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GEOTHERMAL RESOURCES IN THE JIDONG AREA, NORTH CHINA BASIN

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ABSTRACT

During a long period of petroleum exploration, plenty of low-medium temperature geothermal water resources have been discovered in dozens of drill-holes in the Jidong Oil Field, North China Basin. There are five main thermal abnormal zones in the Jidong area with potential for geothermal resources development: the Matouying uplift, Begezhuang-Xinanzhuang uplift, Laowangzhuang-Tian-zhuang uplift, Jianggezhuan uplift and the Gaoliu fracture zone in the Nanpu depression. The total surface area of these five zones is about 1900 km^2. The total recoverable heat from the hot water has been estimated to be 2.0 x 10^{18}J.

1. INTRODUCTION

The exploration scope of the Jidong Oil Field covers mainly on land areas to the south of Yanshan Mountain and off shore Bohai Bay. Its land area is about 3600 km^2 which involves partially both Tangshan city and Qinghuangdao city of Hebei Province (Fig. 1).

A network of railways and country roads facilitates transportation in the area. Jingtang port on the east coast is a major port in northern China. In Tangshan region there are abundant natural resources, such as coal, oil and gas etc; and a variety of industries including steel, power generation, pottery and porcelain crafts. Being called "granary of Jidong", wheat, corn, rice, cotton, peanut, vegetables, fruits are grown here. Stockbreeding and aquaculture are well developed, too.

Tourism has blossomed in Jidong in recent years due to some famous historic sites and beautiful summer resorts, such as the Great Wall at Shanhaiguan, Nandaihe, Beidaihe and Golden Beach summer resorts, and many others.

2. REGIONAL GEOLOGICAL SETTING

The area is a part of the Bohaiwan Meso-Cenozoic sedimentary basin. Three groups of major faults, namely NE, NW, and EW fault systems, control the formation and evolution history of the basin. The general structural pattern consists of six pairs of uplifts and depressions according to the thickness of the Meso-Cenozoic strata. They are Nanpu, Jianhe, Leting, Shijiutuo, Changli and Qinhuangdao depressions; Xihe, Laowangzhuang, Xinanzhuang, Bogezhuang, Matouying and Jianggezhuang uplifts (Fig. 2).

The Yanshan fold-belt is to the north of the area, seperated from the Bohaiwan Basin by the Ninghe-Changni Fault, the largest fault in the region. The displacement of basement rock is up to 1500-3000m, with the upthrown basement rocks buried from 500 to 1000m, and the downthrown buried from 2500 to 4000m, and forming three depressions: Changli, Leting and Jianhe.

Seven other faults are the West Laowangzhuang, East Laowangzhuang, Xinanzhuang, Bogezhuang, Hongfangzi, Zhangjiapu and Leting-Luannan faults, which delimits the numerous uplifts and depressions.

The Gaoliu fault, located in the Nanpu depression, is only developed in the cover layers. It traverses the Nanpu depression from the Xinanzhuang fault in the west, to the Baigezhuang fault in the east. It acts as a main thermal source fault because of the intense movement at the end of the Cenozoic era.

3. MAJOR THERMAL AQUIFERS

Upon the crystalline basement of the area, there are four sets of sedimentary formations, i.e. Protozoic, Paleozoic, Mesozoic and Cenozoic strata. Thermal aquifers are found in all these strata. However, due to extension and thickness, only the sandstone formations in upper Tertiary and limestone strata in lower Paleozoic serve as practical thermal water aquifers for geothermal development in the area.

The upper Tertiary includes the Guangtao formation (Ng) and Minghuazheng formation (Nm) which are aluvial sandstone formations with interbeded sandstone and mudstones. The total thicness varies from 1000 to 2400m.

The Lower Paleozoic includes the Majiagou formation (Om) and Fujunshan formation (Ef), both composed of limestone and dolomite. Fractures and even caves are developed in the rocks that can form good aquifers. This has also been evidenced by drill-holes.

4. GEO-TEMPERATURE PATTERN

A geothermal anomaly in the Jidong field is defined as an area where the geothermal gradient is greater than 3.5°C/100m or heat flow density is higher than 62mW/m^2. The total area of thermal anomalies is about 480 km^2. The occurrence of these anomalies is controlled by geological structures.

