Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

The Application of Comprehensive Geophysical Prospecting Methods in Tangtou Geothermal Exploration, Shanxi province

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Keywords: geophysical prospecting, CSAMT, Tangtou hot spring

ABSTRACT

Tangtou hot spring is a typical manifestation in Hunyuan County, Shanxi Province. Tangtou area is located in the intersection part of Mount Heng uplift zone and Tanghe fault zone. The reservoir is structural fracture type. Comprehensive geophysical prospecting methods are applied in geothermal exploration to identify the geological condition (Yan, 2014). Based on geological, hydrogeological data, the methods of gravity, magnetic and CSAMT are implemented in this geothermal exploration. The research indicates that Tangtou area exists two faults, NW and NS direction, which control the distribution of hot spring. The paper discusses the prospect of geothermal resources exploration and provides the basis for further utilization.

1. INTRODUCTION

Shanxi Province is one of geothermal resources abundant area in China. It is closely related to the geological structure and water distribution of Shanxi Province (Hao, 2015). Hunyuan tangtou geothermal anomalous area is located in Tanghe river valley and first-grade terraces along the coast, east of Tangtou village. Tangtou spring is abundant, the temperature is about 63 ℃ and flows continuously. Far in 1400 years ago, the Northern Wei Dynasty had been built a palace for spa treatments. Currently, there is a lack of regional exploration and evaluation of geothermal resources. Blind developments have certain risk and will lead to the geothermal resources waste. In this paper, the regional fault is studied by means of geophysical methods, to identify the position, attitude, distribution. And it provides the basic data for the development of geothermal resources.

2. GEOLOGICAL SETTING

Datong area is situated in the north of North China platform, across two secondary tectonic units of Shanxi middle uplift and Yanshan subsidence zone (Shanxi Bureau of Geology and Mineral Resources, 1989). The exploration area is between Yanshan fault block and Wutai mountain fault fold belt. The thickness of Cenozoic is relatively thin, and some Archean metamorphic rocks are exposed to the surface. The quaternary strata are mainly alluvial-diluvial deposit, and the lithology is comprised of sand gravel, sand gravel, soil, clay. The underlying bedrock is Neoarchean metamorphic rock. The lithology consists of various gneiss, metamorphic granulite, granulite and amphibolite.

The fault is abundantly existent in the area, Tanghe fault and Heng mountain fault are mainly faults (Figure 1):

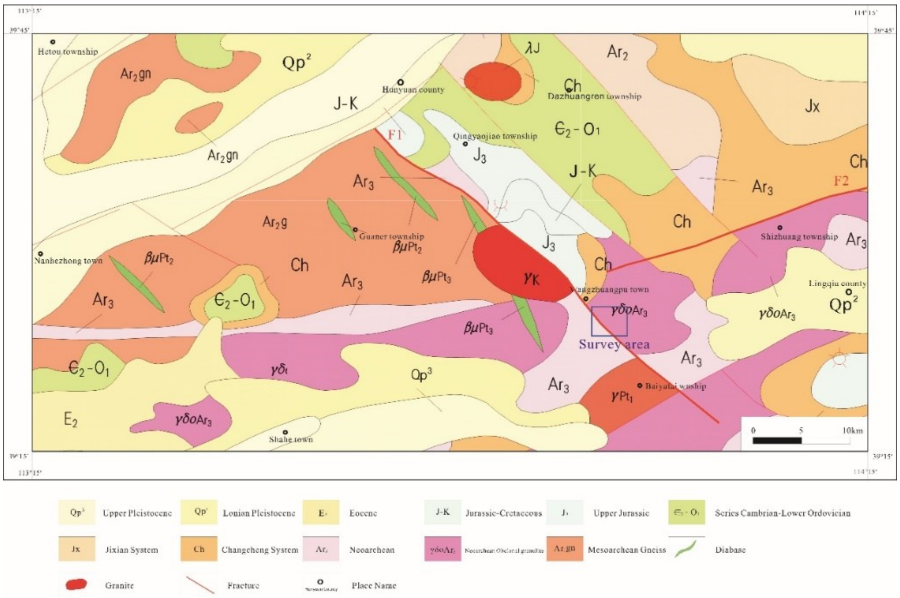

Figure 1: Regional geological map of exploration area

Tanghe fault trends NW, across the east section of Heng and Wutai mountains and presents a series of step normal faults and cut the south Heng mountain piedmont fault at the south of Wangzhuangbao. Northern section of Tanghe fault is located in the exploration area, and fracture zone is mainly distributed in the Tanghe river valley, with a length of about 3~6km. Tangtou hot spring lies in the Tanghe fault fracture zone.

