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Study on the characteristics of geothermal system in Yanqing Geothermal Field

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ABSTRACT

Geothermal resource is a renewable energy. The development and utilization of geothermal resource in Beijing has been going on for nearly 50 years. Geothermal resource has became an important part of the energy structure and has made outstanding contributions to economic development and environmental improvement in Beijing. According to the geological structure, geothermal geological conditions, economic and technological conditions, 10 relatively independent and certain connections geothermal field are divided. Yanqing geothermal field is one of them in which there are more than 20 geothermal wells. On the basis of collecting the geological information and exploration achievements, the Yanqing geothermal system is discussed and studied in this paper. The reservoir cap-rock of Yanqing geothermal field are Quaternary and Cretaceous-Jurassic strata, with average geothermal gradients of 3.37℃/100m and 2.14℃/100m, respectively. The geothermal reservoir is Wumishan formation of Jixian system, the average geothermal gradient is 1.36℃/100m. The grid connection formed by the NE-trending and nearly NS-trending structure is conducive to supply the uplift fracture zone from deep geothermal reservoir, furthermore, the deep heat flow is conductive and diffused in the whole Yanqing basin. The gird connection forms a better heat conduction and water channel. The characteristics of geothermal field indicate that the formation temperature is mainly related to bedrock relief.

1. INTRODUCTION

The main source of heat in the earth's interior is the decay of radioactive elements, which are constantly undergoing thermonuclear reactions, releasing huge amounts of energy. Thermal energy is continuously transmitted to the surface through the thermal conduction of the earth, volcanic eruptions, earthquakes, deep water circulation, hot springs and other channels. Geothermal energy is a renewable energy, which has the characteristics of wide distribution of resources, low pollution to the ecological environment and low operating cost in the development. With the rapid growth of energy demand and the consideration of climate change, the utilization of geothermal energy becomes more necessary (Bertani, 2005; Lund and Boyd, 2005; Bilgen et al, 2008).

The geothermal resources in Beijing are mainly distributed in the plain area (including Yanqing basin). The types of geothermal resources in Beijing are mainly low temperature (< 150℃) sedimentary system. The main thermal reservoir is the siliceous dolomite of Wumishan formation of Jixian system. According to geological structure and geothermal geological conditions, Beijing area is divided into 10 relatively independent and connected geothermal fields (Figure 1) (Beijing Municipal Bureau of Land and Resources, 2006) with a total area of 2,760 km^2. Currently, the geothermal heating space is about 2 million m^2 and the agricultural greenhouse is about 400,000 m^2. The economic and social benefits are significant.

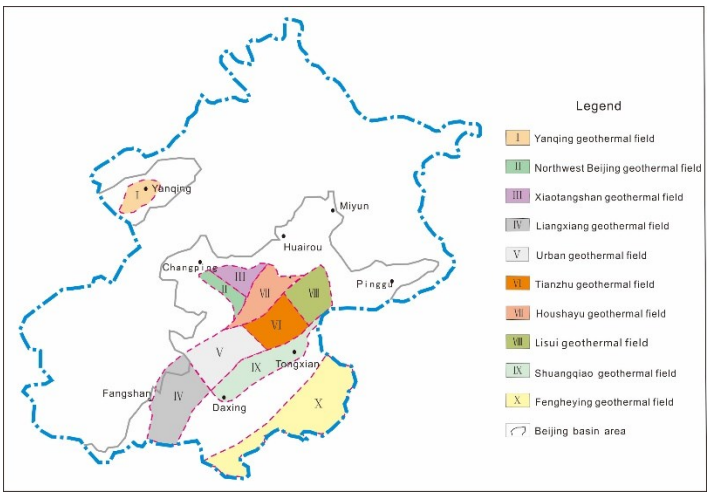

Figure 1: The distribution diagram of Beijing geothermal resources

Geothermal system mainly refers to the geological unit of complete thermal energy and fluid transport process in geothermal field, which can be divided into different categories according to different factors. According to the reservoir temperature, it can be divided into high-temperature geothermal system (T>150℃), medium-temperature geothermal system (150℃>T>90℃) and low-temperature

geothermal system (T<90℃). According to the physical state of reservoir, it can be divided into liquid geothermal system, gas-liquid two-phase geothermal system and steam geothermal system. According to geological characteristics and properties, it can be divided into volcanic system, convection system, sedimentary system, geopressure system, hot dry rock system and shallow geothermal system (Axelsson, 2008).

Yanqing geothermal field is a conductive, low-temperature, sedimentary system, and more than 20 geothermal ells have been drilled. Based on the collection of previous geothermal geology, hydrogeology and research results, this paper systematically discusses the geological, structural and geothermal field characteristics of the geothermal field, and summarizes the characteristics of the geothermal system of Yanqing geothermal field.

