Proceedings World Geothermal Congress 2023
Beijing, China, April 17 – 21, 2023

Heat storage structure and accumulation of deep geothermal in Jizhong Depression

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Keywords: Jizhong Depression; Carbonate heat storage; Integrated geophysics.

ABSTRACT

The deep structure of Jizhong Depression shows a stepped descending pattern in east-west trend and three sections sinking in north-south trend. The main faults in Jizhong Depression are NE, NW and nearly EW trending. NE-trending faults (such as Daxing fault, etc.) are most developed, controlling the convex-concave boundary, the depression is separated by Uplifts, presenting a structural pattern of "multiple convex-multiple concave, alternating with convex-concave". According to geophysical results such as regional MT and gravity gradient survey, the depression stepped descends form Taihang uplift to the east. The nearly EW trending faults developed in tectonic transition position within the depression, which have obvious strike-slip properties and play an important role in controlling the tectonic pattern, sag distribution and sedimentation. Jizhong Depression is divided into three sections by Xushui-Wen'an and Wuji-Hengshui fault zone: north section, middle section and south section. The subsidence is roughly uniform in the north-south sections, and the largest subsidence is in the middle section.

The heat storage distribution of deep carbonate rocks is strictly controlled by convex-concave structure, the burial depth of the carbonate rocks varies greatly in different tectonic units. Generally, there are only Proterozoic carbonate rocks with burial depth of 300-3000m in the convex areas, Paleozoic carbonate rocks with burial depth of 500-3000m and Proterozoic carbonate rocks with burial depth of 2000-8000m in the depression areas. There are Cambrian-Ordovician carbonate thermal reservoirs in the depression areas, which gradually get deeper from the north to middle, shallower from the middle to south. The burial depth of Proterozoic carbonate rocks in the depression areas is generally greater than 4000m. There is generally no Paleozoic carbonate rock in the convex areas, and the carbonate rock heat reservoirs are Wumishan Formation of Jixian System and Gaoyuzhuang Formation of Changcheng System in Proterozoic. As a whole, it is shallow in the west and deep in the east, deep in the middle and relatively shallow in the north and south.

Deep geothermal occurs in the thick Cenozoic overlying part of the thick reservoir which beside structure-magmatic belt. Comprehensive geophysical results show hydrothermal type geothermal resources mainly buried depth is between 33-35 km of the mantle uplift position. It indicates that the main body belongs to the conduction geothermal resource accumulation mode of sedimentary basin. The characteristics of MT and Bouger gravity anomaly indicate the fault structures are well developed in this region, and the distribution of hot fields (Wells) is obviously controlled by faults. Based on the regional aeromagnetic pole residual anomalies, deep intrusive bodies are widely distributed and closely related to fault structures. In general, the deep heat source is not only from mantle uplift, the occurrence of hot fields is closely related to magma intrusion and deep faults. The most favorable area is the side of structure-magmatic belt. "mantle uplift + rock mass + fault + carbonate + Cenozoic thick overburden" jointly control the distribution of deep hot fields/Wells (groups). It indicates that the heat transfer of deep geothermal is multiple.

