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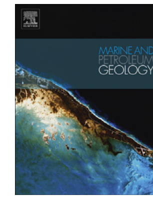

Research paper

# A comparative study between present and palaeo-heat flow in the Qiangtang Basin, northern Tibet, China

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ABSTRACT

The Qiangtang Basin is a significant prospective area for hydrocarbon and gas hydrate resources in the Tibetan Plateau, China. However, relatively little work has been performed to characterise heat flow in this basin, which has restricted petroleum and gas hydrate exploration. In this study, we compare present and palaeo-heat flow in the Qiangtang Basin to provide information on geothermal regime, hydrocarbon generation and permafrost that is necessary for further petroleum and gas hydrate exploration. We base our study on temperature data from a thermometer well, thermal conductivity tests, vitrinite reflectance data, homogenisation temperature data from fluid inclusions, stratigraphic information and a time-independent modelling approach. Our results indicate that in the central Qiangtang Basin, the present thermal gradient is approximately 15.5 °C/km, and heat flow is approximately 46.69 mW/m$^2$. Heat flow in the Qiangtang Basin is not relatively stable since the Early Jurassic, as previous research has suggested, and it is generally decreasing with time. Additionally, there is a clear difference between the hottest thermal regime of the southern and northern Qiangtang Depressions during Cretaceous to Pleistocene time. In the southern Qiangtang Depression, the palaeogeothermal gradient is approximately 32.0 °C/km, and palaeo-heat flow is approximately 70 mW/m$^2$. However, in the northern Qiangtang Depression, the palaeogeothermal gradient exceeds 81.8 °C/km, and palaeo-heat flow is greater than 172.09 mW/m$^2$. The high thermal regime in the northern Qiangtang Depression is driven mainly by hydrothermal convection. Gas reservoirs are possible targets for hydrocarbon exploration in this depression. Currently, the northwestern part of the northern Qiangtang Depression is the most favourable area for gas hydrate exploration in the Qiangtang Basin.



## 1. Introduction

Heat flow measurements not only provide fundamental information for the study of lithospheric thickness (Bodri and Bodri, 1985; Kroeger et al., 2013; Mareschal and Gliko, 1991; Meng and David, 2006; Rolandone et al., 2013) and tectonic evolution (Grall et al., 2012; Lin, 2000; Lysak, 1992; Nagihara, 2010) but are also important for hydrocarbon exploration (Carminati et al., 2010; Hudson and Hanson, 2010; Zuo et al., 2011) and hydrogeologic research (Pasquale et al., 2013; Wang et al., 1985) in sedimentary basins. Systematic heat flow measurements in China were first initiated in the 1970s. Thus far, heat flow has been measured for most tectonic units, and a contour map showing heat flow patterns for continental China has been compiled (Hu et al., 2000; Lysak, 2009). However, in the central Tibetan Plateau, heat flow density data are scarce. More unfortunately, the available data, which are mainly derived from hot spring or sinter measurements, are often influenced by upward groundwater movement (Majorowicz and Jessgp, 1981; Tong et al., 1981). Exploration of energy and mineral resources in the central Tibetan Plateau is restricted by the lack of reliable heat flow data, especially in the Qiangtang Basin.

The Qiangtang Basin (Fig. 1) is a Mesozoic petroliferous basin located in central northern Tibet, which is also the low temperature centre of the Tibetan Plateau (He et al., 2012). At present, hydrocarbon anomalies (e.g., surface oil, bitumen shows and gas shows) have been discovered in more than 200 outcrops in this basin (Wang et al., 2009). The Qiangtang Basin is regarded as one of the most promising petroliferous basins in the Tibetan Plateau (Guo

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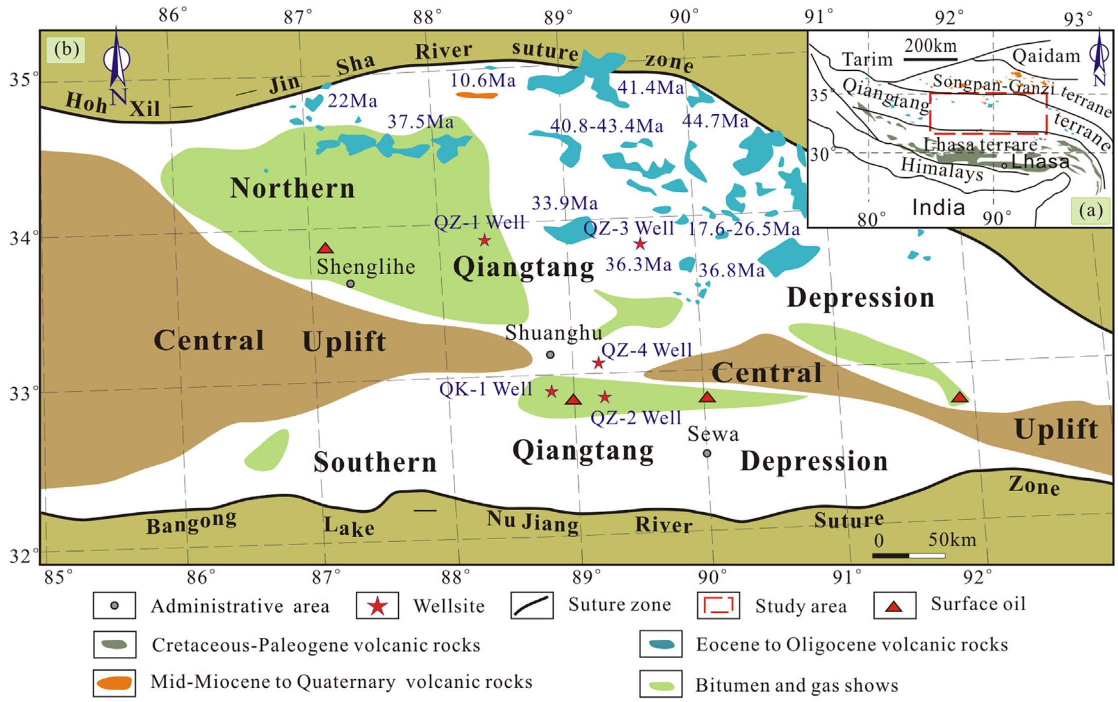


