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Genetic Mechanism and Development Prospects of Gaoyang Geothermal Field and Its Adjacent Areas

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ABSTRACT

As a green and renewable energy, geothermal energy plays an important role in solving the pollution problem in Northern China. Gaoyang Geothermal Field, near Xiong'an New Area, is rich in geothermal resources. It is located in Jizhong Depression of Bohai Bay Basin, at carbonate strata of Jixian system and Changcheng system of Mesoproterozoic and the underlying stratum of Archean. Among them, the Wumishan Formation of Jixian System is the main stratum where Gaoyao Geothermal Field karst reservoirs developed. The buried depth of the top of karst reservoirs of 3600m is the boundary of Gaoyao Geothermal Field. The main body of Gaoyang geothermal field is located in Gaoyang low basal bulge, Lixian Slope and covers a small area of Baoding Sag and Raoyang Sag. Gaoyang geothermal field locates in the area with high karst reservoirs top surface temperature. Temperatures of the middle and northern part of Gaoyang low basal bulge, the western boundary and the junction area of Lixian Slope and Raoyang Trough can reach as high as 120°C, meanwhile the temperature of southern part of the geothermal field and the middle and eastern part of Lixian Slope is lower than 100°C.The density of temperature contours are similar in each direction, with the Northeast-Southwest direction are sparser than the Northwest-Southeast Direction. The hydrochemical characteristics of geothermal water of Wumishan Formation of the Jixian System in Boye Area is Cl-Na type, and its total dissolved solids (TDS) is about 5000mg/l. The content of Cl^- (2300mg/l) is obviously higher than Xiongxian, Rongcheng, while the content of $SO4^{2-}$ (123-133mg/l) is higher than Jizhong Depression's Xiongxian, RongCheng, Bazhou, but lower than Tianjin geothermal field, Liangxiang geothermal field. This implies that Jizhong depression belongs to a different geothermal system from Tianjin, Liangxiang area. The conceptual model of Gaoyang geothermal field suggests that the atmospheric precipitation of Taihang Mountain is the supplier of groundwater and the piedmont fault of Taihang Mountain connects the atmospheric precipitation with the reservoirs. Atmospheric precipitation flows through piedmont fault, Hengshui Fault, Anguo Fault, Baichi Fault and through unconformities, and migrates to Gaoyang low basal bulge, Lixian Slope and Shenze low basal bulge, where it formed traps. The water is then heated by heat convection when it flows through faults and bedrocks, and forms the Gaoyang geothermal field. The Gaoyang geothermal field has a great potential and it is worth for exploration and exploitation.

1. INTRODUCTION

Geothermal energy is a green, low-carbon, and renewable energy. When compared with wind energy and solar energy, geothermal energy is not affected by seasonal factors, climate, day and night changes, etc., and can be used efficiently (Li and Wang, 2015). What's more, geothermal energy is of great significance for improving energy structure and solving environmental problems (Zhuang, 2010).

According to their temperature, geothermal resources can be divided into three types: high temperature (>150°C), medium-to-low temperature (90-150°C) and low temperature geothermal resources (<90 °C) (Yan et al., 2009). Controlled by plate tectonics, China is rich of medium-to-low temperature geothermal resources. Considered the population distribution and climatic conditions of China, the development of medium-to-low temperature geothermal energy is mainly concentrated on sedimentary basins in North China and other regions, and mainly used for direct utilization such as space heating, hot spring bath, greenhouse planting and aquaculture feeding. In recent years, heating in winter has caused serious air pollution and haze. With the implementation of relevant policies to encourage the use of renewable energy to replace the burning of coal as heating source in winter, the development and utilization of geothermal energy will get more and more support from government and related companies.

The Xiong'an New District, to which belong the nearby geothermal fields of Niutuozhen, Rongcheng and Gaoyang, is one of the most abundant resource areas of the Beijing-Tianjin-Hebei Plain. Thus, the use and development of geothermal energy can provide clean and stable heat for Xiong'an New District. Currently, there have been many studies on geothermal resources of Niutuozhen geothermal field and Rongcheng geothermal field (Chen et al., 1982; Guo and Li, 2013; Wang et al., 2013; Kong et al., 2014, 2017; Li et al., 2014; Pang et al., 2014; Wang et al., 2016; Li et al., 2017; Pang et al., 2018; Yang et al., 2018), but relatively few research on the Gaoyang geothermal field and even its extension has not been scientifically defined, which can hardly guide its scientific development. For this reason, this paper focuses on the study of regional structure, and the stratigraphic, geothermal and hydrochemical characteristics of the Gaoyang geothermal field. Combined with the latest geothermal exploration results, its genetic model is analyzed, which can provide a reference for further development of this geothermal field.

2. GEOLOGICAL BACKGROUND

Previous studies generally believed that Gaoyang geothermal field is located in the Gaoyang low basal bulge and its adjacent areas, but its specific location is not given (Zhang, 1998; Liang et al., 2010; Liu et al., 2013; Liu et al., 2018). Actually the Gaoyang geothermal field is located in Jizhong Depression (Grade II), Bohai Bay Basin North China Plate (Grade I; Yang and Xu, 2004) (Fig. 1).

