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EXPLORATION AND DEVELOPMENT OF GEOTHERMAL RESOURCES IN TIANJIN

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ABSTRACT

Tianjin is the first city in China where geothermal exploration has been carried out. Geothermal exploration was initialized in the 1970's. Tianjin is placed in geological tectonic unit I in the northern part of the China platform. Tectonic unit II comprise the Yansan mountainous compression zone and North China graben basin. Tectonic unit III consists of one uplift zone and two depression zones. Geothermal anomalies have been recognized in ten different areas. Seven geothermal fields have already been explored. Since the 1990's, the geothermal water has been used mainly for space heating. Geothermal water for heating covers an area of more than 12,000 × 10^3 m^2 and delivers a volume of 100 × 10^3 of hot water for bathing in residential homes in Tianjin. The pressure of the geothermal reservoir is continuously dropping. For this reason geothermal reinjection is carried out in Tianjin.

1. GEOLOGY TECTONIC CHARACTERISTIC

Tianjin is placed in the geological tectonic unit I in the northern part of the China platform (Figure 1). The Ninghe fault is the boundary that divide the mountain area in the north form the plains in the south. The different geological and tectonic characteristics of the two areas are obvious.

The mountain Jixian-Baodi uplift zone in the northern part belongs to tectonic unit III and the Yansan mountainous compression zone, of Paleozoic and Proterozoic age, belongs to tectonic unit II. The majority of tectonic elements strike east-west, whereas, some strike NW-SE, NE-SW NNE-SSW. Densely distributed faults dominate the geologic strata.

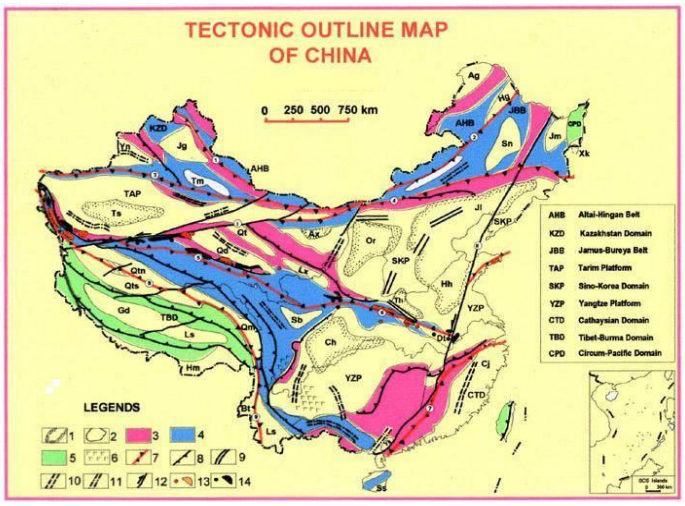

FIGURE 1: Tectonic outline map of China

The plains in the south belong to tectonic unit II including the Mesozoic and Cenozoic North China graben. Tectonic unit III consists of one uplift zone and two depression zones; the Cangxian uplift, the Jizhong depression, and the Huanghua depression. The strikes of the tectonic elements, in both tectonic units III and IV, are NNE-SSW only. The types of tectonic alternate like a group of wild geese (Figure 2).

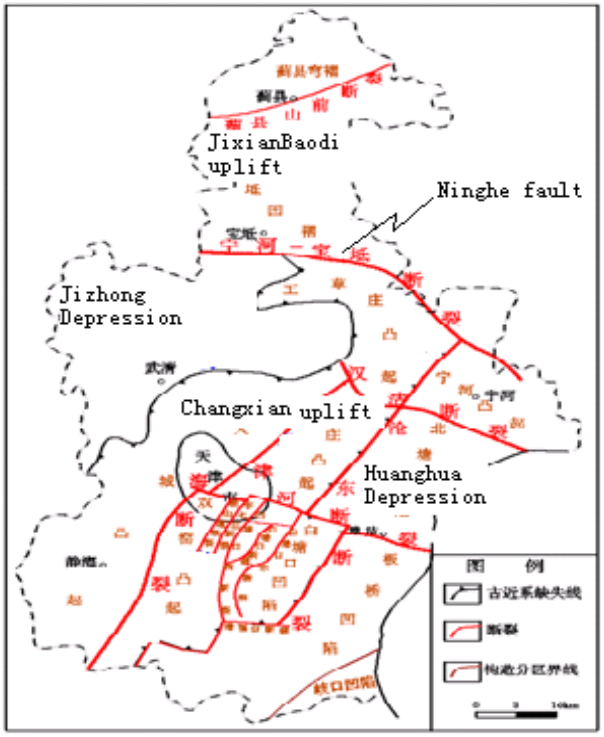

FIGURE 2: Tectonic map of Tianjin

2 GEOLOGIC STRATA

The Tianjin region mostly contains Quaternary units, from the Archeozoic to the Cenozoic, with the exception of Eogene strata and Carbonic to upper-Ordovician strata.

