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The Characteristics of the Dongying Formation Reservoir in Tanggu, Tianjin, China

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ABSTRACT

At present, five geothermal reservoirs have been developed in Tianjin, the annual production is 2500×10^4 m^3. They are used for space heating, greenhouse, spa and domestic hot water etc.. Along with rapid economic development the demand for geothermal is gradually increasing, so it is necessary to find a new geothermal reservoir for economic development. Through recent years exploration work, the Dongying formation reservoir has been found. The paper describes the characteristic of the Dongying formation and its development prospect.

1. INTRODUCTION

Geothermal resources as a kind of green renewable energy, have received widespread concern in all walks of life. For many years, the exploitation has been concentrated mainly in Minghuazhen reservoir, Guantao reservoir and Wumishan reservoir in Tianjin. The geothermal wells of Minghuazhen and Wumishan reservoir are located mainly in urban areas and the new four-zone, the geothermal wells of Guantao reservoir are concentrated mainly in the Dagang District, Tanggu District and Wuqing District. As a whole, the water level and reservoir pressure of the Tianjin reservoirs have the quick decline trend and indeed form a cone of depression due to concentrated mining. The concentrated mining areas have been classified as limited mining areas in the document "The Development of Geothermal Resources in Tianjin Use Planning (2006-2010)", but the strong requirement of economic development in Tianjin has created the rising rapid demand for clean energy, especially in the core area of Tianjin Binhai New Area, the Tanggu District. Therefore it is necessary to search, explore and objectively evaluate new energy sources for development.

According to the existing data, the Paleogene Dongying is widely distributed as inland lacustrine clastic sediments in the Huanghua Depression. Oil well logging data show that the Dongying formation has more than 20% porosity and better rich water, has passed the first successful exploitation of perforation, has a certain potential for development, the study of Dongying reservoir has been gradually concerned. Tianjin Geothermal Exploration and Development Institute has completed the report "Tanggu District Dongying reservoir geothermal resources survey in Tianjin" in January 2007 ~ December 2008 in order to develop a new reservoir.

2. GEOLOGICAL BACKGROUND

2.1 Features of geological structure

The Dongying Formation is mainly distributed in Tanggu District of Huanghua Depression and Wuqing district of Jizhong depression in Tianjin. Regional tectonic location of the survey area is located in the Huanghua Depression, the Depression is located in the east of Tianjin, adjacent to the Cangxian uplift. In the west and north bounded by Cangdong fault and Ninghe fault respectively, is the Yanshan Movement long-term subsidence, exacerbated since the beginning of the Cenozoic. The biggest difference is in the Eogene area of extensive development and the depression center is located in the southern section of the Huanghua Depression (outside of Tianjin city) and the thickness is about 5000m. The Neogene depression center is located in the middle section of the Huanghua depression and the thickness is about 2500m, the depression center of the Quaternary is located in north section of the Huanghua depression and the greatest thickness is 600m. The bedrock roof is mainly Mesozoic and Upper Paleozoic Carboniferous - Permian, the depth of roof has large differences, on the whole, to deepen from west to east from 1400 ~ 5000m, the deepest section is located in the north-east of Ningchegu and in the north-west of Tianjin Technological Development Zone and Guanggang reservoir. The NNE, NWW and NW faults are richer, the main faults of big influence are NNE Cangdong fault and NWW Haihe fault. There are rich convex and depressions in the inside influenced by the cross-impact faults, there are Ninghe convex, Beitang depression, Banqiao depression and Qikou depression from the north to the south. The survey area contains the Beitang Depression and Banqiao Depression (Figure 1), which is bounded by the Haihe fault.