4.1 High Geothermal Anomalies Correspond to Uplifts

As was described in Chen (1988) for the whole North China Basin (the study area of this paper is in the northmost sector of the basin), most of the geo-temperature anomalies can be related to the occurrence of pre-Cenozoic basement uplifts. In northern part of the study area, a low temperature zone is formed along the piedmont of the Yanshan fold belt, which is dominated by cooler southbound groundwater flow seeping into the northern part of the area.

The higher geo-temperature anomalies occur in basement uplift area, such as Xihe, Laowangzhuang, Bogezhuang, Jianggezhaung and Matouying uplifts, as well as Tanghai "buried hill". The geo-temperature gradient of the sedimentary cover is 3.5-3.7 °C/100m, with corresponding heat flow 62-65 mW/m^2, and the temperature is up to 46-50 °C at 1000m depth.

In contrast, in the lower zones in depressions, the geo-temperature gradient in the sedimentary cover is 2.9–3.1°C /100m, with corresponding heat flow 50–55 mW/m^2, and the temperature is 42-44°C at 1000m. In deeper parts of depressions, for example, the western part of the Leting depression, geothermal gradient is only 2.7-2.8 °C /100m, and the temperature at 1000m is less than 40 °C. As for the transitional zones, geo-temperature gradient and deep temperature are between the two cases as discussed above. The general framework of this geo-temperature pattern is summarized in Fig. 3.

4.2 Vertical Variation in Gradients is Controlled by Lithology

Lithology determines the thermal conductivity of rocks and sediments, and therefore controls the geo-temperature gradients. In the Cenozoic cover, thermal gradient can be related to the ratio of sandstone to mudstone, higher in mud sections, and lower in sandstone sections. Taking the lower section of Nm formation of well N42 as an example, its geothermal gradient is 3.76°C /100m, corresponding to a sand/mud ratio 25 to 75, but for Ng formation, its geothermal gradient decreases to 3.27°C /100m, with a sand : mud ratio 43 :57. Another example is well X-2, the geothermal gradient is up to 3.69 °C /100m corresponding to sand : mud ratio 40: 60, but its geothermal gradient drops to 2.62 °C /100m when sand : mud ratio changes to 75:25.

Since the thermal conductivity of the Pre-Cenozoic, Paleozoic and Pre-Paleozoic rocks are 1.4-1.6 times as high as the Cenozoic formation, geothermal gradients in these rocks are about 2.5 to 3 °C /100m. There are some exceptions. In Jurassic, Lower Paleozoic and some coal-bearing strata, the geothermal gradients can reach 3.5 to 4.0 °C /100m as evidenced by logging data. But in some thick dolomite, carbonate, and granophyre formations, the gradients may be as low as 1.5-2.0 °C /100m.

4.3 Local Geothermal Anomalies

On a relative homogeneous geothermal background controlled by structure patterns of uplifts and depressions, geothermal water migrates through faults in some places and creates local geothermal anomalies with geothermal gradients up to 7 °C /100m. This is evidenced in some high temperature drill-holes located in the eastern sector of Gaoliu fault zone and the western sector of the Matouying uplift. Well N70x1 is the hottest hole with a temperature is up to 109 °C at 1328m in the Ng formation. It is a rare instance in Meso-Cenozoic sedimentary basins in North China. Three groups of faults, striking NW, EW and NE respectively, converge here to form a good conduit for the thermal water to flow upward, resulting in higher thermal gradient in the sedimentary cover.

5. WATER CHEMISTRY

Salinity of the thermal water is quite low in the area. By vertical sequence, in the upper Tertiary, the salinity is between 0.43 and 2.25 g/l, the majority of which is 0.8-1.5 g/l (based on data of 86 drill-holes). The salinity of the Ordovician is 0.8-2.95 g/l, and the Cambrian is 1.28-4.01g/l (12 drill-holes). The tendency is for the salinity to rise with increased depth, but not with increased temperature.

Cl^- and $HCO3^-$ are the major ions in the thermal water and increase with salinity. SO_4^{2-} is low and not affected by salinity. K^+ and Na^+ are major ions and they increase linearly with salinity. Mg^{++} and Ca^{++} are low and not affected by salinity.

The chemical content of thermal water from Ng and the lower section of Nm is low in SO_4^{2-} and high in Na^+. The water chemical types are HCO_3-Na, HCO_3-Cl-Na, Cl-HCO_3-Na and Cl-Na.

Based on samples from 16 drill-holes, the average salinity of thermal water in the lower Paleozoic is 1.57±0.19 g/l. Their chemical types are HCO_3-Na, HCO_3-Cl-Na and Cl-HCO_3-Na.