2. GEOLOGICAL SETTINGS

2.1 Strata

According to the drilling data in Yanqing geothermal field, the main sedimentary strata from new to old are Quaternary, Cretaceous-Jurassic and Wumishan formation of Jixian system (Beijing Bureau of Geology and Mineral Resources, 1982), which are described as follows:

(1) Quaternary: The sediments are mainly distributed in Yanqing basin and river valley. The maximum thickness of quaternary sediments in the basin is 800-1000m, and the lithology is mainly composed of clay soil, gravel layer and medium-coarse sand layer. Alluvium consists of gravel, coarse gravel, sticky sand, sticky sand and sand composed of rhythm layer.

(2) Cretaceous – Jurassic: The lithology is mainly volcanic glutenite, tuff, andesite and polymictic conglomerates.

(3) Wumishan formation of Jixian system: The formation was deposited by carbonate phase. The deposition thickness of the standard geological section in Yanqing is 2385 m, and the main lithology is gray, gray-black dolomite and siliceous dolomite.

2.2 Structure

The structures in Yanqing basin are relatively complex. The structures are mainly NE-trending and NS-trending (Figure 2).

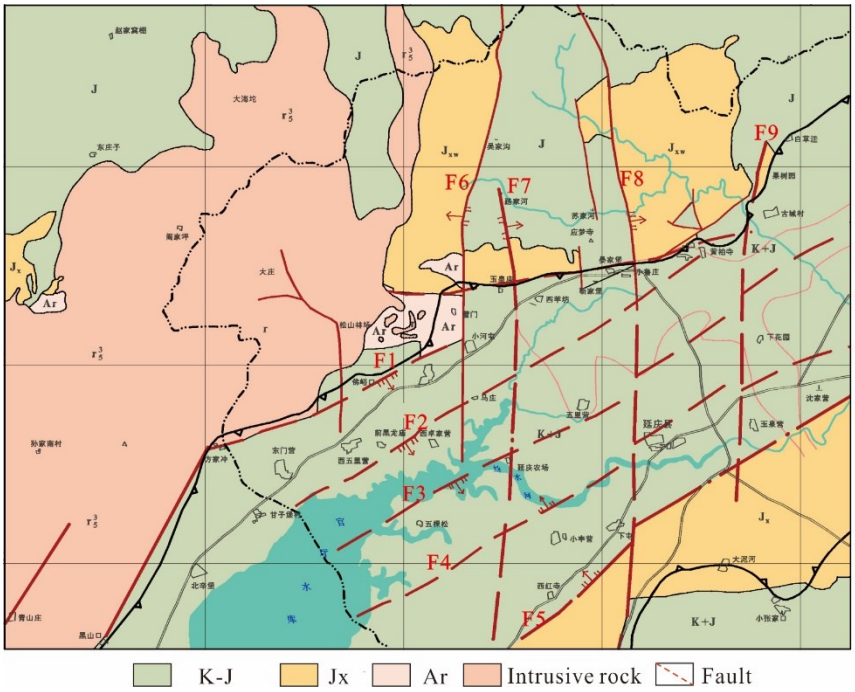

Figure 2: Geological structure map of bedrock in Yanqing basin

(1) NE-trending faults

Foyukou—Huangbaisi fault (F1) is a normal fault which constitutes the northern boundary of Yanqing basin, and the trend is from the NE to the NEE, with a dip angle of about 70°. Wuliying—Gucheng fault is located in the north of Yanqing basin, and it is a hidden fault. It is a normal fault with a SE proneness. Zhuojiaying fault (F3) is a normal fault with a SE proneness and controls the distribution of Wuliying uplift and fault depression center of the basin. Xisangyuan—Gujiaying fault (F4) is normal fault with a NW proneness which is concealed under the Quaternary. Kangzhuang—Shenjiaying fault (F5) is regional normal fault, trending NE and inclining to NW. The fault controls the southern edge of Yanqing basin, and to the northwest of the fault is Yanqing basin. Cenozoic era has a strong subsidence, especially in the Quaternary period.

(2)NS-trending faults

Zhangshanying fault (F6): The outcrop length of the fault in the mountainous area is about 12 km, extending southward and entering the quaternary formation. The strike of the fault is 15°, the fracture zone is wide ranging from 20 to 30m, the width of the affected zone is more than 100 m, the fault inclines to the west or northwest, and the angle is 50-75°. Lujiahe fault (F7) is a reverse fault which strikes NW355°, inclines to east. Jinjiabao fault (F8) is a reverse fault. The width of fracture zone is 8 – 10 m. Gucheng—Suzhuang fault (F9) outcrops in the mountains at the north of Gucheng. The fault inclines to the west, and the dip angle is steep.

