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Potential Assessment of Geothermal Resources in WG3 Well, Wugong County, Xianyang City, Shaanxi Province, China

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ABSTRACT

Geothermal development have been carried out for almost 10 years, and there are 9 geothermal wells in Wugong country, Shaanxi province. However, for a long time, this area has been limited to basin-level macro-study in plane, and lacks of microscopic quantitative characterization of reservoir physical properties and temperature distribution in vertical direction.In order to clarify the potential of thermal resources in the study area, this paper systematically combs and studies the fracture structure, thermal reservoir, basement distribution and heat source characteristics based on well WG3. Microscopically, geophysical logging and pumping test are used as basic methods to delineate the potential of single well geothermal resources.The study shows that the thermal reservoir porosity of Neogene Lantian-Bahe Formation in WG3 well is 18.55-42.69%, permeability is 9.56-957.96 mD, the measured temperature of roof is 75.88℃, the measured temperature of floor is 94.45℃, and the average temperature is 85.17 ℃ .The porosity of thermal reservoir of Neogene Gaoling group is 2.13-31.03%, permeability is 0.01-310.321 mD, measured temperature is 94.45℃, floor temperature of 116.63℃ and average temperature of 105.54℃. When the static liquid level of geothermal well is + 11.5m and the large drop distance is 41m, the outlet water temperature is 102℃ , 142m^3/h, and the maximum outlet water volume is 188m3/h at 71.75m. According to the calculation, the protection radius of rights and interests of single well is 3668.90 m under the condition of 100-year exploitation of this geothermal well. The systematic evaluation of geothermal resources in WG3 well can provide geological and engineering support for the development and construction of the first "smokeless city" in Shaanxi Province in the future.

1.INTRODUCTION

Wugong County is located in the hinterland of Guanzhong Basin. It is connected to Yangling Demonstration Zone and Fufeng County in the west, Xingping City of Xianyang city in the east, Weihe River in the south, and Qianxian in the north. It is one of the birthplaces of the Chinese nation's farming civilization. At present, with the adjustment of economic structure, the path of green and low-carbon sustainable development has become an urgent requirement for the economic development of Wugong County.

The geothermal geological conditions of Wugong County are superior, and it is of great significance to analyze the potential of geothermal resources. The previous research results showed that the study area has favorable geothermal conditions for the formation of medium-low temperature geothermal resources. In recent years, Sinopec Green Geothermal Energy Development Co., Ltd. has continued to carry out a large number of geophysical exploration and drilling works in this region,7 geothermal production wells have been drilled. And the first "Smokeless city"in Shaanxi Province that uses geothermal clean energy for heating has been created.

2.GEOLOGICAL BACKGROUND

2.1Geological structure

The study area is located in the Xi'an Sag of Guanzhong Basin, about 1500m south of the fault on the north bank of the Weihe River, and the geological structure is stable. According to the previous research results on the division of the Guanzhong basin's tectonic division (Wang Xing, 2005; Liu Fang et al., 2008), the distribution fault in the area is near the east-west fault of the Weihe River (F_1), and the northeast-eastward Fufeng-Liquan— Shuangquan fault (F_2) and the northwest-oriented Lushan-Dumb fault (F_3).

Zhiyuan Ma (2015, 2016, 2018) showed that the chemistry types of water in the Guanzhong Basin were mainly SO_4 - Na type in the Xi'an area north of the Weihe fault, and the main chemistry type of water in the Xianyang area was Cl-Na type. The supply of geothermal water in the Xianyang area to the north of the fault mainly comes from the Beishan Mountain, while the supply of geothermal water in the Xi'an sag south of the north bank of the Weihe River is mainly from the Qinling Mountains.

2.2 Geothermal reservoir

The division of the strata encountered in the study area indicates that the Quaternary Qinchuan Group and the Sanmen Formation are deposited in the area from top to bottom, the Neogene Pliocene Zhangjiapo Formation, the Lantian Bahe Formation, and the Miocene Gaoling Group, of which Zhang Jiapo The group is the regional cover, and the Lantian Bahe Formation and Gaoling Group are the main development zones in the area.

