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ScienceDirect

Natural Gas Industry B 5 (2018) 226–234

www.elsevier.com/locate/ngib

Research Article

# Present-day temperature–pressure field and its implications for the geothermal resources development in the Baxian area, Jizhong Depression of the Bohai Bay Basin ☆

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Received 14 August 2017; accepted 25 October 2017
Available online 19 June 2018

**Abstract**

The Baxian area in the Jizhong Depression, west of the Bohai Bay Basin, is rich in geothermal resources, where Xiong County was built as the first smokeless city in China and the Xiong-county Model has become the geothermal resources demonstration model in China. In this study, the present-day geothermal gradient and the horizontal distribution characteristics of the temperature and pressure at different depths in the Baxian area were studied based on massive measured temperature and pressure data of the boreholes, and then the relationship was also discussed between the temperature–pressure field and the geothermal resources. The following findings were obtained. (1) The present-day geothermal gradient of the Baxian area is within the range of 21.8–73.5 °C/km, averaging 33.5 °C/km. (2) Its strata temperature increases as the depth increases. The horizontal variations of the geothermal gradient and strata temperature correspond to the basement relief very well. As the abnormally high temperature areas, the northern Niutuozhen Uplift, the Central Baxian Depression and the central East Langgu Depression possess huge geothermal resources and will be the most favorable exploration targets. (3) The formation pressure of the Baxian area is characterized by normal pressure and weak overpressure, and its horizontal distribution varies at different depths. The middle–strong overpressure generally developed at the depth of 4000 m in the southern Langgu Depression and southern Baxian Depression. This study is of important guiding significance for the exploration and development of geothermal resources in the Baxian area.


*Keywords:* Bohai Bay Basin; Jizhong Depression; Baxian area; Geothermal resources; Temperature; Pressure; Geothermal gradient; Abnormally high temperature area; Overpressure

In recent years, oil and gas exploration in China has been increasingly challenging, and air pollution caused by fossil fuels, especially in Beijing, Tianjin and Hebei Province, has also deteriorated. Thus, the development and utilization of clean and renewable energy is extremely urgent. According to Wang Jiyang et al. [1], the total quantity of geothermal resources in the dry-hot rocks with a depth of 3–10 km in China is $2.09 \times 10^7$ EJ (1 EJ = $10^{18}$ J), equivalent to 715 trillion tons standard coal, indicating the great potential and prospects of geothermal resources in China. The 13th Five-year Energy Plan of China has firstly included the development of

☆ Project supported by PetroChina's Major Science and Technology Project (No. 2014E-35, 2017E-15), and School-Enterprise Cooperation Project of PetroChina Huabei Oilfield Company (No. HBYT-YJY-2015-JS-222).
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Peer review under responsibility of Sichuan Petroleum Administration.

https://doi.org/10.1016/j.ngib.2017.10.006

geothermal energy. This also reflects the position of geothermal energy in the future energy mix. The extension in Late Mesozoic made the crust in North China stretch and thin, enabling this region to become an abnormally hot area which is a favorable target for the development of dry-hot rocks. According to the previous evaluations on the dry-hot rock resources in North China based on a large number of geothermal resources parameters, the total quantity of dry-hot rock resources is $1.81 \times 10^6$ EJ, equivalent to 61.7 trillion tons standard coal [1]. The Bohai Bay Basin in North China is a typical rift basin, where the current geothermal gradient and the geothermal flux are generally high. It is not only an important hydrocarbon accumulation area but also contains a large quantity of geothermal resources [1–5]. The Xiongxian County, one of China's famous demonstration areas of geothermal energy development and utilization, is located in the Jizhong Depression, western Bohai Bay Basin.

The current geothermal flux in the Jizhong Depression ranges from 48.7 to 79.7 mW/m$^2$. Its planar distribution is related to the topography of the basement; also, geothermal fields are widely distributed in the high-geothermal flux arching areas [6]. According to Liang Hongbin et al. [3], there are three geothermal water systems in the Jizhong Depression, i.e. the Proterozoic–Lower Paleozoic weak alternate belt, the Upper Paleozoic–Paleogene alternate blocking belt, and the Neogene strong alternate belt. Thermal reservoirs are mainly divided into three types: pore type, fracture type and fracture–cave type. Chen Moxiang et al. [2] analyzed the measured temperature of the borehole and concluded that the geothermal gradient of the caprock with a depth of 0–2000 m in the Niutuozhen bulge ranges from 35 to 70 °C/km, and the planar geothermal anomaly is mainly caused by the basement relief and the variation of rock thermal conductivity in vertical–lateral direction. According to the well temperature logging curve, Li Weiwei et al. [4] believed that heat transfer in the caprock (0–1400 m) in geothermal fields in Xiongxian County is realized by conduction and the average geothermal gradient is 51 °C/km. In these areas, the shallow medium–low temperature hydrothermal resources have been widely used for hot spring bath, heating, fish farming and other industries [2]. As for the enhanced geothermal system (EGS, applicable to power generation), its economic reservoir temperature is 150 °C and the optimal recovery temperature is about 200 °C [7]. The temperature measured at the depth of 6027 m in Well Niutuozhen East 1 in the Baxian depression is 201 °C [8], which provides a valuable evidence for the development of EGS.

