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Study on Genetic Mechanism of Geothermal System in Arxan Area based on Integrated Geophysical Method

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ABSTRACT

Arxan area is a famous enrichment area of groundwater thermal resources in China. The tectonic movement in the area is intense and the magmatic activity is frequent. The exposed temperature of hot spring groups suffers great differences. In order to reveal the regional geothermal geological characteristics and put forward the genetic model of geothermal water, the integratede geophysical methods of satellite gravity, magnetotelluric (MT) and controlled-source audio magnetotelluric (CSAMT) are used to detect Yinjianggou hot spring, and the geophysical field characteristics of Arxan area are obtained. Regional geological, hydrogeological and geochemical data are combined and used for the comprehensive geological interpretation, indicating that the hot spring in Arxan area is a low medium temperature geothermal systems of convective type: (1) It belongs to a low and medium temperature hot water geothermal system, because no special heat source such as magma chamber is found in the area. (2) The heat source, thermal reservoir and caprock in the geothermal system were formed in the late Jurassic. Large-scale volcanic activities entrained mantle materials to the near surface. The groundwater underwent components exchanging in heat diffusion, forming a heat fluid with high mineralization. (3) There is a nearly vertical tension torsion secondary fault underground in Yinjianggou area. Driven by hydraulic pressure difference, the thermal fluid migrates upward along the structure, exposes at the caprock break, and forms a medium low temperature hot spring after mixing with shallow fissure water.

1. INTRODUCTION

The Arxan region is located in the Daxinganling fold belt and has undergone long-term tectonic evolutionary processes with frequent magmatic activity[1]. The region is rich in geothermal resources, which are manifested in a wide distribution of hot springs under tectonic control. There are different views on the formation mechanism of hot springs in the Arxan region. According to Tang etc.'s analysis of the geological structure and volcanic activity in the Arxan region, the hot springs are formed by the superheated basaltic magma near the upper crust as a heat source, which receives atmospheric precipitation recharge from the upper reaches of the AlshanGaole and converges along the fault to the oblique core or downstream lowlands, heating the deeply circulating groundwater[2]. Han etc. used geophysical and geochemical exploration techniques to explain the genesis of the hot springs and concluded that the hot springs in the Arxan region belong to a medium- to low-temperature convective geothermal system[3]. Due to the lack of deep data in previous studies of heat sources and thermal reservoirs in thermal storage areas, and the difficulty in forming a unified understanding of regional hydrogeological and geochemical data, the formation of hot spring systems in the Arxan region has been considered a major problem. Therefore, the spatial structure of stratigraphic contact zones, fracture zones and the tectonic features of their fracture zones associated with the formation of geothermal systems need to be studied in more detail. In this paper, the integrated geophysical methods of satellite gravity, magnetotelluric (MT) and controlled source audio magnetotelluric (CSAMT) were applied to explore the Yinjianggou hot springs in three dimensions, and the hydrogeological and geochemical data were combined to establish a conceptual model of the geothermal system in the Yinjianggou area, which provides a basis for subsequent geothermal resource development and evaluation.

2. OVERVIEW OF REGIONAL GEOLOGY AND HYDROGEOLOGY OF YINJIANGGOU AREA

The stratigraphy of the Arxan region belongs to the Tianshan-Xing'anling stratigraphic zone, Xing'anling stratigraphic subzone, and Ulanhot subzone[4]. The stratigraphy in the area is poorly developed and incompletely exposed. The terrane is located in the South Mongolia-Xing'an orogenic belt between the Siberian terrane and the North China terrane, and is adjacent to the Late Paleozoic accretionary orogenic belt of the northern section of the Daxinganling in the southeast, which belongs to the post-arc margin zone of the West Pacific subduction plate [5]. The Paleozoic strata in the study area were strongly folded and subjected to different degrees of regional metamorphism, and in the Mesozoic, the eastern margin of the Eurasian continent began to enter a phase of activity along the western Pacific margin under the influence of the northwestward subduction of the Kula plate, and the most distinctive features of this tectonic phase are the strong development of north-eastward rifting tectonics during the Yanshan period, a series of north-east-north-eastward volcanic basins and uplifts, and coeval strong medium-acid volcanic -The intrusive activity of magma. Intrusive and volcanic rocks are widely distributed in the Yinjianggou area, and the exposed strata are dominated by the Late Jurassic Baiyin Gaolao Formation (J_3b) [6], and Yanshanian intrusive orthogonal granites ($J\xi\gamma$) are scattered throughout the area (Figure 1).