Beitang depression: the Beitang depression is located in the northern part of the Huanghua Depression, bounded by Cangdong fault in the west and connects the Panzhuang convex, is bounded by Hangu fault in the north and connects the Ninghe convex, is bounded by Haihe fault and connects Banqiao depression, the depth of bedrock roof as a whole shows is shallow in the West and deep in the East, and the Cenozoic thickness is 1300 ~ 5000m. The depressions is further divided into the Qinghe next depression, the belt of Chadianxinhe fracture structure, Hangu next depression, the belt of Dashentang fracture structure, Beitang next depression, the nose tectonic belt of Tanggu, which shows NE line-to-line arrangement, the nose tectonic belt of Tanggu shows north-west spread and is located in south edge of the depression, bounded by Haihe fault in the south, bounded by Tangbei fault in the north, bounded by Cangdong fault in the west, the east side of into the sea, and connected with Xinguang half anticline. The cross-section trend of the Haihe Fault and Tangbei fault is contrary, there is an east-west strip base block in the middle of the fault, which affects the Paleogene sediment distribution.

Panqiao Depression: Panqiao Depression is located in the South of Huanghua depression, West to Cangdong fault bounded and adjacent to Baitangkou depression, North to the Haihe fault bounded and connected to Beitang depression. The bedrock roof as a whole shows west and east deep, the Cenozoic thickness is 1500 ~ 5000m. The fault zone Shajingzi consists of low uplift zone in Shajingzi and known as the low uplift zone of Beidagang or Beidagang tectonic zone, the Neoproterozoic and Palaeozoic were drilled. In the drilling, the sediment thickness is

generally more than 2000m in the most areas, the roof of bedrock is the Mesozoic.

2.2 Stratigraphic Characteristics

The Dongying formation generally distributes in other regions in addition to the west side near Cangdong fault. According to lithological features, the Dongying formation can be divided into East I, II, III, three paragraph from top to bottom. The main lithology is fine-grained sandstone with interbedded shale in the East Ⅰ paragraph, the upper is shale and the lower part of fine-grained sandstone; the main lithology is shale and fine sand strata folder in East Ⅱ ; the main lithology is fine-grained sandstone and thin mudstone in the East III paragraph. The roof depth is 1500 ~ 2300m (Figure 1), shows the characteristics of West shallow and East deep, the depth is1500m near the Cangdong fault while the depth is more than 2000m in the east. The thickness is 100 ~ 660m and the change is large (Figure 2), the overall performance is thin in the central and thick in both sides of the North and the South, the stratum changes deep to north, east and south to center around Hetou, the thickness of stratum generally less than 240m from the Hetou to Xingang in the middle. For example, the T06 well is 131m in the west part and T38-2 well is 236m in the east. The thickness changes significantly in the south, the T43 wells is 654m. The thickness changes significantly in the north, the T14 wells is 613m.

