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Characteristics of Geothermal Field Distribution and the Classification of Geothermal Types in the Beijing-Tianjin-Hebei Plain

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ABSTRACT

In this paper, a comprehensive comparison between geothermal temperature distribution and basin structure has been carried out by using modeling a typical geothermal- geological section. It is found that the geothermal field of the Beijing-Tianjin-Hebei Plain is characterized by zoning from east to west, segmentation from south to north, and vertical layering of the strata. From west to east, the geothermal field can be divided into five belts: the western sag, the central bulge, the eastern sag belt, the Cangxian uplift belt and the Cangdong sag belt. It is discovered that heat flow and cap-rock geothermal gradient are relatively high at basal bulge belts, but relatively low at sag belts. From north to south, the geothermal field of the Jizhong depression is divided into north, middle and south segments by the Xushui - Anxin and the Hengshui faults. Geothermal distribution in these segments also exhibits alternations between high and low values, which are similar to their basement structures. Vertically, the geothermal field within the overburden and underburden of the basal bulge belts displays a hierarchical structure of "mirror reflection". Abnormal geothermal field distributions are found to be confined to basement uplift belts, which is caused by the inhomogeneous heat conduction of the shallow basin deposits in both horizontal and vertical directions after tectonic movements. Therefore, according to the relationship between the degree of the basement uplift and the geothermal gradient of the cap rock, the geothermal type of the Beijing-Tianjin-Hebei Plain can be sub-divided into 5 types: the high convex, the convex, the low convex, the deep imbedded and the exposed. Among these, the high convex and the convex are the primary targets for geothermal exploration and development.

1. INTRODUCTION

Geothermal resource is a clean and environmentally friendly renewable energy. Due to its large reserves, wide-spread distribution and high utilization factor, geothermal resources have drawn more and more attention and have been developed vigorously in China. In the Beijing-Tianjin-Hebei (BTH) Plain, the Xiongxian Model, a new geothermal resource utilization model for space heating, has been promoted rapidly in places such as Rongcheng, Gaoyang, Boye, Gucheng, Xinji, Weixian, Bazhou and Daming during recent years. They are forming one of the largest geothermal urban agglomerations in China, and by the end of 2016, they had provided direct geothermal space heating for 7,100,000 square meters of construction area.

The 87,000-square-kilometer-BTH Plain is rich in geothermal resources. The current annual exploited geothermal resource only accounts for about 0.4% of its entire recoverable reserves, showing great potential. In order to develop the geothermal resource more economically and efficiently, this paper provides a comprehensive analysis of the distribution, forming mechanism and main controlling factors of the abnormal geothermal field in the BTH Plain. This study was based on previous studies (Yan et al., 2000; Tao et al., 1999; Lee and Cho, 2002; Gutierrez et al., 2000), latest geothermal exploration data, and characteristics of basin structure (Qiao et al., 2002; Dong et al., 2013). This paper aims to find the favorable geothermal areas in the BTH Plain.

2. Plane Distribution of the Geothermal Field

The main part of BTH Plain is located at the Jizhong depression and the Cangxian uplift of the Bohaiwan Basin. The Bohaiwan basin is a superimposed basin. The mesozoic- cenozoic folded basement of the basin is consisted of late paleozoic continental- transitional facies clastic rocks, middle- late proterozoic shallow marine platform carbonate rocks and archeozoic metamorphic rock series(Zhang. et al., 2001; Wu et al., 2015; Wu and Wang, 2010), intensively compressed and denudated during Indosinian- Yanshanian movement. The dominant sediments in the BTH Plain are large and thick river-lacustrine clastic rocks developed in the period of the Paleogene strong fault depression and the period of the Neogene Quaternary depression, with a maximum thickness of more than 8000 m. The sandstone of the shallow Neogene Guantao Formation and the deep karst bedrock from the Ordovician and the Wumishan formation of the Jixian system are the most important geothermal reservoirs under exploitation at present stage (Table 1).

The NE-strike structural line in the BTH Plain clearly shows the N-S sub-zones and E-W subsections of the basin structure (Figure 1). Based on burial depth, the Cenozoic basement can be divided into western sag belt, central bulge belt, eastern sag belt, Cangxian uplift belt and Cangdong sag belt from west to east, which together formed the concave and convex structural framework of the Study area. The NW-strike Xushui–Anxin Fault and Hengshui Fault separate the Jizhong depression into the northern, middle and southern parts. There are significant differences in the trends of the sag-controlling extensional faults, the depths of the slip-detachment faults and burial depths of the basements in the central bulge belt (Yang, 2009; Lao et al., 2010.). For example, the burial depth of the basement in Rongcheng basal bulge and Niutuozhen basal bulge is about 800 to 1000m. In Gaoyang low basal bulge, burial depth is about 3200 to 3500m. Further south in Ningjin basal bulge, the depth is only about 2000 to 2500m. The north-south sub-zones and east-west subsections determine the distribution of the geothermal field in the BTH Plain.

Table1. Calculated geothermal gradients and heat flow values of typical boreholes in the BTH Plain

Well	Area	Tectonic Location	Well Depth, m	Geothermal Reservoirs	Formation Temperature,℃	G_{cap}, ℃/100m	q_s, mW/m^2
HJT- 1	Xiongxian County	Niutuozhen basal bulge	1507	Jxw	64	4.62	79.46
NMTC- 1	Bazhou City	Niutuozhen basal bulge	4010	Jxw	102	4.50	77.40
GD- 1	Tianjin City	Shuangyao basal bulge	2300	O	65	3.78	65.11
CN- 1	Rongcheng City	Rongcheng basal bulge	1880	Jxw	56	4.13	71.04
DR- 3	Xianxian County	Xianxian basal bulge	1900	Jxw	86	3.89	66.99
XYJY- 1	Gucheng County	Cangxian uplift	3000	O	85	3.51	60.37
ZYGJC- 2	Xinji City	Shulu sag	2926	O	82	2.98	51.26
WQJY- 1	Gaoyang County	Gaoyang low basal bulge	1800	Ng	80	4.09	70.41
DFJY- 1	Boye County	Gaoyang low basal bulge	3758	Jxw	110	3.32	57.02
XZQ- 1	Weixian County	Qiuxian sag	1982	Ng	58	2.58	44.40
JATC- 1	Daming County	Guanxian sag	1713	Ng	55	2.84	48.88

Note: G_{cap} represents the Cenozoic average geothermal gradient from borehole (℃/100m), calculated with a temperature of 12℃ in 200m thickness constant subsurface temperature zone; q_s is the geothermal heat flow value (mW/m^2), calculated with 1.72W/ (m.K) average thermal conductivity in the Cenozoic.