In northern mountain area of 640 km^2 Archeic, Proterozoic and Paleozoic strata are exposure in most parts, with only few areas covered by Quaternary sediments.

The southern area is about 8,700 km^2, with thick Cenozoic, Mesozoic, Paleozoic and Proterozoic deposits, discovered by exploration drilling

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3 GEOTHERMAL CHARACTERS

3.1 Surface geothermal characteristic

A great deal of surface temperature measurement data and much of the drilling exploration data show that:

- Geothermal is controlled by tectonic
- The bedrock controls normal and reverse faulting
- Generally, uplift coincides with geothermal anomalies

The bedrock has a very thin cover in northern mountain area where cold water mixes with the groundwater. It is low value area with regards to the geothermal gradient. For instance the well depth of well JX-01, in Jixian, is 2000 m but the fluid temperature is only 40°C.

The south plain area which covers around 77% of Tianjin has widespread geothermal resources. The distribution of geothermal fields is mainly controlled by tectonic alternation of horsts and grabens. There is a high geothermal gradient, in the centre, at the Cangxian uplift, and there are low geothermal gradients on the two sides where there is down-faulting in the Jizhong depression and Huanghua depression.

There are 10 geothermal anomalous areas, where the geothermal gradient is higher than 3.5°C/100m. 7 areas are located in the Changxian uplift zone (Figure 3). The control area is 84.4% of the area with geothermal anomaly. Although the Tanggu and Dagang area do not have geothermal anomalies, the temperature gets higher with depth, according to the geothermal gradients. Hot water extracted in these areas is used extensively for heating and bathing (Table 1.).

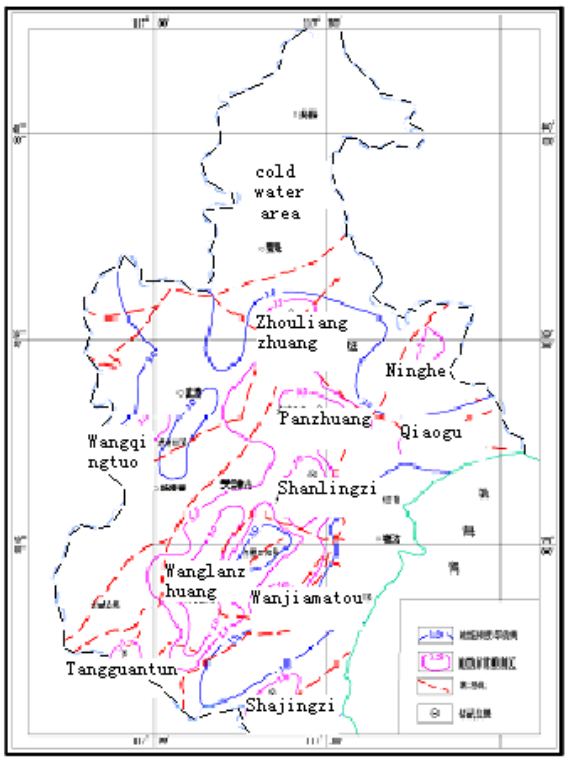

FIGURE 3: Geothermal gradient

TABLE 1: Geothermal anomaly areas

Name	**Tectonic**	**Area (km^2)**	**Geothermal gradient (°C/100m)**
Wanglanzhuang	Shuangyao uplift	534	8.0
Shanlingzi	Dongzhuang uplift	315	8.3
Wanjiamatou	Xiaohanzhuang uplift	235	8.8
Panzhuang	Panzhuang uplift	610	6.9
Zhoiuliangzhuang	Wangcaozhuang uplift	180	5.5
Qiaogu	Tectonic belt	90	5.5
Wangqingtuo	Dacheng uplift	114	5.0
Shajingzi	Tectonic belt	190	4.5
Tangguantun	Shuangyao uplift	40	7.6
Ninghe	Ninghe uplift	20	5.5

3.2 Vertical geothermal characteristic

Heat conducted in geothermal fields in the depositional basin is mainly controlled by the thermal conductivity. The thermal conductivity changes with the different lithology, structure and porosity of the rock etc, as the inverse ratio of the geothermal gradient.