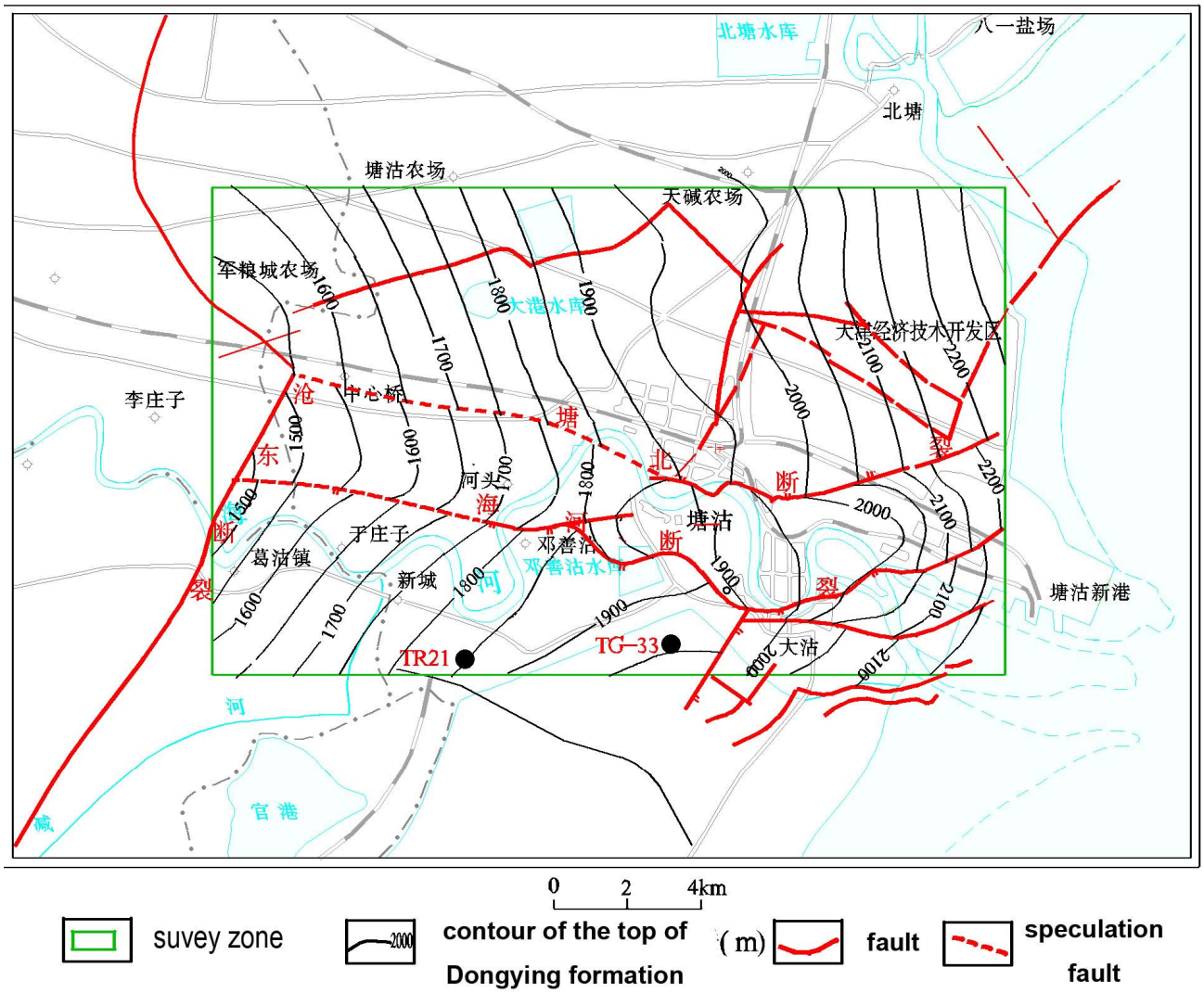

Figure 1: The top contour of Dongying formation

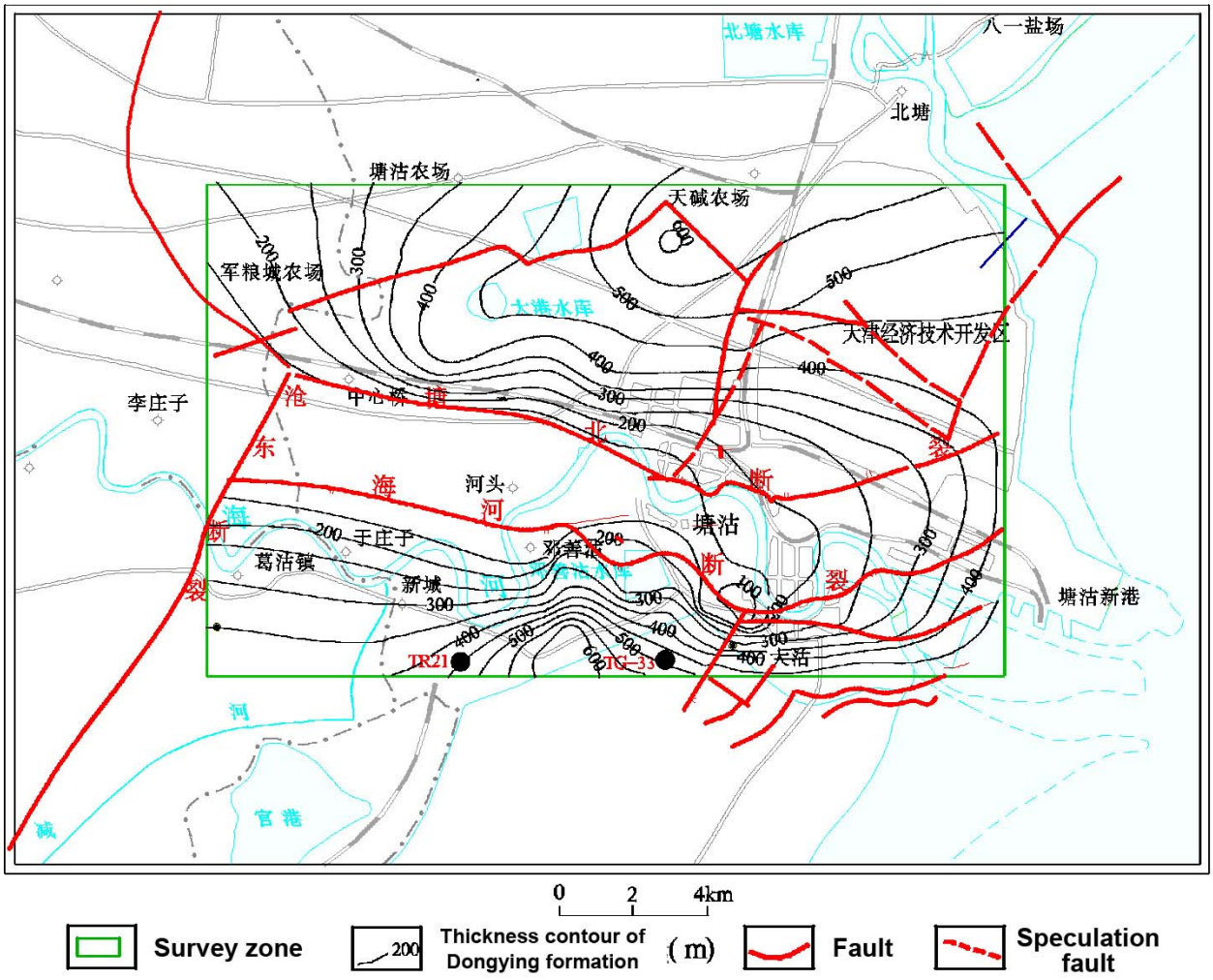

Figure 2: The thickness contour of Dongying formation

The overall changes have two characteristics:

(1) The thickness has substantial connection with the ancient structure, the thickness is thin in the tectonic belt in the nose ("convex"), the thickness changes to south and north (“depression”), the thickness is west thin and east deep in the Haihe fault zone. All of this shows that the convex controls the stratum development.

(2) The thickness of stratum changes deep in the Banqiao depression and Beitang depression of North-South both sides of the Haihe fault, the thickness isoline accords with the trend of Haihe fault showing the east-west direction. The maximum thickness is located in the northeast of the northern side of Tanggu Station about 2.8km, the thickness of T14 Well is 613.5m, for the deposition center of Dongying Formation.

There is coarse lithology near the source in the west according to lithology changes (near the Cangdong fault), fine lithology to the deposition center, there is mainly mudstone. the single-layer thickness is up to 65m in the typical T40 (in the northeast of about 2.5km o f T14 wells), the stratum is integrated with the underlying Shahejie formation.

3. RESERVOIR CHARACTERISTICS

Dongying reservoir in Tianjin Binhai distributes widely, buried under the Neogene Guantao Formation, Dongying reservoir is rocks for thermal energy storage, geothermal fluid enrichment in the sandstone and pebbly sandstone, which has the high interconnectivity and larger effective porosity.