3. CHARACTERISTICS OF GEOTEMPERATURE IN YANQING BASIN

It is a key problem to study the geotemperature in geothermal system. The study of geotemperature can provide basis for the exploration and evaluation of geothermal resources in the early stage. It can also optimize the well location in the later development and utilization. In the study of the characteristics of geotemperature, the temperature measurement data from boreholes are mainly used.

3.1 Geothermal gradient

Geothermal gradient, also known as geothermal temperature increase rate, generally refers to the growth rate of formation temperature increasing with the depth, expressed in ℃/100m or ℃/1km, and its calculation method:

$$\theta = 100 \times （\mathrm{T} - \mathrm{T_0}）/(H - H_0) \qquad （1）$$

where θ, *T, T0, H, H0* are geothermal gradient, temperature at some depth, temperature of constant temperature zone, depth of the formation, depth of constant temperature zone, respectively.

The depth of constant temperature zone in Beijing is 30m, and the temperature is 13.5℃. According to formula (1) and the temperature measurement data of geothermal wells in the research area, the geothermal gradient of each formation and the geothermal gradient of each geothermal well were calculated respectively.

Table 1 lists the geothermal gradient of each formation and geothermal well. The results show that the geothermal gradient of the Quaternary ranges from 1.80 ℃ to 4.65℃/100m, and the average geothermal gradient is 3.37℃/100m. The geothermal gradient of Cretaceous-Jurassic strata ranges from 1.18 ℃ to 3.56℃/100m, and its average geothermal gradient is 2.14℃/100m.The geothermal gradient in the Wumishan formation of Jixian system ranges from 0.20 ℃ to 3.85℃/100m, and its average geothermal gradient is 1.36℃/100m.The geothermal gradient of geothermal wells is 1.77~3.20℃/100m, and the average geothermal gradient is 2.09℃/100m.

Table 1: Geothermal gradient in different layers of geothermal Wells in the study area

Well NO.	Quaternary （℃/100m）	Cretaceous-Jurassic （℃/100m）	Wumishan formation （℃/100m）	geothermal wells （℃/100m）
W1	4.29	1.54	1.15	2.19
W2	2.86	3.03	3.85	3.20
W3	2.70	3.41	0.76	2.42
W4	3.71	2.42	1.36	2.25
W5	3.94	1.96	1.60	2.18
W6	2.94	2.10	1.40	2.08
W7	1.80	2.57	0.20	2.02
W8	3.38	1.76	1.51	2.04
W9	3.21	1.83	1.31	1.79
W10	2.59	1.83	1.69	1.90
W11	3.52	1.56	1.14	1.81
W12	3.92	1.40	1.59	1.95
W13	3.75	1.72	1.32	2.03
W14	3.22	1.77	1.60	2.00
W15	2.89	1.18	1.39	1.84
W16	2.65	1.98	0.52	1.77
W17	2.87	1.85	2.08	2.21
W18	3.36	3.56	0.64	2.27

W19	4.44	2.47	1.41	2.16
W20	4.65	2.88	1.54	2.16
W21	3.82	2.32	0.65	1.86
W22	3.65	1.83	1.32	1.94
average	3.37	2.14	1.36	2.09

The geothermal gradient can basically reflect the vertical distribution characteristics of the geotemperature field. The geothermal gradient is relatively high in the Quaternary and Cretaceous - Jurassic strata, and relatively low in the Wumishan formation of Jixian system. In the geothermal gradient value of geothermal Wells, except for W2 well, the other geothermal wells have a small variation range. The high geothermal gradient of W2 well is likely to be affected by deep reservoir or thermal conductivity structure.

3.2 The relationship between the buried depth of Wumishan formation and temperature

Generally, the plane distribution of geotemperature field is closely related to the distribution of deep stratum undulation and structure. In order to further the study of the characteristics of geotemperature field and geological factors, a plot of the relationship between burial depth of Wumishan formation and geotemperature field is carried out by using the data of the geothermal wells (Figure 3). It can be more intuitive representation of the Wumishan formation fluctuation characteristics and the corresponding temperature characteristics of can be compared and analyzed.

