Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Heat Sources of Hot Dry Rock in the Gonghe Basin, Northeastern Tibetan Plateau

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Keywords: Heat source; Hot Dry Rock; Gonghe Basin; Heat anomaly

ABSTRACT

The Gonghe basin, which is located at the northeastern edge of the Qinghai-Tibetan Plateau, was selected as the first pilot demonstration site to explore the hot dry rock (HDR) geothermal resources in China. Several geothermal boreholes have been already drilled to target the Indosinian granite in the Gonghe basin. At a depth of 3760 m, a high bottom-hole temperature (BHT) of 210 °C is identified. The temperature gradient ranges from 12.4 to 109.6 °C km^{-1} and the mean heat flow is 119.3 mW m^{-2}, which is significantly higher than the regional background of 74-75 mW m^{-2} at the northeastern margin of the Tibetan Plateau. A lot of geological, geophysical and geochemical work have been carried out to identify the heat sources that lead to the abnormal high heat flow, but a systematic summarization on these works is still missing. In this paper, we will review the factors of radiogenic heat production, cooling of magma chambers, fault fraction and deep water circulation to cause the high heat flow anomaly. Further work that should be done in the future will also be presented for revealing the heat sources.

1. INTRODUCTION

The exploitation of hot dry rock (HDR) is considered as the future of geothermal energy. In the continental area of China, the HDR geothermal resources are estimated as 20.9×10^6 EJ, and if 2% of it is exploited, it is equivalent to 4400 times of total annual energy consumption during the year 2010 in China (Wang et al., 2012).

The great potential of HDR geothermal resources set off a boom for HDR resources exploration in China. The drilling campaign was carried out in the Tibetan Plateau, Northeast China and South China, respectively. Among them, the Gonghe Basin in the Qinghai-Tibetan Plateau is found as a highly geothermal abnormal region of the Mediterranean–Himalayan geothermal belt. An average heat flow of 119.3 mW/m^2 is identified (Zhang et al., 2018) with the heat flow background of in the 74-75 mW/m^2 in the northeastern Tibetan Plateau.

With the exploration activities in the Gonghe Basin, much of the geophysical and geochemical work has been done to identify the heat source. Besides, several boreholes have been drilled to target the HDR granite reservoir. And the field test for HDR reservoir stimulation is now in preparation as the demonstration site. Nevertheless, there are significant controversies between different views on why there is heat anomaly in the Gonghe Basin. Here in this work, we will review the existing works and summarize the views on the heat source of HDR in the Gonghe Basin. The outlook will focus on what to do for next step to settle the claim.

2. GEOLOGICAL BACKGROUND

The Gonghe Basin, located in the northeastern part of the Qinghai-Tibetan Plateau, extends in the NWW direction and has a total area of 21,186 km^2. Lying between the Qilian, Kunlun and Qinling Mountains, it is surrounded by the Qinghai South Mountain fault to the north, Heka South Mountain fault to the south, Ela Mountain fault to the west and the Waligong tectonomagmatic belt to the east (Fig. 1). The tectonic structures of the study area are mainly controlled by the NW-NWW faults including the Qinghai South Mountain fault and Heka South Mountain fault and the NNW faults of Ela Mountain and Waligong tectonomagmatic fault zones. Since the late Mesozoic, the ongoing collision between the India and Eurasian plates create the faults above (Yin and Harrison, 2013). The latest activities on those faults occurred in the Quaternary (Bao et al., 2009).

The basement in the Gonghe Basin consists of Triassic sandy slate and Indosinian acidic volcanic rocks. The target reservoir for the HDR exploitation is the granite and granodiorite. Above the basement, there is the thick Paleogene, Neogene and Quaternary lacustrine strata (Xue et al., 2013). Both the Neogene and Quaternary sandstones form the shallow hydrothermal reservoirs.