1. INTRODUCTION

The Jizhong Depression was formed on the basis of the occurrence of fracture- depression in the Middle-Cenozoic of the North China Craton, and a more complete stratigraphy of North China is preserved within it. In the study of carbonate rocks: Chi, Xiaoyan, and Sun, Weifeng (2011) concluded that the Jizhong Depression was part of the Ordovician North China Land Surface Sea and formed a set of carbonate stratigraphy. Wu Xingning,Li Guojun et al.(2011) used sedimentary petrology and reservoir geology to suggest that the Jizhong Depression developed a carbonate subduction-hosting reservoir in the Gayuzhuang Formation of the Changcheng System, the Wuzhishan Formation of the Jixian System and the Fujunshan Formation of the Cambrian System. Wu, Xingning, and Lv, Yuzhen (2011) concluded that the Yangzhuang, Huancunzhuang, and Bantou formations are the most dominant cover of the subducted carbonate inclusions in the Middle and Upper Paleozoic of the Jizhong Depression. Chen Qinghua, Laogao et al. (2013) systematically summarized the oil and gas enrichment pattern of the deep paleo submerged mountains (depth >4000m) in this area, and accurately analyzed the tectonic pattern of the deep paleo submerged mountains and determined the paleo submerged mountain stratigraphy by using the results of various seismic attribute parameters analysis and regional stratigraphic comparison. In the study of geothermal genesis, Shihui Lin and Yuling Gong concluded that the geothermal temperature spreads in the direction of tectonic and fracture extensions, and the distribution range is basically consistent with the underlying basement structure. The main body spreads in the NNE direction. Horizontally, the geothermal gradient shows a low-high-low distribution, which is consistent with the concave, convex and concave distribution of regional geological structures; vertically, the geothermal gradient tends to decrease with increasing depth. Chang Jian, Qiu Nansheng, Zhao Xianzheng et al. concluded that the geothermal gradient and heat flow in the Jizhong Depression are gradually increasing from west to east (from the basin edge to the interior), and the geothermal gradient and heat flow in the convex area are relatively high, while the depression area is low, which corresponds well with the topographic relief of the basement, and its lithospheric thermal structure is a typical "cold crust-hot mantle" type. type. Wang Guiling, Zhang Wei et al. considered that the conduction type geothermal resource formation model in the sedimentary basin of Beijing-Tianjin- Hebei region, the heat generation in the upper mantle and the radioactive decay heat generation in the bedrock mainly heats up the shallow strata by conduction, forming thermal reservoirs in the high porosity and high permeability aquifers, and the uppermost sedimentary cover plays an insulating effect for the thermal reservoirs, while the thermal convection in the plain area is a useful supplement, mainly through the fracture-based hydraulic and thermal conductivity channels. The thermal convection in the plain area is a useful supplement, mainly through the fracture-based water-conducted heat transfer channels. In the application of geodetic electromagnetic bathymetry to a geothermal prospect in Baoding, Shangbin Jiao, Tao Dai, and Lei Ren introduced the application of geodetic electromagnetic bathymetry to the geothermal resource exploration in eastern Baoding, and identified the distribution characteristics of fracture zones and their water content in the area, and determined the location and depth of the thermal reservoir. In the evaluation and development of geothermal resources in the Jizhong Depression, Liang Hongbin, Qian Zheng et al. concluded that there are three major geothermal water-bearing systems in the area, namely, the weak alternating zone of the Proterozoic -Lower Paleozoic, the alternating blocking zone of the Upper Paleozoic-Paleocene, and the strong alternating zone of the Neoproterozoic, and the thermal reservoirs are divided into three types: pore type, fracture type, and fracture-cave type. Among them, the bedrock fracture type thermal reservoir has high temperature and high thermal energy. In the study, Yajuan Zhao and Shuyin Niu focus on the geothermal anomaly of Hebei Plain by analyzing the geological and tectonic characteristics of the study area, the evolution characteristics of sub thermal column of North China mantle, the characteristics of temperature field, the geothermal heat flow value and the geothermal resource distribution and thermal storage characteristics, etc. to explore the control of fracture tectonics on the geothermal heat source of Hebei Plain. The role of fracture tectonics on the geothermal heat source of Hebei Plain is discussed, and it is proved with the mantle branch tectonic theory.

The distribution status of deep carbonate thermal storage is not yet clear. The Beijing-Tianjin-Hebei region is one of the important deposit areas of medium and low temperature hydrothermal geothermal resources in China. The thermal reservoir of the Jixian System Wuzhishan Group in the region is characterized by large storage thickness ratio, karst fissure development, good connectivity, excellent water quality and high temperature, and is the best bedrock thermal reservoir in the region. It is the best bedrock thermal reservoir in the region. The lower Great Wall System is a good carbonate thermal reservoir in the Gaizhuang Group. The geothermal exploration depth in Beijing, Tianjin and Hebei is shallow, and the spatial distribution is uneven. The degree of geothermal exploration and exploitation varies greatly from region to region, and the geothermal exploration area is mainly concentrated in a few geothermal fields such as Niutuozhen, mainly exploiting the sandstone thermal reserves of the Neoproterozoic Pavilion Tao Formation and carbonate thermal reserves of the Jixian System Wuzhishan Formation at a shallow depth of 3000m. As the second space that can be developed on a large scale in the future, only a small number of boreholes have been drilled to expose the carbonate thermal reserves at 3000-6000m. Due to the lack of systematic scientific investigation, the geothermal wells currently being developed and utilized are mainly concentrated on the top of the Jixian System Wuzhishan Group, the bottom boundary of the deep Wuzhishan Group carbonates is unclear, the development potential of the Changcheng System Gaoyuzhuang Group carbonates still needs to be further identified, and the deep distribution status of the deep carbonate thermal reservoirs in the vast plain area has not been investigated clearly, which brings difficulties to the rational development and utilization of geothermal resources and planning.

