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Preliminary Study of Characteristics of Haidian Geothermal Field, Beijing City, China

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ABSTRACT

Geothermal resources have been developing rapidly in Beijing city since 2000, distributed in ten large geothermal areas. Haidian area, an uplift region, is a stable production low-medium geothermal field, which belongs to the northwest geothermal field of Beijing city. There are two main controlling structures: Babaoshan fault and Huangzhuang-Gaoliying fault. It's difficult to prove the characteristics of the Haidian geothermal field because of the urban environment. This paper discusses reservoir, production, temperature, hydrochemistry, as well as other parameters of the Haidian geothermal field by study of the data of geothermal wells in this area. The research shows that the different geothermal conditions are affected by the Babaoshan fault in this area.

1. INTRODUCTION

Geothermal energy is a clean, renewable, and environmentally benign energy source, which stems from the Earth's outward heat-flux. With the rapidly growing demand for energy, and increasing concern for climate change, utilization of geothermal energy is becoming more desirable (Bertani, 2005; Bilgen et al., 2008; Lund et al., 2005). Beijing is the one of the cities that is exploiting and utilizing geothermal resources. The exploration and development of geothermal resources in Beijing basin started in the early 1970s, and has developed rapidly since 2000. The Beijing basin has been mainly divided into ten large geothermal areas (Figure 1) on the basis of geological and geothermal conditions. The total area is about 2,763 km^2. Several small geothermal fields compose these ten geothermal areas.

Geothermal system has several classifications due to different conditions. Based on geological conditions, the main geothermal systems in Beijing basin is sedimentary system. The reservoir temperature depends on geothermal gradients, in other words, heat conduction in formation. Major faults and fractures also play an important role in sustaining the geothermal activity through providing the main flow paths. There were a total of 496 geothermal wells in Beijing City until 2013 and the highest water temperature was 117 ℃ in Fengheying geothermal field.

Haidian geothermal field is a stable production, liquid-dominated, low-medium temperature field, which belongs to the northwest Beijing geothermal field. Geothermal water is used for heating buildings and bathing. The city environment makes it hard to use traditional geological and geophysical methods to find out the geothermal and geological characteristics. This paper discusses the characteristics of Haidian geothermal field by analyzing the data from several geothermal wells.

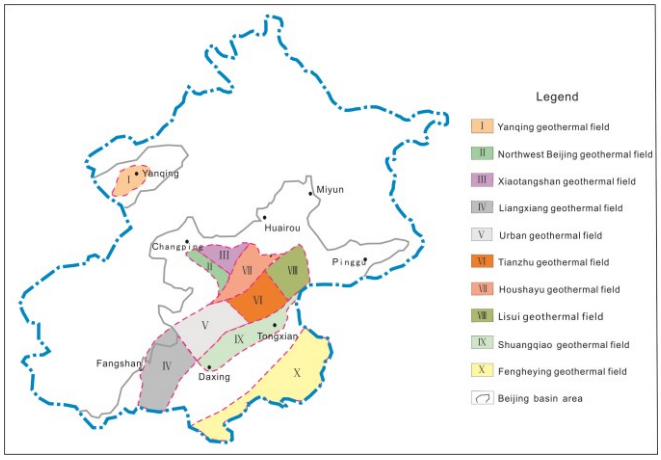


Figure 1. The distribution diagram of Beijing geothermal resources.

2. GEOLOGY SETTINGS OF HAIDIAN GEOTHERMAL FIELD

Haidian geothermal field is located within the city of Beijing, 11 km from the center. Many faults and geology structures formed the complicated geological condition. There are two main SW-NE trending faults controlling the tectonic framework: Babaoshan fault and Huangzhuang-Gaoliying fault. Babaoshan fault extends across the Hadian geothermal field. The northwestern part of Huangzhuang-Gaoliying fault is an uplift region, the southeastern part is a relative depression. Figure 1 shows the basic geological conditions. Generally, there are three geological key factors: geothermal reservoir, cap rocks, permeable structures are essential with sedimentary system.

