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Exploration Prospect Evaluation of Geothermal Resources in Shangqiu Protuberance in Southern North China Basin

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ABSTRACT

In this paper the magnetotelluric (MT) method was applied to study the deep stratigraphic structure in eastern region and concealed faults of Taikang Uplift. Four MT profiles had been deployed which provided 97 sounding points, the two-dimensional skewness and structural trend of the MT data used to be calculated and analyzed. The reliable underground geoelectric models were obtained by conducting two-dimensional inversion method of NLCG on the data in TM and TE mode with joint inversion. The results prove that the electrical structure of Shangqiu protuberance has typical stratification characteristics longitudinally, it can be divided into three layers from top to bottom: low resistivity layer, relatively high resistivity layer and high resistance layer. Geological map of basement rock was delineated according to the electrical structure model and integrated study of regional gravity, aero-magnetic, earthquake and geologic information. Meanwhile, two blocks of geothermal resources prospecting area were delineated on the basis of preferably correlation between abnormal high resistance caused by deep basement protuberance and high value area of regional geothermal field.

1. INTRODUCTION

The magnetotelluric sounding method is a very effective geophysical exploration method for geothermal field exploration, and its exploration effect has been confirmed by the results of various geothermal field surveys .Flovenz and Georgsson (1976). The principle is mainly based on the analysis of resistivity anomalies to speculate underground formation depth and position of fault structure, occurrence and direction so as to explore the deep thermal storage structure. In fact, the conductivity of the rock is largely determined by the pores in the rock or the aqueous solution in the fracture. Therefore, the low resistivity becomes an indicator of the existence of the subsurface fluid, resulting in the resistivity of the thermal storage structure area being lower than that of the surrounding rock area, anomaly features of low resistivity is formed in that area. It is possible to directly predict the location of the thermal storage structure in the geothermal field according to the anomaly of the resistivity.

The application of the MT method in geothermal investigation is mainly to find out the deep geological features and the distribution of underground fluids that is conducive to delineate geothermal anomaly prospecting area. The geothermal MT exploration in Tianjin began in 2001, which has completed the geothermal investigations of Wanjia Wharf, Ninghe-Panzhuang, Zhouliangzhuang, Southwestern Tianjin, Baodi district and Binhai new-region, some results have been obtained by using the residual resistivity equivalent coil. Xuemei Li and Ruiping Nie (2010). In the geothermal investigation of Yinchuan Basin, the vertical resistivity of 20Ω·m is defined as the thermal reservoir range by MT method combined with geothermal gradient data. It is inferred that the thermal reservoir area is a low resistivity and high conductivity area. Qi Wang and Zhipeng Zhao (2016). In process of geothermal investigation in Kaifeng depression, the formation was electrically stratified by MT method. The main anomaly area was delineated according to the contour of the high-resistance substrate resistivity less than 45 Ω·m. Jianliang Zhao and Tianzhen Chen (2010).

Based on the conductivity structure model obtained from the four geoelectric survey sections in the eastern section of Taikang uplift, combined with the regional gravity, aeromagnetic, seismic and regional geological data, the electrical structure characteristics and main fault structure characteristics in the deep part of Shangqiu uplift are discussed. Meanwhile, geothermal resources prospecting area were delineated on the basis of preferably correlation between abnormal high resistance caused by deep basement protuberance and high value area of regional geothermal field. It is expected to provide new evidence and information for subsequent evaluation and target optimization of geothermal resources.

2. REGIONAL GEOLOGICAL BACKGROUND

Taikang uplift, located in the central and eastern part of Henan province, which is a secondary tectonic unit in the northern part of southern North China basin. Hanlin Xu and Zongju Zhao (2003). It is adjacent to the Songji uplift in the west and the Huaibei uplift in the east, sandwiched between the Kaifeng depression and the Zhoukou depression(Figure 1). The overall tectonic pattern is "two depressions with one uplift". And its secondary tectonic units can be further divided into Yanling uplift, brick-building depression, Tongxu uplift, Xingkou depression and Shangqiu uplift (Figure 1a). Ziming Sun (1996). The uplift was distributed in the NWW direction. In the early stage, it was mainly affected by the intense south-north compression of the Qinling-Dabei orogenic belt in the Indosinian period, and formed the NWW-trending fold-thrust nappe structure roughly in line with the main trend. In the later stage, it was superimposed on the NE-NNE direction structure by the influence of the Tanlu strike-slip fault. Hanlin Xu and Zongju Zhao (2004).

