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Application of Comprehensive Geophysical Rospecting Method in the Detection of Goaf in Shanxi Wuyang Coal Mine

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Abstract: *The accumulated water in the goaf of coal mine is a serious threat to the safety of coal mine production. In order to effectively detect the accumulated water in the goaf within the mine area and to find out the fault conductance water content, the ground transient electromagnetic method and direct current sounding are used to detect. As the buried depth of coal seam in the area is 600m~900m, current test, wire frame size test, frequency size test and overlay times were carried out. Finally, construction parameters were selected as 720m×720m wire frame, 20A current, transmission frequency 6. 25Hz, overlay times 256 times and large constant source center loop device was used in the device. According to the test and research, it is found that the depth of the blind area is about 80m based on the size of wire frame L, the measured depth h and the turn-off time t, combined with the measured data. In order to detect the water content of quaternary system and weathering crust in the detection area, the direct current sounding work has been carried out. The results show that: By using the collected TEM data, Voxler platform for 3D data modeling and topographic data for bleaching, the 3D apparent resistivity model is studied, and the spatial distribution characteristics of goaf and water-rich area are intuitively displayed. The results of measurement are more intuitive, and the reliable and real basis is provided for the later drilling layout and coal mine water control work.*

Keywords: *TEM; A blind spot; Mine Gob; Voxler 3D; Direct current sounding*

1. Introduction

China is rich in mineral resources, especially coal mining has a long history. During the mining process, a large number of goafs were formed, which seriously threatened the safety of various engineering construction and people's living. According to the 2021 research report, there are currently 20,000 km^2 of subsidence areas, distributed in 23 provinces and 151 counties and cities.In 2010, Wangjialing Mine had a flooding accident, causing serious personal injury and huge economic losses. The geophysical prospecting method is a kind of low cost, fast efficiency suitable for large-scale investigation means in the production practice has been widely recognized.

TEM is sensitive to low-resistance anomalies and can be used to detect goafs and water-rich anomalies. Qin Qingyan[1] studied the water accumulation goaf of Sangshuping Coal Mine, and analyzed the transient electromagnetic response characteristics. Mou[2] carried out TEM test on the known goaf, and proposed to optimize the detection parameters and improve the detection accuracy of the shallow buried goaf. Liu Shucai et al. [3] proposed that the comprehensive exploration of transient electromagnetic method and seismic exploration reduced the multi-solution problem of geophysical data. Song Yulong et al. [4] used the magnetotelluric method to detect the coal mine goaf, and the results showed that the high resistivity anomaly in the non-water-bearing goaf and the low resistivity anomaly in the water-bearing goaf. Su Chao[5-7] used static correction and forward modeling to verify the controlled source audio magnetotelluric method.

Zhong et al. [8] used ground and underground transient electromagnetic methods to jointly detect coal mine water-rich areas. Wang Shidan[9] summarized the method selection of goaf detection and the combination of comprehensive geophysical methods under different conditions. Fu Tianguang[10] proposed to use shallow two-dimensional seismic method and transient electromagnetic method to comprehensively detect coal mine goaf. Su et al[11] . used TEM and CSAMT to detect the water accumulation area in shallow goaf.

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This exploration is mainly to detect the goaf and water-rich layer of No. 3 coal seam. The burial depth of No. 3 coal seam is 600m~900m, mainly based on transient electromagnetic method exploration. For the shallow Quaternary area, direct current sounding is used for supplementary exploration. A small amount of long-distance electrical sounding is laid in typical areas such as boreholes and collapse columns to guide transient electromagnetic method exploration.

2. Regional geology

Lu'an mining area is located in the west of the middle section of Taihang Mountain and the west of Changzhi Basin. The exploration area is a loess hilly landform, the surface is covered by the quaternary system, and there are sporadic bedrock outcrops at the central cliff. The terrain of the exploration area fluctuates greatly. The highest point is in the southwest, with an elevation of +1103. 3m. The lowest point is located in Yanggou in the northeast, with a elevation of +913. 3m, and the maximum height difference is about 190m(fig.1).

2.1 Strata

Most of the exploration area is covered by loess, and the Upper Permian Shiqianfeng Formation and Upper Shihezi Formation are sporadically exposed. Now the strata in this area from old to new are described as follows:

(1)Middle Ordovician Shangmajiagou Formation(O_2s), lithology is limestone, dolomite limestone, marl.

(2)Carboniferous Benxi Formation(C_2b), 3. 65~ 27. 28m thick, composed of mudstone and limestone.

(3)Upper Carboniferous Taiyuan Formation(C_3t), 15. 30~34. 72m thick. The lithology is medium-fine grained sandstone. 15-3# is a mineable coal seam located in this section, with an average thickness of 1. 34m. The roof of coal seam is mudstone, sandy mudstone, siltstone and fine sand.