The geothermal genesis of deep carbonate thermal storage needs to be identified. Based on the regional thermal background and thermal anomaly, it is an important element and fundamental work of geothermal exploration to carry out the analysis of deep thermal sources and shallow thermal control structures, and to explore and analyze the basic elements of geothermal system formation-thermal sources, channels, thermal storage and capping layers. At present, the research on heat sources in China is mainly focused on the Himalayan high temperature geotropic, and the residual heat of magma intrusion, decay heat of radioactive elements, frictional shear heat of faults and thermal refraction of sedimentary cover, and deep thermal action are considered as the heat sources of high heat flow background in this region. The heat source analysis and heat transfer mechanism studies in the Beijing-Tianjin-Hebei region are relatively weak, mainly focusing on the local geothermal field scale, lacking fine studies on the regional scale, and the vertical distribution characteristics of deep carbonate rocks have not been identified. The relationship between deep tectonics and geothermal resource endowment is still unclear, the evaluation of regional thermal fluid renewal capacity is still inconclusive, and the renewal capacity of deep carbonate thermal reservoir hydrothermal fluid and heat source mechanism and heat transfer mechanism need to be further explored. Therefore, we analyze the distribution of deep mantle thermal column, distribution of deep major fractures, distribution of deep carbonate thermal reservoirs, distribution of tertiary sub- tectonic units such as tertiary four, tertiary five and tertiary six tectonic units of geotectonic, and their spatial and coupling relationships with geothermal fields, so as to identify the mechanism of deep geothermal genesis in Jizhong Depression.

2. GEOLOGICAL BACKGROUND

Jizhong Depression is a Middle and Cenozoic fault depression basin developed on the North China Craton. As a sub-tectonic unit of the Bohai Bay Basin, it is bounded by the Yanshan Uplift to the north, the Xinghheng Uplift to the south, the Taihang Uplift to the west and the Cangxian Uplift to the east, with a north- east-south-west trend and an area of about $3.2\times10^4 km^2$. Regionally, the Jizhong Depression is divided into three zones: south, middle and north by two near east-west-north-west transformation zones (i.e. Wuji-Hengshui transformation zone and Xushui-Anxin-Wen'an transformation zone), among which, the southern zone includes Shijiazhuang Sag, Jinxian Sag, Shulu Sag, Wuji-Gaocheng low Uplift and Ningjin Uplift; the central zone includes Raoyang Sag, Baoding Sag, Shenxian Sag, Gaoyang Uplift, Shenze low Uplift and Lixian slope; the northern zone includes Beijing Sag, Dachang Sag, Langgu Sag, Xushui Sag, Wuqing Sag, Baxian Sag, Daxing Uplift, Niutuo Uplift, Rongcheng relief, Nubei slope, Yangcun slope and Wen'an slope. The basement of Jizhong Depression mainly developed a set of metamorphic rocks in the Taikoo and Lower Paleozoic. In the Middle and Late Paleogene and Middle Ordovician, the shallow marine carbonate rocks mainly developed in the Jizhong Depression area under the influence of marine erosion, and the deposition thickness reached ~5000m (Zhao Xianzheng et al., 2010; Lu Shiguo et al., 2011). During the Late Ordovician-Late Carboniferous period, the Caledonian and Hercynian movements caused the overall uplift of the Jizhong Depression and long-term denudation (Du Jinhu et al., 2002; Lu Shiguo et al., 2011). During the Permian period, the Jizhong Depression deposited a set of sea-land interfacial clastic rocks with carbonate rocks, which are about 700-800m thick (Du Jinhu et al., 2002). The strong extrusion in the Early Mesozoic (caused by the Indochinese movement) caused a series of folds in the Jizhong Depression in the Triassic-Jurassic, and suffered from strong denudation, and only a small number of strata of this period was deposited in the southern part of the depression (Yang, Minghui et al., 2001; Wu, Zhiping et al., 2007). In the Late Cretaceous, the tectonic stress field in the Jizhong Depression changed from extrusion to extension, and the magmatic activity was strong, and a set of terrestrial clastic rocks with coal and volcanic strata developed (Sun Dongsheng et al., 2004a, 2004b). During the late Eocene, under the influence of the deep mantle convection induced by the subduction of the Pacific plate, the whole North China region was in a state of post-arc extension, and the Jizhong depression also entered into a stage of strong extensional and fracture evolution, controlled by the fault block lift-off, and developed a large number of NE-NNE and NW directional subduction structures. This period mainly deposited terrestrial lacustrine sandstones and mudstones with some marl and gypsum (Yang Minghui et al., 2002; Cui Zhouqi, 2005; Zhang Wenzhao et al., 2008). In the Neoproterozoic, the post-arc tensioning in North China weakened, and the Jizhong depressional area entered the depressional evolutionary stage, where the overall subsidence was dominant and mainly developed fluvial-phase sandstones and mudstones (Liang, Sujuan, 2001; Dong, D. et al., 2013).

