Present-Day Heat Flow and Thermal History in the Jianghan Basin*

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Abstract

Pre-Cenozoic marine residual basin is the second main direction of oil and gas exploration in China. Present heat flow and thermal history have a close relationship with hydrocarbon generation, migration, accumulation, and dynamics process; the study of thermal regime may offer valuable information for further exploration.

Geological Setting

The Jianghan Basin is located in the east of Middle Yangtze Plate (Figure 1), The Jianghan Basin constitutes the former Sinian metamorphic basement since the Late Proterozoic, and it further developed the Passive continental margin basin from the Caledonian to Early Indosinian, and the foreland basin from the Late Caledonian to Late Indosinian. It was the structural residual basin as the basin experienced strong extrusion and thrust nappe event caused by Tongbai orogen and Jiuling-Xuefeng orogen in the Yanshanian (during the Middle Jurassic to Cretaceous). The Jianghan Basin was the extensional basin in the Late Yanshanian to Early Himalayan, the rift basin in the Late Cretaceous to Paleocene, and the depression basin in the Neogene to Quaternary.

Present-Day Heat Flow of Jianghan Basin

Present-day geothermal gradients

The geothermal temperature gradient varies with depth due to variation of thermal conductivity, and regionally due to the variations of deep heat flow. The temperature data in this study comprise systematic temperature-depth profile from nine wells and some 365 oil–testing temperature data (Figure 2). However, borehole temperature is usually greatly disturbed during drilling. Only after the temperatures between the borehole fluid and the surrounding rocks are equilibrated, can the temperature field be called steady state. Usually after a period equivalent to 3–10 times the time interval required for drilling, the well and the surrounding rocks can recover fully from thermal perturbations caused by fluid movements. The measured temperature can then be regarded to be the formation temperature (Qiu, et. al., 2007). Therefore, the most important temperature data used to characterize the geothermal field of sedimentary basins are those from systematic steady-state temperature measurements.

Nine boreholes selected for systematic temperature measurements were all drilled at least one year before the temperature measurements were carried out. The successive data acquisition system provided by R. G England company are used to these boreholes temperature measurements, the probe is platinum electrode, the measurement resolving is 0.1°C, time interval of data record is 0.01 m, measurement speed is 4.0‐5.0 m/min. The systematic borehole temperature measurements in the Jianghan Basin were carried out (Figure 2a). The oil–testing temperature data of 18 thermal history modeled wells are also available, which provided by Exploration Department of South Company of Prospecting, SINOPEC. The oil–testing temperature data likely are reliable for they were tested directly from oil reservoirs several days or longer after drilling.

Based on systematic steady state and oil-testing temperature, the geothermal gradient values in 27 wells were calculated. The arithmetic mean thermal gradient from the wells data in the basin is 33.59°C/km, Base on these calculated gradient values and known data we obtained the geothermal gradient distribution (Hu, et. al., 2001). Figure 3 shows the contours of average geothermal gradient in the depth interval of zero to 4,000 m in the Jianghan Basin. The highest thermal gradients up to 39.3°C/km occur in the Qianjiang sag, Xiaoban sag has a higher average thermal gradient of ~ 36°C/km. The lowest thermal gradient of smaller than 20°C /km occurs in the Xingou uplift, west and northwest margins of the basin.

Thermal conductivity

Thermal conductivity is an important parameter in calculating the heat flow, and its variations are related to the mineral composition of the lithological profile and porosity. In our study, 124 core samples were tested to obtain the thermal conductivity (K) values. Each sample was tested three times under the same conditions (water-unsaturated). The thermal conductivity value of a sample was taken as the average value of the three measured values. TCS thermal conductivity instrument which made in Germany was used in measuring with a range is 0.2~25 W/ (m • k), precision is 3%. The measured samples included mudstone, sandstone, limestone, dolomite, anhydrite, with thermal conductivity values of 0.882–10.127 W/ m • k, with a mean of 2.57±0.3 W/ m • k. Mudstone and sandstone showed low values and wide variation, while the dolomite and limestone showed higher values but a relatively narrow range, because the classic rocks have variable mineral compositions and degrees of compaction.

