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Potential Analysis of Hydrothermal Geothermal Resources in Xixian New Area

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ABSTRACT

The middle-deep sandstone in Guanzhong Basin is the main rich layer of geothermal resources. In recent years, the exploration and development of geothermal resources are mainly concentrated in Xianyang City, and the potential of geothermal resources in Xixian New Area is unclear. Through the basic geological conditions research, tectonic and hydrogeology survey, the results show that the Xixian New Area is located in the central part of the Guanzhong Basin, the main thermal reservoirs include the Neogene Zhangjiapo Formation, Lantian-Bahe Formation and Miocene Gaoling Group, which are all sandstone pore-type thermal reservoirs with thick layered distribution. In particular, the Lantian-Bahe Formation and Gaoling Group have moderate burial depth with high thermal reservoir temperature and large water-yield capacity, which form the dominant thermal reservoirs for geothermal development and utilization in this area.

Combined with the geological structure features and geological characteristics of thermal reservoirs in Xixian New Area, Monte Carlo method is used to simulate and estimate the expected annual recoverable geothermal resources in the middle and deep layers of the area, preliminary results shows that there are 3.70×10^{16}J reserves, equivalent to 126 million tons of standard coal.

It is estimated that the geothermal resources in this area can be used for heating in winter for about 1.76×10^{8}m^2 energy-saving buildings according to the converted heat consumption of 0.21GJ /m^{2}a. According to the new district planning, the total urban and rural construction land in Xixian New Area is 360km^2, of which the urban construction land is 272km^2. The new district has a population capacity of 2.72 million, which requires a building area of 1.36×10^{8} m^2 per capita of 50m^2. Therefore, through reasonable planning, the medium-deep geothermal resources can theoretically fully meet the thermal energy demand of building heating in the planning area. Geothermal energy utilization is an important part of carbon dioxide emission reduction in the region, which is conducive to achieving regional carbon neutrality goals.

1. INTRODUCTION

Guanzhong Basin is an east-west Cenozoic faulted basin sandwiched between Ordos Basin and Qinling orogenic belt. Before the 1990s, resource exploration mainly focused on petroleum exploration [1-3]. Although oil and gas exploration has not made substantive breakthroughs, a large number of basic research has laid a foundation for the exploration and development of geothermal resources, especially in the 21st century, The emphasis on environmental protection has promoted the transformation of the utilization mode of geothermal resources in this area from hot spring bathing to building heating. This large-scale utilization mode of geothermal resources has gradually recognized the value of geothermal resources as clean energy.Different scholars have made in-depth analysis on the formation mechanism of geothermal field in Guanzhong Basin from the aspects of supply source, heat source and hydrochemical type, and calculated the prospective resources of the basin [4-7].More than 230 geothermal wells have been drilled in Guanzhong Basin, with the wellhead temperature can reach 120 ℃ and the maximum flow of nearly 300m^3 / h [5,7].Since the previous research work mostly focused on the overall basin or key areas of Xi'an and Xianyang, no special research has been conducted on the geothermal resource potential of Xixian new area.

In 2014, the State Council approved the establishment of a national-level Xixian new area, located between Xi'an and Xianyang city. The overall urban planning of Xixian New Area (2016-2030) was completed in 2017. The planning area covers 882 km^2 and the total urban and rural construction land is 360km^2, including 272 km^{2}of urban construction land [8, 9].The energy demand of new buildings for heating in winter is huge. The rich geothermal resources in the region are of great significance to the achievement of the strategic goal of carbon neutrality. Scientific assessment of the geothermal resource potential in the area is the basis for rational planning and utilization of geothermal resources, which has important guiding significance for the construction of Xixian new area with the theme of innovative urban development mode.