3. DIVISION AND CHARACTERISTICS OF REGIONAL TECTONIC UNITS

According to the characteristics of regional gravity and magnetic fields, based on the location of the identified fracture boundaries and combined with petroleum geology and geological records, the Jizhong Depression can be divided into 21 level IV tectonic units, among which the Niutuo Uplift is subdivided into Niutuo Uplift and Niubei Slope, and the Gao Yang Low Uplift is subdivided into Gao Yang Low Uplift and Lixian Slope and other level V tectonic units, totaling 23 tectonic units (Figure 1). From the spread of each tectonic unit, comprehensive geophysical profile and comprehensive geological characteristics, the overall tectonic pattern of Jizhong depression area shows that the main tectonic orientation is northeast, and the tectonic units are distributed convexly and concavely, showing the characteristics of step-like subsidence in east-west direction and uneven subsidence in north-south direction.

3.1 East-west convex and concave distribution

As can be seen from Figure 1, except for the Shenze Low Uplift and the Shenxian Depression, each level IV tectonic unit is macroscopically spreading in the NE direction, with the "two concave and one convex", concave and convex distribution pattern from west to east, with faults separating the level IV units. It is 50-100km long from north to south and 10-30km wide from east to west.

3.2 Stepped fracture in the east-west direction

The survey results show that from west to east, both the uplift area and the depression area show a gradual thickening of the Cenozoic boundary, a gradual deepening of the top surface of carbonate rocks, and a characteristic east-west stepped subsidence in the profile. For example, the top surface depth of carbonate rocks is 1000m in the Daxing Uplift, 1200m above the plain in the Taihang Mountains Uplift, 2000m in the Cangxian Uplift, 1500m in the Beijing Sag, 3000m in the Dachang Sag, 2500m in the Baoding Sag and 3800m in the Raoyang Sag on both sides of the Gaoyang Low Uplift in the middle section, 2500m in the Shijiazhuang Sag and 3500m in the Jinzhou Sag on both sides of the Wuji-Gaocheng Low Uplift in the south. The Jinzhou Sag is about 3500m.

From the comprehensive geophysical profile, it can be proposed that the Uplifts and Sags are contacted with positive faults at higher angles, and the change of stratigraphic depth within the fault block is relatively small, and the break distance is mainly concentrated in the contact area, and from the profile, it shows a step-by-step decline from west to east.