Present-day heat flow

The heat flow distribution is obtained base on the thermal gradient and the corresponding thermal conductivity for a given depth interval. In order to obtain a valid heat flow value, the equilibrium temperature gradient must be obtained in combination with a value for the thermal conductivity of materials through which the temperature gradient is measured (Beck, et. al., 1988). However, it is difficult to obtain the reliable heat flow value from field data. Firstly, the temperature field usually is greatly disturbed during drilling; the temperature measurement is difficult to be carried out in near steady state. Secondly, climate change, underground water, topography, etc. also perturb subsurface temperatures significantly (Kukkonen, et. al., 1998). In our study, some abrupt changes of temperature in Figure 5a may be affected by the groundwater, but they do not affect the regional thermal field of the basin. The heat flow, calculated from systematical steady-state temperature data and thermal conductivities in the corresponding depth intervals, are called measured heat flow. The measured heat flow can help to evaluate the deep thermal state of the crust and upper mantle and is relevant to the deep processes that shaped the tectonothermal structure of the Jianghan Basin.

Nine measured heat flow values were calculated based on the systematic temperature data and measured thermal conductivities. In our studies, some wells have no sample to measure the thermal conductivity. In such a situation, we use the thermal conductivity of corresponding strata to calculate heat flow. Our results show that the heat flow value in the Jianghan Basin ranges from 41.9 to 60.9 mW/m^2. The statistical average for the nine measured heat flow values is 52.3 ± 6.3 mW/m^2. It is lower than the mean terrestrial heat flow of continental areas in China and close to the Sichuan Basin (Wang, et. al., 1986). The heat flow contour map of the basin (Figure 5) was constructed based on the nine measured values and 35 known data of basin center and basin margin. The heat flow is highest in the center of the Yuan'an sag, with heat flow greater than 60 mW/m^2. The second higher heat flow occurs in the Qianjiang, Xiaoban sags and in the southern Jiangliang sag. The lowest heat flow value of smaller than 45 mW/m^2 occurs in the Hanshui sag and Jingshan area.

Most of the oil fields are distributed in the areas of higher heat flows (Figure 4). In recent years, some oil fields have been found in the Yuan'an, Herong, Qianjiang and Xiaoban sags, which are corresponding to the high heat flow distribution area (greater than 50 mW/m^2) in the basin. The heat flow in the northeast of the basin is low, however, few oil fields were found. In the petroliferous basin, the relative low heat flow may deepen the threshold of organic matter maturation.

Thermal History Reconstruction

Thermal indicator

Thermal indicator data in the Jianghan Basin include several hundreds of Ro values from 18 drilling holes. Figure 5 shows the 402 Ro values with depth from the 18 wells studied. All the Ro data were provided by Exploration & Development Research Institute, SINOPEC Jianghan Oil field Company, and generally reveal a moderate to high thermal and maturity level for the sediments in the basin. In addition, Guo et al. (2005) tested some apatite samples from Well DS3 and these fission track data were referred to in our thermal modeling. The samples fission track age is younger than the age of the strata, The AFT length distributes broadening and the AFT length decreases with the increase of burial depth of samples, which indicates all the AFT experienced an annealing to some extent. The several peaks of AFT length distribution in the samples indicate that the region has experienced significant tectonic uplift. The AFT ages become zero in the depth range of ~3,000m, giving the partial annealing zone (PAZ) of AFT up to ~3,000m (Figure 2). Yuan et al. (2010) study the onset of uplifting for the Jianghan Basin after Indosinian event by the combination of analysis of AFT ages with modeling of fission track length distribution, the result show that two episodes of uplifting occurred within 157–97 Ma and 10–0 Ma.

Methods and thermal history modeling result

The thermal history for the Jianghan Basin was reconstructed from the inversion of Ro data based on the kinetic model of Sweeney and Burnham (199) and incorporating the AFT data as constraints on potential time–temperature paths based on the empirical kinetic model of laboratory annealing data in Durango apatite (Laslett, et. al., 1982).

Eighteen wells from various exploration blocks of the Jianghan Oilfield were selected for 1-D thermal modeling using BasinMod 1-D version 5.4 (Platte River Associates, 2003). Stratigraphic data (e.g. well markers) were obtained from the well completion reports of the Exploration and Production Research Institute of the Jianghan Oilfield Company, SINOPEC. Default parameters in the BasinMod 1-D were used for the initial porosity, matrix density, and heat capacity. The bottom ages of each stratum and thermal conductivity data are listed in Figure 2. The paleo-surface temperature is set as 17°C during the geological evolution. Mechanic compaction, coupled with the Falvey and Middleton reciprocal porosity-depth relationship was used to model the burial history, erosion data from documents (Yuan, et. al., 2007; Wang, et. al., 2002).

