Study on geothermal genesis in Juxian area, Shandong Province

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Abstract. In order to explore and develop geothermal resources in Juxian area, Shandong Province has studied the causes of geothermal in Juxian area. On the basis of field investigation, drilling and logging, and water quality inspection in Juxian area, the metallogenic conditions were analyzed from the aspects of geothermal source, geothermal storage, caprock, and geothermal channel formed by geothermal water, and finally the geothermal causes in Juxian area. The surface water and atmospheric precipitation in the study area infiltrated through the fault near the Yishu fault, and after 3,150 m deep circulation, the heat was obtained by the normal geothermal heating method, while dissolving the mineral components in the surrounding rock, and finally gathered in the Qingshan Group andesite, it forms high-quality hot mineral water rich in minerals such as fluorine, strontium, lithium, metaboric acid and metasilicic acid. The andesite caprocks of the Qingshan Group effectively hindered the loss of the geothermal water and heat energy of the geothermal water gathered here. The geothermal water enters the geothermal well through faults and strata dissolution holes, and surges up to the surface.

1. Introduction

As an extremely important basic resource for the development of human society, energy is not only the key to national economic growth, but also an important guarantee for national security and stable social development. In order to maintain the rapid and stable development of the country's economy and society, it is necessary to ensure a stable supply of energy [1, 2]. Geothermal energy is an important member of the clean energy family. It is a renewable resource that combines heat, mine and water. It has the advantages of wide resource coverage, large reserves, little pollution to the ecological environment, easy development and recycling, and recycling. As a result, more and more countries are favored and concerned [3].

Shandong Province is rich in geothermal resources, has huge development potential, and has significant energy saving and emission reduction effects [4]. In order to promote the economic development of Juxian and develop the local tourism industry, Shandong Province proposed to explore deep hot water resources in the area to prepare for further development and utilization in the later period. However, there has not been a systematic and comprehensive analysis of the causes of geothermal
resources in Juxian County. It is necessary to further study the causes of geothermal resources in Juxian area to provide a theoretical basis for the further exploitation and utilization of geothermal resources.

2. Regional geological structure
The topography of Juxian is high in the north and low in the south, surrounded by mountains, with hills, plains and depressions in the middle. The large fault in Juxian County is the Yishu fault zone, extending in the direction of NNE10°-25°, narrow in the south and wide in the north. The Yishu fault zone is a series of long-term, multiple-activity fault zones. Since the Paleozoic, it has experienced long-term and complicated activities, and has been active until the Mesozoic and Cenozoic, controlling the Cenozoic stratigraphic deposition and volcanic activity on both sides. Since the Quaternary period, the Yishu fault zone has inherited the compressive and torsional fault movement of the northeast-direction principal stress of the Neogene, which plays a decisive role in the regional geological structure in Juxian.

The Yishu fault zone is a super-large fault tectonic zone running through the eastern part of my country. It has a large scale, a long active time and a large cutting depth. It can transfer heat energy in the region to the surface of the crust and is an ideal heat control structure. Many secondary fault structures are derived from both sides of each of its main faults, providing space for groundwater storage, migration and deep cycle heating.

3. Analysis of formation conditions of regional geothermal
The formation of a geothermal system generally must have four basic elements, namely, a natural heat source with a large amount of heat output, a well-permeable heat channel, a heat storage layer capable of storing heat, and a dense cover [5]. Geothermal reservoir is referred to as geothermal storage for short. It refers to the formation, rock mass or structural zone buried underground, containing thermal fluid, capable of enriching and storing geothermal energy, and having effective voids and permeability. The geothermal fluid in the thermal storage can be developed and utilized by people through direct mining. The caprock refers to the impermeable or weakly permeable rock layer covered on the thermal reservoir or aquifer. It mainly plays the role of thermal insulation and water trap in the formation of the geothermal system. It is also an important condition for the formation of geothermal fields and the production of superheated steam. Geothermal channels refer to fissure structures in geothermal sources, geothermal reservoirs, and caprocks. These structures generally provide channels for the transfer of thermal energy flow or thermal fluid.

3.1. geothermal sources
Magma hydrothermal activity and radioactive element decay in the deep earth are the main sources of heat in Juxian area. There are multiple stages of magmatic activity in the area, which generates a lot of heat, coupled with the development of fault structures, strong activity, and friction generates heat, which is also an important source of heat. The groundwater is deeply cycled along the fault zone to obtain deep heat, and the underground hot water resources are formed at the appropriate parts of the structure.

3.2. geothermal storage
The Juxian area is located in the geothermal area of the Yishu fault zone. Its geothermal storage type is a fissure-band geothermal storage, and the scale and temperature of the geothermal storage are controlled by the scale of the fault and the degree of structural fissure development in the fracture zone. Fractures and fissures are both geothermal water flow channels and storage spaces for hot water. Therefore, in the development zone of the fault structure, especially at the composite parts of deep and large fault zones and the intersection of multiple fault zones across multiple structural units It is often easier to form an abnormal geothermal water zone [6].

The andesite distribution area of the Qingshan Group in the Juxian area, the type of groundwater is spouted rock pores and fissure water. This layer has a dense structure, the original pores are not developed, and the water content is very small. Only in the structurally favorable areas, the structural fissures are developed and the groundwater is fully stored Migration space.
3.3. geothermal Caprock
According to regional data and field investigations in the Juxian area, the overlying strata in the thermal storage area are mainly Andesite from the Cretaceous Qingshan Group, which is a typical metamorphic rock cap. The structure of this layer is dense, the original pores are extremely undeveloped, the water content is very little, the sealing is good, and it has good water insulation and heat preservation conditions.