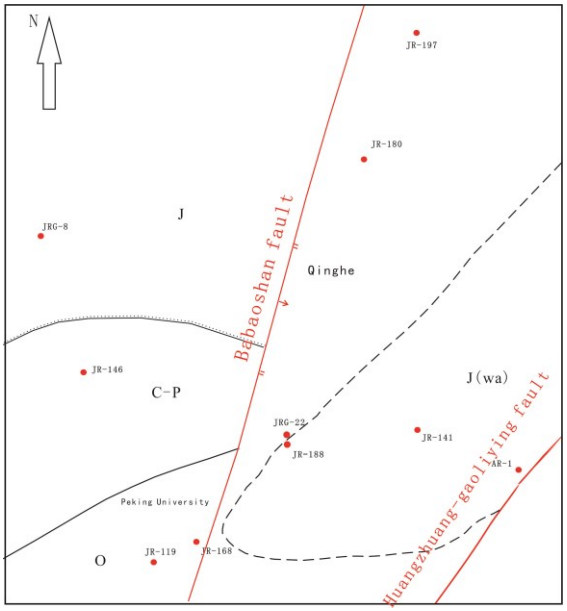


Figure 2. Geological map and location of the wells.

Geothermal reservoir: the reservoir rocks in Haidian geothermal field are mostly dolomite of wumishan formation which belongs to Jixian System (Jx) in middle Proterozoic group. The others are limestone of Cambrian system and Ordovician (∈-O) system. Intensively developed karst is the similar characteristics in these formations.

Cap rock: The formations of Quaternary sediments (Q), Jurassic volcanic rocks (J), and sedimentary rocks of Permo-carboniferous system (P-C), Qingbaikou system (Qn) compose the reservoir cap. Generally, volcanic rocks and sedimentary rocks are low permeability tight rocks. It is an advantage for heat preservation.

Permeable structures: The cross Babaoshan fault in Haidian geothermal field plays an important role. The trend of Baobaoshan fault is SW-NE direction. This fault is characterized by multiperiodic activity and the fault nature varied in different structural stage. In the early stage, it was a great compress-torsional overthrust fault, however, more small normal faults gradually appeared as time change. This characteristic caused a linear fracture zone and broken formation. More flow paths were created. Karstication in reservoir formed a natural environment for geothermal water preserve and migration.

3. SAMPLING AND ANALYTICAL METHODS

The previous study of Haidian geothermal field was limited. The accuracy of geophysical prospecting was a low level because of urban environments. Original data from geothermal wells is particularly important for study of strata and the reservoir. The summary of each well mentioned in this paper in Haidian geothermal field is shown in Table 1. Well JR-119 was the first exploration well to be drilled in 2000. JR-188 and JRG-22 are doublets.

Table 1. The summary information of wells in Haidian geothermal field.

Well No.	Year drilled	Depth (m)	Temperature (℃)	Capacity (m^3/d)
JR-119	2000	3168	59	2232
JR-141	2003	3671	53	2409
JR-146	2003	3508	59	1979
AR-1	2004	3326	53	2016
JRG-8	2004	2300	36	1965

JR-168	2005	3218	63	2555
JR-180	2009	3406	60	1441
JR-188	2009	3018	55	2409
JR-197	2009	3608	55	1328
JRG-22	2010	3088	55	2296

3.1 Sampling

Sampling and analysis are essential in the characterization of geothermal field in primary stage. Good quality samples was demanded in order to obtain valuable information. In this study, water fluid samples from these geothermal wells were analyzed for chemical compositions, and cuttings were collected for determining the stratigraphic sequence.

Water samples from these ten wells were collected into test bottles during the discharge, and preserved accordingly. Drilling cuttings from the rock formations were collected every two meters. The cuttings were cleaned and dried at the rig-site. Representative species were picked out for rock-mineral determination.

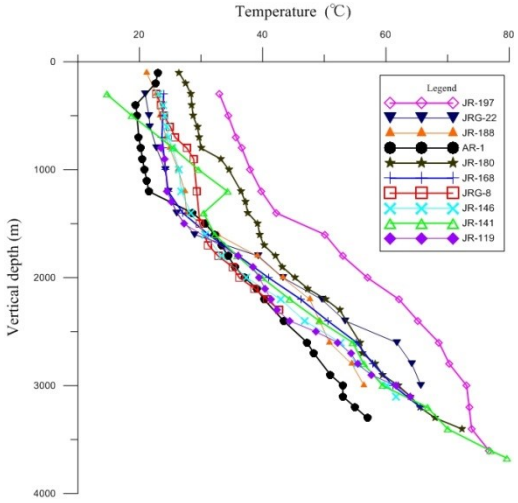


Figure 3. Formation temperature curves of ten wells in Haidian field.

3.2 Analytical methods

Geophysical logs are highly advanced techniques to detect the changes of physical characters of strata. The aim of well logging is to study the well, and obtain more information of boreholes and the reservoir. Apparent resistivity, SP, gamma-ray, inclination, and temperature logs were performed by BIGPE (Beijing Institute of Geological and Prospecting Engineering). Temperature log data was widely used in this study. Because temperature log in boreholes provides a wide variety of information on, for example, the geothermal gradient and heat flow, the effect of aquifer flow on subsurface temperatures, and the mechanics of fault zones (Helm-Clark et al., 2004). Figure 2 shows the relation of measured temperatures and depth of ten wells in Haidian geothermal field.