The reconstructed thermal history derived mainly from Ro data and incorporated with AFT data from the different boreholes. The results show that the basin was in a stable stage before Indosinian movement, the paleo-heat flow was between 55 mW/m^2 and 60 mW/m^2. The heat flow was elevated during the late Indosinian to early Yanshan period and it reached its maximum value of ~68 mW/m^2 in 157Ma, Since the late Himalayan epoch (~43Ma), the Jianghan basin was subjected to a deposition withering period accompanied by a cooling episode (Figure 5).

Conclusions

1. The average geothermal gradient value is 33.59±5.1°C/ km, while the heat flow values range from 45 mW/m^2 to 60.9 mW/m^2 with an average value of 52.3 ± 6.3 mW/m^2 in the Jianghan Basin.
2. Thermal history reconstruction shows that the basin was in a stable stage before Indosinian movement, the paleo-heat flow was between 55 mW/m^2 and 60 mW/m^2. The heat flow was elevated during the late Indosinian to early Yanshan period and it reached its maximum value of ~68 mW/m^2 in 157Ma, Since the late Himalayan epoch (~43Ma), the Jianghan basin was subjected to a deposition withering period accompanied by a cooling episode.

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Website

Platte River Associates Inc., 2003, Basin 1-D manual to accompany the September 2000 release: 2790 Valmont Road, Boulder, Colorado, 80304–2906, USA. Web accessed 12 June 2013. **http://platte.com/**