2. GEOLOGICAL BACKGROUND

The pre Cenozoic basement of Guanzhong Basin is composed of several tilted fault blocks, which is generally in an asymmetric ladder shape. It is connected with Ordos Basin by the north piedmont fault zone and Qinling orogenic belt by the Qinling piedmont fault zone in the south, with an area of about 3.9×10^{4}km^2。Many east-west fault zones are developed in the basin. Among them, the main basin controlling faults such as the north edge fault zone of Qinling Mountains, the Weihe Fault Zone and the south edge fault zone of Beishan are inherited and developed basement ultra deep faults, which have the characteristics of multi-stage activity, and which not only promotes the radial movement of groundwater, but also helps to bring deep heat into shallow reservoirs [10,11].According to the Cenozoic structural characteristics, Xixian new area is mainly located in Xi'an depression, north slope fault terrace and Sanyuan fault terrace.

With the evolution of the basin pull apart since the Eocene, the Guanzhong Basin was mainly deposited in the river-lake phase, forming the main thermal reservoirs of the present day. Due to the undulating basement of the pre-Cenozoic sedimentary basin and the fact that the basin was controlled by syngenetic faults during deposition, the distribution of each thermal reservoir within the basin varies considerably. The overall pattern is that the burial zone north of the Weihe Fault becomes progressively shallower, while the depressional zone south of the Weihe Fault is deeper. The Quaternary loess deposits, which are widespread throughout the basin, provide good insulation and are a good cover for geothermal fields [12-15]. The favourable tectonic evolution of the Guanzhong Basin makes it have a good stratigraphic structure of source, storage and cover, which is conducive to the formation of high-quality large geothermal fields.

3 THERMAL RESERVOIR CHARACTERISTICS

According to regional tectonic evolution studies, the Guanzhong Basin was formed and evolved through four stages: early Cretaceous - pre-Paleocene extrusive uplift, Eocene - Oligocene slip pullout, Neoproterozoic tensional fracture and Quaternary continuous development [3]. Since the Eocene, with the evolution of the basin pull-apart, the Guanzhong Basin has formed sand and gravel deposits mainly in the river-lake phase, among which the Gaoling Group (N_1gl), the Lantian-Bahe Formation (N_2b+l), and the Zhangjiapo (N_2z) Formation are the main thermal reservoirs exploited under current economic and technical conditions due to their moderate burial and good pore-permeability conditions, and the depth of exploitation is generally less than 3500 m. Among them, the Palaeocene Eocene Honghe Formation (E_2h) and the Oligocene Bai Luyuan Formation ($E_{2-3}b$) can also be used as thermal storage in some areas [4, 12,13].