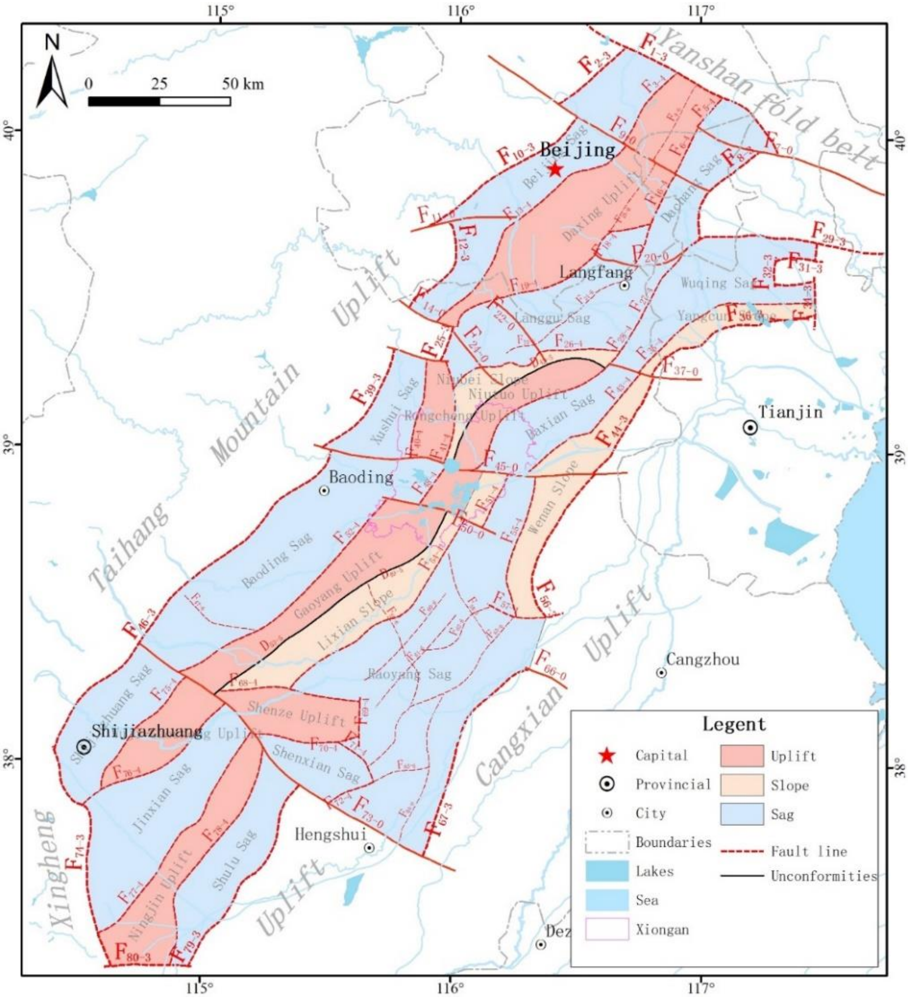

Figure 1 Zoning map of level IV/V tectonic units in the Jizhong Depression

3.3 North-south direction is divided into three sections of uneven subsidence in the north, middle and south, and the north and south ends are tilted to the middle

Regionally, the Xushui-Wen'an fault zone and the Wuji-Hengshui fault zone separate the Jizhong Depression into three sections: north, middle and south. The comprehensive geophysical results reflect that in the north, middle and south sections of the Jizhong Depression, there are large differences in the thickness of the neotenic boundary and the burial depth of the top surface of carbonate rocks in both the raised and depressed areas, especially the differences between the south and north sections and the central area are obvious, indicating that there are large differences in the sinking amplitude of the three sections, with the middle section having the largest sinking amplitude. Taking the burial depth of the carbonate top surface in the central raised area as an example, the Daxing raised area in the northern section is about 1000 m, the Gaoyang low raised area in the middle section is about 3200 m, and the Wuji-Gaocheng low raised area in the southern section is about 2800m. The depression area also has the same characteristics.

In the northern part of the Jizhong Depression, from the northward Daxing Uplift to the southward Rongcheng Uplift and Niutuo Uplift, the depth of burial of the top interface of carbonate rocks deepens from 1000m to 1300-2000m, even within the Daxing Uplift, the L1 line is 660m and the L3 line is 800-1000m in the north, indicating that the fault block generally shows a southward dip.