The lithologic and structure of the Cenozoic unit is different from that of the bedrock, thus, there are different geothermal characteristic:

The Cenozoic unit is made of sandstone and clay, with an incoherent structure and large porosity, so the thermal conductivity is low and the geothermal gradient higher than for lower parts of the bedrock. The Quaternary unit contains more clay, and therefore the thermal conductivity is lower and the geothermal gradient is higher than of the Tertiary system, especially in the uplift zones and in locations characterized by deeper faults; The geothermal gradient of the Quaternary unit is much higher than in other places.

On the other hand, the Tertiary system, belonging to the lower part of Cenozoic unit, contains more sand and the structure is more compact, thus, the thermal conductivity is higher and the geothermal gradient lower than that for the Quaternary system. Compared with cap rock, the structure of bedrock is more compact and the thermal conductivity, therefore, are higher and the geothermal gradient lower. The geothermal gradient of the bedrock is control by lithology, permeability and tectonic. Overall, the geothermal gradient is high in carbonate rocks and is low in shale and mudrock.

3.3 Geothermal field reserves

Seven of tern geothermal fields have been explored. The Tertiary system reservoir reserves is $39,830\times10^3m^3/a$, and the bedrock reservoir reserves is $20,140\times10^3m^3/a$ (Table 2).

TABLE 2: Geothermal resources reserve ($10^3m^3/a$)

Geothermal field resource reserves		Wanglanzhuang	Shanlingzi	Tanggu Hangu Dagang	Wuqing	Wanjiamatou	Panzhuang	Ninghe	Total
Tertiary	Total reserves	15210	6010	10440	1180	730	3100	3160	39,830
	Reserves class	B	C	B+C	C+D	C+D	C+D	C+D	-
	Minghuazhen	9887	3907	6786	767	730	3100	3160	28,336
	Guantao	53235	21035	3654	413	-	-	-	11,494
Bedrock	Total reserves	6260	11780	-	-	2100	-	-	20,140
	Reserves class	B	C+D	-	-	-	-	-	-
	Ordovician system	1815	3416	-	-	-	-	-	5,231
	Hanwu system	63	118	-	-	-	-	-	181
	Jixian system	4382	8246	-	-	2100	-	-	14,728
Total		59970							

4 GEOTHERMAL DEVELOPMENT AND UTILIZATION

4.1 Geothermal reservoir

There are tow kinds of geothermal reservoirs in Tianjin: The porous Cenozoic sandstone reservoirs made by continental deposition and the fractured Paleozoic and Proterozoic limestone reservoirs made by marine deposition. The porous geothermal reservoirs include the Minghuazhen and the Guantao formations in the Tertiary system. Fractured geothermal reservoirs include the Ordovician Hanwu and Jixian systems. The different geothermal have different age, lithology and hydrological qualities.

4.2 Geothermal development

In 2007, there was a total of 314 geothermal wells in Tianjin, 36 were reinjection wells. The hot water production was $25,838 \times 10^3$ m^3 annually, and geothermal space heating covered an area of about $12,000 \times 10^3$ m^2. 100×10^3 families enjoyed geothermal hot water for domestic purposes. Reinjection reached a volume of $4,093 \times 10^3$ m^3, with a reinjection rate of about 15.8 % (Table 3).