Heng mountain fault is mainly south piedmont thrust fault and the direction is NEE trend from Xinzhou city to Wangjiabao. In the exploration area, the fault is EW trend, and transformed into normal fault by Cenozoic structure.

The depth of tangtou geothermal well is 63.31m. The geothermal reservoir is Quaternary strata with good permeability. The geothermal water is supplied directly by Tanghe river and Heng mountain fault zone and heated by deep thermal source.

3. GEOPHYSICAL EXPLORATION METHODS

Due to the exploration area located in a basin and covered by sediment, surface geology methods are not effective to find out hidden fault. Geophysical exploration has become an indispensable and important way to ascertain the fault (Deng, et al., 1989). The commonly geophysical methods include shallow seismic exploration, gravity exploration, magneticsurvey, controllable source audio magnetotelluric sounding (CSAMT), high density resistivity, and micromotion sounding. Different methods can be applied for different geological conditions. A single geophysical method restricted by external factors has multi solutions. Comprehensive geophysical methods have been widely applied to ascertain the characteristics of faults with different depths in recent years (wei and He, 2018). Therefore, this exploration adopts comprehensive geophysical methods.

Magnetic survey and gravity survey are selected for finding out the distribution characteristics of magnetic geological bodies, bedrock relief, and position of faults. Based on the preliminary work, CSAMT method is arranged to find out the attitude of stratum and characteristics of faults. The measured area is 9 km^2 and the basic network is 100 m×250 m. The layout of CSAMT is a total of 10km.

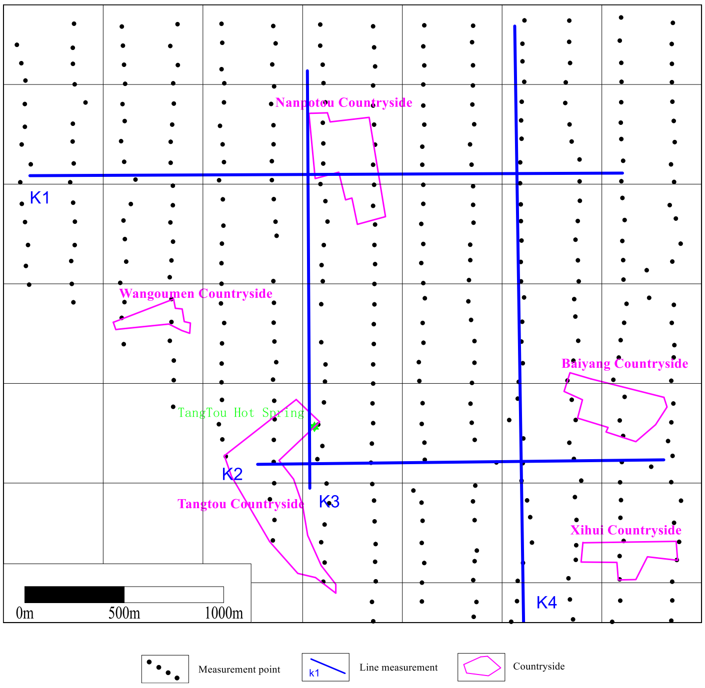

Figure 2: Layout of geophysical prospecting work

4. RESULTS

4.1 geophysical characteristics

The strata in the exploration and surrounding areas mainly include Quaternary, Archaeozoic and intrusive rocks. Therefore, the physical characteristics of strata in the above-mentioned are collected (Table 1). According to the collected data, there are some physical differences among strata of different ages which provide a good geophysical precondition for using gravity, magnetic, CSMAT in the exploration area and its surrounding areas to carry out preliminary exploration.

