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A Discussion of Methodology Study on Geothermal Reservoir Evaluating

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ABSTRACT

Geothermal reservoir, also called thermal reservoir, is a carrier and rock storage of geothermal resource, of which accurate characterization and evaluating is the basis of geothermal exploration and development. The paper started with fundamental and basic research way of evaluating on geothermal reservoir, stipulated the main contents of the evaluating, and also discussed the voluation range of the evaluating parameters on the basis of sandstone pore-type reservoir of the Neogene Guantao Formation and the carbonate carst-fissure-type reservoir of Cambrian, Ordovician and Mesoproterozoic Jixian in North China area. Ultimately, on account of producing data analysis, an evaluating method has been established for sandstone pore-type reservoir and the carbonate carst-fissure-type reservoir, and the parameters of which like reservoir temperature, water yield, reinjection proportion, petrophysical properties were assigned to obtain geometrical mean as a comprehensive evaluating index, upon which the reservoir was divided into three ranks, for instance, type Ⅰ, type Ⅱ and type Ⅲ, corresponding to high-, middle- and low-quality geothermal reservoirs respectively, and the reservoirs in the same rank can be classified according to their index bulk, thus accomplish synthetic evaluating of geothermal reservoir.

1. INTRODUCTION

With the rapid development of geothermal industry, studies on geothermal resources become more and more thorough, as well as higher and higher requirements for descripting and evaluating of geothermal resource and reservoir (Shi et al., 2004; Liang et al., 2010; Lu et al., 2012). Geothermal reservoir is the carrier and storage of geothermal resource, of which accurate charactering and evaluating are basement of exploring of geothermal resource (Chen, 1991; Chen et al., 1994; Liu et al., 2005). As there are no criterion for geothermal reservoir evaluation, when exploring and developing process of hydrothermal geothermal, criterion and specification for oil reservoir evaluation is used for reference (Zhou et al., 1987; Chen, 1988; Wang, 1997; Yan et al., 2000; Wang et al., 2002; Dai et al., 2007). The paper discussed the voluation range of the geothermal reservoir evaluating parameters on the basis of sandstone pore-type reservoir of the Neogene Guantao Formation and the carbonate carst-fissure-type reservoir of Cambrian, Ordovician and Mesoproterozoic Jixian in North China area. Ultimately, on account of producing data analysis, an evaluating method has been established for sandstone pore-type reservoir and the carbonate carst-fissure-type reservoir.

2. CLASSIFICATION OF GEOTHERMAL RESERVOIR FEATURE

2.1 Classification on temperature

In the state criterion of geothermal, the geothermal reservoir is divided into three types, i.e. high-temperature, middle-temperature and low-temperature according to typical temperature of geothermal reservoir. The typical temperature of geothermal reservoir between 25 ℃ and 90℃, 90℃ and 150℃, higher than 150℃, are called low-temperature, middle-temperature and high-temperature geothermal reservoir in order.

2.2 Classification on geothermal fluid yield

According to geothermal fluid yield of single well, high-, middle- and low-production geothermal reservoir and their production value range were defined (Table 1) on the data basis of 187 geothermal wells from Hebei, Shanxi and Shandong Provinces in North China.

Table 1 Classification on geothermal fluid yield

Geothermal reservoir production type	Geothermal fluid volume，m^3/d
high-production	$V \geq 2400$
middle-production	$2400 > V \geq 1200$
low-production	$V < 1200$

2.3 Classification on degree of porosity of geothermal reservoir

Clastic rock and carbonate rock are divided into high-, middle- and low-degree of porosity geothermal reservoir, and their value ranges are defined (Table 2 and Table 3).

Table 2 Classification on degree of porosity for geothermal reservoir of clastic rock

Geothermal reservoir porosity type	Degree of porosity，%
high-degree of porosity	φ≥25
Middle-degree of porosity	25＞φ≥15
Low-degree of porosity	15＞φ

Table 3 Classification on degree of porosity for geothermal reservoir of carbonate rock

Geothermal reservoir porosity type	Degree of porosity，%
high--degree of porosity	φ≥5
Middle--degree of porosity	5＞φ≥2
Low--degree of porosity	2＞φ≥0.2

Figure 1 illustrates geothermal reservoir degree of porosity range developing sandstone of Neogene Guantao Formation, i.e. there are 13 wells representing the degree of porosity between 15% and 25%, and 39 wells representing that higher than 25%.