The groundwater types in the Yinjianggou area are mainly loose rock pore water and bedrock fracture water, which are recharged by atmospheric precipitation infiltration and mainly discharged by spring discharge and runoff to rivers and valleys. The surface valleys in the study area are developed and lithologically broken, showing the characteristics of easy drainage and difficult sink. The flow rate of Yinjianggou hot spring is more than 10 m^3/h, the water temperature is 36.5℃, the mineralization is 774.32 mg/L, and the pH value is 8.06.

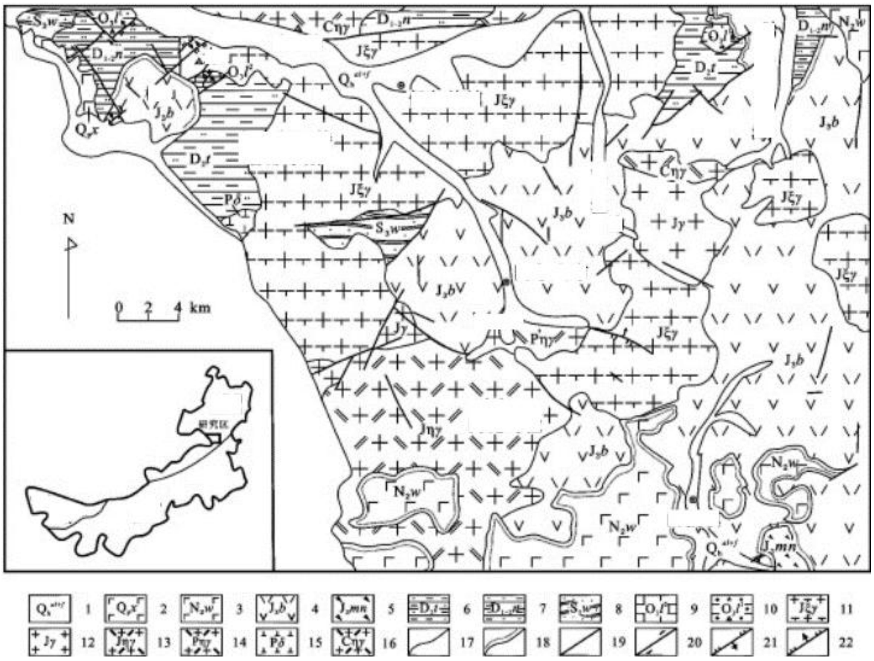

Figure 1: Distribution of magnetotelluric survey points in Yinjianggou and its surrounding areas in Arxan, Inner Mongolia

(1-Holocene alluvial sand gravel, swamp and silt; 2- Pleistocene Xikou formation; 3- Neogene Wuchagou formation; 4- Baiyingolao formation of Upper Jurassic; 5- Manitu formation of Upper Jurassic; 6- Tharbagite formation of Devonian; 7- Loach River formation of Middle Lower Devonian; 8- Upper Silurian woduhe formation; 9- The second member of Upper Ordovician Ganhe formation; 10- The first member of Upper Ordovician Ganhe formation; 11- Jurassic syenogranite; 12- Jurassic granite; 13 Jurassic adamellite; 14- Permian adamellite; 15- Permian diorite; 16- Carboniferous adamellite; 17- Geological limits; 18- Unidentified fault; 19- Translational fault; 20- Reverse fault; 21- Normal fault.)