Table 1. List of major fracture characteristics around the study area

Numbering	Name	Level	Property	Lgength(Km)	Attitude
F_1	Weihe Fault	Control basin	Compress first, then stretch	＞300	Going closer to the east, leaning south, tilting 65°
F_2	Fufeng-Liquan-Shuangquan Fault	Control basin	Tension	Unknow	Going north and east, tending to the south
F_3	Long County - Qishan - Yabai Fault	Control unit	Torsion	75	The overall trend is 310°, which tends to the north, and the inclination is 60°-80°

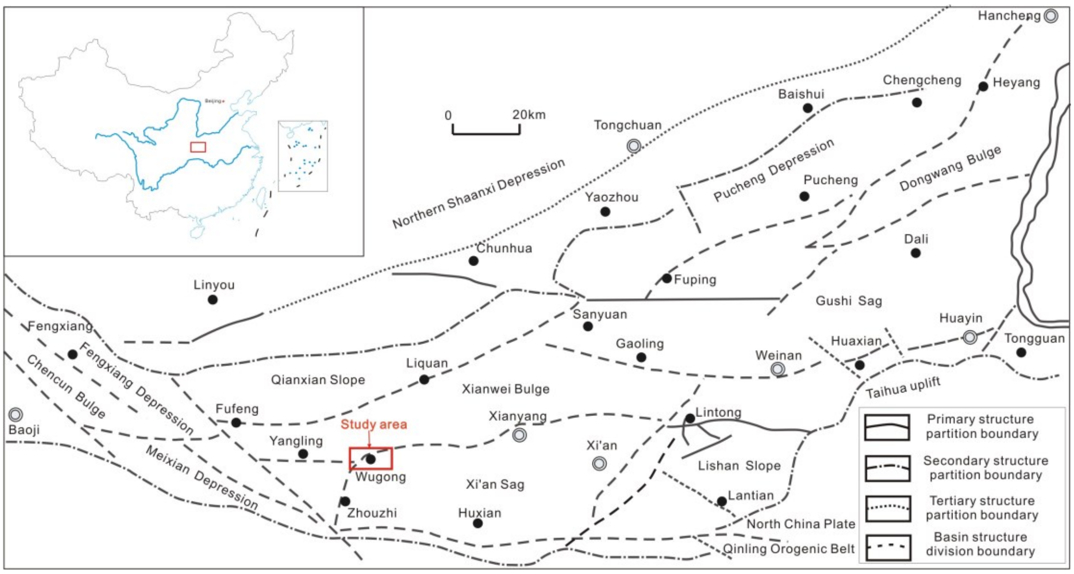


Fig1: Structural zoning map of Weihe basin（According to Wang xing, 2005）

Table 2. Summary of lithology characteristics of WG3 well

Formation system					Thickness（m）	Lithological characteristics
Erathem	System	Series	Group	Formation		
Cainozoic Erathem	Quaternary System	Holocene Series、Upper middle Pleistocene Series	QinChuan Group		440.0	The top is aeolian loess, gray-yellow clay layer; the upper part is variegated, gray-white sand layer, gravel layer is yellowish clay layer; the lower part is gray-yellow, blue-gray clay and gray-white pebbly sandstone.
		Lower Pleistocene Series		SanMen Formation(Q_1^s)	282.2	Grayish brown, grayish yellow clay with a grayish fine sand layer.The sand layer is mainly composed of quartz and contains gravel.

Neogene System	Pliocene Series	YongLeDian Group	ZhangJiaPo Formation(N_2^z)	480.0	Brown-red, taupe mudstone and grayish white, brownish yellow fine sand, medium sand, coarse sandstone are not equal thick interbed. The sandstone is mainly quartz, sub-angular, and contains gravel.
			LanTian-BaHe (N_2^{l+b})	1094.0	The purple-red, brown-red mudstones are blue-grey mudstones with grayish white, gray-yellow fine sand, medium sand, and coarse sandstone. The fuchsia, blue-gray mudstone is better cemented, harder, and the brown-red mudstone is soft; the sandstone is mainly quartz and contains gravel.
	Miocene Series	GaoLing Group		946.0	Fuchsia, brown-red mudstone, sandy mudstone and gray-white fine sand, coarse sandstone are not equal to each other. Mainly mudstone. Mudstone is well cemented and hard. The sandstone is mainly quartz and contains gravel.

2.3 Bedrock

The bedrock refers to the lithology before the Neogene in the basin, and the bedrock facies structure plays an important role in controlling the distribution of geothermal resources and the distribution of geothermal gradients in the sedimentary basin (Qin Xinchang, 2005). The study area is located south of the fault on the north bank of the Weihe River. According to the results of previous studies (Wang Xing, 2005; Liu Fang, 2008), the basement is granite in Yanshanian period(Fig. 3).