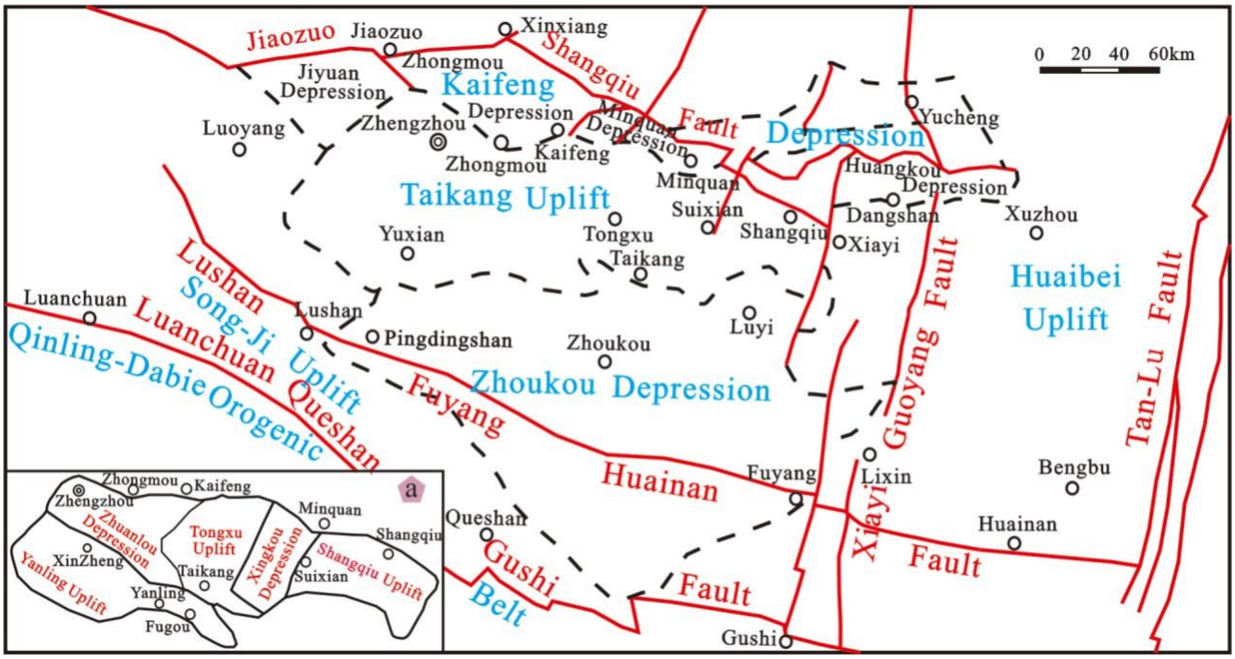

Figure 1: Present-day structural framework of the Southern North China basin

Shangqiu protuberance is located in the eastern section of Taikang uplift. In the north, Jiaozuo-Shangqiu fault is bounded by Huangkou depression, while in the west, Suixian fault is bounded by Xingkou depression. It is located along the line from Suixian county to Shangqiu city of Henan province with an area of about 2.5×10^3km^2. The surface of the area is covered by the Quaternary system, and the Neogene, Carboniferous-Permian, Ordovician, Cambrian and Archean Eonothem crystalline basements are developed under the overburden. Archean Eonothem is a set of ancient metamorphic rock. It is the main ore-bearing strata of regional metamorphic rock-type magnetite. The Cambrian-Ordovician is an ancient buried mountain area under the caprock. It is generally subjected to weathering and erosion, and the Carboniferous-Permian is the main coal-bearing strata in the area. The previous studies degree on Shangqiu protuberance are relatively high, but most of them concentrated on exploration and development of petroleum, iron ore, coal, etc. Wenyong Li and Bin Xia (2004). Minghui Yang and Siming Wang (2009). Guoqing Liu and Tiezhuang Zhang (2013). Wenqian Li (2014). The special geothermal resources survey lacks the necessary research work, which requires further understanding and evaluation of the potential of the regional thermal resources.

3. DIMENSIONALITY ANALYSIS AND STRUCTURAL TREND ANALYSIS

3.1 Data Acquisition and Processing

The distribution of magnetotelluric sounding points in the study area is shown in Figure 2. Four magnetotelluric sounding sections (numbered L1-L4) are arranged from west to east. The four sections include 97 wide-band magnetotelluric sounding points with a distance of about 1km. Among them, L1 survey line is distributed in EW direction, and 25 depth sounding points are designed. The other three survey lines are basically perpendicular to the arrangement of Jiaozuo-Shangqiu fault, there are 27, 27 and 18 depth sounding points are designed respectively. The field data collection was completed within 8-9 months in 2017. Two sets of mtu-5 broadband magnetotelluric instrument produced by phoenix company of Canada were used for the acquisition instrument, which acquisition time was above 3h.

