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Analysis of HDR resources development potential in North China

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ABSTRACT

North China mainly includes Beijing, Tianjin, Hebei, Shandong and Henan province. With an area of 410,000 square kilometers and a population of 250 million, the region has two municipalities directly under the Central Government, three provincial capitals, 34 prefecture-level cities and 394 county-level administrative units. North China is tectonically located in the North China Plate, which is composed of Mesozoic-Cenozoic rift basin-Bohai Bay basin and its surrounding uplift area. This area is the most abundant area of hydrothermal geothermal resources in China, and it is also the favorable area of HDR（hot dry rock）resources. The potential of HDR resources is 1.81×10^{24}J. North China area is also an important oil and gas exploration area in China. After more than 60 years of oil and gas exploration and development practice, five oil and gas fields have been discovered, and a large number of well data have been accumulated. Preliminary statistics show that deep wells are mainly distributed in Jizhong, Huanghua, Linqing and Jiyang Depressions. There are 44 wells with a drilling depth of 4000-7026m and a bottom hole temperature of 129.5-235℃. The bottom hole temperature of 28 wells exceeds 150℃. The strata drilled include sandstone, mudstone and limestone from Paleogene to Mesoproterozoic. Carbonate rocks, including dolomite and limestone, are the main potential reservoirs for EGS projects, and have the temperature and geological basis for large-scale development of HDR resources. The HDR in North China is buried relatively deep, mostly in 4000-6000m, and the temperature is not high (150-200℃). If it is used for power generation, the resource utilization rate is generally less than 10%. If it is used for space heating, the resource utilization rate can reach more than 90%. Moreover, the haze in North China is very serious during the winter heating season, and the demand for green and clean heating is extremely urgent. Considering resource quality and market demand comprehensively, the utilization direction of HDR resources in North China should be mainly heating, supplemented by power generation.

1. INTRODUCTION

The North China areas referred in the paper are situated at middle and south part of the Bohai Bay Basin, consists of Beijing and Tianjin Municipalities, Hebei and Shandong Provinces and Northern the Henan Province. The districts cover a total area of 410 000 square kilometers, reside in 0.25 billion population, and have 2 Municipalities, 3 capital Cities, 34 prefecture-level Cities and 394 County-level administrative unit, political center and one of the more developed and densely populated areas in China. The haze contamination in the areas is so serious in winter space-heating period that it is nominated as the key area in the State Council's “Three-year Action Plan to Win the Blue Sky Defense War” in 2018. The country has asked these regions to speed up energy restructuring, build clean, low-carbon and efficient energy systems, and effectively promote clean space-heating in the North Area of China.

2. GEOGRAPHIC RANGE OF THE NORTH CHINA AREAS AND THEIR GEOTHERMAL RESOURCES

The North China areas referred in the paper are situated at middle and south part of the Bohai Bay Basin, consists of Beijing and Tianjin Municipalities, Hebei and Shandong Provinces and Northern the Henan Province. The districts cover a total area of 410 000 square kilometers, reside in 0.25 billion population, and have 2 Municipalities, 3 capital Cities, 34 prefecture-level Cities and 394 County-level administrative unit, political center and one of the more developed and densely populated areas in China. The haze contamination in the areas is so serious in winter space-heating period that it is nominated as the key area in the State Council's “Three-year Action Plan to Win the Blue Sky Defense War” in 2018. The country has asked these regions to speed up energy restructuring, build clean, low-carbon and efficient energy systems, and effectively promote clean space-heating in the North Area of China.

Geothermal, particularly the Hot Dry Rock resource attracts more and more attentions in the past few years for its low-carbon, clean and huge reserves (Tester et al.,2006; Genter et al., 2010; Günter et al., 2013; Olasolo, et al., 2016; Albert, 2018). There are abundant geothermal resources in Cenozoic sandstone, Lower Paleozoic limestone and Mesoproterozoic dolomite in North China (Chen, 1988; Wang et al., 1990; Yan et al., 2000; Wang et al., 2012; Wang, 2015). This area is the most abundant area of medium-low temperature hydro-geothermal resources in China. The amount of geothermal resources is equivalent to 471.6 billion tons of standard coal (China Geological Survey, private correspond, 2016), and the area of geothermal space-heating in Xiong County alone has reached 5.7 million square meters, which is called as a nationally renowned "smokeless city". At the same time, North China is also a favorable area for Hot Dry Rock (HDR) resources. The potential of HDR geothermal resources is estimated at 61.7 trillion tons of standard coal (Wang et al., 2012). If the large-scale exploitation and utilization of HDR resources can be realized, it will be of great significance to adjust the energy structure in this area.