After comparing the major chemical contents and trace elements of the thermal water to China National Standard for Portable Water (GB5749-85), China National Standard for Natural Mineral Portable Water (GB8537-8) and China National Provisional Standard for Medical Treatment Mineral Water, we can claim that groundwater from the upper section of Nm, such as wells TG-3, HG-1 and DC-2 is portable in terms of chemical and toxicological indexes. Geothermal water from Ordovician aquifer contains high silica and trace elements such as Li and can be utilized as mineral water for medical treatment.

6. ASSESSMENT OF THE RESOURCES

Taking the high potential sandstone reservoirs of the upper Tertiary and limestone reservoirs of the lower Paleozoic into account, we can calculate thermal water resources, both stored and recoverable quantities (based on present exploiting technology available) for each reservoir. The total area is divided into 13 sectors with a total area of 3470 km^2.

6.1 Total Stored Thermal Water

Using the volumetric method, we have

$$Q = A\cdot b\cdot \varphi \qquad (6\text{-}1)$$

And

$$Q_H = A\cdot b\cdot \varphi(\rho\cdot c)(T-T_f) \qquad (6\text{-}2)$$

Where, Q- stored thermal water, A-area, b-thickness of the reservoir, φ-effective porosity, Q_H-heat, ρ·c-volumetric heat capacity, T-average temperature of thermal water, T_f -reference temperature.

Stored thermal water in the Nm group is $3.6x10^{11}m^3$, its total heat is $48.1x10^{18}$J. The figure for the Ng group is

$2.2x10^{11}m^3$, its total heat is $36.3x10^{18}$J. If the area of the lower Paleozoic aquifer is 880 km^2, then its stored thermal water is $30.2x10^8m^3$ and its total heat is $78.2x10^{16}$J.

6.2 Recoverable Thermal Water Resources

For the upper tertiary, we use the maximum drawdown method (Marshall et al., 1983). On the lines of the design, the additional allowed maximum depth is 150m, the exploiting period is 20 years, the expected pumping rate is 72 m^3/d, the radius of the well is 0.1m. Use the following formula:

$$Q = N \cdot q \cdot p \quad (6\text{-}3)$$

And

$$Q_H = N \cdot q \cdot p\ (\rho \cdot c)(T - T_f) \quad (6\text{-}4)$$

Where,
Q - recoverable water, Q_H - heat quality of recoverable reserve, N- number of well, other symbols as in equations (6-1) and (6-2).

The calculated recoverable thermal water in Nm formation is 3.7 x 10^9 m^3, its total heat is 49.1 x 10^{16} J. For Ng formation these numbers are 2.8 x 10^9 m^3 and 45.4 x 10^{16}J. For the whole area, $6.5x10^9$ m^3 and $9.5x10^{17}$J respectively, which is equavelent to the heat of $3.2x10^7$t of standard coal.

For the lower Paleozoic formation, the recoverable coefficient method (Nethenson, 1975) is used. The recoverable coefficient is taken as 0.15, the calculated recoverable thermal water is $4.5x10^8$ m^3, its total heat is $11.7x10^{16}$J, which is equavelent to the heat of $3.6x10^7$t of standard coal.

7. CURRENT STATUS OF UTILIZATION

There are many low-medium temperature thermal water holes in this area. Up to now, limited utilization projects have been completed to make use of the thermal water resources in the area. The following are some examples.

Well N-34x1 is located in the base of the Oil Field whose inflow formation is Nm. The water temperature is 56°C, pumping rate is $1200m^3$ a day. It is mainly utilized for bathing purpose in hotels and apartment buildings. Annual water consumption is $30x10^4m^3$, which is equivelant to 3,000 tons of coal.

Well N-73 is located to the south of Daqinghe salina whose inflow layer is Ng. The water temperature is 75-78 °C, artesian flow is $2000m^3$/d. It is mainly utilized for space heating and bathing. The total heating area is $45x10^3$ m^2 equavelent to $20.4x10^3$ tons of coal. In addition, it reduces the emission of CO by 463.65 tons and SO_2 by 326.8 tons. Since there are no chimneys, the air in the area is very clear.

Well HC-1, whose inflow layer is the Ordovician limestone, is just 1 kilometer from Fengnan township. The water temperature at the wellhead is 96°C, artesian flow rate is greater than $2000m^3$/d. It is mainly utilized for pisciculture, which has made profits of more than 300,000 RMB yuan each year since 1987.