Table 1: Physical parameters of strata in different ages

Stratum	Physical parameters		
	Magnetic susceptibility （10^{-5}SI）	Bedrock resistivity （Ω.m）	Density (g/cm^3)
Quaternary	weak	low	2.12
Archaeozoic	medium -high	medium-high	2.81
Intrusive rocks	weak	high	2.34

4.2 Magnetic survey

Magnetic data can be used to study the burial depth of magmatic rocks which control geothermal resources and the spatial distribution of igneous rocks which control underground hot water resources (Liu, 1989). As shown in figure 4, the region's magnetic anomaly △ T value range is between -300 and 140 nT, and most of the region's magnetic anomaly value is lower than 0 nT. It indicates no magmatic intrusions in the exploration area. The magnetic measurement value of the south side is relatively low, and that of the north side is relatively high, ranging from 0 to 140 nT. The magnetic strata are mainly high magnetic archean gneiss. On the whole, the magnetic anomaly on the north side is higher than that on the south side, and it is inferred that the gneiss on the north side is relatively intact. There is an obvious low magnetic anomaly zone from tangtou hot spring to Yangshuwan village. According to the situation of tangtou hot spring, it is related to fracture zone.

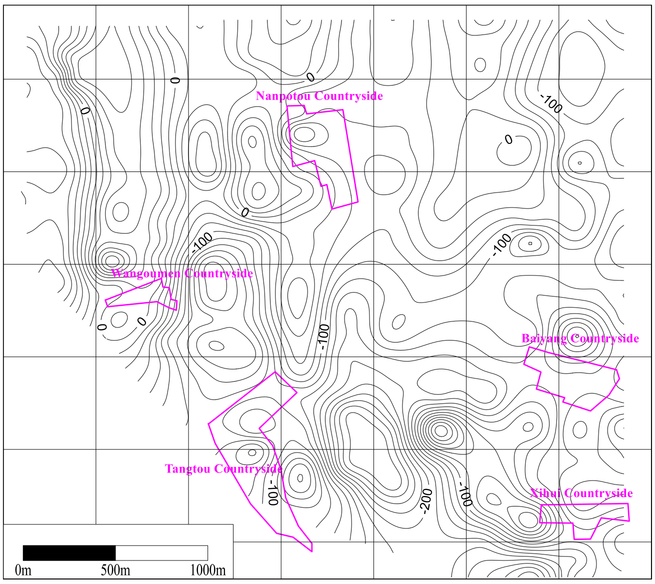

Figure 4: ΔZ magnetic anomaly contour map

4.3 Gravity exploration

Gravimetry is a conventional geophysical exploration method, which is highly efficient and free from electromagnetic interference, and has significant effects in responding to bedrock undulation and fracture occurrence (Wang, Xiong, and Pang, 1993). The variation range of bouguer gravity value in the exploration area is about 2mGal which is relatively stable (Figure 5), and the bouguer value on the north side is higher than that on the south side. It is inferred that the bedrock strata on the north side are relatively intact, and the buried depth is slightly shallower than that on the south side. There is a dense belt of bouguer gravity anomaly contour from Tangtou village to Xihui village. It is inferred that there is a fault in the northwest direction, named as F1 fault. Based on geological data, it is concluded that F1 fault may be related to tanghe fault. To the south of Baiyang village, a dense belt of bouguer gravity anomaly contour near east-west direction appeared, extending westward and ending at F1 fault, which was named as F2 fault. Tangtou hot spring is located in the middle of the inferred fault and fracture zone. The abundant water may be affected by the fracture of underlying bedrock.