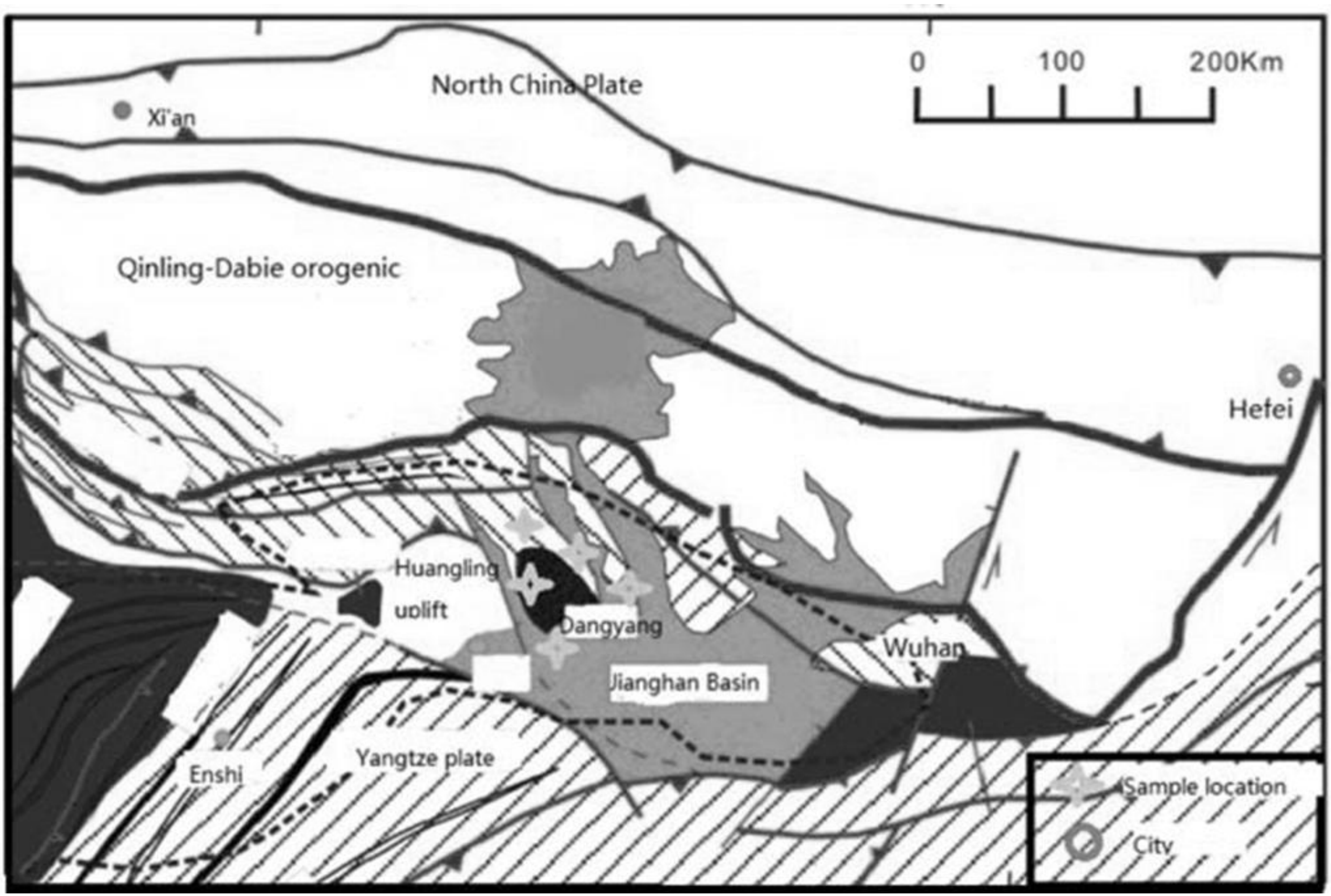

Figure 1. Geology of the Jianghan Basin and sample location.

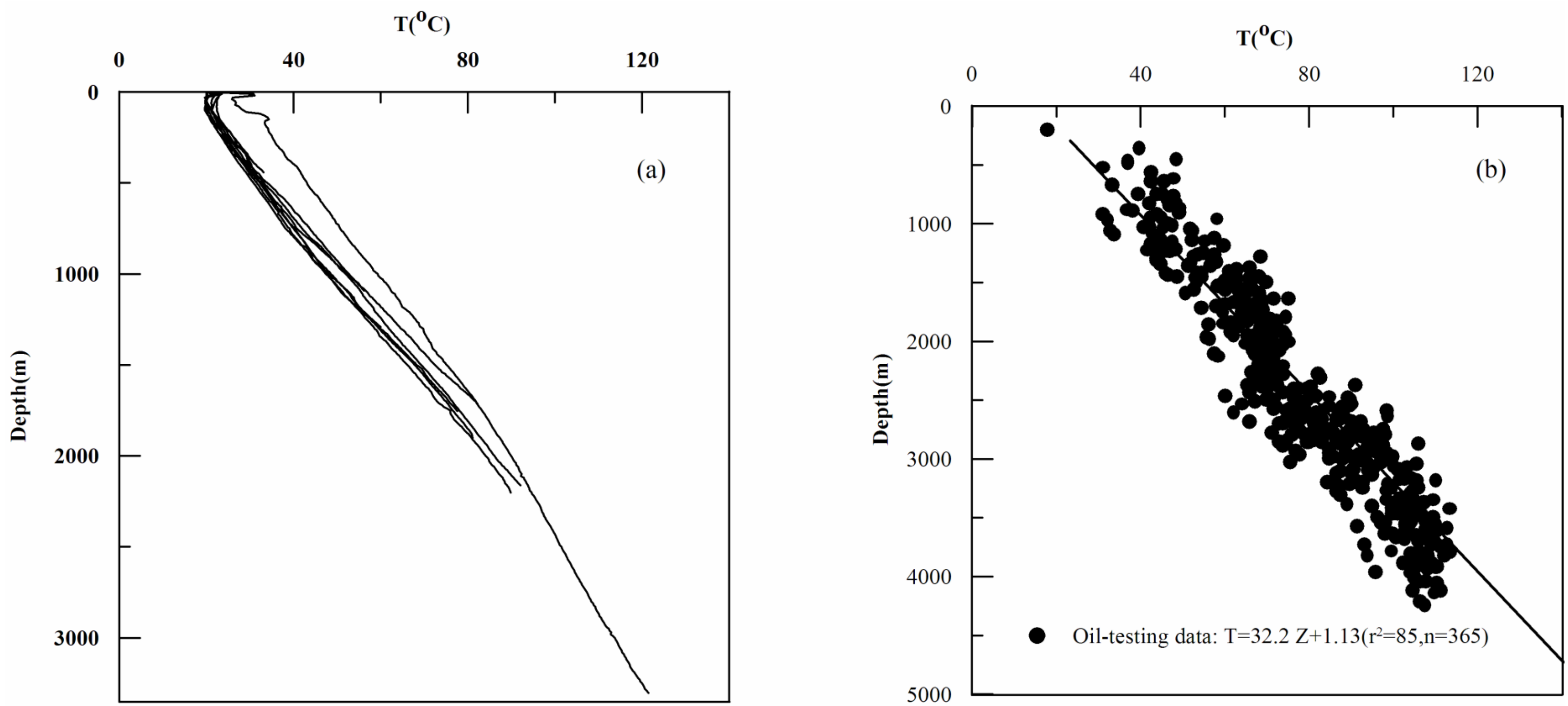

Figure 2. (a) Temperature profiles in wells systematical temperature measurement. (b) Temperature data from oil testing.