2.1 Geothermal heat flow

Based on the results of previous studies (Gong et al., 2003; Chang et al., 2016; Wang et al., 2002) and the latest geothermal exploration data that we acquired (Table 1), the horizontal distribution map of the geothermal heat flow in the BTH Plain has been compiled and is demonstrated in Figure 2. The map shows that the distribution pattern of the geothermal heat flow value are basically consistent with the basin structure.

From west to east, the central bulge belt and the Cangxian uplift zone are the high geothermal heat flow zones with geothermal heat flow values of 64～92 mW/m^2. The western sag belt, eastern sag belt and Cangdong sag belt are the low geothermal heat flow zones with geothermal heat flow values of 50～58 mW/ m^2. The slope zones between the bulge /uplift belts and the sag belts are characterized by medium geothermal flow, whose average value is about 58～72 mW/ m^2. Weighted by area, the mean geothermal heat flow value of the bulge /uplift belts and the sag belts is about 61.7 mW/ m^2, which is close to the average value of Northern China (62 mW/ m^2) and global value (63 mW/ m^2) (Chapman and Rybach, 1985; Lee, 1970; Cermark and Rybach, 1989). This indicates that in heat conduction basin such as Bohaiwan Basin, while the heat flow moves from the bottom of the basin to the sedimentary cover, the heat transfers laterally in the sag zones and converges in the basement uplift/ bulge zones (Figure 2).

The central bulge zone in the Jizhong Depression has the strongest character of north-south sub-zones. The highest geothermal heat flow values of northern, middle and southern parts all occur in their basement altitudes. The values of the Xiongxian County in Niutuozhen basal bulge in the northern is as high as 92 mW/ m^2. However, in Gaoyang low basal bulge and Ningjin basal bulge, the value is only about 75 mW/ m^2.

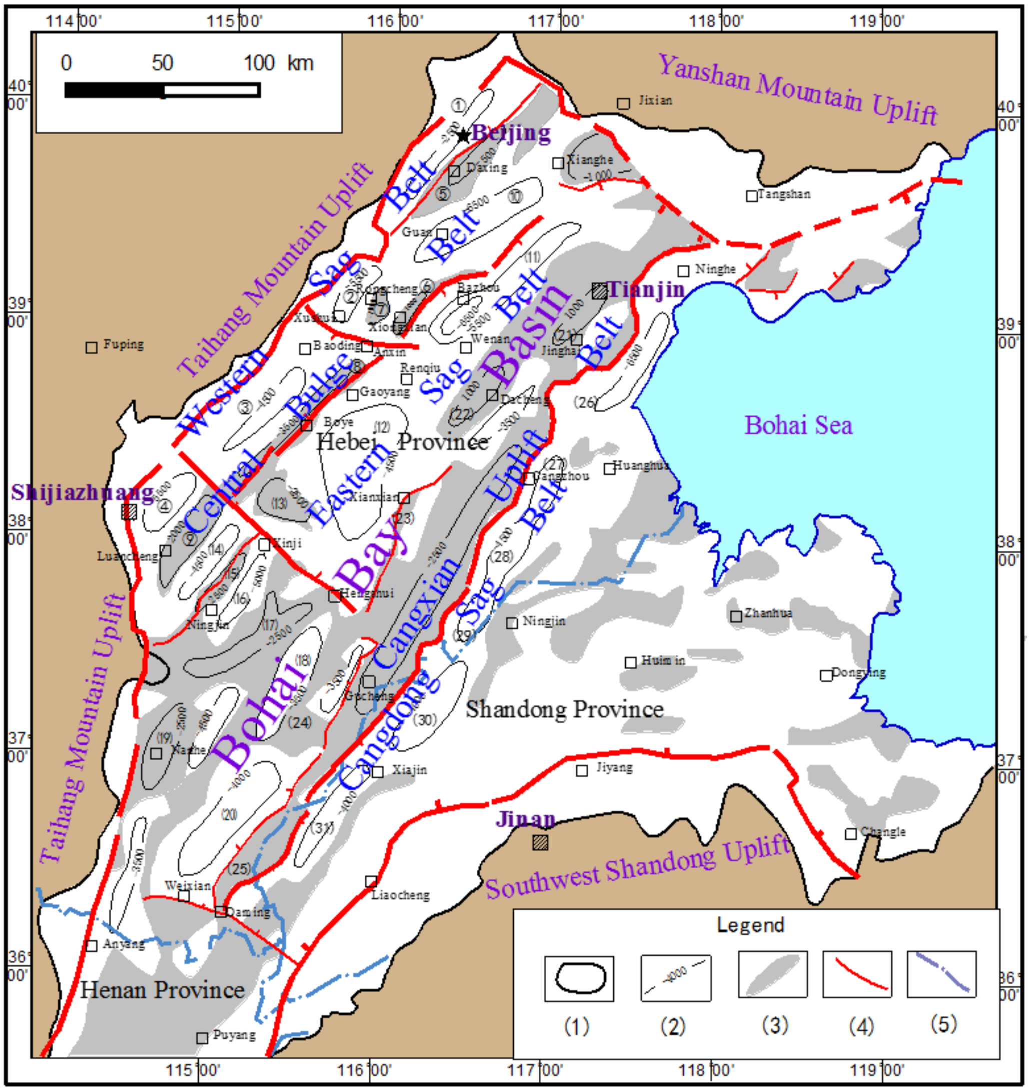


Figure 1: Bedrock depth and simple structural division map of the Beijing-Tianjin-Hebei Plain

