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Potential evaluation of Hot-dry Rock resources in Longchuan Basin

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ABSTRACT

Longchuan basin in western Yunnan is a Neogene rift basin located in the Yunnan-Tibetan high-temperature geothermal belt. The basin is developed with faults and strong magmatic activity, which has the potential to form geothermal resources. Based on the comprehensive study of geothermal geology in the study area, this paper analyzes the geological structure characteristics, geophysical information, and geothermal temperature data of Longchuan Basin. The results show that the basin is characterized as a 'hot basin' by high heat flow (75 to 90 mW/m^2), high temperature at the depth of 5000m (above 150°C) with a satisfied thermal background. The study area is mainly sedimentary tertiary sandstone, mudstone, argillaceous sandstone, and other clastic rocks, which have the characteristics of low thermal conductivity and can be used as a good thermal cap. The basement of the basin is dominated by Cambrian metamorphic rocks with shallow burial depth, which can be used as a high-quality hot-dry rock reservoir. Considering the above conditions, it can be inferred that Longchuan Basin has the conditions for forming Hot-dry hot rock resources. In this study, combining the thermal parameters of the study area, a 300m-thick thermal reservoir exploration model was established by the COMSOL software with reference to previous hot-dry rock mining models. Based on the influence law of different extraction factors with heat production efficiency and simulating the operation for 50 years, the geothermal enhancement system development program is optimized to maximize the amount of heat extraction. Based on the optimized mining scheme to estimate the recoverable resources of hot-dry rocks at 5000m in this study area. The result shows that under this scheme, within the burial depth of 5000m in the study area of 2km×2km (reservoir thickness of 300m), the average mining temperature is 175°C and the recoverable resources are 1.66× 10^{15}J/a, equivalent to 5.68×10^{4}t/a of standard coal.

1. INTRODUCTION

Hot-dry rock, as a clean and renewable resource, has the characteristics of wide distribution, stable heat source, large resources and great potential for power generation, etc. Research on hot- dry rock has been appearing in China since 2000, and different scholars have given different definitions of hot-dry rock. In the Chinese Energy Terminology Standard NB/T10097-2008 'Geothermal Energy Terminology' promulgated by the National Energy Administration in 2018, hot-dry rock is defined as a rock that does not contain or contains only a small amount of fluid, has a temperature higher than 180°C, and its thermal energy is utilized under current technical and economic conditions (National Energy Administration,2018). Many scholars have studied that the hot-dry rock base (temperature greater than 150°C) within the 3-10 km burial depth range in mainland China is equivalent to about 715 trillion t~856 trillion t of standard coal, which is widely distributed in southern Tibet, western Yunnan, western Sichuan, and the Bohai Bay area (Wang et al.,2012). The high-temperature thermal fields in Yunnan are mainly distributed in the Tengchong~Ruli area west of the Nujiang River, with about 20 locations, which is an important part of the Tibetan-Tiannan high-temperature geotropic (Wang et al., 2012).

Longchuan Basin is located in the high-temperature hot water area of western Yunnan Gaoligong Mountain-Tengchong subregion Yingjiang-longchuan high-temperature hot water belt, which has abundant hydrothermal resources. At the same time, it can be inferred from the data of regional aeromagnetic measurements that this basin has a potential for hot-dry rock resources. This paper analyzes the geology and geothermal conditions of the study area, divides the favorable blocks for hot-dry rock, and evaluates the potential of recoverable resources, in order to provide some guidance for the future development of hot-dry rock in Longchuan Basin.

