed at the southeast part of the work area with thickness variation of 300 - 1300m. The north end of each main survey line presents great variation in gravels thickness with the maximum value reaching 2100m. From Figure 8b we find that the zone upper Tertiary gravels are mainly developed is well BD6-centered SW-NE-oriented band at the center part of the work area. It is inferred upper Tertiary gravels are blind sediments mainly developed at the lower wall of the fringes of thrust fault TZ with thickness variation of 300 - 4300m. Tracing this set of gravels in terms of their extension and thickness is the key interest for Oilfield experts.

![Figure 8](image1.png)

**Figure 8.** The distribution of 3D inversion resistivity at different elevation for BD area

![Figure 9](image2.png)

**Figure 9.** The thickness map of Quaternary and upper Tertiary gravels for BD area with 3DMT

High attention from seismic data interpreters of Oilfield has been attracted to our interpreted results in terms of gravels distribution and lithology variation information has been taken into account in building initial velocity model, which lays a foundation for high-precision pre-stack depth migration of seismic data.

4. Results assessment
Seismic data generally reflects differences in wave impedance of subsurface medium, while MT data reflects differences in resistivity of subsurface medium. So both of them reflect subsurface layer’s fluctuation in lateral and vertical direction from different sides. [4]Integration of seismic data and MT data can provide more vivid and more objective information on subsurface layers’ lithologies, remedying the deficiency of information limitation obtained from single geophysical method [4]. Inverted resistivity of MT data only provides electrical property, which is sensitive to laterally variation in sediments. Arenaceous mudstones developed in this area (encountered at depth of 1200m-5000m at well BD3) presents low resistivity, while layers with abundant gravels (encountered at depth of 0m-1200m at well BD3, and 1300m-4400m at well BD6) presents obvious high resistivity, which has no distinct reflection in seismic data (Figure 10). Instead, they present normal reflection without any anomaly in seismic data. So the MT survey has played an important role in defining gravels distribution in this area, especially, in detecting locally developed gravels of upper Tertiary.
Using the high-speed gravel distribution provided by MT data, especially the hidden conglomerate distribution of the tertiary (the high-speed layer not considered in the early seismic velocity modeling), the velocity model are reconstructed for the prestack depth migration processing of seismic data. And the buried depth accuracy of the target layer is increased from 10% in the early stage to 2.5%, avoiding the deep structural interpretation error caused by the velocity trap.

5. Conclusions
In complex areas, to predict lithology abnormal bodies which affect velocity variation of rocks in advance can decrease drilling risks and improve interpretation precision of deeply-seated structures or targets to some degree.

Effectively identifying lithology of thick gravels with MT survey in BD area is based on resistivity contrast between arenaceous mudstones and gravels, which is more obviously reflected on MT data than wave impedance difference on seismic data. This confirm us that MT survey has played an important role in defining locally developed gravels in this area. From this case we can further get the conclusion that MT survey presents its obvious advantage in detecting locally developed lithology abnormal bodies and is a supplement to seismic survey in defining lithology anomalies, especially in finding velocity traps for seismic processing.

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