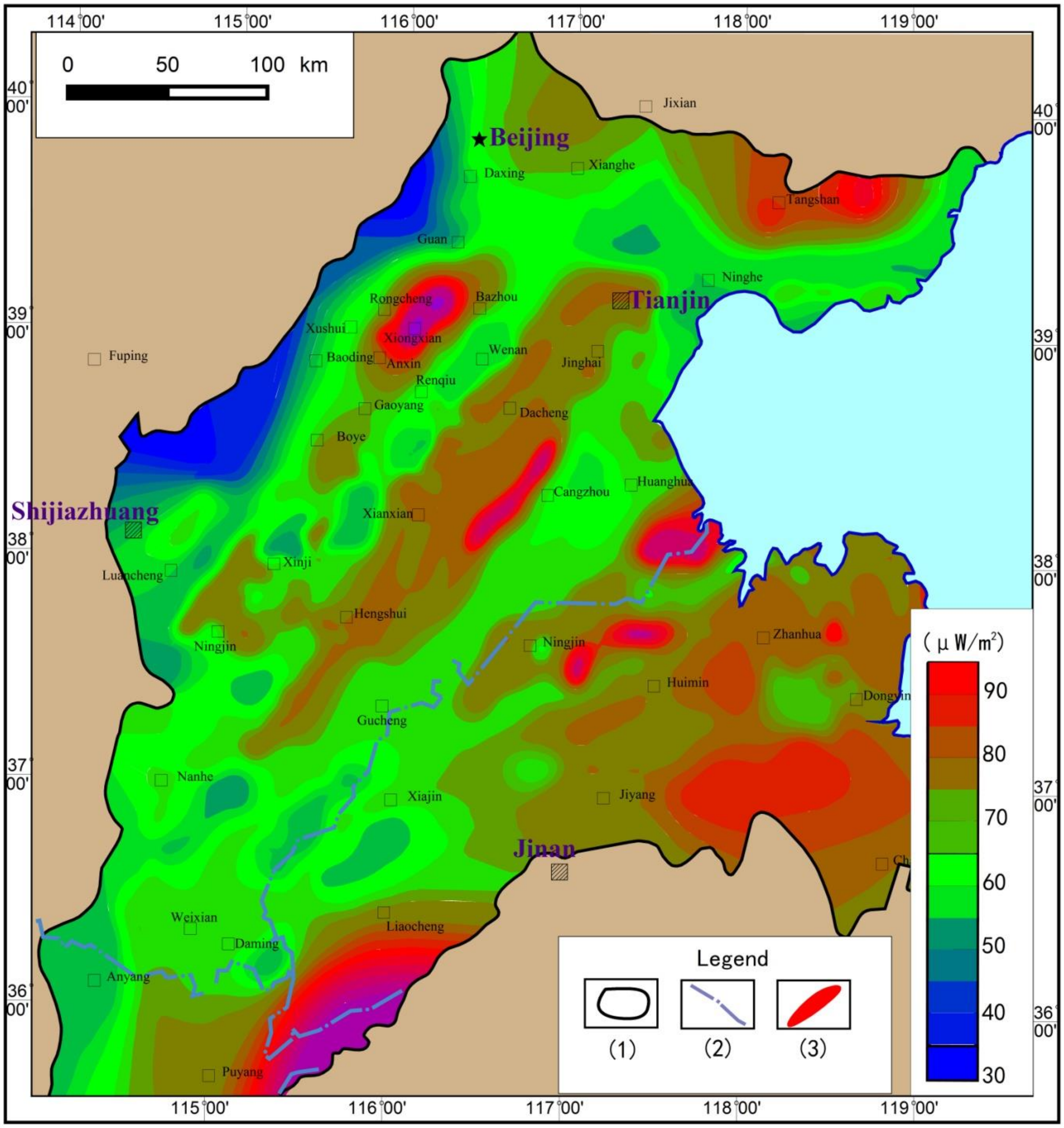
Legends： (1) Basin boundaries, (2) buried contours of bedrocks, (3) basement uplift belts, (4) faults, (5) provinces boundaries.

Tectonic units: (1) Beijing sag； (2) Xushui sag； (3) Baoding sag； (4) Shijiazhuang sag； (5) Daxing basal bulge； (6) Niutuozhen basal bulge； (7) Rongcheng basal bulge； (8) Gaoyang low basal bulge； (9) Wuji- Gaocheng basal bulge； (10) Langgu sag； (11) Baxian sag； (12) Raoyang sag； (13) Liucun basal bulge； (14) Jinxian sag； (15) Ningjin basal bulge； (16) Shulu sag； (17) Xinhe basal bulge； (18) Nangong sag； (19) Jize basal bulge； (20) Qiuxian sag； (21) Shuangyao basal bulge； (22) Dacheng basal bulge； (23) Xianxian basal bulge； (24) Minghuazhen basal bulge； (25) Guantao basal bulge； (26) Banqiao sag； (27) Cangdong sag； (28) Nanpi sag； (29) Wuqiao sag； (30) Dezhou sag； (31) Guanxian sag.