In the southern part of the Jizhong Depression, the depth of the top interface of the carbonate rocks in the Jinxian Depression is 1700m in the southern part and 4100m in the northern part, showing the characteristic of dip to the north.

4. REGIONAL CARBONATE ROCK CHARACTERISTICS

Regionally, the overall feature is that carbonates are distributed throughout the Jizhong Depression, and the general appearance of the top surface depth of carbonates is shallow in the northwest, gradually deepening in the southeast, generally deeper in the central part, and then gradually becoming shallower in the southwest.

The distribution of regional carbonate rocks is obviously controlled by geological structure, which is synchronized with the overall geological structure and shows that the top surface depth of carbonate rocks is shallower in the raised area than in the depressed area, with an east-west step-like fracture and a north- south pattern of sinking in three sections.

(1) The depth of burial of the top surface of carbonate rocks is greater in the depression area than in the raised area (Figure 2). The minimum depth of burial in the entire Jizhong Depression is 2072m on average and the maximum depth of burial is 3690m on average, while

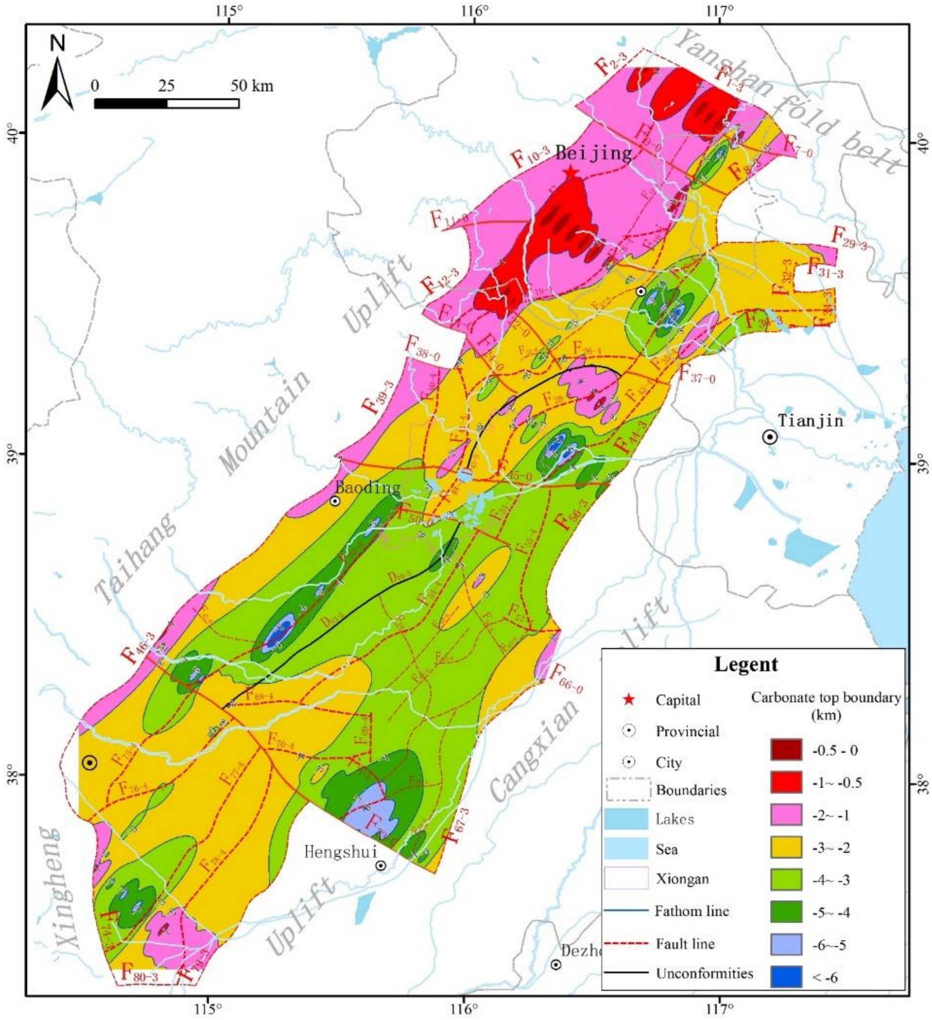

Figure 2 Carbonate thickness contour map in the Jizhong Depression region

the minimum depth of burial in the depression area is 3480m on average and the maximum depth of burial is 5097m on average. The minimum burial depth in the raised area between Xushui Fault and Hengshui Fault (middle section of Jizhong Depression) is 3066m and the maximum burial depth is 5233m, while the minimum burial depth in the depression area is 3933m and the maximum burial depth is 7666m. The southern part is more complicated, with the smaller value of 1580~2900m in the raised area and the larger value of 3100-4800m. The depression area has a smaller value of 1600~2400m and a larger value of 1600~5800m.