**Figure 1.** (a) The regional tectonic setting of Tibetan Plateau with a box showing the outline of the field of view in (b). Distribution of Cenozoic volcanic rocks in the Tibetan Plateau had been shown in it. Modified from (Lai and Qin, 2013). (b) Simplified geological map of the Qiangtang Basin. The well sites, hydrocarbon anomalies and Cenozoic volcanic rocks had been shown in it. Modified from (Deng and Sun, 1998; He et al., 2012).

et al., 2008; Wang et al., 2009) and as a significant prospective area for gas hydrate resources in China (He et al., 2012; Wu et al., 2010). Although heat flow studies in this basin were initiated in 1976, only five heat flow measurements have been obtained, which range from 50 to 19,250 mW/m$^2$ and were collected from spring water in the Shuanghu and Sewa areas (Tong et al., 1981) (Fig. 1). On the basis of the tectonic evolutionary characteristics of the Qiangtang Basin, Zhao et al. (2000) suggested that its thermal regime is relatively stable since the Early Jurassic; thermal history simulation produced a present-day heat flow of 41 mW/m$^2$, but the simulation results were inconsistent with measurements of vitrinite reflectance (Zhao et al., 2000). Such thermal history simulations cannot effectively guide hydrocarbon resource assessment in this basin. Additionally, permafrost thickness is crucial to the formation of gas hydrates in terrestrial environments (Collett et al., 2011; Wu et al., 2010). Based on the statistical relationships among mean annual ground temperature, altitude, latitude and continentality, Wu et al. (2010) concluded that the thickness of permafrost in the Qiangtang Basin ranges from 100 to more than 200 m. However, in July 2012, a well kick occurred in well QZ-4 at 50 m depth (Fig. 1), indicating that the actual thickness of permafrost in the central Qiangtang Basin is only approximately 50 m. The geological survey results show that the well QZ-4 is located in a discharge region, and abundant sulphur-rich sinter has been discovered in the shallow layer surrounding the well head. It is reasonable to infer that the thickness of permafrost in this basin is likely affected by geothermal conditions. The lack of heat flow data has clearly restricted petroleum and gas hydrate exploration in the Qiangtang Basin.

The first thermometer well (well QK-1) in the Qiangtang Basin was installed for the purposes of this study in the Longeni area (Fig. 1). On the basis of thermal conductivity test results from core samples and the approximately steady temperature profile in this well, present-day heat flow in the central Qiangtang Basin will be calculated. In addition, core sample data from four wells drilled in the Qiangtang Basin (wells QZ-1, QZ-2, QZ-3 and QK-1) will be integrated to determine palaeo-heat flow; these data include stratigraphic information, vitrinite reflectance data and homogenisation temperature data from fluid inclusions. Furthermore, we will compare present and palaeo-heat flow in the Qiangtang Basin to provide information on geothermal regime, hydrocarbon generation and permafrost that is necessary for further petroleum and gas hydrate exploration and to fill the knowledge gap in Tibetan Plateau heat flow dynamics.

## 2. Geological setting

The Qiangtang Basin (Fig. 1) is a Mesozoic marine sedimentary basin overlying folded Paleozoic basement rocks (Wang et al., 2010). It is bounded by the Hoh Xil–Jinsha River suture zone to the north and the Bangong Lake–Nujiang River suture zone to the south, and it comprises the northern Qiangtang Depression, the Central Uplift and the southern Qiangtang Depression (Fig. 1) (Fu et al., 2010). The basin initiated as a foreland basin in the Early Triassic and evolved into a rift basin in the Early Jurassic, with uplift and erosion occurring after the Eocene (Fu et al., 2009). During the Early Cretaceous, the Bangong Ocean closed as a result of northward subduction beneath the Qiangtang Terrane and Qiangtang-Lhasa collision, causing large-scale marine regression in the Qiangtang Basin (Fu et al., 2009). The water retreated from the northwest of the northern Qiangtang Depression. The present tectonic framework of the Qiangtang Basin developed mainly as a result of the rise of the Tibetan Plateau during the Early Miocene (2.3–5.3 Ma) (Liu et al., 2003; Wang et al., 2002). From the Early Triassic to the Late Jurassic, the basin was filled by marine strata predominantly including marls and marly carbonates. From the Late Jurassic to the Eocene, marine facies were gradually replaced by alluvial, fluvial and lacustrine facies. The marine strata are widespread in the Qiangtang Basin, with thicknesses of