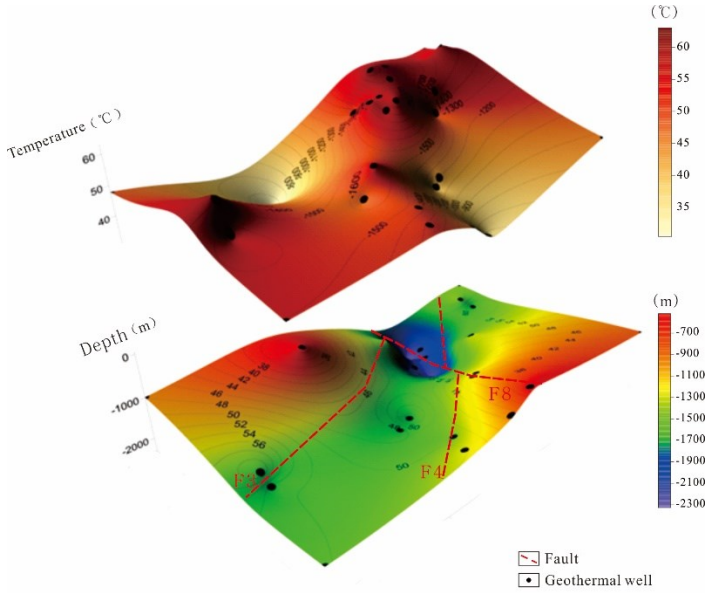

Figure 3: The relationship between burial depth and geotemperature field in Wumishan formation

The figure above mainly indicates the temperature characteristics of Wumishan formation. The figure below mainly shows the buried depth of Wumishan formation. Warm colors represent the areas with shallow buried depth of the roof of the Wumishan formation, while cool colors represent the areas with deep buried depth. Compared with the temperature curve of Wumishan formation, it reflects the geological structure characteristics. In the raised area on the NW and SE side, due to the shallow buried depth of Wumishan formation, the thickness of cap rock is thin, while the formation temperature is low. In the depression, the thickness of cap rock is large and the formation temperature is high. The formation temperature on the south west side is relatively low, which shows the typical characteristics of sedimentary conduction geothermal system.

The above illustrates the relationship between geotemperature field and geological conditions. Zhuojiaying fault, Kangzhuang-Shenjiaying fault and Xishangyuan-Gujiaying fault have established the main tectonic pattern of the study area. Most of the existing geothermal Wells are distributed in the central zone of the fault depression basin. The temperature is generally 60~70℃ and the production is 2000~3000m m^3/d. The formation temperature is mainly controlled by the factors of stratum undulation shape and deposition thickness caused by faults.

4. CHARACTERISTICS OF GEOTHERMAL SYSTEM IN YANQING BASIN

The geothermal system in Yanqing basin is a typical conductive low temperature geothermal system. Geothermal reservoir, cap rocks, permeable structures are essential.

4.1 Geothermal reservoir

Wumishan geothermal reservoir has unique advantages, such as wide distribution and large deposition thickness. This group is the most widely distributed thermal reservoir in Beijing area, accounting for more than 90%. Wumishan formation is a set of magnesium-rich carbonate rocks in the study area, mainly composed of chert banding dolomite, stromatolite dolomite, bituminous dolomite. The Wumishan formation is in unconformity with the overlying Cretaceous - Jurassic strata, and the buried depth of the roof is relatively shallow, ranging from 500 to 2400m. Many fractures and holes in the carbonate strata are formed by developed structures in Yanqing basin. The connected fractures increase the activity of groundwater, enhance karstification, and form a good groundwater channel. Therefore, Wumishan formation is good geothermal reservoir.

4.2 Permeable structures

The NE and NS trending faults are meshed in the basin. Hundreds to thousands of square meters of uplift and depression zones are formed in the basement of basin. This grid connection formed by the NE-trending and NS-trending structure is conducive to supply the uplift fracture zone from deep geothermal reservoir, furthermore, the deep heat flow is conductive and diffused in the whole Yanqing basin. The gird connection forms a better heat conduction and water channels.

4.3 Cap rock

Caprock is a necessary factor in sedimentary geothermal system, which mainly to preserve heat transferred from within the earth's crust. The cap rock is constituted by quaternary and cretaceous - Jurassic strata. They are characterized by low permeability and thicker deposits which is not conducive to thermal conduction or convection in deep strata.

5. CONCLUSIONS

First, Yanqing geothermal field is a conductive, low-temperature, sedimentary system. The cap rocks are Quaternary and Cretaceous - Jurassic strata with average geothermal gradient of 3.37℃/100m and 2.14℃/100m, respectively. The reservoir is Wumishan formation of Jixian system with an average geothermal gradient of 1.36℃/100m. The formation temperature is mainly controlled by the factors of stratum undulation shape and deposition thickness.

Second, the NE and NS trending faults form a grid of connections in the basin. This grid connection is conducive to supply the uplift fracture zone from deep geothermal reservoir and forms a better heat conduction and water channels.

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