The second member(C_3t_2):The lithology is mainly limestone (K2, K3, K4), with mudstone and medium-fine sandstone. The main coal seam (11#, 12-1#, 12-2#, 13#).

The third section(C_3t_3):the lithology is mainly mudstone, sandy mudstone, medium-fine grained sandstone. It is composed of black coal seams, partially intercalated with thin layer of marl.

(4)Lower Permian Shanxi Formation(P_1s)

Thickness 46. 46~69. 36m, The main coal-bearing strata. Lithology-fine grained sandstone, siltstone, sandy mudstone mudstone, carbonaceous mudstone. The main mining 3# coal seam is located in this layer, with an average thickness of 5. 54 m. The buried depth is about 630~900m. The roof is mainly mudstone and sandy mudstone, locally siltstone or medium-fine grained sandstone. The floor is mainly mudstone and sandy mudstone, and locally fine-grained sandstone or siltstone.

(5)Lower Permian Lower Shihezi Formation (P_1x)

The thickness is 56. 02~80. 05m. The lithology is medium-fine grained sandstone, siltstone, sandy mudstone, mudstone, etc.

(6)Upper Permian Upper Shihezi Formation (P_2s)

The thickness is 402. 64~534. 30m. According to the characteristics of lithologic combination, it is divided into three sections:upper, middle and lower. Upper segment (P_2s_3): thickness 201. 91~265. 08m. Lithological mudstone and sandy mudstone are the main types, with medium-fine sandstone.

Middle segment(P_2s_2):The thickness of this segment is 91. 84~153. 95m. The lithology is mainly coarse-medium grained sandstone, with mudstone and sandy mudstone.

The lower segment (P_2s_1):133. 89~232. 48m thick. The lithology is mainly mudstone, sandy mudstone and siltstone.

2.2 Main aquifers

The aquifer in the minefield can be divided into four aquifers (groups) from new to old. It is mainly composed of Quaternary pore phreatic aquifer, Permian sandstone fissure water-bearing rock group,

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Upper Carboniferous thin limestone karst fissure water-bearing rock group and Middle Ordovician limestone karst fissure water-bearing rock group. The above Quaternary pore phreatic aquifer is rich in water, and the sandstone fissure phreatic water and limestone karst fissure water-bearing rock group are rich in water.

2.3 Geophysical characteristics

Shallow electrical conditions, complex terrain conditions and vegetation conditions have caused some difficulties in the layout of field construction wireframes. The workload of terrain correction is increased in data processing. The shallow part of the area is covered by the Quaternary and weathering crust, and the grounding conditions are relatively good.

In the middle and deep electrical conditions, the detection area is mainly 3 coal seam goaf, and the thickness of coal seam is about 5. 5m. The coal seam is not mined, and each stratum has the characteristics of layered distribution, and the conductivity is relatively uniform in the horizontal direction. When the coal seam is mined, there is a significant electrical difference between the rock layer and the surrounding rock. After the goaf area is rich in water, the whole is low resistance anomaly, and the groundwater is not filled, it is high resistance anomaly. It is also significantly different from the resistivity of coal measure strata, so it has good geological conditions for mid-deep transient electromagnetic exploration.

3. Geophysical method principle

3.1 Transient electromagnetic method

The transient electromagnetic method (TEM) is a method that uses an ungrounded loop or a grounded electrode to send a pulsed primary electromagnetic field to the ground, and uses a coil or a grounded electrode to observe the spatial and temporal distribution of the secondary electromagnetic field generated by the underground eddy current induced by the pulsed electromagnetic field. By analyzing the time and space characteristics of the secondary vortex electromagnetic field, the geological problems such as goaf detection and water-rich area division are solved.

TEM is a pure secondary field measurement. Therefore, compared with the frequency domain electromagnetic method, it has the advantages of sensitive response to low-resistance geological bodies, high vertical and horizontal resolution, large exploration depth, not affected by high-resistance overburden on the surface, and high work efficiency.

For the central loop device, Bai Denghai et al[12] derived a calculation method suitable for the whole period.

$$\rho = \frac{L^2\mu}{4t} \times \frac{1}{k^2} \tag{1}$$

$$k = \frac{L}{2}\sqrt{\frac{\mu}{\rho t}} \tag{2}$$

where L is the radius of the emission frame, is the permeability of the uniform half-space (approximately $4\pi\times10^{-7}$H/m), and t is the time. The value time of t is to start timing after shutdown.

The detection depth of transient electromagnetic method can be approximated as[13,14]:

$$h = g\sqrt{\rho t} \tag{3}$$

h is the detection depth, **ρ** is the apparent resistivity, **t** is the observation time, g is the empirical coefficient, and the value of g is related to the formation parameters.