3 GEOTHERMAL GEOLOGICAL CHARACTERISTIC IN THE NORTH CHINA AREAS

The North China areas are located in the North China plate tectonically, mainly in the central and southern areas of the Bohai Bay Basin, a Mesozoic and Cenozoic faulted basin developed on the North China platform. In this area, the strata from Upper Proterozoic to Paleozoic are parts of the stable North China platform. Since the Mesozoic and Cenozoic, the result of successive geological events of the Indosinian, Yanshanian and Himalayan movements enable the areas to become as a tectonic active zone, and evolved into a large-scale extensional faulted basin superimposed on the North China platform. The basement is composed of the Archean, Proterozoic and Paleozoic strata with a fluctuating top surface, whereas the caprocks are Mesozoic and Cenozoic strata with a varied thickness. According to the difference of geological structure evolution and the distribution of the Paleogene system, it can be divided into six sub-structural units, i.e. Jizhong Depression, Huanghua Depression, Linqing Depression and Jiyang Depression, as well as Cangxian uplift and Chengning uplift. It can be further divided into 89 positive and negative structures in the depression and uplift areas, among which there are 43 sags and 46 bulges.

The geo-temperature field of geothermal geological background is relatively high overall in the area resulted by features of the stratigraphic, shallow and deep tectonics and tectonic activity. The geothermal gradient of the Cenozoic caprock is 3-4℃/100m, and the front zone of the Taihang Mountain is deeply influenced by cold water that generally less than 3℃/100m, whereas the geothermal gradient of basement uplift is higher than 5℃/100m (Fig. 1). The Mesozoic and Paleozoic strata have higher thermal conductivity and lower geothermal gradient due to the denser rocks. The Mesozoic geothermal gradient is 2.5-3℃/100m, while that of Paleozoic and Pre-Cenozoic is 1-3℃/100m. The general geothermal gradient of Mesoproterozoic dolomite reservoir with active hydrothermal convection is 1-2℃/100m.