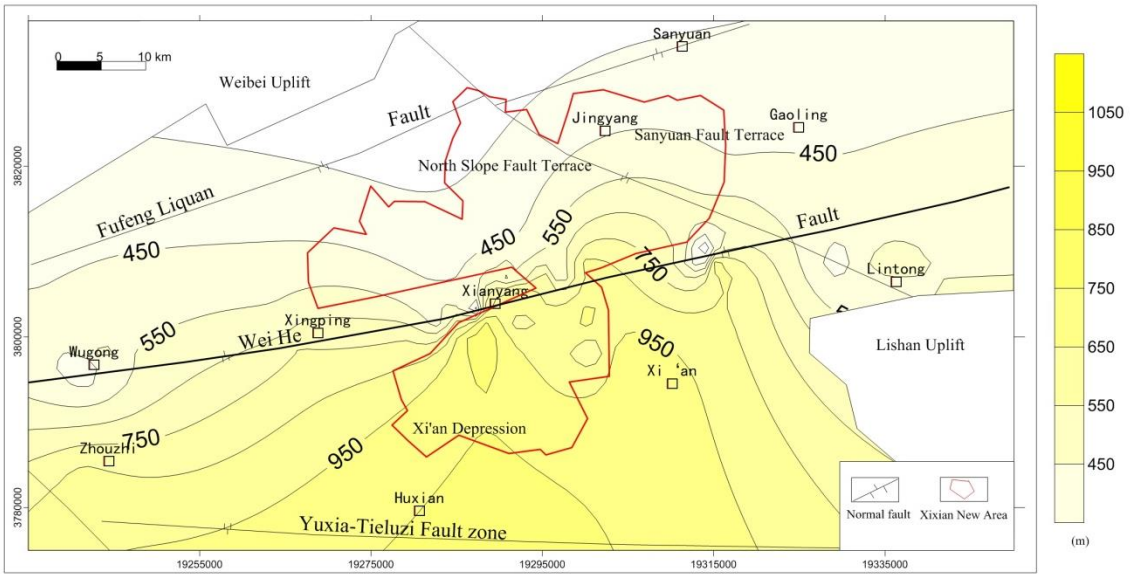

Fig1 Thickness Distribution Map of N_2z

3.1 Zhangjiapo formation

According to the analysis of field outcrop survey and geothermal well logging data, the Zhangjiapo Formation is dominated by grey-yellow mudstone and siltstone, with a small amount of medium and coarse-grained sandstone and siltstone interbedded, which is judged to be a delta phase depositional environment. The thickness of this group in Xixan new area ranges from 350 to 1120m, with an average of 855m (Figure 1); according to the available drilling data, the sand-thickness ratio ranges from 6.6% to 22.0%, with an average of 12.7%; the thermal storage temperature is generally in the range of 50°C to 80°C, with an average of 75.7°C.

3.2 Lantian Bahe formation

Lantian-Bahe Formation is composed of Lantian-Bahe Formation, which is not easily distinguished, so it is collectively called Lantian-Bahe Formation. The Bahe Formation was formed by alternating river and lake phases of deposition, with the early river phase depositional environment containing mostly conglomerate layers, and with the evolution of the depositional environment to the lake phase, deposition of unequal thickness interbedded deposits of yellowish brown mudstone intercalated with light greyish yellow fine sandstone. The Lantian Formation was partially denuded by local geological uplift movements before receiving deposition, and the stratigraphic lithology is dominated by brownish-red mudstone, sandy mudstone, conglomeratic sandy mudstone, mudstone and other shallow lacustrine deposits [13].

Combined with the analysis of drilling and logging data, it is believed that the thickness of the Lantian-Bahe Formation in the Xixian new area ranges from 800m to 1150m, with an average of 960m (Figure 2); the sand-thickness ratio is generally in the range of 15.0% to 34.8%, with an average of 25.0%, according to the available drilling data; the thermal storage temperature ranges from 80°C to 112°C, with an average of 100.8°C.