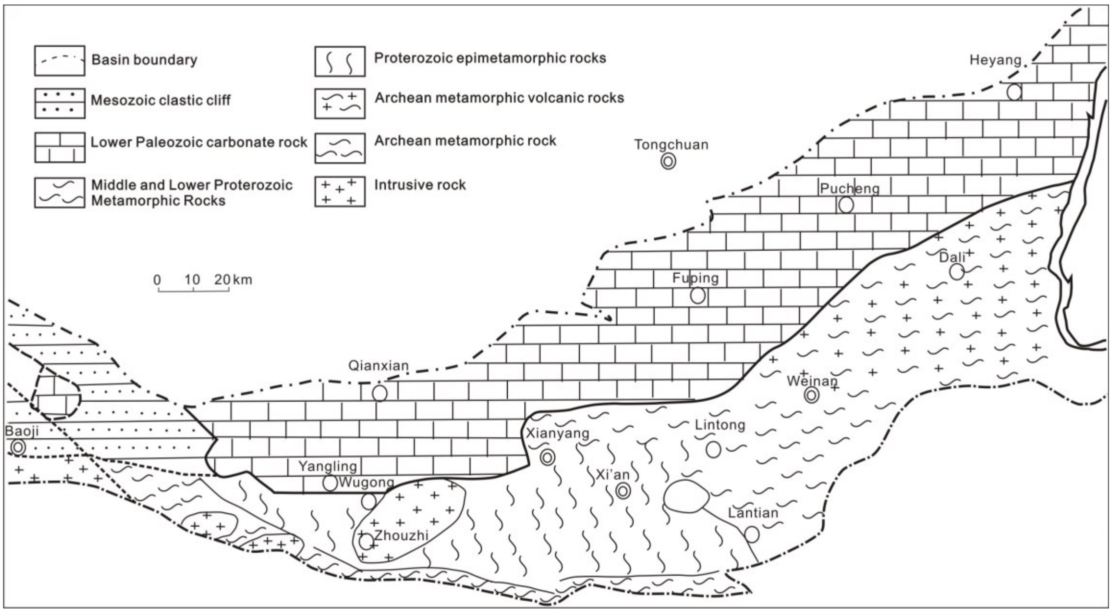


Fig 2: Basal lithofacies zoning map of Weihe basin（According to Wang xing, 2005）

2.4 Heat source

According to previous research data (Liu Fang, 2008), the heat transfer of the core temperature is the most important heat source in the Guanzhong Basin. The upper mantle temperature is about 1100-1300℃, while the 25km depth is generally 500-600℃.The temperature of the left and right thermostats is 15 to 20℃ in the place 100 meters below the surface.

Compared with the north and south sides of the Guanzhong Basin, the Moho surface is a north-east eastward spread, a south steep northerly ridge, and the Xi'an sag and the Gushi sag form two elliptical local uplifts (Fig. 3). The Moho face in the Xi'an sag is about 33km deep, and the Moho face in the Gushi sag is about 30km deep. The Moho face of the Ordos block in the north is 42~44km deep, and the Moho face in the Qinling Mountains is buried at 43~47km. The Moho surface of the Guanzhong Basin is 12 to 14 km above the north and south sides, and the conduction heat flow provided by the upper mantle is larger than that of the surrounding area.