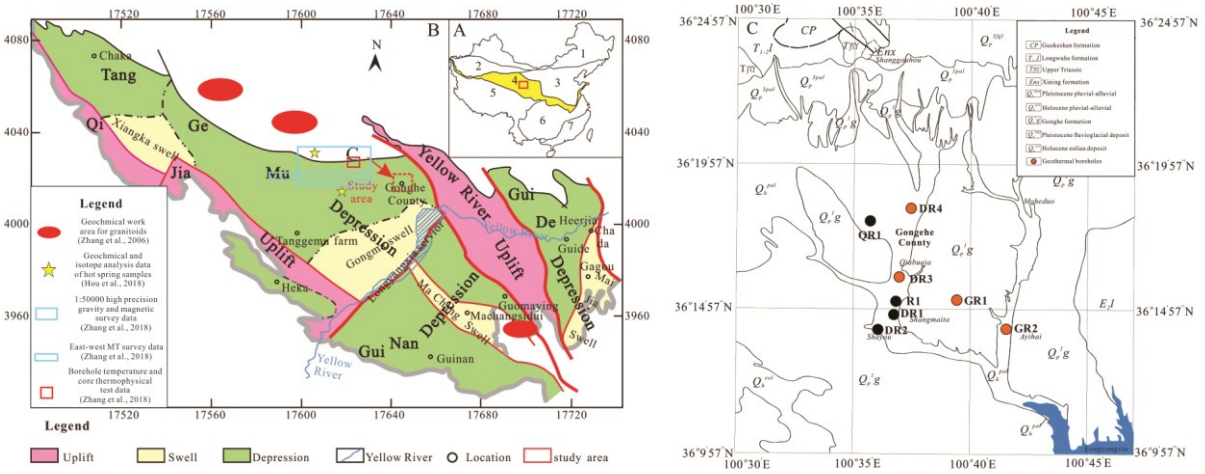


Figure 1: The location of Gonghe Basin (Modified from Zhang et al., 2018). Existing works are shown on the figure.

3. HEAT ANOMALY IN THE GONGHE BASIN

The Gonghe Basin in the northeast Tibetan Plateau belongs to the Mediterranean–Himalayan geothermal belt. Since 1980s, the geothermal studies in the Tibetan Plateau has been carried out and lots of heat flow data are accumulated. Jiang et al. (2016) packed all the data and show that the regional heat flow in the northeast Tibetan Plateau is about 74-75 mW/m^2.

During the campaign carried out by the Chinese Geological Survey and Qinghai Government from 2013 to 2017, 4 boreholes named DR3, DR4, GR1 and GR2 were implemented in the Qiabuqia area of Gonghe Basin to gain insight into the HDR resources. Their bottom-hole temperatures are 180 , 178 , 210, and 182 ℃ at the depth of 2886, 3102, 3760 and 3000 meters, respectively. Overall, the temperature logs for wells inside the region indicate that temperature is higher than 150 ℃ at depths over 2200m.The average temperature gradient in the basement granite is estimated at 6.7-6.8 ℃/100m and the heat flow is calculated as 116.3–122.3 mW m^{-2} (Zhang et al., 2018). In terms of the regional background heat flow level of the northeastern Tibetan Plateau as 75 mW/m^2, the heat accumulation here is considered as an anomalous heat flow.

4. CONTROVERSY ON THE GENETIC MECHANISM OF HEAT ANOMALY

Lots of work have been carried out based on the geological, geophysical and geochemical data to identify the reasons that lead to the heat anomaly in the Gonghe Basin. Here we summarize them as following:

(1) High concentration of the heat-producing elements in the basal granite

Sun et al. (2011) pointed out that there is the gravity low anomaly reflected by the Seismic data, which indicates the existence of granite. This has been verified by the boreholes in the Qiabuqia area. Afterwards, Li and Li (2017) support this idea that the heat is accumulated form the radiogenic isotopes with the evidence of He isotopes analysis of the geothermal fluid. Liu et al. (2016) also bolster this view by comparing the hydro-chemistry in the hot spring of Gonghe basin and Tengchong spring, whose heat source is from the magma chamber, and concluded the heat source in the Gonghe Basin should be not connected to the magma chamber.

(2) Heat conduction from the mantle plume

Yan et al. (2013) claimed that there is a 150 km width low-velocity zone as a mantle plume on the east Kunlun orogen where the Gonghe Basin lies in based on the broad band seismic observation data. And they indicate that it is right this mantle plume forms the heat anomaly within 1-40 km below the Gonghe Basin.