The depth of the blind zone is mainly affected by the turn-off time t and the apparent resistivity ρ. The depth of the blind zone (D) can be calculated according to the following formula[14].

$$D_{min} = \sqrt{\rho t_{min}} \tag{4}$$

The increase of detection depth means the increase of observation time t. Due to instrument reasons, the first acquisition time cannot start from 0s, resulting in the detection depth not starting from the surface, and there is a blind area of detection and interpretation. Generally, the larger the detection depth is, the larger the wireframe radius L is, and the larger the blind area is.

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3.2 Direct current sounding

The DC resistivity sounding method is to supply pulse current to the underground through two power supply electrodes, forming a stable artificial electric field in the underground half space. With the gradual increase of the distance between the power supply electrodes, the penetration depth of the artificial electric field also increases. The measuring electrode is used to detect the electrical changes at different depths to understand the spatial distribution of the target layer. Through the analysis and interpretation of the observation results of each measuring point along the measuring line, the buried depth and electrical changes of the target layer are further understood.

3.3 Test and parameter selection

The depth of the target layer in this exploration area is about 500~900m. The wireframe tests of 720m×720m and 840m×840m were carried out. 6. 25Hz, 2. 5Hz emission frequency test; 15A, 20A current test; The number of stacks was 128 times, 256 times, 512 times. Considering the constraints of data acquisition quality, efficiency and detection depth, the final construction parameters are selected as follows: launch frame 720m×720m, launch frequency 6.

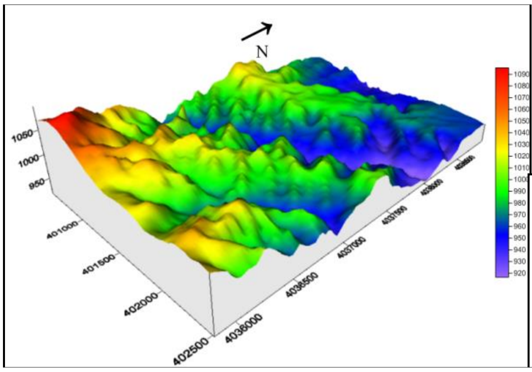

Figure 1: Three-dimensional sketch of terrain

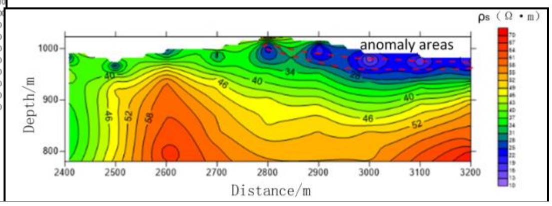

Figure 2: Pseudo section diagram of apparent resistivity of L1160 line of electric sounding

4. Data interpretation

Fig 2 is the apparent resistivity pseudo-section diagram of L1160 line pile number 2400 m~3200 m electrical sounding. The horizontal distance is 2900m~3200m, the elevation is 950m~980m, and the apparent resistivity is less than 28Ω·m. The surface of this area is covered by Quaternary, and the thickness of Quaternary is about 20m~30m. The elevation is 920m~950m, and the apparent resistivity is about 30Ω·m~50Ω·m. In this depth range, the apparent resistivity is relatively high, which is speculated to be a weathered layer and relatively high resistivity anomaly. The elevation is 765m~920m, and the apparent resistivity is greater than 50Ω·m, which is the electrical reflection of bedrock.

