Present Geothermal Field of the Chagan Sag in the Yingen-Ejinaqi Basin of Inner Mongolia, NE China

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Abstract. The aim of this work is to discuss the present geothermal field of the Chagan sag of the Yingen-Ejinaqi Basin in Inner Mongolia, NE China. In this study, the rock thermal conductivity and heat generation of the Chagan sag were tested, and the geothermal gradient of the Chagan sag was calculated. It is concluded that the geothermal gradient of the Chagan sag can be divided into three sections, i.e., $K_2$, $K_1$, and $K_b$. The heat flow of the Chagan sag is 70.6 mW/m$^2$, indicating that this sag is in a geothermal state between tectonic active area and tectonic stable area. The results may provide significant geothermal information for the evaluation of geothermal resources in the Chagan sag.

1. Introduction

Geothermal field plays an important role in the process of hydrocarbon generation and basin evolution. The study of geothermal field in a basin is of great guiding significance for the evaluation of oil and gas resources, and can also provide scientific basis and constraints for basic problems such as basin genetic dynamics and tectonic-thermal evolution.

This work tested rock thermal conductivity and heat generation rate of the Chagan sag in Inner Mongolia, and calculated the geothermal gradient of four wells and the first heat flow data to discuss the present geothermal field of this sag. The results can provide geothermal information for the evaluation of geothermal resources in the Chagan sag.

2. Methods

The Yingen-Ejinaqi Basin in NE China is a Mesozoic rift basin which is developed on the Precambrian crystalline basement the Paleozoic fold. The Chagan sag is located in the eastern margin of the Yingen-Ejinaqi Basin, which is the most promising sag for oil and gas exploration in this Basin (Fig. 1). More than 50 million tons of oil reserves have been discovered, and two oil fields of the Jixiang and Ruyi oil fields have been established, indicative of a good exploration prospect.

Till now, more than 100 wells have been drilled, which has provided guarantee for the steady-state temperature measurement, rock thermal conductivity and rock thermal generation data. In 2016, a team of Xi’an Jiaotong University, Chengdu University of Technology, Institute of Geology and...
Geophysics, Chinese Academy of Geological Sciences and Zhongyuan Oilfield jointly conducted systematic steady-state temperature measurements of four typical wells in the Chagan sag. In addition, 169 rock thermal conductivity data and 90 rock thermal generation rates were tested. The specific research methods are as follows.

\[ q = -K \times G \]  

Where \( q \) is heat flow, mW/m\(^2\); \( K \) is rock thermal conductivity, W/(m\( \cdot \)K); \( G \) is geothermal gradient, °C/km; negative sign indicates that heat flow flows from the interior of the earth to the surface.

Figure 1. Map showing structural unit division and drill wells in the Chagan sag of the Yingen- Ejinaqi Basin in NE China (a-Yingen-Ejinaqi Basin; b-structural division of the Chagan sag).
2.2 Calculation of geothermal gradient
Geothermal gradient is refined as the increase of temperature with increasing depth beneath the Earth's surface. It can be calculated by the Equation (2) with steady-state temperature measurement data of the system.

\[ G = \frac{(T_2 - T_1)}{(Z_2 - Z_1)} \]  

Where \( G \) is geothermal gradient, °C/km; \( Z_1 \) and \( Z_2 \) are top and bottom depth of condensation section, respectively, km; \( T_1 \) and \( T_2 \) are formation temperature corresponding to \( Z_1 \) and \( Z_2 \), °C; negative sign indicates that the direction of heat flow is opposite to that of geothermal gradient.

2.3 Calculation of rock thermal conductivity and heat generation rate
According to the percentage of sandstone, mudstone and magmatic rock, the thermal conductivity \( K \) and thermal generation \( A \) of different strata can be obtained by using the weighted average Equations (3) and (4).

\[ K = K_s P_s + K_n P_n + K_m P_m \]  

\[ A = A_s P_s + A_n P_n + A_m P_m \]  

Where \( K_s, K_n, K_m, A_s, A_n, A_m, P_s, P_n \) and \( P_m \) are the rock thermal conductivity, heat generation rate and the percentage of sandstone, mudstone and magmatic rocks.

3. Calculation results
The rock thermal conductivity of the Chagan sag is calculated by weighted average formula. The thermal conductivity of the first and second members of Bayinge bi Formation is high, which are 2.38 W/(m·K) and 2.33 W/(m·K), respectively. The second and first members of Suhongtu Formation contain certain magmatic rocks, and the thermal conductivity of magmatic rocks is relatively low. As a result, their thermal conductivity is relatively low, which are 1.78 W/(m·K) and 2.21 W/(m·K), respectively. The Yingen Formation has a shallow burial depth, with loose rocks and large porosity, and the rock thermal conductivity is relatively low as only 1.85 W/(m·K). The heat generation rate of rocks is highest in the Yingen Formation as 2.70 μW/m³, followed by the first and second members of the Bayinge bi Formation which are 2.46 μW/m³ and 2.61 μW/m³, respectively, and the first and second members of the Suhongtu Formation have the lowest heat generation rate as only 2.20 μW/m³ and 2.14 μW/m³, respectively.

A total of 193 system steady-state temperature measurement data were obtained for the wells Xiang 2, Xiang 5, Yi 5 and Yi 7. The Cenozoic strata are affected by solar radiation, groundwater disturbance and other factors, which are not considered in the calculation. The relationship between temperature and depth indicates that it can be divided into three sections, i.e., \( K_{2w} - K_{1s}^{upper} \), \( K_{1s}^{lower} - K_{1b} \) (Fig. 2). The geothermal gradient of \( K_{2w} - K_{1s}^{upper} \) section in the Wuliji fault nose structural belt is calculated to be 27.3 °C/km, that of the well Yi 7 in uplift area is 33.6 °C/km, and that of \( K_{1s}^{lower} - K_{1s}^{upper} \) section is 37.6°C/km and that of \( K_{1b} \) section is 27.4 °C/km.

Figure 2. Relationship between steady-state temperature and depth in the Chagan sag.

The terrestrial heat flow of the four wells was also calculated by the thermal resistance method with the rock thermal conductivity and geothermal gradient data [6]. The terrestrial heat flow of the Wuliji fault nose structure lies between 61.0 and 81.0 mW/m², with an average value of 70.9 mW/m², and
that of the Central structure belt ranges from 65.1 to 69.1 mW/m², with an average value of 67.5 mW/m². The terrestrial heat flow of the Chagan sag is 70.6 mW/m², which is higher than that of the global continent (63 mW/m²), indicating a high geothermal background.

4. Conclusions

(1) The relationship between the steady-state temperature measurement data and depth in the Chagan sag system suggests that the geothermal gradient can be divided into three sections, i.e., $K_{1s}^{upper}$-$K_{1s}^{lower}$, $K_{1s}^{lower}$-$K_{1s}^{upper}$, and $K_{1b}$. The $K_{1s}^{lower}$-$K_{1s}^{upper}$ section has the highest geothermal gradient, with an average value of 37.6°C/km, and the $K_{1b}$ section has the lowest geothermal gradient, averaging 27.4°C/km.

(2) This work first obtained four terrestrial heat flow data, which are 68.35 mW/m² for the well Xiang 2, heat flow of 71.00 mW/m² for the well Xiang 5, heat flow of 75.8 mW/m² for the well Yi 5, and heat flow of 67.3 mW/m² for the well Yi 7. The heat flow of the Chagan sag is 70.6 mW/m². The high heat flow reveals that this sag is in a geothermal state between tectonic active area and tectonic stable area.

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