3. GEOPHYSICAL FIELD CHARACTERISTICS

3.1 Satellite gravity anomaly and Moho characteristics

The data in this paper are derived from the Bouguer gravity anomaly published on the "International Gravimetric Brueau" (BGI) website to an accuracy of 2'*2'. The depth of the Moho surface in the Arxan region is calculated by referring to the park-oldenberg formula, which is given by

$$F[h(x)] = \frac{F[\Delta g(x)]e^{(kz_0)}}{2\pi G\rho} - \sum_{n=2}^{\infty} \frac{k^{n-1}}{n!} F[h^n(x)]$$

where $F(\Delta g)$ is the Fourier transform of the gravity anomaly; the upper 10 km gravity anomaly is chosen as Δg; the initial value of the regional interface undulation z_0=36 km is given according to the deep reflection seismic profile; G is the gravity constant; referring to the relevant information in the early research literature of Feng et al, the density difference between the upper mantle and the lower crust in the Arxan region ρ is set to 0.64 g/cm^3[7]; k is the wave number; $h(x)$ is the fluctuation value of the main leveling interface, which can be set as 0. Bring the above parameters into the formula to calculate the depth of the Moho surface in the Arxan, as shown in Figure 2.

The magnitude of the Bourg gravity anomaly in the Arxan region ranges from -128 to -84 mgal, and the trend of the anomaly and trap decreases slowly from north-west to south. The Moho surface depths in the Arxan region range from 38.9 to 39.3 km, and the distribution trend is similar to that of the Bouguer gravity anomaly, with the contours changing gently in a closed pattern, showing a subsidence trend with a low center and high surroundings.

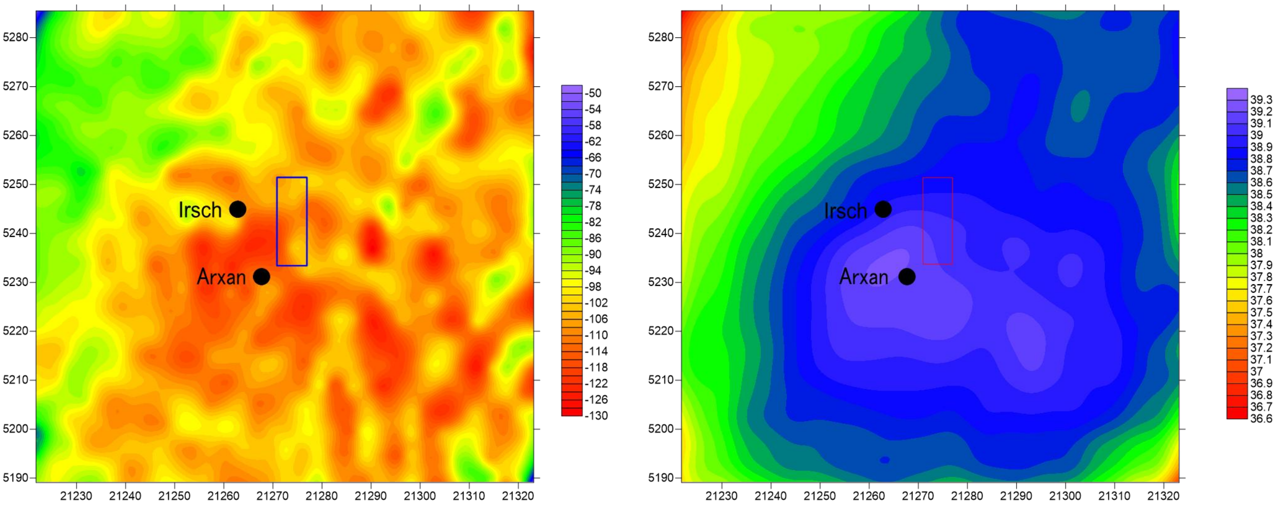

Figure 2: Bouguer gravity anomaly and Moho depth map of Yinjianggou and its surrounding areas in Arxan, Inner Mongolia.

3.2 Deep electrical characteristics

The MTU-5 satellite synchronous magnetotelluric instrument from Phoenix was used for the field MT data collection. The survey line is about 13km long, with 6 magnetotelluric survey points laid out from south to north along the topography of Yinjianggou. The Winlink software was used for inversion, and the results is shown in Figure 3.