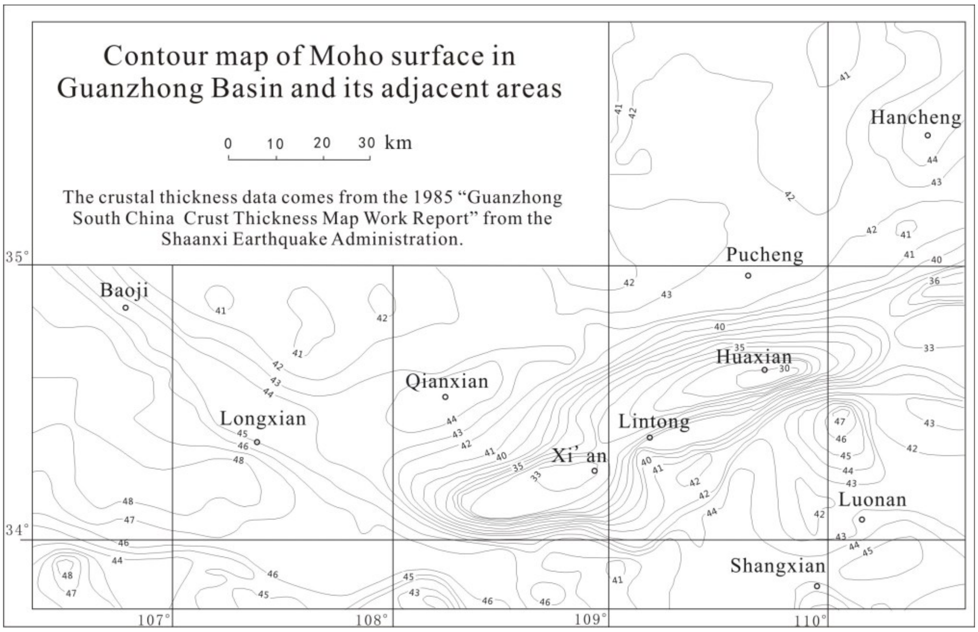


Figure 3: Isobath map of the Moho area in the Guanzhong Basin and its adjacent areas (according to Su Gang, 1987)

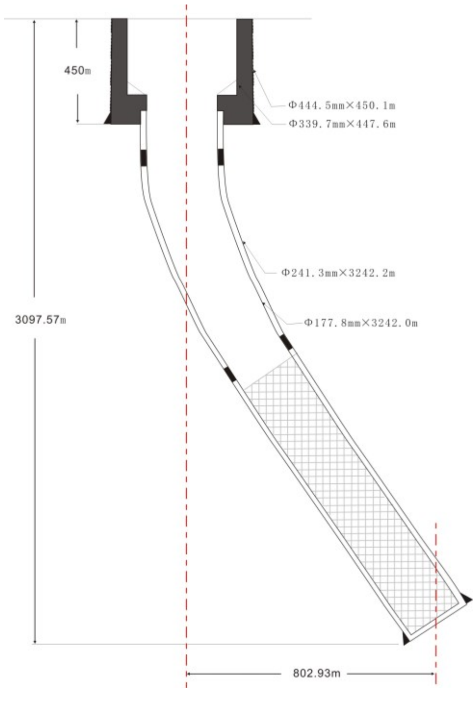


Figure 4: Schematic diagram of WG3 well structure

3.GEOTHERMAL WELL PROJECT

3.1 Well completion technology

The well is a directional geothermal well, the well depth is 3242.00m, the vertical depth is 3097.57m, the horizontal displacement is 802.93m, and the direction is 109.53°, 0-800.00m is a vertical section, and 800.00m-3242.00m is an inclined section.

The well structure is divided into two sections. The well depth from 0.00-450.12m, the diameter is φ444.50mm, and the φ339.7mm oil seamless steel pipe is inserted into the 0.00～447.58m . And this section is pump chamber section, which is level with the ground. In the annular gap outside the casing of the pump chamber section of φ339.7mm, the entire well section of the G-class oil well cement is used for sealing. From 450.12~3242.00m, the diameter of the well is φ241.3mm, and the seamless steel pipe of φ177.8mm is inserted into the well section as the production casing with a length of 2839.07m. Between φ339.7mm casing and the φ177.8mm casing the water is sealed by the joint umbrella type sealing tool and the G grade oil well cement.

3.2Geophysical logging

3.2.1Geothermal reservoir properties

（1）Lantian Bahe Formation

The geothermal reservoir has a burial depth of 1202.2 to 2296.2 m and a thickness of 1094.0 m. The lithology is mainly purple-red, brown-red mud with blue-grey mud and gray-white, gray-yellow fine sand, medium sand, and coarse sandstone. The fuchsia, blue-gray mud is better cemented, harder, and the brown-red mud is soft; the sandstone is mainly quartz and contains gravel. According to the electric logging data, the porosity of the thermal reservoir sandstone is 18.55-42.69%, the permeability is 9.56-957.96 mD, the measured temperature of the roof is 75.88°C, the measured temperature of the bottom plate is 94.45°C, and the average temperature is 85.17°C. The hot reservoir section has good water solubility.

