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High-quality heat flow determination from the crystalline basement of the south-east margin of North China Craton

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ABSTRACT

Very few of heat flow data have come from the crystalline basement in the North China Craton but rather from boreholes in the sedimentary cover of oil–gas basins. Explorations for hot dry rock (HDR) geothermal resources and porphyry gold deposits in eastern China offer now valuable opportunities to study the terrestrial heat flow in the crystalline basement. In this study, we obtained continuous temperature logs from two boreholes (the LZ borehole with a depth of 3471 m and the DR borehole with a depth of 2179 m) located in the south-east margin of the North China Craton. The boreholes have experienced long shut-in times (442 days and 261 days for the LZ borehole and DR borehole, respectively); thus, it can be expected that the temperature conditions have re-equilibrated after drilling and drill-mud circulation. Rock thermal conductivity and radiogenic heat production were measured for 68 crystalline rock samples from these two boreholes. The measured heat-flow density was determined to be 71.8 ± 2.3 mW m^{-2} (for the LZ borehole) and 91.5 ± 1.2 mW m^{-2} (for the DR borehole). The heat flow for the LZ borehole is close to the value of 75 mW m^{-2} determined in the Chinese Continental Scientific Drilling main hole (CCSD MH), both being in the Sulu-Dabie orogenic belt and thus able to verify each other. The value for the DR borehole is higher than the above two values, which supports former high heat-flow values determined in the Bohai Bay Basin.

1. Introduction

Geothermal studies in the North China Craton (NCC) started from 1970s. The first group of terrestrial heat-flow data was published by the Geothermal Research Division, Institute of Geology, Chinese Academy of Sciences (1979). Since then, more heat-flow data have been reported for the continental area of China. These data have been shown on several heat-flow maps (Wang and Huang, 1988, 1990; Hu et al., 2000; Wang et al., 2012). According to our latest statistics of December 2014, without counting the heat flow estimated from oil test temperature, 402 data have been compiled in the NCC (Fig. 1). Most of the heat-flow data are from the sedimentary cover of petroliferous sedimentary basins. So far, no heat-flow data in the NCC have been reported from the continuous temperature logs and thermophysical property analysis of the crystalline basement. The existing data of the NCC show a large scatter with values ranging from 25.5 to 140.0 mW m^{-2}. Approximately 65% of the data were determined using temperature data from a shallow depth ($\leqslant$1 km). However, temperatures measured within the shallow sedimentary rocks of high permeability and porosity could be affected by advective heat transport processes overprinting the terrestrial heat flow, which, by definition, is the heat transferred by conduction (diffusion). It is expected that advective overprint is weaker in the crystalline basement due to the generally low rock permeability and porosity (Guillou-Frottier et al., 2013; Jessop, 1993; Nathenson and Guffanti, 1988).

The LZ borehole (119°59′42″E, 37°24′16″N) located in the Jiaodong Peninsula, 30 km east of the Tan-Lu Fault Zone and 90 km north-west of the Sulu-Dabie orogenic belt, is an exploration borehole for gold mines drilled by Shandong Gold Mining Co., Ltd. This borehole was cased down to 500.75 m and the bottom depth is

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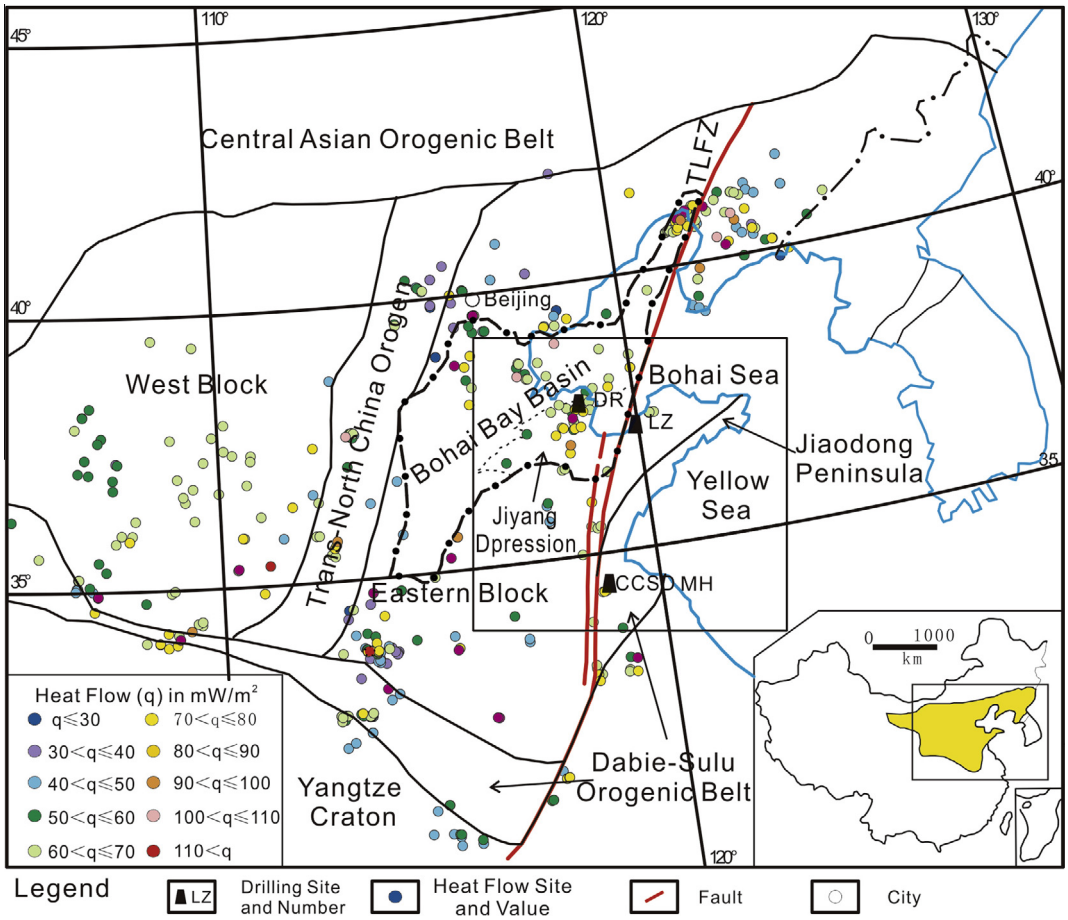