Complete water quality analysis was carried out at BIGPE lab for individual chemical components in liquid samples. Representative chemical compositions in this study are Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4, HCO^{-}, SiO_2.

4. RESULTS AND DISSCUTION

4.1 Temperature maps and cross-section

Based on the formation temperature from these ten geothermal wells, six maps at 500, 800, 1400, 1800, 2600, 3000 m b.s.l. (Figure 3) and one vertical cross-section (A-A') (Figure 4) were constructed so as to evaluate the temperature distribution of the geothermal field. The A-A' cross-section was drawn in nearly E-W direction which cuts through JR-119, JR-168, JR-188, JR-141, AR-1 and Baobaoshan fault.

Temperature maps in Figure 3 indicate that the temperature increased in a northeast direction, which appears to be the location of the up-flow zone, whereas on the southwestern part of Baobaoshan fault, the temperature decreased, which indicates that there seems be a cold flow pattern.

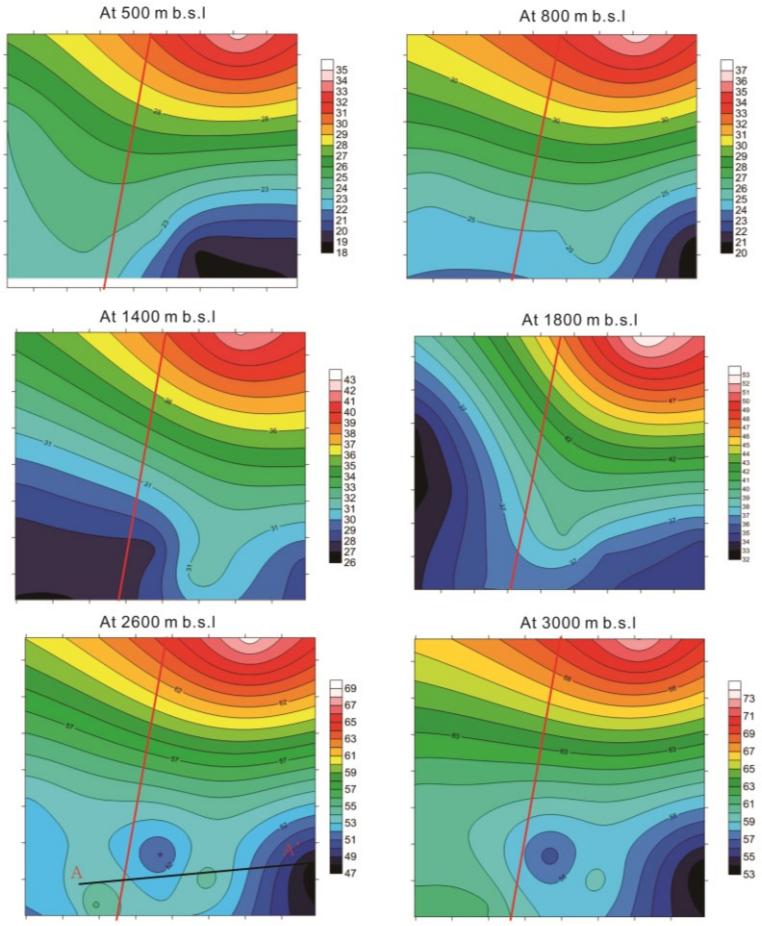


Figure 4. Temperature maps at 500 m, 800 m, 1400 m, 1800 m, and 3000 m b.s.l. (red lines represent Baobaoshan fault, A-A' is the vertical cross-section).

The consistent result can also be observed from the vertical section A-A' in the east of Babaoshan fault (Figure 4). The temperature declined from JR-141 towards AR-1 direction and east axis. It proved there exists a cold pattern, probably due to the cold aquifer of Wa conglomerate formation in shallow depths. Wa conglomerate formation appears between 300-1500 depths in well JR-188, JR-141, AR-1. This formation was principally formed at late Jurassic. The composition of the rock is similar to J*xw* formation, mostly dolomite and limestone. The hydraulic connection with surface water and lithologic character leads to be a great water-bearing layer. Lost circulation frequently occurred while drilling through this formation. Therefore, the temperature distribution of Haidian geothermal field is great affected by Wa conglomerate formation. The west boundary of Wa conglomerate formation BaoBabaoshan fault is controlled by Babaoshan fault. This caused that Wa conglomerate formation only exists in the southeast part of Babaoshan fault resulting in lower formation temperature in the field due to the rock characteristic. Also, a large fracture belt produced by an overthrust fault is easily recharged by precipitation and cold water in shallow formation. The result is a lower geothermal gradient in the whole field by comparison with other geothermal fields in Beijing.