Interference sources such as high-voltage power lines, highways, railways and mobile communication facilities are very complex and near field interference is serious. Through the comparison and analysis of measurement experiments and results, it is determined that in process of data collection, the collection time of measuring points on L1 and L3 is carried out synchronously treated as distant references to each other, the same to L2 and L4 with removing local noise by correlation analysis. After data processing of measuring points by the remote reference method, the apparent resistivity, rate and phase curves of most measuring points are generally of good quality in the range greater than 0.1HZ. Figure 3 shows the apparent resistivity and phase contrast curves before and after the remote reference processing of the L3-6 measuring point in the work area. It can be seen from the figure that the curve shape is relatively stable at frequencies above 10 Hz, and the apparent resistivity is about 10 Ω•m. From 10Ω•m, the apparent resistivity curve rises or falls with an asymptotic trend of around 45°, which is typical near-source interference. The overall shape change of the curve after far reference processing is obviously reasonable compared with the curve before the far reference processing, especially for the jump problem caused by magnetic field interference in the middle and low frequency bands of the data, and even the near field effect can be improved to some extent.

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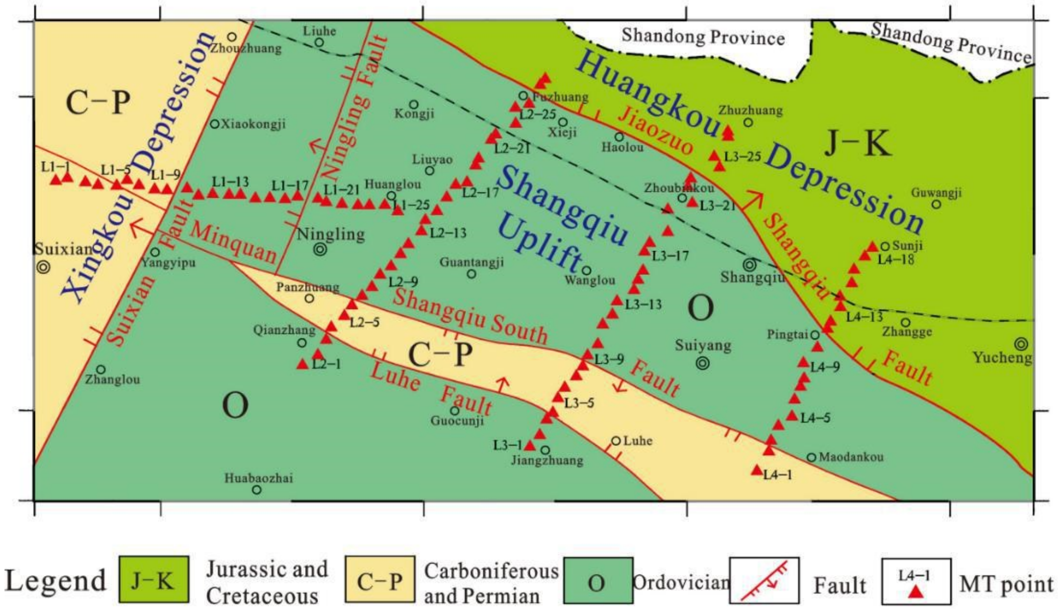