Gaoyang low basal bulge is generally distributed in northeast direction, and its west side is connected with Baoding trough (Han et al., 2017), while its east side is connected with Raoyang trough (Lixian slope) (Yu et al., 2017). The buried carbonate strata mainly include the Changcheng System and Jixian System of Mesoproterozoic, and the underlying strata of Archean. Through analyzing seismic sections, we conclude that the major faults of Gaoyang low basal bulge are the piedmont of Taihang Mountain on the west side and the Masi fault on the east side. The piedmont of Taihang Mountain was formed during the sedimentary period of the Sha IV section of Kongdian Formation, and meanwhile the west wing of the Gaoyang low basal bulge rotated. The formation of Masi fault was relatively late, and it was strongly active during the sedimentary period of the Sha III section of Kongdian Formation. Meanwhile, the east wing of the Gaoyang low basal bulge rotated. At that time, a complete uplift shape of Gaoyang low basal bulge was formed. Subsequently, it was transformed through a series of secondary faults and finalized.

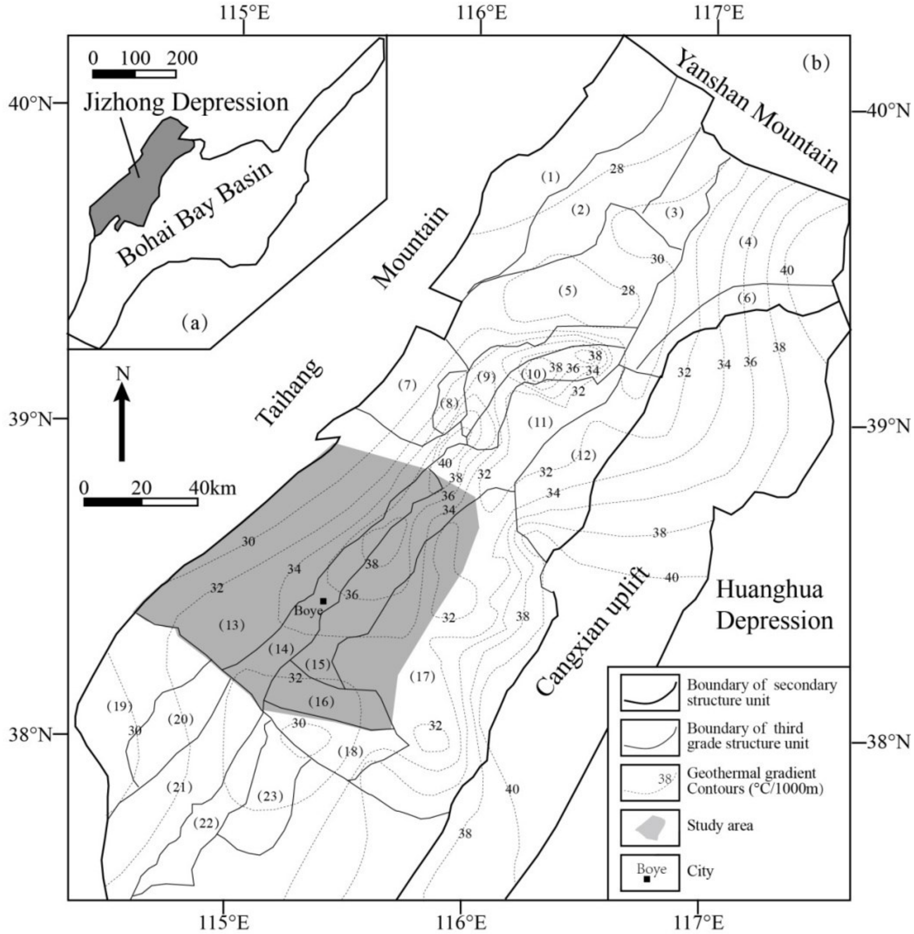

Figure 1: (a) Location of Jizhong Depression of Bohai Bay Basin. (b) Tectonic units and isothermal map of present-day geothermal gradients of Jizhong Depression, showing the location of Gaoyang Geothermal Field (modified from Chang et al., 2016).

(1) Beijing trough; (2) Daxing basal bulge; (3) Dachang bulge; (4) Wuqing bulge; (5) Langgu trough; (6) Yangcun slope; (7) Xushui trough; (8) Rongcheng basal bulge; (9) Niubei slope; (10) Niutuozhen basal bulge; (11) Baxian trough; (12) Wenan slope; (13) Baoding trough; (14) Gaoyang low basal bulge; (15) Lixian slope; (16) Shenze low basal bulge; (17) Raoyang trough; (18) Shenxian trough; (19) Shijiazhuang trough; (20) Wuji-Gaocheng low basal bulge; (21) Jinxian trough; (22) Ningjin basal bulge; (23) Shulu trough.

Strata of the Cenozoic, Cambrian and Ordovician of the Lower Paleozoic, the Jixian System and Changcheng System of Mesoproterozoic, and granite and metamorphic rocks of the Archean, were developed in Gaoyang geothermal field and its surrounding areas. Strata of upper Proterozoic, Paleozoic and Mesozoic that were deposited above the Wumishan Formation of the Jixian System, were partially denudated (see Table 1, Figure 2).