2. GEOLOGICAL CONDITION

Longchuan Basin is located in Ruili counties in west Yunnan, which is a narrow fault basin spreading in a north-easterly direction, belonging to the western Yunnan micro-basin group (Zhang et al., 2021). As shown in Figure 1, the tectonic pattern of the basin is influenced by the long-term multiple strong activities of the Longling-Ruili deep major fault in western Yunnan, which shows asymmetric skip-shaped fractures in both horizontal and vertical directions, and can be divided into secondary tectonic units such as the southeast uplift overburden zone, the central fracture zone, the slope fault step-block zone, and the northwest slope overburden zone (Chen et al., 1994). Since the Mesozoic, the study area has been strongly tectonically active, with relatively developed fold faults, frequent high-temperature metamorphism, granite intrusion, and volcanic eruption activities in the near areas, which can provide heat conduction channels as well as abundant heat sources. Previous drilling data show that the study area is mainly sedimentary with clastic rocks such as mudstone, sandstone, and sandy mudstone of the Pliocene, Miocene Manangba Formation, and Nanlin Formation of the Tertiary System (Chen et al., 1994), which can be used as a good thermal cover. The basin is underlain by Cambrian strata with different lithologies on the east and west sides, with slate, schist, and gneiss dominating in the east and metamorphic granite in the west (Zhao et al., 1994).

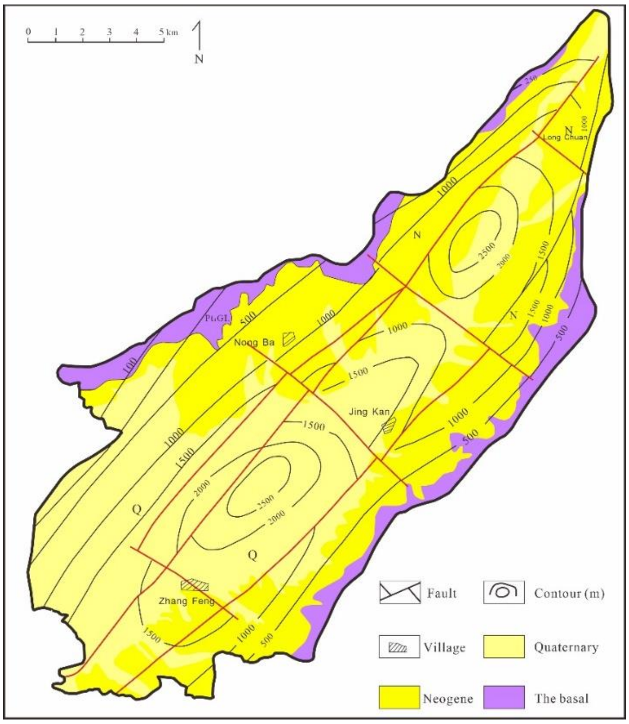

Figure 1: Longchuan Basin tectonics and basement depth distribution (modified from Dong,1993).

3. GEOTHERMAL CHARACTERISTICS

There are a lot of complicated indicators for hot-dry rock blocks. The most important factor is the deep temperature distribution pattern, which is mainly influenced by the geothermal heat flow distribution, deep stratigraphic temperature distribution, and rock thermal conductivity and heat generation rate.

3.1 Characteristics of the distribution of heat flow

Heat flow refers to the heat transferred from the interior of the earth to the ground through rocks and emitted to the atmosphere at the surface. It is usually used to reflect the regional geothermal background and the nature of the heat source in the geothermal anomaly area. Yunnan belongs to the high heat flow background area. The geothermal field has the trend of west-high east-west (the highest in Tengchong area) and decreases in a wave-like manner from west to east. In this study, according to the data collected from relevant oil drilling and hot spring heat wells and the heat flow data of Tengchong area near the study area combined with the analysis of geological data of the study area, it is concluded that the distribution characteristics of the Longchuan ground going heat flow correspond to the tectonic relief, indicating that the distribution of the Longchuan basin ground temperature field is influenced by the basement tectonic morphology. The geothermal heat flow value of Longchuan basin depression part is about 70-85 mW/m^2, and the heat flow value of basin edge is about 90 mW/m^2 higher than the national average (63.5 mW/m^2), which belongs to medium-high heat flow area and has good potential for geothermal resource development (Huang et al., 2020; Zai et al., 2021).

3.2 Deep temperature distribution characteristics

There is a lack of ultra-deep drilling data of 1000-5000m hole depth in the study area so that deep buried ground temperature cannot be obtained by direct measurement. Based on the known temperature gradient, heat flow, and surface reference temperature, the analytical solution of the one-dimensional steady-state conduction equation is used to find the expressions as follows.

$$T_Z = T_0 + \frac{qH}{K} - \frac{AH^2}{2K} \quad (1)$$

Where H is the target layer thickness (km), T_0 is the target layer top surface temperature (℃), q is the heat flow (mW/m^2), A is the heat generation rate (μW/m^3), K is rock thermal conductivity (W/(m·k)). In the calculation, the above parameters were calculated using the collected data and part of the measured data (Zhou and Xiang, 1997).