Figure 2: MT stations along the profile from Suixian to Shangqiu

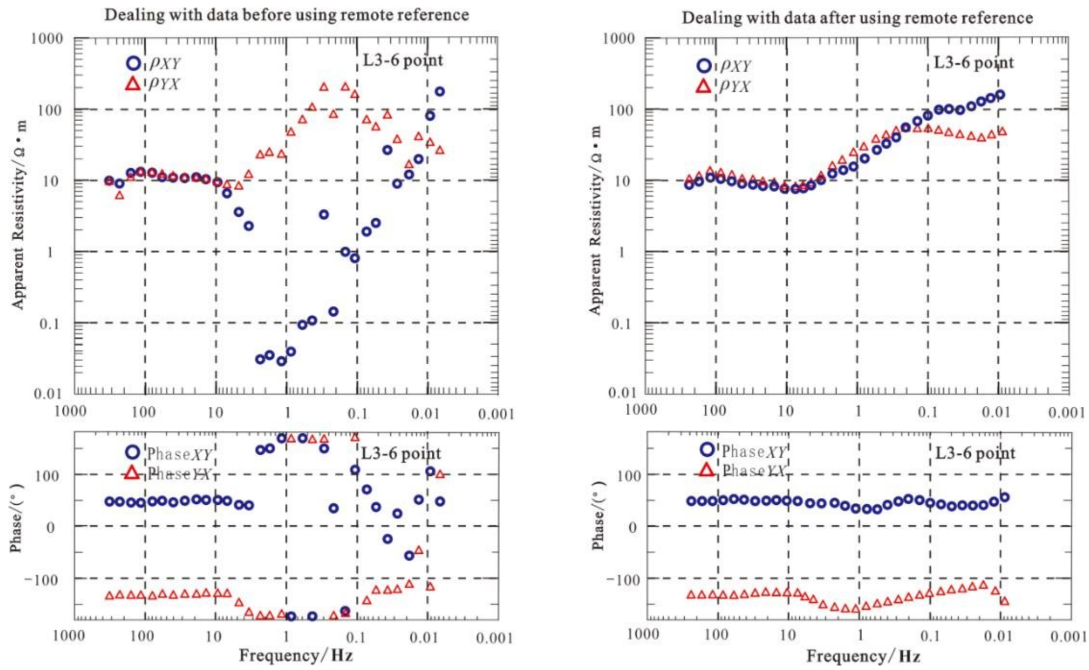

Figure 3: Result comparison of the application of remote reference technique（with the example of site L3-6）

3.2 Dimensional Analysis and Structural Trend Analysis

After obtaining the frequency-dependent impedance tensor information, in order to eliminate the influence of local distortion in the geomagnetic response, it is necessary to obtain parameters of regional structural impedance and strike, thereby further confirming suitable data processing and inversion methods. JianXin Liu and Xiaozhong Tong (2012). At present, there are many methods for decomposing impedance tensors, including Swift decomposition, Swift (1967), Bahr decomposition, Bahr (1991) phase tensor decomposition , Caldwell and Bibby (2004), Moorkamp (2007), and G-B decomposition. Swift (1967). The Swift decomposition and Bahr decomposition method mainly determine whether the magnetotelluric sounding data satisfies the parameters of the two-dimensional requirement. The phase tensor decomposition and G-B decomposition are mainly used to analyze the electrical principal axis direction of the regional structure.

In this paper, the dimensionality analysis of all magnetotelluric data is carried out by Swift decomposition and Bahr decomposition method. The two-dimensional deviation is an important parameter reflecting the dimension of the electrical structure of the underground medium. In general, when the value of the two-dimensional deviation is less than 0.3, it can be approximated as a two-dimensional case. Since the study area includes 4 magnetotelluric sounding profiles, this paper only selects the L2 line for dimensionality analysis. Figure 4 is a two-dimensional deviation of the L2 section. It can be seen from the figure that the two-dimensional deviation of most of the measuring points along the line is less than 0.3, indicating that the electrical structure of underground medium generally satisfies two-dimensional hypothesis that can be used in two-dimensional inversion interpretation.

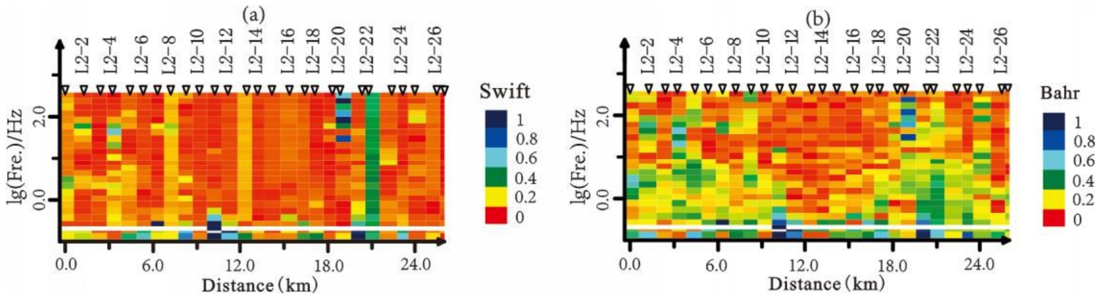

Figure 4: Analysis result of L2 line Swift(a) and Bahr(b) skewness along the profile

The G-B decomposition method is currently the most widely used tensor decomposition method, JianXin Liu and Xiaozhong Tong (2012), which can separate the regional structural impedance and the local electric field distortion effect from the observed impedance tensor, thereby restoring the undistorted region two-dimensional impedance tensor. In this paper, the structural trend analysis of the L1-L4 section is carried out by the G-B decomposition method, and the statistical results of each section are shown in the form of a rose diagram in Figure 5. It can be seen from the figure that the electrical principal axes in the L1 and L2 cross-sectional areas are 120° and 30°, and the electrical main axes in the L3 and L4 cross-sectional areas are about 135° and 45°. According to the regional geological and structural data, the main tectonic trend of the L1 and L2 sections is about SE120°, and the main tectonic trend of the L3 and L4 sections is about SE135°. Therefore, all the geomagnetic data of each section are rotated to the structural direction of each region (i.e., the L1 and L2 sections are rotated to SE120°, the L3 and L4 sections are rotated to SE135°), and then two-dimensional inversion is performed.