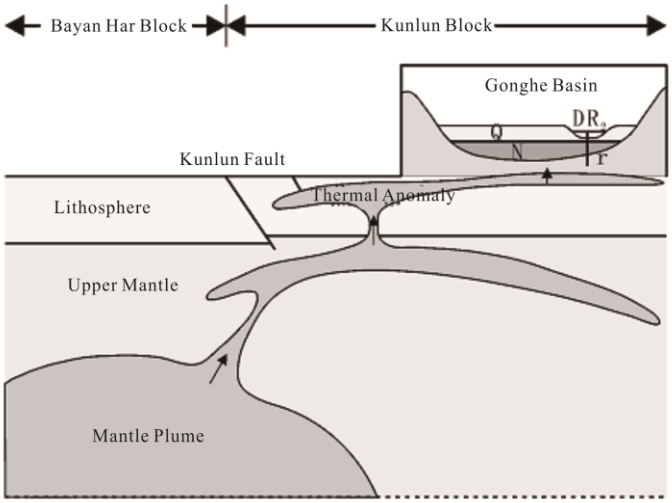


Figure 2: Aggregation pattern graph of geothermal energy in shallow of Gonghe basin (Modified from Yan et al., 2013)

(3) Tectonic activities

Zhao et al. (2016) emphasized that the heat production from the granite is not enough to form the heat anomaly in the Gonghe Basin. They claim that there are still tectonic activities such as shear friction caused by continuous extrusion stress field Qaidam fault. The material in the mantle is to Gonghe in horizontal direction in Qinghai-Tibetan plateau. So they concluded it is the pushing force formed by the collision of India plate and Eurasian plate during the Himalayan orogenic period causing the heat anomaly.

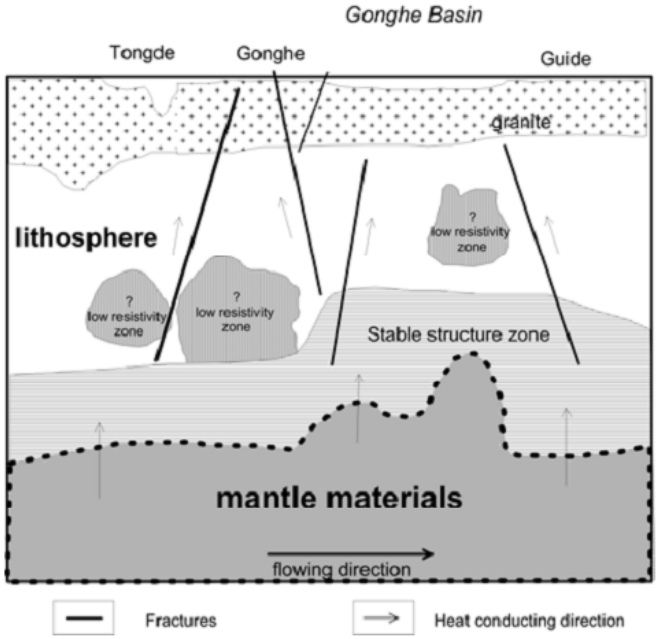


Figure 3: The tectonic activities heating model for the HDR in the Gonghe basin (Zhao et al., 2016)

(4) The duplicate effect of radiogenic heat of thickened crust and the cooling of shallow magma chamber beneath the Gonghe Basin

Zhang et al. (2018) carried out the temperature logging and measured the heat production rate of U, Th, K concentrations. They also constructed a 1-D theoretical crustal thermal structure model and show that the heat anomaly is caused by the duplicate effect above. However, during the simulation process, only the transient heat conduction process of the magma chamber was considered, and the spatial heterogeneities of media were ignored by using the two-dimensional computational model. In future works, real three-dimensional stratigraphic model should be set up based on precise seismic interpretations and more drilling data. In addition, more restrictions from geological, geophysical and geochemical research should be imposed on the magma chamber in subsequent studies.

5. OUTLOOK

It could be found from the existing works that most geophysical and geochemical data were concentrated in the Qiabuqia area, where the boreholes were located. To verify the claim, a larger-scale field survey including the geochemical and geophysical work

should be carried out. And a systematic view on all the existing geophysical and geochemical data should be implemented.

ACKNOWLEDGEMENTS

This research is supported by the National Key Research and Development Project (2018YFB1501801).

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