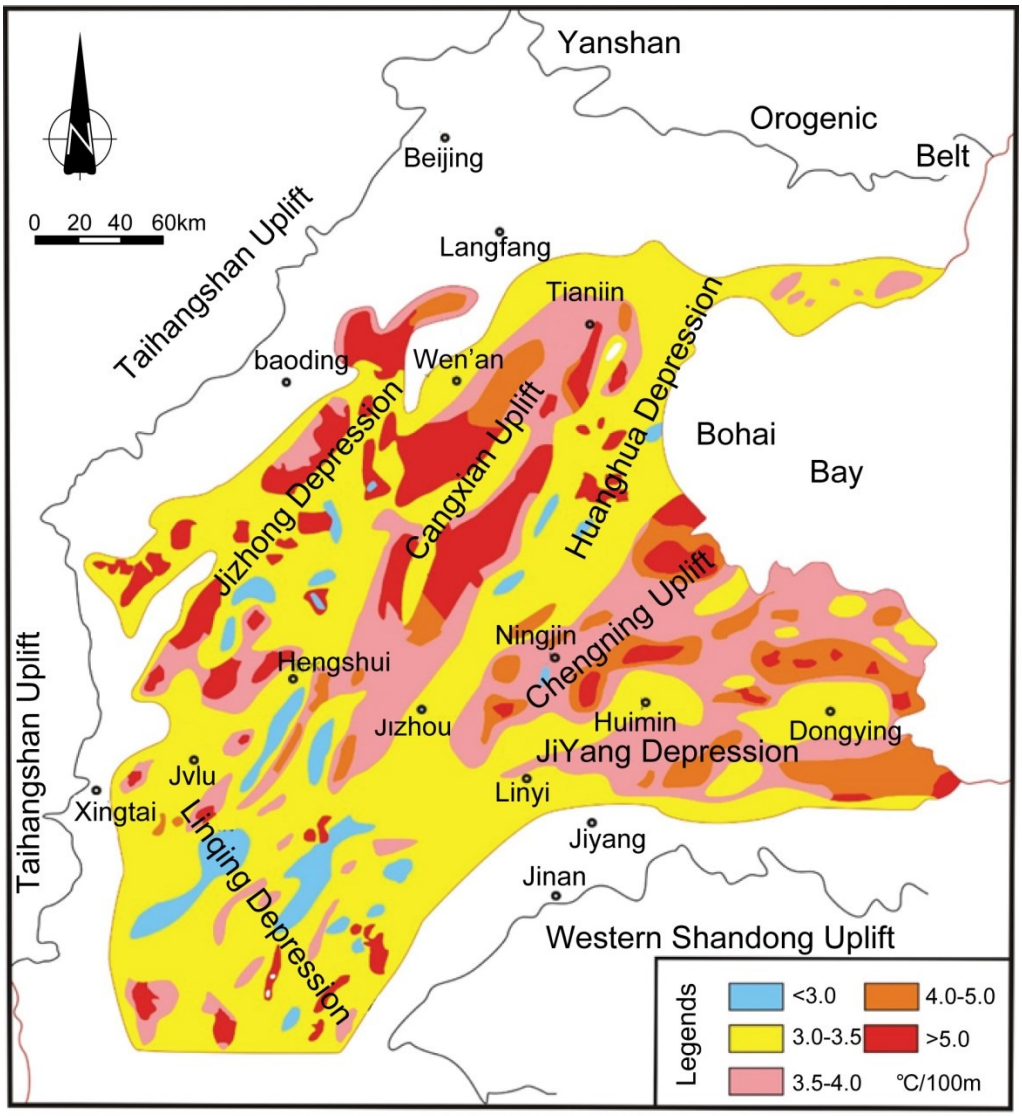

Figure 1: Distribution map of geothermal gradient of Cenozoic caprock in the North China areas (Modified after Chen, 1988)

If the carbonate buried hill of Paleozoic and Pre-Cenozoic is used as the potential HDR reservoir, the main caprock is Cenozoic strata except some Mesozoic deposits exist in some areas. Assuming that the geothermal gradient of the caprock is 3℃/ 100m~5℃/100m, if 150 ℃ ~ 200℃ is taken as the temperature range of the target HDR reservoir, the buried depth of the target HDR reservoir is about between 3000m~5000m (Fig. 2). In areas with similar caprock thickness and higher geothermal gradient, the buried depth of HDR is relatively shallow, and that of HDR is relatively deep in areas with low geothermal gradient. The higher the thickness of caprock is, the higher the temperature of HDR is in the area where the geothermal gradient of caprock is similar.