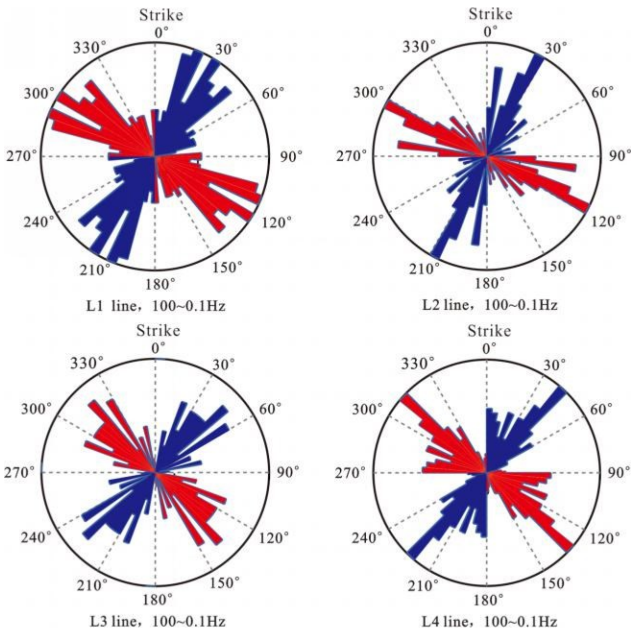

Figure 5: Rose diagram showing analysis result of L1-L4 lines electrical principal axes

4. MT DATA INVERSION AND ANALYSES

According to the electrical structure obtained from inversion, four two-dimensional inversion models of electrical structure are drawn in combination with geological conditions (Figure 6a, b, c, d). The abscissa axis on the graph represents the section line. Longitudinal coordinates on the graph represent inversion depth. The isoline 4000m of filling color on the cross section represents the logarithmic value commonly used in shallow medium resistivity. The red represents high resistivity and the green represents low resistance. Transition color represents intermediate resistivity.

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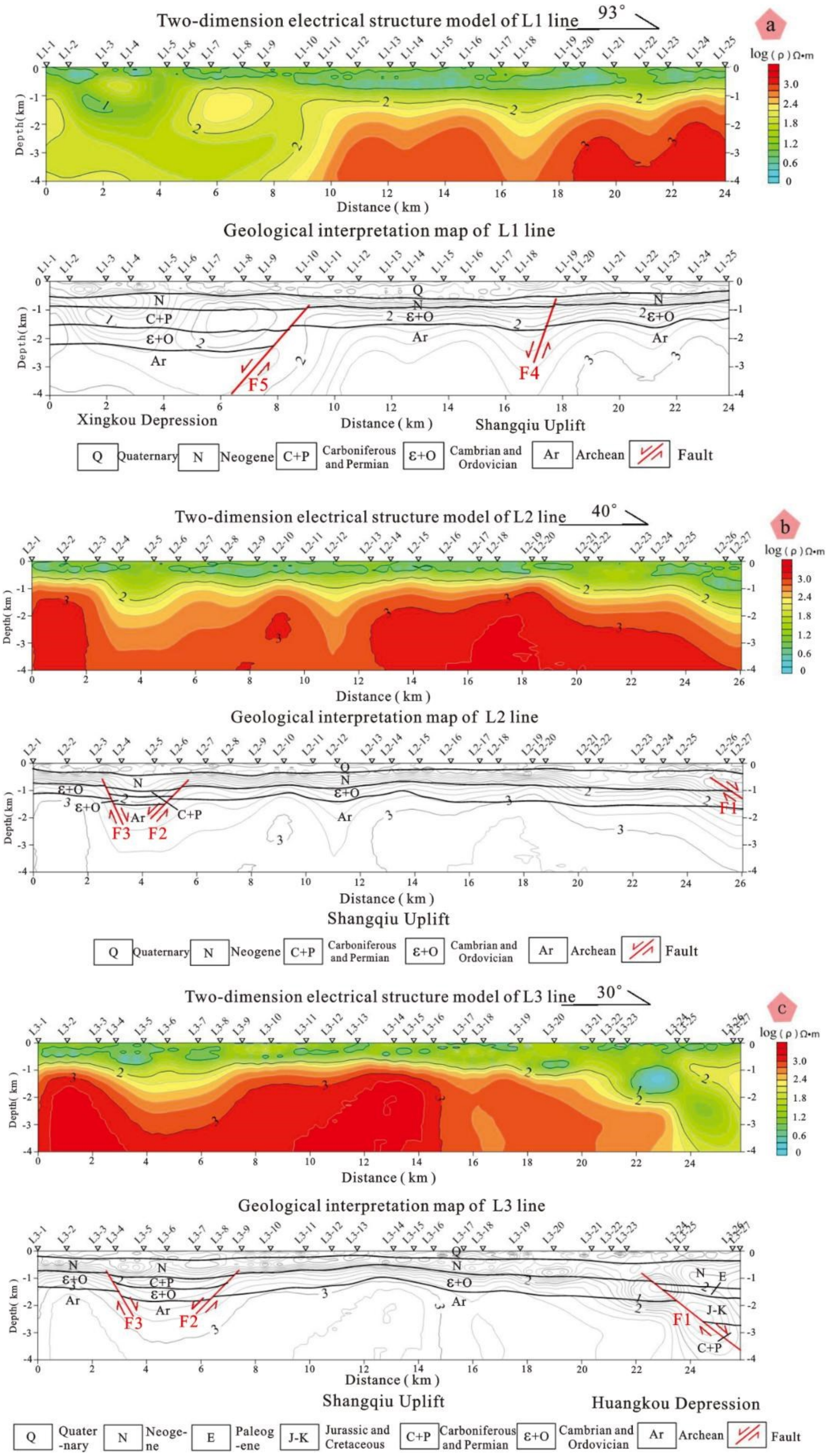