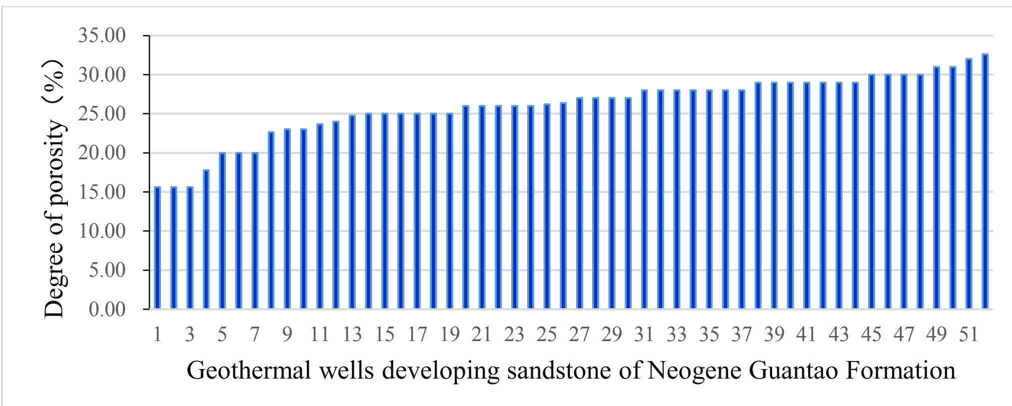

Fig.1 Histogram of degree of porosity for sandstone geothermal reservoir of Neogene Guantao Formation wells in North China area

Figure 2 illustrates geothermal reservoir porosity range developing limestone of Cambrian and Ordovician, i.e. there are 5 wells representing the degree of porosity lower than 2% and higher than 0.2%, 5 wells representing that between 2% and 5%, and 8 wells representing that higher than 5%.

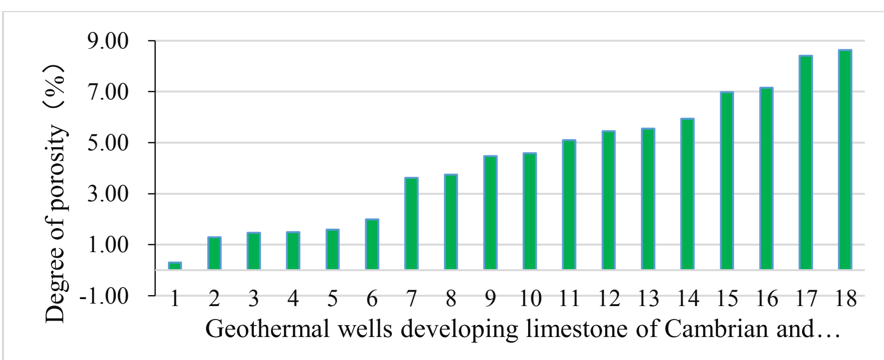

Fig.2 Histogram of degree of porosity for limestone geothermal reservoir of Cambrian and Ordovician wells in North China area

Figure 3 illustrates geothermal reservoir porosity range developing dolomite of Mesoproterozoic Wumishan Formation, i.e. there are 20 wells representing the degree of porosity between 2% and 5%, and 30 wells representing that higher than 5%.