2.2 Geothermal gradients of cap rocks

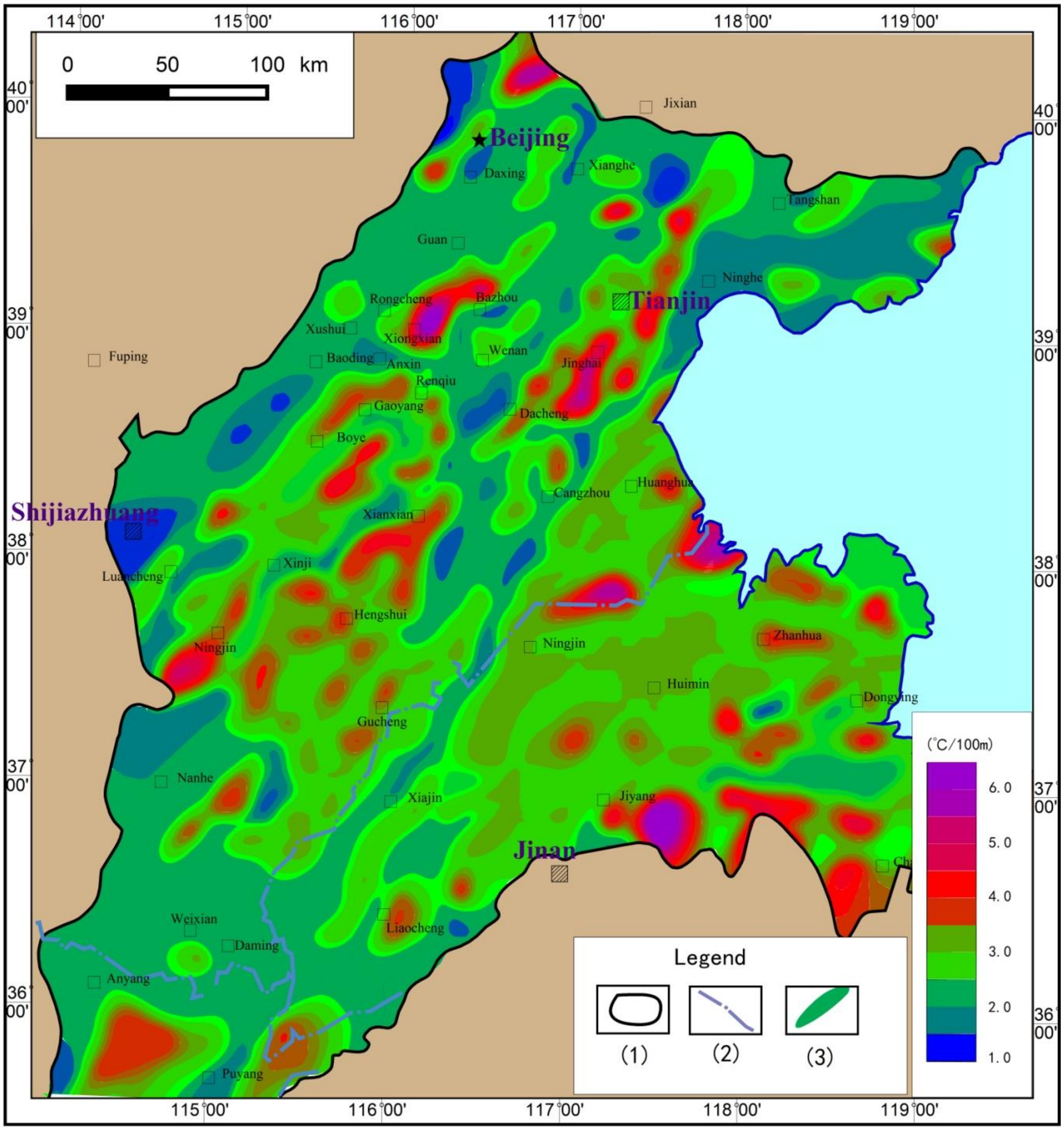
The variation of geothermal gradient in the basin's cap rocks may directly reflect the difference between the geothermal fields in different near- surface tectonic zones. In the BTH Plain, the geothermal gradients in Cenozoic clastic cap rocks are clearly featured by structural zonation and segmentation (Figure 3) (Xiong and Zhang, 1988). High geothermal gradient zones are distributed in central bulge of the Jizhong depression and the Cangxian uplift with the main value sitting between 3.5 and 4.5 ℃/l00m. In Xiongxian and Jinghai, the value is as high as 7.5℃/l00m. In contrast, in most areas of western sag belt, eastern sag belt and Cangdong sag belt, the geothermal gradient is lower than 2.5℃/l00m. The closer to Taihang Mountain and Yanshan Mountain where the cold water supplied, the lower the geothermal gradient is (Zhou, 1987).

The structural segmentation mainly appears inside the Jizhong depression. There are three high geothermal gradient zones along the central bulge belt, Niutuozhen basal bulge in the north, Gaoyang low bugle in the middle and Ningjin basal bulge in the south. While most of the north part in the eastern sag belt (north to Xushui- Anxin Transfer Zone) has low geothermal gradient value, usually lower than 2.5 ℃/l00m, the middle and south part of the eastern sag belt has a higher geothermal gradient value, usually 3~3.5℃ /l00m, especially in Renqiu, Sunhu and Wuji buried hills, where the value can reach 3.5~5.0℃/l00m.



Legends： (1) Basin boundaries, (2) Provinces boundaries, (3) Heat flow values range.

Figure 2: Contour map of heat flow in the Beijing-Tianjin-Hebei Plain



Legends： (1) Basin boundaries, (2) Provinces boundaries, (3) Geothermal gradient values range.

Figure 3: Contour map of geothermal gradient in the Beijing-Tianjin-Hebei Plain

3. MODELING OF TEMPERATURE DISTRIBUTION IN A GEOTHERMAL FIELD

The distribution of geothermal field in the BTH Plain shows that it is positively associated with the basement undulation, which was well understood in previous studies. The phenomenon that the bulge/ uplift zones usually have high temperature abnormality in the sedimentary basin was attributed to the thermal refraction effects during the thermal- conduction (Xiong and Zhang, 1984).

3.1 Modeling of temperature distribution in a conceptual geothermal reservoir

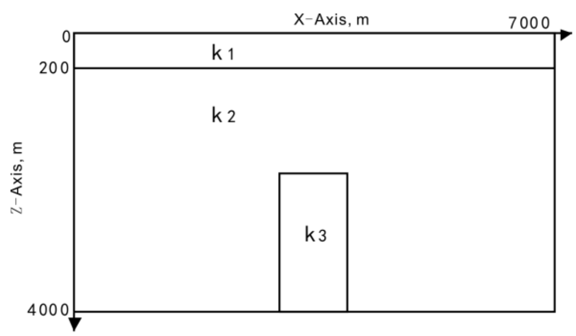
It was proved that positive correlation exists between basement morphology and geotemperature-depth curve. In this paper, we constructed a conceptual geothermal reservoir with a width of 7km and a depth of 4km. As shown in Figure 4a, a paleouplift with a width of 1km and a height of 2km was placed at the bottom of the conceptual geothermal reservoir. It is assumed that the caprock had a thickness of 200 m. In this model, we ignored the “refraction effect”. The modeling was conducted using the two-dimensional thermal conductance equation as follows:

$$\frac{\partial}{\partial x}(k_x \frac{\partial T}{\partial x}) + \frac{\partial}{\partial z}(k_z \frac{\partial T}{\partial z}) + Q = \rho c \frac{\partial T}{\partial t} \quad (x,z) \in D \tag{1}$$

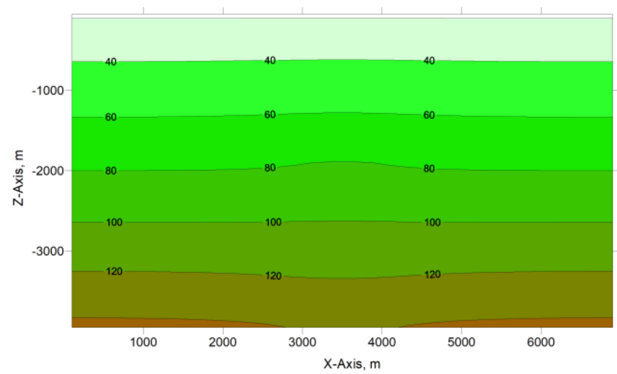
Where T is paleogeotemperature; t is time (s); k is underground rock heat conductivity (W/m·°C); ρ is stratum density (kg/m^3); c is the specific heat of underground rock (J/kg·°C); Q is abnormal geothermal source such as rock mass intrusion (W/m^3).