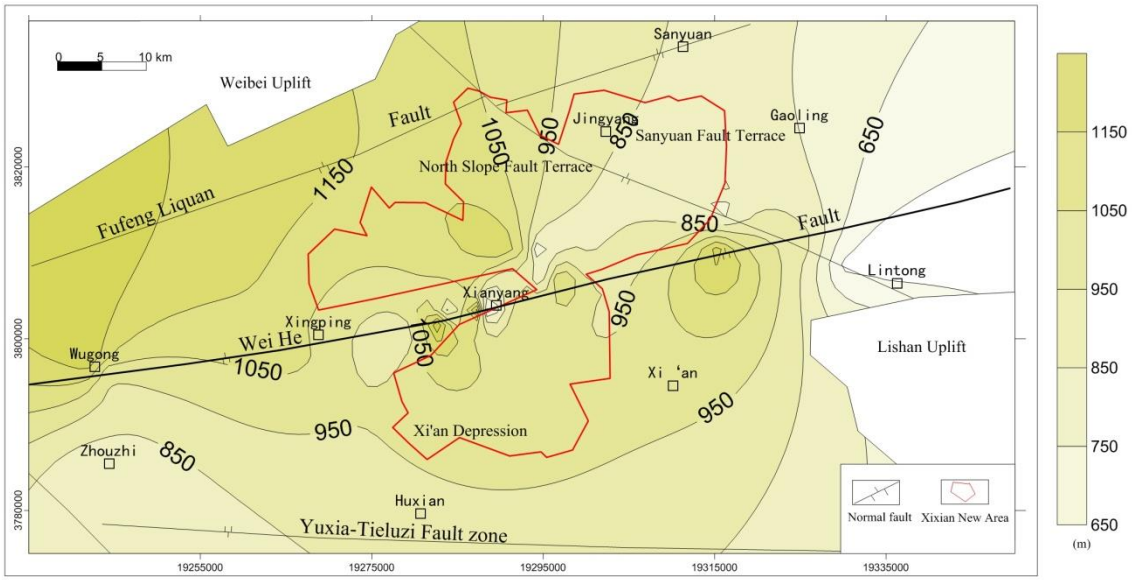

Fig2 Thickness Distribution Map of N_2b+l

3.3 Gaoling group

The Gaoling Group in Guanzhong Basin is generally deeply buried and few geothermal wells have been drilled through this formation, with existing exploratory wells generally exposing strata less than 500m thick. The Gaoling Group can generally be further divided into the upper Koujiacun Formation (N_1k) and the lower Lingshuigou Formation (N_1l), which is generally composed of conglomerate bearing sandstones and medium to coarse sandstones and is presumed to have formed in a fluvial depositional environment. The Koujicun Formation is mainly composed of mudstones, silt-bearing mudstones interbedded with fine sand and fine to medium sandstones, and is presumed to have formed in a deltaic depositional environment. Due to the paucity of information geothermal studies are generally carried out as a unified study of the Gao Ling Group.

According to the drilling and logging data and geological analysis, the depth of the Gaoling Group formation in Xixian new area is generally 2100m-3000m (Figure 3), with a thickness of 500m-900m, averaging 610m; according to the available drilling data, the sand-thickness ratio is 12.6%-38.7%, averaging 27.5%; the thermal storage temperature is 91°C-120.0°C, averaging 116.1°C.

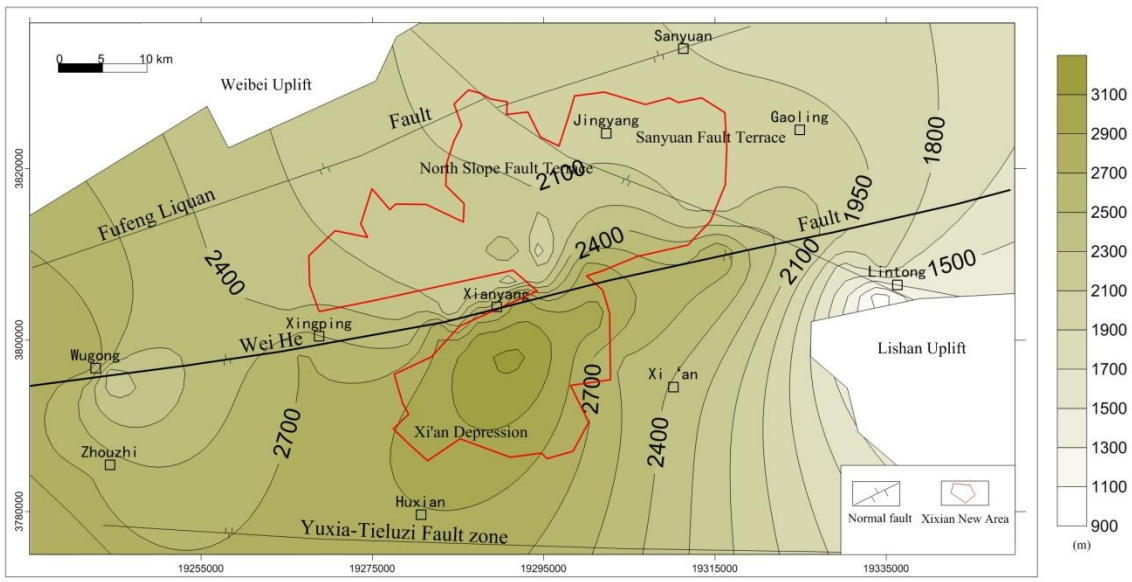

Fig3 Top Depth Contour Map of N_1gl

3.4Thermal storage properties

In geology, generally, with the increase of burial depth, compaction gradually increases and porosity decreases. This pattern is evident in the three sets of thermal reservoirs in the area. The porosity analysis data from the existing well data around the area shows that the porosity of the upper thermal reservoir, Zhangjiapo, is generally between 30-35%, decreasing to 25-30% in the middle thermal reservoir, Lantian Bahe Formation, and further decreasing to 15-20% in the lower Gaoling Group thermal reservoir, with increasing burial depth, compaction enhances and porosity decreases significantly (Figure 4).