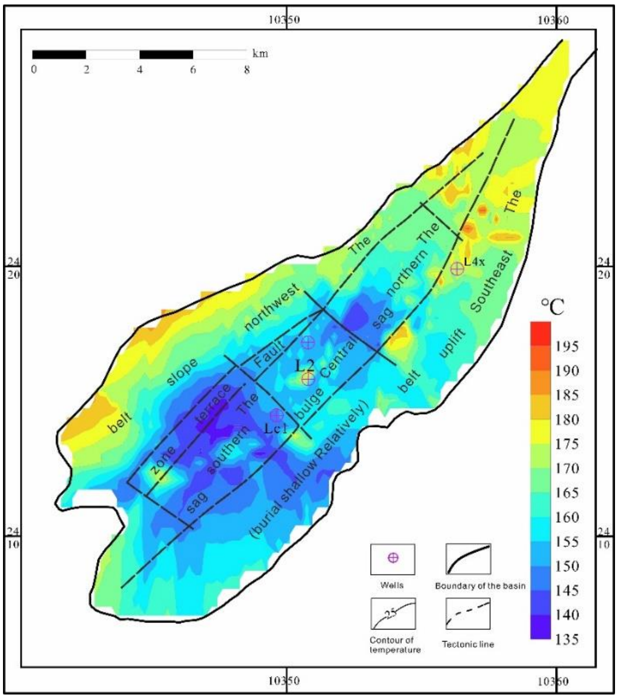

Figure 2: Temperature distribution of 5000m depth interface in Longchuan Basin.

The temperature distribution at 5000m in Longchuan is calculated and drawn (Fig.2), and the temperature at 5000m depth in the study area ranges from 135-200℃ (average about 161.8℃). From the temperature distribution at this depth, the temperature in the southern depression, northern depression, and fault zone in Longchuan are generally low about 150℃ on average, while the temperature in the northwest slope zone, northern depression, and southeast uplift zone generally reaches 170-180℃, which can be used as high-quality hot-dry rock reservoir.

4. HOT-DRY ROCK RESOURCE ESTIMATION

The estimation of hot-dry rock resources generally uses the volumetric method, but the area circled by the same geothermal contour is different, i.e., there is a natural area difference. That is why using this method has a certain error. Secondly, those factors cannot be considered in the volume method during the process of hot-dry rock mining, such as the heat loss, the influence of injection well on reservoir temperature, and the exploitation life of this reservoir. loss in the process of hot-dry rock mining, the influence of dry hot rock injection well on reservoir temperature, and the service life of dry hot rock well cannot be considered in the volume method. This study refers to the thermo-hydro-mechanical model of dry hot rock geothermal reservoir proposed by Musa D.Aliyu and combines with the study about the optimal injection and production rate of hot-dry rock reservoir exploitation project in Gonghe Basin(Xiaoxue Yan et al.), and proposes a hot-dry rock reservoir exploitation model for the geological and geothermal conditions in the study area, as shown in figure.3 (Yan et al., 2019; Musa and Rosalind, 2021).

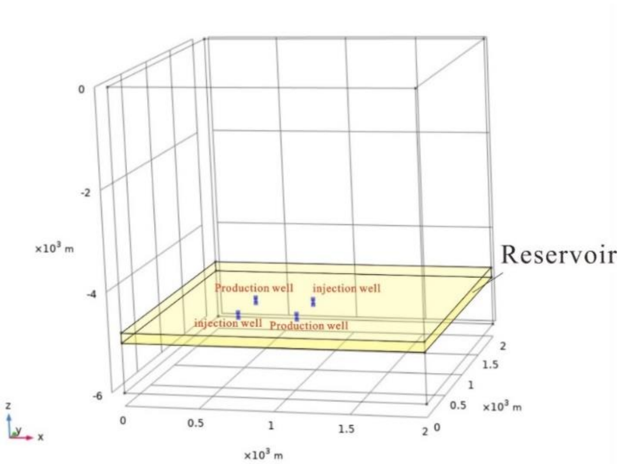

Figure 3: Development model of hot-dry rock favorable block in Longchuan Basin.