Strata of Quaternary to Guantao Formation of the Neogene are distributed throughout the region, with a thickness of 2000m. These strata show unconformity contact with strata of Paleogene. The strata of Paleogene include the Dongying Formation, the Shahejie Formation and the Kongdian Formation. The sedimentation scope of them covers the entire study area, with an average thickness of about 2000m and the thickest area can reach 3000m. Strata of Paleogene are in unconformity with the Wumishan Formation of the Jixian System, and with strata of Cambrian and Ordovician. The Wumishan Formation is distributed in the central and northern parts of Gaoyang geothermal field, and the strata of Cambrian are mainly distributed in the middle, while strata of Ordovician are distributed in the south. The underlying layers include the Yangzhuang Formation and the Changcheng System which are partially distributed in Gaoyang geothermal field, with a thickness of about 3000m. Layers of Archean are partially distributed within the study area, which are overlaid by the Changcheng System.

Table 1: Lithology and stratigraphy of Gaoyang Area

<table>
<tr><th colspan="3">Stratigraphic System</th><th>Lithology</th></tr>
<tr><td colspan="3">Cenozoic</td><td>Gray-black, gray-green mudstone</td></tr>
<tr><td colspan="3">Ordovician</td><td>A large suite of dolomite, mud-limestone, dolomite-limestone</td></tr>
<tr><td colspan="3">Cambrian</td><td>Dolomite, Oolitic limestone, brown-red mudstone, dolomite-limestone</td></tr>
<tr><td rowspan="7">Mesoproterozoic</td><td rowspan="2">Jixian System</td><td>Wumishan Formation</td><td>A large suite of dolomite, mud-limestone, siliceous-dolomite with shale, dolomite-limestone</td></tr>
<tr><td>Yangzhuang Formation</td><td>Gray, pale red dolomite, with gray, light color mud-limestone, siliceous-dolomite</td></tr>
<tr><td rowspan="5">Changcheng System</td><td>Gaoyuzhuang Formation</td><td>Gray, gray-brown, pale red (mud) dolomite, dolomite-limestone, with siliceous-dolomite, shale</td></tr>
<tr><td>Dahongyu Formation</td><td>Gray, gray-brown, mauve dolomite, siliceous-dolomite, with siltstone-sandstone, and trachyte in the middle parts</td></tr>
<tr><td>Tuanshanzi Formation</td><td>Gray, charcoal grey mud-limestone with dolomite, gray sandy-dolomite in the bottom</td></tr>
<tr><td>Chuanlinggou Formation</td><td>gray, grey-black shale, carbonaceous-mudstone, sandy-mudstone with sandstone, sandy-mud-dolomite</td></tr>
<tr><td>Changzhougou Formation</td><td>Greyish white, gray, pale red sandstone, quartz sandstone, with shale and dolomitic rock in the upper part</td></tr>
<tr><td colspan="3">Archean</td><td>Gray, pale red granite, and metamorphic rocks</td></tr>
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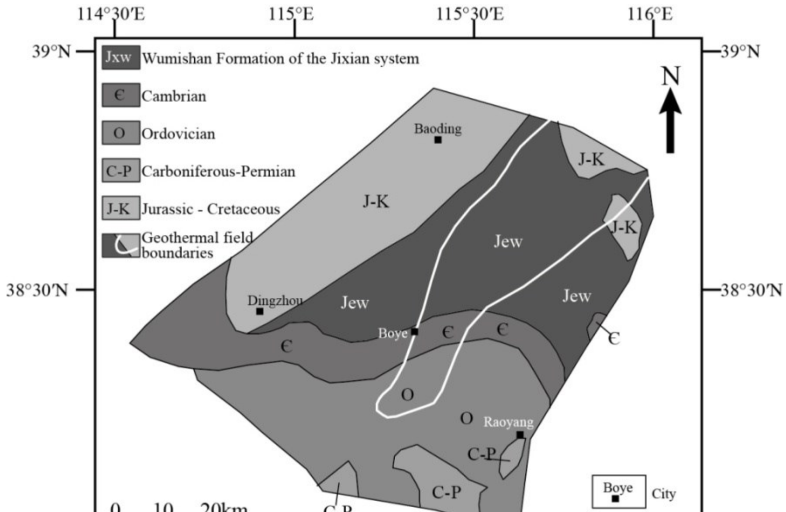

Figure 2: Distribution of pre-Paleogene strata in Gaoyang Geothermal Field.

Pre-Mesozoic rocks of Gaoyang low basal bulge and its adjacent areas mainly include strata of Archean, the Wumishan Formation of Mesoproterozoic, as well as strata of Cambrian, Ordovician, Carboniferous-Permian. Among them, the Wumishan Formation is mainly developed in the northern part of Gaoyang geothermal field, and the Cambrian rocks are exposed in the middle. Ordovician rocks are in the southern part, while strata of Carboniferous-Permian are in the southern tip of the geothermal field. The karstic rocks mainly include Archean strata, the Wumishan Formation of Mesoproterozoic, and strata of Cambrian and Ordovician, among which is the Wumishan Formation in the northern part, Cambrian rocks in the middle, and Ordovician rocks in the southern part. All of them have potential to contain geothermal resources.