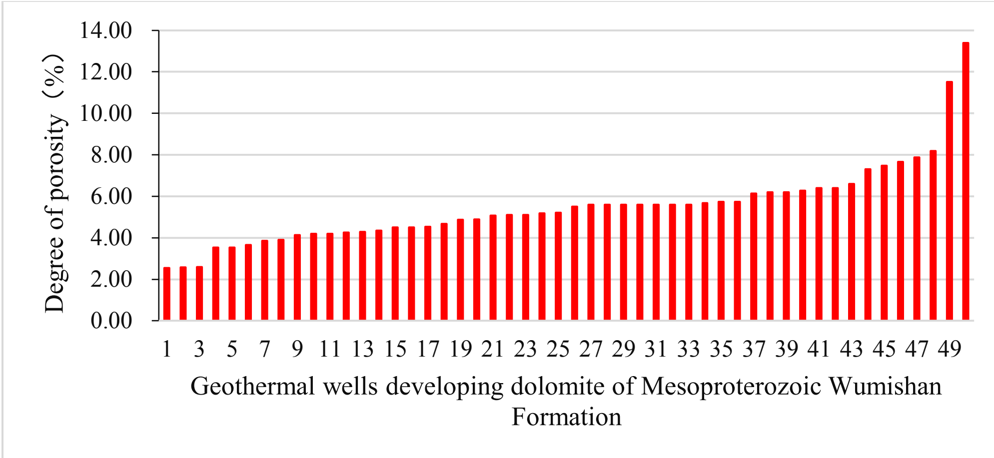

Fig.3 Histogram of degree of porosity for dolomite geothermal reservoir of Mesoproterozoic Wumishan Formation wells in North China area

According to above statistical analysis on geothermal wells with different strata and lithology, the possibly reasonable thresholds were given to divide high-, middle- and low-degree of porosity for geothermal reservoir of sandstone and carbonate rock in North China area. For instance, the thresholds for porosity-type geothermal reservoir of Neogene sandstone to divide high-, middle- and low-degree of porosity are higher than 25%, between 25% and 15%, and lower than 15% for each valve value, and that for carbonate carst-type geothermal reservoir of Ordovician, Cambrian and Mesoproterozoic are higher than 5%, between 5% and 2%, and between 2% and 0.2%, respectively.

2.4 Classification on degree of permeability of geothermal reservoir

Clastic rock and carbonate rock are divided into high-, middle- and low-degree of permeability geothermal reservoir, and their value ranges are defined (Table 4 and Table 5).

Table 4 Classification on degree of permeability for geothermal reservoir of clastic rock

Geothermal reservoir permeability type	degree of permeability, mD
high-degree of permeability	K≥500
middle-degree of permeability	500＞K≥100
low-degree of permeability	K＜100

Table 5 Classification on degree of permeability for geothermal reservoir of carbonate rock

Geothermal reservoir permeability type	degree of permeability, mD
high-degree of permeability	K≥100
middle-degree of permeability	100＞K≥10
low-degree of permeability	K＜10

According to above statistical analysis on geothermal wells with different strata and lithology, the possibly reasonable thresholds were given to divide high-, middle- and low-degree of permeability for geothermal reservoir of sandstone and carbonate rock in North China area. For instance, the thresholds for permeability-type geothermal reservoir of Neogene sandstone to divide high-, middle- and low-degree of permeability are higher than 500%, between 500% and 100%, and lower than 100% for each valve value, and that for carbonate carst-type geothermal reservoir of Ordovician, Cambrian and Mesoproterozoic are higher than 100%, between 100% and 10%, and lower than 10%, respectively.

3. EVALUATION OF GEOTHERMAL RESERVOIR

3.1 Temperature feature of geothermal reservoir

According to average temperature of middle-part geothermal reservoir from logging data, calculation of geochemical geothermal thermometer and geothermal gradient, an evaluating standard on temperature feature of geothermal reservoir for North China area was established as shown in table 6.

Table 6 An evaluating standard on temperature feature of geothermal reservoir

Geothermal reservoir temperature type	Temperature range（℃）	Parameter value range
High-temperature geothermal reservoir	≥150	100
Middle-temperature geothermal reservoir	[120,150）	100
	[90,120）	[70,100）
Low-temperature geothermal reservoir	[30,90）	[10,70）

The ranks of geothermal reservoir on temperature are mainly considered the state standard of China– GB/T 11615-2010 Geologic exploration standard of geothermal resources as a reference, and the parameter value ranges of which are geometrical means of comprehensive evaluation of geothermal reservoir.

3.2 Yield feature of geothermal fluid in single well

According to yield of geothermal fluid in single well from pumping test and adjacent area comparison, an evaluating standard on yield feature of geothermal fluid in single well for North China area was established as shown in table 7.

Table 7 An evaluating standard on yield of geothermal fluid in single well

Geothermal reservoir yield type	Yield range of geothermal fluid（m^3/d）	Parameter value range
High-yield geothermal reservoir	≥2400	100
Middle-yield geothermal reservoir	[1200, 2400）	[50, 100）
Low-yield geothermal reservoir	＜1200	[10, 50）

The ranks of geothermal reservoir on fluid yield are mainly considered the actual yield of geothermal wells as the only reference, and the parameter value ranges of which are geometrical means of comprehensive evaluation of geothermal reservoir.