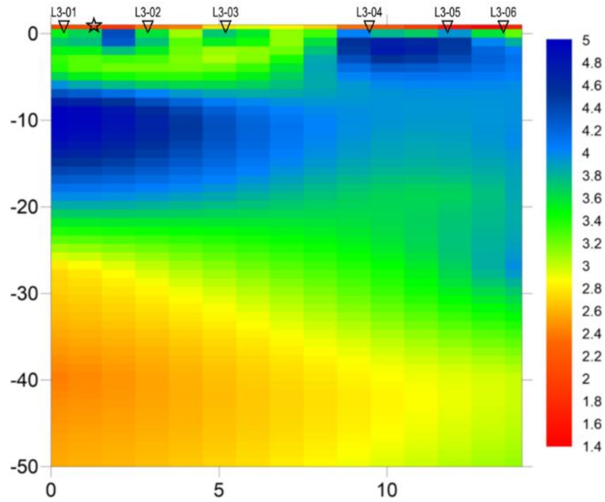

Figure 3: 2D inversion result of magnetotelluric (star type is known hot spring location).

The variation of resistivity with depth can be roughly divided into four main parts: 0~1km is a relatively low resistance layer, 2~8km shows a south low and north high resistivity along the profile in the lateral direction, 9~28km shows a high resistance layer in the middle and lower crustal part, 29~50km shows a relatively low resistance in the bottom of the crust to the top of the mantle.

Collectively, it can be seen that the granitic basement overlying volcanic clastic cover constitutes the basic outline of the Arxan volcanic basin, exhibiting gravity anomaly characteristics consistent with the low gravity anomaly and multi-trapping distribution in the Bouguer gravity anomaly and Moho depth map of Yinjianggou and its surrounding areas in Arxan. The magnetotelluric profile reveals that the crustal resistivity in the study area is greater than 3000 Ωm, which manifests itself as a cooled magmatic stratigraphy in terms of electrical structure [8]. The presence of magmatic capsules is ruled out as the resistivity of the melt is generally less than 10 Ωm [9]. Given the age of the shallow intrusions and the absence of melt activity in the crust, this paper concludes that the geothermal system in the Yinjianggou area was not heated by a special additional heat source such as magma capsules, but by a higher geothermal heat flux in the dense magmatic basement.

3.3 Exploration and interpretation of CSAMT

This field data acquisition uses the V8 multi-function electrical instrument of Phoenix Company in Canada. The detection frequency is 0.5~9600 Hz, with a total of 44 frequency points, a transceiver distance of 10~13 km, and a measuring point distance of 50 m.Four east-west CSAMT lines were laid in the hot spring area from south to north, and the L2 line was an encrypted line through the hot spring outcrop location, point 211 was located about 30 m southeast of the hot spring and is used to find out the stratigraphic information related to the hot spring outcrop. Data preprocessing adopts Phoenix CMT software. After subsequent processing of wild value removal, noise removal, static correction and near-field correction, the nonlinear conjugate gradient (NLCG) algorithm is used for 1D and 2D inversion simulation. The inversion depth is 2500 m, and the inversion fitting error is less than 5%. Based on the resistivity distribution characteristics, the results of 2-D inversion geological interpretation of CSAMT in Yinjianggou hot spring area were plotted by combining the regional stratigraphy, magmatic rock distribution pattern and drilling data (Figure 4).