The main faults developed in Gaoyang low basal bulge and its surrounding areas mainly include Hengshui fault, Gaoyang fault, Anguo fault, Chu’an fault and Baichi fault. Among them, the Gaoyang fault and the Anguo fault are nearly parallel, with NW strike. The Gaoyang fault affects the Wumishan Formation, and the Anguo fault is affecting Paleogene strata. The Baichi fault and the Chu’an fault are inclined to the southwest. The Baichi fault is cutting the Wumishan Formation (Fig. 4). The Hengshui fault strikes to the northeast, intersects the Anguo fault, and ends at the Xushui-Baoding-Shijiazhuang fault in the northwest.

According to the Geologic Exploration Standard of Geothermal Resources (GBT11615-2010), geothermal field refers to "regions that have a certain quantity and quality of geothermal resources, confirmed by geothermal exploration, which can be economically developed". Their geology and tectonic features are not emphasized. In the exploration practice, the buried depth of the probable geothermal reservoir is one of the most important factors to determine the cost of development. Therefore, this paper takes the data of the deepest geothermal well in the study area as the reference, and defines the deepest buried depth of the top of karst thermal reservoir in 3600m. Geothermal resources beyond this depth are difficult to develop because of economic hurdles, and then are not considered as part of the Gaoyang geothermal field.

The Gaoyang geothermal field was defined by data from the surrounding oil and gas wells and by the depth of the top of the karst thermal reservoir. Accordinly, the field is mainly located in the Gaoyang low basal bulge, the Lixian slope, and covers a small area of Baoding and Raoyang troughs (Fig. 3). The north limit of Gaoyang geothermal field is the Niutuozhen uplift, its northeast limit is the Baxian trough, its south boundaries are the Shijiazhuang and Shenxian troughs, while its east side is the eastern part of the Raoyang trough. The marine karst reservoirs of the Wumishan Formation of Mesoproterozoic, and the Cambrian and Ordovician layers of Lower Paleozoic present large thickness and are widely distributed, thus, they are important thermal reservoirs in the Gaoyang geothermal field.

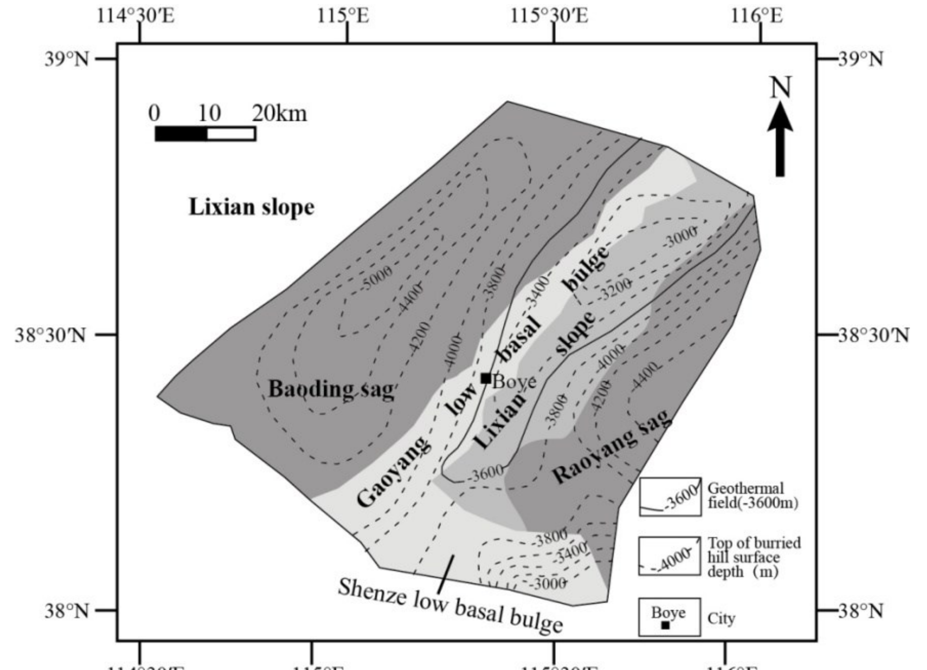

Figure 3: Contour map of the top of karst reservoirs in the study area.

Marine carbonate rocks are widely exposed in the Gaoyang geothermal field. The thermal reservoirs are the Wumishan Formation of Jixian System and the rocks of Cambrian and Ordovician systems. The buried depth of the top of karst thermal reservoir is between 3000-3300m. The buried carbonate rocks are from the Wumishan Formation, and from strata of Cambrian and Ordovician, from north to south.