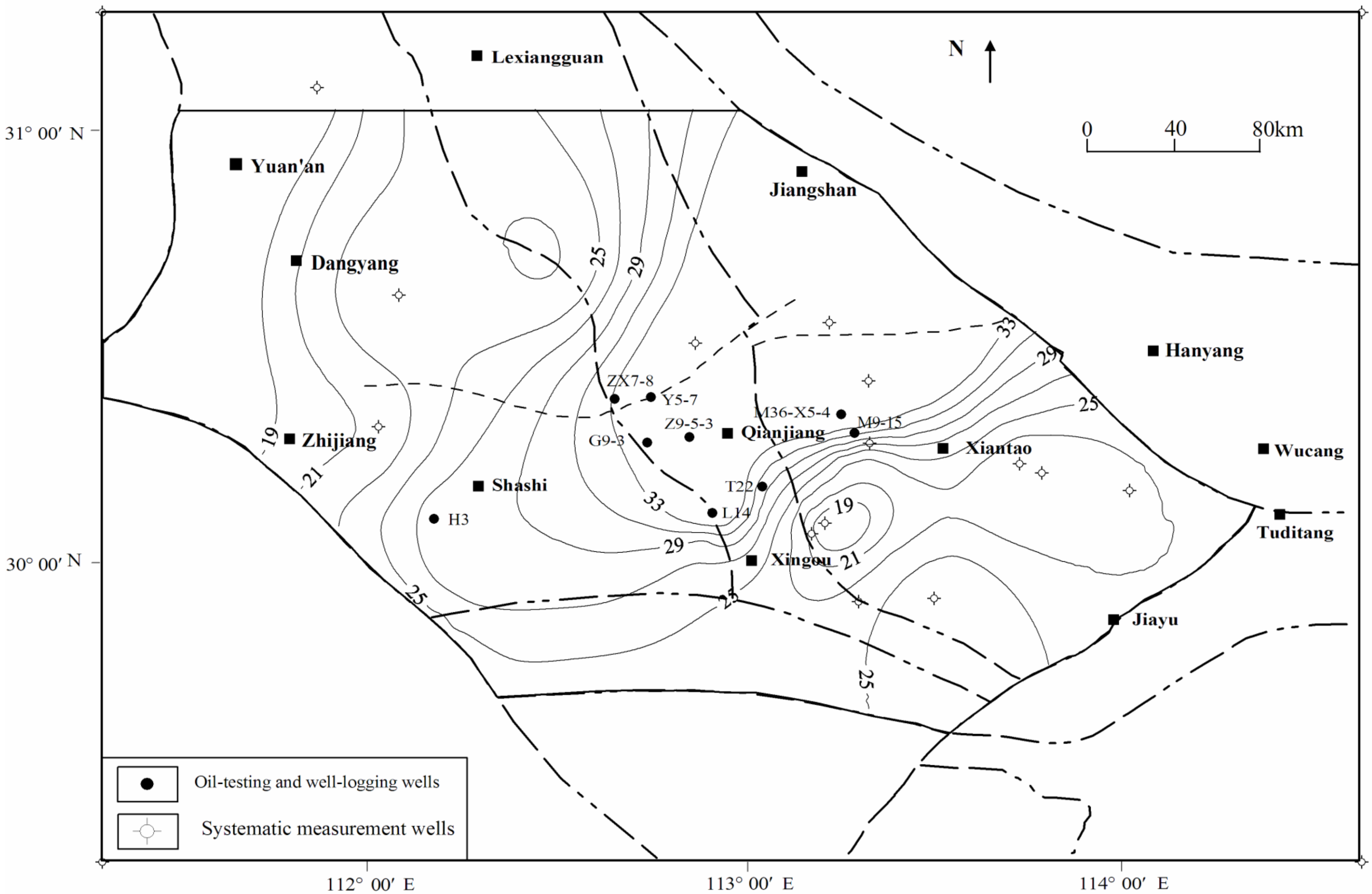

Figure 3. The average geothermal gradient contour over the depth interval of zero to 4,000 m in the Jianghan Basin (°C/km).

