Thermal history of the Sichuan Basin, SW China: Evidence from deep boreholes

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Abstract The Sichuan Basin is a superimposition basin composed of terrestrial and marine sediments that is well known for its abundant petroleum resources. Thermal history reconstruction using paleogeothermal indicators, including vitrinite reflectance and thermochronological data, shows that different structural subsections of the Sichuan Basin have experienced various paleogeothermal episodes since the Paleozoic. The lower structural subsection comprising the Lower Paleozoic to Middle Permian (Pz–P2) successions experienced a high paleogeothermal gradient (23.0–42.6°C/km) at the end of the Middle Permian (P2), whereas the upper structural subsection comprising Late Permian to Mesozoic strata underwent a relatively lower paleogeothermal gradient (13.2–26.9°C/km) at the beginning of the denudation (Late Cretaceous or Paleocene in the different regions). During the denudation period, the Sichuan Basin experienced a successive cooling episode. The high paleogeothermal gradient resulted from an intensive thermal event correlated to the Emeishan mantle plume. The heat flow value reached 124.0 mW/m² in the southwestern basin near the center of the Emeishan large igneous province. The low geothermal gradient episode with heat flow ranging from 31.2 to 70.0 mW/m² may be related to the foreland basin evolution. The cooling event is a result of the continuous uplift and denudation of the basin.

Keywords Paleotemperature gradient, Paleo-heat flow, Vitrinite reflectance, Emeishan mantle plume, Sichuan Basin


1. Introduction

The Sichuan Basin in southwestern China is an oil- and gas-bearing basin that is generated on the Yangtze Craton, which was depressed in the Paleozoic-Early Mesozoic and was deformed in the Late Triassic-Late Cenozoic. The recent discovery of the giant Puguang gas field (Ma et al., 2007, 2008; Liu et al., 2009) reveals new petroleum exploration prospects in the basin.

The thermal history reconstruction of sedimentary basins is important in the study of basin dynamics and petroleum geology (Morgan, 1984; Wang, 1996). This history can provide evidence for the tectonic evolution of sedimentary basins. Based on the results of thermal history reconstruction, the histories of hydrocarbon generation and migration and the location of hydrocarbon kitchens can be revealed. There are two different approaches to thermal history reconstruction: The paleo-temperature indicator method and the tectonic-thermal modeling method, which apply to the basin scale.
and lithosphere scale, respectively. There have been reports on thermal history reconstruction based on paleo-temperature indicators for some areas of the Sichuan Basin, such as the western margin of the basin, which is adjacent to the Qinghai-Tibet Plateau (Wang et al., 1998; Kirby et al., 2002; Richardson et al., 2008; An et al., 2008; Tian et al., 2012), and on the thermal history or hydrocarbon generation history of the northeastern basin where the Puguang gas field is located (Lu et al., 2005; Shen et al., 2007; Qiu et al., 2008; Chang et al., 2010; Tian et al., 2010, 2011). Most studies focused on the uplift history or the hydrocarbon generation history since the Late Mesozoic. During the Early Permian-Middle Triassic, the Sichuan Basin experienced regional lithospheric extension and Emeishan mantle plume development, both of which importantly influenced the thermal evolution (Zhu et al., 2010a; He et al., 2011). The thermal effects of lithospheric extension and the Emeishan mantle plume have been simulated based on different geodynamical models and discussed by He et al. (2011, 2014a), and the results show that the thermal evolution of the inner zone above the plume head was greatly influenced by plume activity, but the outer zone and its outside area where the Sichuan Basin is located were only slightly affected (He et al., 2011). The high paleo-heat flow value reached ~120 mW/m² in the southwestern basin near the center of the Emeishan Large Igneous Province (ELIP) at the middle-late Permian (Zhu et al., 2010a).

However, neither work provided exact evidence for the paleogeothermal regimes during the particular time periods because of the lack of deep borehole data or the defect of the retrieval methods. In this paper, the thermal history of the basin is systematically reconstructed based on a large paleo-thermal indicator datasets (R₀, AFT, etc.), and the paleo geothermal regimes display a marked difference. Both the geodynamic mechanism as revealed by the thermal history and the effect of thermal evolution on the hydrocarbon source in the basin are discussed herein.

2. Geological setting

The Sichuan Basin is in the western margin of the Yangtze Craton, bounded on all sides by fold-thrust belts, i.e., the Micangshan and Dabashan belts in the north, the Longmenshan belt in the west, the Eastern Sichuan fold belt in the east, and the Southwestern Sichuan fold belt in the south (Guo et al., 1996; Meng et al., 2005; Liu et al., 2006; Richardson et al., 2008) (Figure 1). The Emeishan large igneous

Figure 1 Sketch map showing the geological setting of the Sichuan Basin. Modified after Meng et al. (2005) and He et al. (2006).