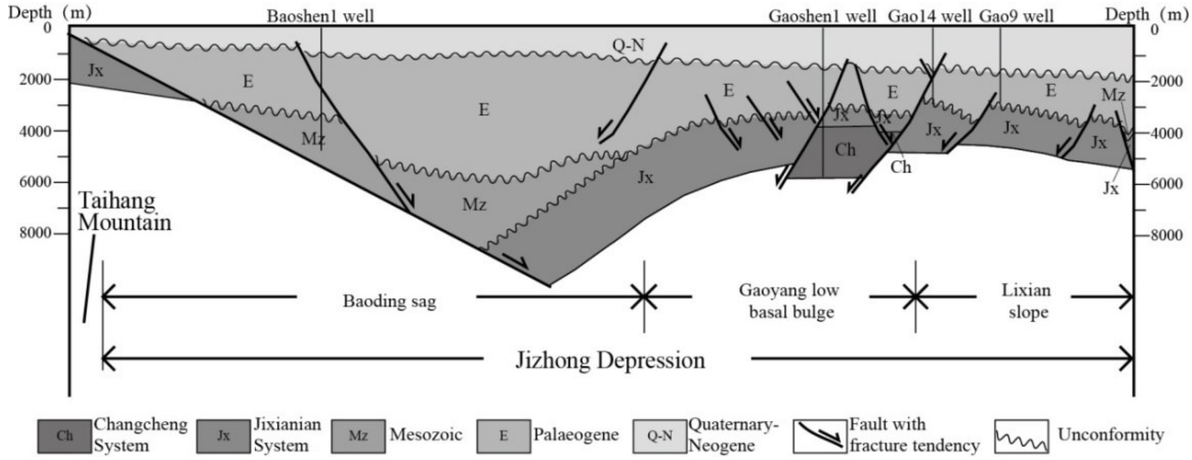

Figure 4: Geological cross section of structural units of the Gaoyang Geothermal Field.

The lithology of the Wumishan Formation is dominated by dolomite, with a few dolomite-limestone. After a long geological history of erosion, weathering and leaching, structural fractures, structural dissolution fractures, intergranular dissolution pores, inter-crystalline dissolution pores, algae framework pores, dissolution pores and karst caves were quite developed. The porosity of reservoir is mainly distributed below 6.0%, with an average of 3.5%-4.5%. The range of permeability varies greatly, from 0.01 to 1000mD, and 87.8% of them distributed between 0.01 and 100mD, with average permeability of 35-40mD. Therefore, the karst-fracture reservoirs of the Wumishan Formation can be defined as high porosity and high permeability reservoirs. From the viewpoint of karst facies, the Wumishan reservoirs are mainly developed in the percolation zone and water underflow zone. In terms of sedimentary facies, the Wumishan reservoirs are mainly developed in the upper part of the subtidal zone to the intertidal zone, with algal reef and algal mats widely developed. The current features of the thermal reservoirs are combined effects of sedimentary facies and karstification.

The lithology of Cambrian and Ordovician strata is also mainly dolomitic, with a few dolomite-limestone. After a long geological history of erosion, weathering and leaching, structural fractures, structural dissolution fractures, intergranular dissolution pores, inter-crystalline dissolution pores, algae framework pores, dissolution pores and karst caves were quite developed in these rocks. The average porosity of reservoir is 4% to 5%. The range of permeability varies greatly, from 0.01 to 1000mD, and mainly distributed between 0.01 to 100mD, with an average of 35-40mD. Therefore, the karst-fractures reservoirs of the Cambrian and Ordovician can be defined also as high porosity and high permeability reservoirs. From the viewpoint of karst facies, reservoirs of Cambrian and Ordovician are mainly developed in the percolation zone and water underflow zone. In terms of sedimentary facies, the Cambrian and Ordovician reservoirs are mainly developed in the tidal flat sub-facies, with limestone flats developed most, then the dolomite flats, then limestone-dolomite flats. However, reservoirs are not developed in mud limestone flats and open-sea facies. This is due to the fact that secondary pores, which provide space for fluids migration, are not usually developed in the mud flats and open sea. Therefore, the characteristics of the current thermal reservoirs of the lower Paleozoic are the combined results of favorable sedimentary facies and karstification.

The thickness of thermal reservoirs of Gaoyang geothermal field reach its maximum in the middle part, to more than 700m and reduced to the north and to the south, to less than 200m. The largest porosity and permeability are in Boye area which is the central part of Gaoyang geothermal field, and its porosity can be as high as 5%, while its permeability can be as high as 30mD. Both decrease to the northwest, southwest, and northeast. In the areas of Baoding and Dingzhou, porosity is less than 2% and permeability is less than 5mD, while in Raoyang the porosity is less than 3% and permeability is less than 10mD.

3. GEOTHERMAL FIELD AND RESERVOIRS DISTRIBUTION CHARACTERISTICS

Using the temperature data of regional geothermal wells and oil wells, the isothermal map of the top of karst thermal reservoirs of Gaoyang geothermal field was drawn (Fig. 5). It can be seen that Gaoyang geothermal field is located in a region with a high temperature of karst thermal reservoir. The northwest part of Gaoyang geothermal field belongs to the middle and north part of Gaoyang low basal bulge, while the northeast part belongs to the junction areas of Lixian slope and Raoyang trough. These two parts are the highest temperature areas of Gaoyang geothermal field, up to about 120°C.The southern, central and eastern part of geothermal field belong to Lixian slope with temperatures below 100°C. The temperature contours in all directions are similar, with the northeast-southwest direction is sparser than that of the northwest-southeast direction. This suggests that temperature changes rapidly in the northwest-southeast direction, and water supply may come from Taihang Mountain in the northwest.