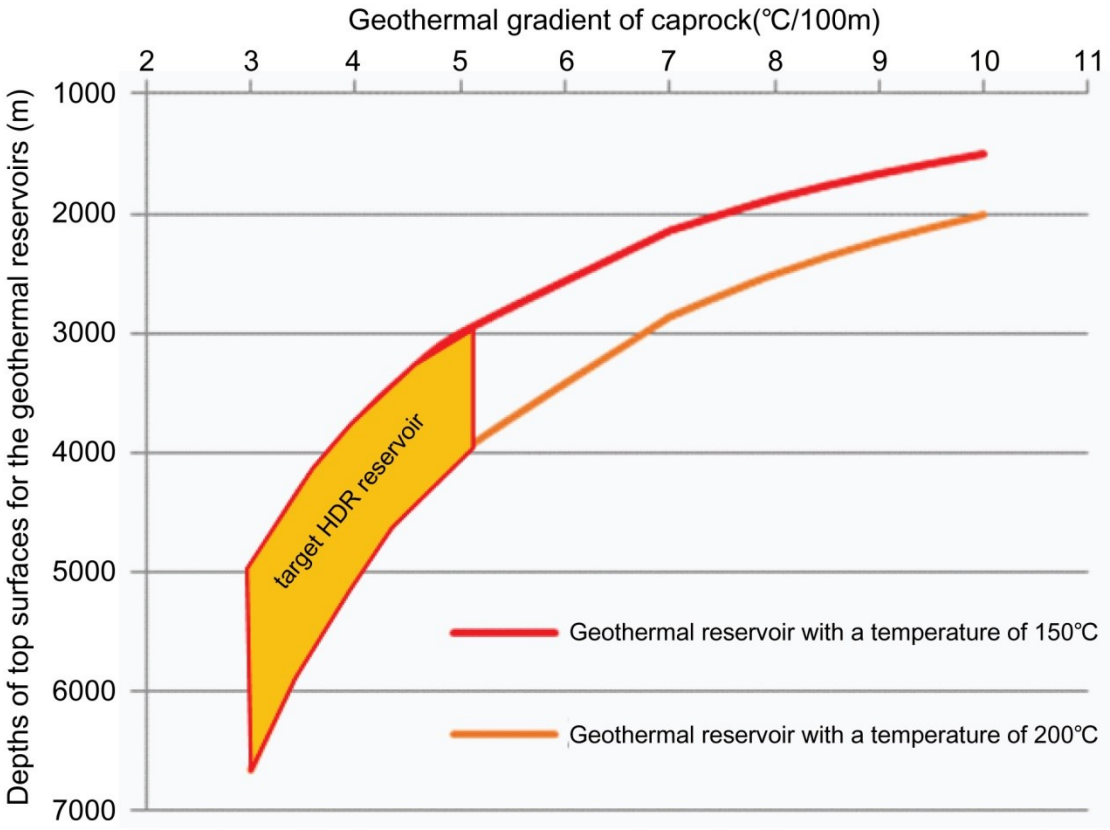

Figure 2: Relationship between geothermal gradient of caprock and target HDR reservoir depth

4 TEMPERATURE CHARACTERISTICS OF THE MAIN DEEP BOREHOLES IN THE AREAS

North China is an important oil-gas producing area in China. After more than 60 years of oil and gas exploration and development practice, five oilfields have been discovered, i.e. Shengli Oilfield, Huabei Oilfield, Dagang Oilfield, Zhongyuan Oilfield and Jidong Oilfield, and tens of thousands of drilling data have been accumulated. In recent years, with the continuous expansion of oil and gas exploration to the deep, deep drilling is gradually increasing, which provides a condition for us to understand the characteristics of deep geothermal field in this area (Li et al., 2006; Ni et al., 2006; Chen et al., 2013; Jiang et al., 2013; Wu et al., 2013; Wu et al., 2015; Du et al., 2017).

In this study, 44 drilling temperature data were collected, including 8 wells in Jizhong depression, 21 wells in Huanghua depression, 12 wells in Linqing depression and 3 wells in Jiyang sag. Figure 3 shows the deep temperature and geothermal gradient characteristics revealed by these drilling wells. The average temperature of boreholes deeper than 4000m is between 148.7-175℃, which basically reaches the temperature range of HDR. The average depth of deep drilling is 4644.4m and the average temperature is 160.7℃ in Jizhong depression, 21 wells in Huanghua depression with an average depth of 4508.8m and an average temperature of 152.5℃. The average depth of deep drilling in Linqing depression is 4387.6m and the average temperature is 148.7℃, while in Jiyang depression there are 3 wells with an average depth of 5364.2m and an average temperature of 175℃.