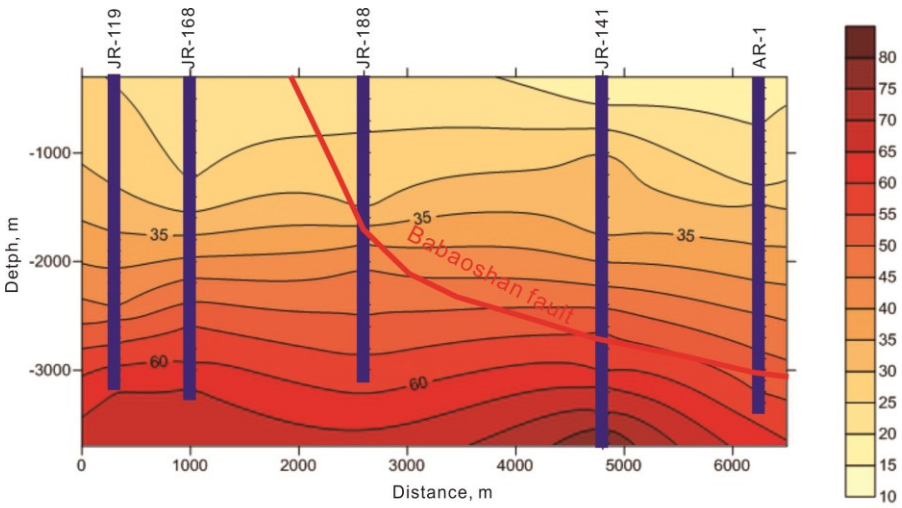


Figure 5. Vertical cross-section A-A' for temperature.

4.2 The chemical characteristics of the thermal water

The relative of chemical compositions of the water fluids from ten geothermal wells are shown in Figure 5. The hydrochemical characteristics were objectively reflected in this field. The water from JR-119, JR-168, JR141, AR-1, JR-188, JRG-22, JR-180, JR-146 were Ca-HCO_3 type, and water from JRG-8, JR-188 were Na-SO_4 type.

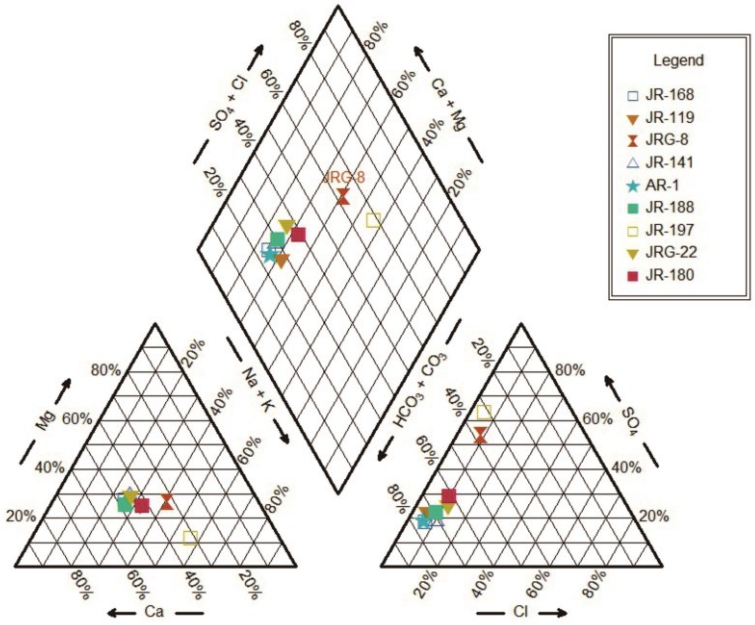
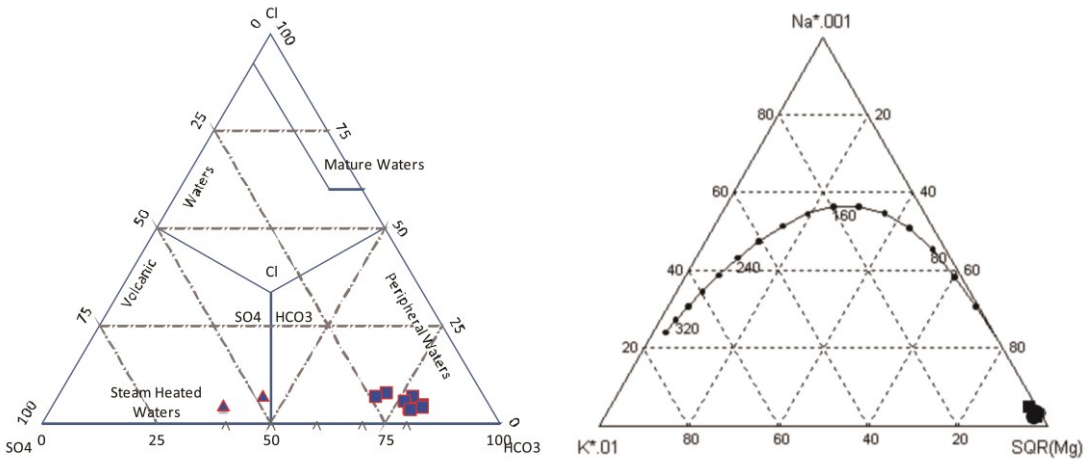