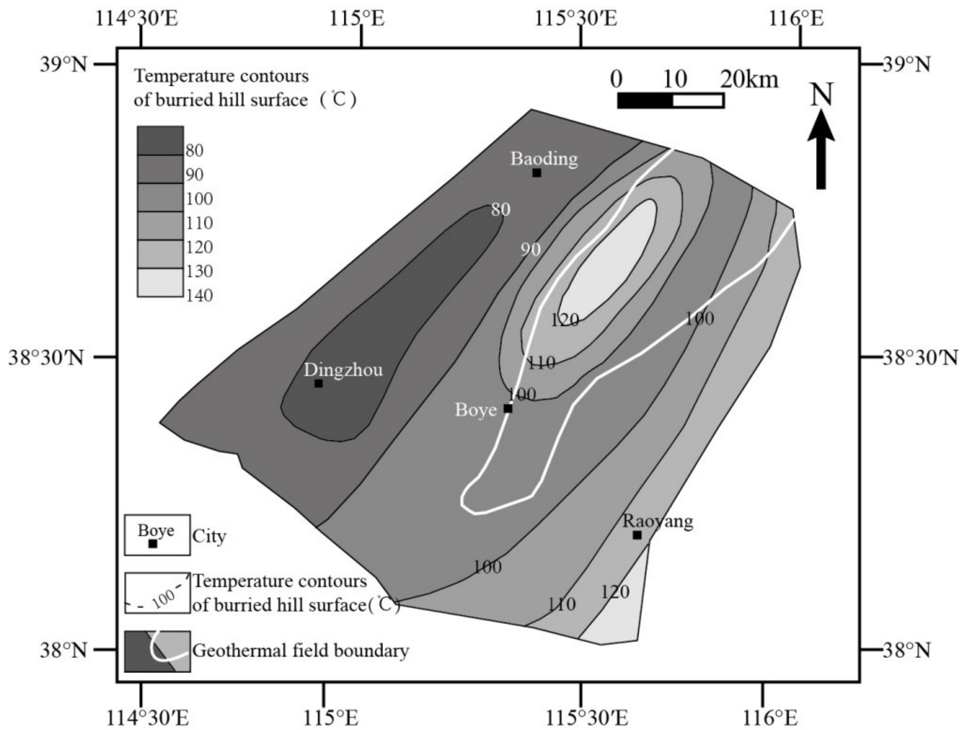

Figure 5: Contour map of the temperature of karst reservoirs of Gaoyang Geothermal Field.

4. HYDROCHEMICAL CHARACTERISTICS OF GEOTHERMAL WATER

The hydrochemical characteristics of the geothermal water of Wumishan Formation of Jixian System in Boye area is Cl-Na type (Fig. 6), which is similar to the Niutuozhen geothermal field (Xiongxian), Rongcheng geothermal field and Bazhou geothermal field in Jizhong depression. However, it is different to the Tianjin Geothermal field in Cangxian Uplift (mainly Cl•SO_4^-Na type; Yang et al., 2018) and Liangxiang geothermal field in Beijing depression (HCO_3•SO_4-Ca•Na•Mg type; Liu et al., 2015). Two geothermal wells in Boye area were drilled about 500-600m into the Wumishan Formation reservoir, and the total dissolved solids was about 5000mg/l. Combined with data of local geothermal wells and oil boreholes (Fig. 7), the total dissolved solids of Wumishan Formation reservoirs of Gaoyang geothermal field is 5-6g/l.

As result of the analysis of geothermal water of the Wumishan Formation of Jixian System in Xiongxian, Rongcheng, Bazhou, Liangxiang, and Tianjin, we conclude that the total dissolved solids (about 5000 mg/l) and content of Cl^- (about 2300 mg/l) in the Boye area is significantly higher than that of other regions. The content of SO_4^{2-} (123 to 133 mg/l) is higher than that of Xiongxian, Rongcheng and Bazhou in the Jixian depression, but lower than that of Tianjin and Liangxiang geothermal fields (Table 2). Based on those analysis, we speculate that the geothermal water of the Wumishan Formation in Jixian system of different areas has similar hydrochemical characteristics, but present significant difference with Liangxiang and Tianjin areas. This shows that they belong to different geothermal systems. In the Jizhong depression, Boye is located on the south side of Rongcheng, Xiongxian and Bazhou, with higher total dissolved solids and content of Cl^- , indicating that water may come from the north side. In Rongcheng, Xiongxian and Bazhou areas which have similar latitudes, the total dissolved solids and content of Cl^- of Wumishan Formation of Jixian System is gradually increased from west to east, which may suggest that there is a large proportion of water supply from the west to the east in the northern part of the Jizhong depression.