According to oil drilling data, the roof depth of Dongying Formation is 1500 ~ 2300m, the thickness is 100 ~ 660m, the ratio of sand and mud is 35% ~ 38%, the porosity is 20 ~ 35%, the permeability is 200 ~ 1000mD. The roof depth is 1500 ~ 2200m and the permeability is 200 ~ 900mD in the south of the Haihe fault; the roof depth is 1600 ~ 2300m and the permeability is 300 ~ 1000mD in the north of the Haihe fault. According to the lithology of Dongying reservoir, there is gray green mudstone and sandstone, interbedded sandstone and conglomerate of about 300m thickness in the underneath of Dongying reservoir, the porosity is 20 ~ 28%, a small number of layers is up to 25 ~ 30%; there is main mud in the middle, has poor water conditions; there is green to mottled gray, red shale and gray sandstone, conglomerate, whose reservoir of about 200m thickness in the upper, the porosity is 22 ~ 35%.

There is thinner single sandstone thickness, generally less than 8m, the maximum thickness of 28m, and the lower part of occasional cinder in the Dongying reservoir well TR21 for the purpose of exploration in this area. According to the pumping test of TG-33 and TR21 geothermal wells, the permeability coefficient of Dongying reservoir is 0.16 ~ 0.22 m/d, a flexible rate is 2.47×10^{-7} ~ 2.68×10^{-7} 1/m. Most of the pore diameter is 0.05 ~ 0.1mm and porosity under observation is 30% ~ 35% on the basis of the structure and porosity of rock type identification in TR21 well rock samples. These pores are a basic condition for water-rich reservoir.

TR21 well is cored at 2225 ~ 2226.8m after the target zones. According the coring, the sandstone is fine-grained sandstone, micro-fine-grained structure, good diagenesis. According Table 1, the reservoir has large porosity, but high clay content. The production of the single well is about 40 m^3/h, the water temperature is 73ºC, the salinity of geothermal fluids is 2993.2mg/l, the water chemistry type is Cl • HCO_3-Na, the value of rNa/rCl is about 1.47.

Table 1: the porosity and permeability of Dongying reservoir in TR21 well

Section	Depth（m）	Thickness（m）	Porosity %	Permeability（$\times10^{-3}\mu m^2$）
East I	1950.1 ~ 1963.1	13.0	27.51	625.25
	1978 ~ 1984	6	26.64	480.03
	1989.4 ~ 1996.7	7.3	23.35	218.93
East II	2073.3 ~ 2090.1	16.8	31.41	908.16
	2202.2 ~ 2207.6	5.4	31.02	812.55
East III	2213.0 ~ 2220.0	7	29.98	725.69
	2249.7 ~ 2256.1	6.4	25.94	389.88
	2272.3 ~ 2278.8	6.5	26.04	406.29
	2284.3 ~ 2312.6	**28.3**	**23.41**	**275.69**
	2320.2 ~ 2324.9	**4.7**	**26.41**	**421.98**

4. RESOURCES

According to the relevant geological data of the survey area, geothermal resources capacity is 1.292×10^{19}J, geothermal resources in fluid-rich paragraph is 0.465×10^{19}J, and recoverable geothermal resources is 0.1163×10^{18}J in the Eogene Dongying reservoir, using the mathematical model.

The hydrostatic reserves are 72.669×10^8 m^3, the flexible reserves 2.189×10^8 m^3, and the volume reserve is 70.48×10^8 m^3 in the Dongying reservoir of survey area.

The recoverable amount is 10585×10^4 m^3 (the exploitation of 100 years), the current production is 22.15×10^4 m^3/a, the development potential is $83.7\times10^4 m^3/a$; the allowable mining strength is 0.3487×10^4 $m^3/a\bullet km^2$, the available geothermal energy is 8.628 MW.

5. DEVELOPMENT AND USE OF GEOTHERMAL

Due to high chloride and fluoride in the geothermal fluids of Dongying reservoir, in the development of thermal fluid it is required to use the process of necessary water treatment in order to achieve industrial, agricultural, and fisheries water standards.