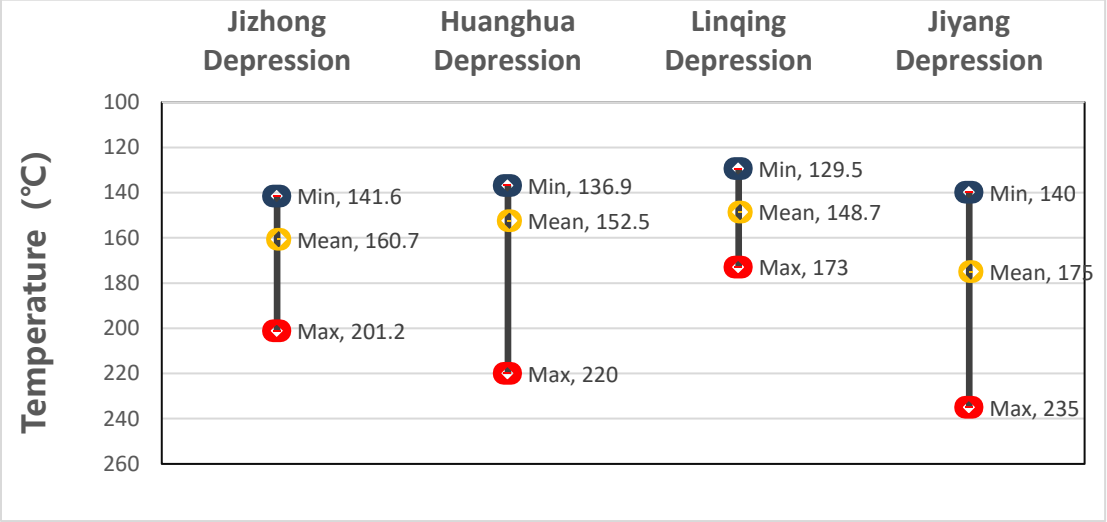

Figure 3: Bottomhole temperatures of boreholes deeper than 4000m in the four depressions of North China

The characteristics of geothermal gradient revealed by deep drilling in four depression areas are shown in figure 4. Because these drilling wells are all in the depression area, the Tertiary strata is thick and the basement is deep, the geothermal gradient is low, the average geothermal gradient is between 2.88-3.28℃/100m, a normal to low range consisting with that of Cenozoic, Mesozoic and Paleozoic strata. The geothermal gradient in Jizhong Huanghua depression and Linqing depression is slightly higher than that in Jiyang depression which is related to the lack of deep drilling data and the lack of representativeness in Jiyang depression.

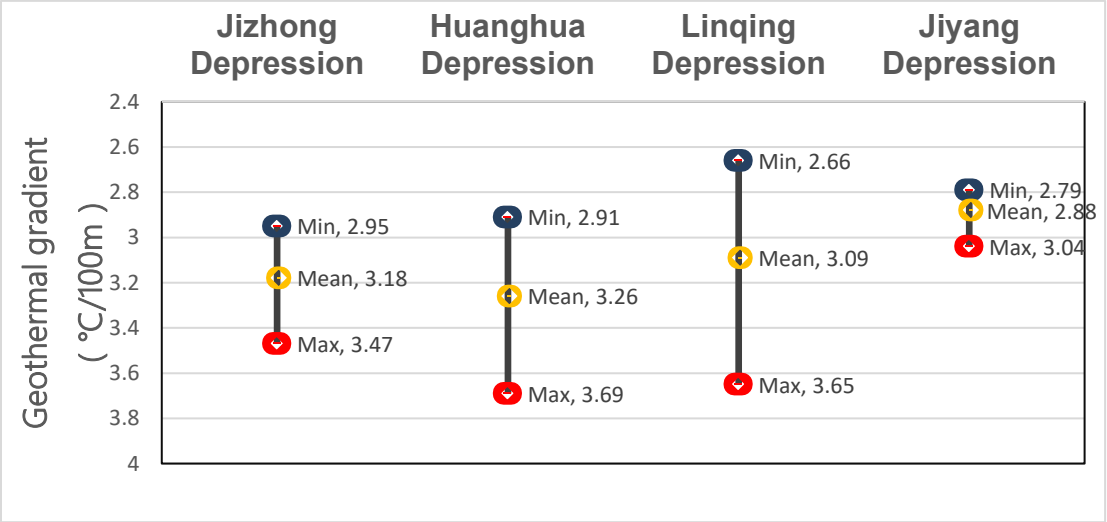

Figure 4: Geothermal gradients of boreholes deeper than 4000m in the four depressions of North China

In the collected data above, there are 8 wells in the depth of more than 5000 m, including 3 in Jizhong sag, 3 in Huanghua depression, 1 in Linqing depression, 1 in Jiyang depression, with an average depth of 5512 m, an average temperature of 186.6 ℃ and an average geothermal gradient of 3.09℃/100m. The general temperature reaches the standard range of HDR. The average geothermal gradient in Huanghua depression is the highest, reaching 3.26℃ / 100m, and in Jizhong depression 3.06 ℃ / 100m, while in Linqing depression and Jiyang depression the geothermal gradient is 2.96 ℃ / 100m and 2.82 ℃ / 100m, respectively. In comparison, HDR resources can be drilled in the lower depth of Huanghua depression and Jizhong depression.