3.4. geothermal channel
Many secondary fault structures are derived from both sides of the Yishu fault zone, which provides space for groundwater storage, migration and deep cycle heating. The nature of NW-trending faults is mostly tensile and torsional, and there are more developed fracture zones, which intersect with NE-trending faults, which further strengthens the degree of fragmentation at the intersection, which is conducive to the communication of hydraulic connections in the thermal reservoir and the formation of geothermal Carrier storage space[7].

The two-dimensional inversion profile of the surface faults in the study area at the controllable source is shown in Figure 1. From Figure 1, it can be seen that there is a good response. F1, F2 and the surrounding faults can be used as channels for deep hot water. Surface water and atmospheric precipitation infiltrate through F1, F2 and surrounding faults to replenish deep hot water.

![Figure 1. Two-dimensional inversion profile of controllable source.](image)

4. Geochemical characteristics of regional geothermal water
The thermal exploration well zk1 has a well depth of 1813.10m, which exposes the Upper Family Wang Family and Lower Family Qingshan Formation of the Quaternary and Cretaceous. The well is a self-flowing well, with a self-inrush flow rate of 132 m$^3$/d, a self-inrush temperature of 38 °C, a recoverable volume of 664 m$^3$/d, and an effluent temperature of 56 °C, which is a low-temperature geothermal resource.

The types of geothermal water are $\text{SO}_4^{2-}$, $\text{Ca}^{2+}$, $\text{Na}^+$, and the pH value is 7.43. The well is rich in various trace elements, as shown in Table 1. According to GB/T11615-2010 "Geothermal Resources Geological Exploration Specification" Appendix E physical water quality standard evaluation[8], fluorine, strontium, lithium, metaboric acid, metasilicic acid, temperature reached physiotherapy value standards, of which fluorine, strontium concentration Can participate in hot mineral water naming, can be named fluoride water, strontium water.
Table 1. Geothermal water mineral content

| Ingredient | Concentration (/mg/L) |
|------------|----------------------|
| K⁺         | 50.48                |
| Na⁺        | 336.40               |
| Ca²⁺       | 497.63               |
| Mg²⁺       | 117.06               |
| Fe²⁺       | < 0.05               |
| Fe³⁺       | 1.07                 |
| Al³⁺       | < 0.01               |
| NH₄⁺       | 0.60                 |
| Cl⁻        | 57.37                |
| SO₄²⁻      | 2362.52              |
| HCO₃⁻      | 225.29               |
| F⁻         | 3.09                 |
| NO₃⁻       | 2.64                 |
| CO₂        | 9.48                 |
| ∑H₂S       | 0.01                 |
| Br⁻        | 0.48                 |
| I⁻         | 0.02                 |
| Sr²⁻       | 11.74                |
| Li⁺        | 1.19                 |
| Ba²⁺       | 0.070                |
| SiO₂⁻      | 31.93                |
| HBO₂⁻      | 2.128                |
| H₂SiO₃⁻    | 41.51                |

5. Analysis of geothermal genesis

The geotherm in the Yishu fault zone is different from the geotherm on the west side in terms of genesis. To the west of the Yishu fault zone, the currently exposed geothermal fields are mostly deep-circulation closed-type hydrothermal systems, while the geothermal outcrops in the fault zone are mostly deep-circulation convective systems, which belong to the "failure control type". The fissure karst water to the west of the Yishu fault zone runs from northwest to southeast, blocked by faults and rock masses, part of the groundwater is discharged in the form of cold water, and part of the groundwater continues deep circulation in the southeast direction along the bottom of the rock mass and the stratum. Under the action of hydrostatic pressure, the groundwater is heated to the ground temperature in the deep cycle, and rises to the shallow part along the fracture channel and rock fissure under the action of the hydrostatic pressure, or it is exposed through the borehole and emerges from the surface, forming shallow geothermal anomalies and hot mineral water self-flow. According to the stratigraphic structure and structural conditions in the Yishu fault zone, secondary faults are developed in the fault zone, especially in the north-east direction, and the underground fissure water flows from the north, east and west sides to the south, which is blocked by the rock mass or fault. Deep cycle heating is carried out, and it continues to move southward along the bottom of the rock mass or through the near-north-south fault fracture zone, enriching at the fault composite site. Covered with a thick Cretaceous caprock, the deep groundwater is in a relatively closed environment. Underground hot water can only be discharged to the surface along the fault to heat the shallow layer.

6. Conclusion

Through the study of hydrogeology in Juxian area, the following two main conclusions about geothermal resources are obtained.

1. The types of geothermal water are $\text{SO}_4^{2-}$, $\text{Ca}^{2+}$, $\text{Na}^+$, and the pH value is 7.43. Fluorine, strontium, lithium, metaboric acid, metasilicic acid, and temperature in geothermal water meet the physiotherapy value standards. Among them, the concentration of fluorine and strontium can participate in the naming of hot mineral water, which can be named fluorine water and strontium water.
(2) The frequent magmatic activities of the Mesozoic Yanshanian in the geothermal area of the Yishu fault zone communicated the heat source in the deep crust. Deep tectonic fissures are developed at and near the structural intersections, providing a good channel and storage place for deep hot water circulation. Hot water deep underground is likely to rise along the fault channel, forming geothermal anomalies. The geothermal system in this area is of deep circulation convection type, and the heat storage type is fissure-type band-shaped heat storage, which is distributed in the depression.

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