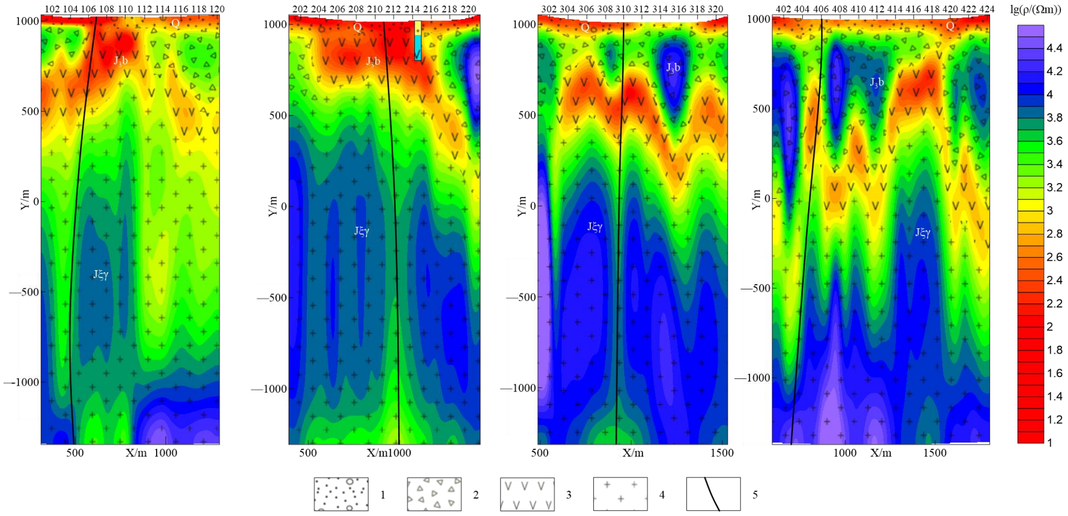

Figure 4: 2D inversion geological interpretation result of controllable source audio frequency magnetotelluric sounding in Yinjianggou hot spring area.

(1- Quaternary gravel pebble layer; 2- Jurassic tuffaceous breccia; 3- Jurassic rhyolitic tuff; 4- yanshanian granite; 5-Fault)

The electrical characteristics of the study area have obvious vertical differences and are stratified, and can be divided into four layers from top to bottom.

1) The resistivity of the surface layer above 40 m is less than 50 Ωm. This layer is the Quaternary alluvium, and the lithology is sand and gravel pebbles.

2) High-resistance bodies with resistivity higher than 1000 Ωm at depths of 40-600 m are consistent with the electrical characteristics of fused tuff breccia in the blocky formations of the Upper Jurassic Baiyin Gaolao Formation (J_3b) exposed at the surface. This type of volcanic rock formation is less fissured and has good water-insulation capacity, and thus has a high resistivity.

3) Low-resistance traps with resistivity less than 100 Ωm from 200 to 1000 m below ground show a strong spatial extension pattern. The rock joints and fissures in this layer are developed, and it is presumed that the rhyolitic tuff in the volcanic clastic cover is broken by the compound action of tectonic and intrusive rocks, forming a good groundwater storage and transport channel, which shows low resistance.

4) The resistivity of the high-resistance zone at the bottom of the burial depth over 1000 m exceeds 3000 Ωm, which is considered to be a dense basement formed by the intrusion of granitic porphyry (Jξγ) of Yanshanian.

The electrical characteristics of the study area have a pattern of "high on both sides and low in the middle" laterally, and it is assumed that there is a tensor fracture with nearly upright production, and the inferred fracture locations are connected on the distribution map of CSAMT in the Yinjianggou hot spring area of Arxan. The fracture structure is similar to the topography.

4. CONCLUSION

Based on the regional geological conditions and comprehensive geophysical analysis, the pattern of hot spring formation in Yinjianggou can be derived and the mechanism of hot spring genesis can be revealed.

Heat source: The analysis shows that the thick and gently varying granite basement formed in the Late Jurassic is the main heat source of the geothermal system in the Yinjianggou area.

Thermal reservoir: The results of CSAMT 2D inversion geological interpretation show that the overlying rock layers in the study area have good water and heat insulation capacity, and the surface and interlayer fissures of the underlying rock layers are developed, which have good water and heat storage capacity.

Cause of thermal fluid: Atmospheric precipitation transported downward along the joint fissures and interlayer fissures and collected in the tectonic fissures of Yanshanian granite body in the deep underground, which formed thermal fluid by heat exchange and component exchange with the surrounding rocks.

Cover: The field inspection is consistent with the borehole data, and the study area is overlain by powder soil and Quaternary sand and gravel pebble layer, and the shallow fracture water is enriched. The geothermal water is mainly mixed by the shallow fracture water during the uplifting process, resulting in the low water temperature of the exposed hot springs.

Thermal channel: Analysis of the two-dimensional inversion results of CSAMT shows that there is a nearly north-south and nearly upright tensor-torsional secondary fracture under the Yinjianggou area, through which the basal heat flow of intrusive rocks can be effectively conducted upward and heated by the thermal conductivity structure.

In the process of downward seepage of atmospheric precipitation along the fracture direction in the thermal reservoir, the thermal fluid is formed by heat exchange and component exchange with the surrounding rock; the thermal fluid is driven by the hydraulic pressure difference and transported upward, and then mixed with shallow fracture water and exposed at the cover breach to form a spring

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