The thermal conductivity values of the caprock (k_1) and paleouplift (k_3) were 0.6 W/(m.℃) and 3.0 W/(m.℃) respectively. The mantle heat flow (q) was assigned as 71.8 mW/m^2 (the average of continental heat flow), while the thermal conductivity of the ambient rock(k_2) were variable during the modeling to find out the influence of basement morphology to the geothermal field (Fig. 4a). The grid number was 70 (X) x40 (Z). The surface temperature was assumed to be 15 ºC. The modeling results are discussed in the following section.

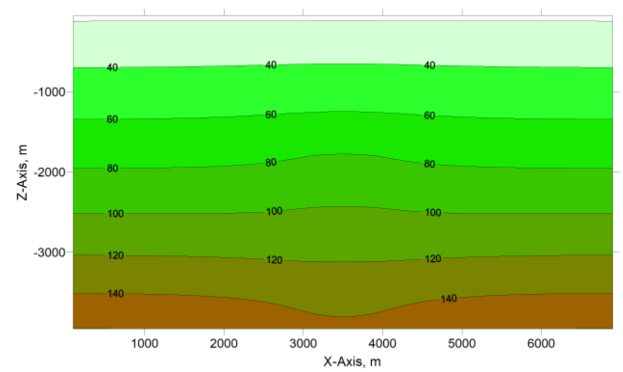
Figure 4(b) to 4(e) demonstrate the temperature distribution in the conceptual geothermal reservoir when k_2 was assigned 2.0, 1.5, 1.0 and 0.6 W/(m.℃) respectively, and the modeling time was 100, 000 years. One can see from these figures that the difference between k_2 and k_3 obviously results in the abnormal high temperature zone in the shallow area. For instance, after 100,000 years, the abnormal high temperature field at the depth of about -2000m in Figure 4(b) with k2=2.0 W/(m.℃) is fairly small, while in Figure 4(d) with k2=1.0 W/(m.℃) it is rather big (about 5℃ greater). To further verify this, k_2 was assigned to be 0.6 W/(m.℃) and the results are shown in Figure 4(e). Although it is hardly to occur in practical, we designed this extremely rare condition of k2=0.6 W/(m.℃) just to reveal the influence of physical properties such as thermal conductivity. Figure 4(e) demonstrate that the abnormal high temperature field above the uplift is about 22℃ greater than its background.



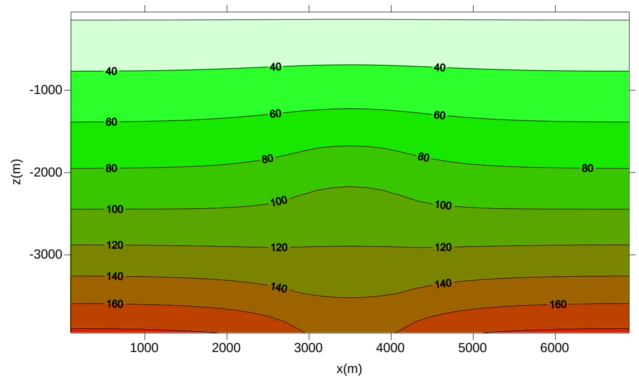
(a) geologic model



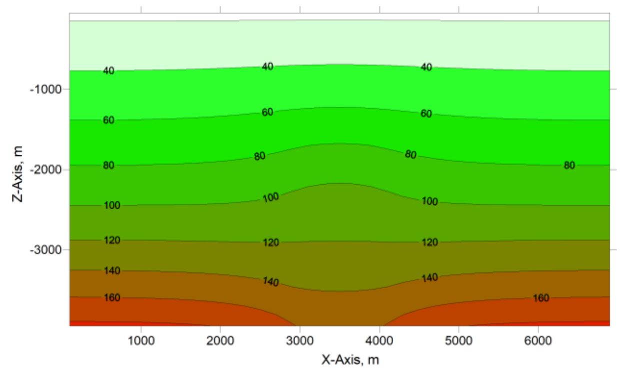
(b) when k_2 equals 2.0 W/(m.℃)



(c) when k_2 equals 1.5 W/(m.℃)



(d) when k_2 equals 1.0 W/(m.℃)



(e) when k_2 equals 0.6 W/(m.℃)

Figure 4: The theoretical model of the paleouplift and its temperature distribution (k1, k2, k3 are the thermal conductivity of the caprock, ambient rock, paleouplift respectively).

The above modeling data indicate that the geothermal abnormal in the shallow area is affected by the underneath basement morphology. The central higher thermal conductivity of paleouplift in the conceptual geothermal reservoir has rapid heat transfer rate compared with its ambient rock. The data profiles show that the isotherm above -3000m is convex (as an arch and of abnormal high temperature field) and the apex of the curve is at the depth of about -2000m, just on the top of the paleolift, while the isotherm below -3000m is concave and of abnormal low temperature field. Compared with its ambient rock, the paleouplift has more rapid heat transfer rate, which results in the positive and negative abnormal geothermal field at the top of and at the root of it respectively. The former may be due to its rapid heat transfer upward and the latter may be the result by the rapid temperature decrease, “escape”, at the bottom. The negative and positive temperature profiles are almost symmetric and look like that there is a “mirror” existed at a specific depth. This phenomenon is referred as to “mirror reflection” and may be used to explain some interesting practical observation of temperature distribution in geothermal reservoirs.

3.2 Modeling of temperature distribution in real geothermal reservoirs

In order to further analyze how the basement undulation affects the geothermal field in vertical and horizontal direction, forward modeling was conducted on a geothermal-geological section through Xiongxian and Rongcheng where geothermal resource is well-exploited (Zhou et al., 1989). The geothermal reservoir profile and the modeling results are shown in Figure 5.