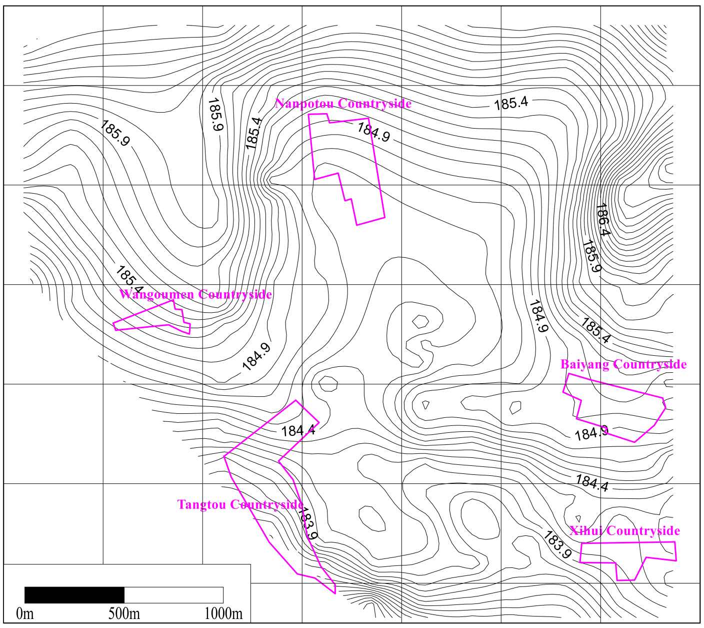

Figure 5: Bouguer gravity anomaly contour map

4.4 Controlled Source Audio MagnetoTellurics Sounding (CSAMT)

CSAMT method is based on finite length grounding electric dipole source, observation of dipole electric and magnetic field at a certain distance from the center. It is widely applied in geothermal exploration because of strong anti-interference, deep detecting depth, high lateral resolution (Tian and Song, 2006; Liu, Huang and Meng, 2006).

The direction of K1 line is 90 degree, and the length is 3 km. As shown in figure 6, the inversion of resistivity value is low in shallow, while that of deep gradually increase. Based on hydrogeological and geological data, the thickness of Quaternary strata is thin, less than 100 m. The abnormal part between low and high resistivity in the shallow caused by Quaternary. It is inferred as the archaean metamorphic rocks. The low resistivity layer at the depth 100-200 m indicates that it is broken metamorphic rock affected by weathering. Horizontally, the inversion of resistivity curve shape is better, but the change is not uniform. At 116-120 and 216 points, dense belts of inversion of resistivity contour appeared. Combined with the gravity plane, it is inferred as fracture zone influenced by F1 fault. The dense belt at point 216 may be caused by inversion boundary effect.

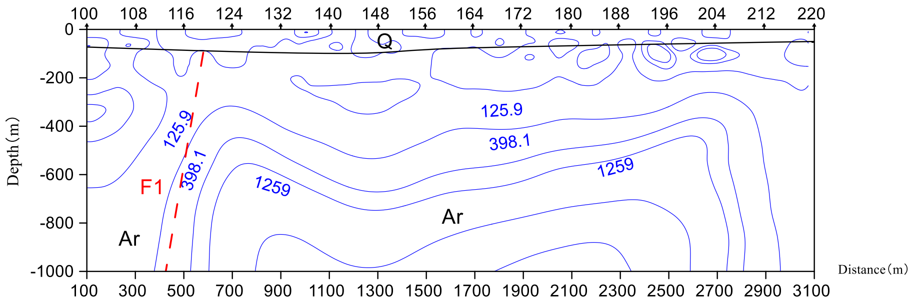

Figure 6: K1 line inversion of resistivity contour profile

The direction of K2 line is 90 degree, and the length is 2 km (Figure 7). From the K2 line inversion resistivity contour profile, the inversion resistivity values are low in the shallow part and gradually increase in the deep part. Inversion resistivity stratification is similar to other lines. Horizontally, the inversion resistivity curve showed a steep drop pattern at point 126, which was inferred to be a fracture zone influenced by F1 fault.