Jidong area with abundant thermal water resources, has many good conditions for larger-scale utilization and has attracted attention of investors from China and overseas. In order to promote utilization of the resource, we'd like to make use of advanced technology from both domestic and foreign producers and sincerely welcome all aspiration persons and entrepreneurs to invest in geothermal utilization projects with high profitable potentials.

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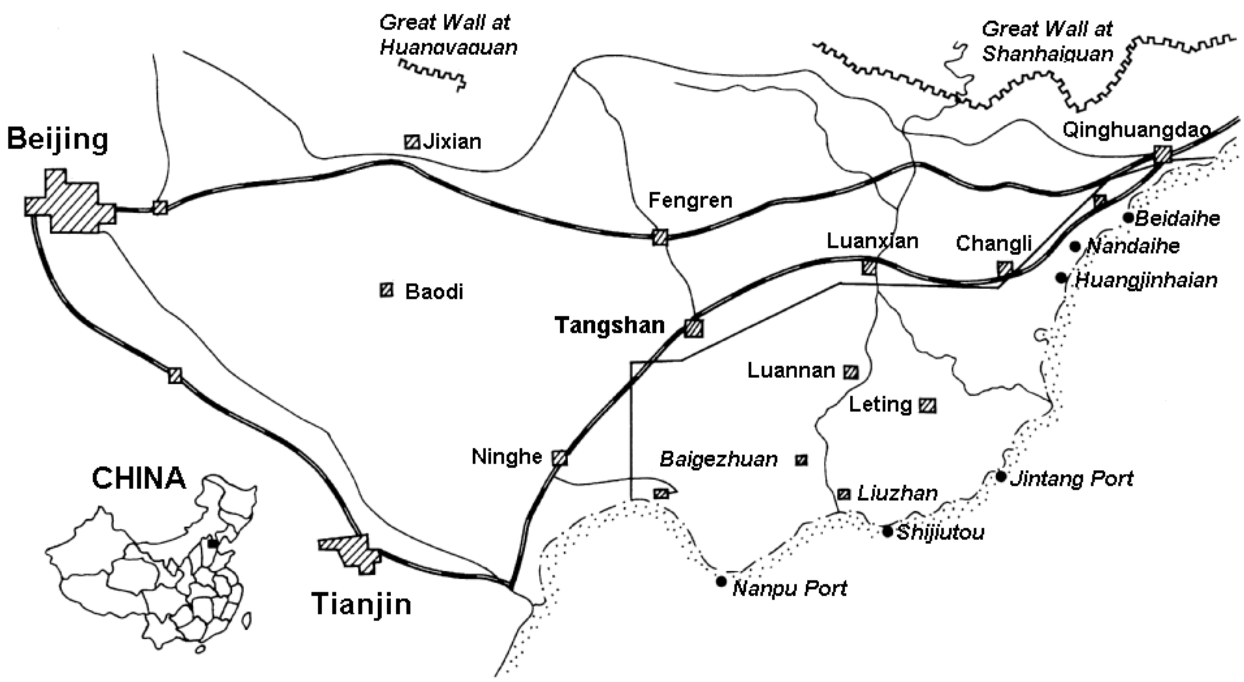

Figure 1. Location map of the Jidong (East Hebei) area.