TABLE 3: Production and reinjection ($\times 10^3 m^3$)

Reservoir	Production reinjection	2001	2002	2003	2004	2005	2006	2007
Nm	Production	3931	4894	6116	7197	7689	5242	4012
	Injection	0	0	0	0	0	0	110
Ng	Production	7030	6474	7484	6954	7224	7598	7644
	Injection	0	0	0	22	86	128	17
○	Production	836	771	898	952	1079	893	725
	Injection	504	489	480	590	590	1094	1072
Є	Production	559	484	410	706	724	715	355
	Injection	0	0	0	0	0	0	0
Jxw	Production	8864	12000	12000	8870	8919	13613	12852
	injection	1184	1240	960	1186	1186	2275	2894
Injection rate		8.0%	8.8%	6.1%	7.2%	7.0%	12.4%	15.8%

The main geothermal production fields are in the Minghuanzhen and t Guantao formations of the Tertiary system in the Cenozoic unit and the Wumishan formation of the Jixian system in Proteozoic unit (Figure 4). The geothermal well in the Minghuazhen and Wumishan formations are distributed in the urban and suburban districts. The geothermal wells with hot water from the Guantao formation geothermal are distributed in the Dagang, TangGu and WuQing districts.

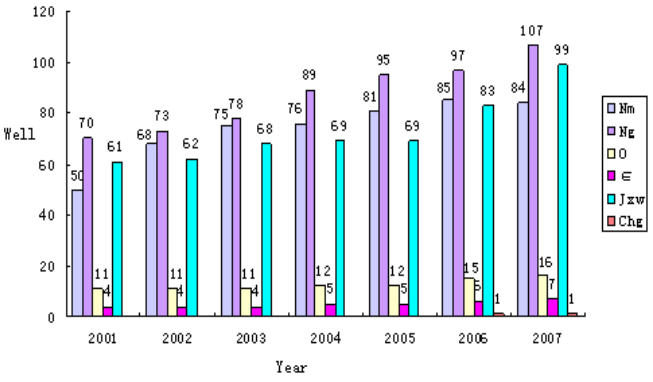

Figure 4 wells in different geothermal reservoir

The number of reinjection wells is increase annually, but the speed of increment is still slow, only 13% of total the number of wells (Figure 5). New techniques for sustainable use have been applied for several years and the hot water production has decreased in recent years, while reinjection appears to have increased. The rate of reinjection and production

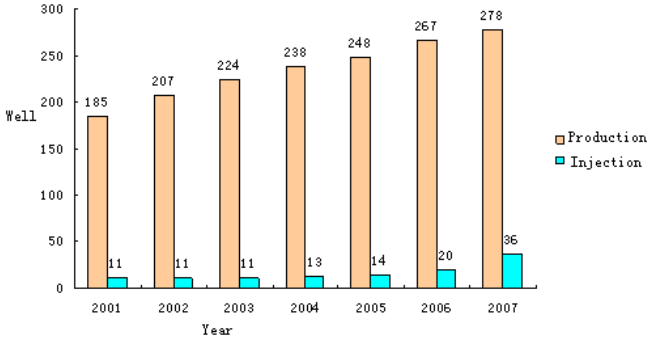

Figure 5 wells of production and injection

is still low.

The geothermal reinjection wells are mainly located in the Wumishang formation of the Jixian Ordovician system and the Guantao formation of the Tertiary system, But the reinjection in the Guantao formation is does not seem to be efficient.

Geothermal reinjection most effective in the Ordovician system with reinjection rates of 100%. Most reinjection wells are situated in the Wumishan formation reservoir. Reinjection was increased from 8% in 2001 to 15% in 2007.

4.3 Hot water utilization

There are 84 geothermal wells in the Minghuazhen formation (include 2 reinjection wells), the production is about 4012 × 10^3 m^3, reinjection is 110 × 10^3 m^3, and most geothermal wells are distributed in the urban and suburban districts. The production is 85.8% of the total, in Tianjin. The hot water is mainly used for heating, industry, farming and bathing.

There are 107 geothermal wells in the Guantao formation, the production is about 7644 × 10^3 m^3, and reinjection is 170 × 10^3 m^3. Most geothermal well are distributed in Tanggu, Dagang and Wuqing. The production accounts for more than 70% of the grand total in Tanggu and Dagang. The hot water is mainly used for heating, industry, farming and bathing. Because the total of dissolved solids in the hot water is low, the water can be used directly for directly (without heat exchange).

There are 16 geothermal wells in the Ordovician system, the production is about 725 × 10^3 m^3, and the geothermal wells are distributed in the urban and suburban districts. The hot water is mainly used for heating. In this area the total of dissolved solids is high and is used indirectly for heating (by the application of heat exchangers).

There are 99 geothermal wells in the Wumishang formation (include 22 reinjection wells), the production is about 12582 × 10^3 m^3, and reinjection is 2894 × 10^3 m^3, with a reinjection rate of 22.5%. Most geothermal wells are distributed in the urban and suburban districts; the production is 49.7% of the total in city. The hot water is mainly used for heating, industry, farming and bathing.