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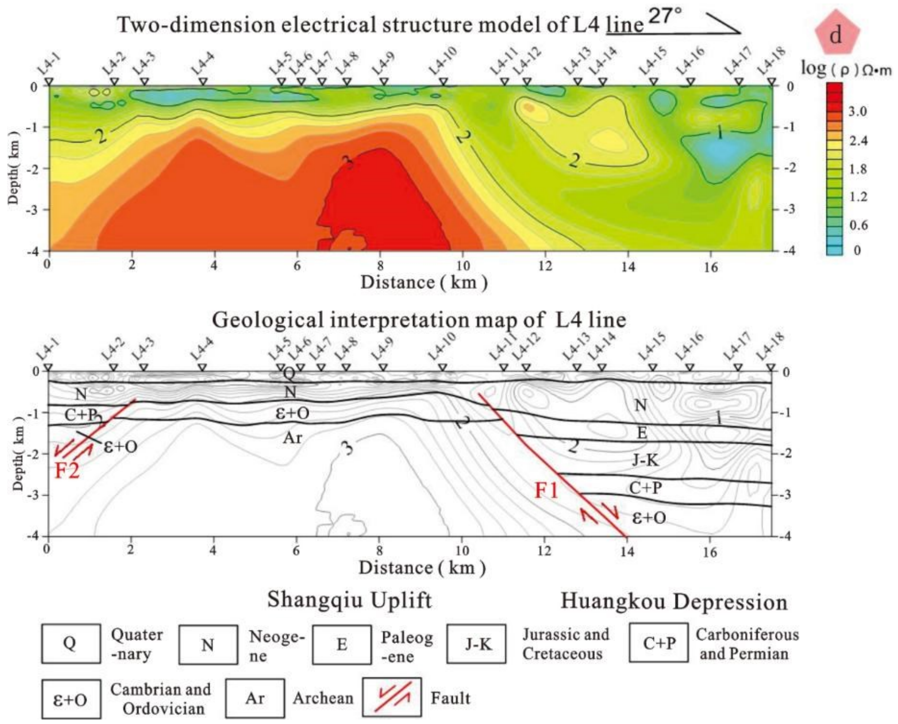


Figure 6: Electrical structure model and geological map of MT inversion in the Shangqiu Uplift（L1-L4 lines）

The electrical structure model of Shangqiu protuberance can be divided into 3 layers vertically: the first electrical layer is a low resistivity layer. Its resistivity is less than 30Ω·m. And These four two-dimensional inversion profiles can be traced continuously; the second layer is medium and high resistivity, which ranges from 30Ω·m to 100Ω·m. Because of the influence of fault structure on the whole thickness of point 3-4 in section L1 and point 5-7 in section L3, there is little difference in the thickness of other areas. The third electrical layer is high resistivity layer, which is more than 100Ω·m and the top surface fluctuates greatly. It is obvious from the figure that the eastern uplift of Shangqiu protuberance is more undulating than the western uplift due to the influence of Tanlu strike-slip fault.

According to the two-dimensional inversion results of L2, L3 and L4 (Figure 6b, c, d), it is found that near points 25-26, 23-24 and 10-11 in L2, L3 and L4 sections, there exists a group of electrical gradient bands F1 inclining northward and extending more than 4000m in the profile, and the resistivity characteristics on both sides of F1 are obviously different. By comparing with regional geological data, it is found that the fault zone is Jiaozuo-Shangqiu fault. The F1 fault starts from Xinfuzhuang in the west, and passes east to Haolou, Shangqiu north and Platform town. The trend of F1 fault is NWW. The northwest end of the fault has a gentle inclination angle. The inclination angle is about 35°.The southeast end inclination angle is steep and the inclination angle is up to 50°.