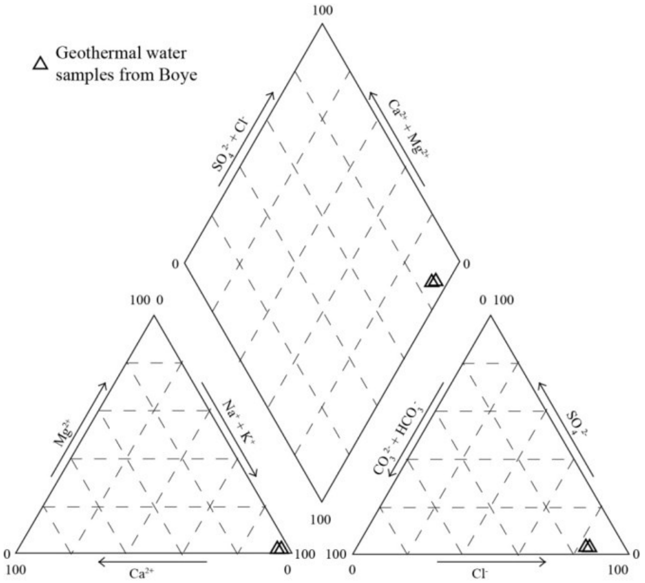

Figure 6: Piper Trilinear Diagram of Geothermal Fluids

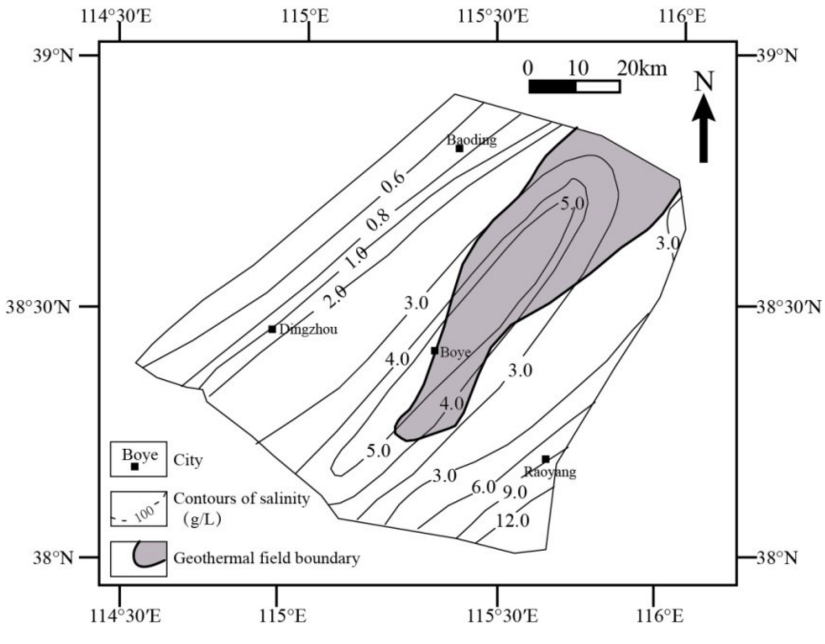

Figure 7: Contour map of total dissolved solids of karst reservoirs of Gaoyang Geothermal Field

Table 2: Hydrochemical characteristics of geothermal water of Wumishan Formation of Jixian System of Boye and its adjacent areas in Gaoyang low basal bulge (unit: mg/l)
(Analysis of Boye, Xiongxian and Rongcheng by Sinopec Key Laboratory of Geothermal Exploitation and Utilization.)

Sample Number	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	TDS
No.1 of Boye	46.5	17.4	1604	144.9	613.1	2314	98.7	5073
No.2 of Boye	66.7	17	1565	154.3	670.5	2251.6	90.2	4629.7
Mean and median of 42 geothermal wells in Xiongxian	46.1/ 47.2	26.1/ 26.5	908.8/ 912.9	62.5/ 62.4	599.2/ 632.3	1174.2/ 1137.9	9.6/ 8.65	2625.0/ 2631.5
Mean and median of 17 geothermal wells in Rongcheng	59.2/ 59.4	31.5/ 30.8	798.4/ 800.3	47.0/ 44.4	699.5/ 703.6	1061.8/ 1055.2	9.1/ 7.7	2549.0/ 2494
Mean and median of 4 geothermal wells in Bazhou	47.7/ 40.5	28.1/ 22.1	961.4/ 959.3	55.0/ 53.8	427.9/ 431.8	1472.4/ 1418.7	5.9/ 5.9	3016.3/ 2845
Mean and median of 6 geothermal wells in Tianjin	37.6/ 35.6	12.3/ 12.8	479.9/ 484.5	76.4/ 72.3	389.7/ 391.5	435.4/ 427.6	338.1/ 344.6	1843.3/ 1863.4
Mean and median of 2 geothermal wells in Liangxiang	67.2	24.3	67.3	9.9	274.0	38.8	128.0	620.0

5. GENETIC MODELS

Combined with the regional tectonic analysis, the geothermal water of the Gaoyang geothermal field was mainly transported through faults and unconformities. The faults that developed in this geothermal field, like faults Hengshui, Anguo, Gaoyang, Chu'an and Baichi, were important channels for geothermal water migration. At the same time, the piedmont fault of Taihang Mountain - Xushui-Baoding-Shijiazhuang fault also played an important role. Geothermal water of the thermal reservoirs was infiltrated from in Taihang Mountain and it was through this fault that the atmospheric precipitation was connected with the heat sources and then heated.

The Cenozoic strata were directly deposited on the Wumishan Formation in Gaoyang area, and the weathering crust that acted as unconformity was a transport layer, providing an advantageous channel for the flow of geothermal water.

In summary, the conceptual model of the formation of Gaoyang geothermal field was depicted as shown in Figure 7. The rain in the western side of Taihang Mountain is the origin of groundwater. The piedmont fault of Taihang Mountain connected the atmospheric precipitation and thermal reservoirs. The water passed through it and the other faults (Hengshui, Anguo, Baichi, Chu'an) and some unconformities, and finally was transported to the Gaoyang low basal bulge, Lixian slope, Shenze low basal bulge, etc., and formed traps. Geothermal water was heated by heat convection through the process of flowing through faults and bedrocks and formed the Gaoyang geothermal field with a high potential of development.