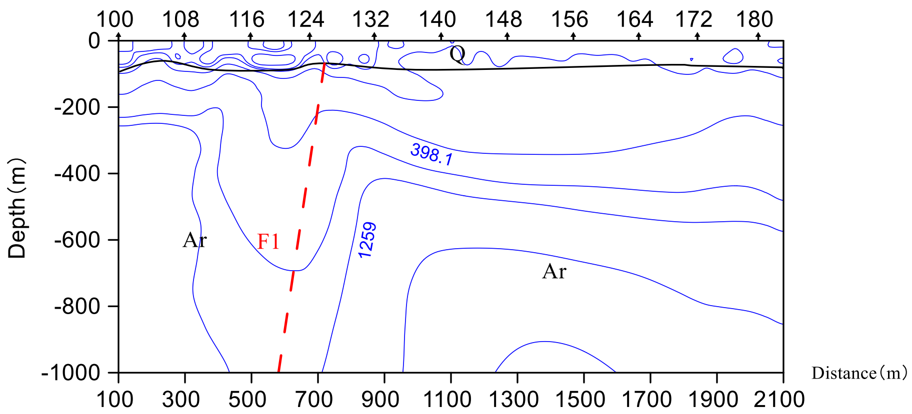

Figure 7: K2 line inversion of resistivity contour profile

The direction of K3 line is 0 degree, and the length is 2 km (Figure 8). Affected by the power supply in mountainous areas, the effective inversion depth of K3 line only reaches 400m. The result shows that the depth of Quaternary is less than 100 m. Dense belt occurred at 116-118 points indicates a fracture zone.

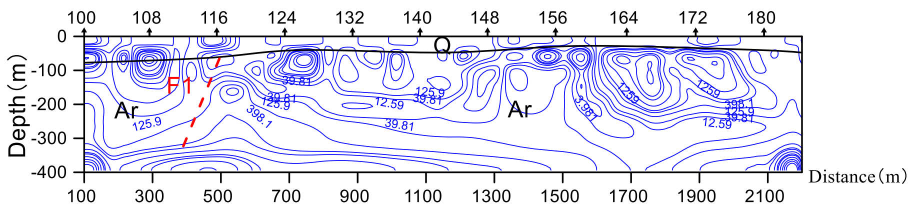

Figure 8: K3 line inversion of resistivity contour profile

The direction of K4 line is 0 degree, and the length is 3 km (Figure 9). The inversion resistivity stratification is similar to K1, K3 lines. Horizontally, the inversion resistivity curve shows a steep fall pattern at point 118, which is inferred to be a fracture zone. Combined with the gravity plane, it is inferred that this fault may be a fault zone formed by the interaction of F1 and F2. The shallow formation is relatively fragmented, and the cutting depth of the formation should be within 1000m.

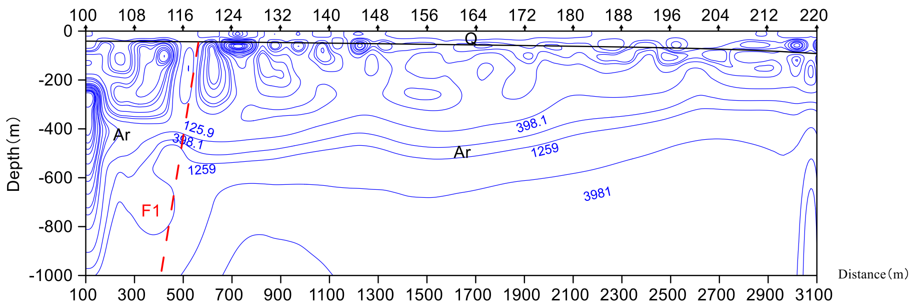

Figure 9: K4 line inversion of resistivity contour profile

4.5 Analysis of Geophysical Exploration

Based on comprehensive analysis of gravity exploration, magnetic measurement and controllable source audio magnetotelluric sounding, F1 and F2 fault were deduced (Figure 10). F1 fault is normal fault with NW strike direction and SW dip direction and is clearly shown in the K1, K2, K3, K4 CSAMT profiles. F1 fault is the mainly fault connecting the deep heat source with the shallow geothermal in the exploration area, which should be related to the tanghe fault. F2 fault is normal fault with EW strike direction and S dip direction and is shown in the K3 line. Due to the influence of F1 fault, the precise position on K3 line is not clear. Based on the regional geological and geophysical data, it is concluded that F2 fault may be a secondary fault of hengshan fault, which is cut by F1 fault. It is also confirmed that the existing tongtou geothermal Wells are located at the intersection of F1 and F2.