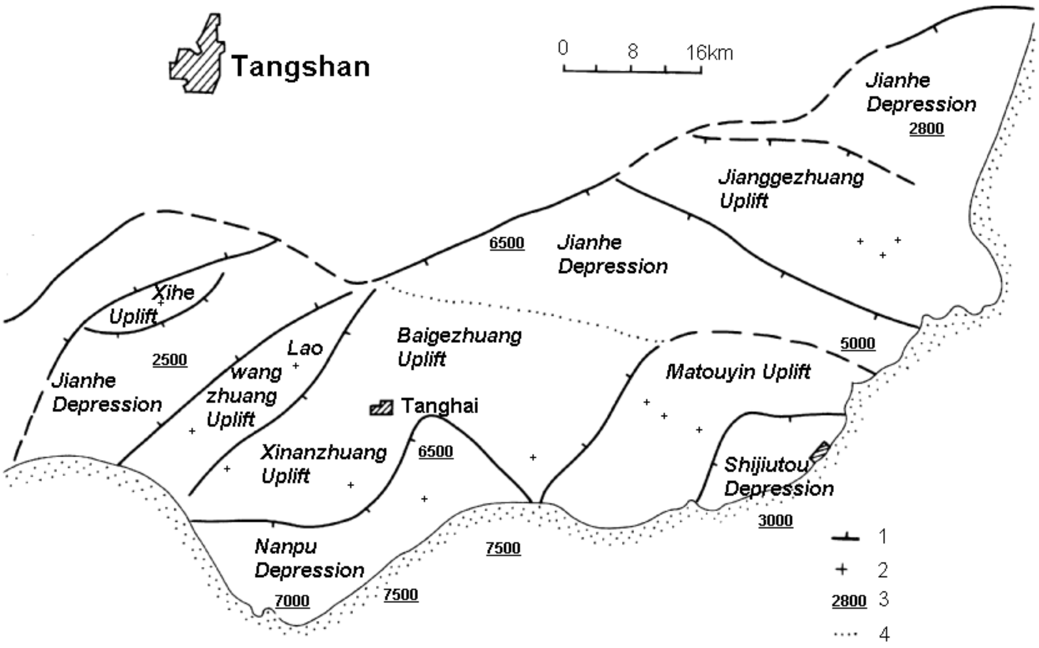

Figure 2. Tectonic framework of the study area. Legend: 1. Fault; 2. Top of uplift; 3. Bottom of depression and depth (meters); 4. Boundery between uplift and depression.

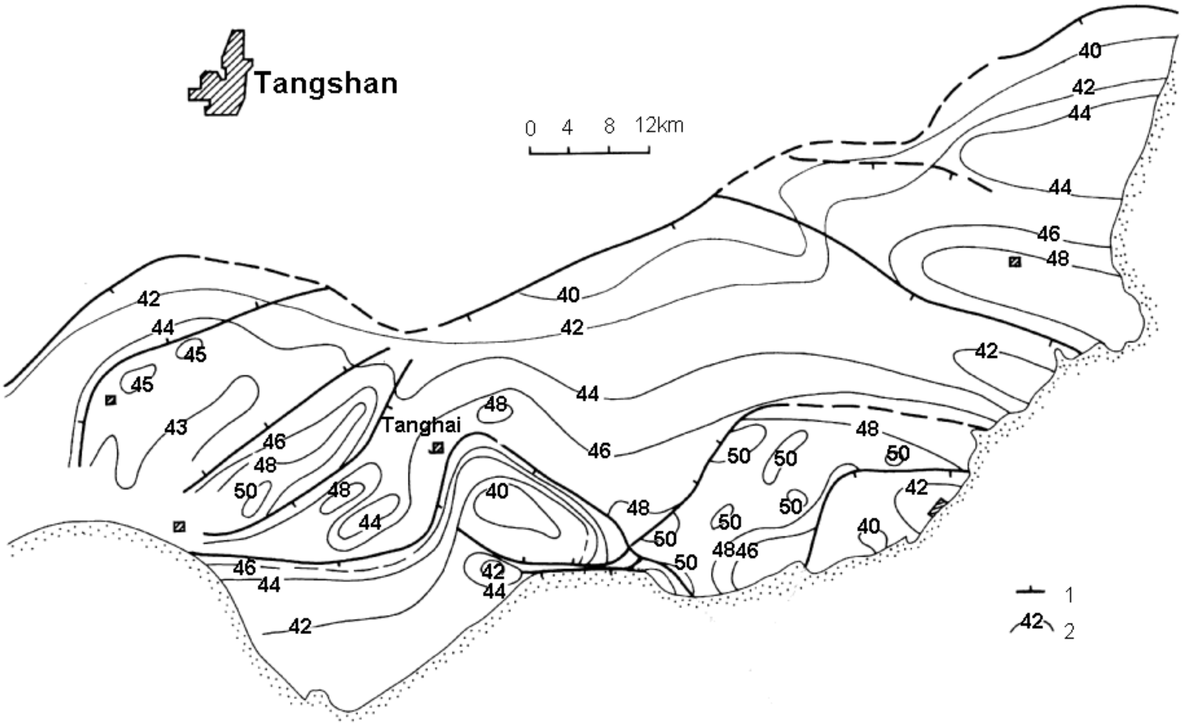

Figure 3. Temperature at the depth of 1000 meters in the study area. Legend: 1. Fault; 2. Temperature contour.