The length of the geological profile chosen for this study was 45-km. From west to east, as shown in Figure 5, the section goes through four tectonic units inside Bohaiwan basin, including the Xushui sag, Rongcheng basal bulge, Niutuozhen basal bulge and Baxian sag. Among these third level tectonic units, the upper boundary of the bedrocks changes from 600~800m in Rongcheng basal bulge and Niutuozhen basal bulge to more than 4000m in Xushui sag and Baxian sag. Cenozoic clastic rocks cover directly on Proterozoic dolomite. The measured geothermal gradient curve at 1000m depth is relatively high at basal bulge belts and low at the sag belts. The highest values appeared at Well X9 in Niutuozhen basal bulge (6.6℃/100m), Well R1 in Rongcheng basal bulge (5.8℃/100m), and Well J1 in Baxian sag (4.6℃/100m). In the other sags, the deeper the basement burial depth is, the lower the geothermal gradient.

The forward modeling is based on the thermal conductivity equation as expressed on Eq. 1 (Wang, 2015). According to the geology model discussed above, the boundary conditions of the modeling were set as follows: the highest overburden quaternary clay's thermal conductivity K1=0.6 W/ (m.℃); Neogene clasolite's thermal conductivity K2=1.39 W/ (m.℃); Paleogene clasolite's thermal conductivity K3=1.45 W/ (m.℃); bedrock's thermal conductivity K4=4.43 W/ (m.℃). The heat flow of the homogeneous Proterozoic basement in deep crust was set as q=1.56 HFU (65.31mw/m^2). The land surface temperature was set as 15℃. The initial geothermal gradient was set as 3.5℃/100m. The length of time for modeling was 500, 000 years. The modeling results are shown in Figure 5. One can see that more than 80% of the modeled temperature data at 1000 m agree with the measured values (see top part of Figure 5).

The following remarks can be obtained according to the modeling: (1) horizontally, the geothermal gradient distribution is associated with the basement depth. The geothermal gradient in the cap rocks above the basement increases with the basal bulge height. This means that the geological structure of the bedrock has obvious control on the geothermal field of the cap rock above it. For instance, the fault displacements of the Niudong and Rongcheng fault that controlled the forming of the Niutuozhen and Rongcheng basal bulge can reach 8000 m and 5000 m respectively. As a result, the geothermal gradient in the cap-rock of the Niutuozhen basal bulge is higher than that of the Rongcheng basal bulge; (2) vertically, the geothermal field of the covers and bedrocks in the basal bulge belts held hierarchical structure of "mirror reflection". Bordered by the unconformity between the Cenozoic and the Proterozoic strata, the temperature versus burial depth curve is a convex arc in the cap rocks above the unconformity but a concave arc in the bedrocks below the unconformity. Besides, the temperature versus burial depth curves are dense and the geothermal gradients are high in the upper cap rocks, while the curves are sparse and the geothermal gradient are high in the bedrocks. These form the asymmetric "mirror layered structure". This phenomenon may be caused by the different thermal conductivities between the cap rocks and the bedrocks according to the results obtained from the conceptual geothermal reservoir in the above section. The high conductivity cap rock has favorable heat preservation effect and form high geothermal gradient. However, low conductivity bedrock has high heat transfer velocity and is easy to form low geothermal gradient; (3) a specific level of convex shaped high- thermal conductive layer with appropriate high- thermal conductivity differences between the upper and lower layers can model the shallow high geothermal anomaly on the buried hill without requiring additional heat source. For the high geothermal gradient anomalies (higher than 7.0℃/100m) of the Xiongxian geothermal field in the Niutuozhen basal bulge, it can be realized by increasing the bedrock's convex degree and the difference of heat conductivities between bedrocks and cap rocks, rather than introducing heat conduction of Niudong Fault.

The zonation and vertical stratification of the geothermal field in the BTH Plain showed in this section have been proved by geothermal exploration and development. This is discussed in the following section.

Firstly, the S-N trend measured geothermal- geological section from Niutuozhen basal bulge to Xinhe basal bulge shows good similarity between the variation of the geothermal gradient in the cap rock and the rolling topography of basement (see Figure 6). The bulge/uplift belts have relatively high geothermal gradient values, while the sag belts have relatively low values. As the basal bulge height gets higher, the geothermal gradient value in the cap rocks above the basement gets higher. For example, the burial depth of the basement in the Niutuozhen basal bulge (Xiongxian) is 8000m, deeper than that of its neighboring Baxian sag, and the geothermal gradient value in the Cenozoic cap rocks of the Niutuozhen basal bulge is higher than 6.75℃/100m. For buried hills of Renqiu, the discrepant of the burial depths of basements at both sides is about 2500 m, and the geothermal gradient value in the Cenozoic cap rocks is about 3.75℃/100 m. While in the deep sag areas, such as the Baxian sag and Raoyang sag, the value is only about 2.25～3.5℃/100m.

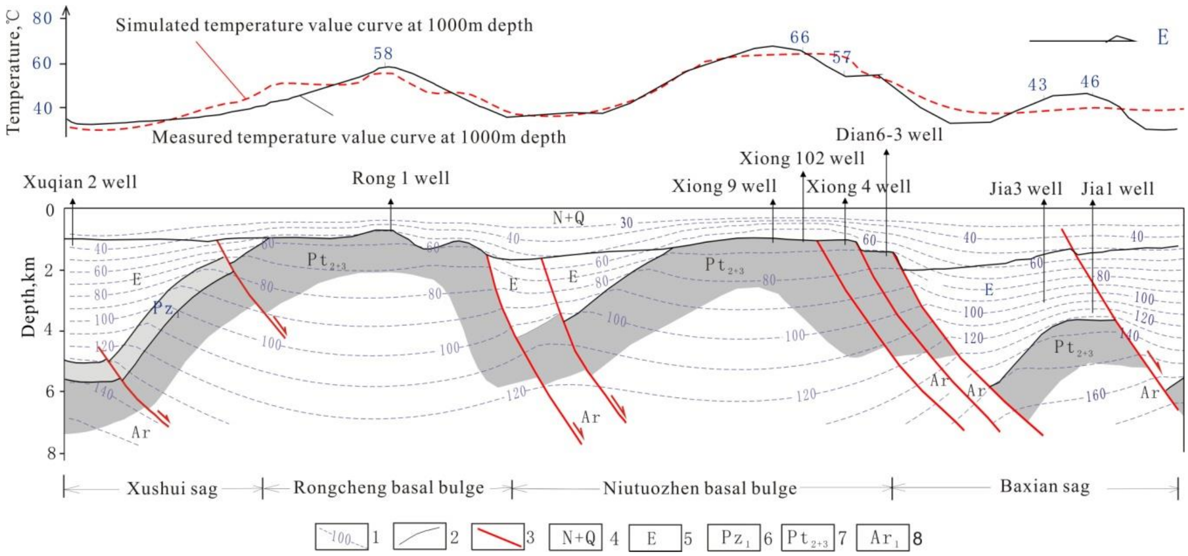


Figure 5: The model and measured temperature data in a profile across the Xushui and Baxian sag