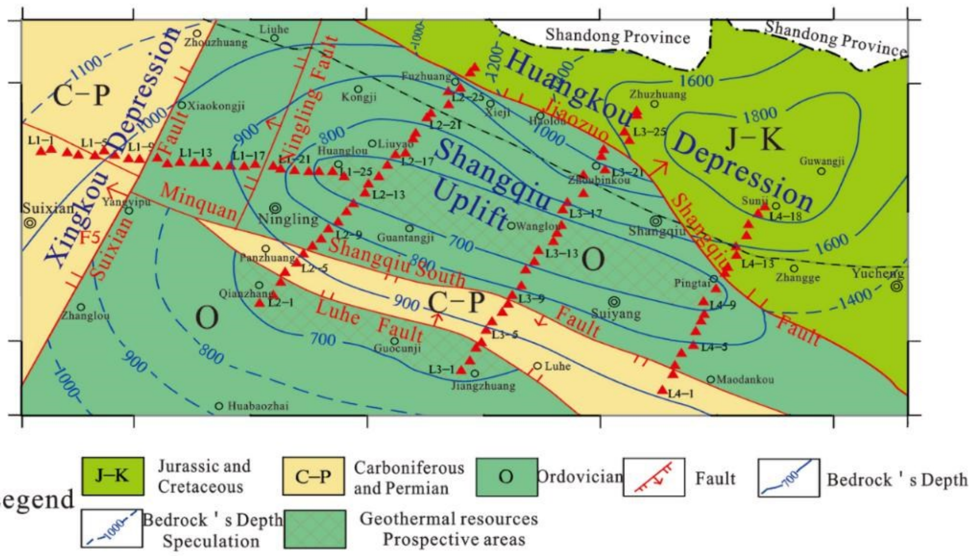
Based on the inversion results of profiles L2, L3, L4, it can be seen that there is a downward depression along the resistivity isoline near points 3-6 on the profile L2, points 3-9 on the profile L3, and point 3 on the profile L4(The latter is called Panzhuang-Luhe sub-depression, which belongs to the secondary tectonic unit of Shangqiu protuberance.). According to the results of coal exploration data in eastern Henan, the basement rocks of the depression area are Carboniferous and Permian coal-bearing strata with a slight dip to the south. The dip angle of the strata is generally between 6 and 10 degrees. Two sets of transverse electrical gradient areas are accompanied by the south and north sides of the depression belt, respectively (F2 and F3). According to the results of geoelectric sounding in the study area, combined with regional geological and seismic data, it can be seen that the F2 fault is Minquan-Shangqiu South fault and the F3 fault is Luhe fault. The trend of F3 fault is NW. Its inclination is NE. The dip angle is 30-65 degrees and fault distance are more than 300 meters. The trend of F2 fault is NW. Its inclination is SW. The dip angle is 35-65 degrees and fault distance are more than 600 meters.

It can be seen from the electrical structure model of L1 profile shown in Fig.6a that there are a set of westward inclined electrical gradient areas (F4 and F5) in the section near the middle of point 9 and 10 and point 18 on the north side of Ningling county. Influenced by the fault structure, influenced by the faulted structure, it is obvious that the bedrock buried depth is from deep to shallow in the whole section from west to east. According to the regional geological data, F4 fault is Ningling fault and F5 fault is Suixian fault. The Suixian fault is a reflection of the Juye fault on Shangqiu protuberance, where is between the two major structural units of the Xingkou sag and the Shangqiu sag in the eastern segment of the Taikang uplift. According to the electrical structure characteristics of L1 profile, the two tectonic units obviously have different electrical structures, and the fault extends downward to 4000m depth.

5. THE EVALUATION OF GEOTHERMAL PROSPECT

Shangqiu protuberance experienced two subsidences and two uplifting activities in the Early Paleozoic. During the subsidence period, carbonate strata were formed, and the uplifting period caused strong erosion of carbonate strata. Middle Carboniferous to Early Perm, the seawater invaded from north to south, and a set of sea-land interaction strata containing coal. From the end of the Triassic to the Paleogene, the Shangqiu protuberance has been in a large uplifting state, the Upper Paleozoic has been completely eroded, and the Lower Paleozoic was also severely denuded. Ziming Sun (1996). The Ordovician buried hills in the study area experienced weathering and erosion for more than 410 Ma before being covered by the Neogene. In general, the longer the sedimentary discontinuity, the stronger the weathering and erosion, and the more the pores, seams and holes of the carbonate rock layer develop. Moxiang Chen (1988). Therefore, the research area has the potential to form a good thermal reservoir.