In the northern area, from Shunyi-Pinggu to Beijing urban area, and then to Fangshan-Zuozhou-Gu'an-Dingxing area, the top surface of carbonate rock is buried less than 1500m, and the depth of burial in Shunyi-Pinggu and Fangshan-Zuozhou area is less than 1000m, and locally less than 500m, other areas with shallow depth of burial are Yongqing-Bazhou and Niutuozhen-Xiong'an area, with depth of burial less than 1000m, and locally less than 500m. There are 2 large areas, one is Sanhe-Dazhuang area, the other is Langfang - Wuqing area, burial depth of 3000 ~ 5000m, Langfang - Wuqing area locally up to 6000~7000m.

(3) The north-south direction is divided into three sections of subsidence, and the central section has the largest subsidence. For example, the minimum depth of burial of carbonate tops in each section is 966m in the northern section, 3066m in the central section, and 2240m in the southern section. the depth of burial of carbonate tops in the adjacent tectonic units corresponding to the tectonic location is 900 to 1300m in the Niutuo Uplift, 3100 to 5600m in the Gao Yang low Uplift, and 2900 to 4800m in the Wuji- Gaocheng low Uplift 2900 ~ 4800m.

5. GEOTHERMAL WELL DISTRIBUTION IN RELATION TO HIGH-CONDUCTIVITY AND LOW-VELOCITY LAYER

From Figure 3, it can be seen that geothermal wells are concentrated in the high-conductivity and low-velocity burial depth in the area of 10-16km.

According to statistics, there are 74 known thermal wells in the area of high-conductivity and low-velocity burial depth of 10-12 km, accounting for 26.62%, 86 thermal wells in the area of 12-14 km, accounting for 30.94%, and 67 in the area of 14-16 km, accounting for 24.10% (Table 1), with the deepening of high-conductivity and low-velocity burial depth, the number of thermal wells keeps decreasing and the temperature at the wellhead keeps decreasing. There is an obvious positive correlation between the distribution of existing geothermal wells and the burial depth of low-velocity high conductors, reflecting that low-velocity high conductors may constitute an important supplementary source of thermal energy for regional geothermal reservoirs.