Figure 6. Piper diagram of water samples from Haidian geothermal field.

The Cl-SO_4-HCO_3 ternary diagram (Giggenbach, 1991) is commonly used for initial classification of the thermal fluids. The diagram indicates several types of geothermal water. Figure 6 shows most of samples plot in the peripheral regions, plots for samples from JRG-8, JR-197 in steam regions. Concerning the piper diagram, it was proved that the water from Haidian geothermal field can be divided into two types. Different geology conditions or effect by other vertical geothermal reservoirs probably caused the results.

The Na-K-Mg ternary diagram (Giggenbach, 1988) is used for evaluating equilibrium between the thermal waters and rock formations. The results are shown in Figure 7. All the samples plot in the immature water region. The element accumulation of magnesium indicates that a cooling effect occurred in the upflow zone. Apparently, the Na-K geothermeter is not valid. The Na-K-Ca cation geothermeter was considered because it is a competitive geothermeter for cold thermal.



Figures 7 and 8. (7) the Cl- The Cl-SO_4-HCO_3 ternary diagram for waters from Haidian geothermal field. (8) Plot of relative NA-K-Mg components of wells in Haidian geothermal field.

4.3 Geothermometry

Geothermometry is widely used in the whole process of geothermal field development for estimating and monitoring the subsurface temperature of the reservoir. Equilibrium between minerals, solutions, and chemical composition changes each contribute to different geothermometers. In this study, SiO_2 geothermometry and cation geothermometry were calculated to estimate the subsurface temperature, based on the equilibrium that was attained in the geothermal reservoir. The comparsion results to the measured temperatures are shown in Table 2.

Table 2. Results of different geothermometers from Haidian geothermal field.

Well no.	T_{qrz} [1]	T_{qrz} [2]	T_{Chal} [1]	$T_{Cristobalite}$ [1]	$T_{Na\text{-}K\text{-}Ca}$ [1]	$T_{K\text{-}Mg}$ [2]	T_{meas}
JR-168	92.22	94.25	61.63	42.04	58.42	68.48	63
JR-119	88.83	91.29	58.02	38.74	60.94	67.28	59
JRG-8	62.95	68.51	30.85	13.82	55.15	54.25	36
JR-141	82.85	86.07	51.68	32.94	61.90	68.70	53
AR-1	80.55	84.06	49.25	30.72	54.92	64.64	53
JR-188	89.53	91.91	58.77	39.43	57.83	68.21	55
JR-197	91.01	93.19	60.33	40.86	63.94	66.63	55
JRG-22	94.44	96.18	63.99	44.21	55.82	63.42	56
JR-146	89.27	91.68	58.49	39.17	58.75	69.88	59
JR-180	94.93	96.60	64.51	44.68	69.97	64.05	60

1) Fournier (1981); 2) Giggenbach (1988).

From Table 2, the estimate temperatures by Chalcedony geothermometer and Na-K-Ca cation geothermometer are reasonable.

5. CONCLUSION

1) Higher temperature formations are in the northeastern part of Haidian geothermal reservoir.

2) Formation temperatures of Haidian geothermal field decline from Babaoshan fault to southeastern part are due to rock characteristic of Wa conglomerate formation. Babaoshan fault plays an important role in Haidian geothermal field. The west boundary of Wa conglomerate formation is controlled by Babaoshan fault.

3) The main water type of geothermal water in Handian geothermal field is Ca-CO_3 type. Two types of geothermal water exist in Haidian geothermal field. Chalcedony geothermometer and Na-K-Ca cation geothermometer are credible for estimate of the reservoir temperature.

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