3.3 Petrophysical properties of geothermal reservoir

Based on logging data and experiments on petrophysical properties, porosity degrees and permeability degrees of the geothermal reservoir were obtained and also the evaluating standards on petrophysical properties of clastic and carbonate geothermal reservoir for North China area were established as shown in table 8 and table 9.

Table 8 An evaluating standard on petrophysical properties of clastic geothermal reservoir

Degree of porosity (%)	Degree of permeability (mD)	Parameter value range
≥25	≥500	100
[15, 25）	[100, 500）	[20, 100）
＜15	＜100	[10,20）

Table 9 An evaluating standard on petrophysical properties of carbonate geothermal reservoir

Degree of porosity (%)	Degree of permeability (mD)	Parameter value range
≥5	≥100	100
[2, 5）	[10, 100）	[20, 100）
＜2	＜10	[10,20）

3.4 Reinjection feature of geothermal reservoir

Analyzing reinjection proportions of the geothermal reservoir utilizing pumping test and adjacent area comparison, an evaluating standard on reinjection feature of geothermal reservoir for North China area was established as shown in table 10 and table 11.

Table 10 An evaluating standard on reinjection feature of clastic geothermal reservoir

reinjection proportions（%）	Parameter value range
[75,100]	[75,100]
[30,75）	[30,75）
＜30	[10,30）

Table 11 An evaluating standard on reinjection feature of carbonate geothermal reservoir

reinjection proportions（%）	Parameter value range
[90,100]	[90,100]
[50,90）	[50,90）
＜50	[10,50）

Reinjection features of the geothermal reservoirs are mainly evaluated through reinjection proportion that controlled mostly by their physical properties. For instance, sandstone porosity-type geothermal reservoir is difficult to reinject that the reinjection proportion thresholds dividing easiness, intermediate and difficulty are 30% and 75% respectively. As carbonate carst-fissure-type geothermal reservoir is easier to reinject that the thresholds of which are 50% and 90% respectively. The parameter value ranges of reinjection features are geometrical means of comprehensive evaluation of geothermal reservoir.

3.5 Comprehensive evaluation of geothermal reservoir

According to geothermal reservoir data of the evaluating area, geometrical means of temperature, yield of geothermal fluid in single well and reinjection are considered as comprehensive evaluation index of the geothermal reservoir if the data is available (see formula 1 for detail). Alternatively, geometrical means of temperature, degree of porosity and degree of permeability are considered as comprehensive evaluation index of the geothermal reservoir if the yield and reinjection data is unavailable (see formula 2 for detail).

$$CI = (T*Q*R)^{1/3} \quad (1)$$

$$CI = (T*\varphi*K)^{1/3} \quad (2)$$

Illustration of abbreviations in the above formulas:

CI——Comprehensive evaluation index of the geothermal reservoir；

T——Parameter value of average temperature of middle-part geothermal reservoir;

Q——Parameter value of yield of geothermal fluid in single well;

R——Parameter value of reinjection;

Φ——Parameter value of degree of porosity;

K——Parameter value of degree of permeability.

As quality of geothermal reservoir is mainly reflected by temperature, yield of geothermal fluid and reinjection that affected by degree of porosity and degree of permeability, temperature, yield of geothermal fluid in single well and reinjection are considered as comprehensive evaluation index of the geothermal reservoir in evaluation consequently, and temperature, degree of porosity and degree of permeability are substitutes for the parameters if the data of yield and reinjection is unavailable.

3.6 Results

On the basis of comprehensive evaluation index of the geothermal reservoir, the geothermal reservoirs are ranked to Ⅰ-type, Ⅱ-type and Ⅲ-type, i.e. high-, middle- and low-quality geothermal reservoirs respectively (see table 12 for detail). The geothermal reservoirs that ranked in the same type should be sorted by their comprehensive evaluation indices.