1. Isotherm; 2. Stratigraphic boundary; 3. Fault; 4. Neogene and Quaternary; 5. Paleogene; 6. Lower Paleozoic; 7. Middle and Upper Proterozoic; 8. Archean

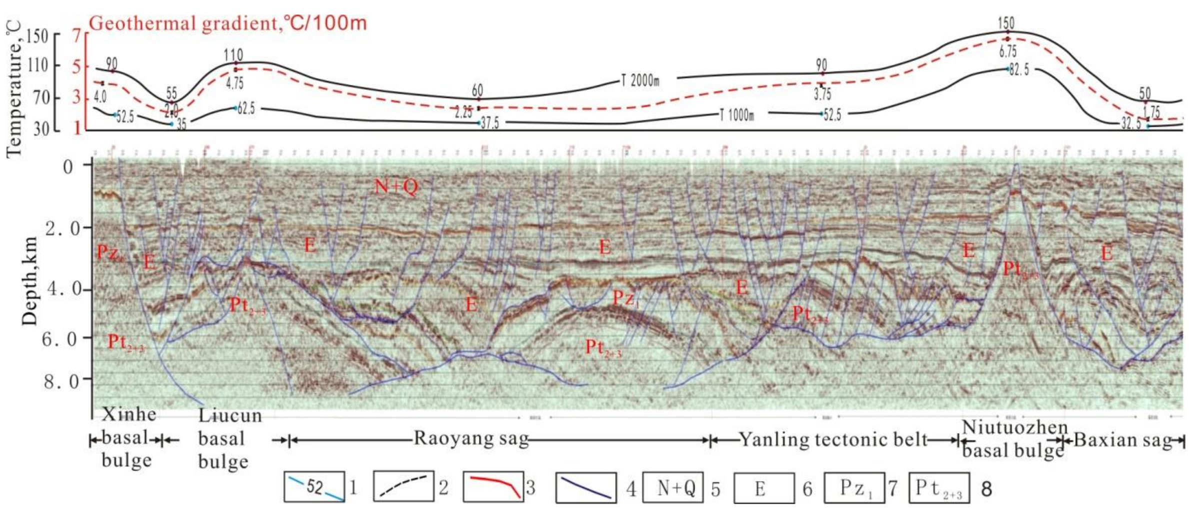


Figure 6: Typical geothermal geological section in Beijing- Tianjin- Hebei region

Secondly, the measured temperature vs. burial depth curves from the BTH Plain also demonstrate the vertical stratification of the geothermal gradients as shown in Figure 7. The curve of Well NJT1 in the southern part of the Niutuozhen basal bulge shows that the geothermal gradient value in the Minghuazhen Formation above the unconformity is about 3 times greater than the value in the Wumishan Formation below the unconformity (4.62℃/100m vs 1.6℃/100m). This observation is consistent with the difference between their thermal conductivity (Chang et al. 2016). The low temperature in the unconformity is due to cold water supply from the flanks. In fact, during the movement of geothermal heat flow from the deep crust to the surface, the thermal transmission velocity changes as the flow passes each geology mass with different thermal conductivity, and therefore causes the vertical stratification of the geothermal gradient. For example, in the temperature vs. burial depth curve of Well ZYGJC2 in the middle part of the Ningjin basal bulge, the geothermal gradient values of Paleozoic Cambrian-Ordovician, Paleogene and Neogene are /100m, 3.0℃/100m, 2.68℃/100m respectively.

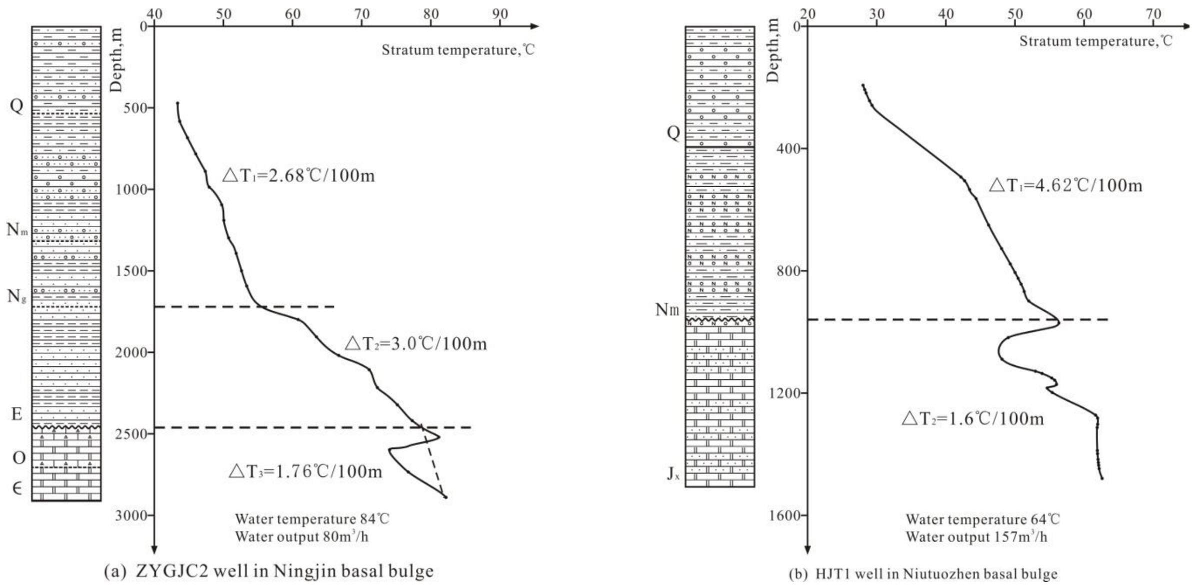


Figure7: Typical drilling depth-temperature curves in the Beijing-Tianjin-Hebei Region