Fig. 1. Map showing the main tectonic units of the NCC (for location of the NCC in China, see inset map). The study area is indicated by a rectangle. Heat flow values available in the study and boreholes studied are shown. TLFZ represents the Tan-Lu Fault Zone.

4006.17 m. The DR borehole (118°32′45″, 37°40′21″) located at the Jiyang Depression, Bohai Bay Basin, approximately 100 km west of the Tan-Lu Fault Zone, is an exploration borehole for hot dry rock geothermal resources and was drilled by Shandong Provincial Lubei Geo-engineering Exploration Institute. The borehole was cased down to 2003.75 m. The bottom depth is 2500.58 m.

This study reports the borehole temperature logs and the measured thermophysical parameters of the crystalline basement, as well as the vertical variations of calculated heat-flow values. A comparison is made with results from the Chinese Continental Scientific Drilling main hole (CCSD MH), which is located in the Dabie-Sulu Orogenic Belt (He et al., 2008). Finally, some geodynamical implications of the heat-flow data are given.

2. Geological setting

The study area is located at the south-east margin of the NCC and divided into two parts by the Tan-Lu Fault Zone (Fig. 1). The western part belongs to the Jiyang Depression, Bohai Bay Basin and the eastern one is the Jiaodong Peninsula. The Jiyang Depression is located in the south-east of the Bohai Basin, which is a Cenozoic rifted basin that originated from regional extension induced by active mantle convection. The Jiaodong Peninsula comprises two tectonic units: the NCC to the north and the western margin of the Dabie-Sulu Orogenic Belt to the south (Figs. 1 and 2).

The NCC consists of an Archean to Paleoproterozoic basement, which has experienced different degrees of metamorphism. The basement is overlain by a Mesoproterozoic to Cenozoic sedimentary cover (Lu et al., 2008; Tang et al., 2013; Zhao and Zhai, 2013). The NCC is sandwiched between the Central Asian Orogenic Belt and the Dabie-Sulu Orogenic Belt, divided into West Blocks and East Blocks by the Trans-North China Orogen (Fig. 2). The eastern portion of the NCC is a best example of cratonic destruction, characterized by high surface heat flow, abundant Cretaceous volcanism, intensive tectonic deformation, low seismic velocities in the upper mantle, and a thin, fertile and high density lithosphere mantle (Carlson et al., 2005; Chen et al., 2008; Chen, 2010; Tian and Zhao, 2011). The widespread development of early Cretaceous magmatism and extensional structures indicates that the eastern NCC was destroyed during this period (Zhu et al., 2012).

The Bohai Bay Basin developed on an Archean–Paleoproterozoic crystalline basement. The area experienced a stable phase from the Middle Proterozoic to the end of the Paleozoic, before an important tectonic transition period started from the Mesozoic, giving rise to basin formation and thermal activity (Chang, 1991; Qi et al., 2008). The basin is considered to be the center of the lithospheric thinning and destruction of the NCC (Chang, 1991; Zhu et al., 2012; Qiu et al., 2014). The Jiaodong Peninsula was formed by collages of the edge of the NCC and Yangtze Craton (Xu et al., 2004). The northward subduction of the Yangtze Craton beneath the NCC by the end of the Triassic formed the Sulu-Dabie Triassic orogen, which extends in an east–west direction for 2000 km and is cut off by the Tan-Lu Fault Zone to the east (Zhang et al., 2009; Wan, 2012; Guo et al., 2012). Large-scale strike-slip movement along the Tan-Lu Fault is one of the significant characteristics of the Mesozoic tectonics in eastern China (Fletcher et al., 1995; Zhu et al., 2009; Deng et al., 2013; Gu et al., 2013). The imaged Moho