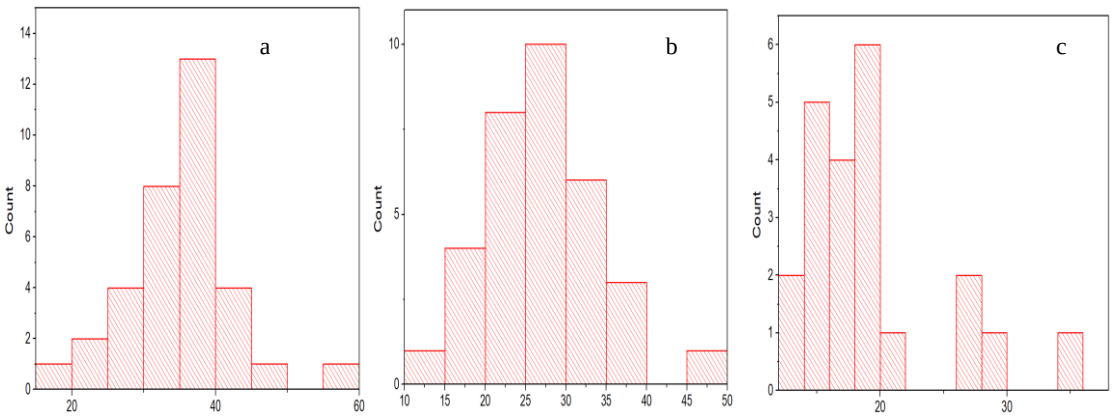

Fig4 Porosity Cylindrical Map of Main Thermal Reservoirs in Xixian New Area (a N_2z, b N_2b+l, c N_1gl)

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4 GEOTHERMAL RESOURCE POTENTIAL

4.1Geothermal resource potential analysis

The three sets of thermal reserves, Zhangjiapo, Lantian Bahe Group and Gaoling Group, are all located in Xi'an New Area. According to the planned urban construction land of 272km^2 as the boundary condition, and the three sets of thermal reserves that are suitable for exploitation under the current economic and technical conditions are the objects of calculation. The expected value of geothermal resources for the three sets of thermal reserves in Xixian new area is 20.36×10^{18} j. The expected value of annual average recoverable geothermal resources is 3.70×10^{16} j according to the simulated calculation of 15% of geothermal resources consumed in 100 years of exploitation (Table 1, Figure 5). According to the building equivalent heat consumption 0.21Gj/m^{2}a estimate, it can provide winter heating for about 1.76×10^8m^2 energy-saving buildings.

The geothermal resource abundance analysis was carried out in the detailed geothermal resource survey report of Xianyang City District, Shaanxi Province in 2000 regarding the geothermal resource exploitation in Beijing, Tianjin, Xi'an and Guanzhong Basin (Xianyang region), in which the unit area thermal reserve of Xi'an City was 86.27×10^{15} j / km^2 and the unit area thermal reserve of Xianyang was 45.13×10^{18} j / km^2[6]. The expected value of thermal reserves per unit area in Xixian new area is 74.85×10^{15} j / km^2, which is between the two, has a certain correlation with Xixian New Area in the structural position.