Table 17 Ranks of comprehensive evaluation for geothermal reservoir

Types of geothermal reservoir	comprehensive evaluation indices
Ⅰ-type	[80,100]
Ⅱ-type	[30,80）
Ⅲ-type	[10,30）

To evaluate geothermal reservoir in North China area, above evaluation method was used based on down-to-earth data of geothermal wells in the area, reflecting actual quality of geothermal reservoir that takes 10, 30 and 80 as thresholds for different ranks. Data of geothermal reservoir for evaluating is collected from the 187 representative wells in North China area which develop geothermal reservoirs of Neogene sandstone of the Guantao Formation, the Cambrian and Ordovician limestone, and Mesoproterozoic dolomite of the Wumishan Formation. The evaluation results show that, there are one well representing low-quality geothermal reservoir from Jiang County of Shanxi Province (green solid sphere in figure 4), 162 wells of middle-quality geothermal reservoir from 10 wells in Shanxi, 18 wells in Shandong and 134 wells in Hebei Provinces (yellow solid sphere in figure 4), and 24 wells for high-quality geothermal reservoir from 7 wells in Langfang City, 7 wells in Baoding City, 6 wells in Cangzhou City and 4 wells in Hengshui City of Hebei Province (red solid sphere in figure 4). The evaluation results on geothermal reservoir are mostly corresponding to actual data during exploration and development in North China area.

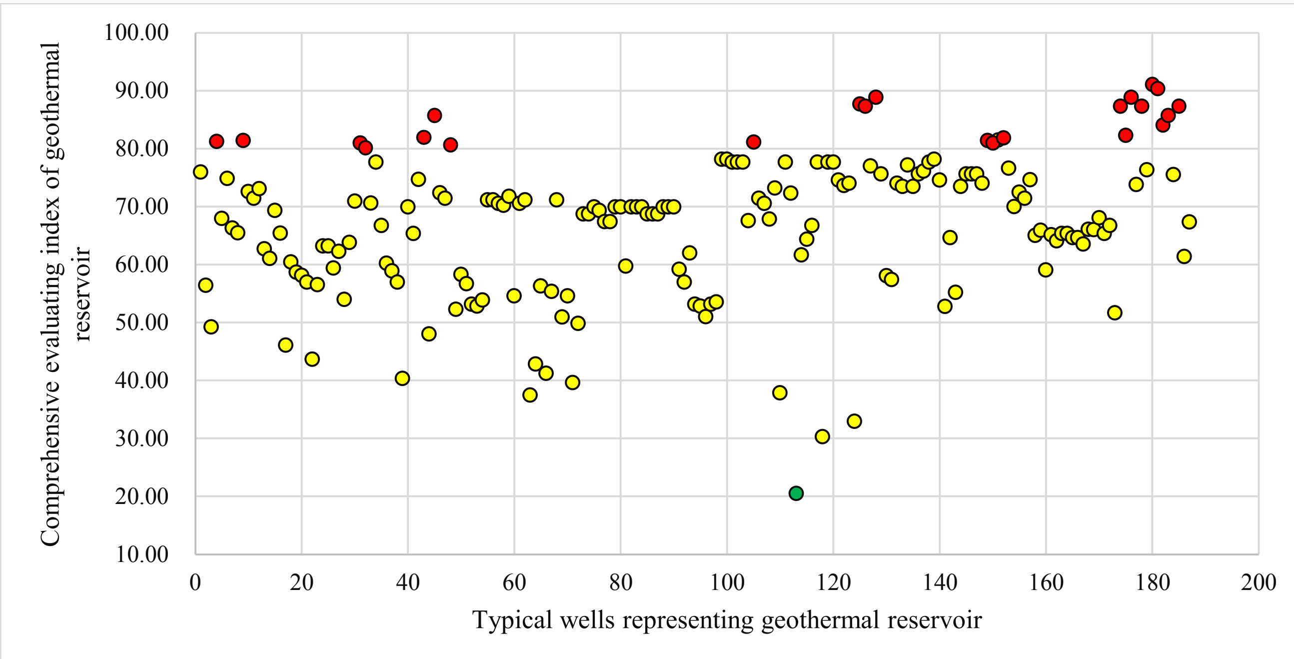

Fig.4 Geothermal reservoir comprehensive evaluating diagram representing typical geothermal wells in North China area

4. CONCLUSIONS

The principal purpose of geothermal reservoir evaluation is to provide necessary geological data for geothermal resource developing and preserving, which can reduce developing hazard, enlarge benefits of society, economy and environment, and maintain sustainable use in geothermal to maximum extent (Yang, 1983; Cao et al., 2000; Chen, 2004; Xu et al., 2009). Based on results of geothermal reservoir comprehensive evaluation, developing suggestions will be proposed in succession.