Within the exploration depth range, Quaternary and Archean strata were developed in the exploration area from top to bottom. The thickness of Quaternary is thin. The type of geothermal resources that can be exploited in this area is tectonic fracture. The scale of fault fracture zone will directly affect the quality of geothermal resources. Due to the low permeability of Archean strata, the development of geothermal resources should be in fracture zone area. The potential development area of geothermal resources is in the south of the intersection of F1, F2 faults, hanging wall of F1 fault.

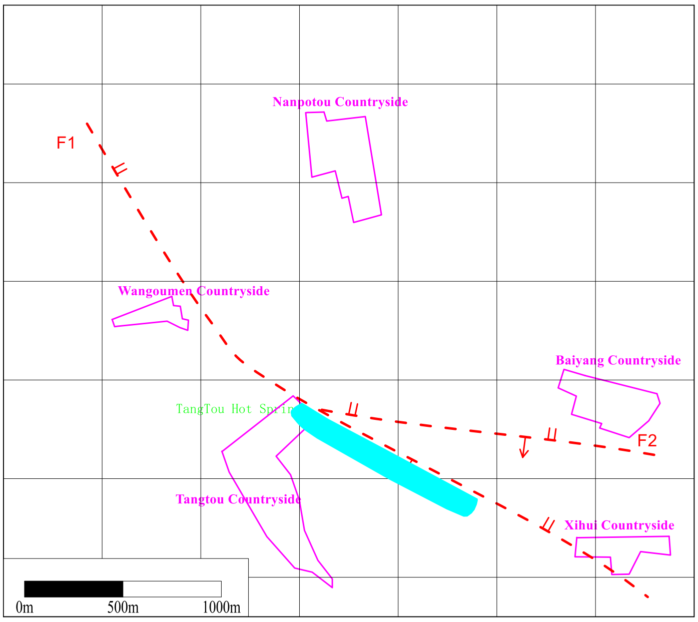

Figure 10: The result of geophysical prospecting

5. CONCLUSION

In the inadequate geothermal exploration area, three geophysical prospecting methods, gravity, magnetic method and controllable source audio magnetotelluric sounding, are applied to comprehensively infer the structural and stratigraphic characteristics of tangtou area and the buried depth of thermal reservoir. The location of tangtou hot spring is exposed at the intersection of faults and the prospect area of geothermal resources is proposed. This exploration will accumulate valuable experience for selecting suitable geophysical prospecting methods in similar areas in the future. Comprehensive geophysical prospecting plays a good leading role in geothermal exploration.

REFERENCES

Hao, Z.J.: Study on Exploitation and Utilization of Geothermal Resources in Shanxi Province, *Shanxi Architecture*, **5,** (2015), 172-173.

Yan, X.H.: Evaluation of Geothermal Resources in Tongtou Geothermal Anomaly Area, Hunyuan county, Shanxi Province, *HuaBei land and resources*, **60**(3), (2014), 67-69.

Shanxi Bureau of Geology and Mineral Resources: Geology of Shanxi, Beijing: Geological Publishing House, (1989).

Deng, Q.D., Lu, Z.X., Yang, Z.S.: The Evaluation of Urban Active Fault Detection and Fault Activity, *Seismodogy and geology*, **2**, (2007), 189-199.

Wei, B., He, F.B.: A Preliminary Study on the Southeast Part of the Yongding River Fault Zone, *Urban geology*, **2**(2), (2018), 31-36.

Liu, G.D.: Principles and applications of integrated geophysical interpretation. In: Progress of Chinese Geophysics in 1980s. Beijing: Scientific Books and Periodicals Press, (1989), 231-242.

Wang, J.Y., Xiong, L.P., Pang, Z.H.: Low-medium Temperature Geothermal System of Convective Type, Beijing: Science Press, (1993), 6-10.

Tian, S., Song, Y.X.: The Application of High Order Horizontal Derivative of Profile Gravity in Geothermal Exploration, *Progress in exploration geophysics*, **29**(5), (2006), 373-376.

Liu, R.D., Huang, L.J., Meng, Y.S.: Application of Controlled Source Audio-frequency Magnetotellurics to Exploration in the Geothermal Field, *Chinese Journal of Engineering Geophysics*, **4**(2), (2006), 86-89.