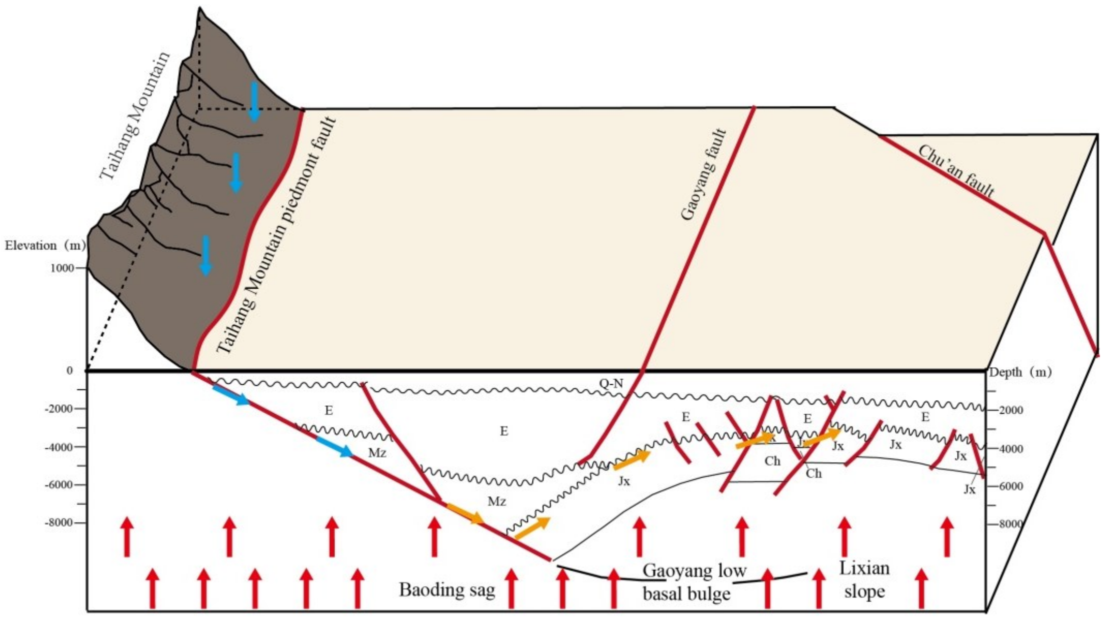

Figure 8: Genetic model of Gaoyang Geothermal Field

6. CONCLUSIONS

(1) Geotectonically, the Gaoyang geothermal field is located in the Jizhong depression of the Cenozoic rift basins of North China Plate. The 3600m line of the top of the karst thermal reservoirs can be defined as the boundary of the Gaoyang geothermal field, and its main body is located in the Gaoyang low basal bulge and the Lixian Slope, and covers a small area of Baoding and Raoyang troughs.

(2) The Wumishan Formation of the Mesoproterozoic hosts the most important thermal reservoirs of Gaoyang geothermal field, which is mainly developed in the northern part of the geothermal field. The current features of the thermal reservoirs are the result of favorable sedimentary microfacies and karstification. The thickness of the thermal reservoirs reaches its maximum in the middle part, up to more than 700m, and reduces to north and south, to less than 200m. Porosity and permeability are the highest in Boye area, which is the central part of Gaoyang geothermal field: porosity is more than 5% while its permeability is up to 30mD, decreasing in northwest, southwest, and northeast directions.

(3) The northwest and northeast parts of Gaoyang geothermal field present the highest temperature, up to about 120°C, while the temperature in the southern, middle and eastern regions is below 100°C. The temperature contours are sparser in the northeast-southwest direction than in the northwest-southeast direction, indicating that temperature changes rapidly in northwest-southeast direction, which may suggest that the water supply may come from Taihang Mountain in the northwest.

(4) The hydrochemical characteristics of geothermal water of the Wumishan Formation in Boye is Cl-Na type, which is similar to te geothermal fields of Niutuozhen, Rongcheng and Bazhou, and different to the Tianjin and Liangxiang geothermal fields. The total dissolved solids and the content of Cl^- in Boye area is significantly higher than that in other areas, while the content of SO_4^{2-} is higher than that of vicinity areas in Jizhong depression, but lower than that of Tianjin and Liangxiang geothermal fields. This shows that the geothermal water of reservoirs of the Wumishan Formation in Jixian System in Jizhong depression has similar hydrochemical characteristics, and it is different from Liangxiang and Tianjin. In the Jizhong depression, the total dissolved solids and the content of Cl^- is gradually reduced from the south to the north and from the east to the west, indicating that the water may come from the north and west parts.

(5) The conceptual model of Gaoyang geothermal field indicates that the atmospheric precipitation from the Taihang Mountain in the west is the source of the groundwater. The piedmont fault of Taihang Mountain connected the atmospheric precipitation and thermal reservoirs, and the water passed through this and other faults, like Hengshui fault, and unconformities and is transported to Gaoyang low basal bulge, Lixian slope, Shenze low basal bulge, etc., and formed traps. The water was heated by heat convection by the process of flowing through faults and bedrocks and formed the Gaoyang geothermal field, with a high potential of development.

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