Data of geothermal reservoir for evaluating in the paper is collected from the 187 representative wells in North China area which develop geothermal reservoirs of Neogene sandstone of the Guantao Formation, the Cambrian and Ordovician limestone, and Mesoproterozoic dolomite of the Wumishan Formation. The evaluation results show that, there are one well representing low-quality geothermal reservoir from Jiang County of Shanxi Province, 162 wells of middle-quality geothermal reservoir from 10 wells in Shanxi, 18 wells in Shandong and 134 wells in Hebei Provinces, and 24 wells for high-quality geothermal reservoir from 7 wells in Langfang City, 7 wells in Baoding City, 6 wells in Cangzhou City and 4 wells in Hengshui City of Hebei Province. The evaluation results on geothermal reservoir are mostly corresponding to actual data during exploration and development in North China area.

REFERENCES <HEADING 1 STYLE>

Cao Yang, Shi Shangming, Li Xueying, Wang Yuhua and Wang Guiping. Comprehensive Evaluation Method of the Geothermal Resources. *Well Logging Technology*, (24), (2000), 511-514. (in Chinese with English abstract)

Chen Hong 2004. Evaluation method of geothermal resources and classification of resources / reserves. *Geothermal Energy*, (1), (2004), 16-19. (in Chinese with English abstract)

Chen Moxiang. Geothermal of North China. *Science Press*, Beijing (1998). (in Chinese with English abstract)

Chen Moxiang. Distribution and application of Chinese geothermal resource. *Natural Resource*, (5), (1991), 40-46. (in Chinese)

Chen Moxiang, Wang Jiyang and Deng Xiao. China geothermal resource: forming features and potential evaluating. *Science Press*, Beijing (1994). (in Chinese)

Dai Wenyu. Formation of geothermal resources and analyses of exploitation regime of thermal groundwater in the urban Beijing area. (2007), Beijing: China University of Geosciences. (in Chinese with English abstract)

Liang Hongbin, Qian Zheng, Xin Shouliang, Zhao Kejing and Zhu Lianru. Assessment and Development of Geothermal Resources in Jizhong Depression. *China Petroleum Exploration*, 15(5), (2010), 63-68. (in Chinese with English abstract)

Liu Shibin. Development, Application and Protection of Geothermal Resource. Chemistry Industry Press, Beijing (2005). (in Chinese)

Lu Qinghua, Zhang Xiaoxi and He Zuoyun. Analyses on Global Development of Terrestrial Heat Utilization. *Energy Conservation and Emission Reduction in Petroleum and Petrochemical Industry*, 2(1), (2012), 39-42. (in Chinese with English abstract)

Shi Shangming, Zhu Huanlai, Liang Yujie and Wang Weixue. Establishment and application of quantitative appraisal system for geothermal resources in sedimentary basin. *Journal of Daqing Petroleum Institute*, 28(5), (2004), 4-9. (in Chinese with English abstract)

Wang Jiyang. Review and Prospect on Geothermal Studies in China in Recent Years. *Acta Geophysica Sinica*, 40(sup), (1997), 249-256. (in Chinese with English abstract)

Wang Liangshu, Liu Shaowen, Xiao Weiyong, Li Cheng, Li Hua, Guo Suiping, Liu Bo, Luo Yuhui and Cai Dongsheng. Distribution features of heatflow in Bohai Bay basin. *Chinses Science Bulletin*, 47(2), (2002), 151-155. (in Chinese with English abstract)

Xu Shiguang and Guo Yuansheng. Basis of Geothermal. *Technology Press*, Beijing (2009). (in Chinese)

Yan Dunshi, Yu Yingtai. Geothermal resource evaluation and application in oil area of Beijing, Tianjin and Hebei areas. *China University of Geosciences Press*, Beijing (2000). (in Chinese)

Yang Yutong. Formation and Evaluating of Geothermal Resources. *Hydrogeology and Engineering Geology*, 5, (1983), 15-17. (in Chinese with English abstract)

Zhou Ruiliang, Liu Qisheng, Zhang Jing and Yang Liqiang. The Geological Features and Exploitive prospects of the Geothermal Field of Salient Type of Bed Rock of Niutuozhen in the Fault Basin of North China. *Bulletin of the 562 Comprehensive Geological Brigade Chines Academy of Geological Sciences*, (7-8), (1987), 17-35. (in Chinese with English abstract)