5 THE PRESSURE CHARACTERISTIC OF HOT WATER

5.1 The pressure characteristic of the Minghuazhen formation

From the curve of water lever and production (Figure 6) it is evident that most geothermal wells are distribute in the urban and suburban districts. In 2008, the water level is continuously drawn down in the urban areas and the Wu Qing districts, larger than Tang Gu.

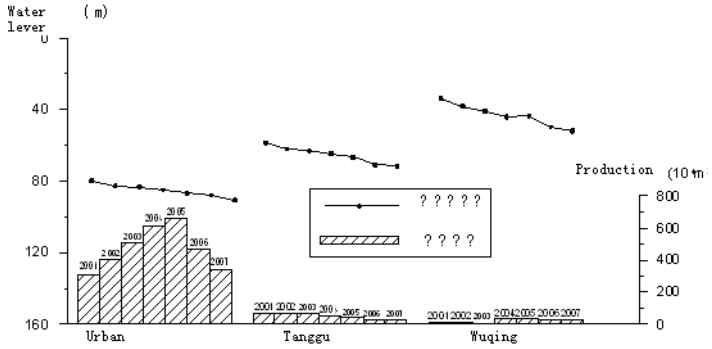

Figure 6 Production and water level of Minghuazhen

5.2 The pressure characteristic of the Guantao formation.

Most geothermal wells are distribute in Tanggu, Dagang and Wuqing, where the water lever is continuously dropping (Figure 7). The Guantao formation in Wuqing located in an environment of deep circulation, where hot water moves slowly in a low permibility reservoir, creating a water lever funnel. The reservoir pressure is low and the drawdown is high. As production continues in TangGu and Dagang, the recharge area gets bigger, and the reservoir pressure equillibrates.

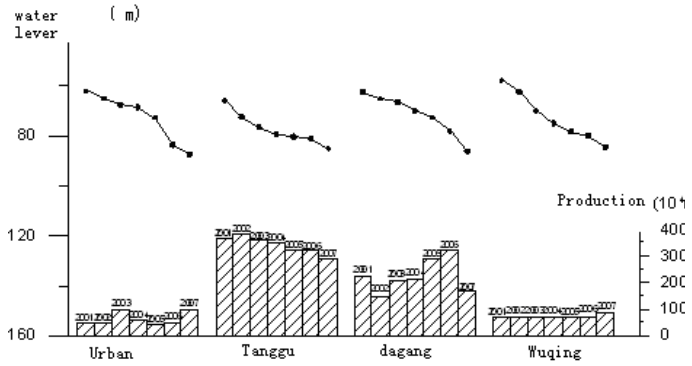

Figure 7 Production and water level in Guantao

5.3 The pressure characteristic of the Wumishan reservoir

The pressure characteristic of the Wumishan reservoir are such, that low values reside in the western part with a water resisting boundary near the Tianjin fault, while high values are recorded in the eastern part by the water in-flow boundary near the Cangdong fault. Generally, the reservoir pressure is related to the production rate, drawdown, and the characteristic of faulting, controlling the in-flow of water.

6. CONCLUSIONS

Ten geothermal anomalous areas which cover the areas 2328km^2 have been delineated. The highest geothermal gradient is 8.8°C/100m. The Geothermal anomalous area is controlled by tectonics.

Seven geothermal fields have been explored. The Tertiary system reservoir has a potential of $39,830\times10^3 m^3/a$, and the bedrock reservoir has a potential of $20,140\times10^3 m^3/a$.

There are two types of geothermal reservoirs in Tianjin: Porous Cenozoic sandstone reservoirs that are made by continental deposition, and fractures Paleozoic and Proterozoic limestone reservoirs that are made by marine deposition.

The Main use of geothermal energy is space heating. More than $12,000 \times 10^3$ m^2 is used for heating and 100×10^3 families enjoy geothermal hot water for domestic purposes, in Tianjin.

Reinjection is the efficient method to control water level drawdown. The rates of resources development and reinjection have risen in the majority of the geothermal reservoirs. Because of space limitations, geology condition, etc. it is difficult to increase the number of reinjection wells. However, reinjection wells needed to create a sustainable environment.

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