Table 1 evaluation results of geothermal resources of sandstone thermal reservoir in Xixian New Area

Thermal reservoir	Geothermal resources (10^{18}j)			Average annual recoverable geothermal resources (10^{16}j)		
	P10	mean	P90	P10	mean	P90
N2Z	2.10	3.62	5.37	0.31	0.54	0.79
N2l+b	4.62	6.50	8.79	1.17	1.62	2.17
N1gl	6.91	10.24	13.76	1.05	1.54	2.06
total	16.12	20.36	24.79	2.96	3.70	4.49

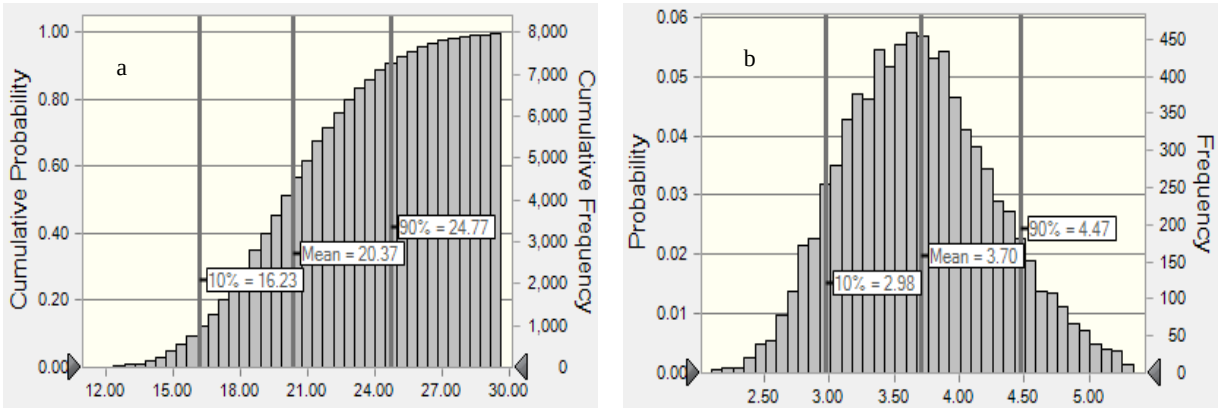

Fig. 5 simulation results of sandstone thermal storage resources and annual recoverable resources in Xixian New Area (a geothermal resources, 10^{18}j, b recoverable resources, 10^{16}j)

4.2Analysis of heating demand in Xixian New Area

According to the plan, the Xixian New Area has a total of 360 km^2 of urban and rural construction land, of which 272 km^2 is urban construction land. The population capacity of the new area is 2.72 million, which requires 1.36 according to 50 m^2 per capita× 10^8m^2 building area. The energy demand for winter heating of the new buildings is huge. Although the medium and deep geothermal resources are fully capable of meeting the demand for winter heating of the buildings in the new district, it is important to plan and utilise the rich geothermal resources in the district in a reasonable manner, to drive the development of related industries with geothermal exploration and build Xixian new area with the theme of innovative urban development mode.

Although the geothermal resources in the Xixian New Area as a whole can meet the heating needs of urban construction planning, there are heterogeneities in the geothermal resources, and the reasonable deployment of mining and irrigation well locations to maximise the use of clean geothermal resources still requires further in-depth research for the underground geological conditions of each construction unit.

5.CONCLUSION

(1) Situated in the central part of the Guanzhong Basin, Xixian new area is mainly located within the Xi'an Depression, the Northern Fault and the Sanyuan Fault Zone in plane. Vertically, three sets of thermal reserves, the Zhangjiapo, the Lantian Bahe Formation and the Gaoling Group, are distributed in the Xixian New Area.

(2) The favourable tectonic evolution of the Guanzhong Basin makes it have a good stratigraphic structure of source, storage and cover, which is conducive to the formation of high-quality large-scale geothermal fields.

(3) The expected value of geothermal resources in the three major thermal reserves of Xixian new area is 20.36×10^{18}j, and the expected value of annual average recoverable geothermal resources is 3.7×10^{16}j, which can provide winter heating for about $1.76\times10^8m^2$ energy-saving buildings.

Xixian new area is located in the central part of Guanzhong Basin, which is rich in geothermal resources. The middle and deep geothermal resources can fully meet the heating needs of buildings in the new area in winter. However, due to the heterogeneity of geothermal resources, it is still necessary to make further geological research in combination with various construction units to reasonably deploy the location of mining and irrigation wells, achieve the balance of mining and irrigation, and maximize the use of clean geothermal resources.

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