（2）GaoLing Group

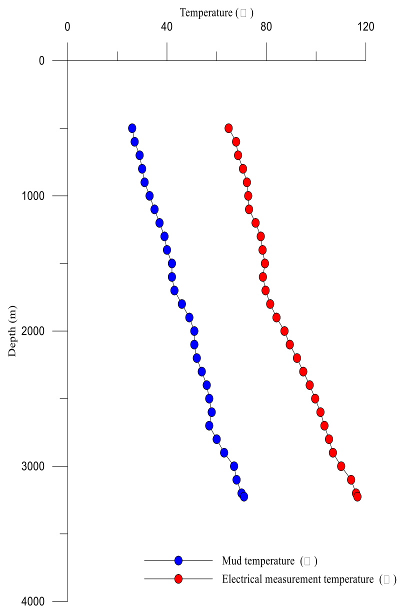
The geothermal reservoir has a burial depth of 2296.2 m to 3242.00 m and a thickness of 946.03 m. The lithology is mainly purple-red, brown-red mud, sandy mud and gray-white fine sand, and coarse sandstone with different thicknesses. Mud is well cemented and hard. The sandstone is mainly quartz and contains gravel. According to the electric logging data, the porosity of the thermal reservoir sandstone is 2.13-31.03%, the permeability is 0.01-310.32 mD, the measured temperature is 94.45°C, the measured temperature of the bottom plate is 116.63°C, and the average temperature is 105.54°C. The sandstone of the hot reservoir section is generally water-rich.

3.2.2Well temperature logging

After completion, the drilling fluid was allowed to stand in the wellbore for 15 hours. We then performed a well temperature measurement under non-steady state conditions and compared the measured data with the temperature of the drilling fluid recorded during the previous drilling. The results are shown in Figure 5. Under the outdoor conditions, the original temperature of the drilling fluid is about 10°C. After circulating in the formation, the temperature rises remarkably.

It should be noted that at this time, the wellbore is still full of drilling fluid, and the drilling fluid is still standing for 15 hours, but it still has a gap with the real formation temperature, and has not yet reached thermal equilibrium with the thermal reservoir. Figure 5 shows that as the depth increases, the temperature of the thermal reservoir increases. At 1600 m, the temperature and depth gradually begin to exhibit a linear relationship. Figure 5 shows that the rate of increase in the average geothermal gradient begins to have a significant tendency to decrease.

If we extend the rest time of the mud in the wellbore, then the electrical formation temperature will approach the thermal reservoir temperature. If we need to make a simple estimate, we can assume the electrical formation temperature as the formation temperature.



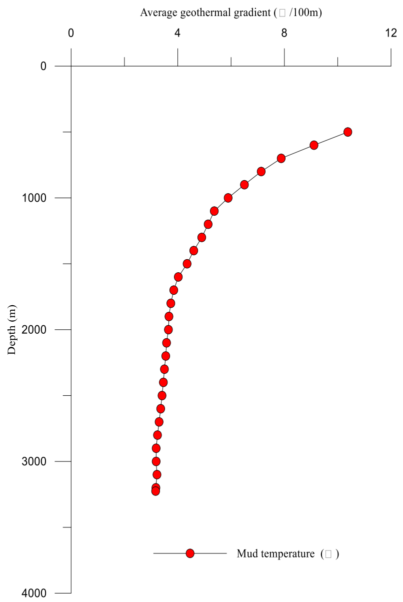


Figure 5: Drilling fluid temperature and logging temperature, geothermal gradient curve

3.3Maximum production

After the completion of the well cleaning work, the still water level was measured, and the still water level was +11.5 m. According to the geological technical design requirements and specifications, we conducted three different drop pumping tests on the well. The contents and results of the test are shown in Table 4.

Table 4. Results of Pumping test

Initial water level(m)	+11.5		
Restore water level(m)	+9.5		
Draw down(m)	10.5	27.5	41.0
Volume（m^3/h）	69.26	114.41	142.24
Temperature（℃）	100	101	102

S/Q=f (Q)、lgQ=f(lgS)、Q=f(lgS) curves were plotted according to the three draw down pump test data are showed in Figure 6, Figure 7, Figure 8. By fitting the curve and judging to determine the gushing water equation as an exponential equation, the equation is as following.

$$\lg Q = \lg n + 1/m \times \lg S \quad (1)$$

The **m** and **n** can be obtained by general methods.