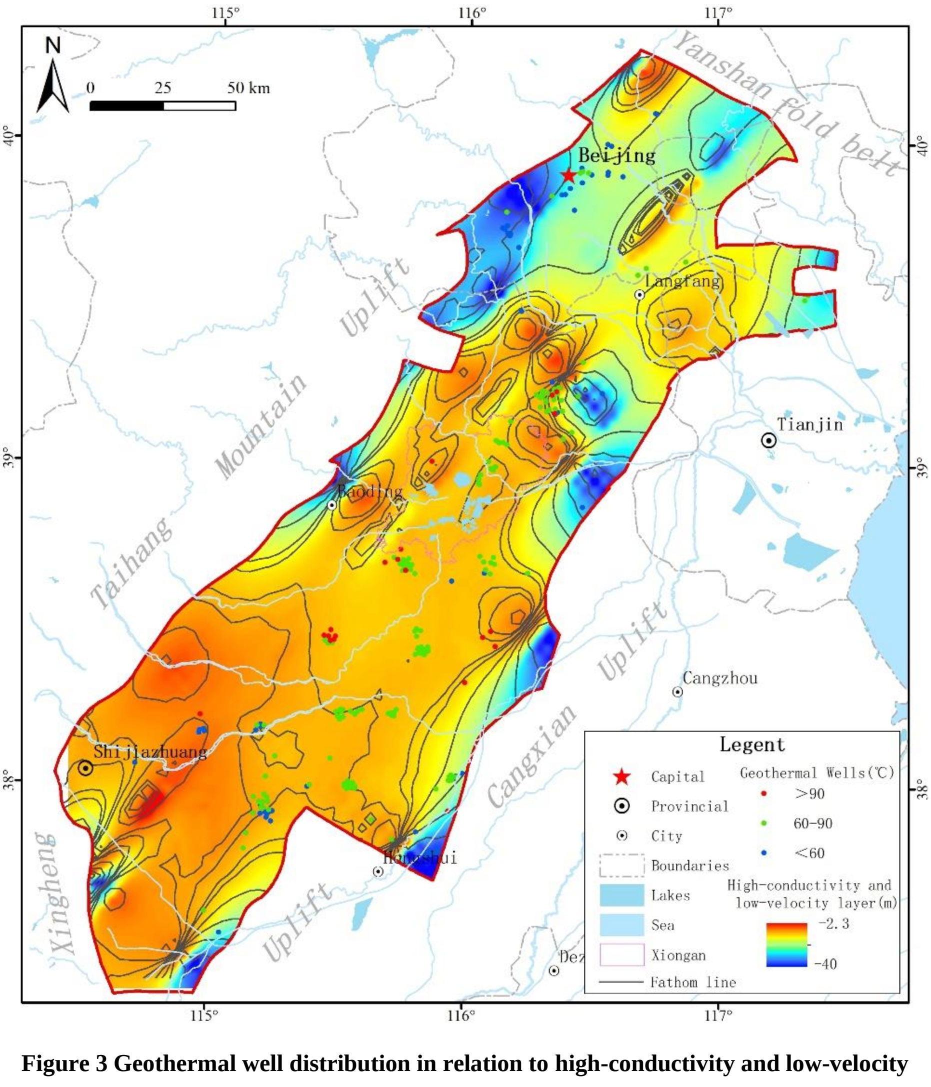

Figure 3 Geothermal well distribution in relation to high-conductivity and low-velocity

Table 1 Relationship between geothermal well distribution and high-conductivity and low-velocity burial depth

high-conductivity and low-velocity burial depth km	Number of geothermal wells	Percentage of		high-conductivity and low-velocity burial depth km	Number of geothermal wells	Percentage of
8 to 10	5	1.80%		16～18	19	6.83%
10 to 12	74	26.62%		18～20	6	2.16%
12～14	86	30.94%		20～22	16	5.76%
14～16	67	24.10%		＞22	5	1.80%

6. CONCLUSION

The spatial relationship between the distribution of known thermal wells and regional geological and geophysical features shows that the distribution of regional thermal wells, especially deep thermal wells, is closely related to regional stratigraphic, tectonic and deep geological structural features, indicating that the formation of deep geothermal resources in the Jizhong Depression is controlled by regional geological conditions, and the formation of geothermal resources on the region has the following laws.

(1) Regional Paleozoic and Proterozoic carbonate rocks and sandstone of Neoproterozoic Pavilion Tao Formation constitute the main geothermal reservoir in Jizhong Depression. The deep thermal reservoir is mainly Paleozoic-Paleogene carbonate rocks, and the carbonate rock distribution area is a prerequisite for the formation of deep geothermal resources.

(2) The thickness of carbonate rock is one of the important indicators reflecting the quality of thermal storage. The thickness size is related to the degree of denudation and the strength of karst. If the thickness is too large, it means that the degree of denudation is small and the dissolution is weak, which is not conducive to the formation of high-quality reservoirs; if the thickness is too small, the degree of denudation is large and the dissolution is strong, the total thickness of the reservoir is small and the heat storage capacity is reduced.

(3) The Moho surface undulation within the Jizhong Depression has a significant controlling effect on the distribution of geothermal wells, and the high-conductivity and low-velocity may constitute an important supplementary source of heat energy for regional geothermal reservoirs.

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