Shangqiu protuberance is a secondary structural of Taikang Uplift. The bedrock has the characteristics of shallow depth and the geothermal gradient is significantly higher than that of the depression area. According to the results of the MT detection in the study area, combined with regional geology, geophysics and borehole exploration data, the geological map of the Shangqiu bedrock was drawn with the resistivity of 100 Ω·m (Figure 7). From the figure, the shape of the bedrock and the direction of the fault can be clearly seen. The depth of the Huanglou-Pingtai anticline and the Qianzhang-Jiangzhuang anticline are only 700m, and the underlying strata of the Neogene are Ordovician. The two-anticline direction are NWW. It is reflected that the basement structure is greatly affected by the north-south extrusion of the Qinling-Dabie orogenic belt. From the local structural form, the anticline has a high temperature and a large gradient, while the two wings have a low temperature and a small gradient. It can be seen from Figure 8 that the 300m deep and relatively high geothermal anomaly (32°C) in the Shangqiu protuberance is in the NWW direction, which is the direction of the Huanglou-Pingtai buried hill uplift (anticline) and the Qianzhang-Jiangzhuang buried hill uplift (anticline). Generally consistent, it reflects the fact that the shallow depth of the bedrock has a large geothermal gradient. According to this correspondence, two geothermal anomalous were identified in the study area, which are the Huanglou-Pingtai geothermal anomaly and the Qianzhang-Jiangzhuang geothermal anomaly (Figure 7). By delineating the geothermal anomaly prospects, it will have important guiding significance for the subsequent exploration and development of geothermal resources in Shangqiu area.



F1: Jiaozuo-Shangqiu fault; F2: Minquan-Shangqiu south fault; F3: Luhe fault; F4: Ningling fault; F5: Suixian fault

Figure 7: Geological map of basement rock of Shangqiu Uplift

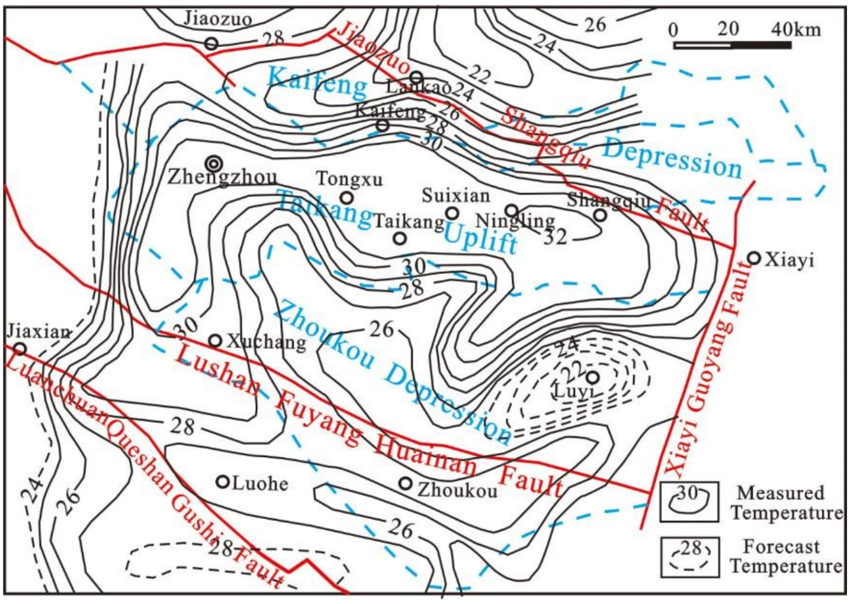


Figure 8: 300 metres isothermal diagram in Eastern region of Henan Province

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6. IN CONCLUSION

The electrical structural features of the Shangqiu protuberance have a horizontal block structure and vertical layering characteristics. From top to bottom, it is characterized by low resistance - medium high resistance - high resistance.

The electrical structure models on both sides of the fault are different. It is concluded that there are two large-scale faults in the area, which are Jiaozuo-Shangqiu fault (F1) and Suixian fault (F5). In addition, the Minquan-Shangqiu fault(F2), Luhe Fault (F3) and Ningling Fault (F4) are also developed inside the Shangqiu protuberance.

By the results of the MT detection, the geological map of the Shangqiu bedrock is constructed with the line of 100 Ω·m. At the same time, the high-resistance anomaly has a good correspondence with the high-value area of the regional geothermal field, and two blocks of geothermal anomalies prospecting area were delineated to promote subsequent geothermal exploration.

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