5 DISTRIBUTION OF POTENTIAL HIGH-QUALITY HDR RESERVOIR

The exploitation of HDR resources is mainly realized by EGS. The high-quality HDR reservoir is mainly characterized by shallow buried depth, high temperature, easily reservoir stimulation, and long-period continuously development. Referring to the experience of EGS field test in Europe and the United States, the pre-Tertiary buried hill reservoir is the most potential HDR reservoir in North China. There are three main types of Cambrian-Ordovician carbonate buried hill, Mesoproterozoic carbonate buried hill and Upper Proterozoic buried hill. After more than 60 years of oil and gas exploration, the buried hill in North China has been generally clear, and some of the buried hill reservoir age and lithology are shown in Table 1. These buried hills are oil and gas reservoirs, which can be used as geothermal reservoirs in places without oil and gas, and also as HDR reservoirs in suitable buried depth and temperature areas. In

Jizhong, Huanghua, Jiyang and Linqing depressions in North China, the buried hill reservoirs with a depth of 3000-5000m are potential high-quality HDR reservoirs.

Table 1: Age and lithology of some buried hill reservoirs in North China (modified after Li et al., 2006)

Depression name	Buried hill name	Age	Lithology
Jizhong Depression	Ma 12	Archean	Metamorphic rock
	Yongqing, Hezhuang, Western Shenxian, Renbei, Suqiao, Nanmeng, Longhuzhuang, Liuqiying, Hexiwu	Lower Paleozoic Ordovician	limestone
	Longhuzhuang, Nanmeng	Fujunshan Formation of Lower Paleozoic Lower Cambrian	dolimite
	Xuezhuang, Liubei, Balizhuangxi, Yanling, Balizhuang, Renqiu	Wumishan Formation of Mesoproterozoic Jixian System	dolimite
	Hejian	Mesoproterozoic Changcheng System	Dolomite, quartzite
Huanghua Depression	Qianmiqiao, Beidagang, Kongxi, Wumaying	Lower Paleozoic Ordovician	limestone
Jiyang Depression	Zhuangxi. Kenli, Binnan, Yihezhuang	Lower Paleozoic Ordovician and Cambrian	limestone
	Wangzhuang	Taishan Group of Archean	Metamorphic rock of crystalized basement
Linqing Depression	Machang	Lower Paleozoic Ordovician	limestone

North China is an important oil and gas producing area in China, where 5 oilfields, i.e. Shengli, Huabei, Dagang, Zhongyuan and Jidong Oilfields, have been discovered and tens of thousands of wells have been drilled and a great deal of geological and geophysical data have been obtained. In the depression with the greatest potential for large-scale exploitation of HDR resources, there is a large amount of oil and gas drilling data, three-dimensional seismic data and a great deal of geological and engineering research results. It lays a solid foundation for developing the site selection description of HDR resources and the construction of HDR EGS project in this area.

6 DISCUSSION ON THE EXPLOITATION AND UTILIZATION OF HDR RESOURCES

North China has developed economy, dense population and energy shortage. At present, the demand for space-heating in winter is the most urgent, the demand for refrigeration in summer is large, and there is electricity demand all year round. Therefore, it is necessary to design scientifically the development and utilization of HDR in order to realize the efficient and economical utilization of resources.

The buried depth of HDR in this area is about 4000-6000m, and the temperature of HDR reservoir is generally between 150℃ and 200℃. By using EGS technology, the wellhead temperature of geothermal fluid produced is about 130-180℃, so it is appropriate to vary the energy demand in different regions and seasons. The geothermal fluid extracted from EGS system is first used for power generation, and the tail water for power generation in winter is used for heating buildings (including office rooms, residence, planting and breeding greenhouse, etc.). Space-heating tailings enter the EGS system and continue to be heated underground and recycled. In summer, the power generation tailings are cooled with the buildings, and the tailings enter the EGS system and continue to be heated underground and recycled. Because the demand of different areas varies greatly in different seasons, the dynamic regulation system should be established to maintain the efficient and stable operation of the EGS system according to energy demands.

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