Conventional geothermal wells are about 1000 m deep, while the drilling depth in the oilfield can reach 4–5 km, which is of great significance for studying the geothermal field of deep crust and EGS. Earlier studies suggest that the formation of geothermal resources in the Niutuozhen bulge is related to the hydrodynamics [9], and the driving force of water flow is fluid pressure. In this paper, based on the measured temperature and pressure data of well drilling in oilfields, a systematic study was carried out of the present-day temperature–pressure field in the Baxian area (the Bazhou area now), and the temperature–pressure distribution at different depths was analyzed. On this basis, the relationship between temperature–pressure field and geothermal resources was discussed, in order to guide the further development of geothermal energy (especially for EGS).

## 1. Geology

The Jizhong Depression is a Mesozoic–Cenozoic sedimentary depression developed on the basement of the North China palaeo-platform. Trending in NE–SW and covering an area of about $3.2 \times 10^4$ km$^2$, the depression neighbors the Yanshan uplift to the north, the Xingtai–Hengshui uplift to the south, the Taihangshan uplift to the west, and the Cangxian uplift to the east. According to the characteristics of basement relief and fault distribution, the Jizhong Depression is divided into multiple secondary structural units, where the geothermal field is mainly located in the arching area (Fig. 1). The Baxian area resides in the central–north of Jizhong Depression, and mainly consists of the secondary structural units such as Baxian depression, Wen'an slope, Niutuozhen bulge, Niutuozhen North slope and Langgu depression (Fig. 1). The bedrocks are mainly the Jixian System Wumishan Formation carbonate rocks in the Baxian depression [10,11], the Cambrian–Ordovician carbonate rocks in the Langgu depression [12], the Archean metamorphic rocks and Mesoproterozoic Changcheng System and Jixian System carbonate rocks in the Niutuozhen bulge [2,4], and the Jixian System Wumishan Formation and Lower Paleozoic Cambrian–Ordovician carbonate rocks, Upper Paleozoic Carboniferous–Permian clastic rocks (interbedded with multiple layers of carbonate rocks and coal) and Mesozoic continental clastic rocks (interbedded with coal and volcanic rocks) in the Wen'an slope [13]. The caprocks are mainly composed of Paleogene and Neogene sand-mud interbeds and Quaternary fluvial deposits. The intense faulting activity since

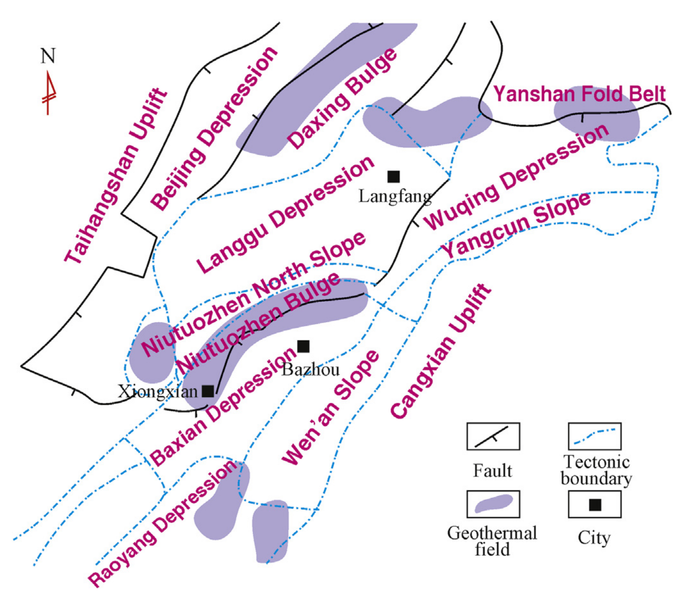


Fig. 1. Regional tectonic map and geothermal field distribution in the Baxian area [3,15].