4. MAIN GEOTHERMAL-CONTROLLING STRUCTURES & GEOTHERMAL TYPES

4.1 Main geothermal-controlling structures

The geothermal fields of the secondary and third level structures inside an extensional basin are mainly affected by thermal insulation property of cap rocks, heat source from igneous rocks, and amplitude of basement uplifts (Yan & Yu. 2000). (1) Thermal insulation property of the cap rocks: the thickness of the quaternary Pingyuan formations in the study area is usually 300-400m. In the Raoyang and Baxian sag, the thickness reaches 600m. Pingyuan formation became good local thermal cap because of large porosity, low thermal conductivity, high thermal resistance (<0.3w/mk), and large thickness (except for the basin boundary and uplift belts). (2) Heat source from igneous rocks: the distribution of intermediate- basic igneous rocks is controlled by Paleogene NE large extensional faults, and most of the acid igneous rocks are forming in Yanshanian and mainly along the NW trending Xushui-Wenan and Xushui faults. There is no significant relationship between the igneous rocks and the distribution of geothermal fields. This indicates that igneous rock is not additional heat source. (3) Amplitude of basement uplifts: as discussed above, the direction of abnormal geothermal fields (geothermal gradient higher than 3.5℃/l00m) is roughly identical to basement uplift belts formed by the NE trend extensional faults (see Figure 1), such as in the central bulge belt and Cangxian uplift. The fundamental reason for this phenomenon is that, the basement uplift and the different cap rocks on the uplift and its flanks caused by tectonic movements led to the upper materials have heterogeneous transverse and longitudinal thermal conductance abilities. The higher thermal conductance ability of the basal bulges/ uplifts attracted the heat flow from the surrounding sags/ depressions during its upward transmission, and finally formed the geothermal gradient value in the cap rocks of the bulges/ uplifts.

Combine the above three factors together, the geothermal- geological background of the BTH Plain is a heat conduction system without additional heat source. The basement uplift belts formed by extensional faults are the main factors of abnormal geothermal field.

4.2 Geothermal types

According to the structure of different geological settings, the burial depths of the basement top surface in basal bulges/ uplifts, the relative basement amplitudes of the two sides of the major extensional faults, and the impacts of cap-rock heat preservation on geothermal gradient values, the distribution of geothermal gradients in the BTH Region is divided into the following 5 types. The details are listed in Table 2 (also see Figure 6). (1) The high convex type: this is a third- grade tectonic unit with basement top surface burial depth of 800 to 1500m and more than 4000m fragmented interval of the major extensional fault. The appropriate thickness of the cap rocks keeps much of the heat from getting out, and the burial depths of the basement top surfaces attracted the heat flow. These factors attribute to the geothermal gradient value (usually above 5℃/l00m) in the cap rocks of bulges/ uplifts. High convex type, represented by Niutuozhen (Xiongxian) basal bulge and Shuangyao basal bulge, should be considered as the main geothermal exploration and development target zone for bedrock Karst geothermal reservoirs. (2) The convex type: this is a third-grade tectonic unit with 2000 to 3000m basement top surface's burial depth and 3000~4000 m fragmented interval of the major extensional fault. The geothermal gradient value of a convex type is usually about 4.0~4.9 ℃/l00m. The well match of the thickness of the cap rocks and the basement amplitude led to a large range of geothermal gradient in the cap rocks of the basal bulge/ uplift (Sandstone geothermal reservoir usually has relative high temperature). In the convex type areas, both the sandstone and the Karst geothermal reservoir have good development prospects. (3) The low convex type: a third-grade tectonic unit with 3000 to 4000m basement top surface's burial depth and a 2000~3000 m fragmented interval of the major extensional fault. The geothermal gradient value of low convex type often ranges from 2.9 to 3.5℃/l00m. The good match of the thickness of the cap rocks and the basement amplitude leads to a large range of geothermal gradient in the cap rocks of the basal bulge/ uplift. The sandstone geothermal reservoir usually has a high temperature. Although both sandstone and Karst geothermal reservoir have development prospects in low convex type, the deep burial depth of karst reservoir raises its exploration risk. (4) The deep imbedded type: this type is represented by Bazhou sag and Raoyang sag, has a very thick Cenozoic fragmental sediments (usually 4000~6000m, locally reaching 8000m) with the geothermal gradient value from 2.25 to 3.5℃/l00m. The burial depth of the Karst reservoir is too deep to exploit. Only the sandstone geothermal reservoir is exploitable. (5) The exposed type: this category can usually be found along basin margins (for example western margin of Baoding sag) and high uplift areas inside a basin (the thickness of cap rocks in Daxing basal bulge is usually 100~300m, with the thickness of Cenozoic fragmental sediments between 0~500m). Thin cap rocks (including bedrock-exposed areas) are easy to lose heat because surface cold water supply is easily accessible. As a result, bare carve type has very low geothermal gradient, usually less than 2.5℃/l00m (Zhou. 1987).

Composite analysis show that the high convex type and convex type should be considered as the main geothermal exploration and development target zone.

Table 2. Classification of geothermal type in Beijing-Tianjin-Hebei region

type	basement depth, m	fault displacement,m	geothermal gradient,℃ /l00m	examples
High convex	800~1500	>4000	>5.0	Xiongxian &Shuangyao
Convex	2000~3000	3000~4000	4.0~4.9	Xinhe & Liucun
Low convex	3000~4000	2000~3000	3.5~3.9	Gaoyang & Renqiu
Deep imbed	4000~6000		2.25~3.5	Bazhou & Raoyang
Bare carve	0~500m		<2.5	Baoding & Daxing

5. CONCLUSIONS

(1) The geothermal field distribution of the BTH Plain is influenced by basin structure, showing characteristics of E-W zoning, and N-S segmentation. From west to east, the geothermal field can be divided into five belts: the western sag, the central bulge, the eastern sag belt, the Cangxian uplift belt and the Cangdong sag belt. The geothermal gradient is relative high at basal bulge belts, but relatively low at sag belts.

(2) Modeling of a geothermal-geological section shows that the characteristics of geothermal fields and basement structures are similar. From north to south, the geothermal field of the Jizhong depression presents the obvious phenomenon of the high and low value alternate distribution, similar to forms of the basement structures. Vertically, the geothermal field of cover and bedrock in the basal bulge belts held a hierarchical structure of "mirror reflection".

(3) Abnormal geothermal field is mainly affected by basement uplift belts formed by extensional faults. According to the relationship between the degree of basement uplift and the geothermal gradient of cap rock, the geothermal field in the Beijing-Tianjin-Hebei Region can be sub-divided into 5 types: the high convex, the convex, the low convex, the deep imbedded and the exposed. Among these, the high convex and the convex are the primary targets for geothermal exploration and development.

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