1/m=0.5215，lgn=1.3075，lgQ =1.3075+0.5215×lgS

According to the principle of S=1.75~2Smax, take S=1.75S to calculate that S=1.75×41.0=71.75m

lgQ = 1.3075+0.5215×lgS =2.275 ,Q = 188.36 m^3/h

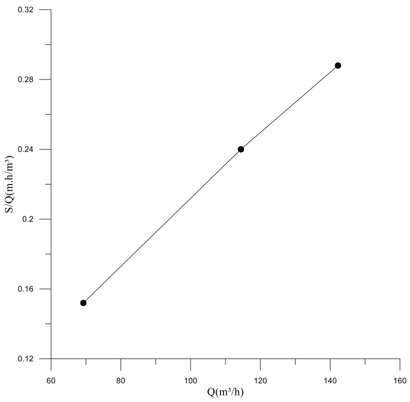


Figure 6: S/Q=f(Q) fitting curve

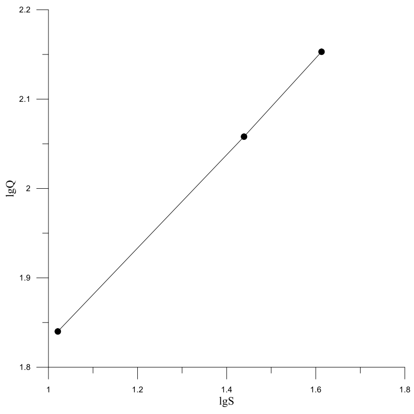


Figure 7: lgQ=f（lgS）fitting curve

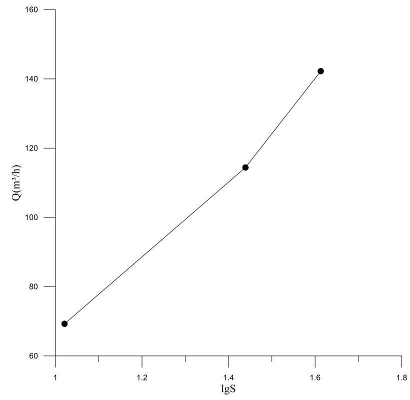


Figure 8: Q=f（lgS）fitting curve

3.4 Mining rights protection radius of single well

For basin-type geothermal field, it can be mined for 100 years in a single well and consume about 15% of geothermal reserves (Department of Reserves, Ministry of Land and Resources, 2010). The radius of influence (R) of geothermal well mining on heat storage is estimated by the following formula. Consider it as the protection radius of single well mining rights:

$$R = \sqrt{\frac{36500Qf}{0.15H\pi}} \quad (2)$$

Q—Geothermal well production, in cubic meters per day (m3/d), taking 3371.16 m3/d;

f—Specific heat capacity of water/storage rock specific heat capacity, beween3～5, taking 3；

H—Thermal reservoir thickness utilized by geothermal wells, taking 256.8m；

R—The radius of influence of geothermal wells for 100 years of heat removal;

Substituting the data into the formula: R=1834.45m, which is the protection scope of the well, and the diameter of the mining affected zone is 3686.90m.

4.CONCLUSION AND SUGGESTION

(1) Wugong County is located in the north side of Xi'an Sag in Guanzhong Basin. It is close to the fault of the north bank of the Weihe River. The conductive heat source from the core is the main source of the study area. According to the temperature logging results. The average temperature rate of the WG3 well is 4°C/100m, which is much higher than the average temperature increase rate of Guanzhong Basin by 3°C/100m.

(2) The main thermal reservoirs in the study area are the Neogene Pliocene Lantian Weihe Formation and the Miocene Gaoling Group. The thermal reservoir porosity of the Lantian Bahe Formation is 18.55-42.99%, the permeability is 9.56-957.96 mD, and the measured temperature of the roof is measured. 75.88°C, the measured temperature of the bottom plate is 94.45°C, and the average temperature is 85.17°C. The thermal reservoir porosity of the Neogene Gaoling Group is 2.13-31.03%, the permeability is 0.01-310.32mD, the measured temperature is 94.45°C, the measured temperature of the bottom plate is 116.63°C, and the average temperature is 105.54°C.

(3) The depth of the WG3 well is 3242m, and the static water level is +11.5m. When the draw down is 41m , the volume of water is 142m3/h and the water temperature is 102°C. The three draw down depths were fitted to determine the gushing water equation as an exponential equation. The calculated maximum water inflow was 188.36 m^3/h when the draw down was equal to 71.75 m. According to the calculation of the allowable extraction amount of a single well for 100 years, the protection radius of the well exploitation is 3668.90m.

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