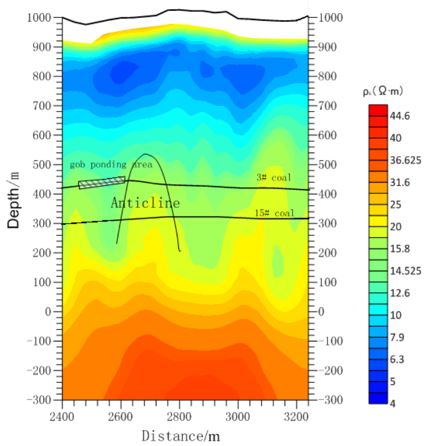

Figure 3: Pseudo section diagram of TEM L1160 line inversion

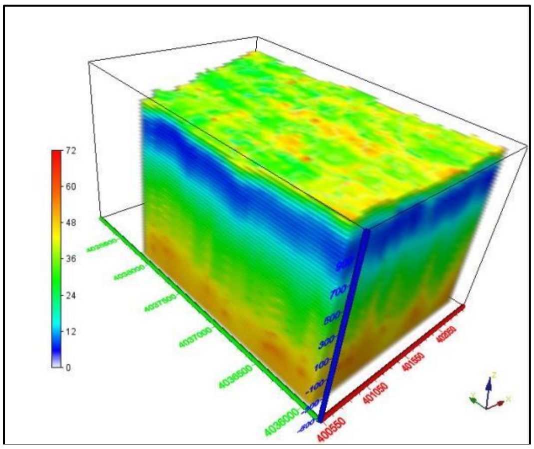

Figure 4: Three-dimensional mode after whitening

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The black solid line in Fig.3 represents 3 coal and 15 coal, and the dotted line F represents 3 coal roof K8, 3 coal floor K7 and Ordovician limestone roof interface, respectively. At an elevation of 950 m~surface, it belongs to the detection blind area. The elevation is 520m~950m, which is mudstone, sandy mudstone and medium-fine grained sandstone of the Upper Shihezi Formation of the Upper Permian System. Among them, 820m~950m is the upper part of the Upper Shihezi Formation (P2s3), the apparent resistivity is 10Ω·m~20Ω·m, and the lithology is mainly mudstone and sandy mudstone. 700m~820m, and the apparent resistivity is 5Ω·m~10Ω·m, which corresponds to the lithology and physical properties of fine-grained sandstone in the middle section of Shangshihezi. 520m~700m, and the apparent resistivity is 10Ω·m~13Ω·m, which is speculated to be the lower section (P2s1). The lithology is mudstone, sandy mudstone and siltstone. 450 m~520 m, the apparent resistivity is 13 Ω·m~15 Ω·m, which is the lower stone box medium-fine grained sandstone, siltstone, etc., including K8 sandstone 3 coal roof sandstone. 410m~450m, and the apparent resistivity is 13Ω·m~17Ω·m, which is the electrical reaction of medium-fine sandstone and siltstone in Shanxi. The elevation is 200 m, the apparent resistivity is greater than 20 Ω·m, and the lithology is Ordovician limestone.

The horizontal distance is 2500 m~2600 m, and the elevation is 450 ~ 500 m. The horizontal layered characteristics of the apparent resistivity contour are seriously damaged, and it is speculated that the area is a low-resistance anomaly caused by goaf.

The horizontal distance is 2600m~2800m, and the apparent resistivity contour shows an inverted ' U ' anomaly. Combined with geological data, the anomaly is caused by anticline.

5. Three-dimensional visualization of abnormal area

This three-dimensional model is generated by Voxler software, a three-dimensional software published by Golden software company. The software can generate scatter data, vector diagram, contour map, three-dimensional stereogram and other graphics to achieve three-dimensional visualization. The model can be viewed at any angle. The model cuts the slice data at any angle and generates the spatial contour surface. According to the abnormal value, the spatial isosurface is analyzed.

Voxler software mapping requires four columns of data, which are three-dimensional coordinate points (X, Y, Z) and measured resistivity ρ. All data points in this work area are summarized to generate a file containing four columns of data. The data is gridded and imported into Voxler. The boundary of the exploration area is used as a whitening file to constrain the grid data and whiten the data outside the area.

The volume rendering of the whitened grid file is performed, and the attributes (color scale) are set to generate a three-dimensional resistivity volume rendering stereogram of the region [15-16].

5.1 VolRender

Using the VolRender module of the software, the terrain data is used to whiten the model, the outer part of the area is removed, only the required three-dimensional map is retained, and the space is filled with different colors. Different colors correspond to different apparent resistivity, as shown in Fig. 4.

5.2 Oblique Image

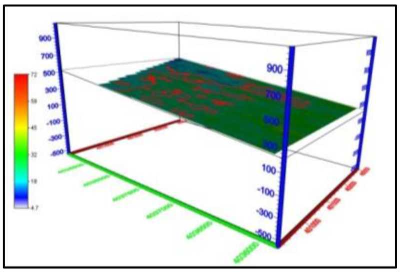

Figure 5: Horizontal section of K8 sandstone

In fig.5 the water-rich layer of the direct roof of No. 3 coal seam is K8 sandstone. According to the buried depth of K8 sandstone, the horizontal apparent resistivity slice of K8 sandstone is removed and filled with color by using the VolRender module of the software. According to the profile, the abnormal

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area is circled according to the resistivity of 15 Ω·m (the resistivity of K8 sandstone in line 1160).

6. Conclusion

(1) In this work, electrical sounding is used to supplement the exploration of TEM blind area, which effectively solves the problem of the exploration blind area caused by the turn-off time of the transient instrument itself.

(2) Transient electromagnetic method and direct current sounding can effectively detect the electrical distribution characteristics of coal mine strata, and have a good effect on evaluating the abnormal area of coal mine goaf and water-rich area.

(3) Using Voxler software to convert two-dimensional results into three-dimensional interpretation, we can more intuitively understand the spatial distribution characteristics of abnormal areas, and clearly show the abnormal range from multiple angles. It has a guiding role for later drilling layout and coal mine production.

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