Geothermal heating using the geothermal fluids is the mainstream direction, which can be utilized in accordance with the characteristics of water, directly or indirectly. To choose the way of heating, there is no strict requirement in water quality to heat indirectly, so the geothermal fluids can generally be used to heat. According to reservoir characteristics of the survey area, the average temperature is around 75ºC, the temperature of geothermal fluids can be used directly for heating, and heat pump technology can be introduced that will enable the utilization of geothermal energy to meet more than 70%. Also, heat pump refrigeration, heating, hot water for triple technology for the development of geothermal energy utilization is an important direction for low-temperature geothermal heat sources.

In addition, through appropriate treatment Dongying geothermal resources can also be used for domestic hot water, hot entertainment, bath and other uses in the survey area, all of this is bound to generate considerable economic and environmental benefits.

6. ENVIRONMENTAL ASSESSMENT

Geothermal resources are renewable resources, but if there is no serious attitude and scientific approach to the development and utilization a certain degree of harm will be brought to human beings, especially in regard to environmental protection, the main issues are the following points.

(1) Temperature harmfulness

The temperature of Dongying geothermal fluid is relatively high. For heating and domestic water, the discharge temperature of geothermal waste water is lower than the provisions of Tianjin Environmental Protection Bureau (35ºC) and lower than the emission standards, so the geothermal waste water will not cause thermal pollution.

(2) Gases harmfulness

The long-term storage of geothermal fluids in underground formations has a more adequate, multifaceted response, and carries certain dissolved gases under the temperature and pressure. In particular, the Dongying reservoir directly covers the upper part of the Shahejie oil and gas layer. In the process of exploitation, the geothermal fluid releases dissolved gases as its temperature and pressure decrease, resulting in environmental hazards.

The main harmful gases in the geothermal fluids are H_2S, CH_4, and NH_4. The geothermal fluid test of TR21 well shows that the content of the gas by volume is 30.2 ml/l in the Dongying geothermal fluids. The gas composition includes CH_4, N_2, CO2, O_2 and trace hydrogen H_2. CH_4 and N_2 account for 74.1% of the gas volume. Therefore, the dissolved gas is reclaimed at the time of exploration and use of geothermal fluids.

(3) The harmfulness of harmful ingredients in geothermal fluids

The maximum allowable emission standards of harmful ingredients (the emission standards of F is 10 mg/l) according to accordance with "the evaluation methods of geothermal resources (DZ40-85)" , the F-content of 3.96 ~

5.00mg/l in this area is lower than the permitted discharge standard in accord with the results of sample analysis.

(4) Eco-environmental benefits

Direct discharge of geothermal fluid will have a lot of heat, so that the surrounding water and soil temperatures rise, which influences biological growth and survival, and destroys ecological balance.

Geothermal fluid containing potassium, sodium, phosphorus and other elements of nature can improve the soil and improve crop yields, but a discharge of a large volume of the salts from geothermal fluids into the farmland will cause serious soil salinization and plate scale. Thus the majority of the geothermal fluid can not be used directly for irrigation. The particular chloride and fluoride in geothermal fluid have an extremely adverse impact on plant growth. The mineralization of geothermal fluid salinity is high, reaching 2700 ~ 4300 mg/l in the area, the water quality is relatively poor, therefore the geothermal fluids are treated in the course of development and utilization to ensure the use of reinjection technology. By using fluid reinjection, we only use the heat of the geothermal fluids.

7. CONCLUSION

Dongying reservoir in Tianjin is located mainly in the Wuqing district of Jizhong depression and the Tanggu District of Huanghua Depression. The survey area is located in Tanggu area of Huanghua Depression. Dongying reservoir has moderate depth in the survey area, and greater coefficient of permeability, the fluid temperature is around 75ºC, the conditions of reservoir are good and are better prospects for the exploitation of reserve energy. However, the mineralization of geothermal fluids is high, water quality is relatively poor, so untreated geothermal fluids can not be used directly for drinking, irrigation and fisheries. In particular, the phenol content of the geothermal fluid is excessively over the standard that is harmful to the human body, so the geothermal fluids need treatment before use. The F, partial silicic acid and temperature have reached a standard of medical mineral water.