In 2005, Sanyal and Butler used numerical models to analyze the influence of different factors on thermal mining efficiency, including fracture spacing, injection well water temperature, injection, and production well spacing, and injection and production rate (Musa and Rosalind 2021). The result shows that the speed of injection production rate is inversely proportional to the heat absorbed by the surrounding rock, the speed of temperature rise, and is directly proportional to the speed of thermal breakthrough. Under the same extraction conditions, well spacing is positively correlated with mining temperature and temperature decline rate. According to the influence rule of the above different factors on the extraction thermal efficiency, the exploitation plan of hot-dry rock in Longchuan Basin with the highest thermal efficiency is optimized. To achieve maximum economic benefits, the objectives of the optimization scheme are the closest well spacing, 50 years of operation, and no more than 160°C reduction in extraction temperature. From the exploitation well temperature curves of different scenarios, after 50 years of simulated migration, the extraction well temperature is just about 160°C, meeting the standard of the optimal mining scheme, under the exploitation plan with well spacing of 400m and injection and production rate of 110 m^3/h. Under this scheme, within the 5000m buried depth of 2km×2km in the study area (300m reservoir thickness), the average extraction temperature is 175°C, and the recoverable resources are 1.66×10^{15}J/a, which is equivalent to 5.68× 10^4T/a of standard coal, indicating that Longchuan Basin has the potential to exploit hot-dry rock resource. In this study, the evaluation of the formation conditions and resource potential of hot-dry rock at depths of 5000m is of great guiding significance to the exploration and development of hot-dry rock in Longchuan Basin.

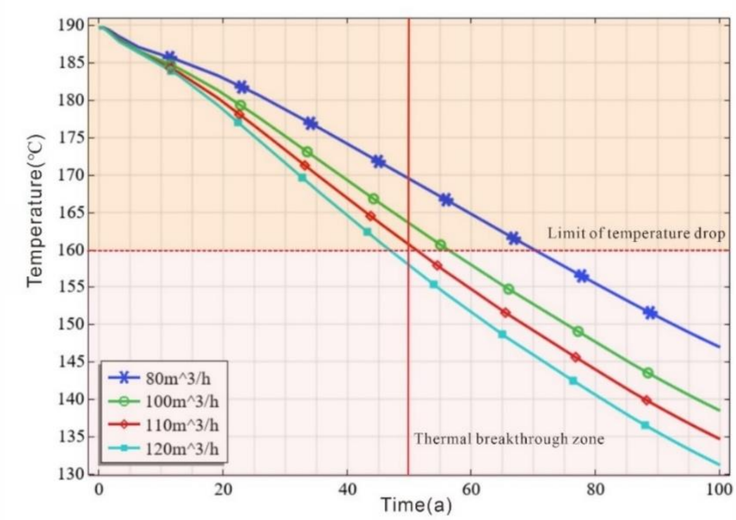

Figure 4: Temperature drop curve under different injection and production rate modes.

(well dist=400m)

5. CONCLUSION

Through the Longchuan basin tectonic evolution, drilling data analysis, integration of the relevant data collected, obtained this study area basement lithology, heat flow, rock thermo-physical properties, etc., Longchuan basin fault extremely developed, strong tectonic activity, with high heat flow background. The distribution characteristics of the deep geothermal field in the Longchuan Basin were estimated using a one-dimensional steady-state equation. The result shows that the temperature of the basin is high. The temperature of the northwest slope zone, the northern depression, and the southeast uplift zone generally reaches 170-180°C, which can be used as a high-quality hot-dry rock reservoir. A specific reservoir development model is established by Comsol to optimize the extraction scheme. Under this plan, the recoverable resources in the study area are 1.66×10^{15}J/a, equivalent to 5.68×10^4t/a of standard coal, within 2km×2km of the 5000m burial depth (reservoir thickness of 300m), indicating that the Longchuan basin has the potential to develop hot-dry rock resources.

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