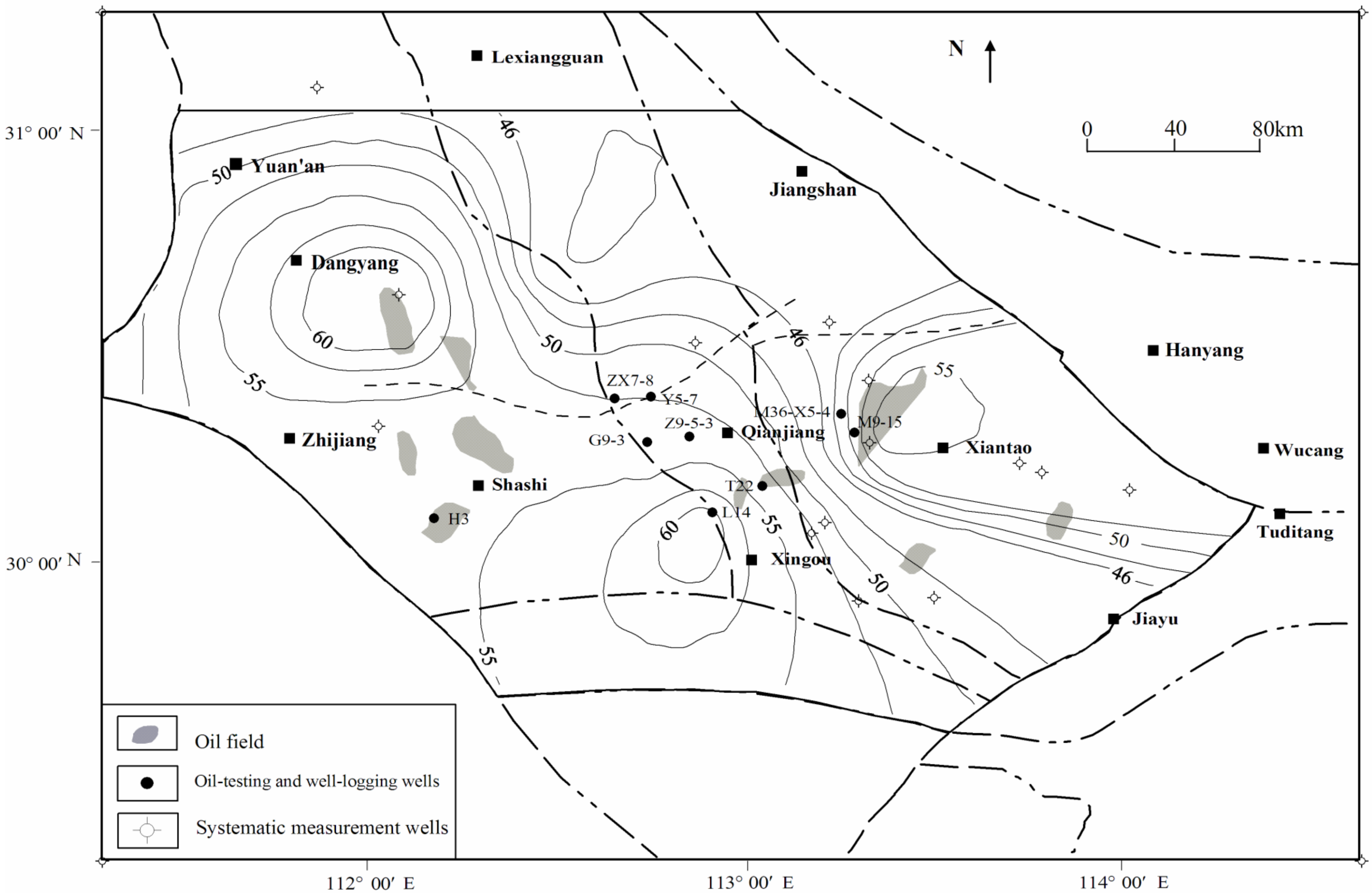

Figure 4. The heat flow distribution in the Jianghan Basin (mw/m^2).

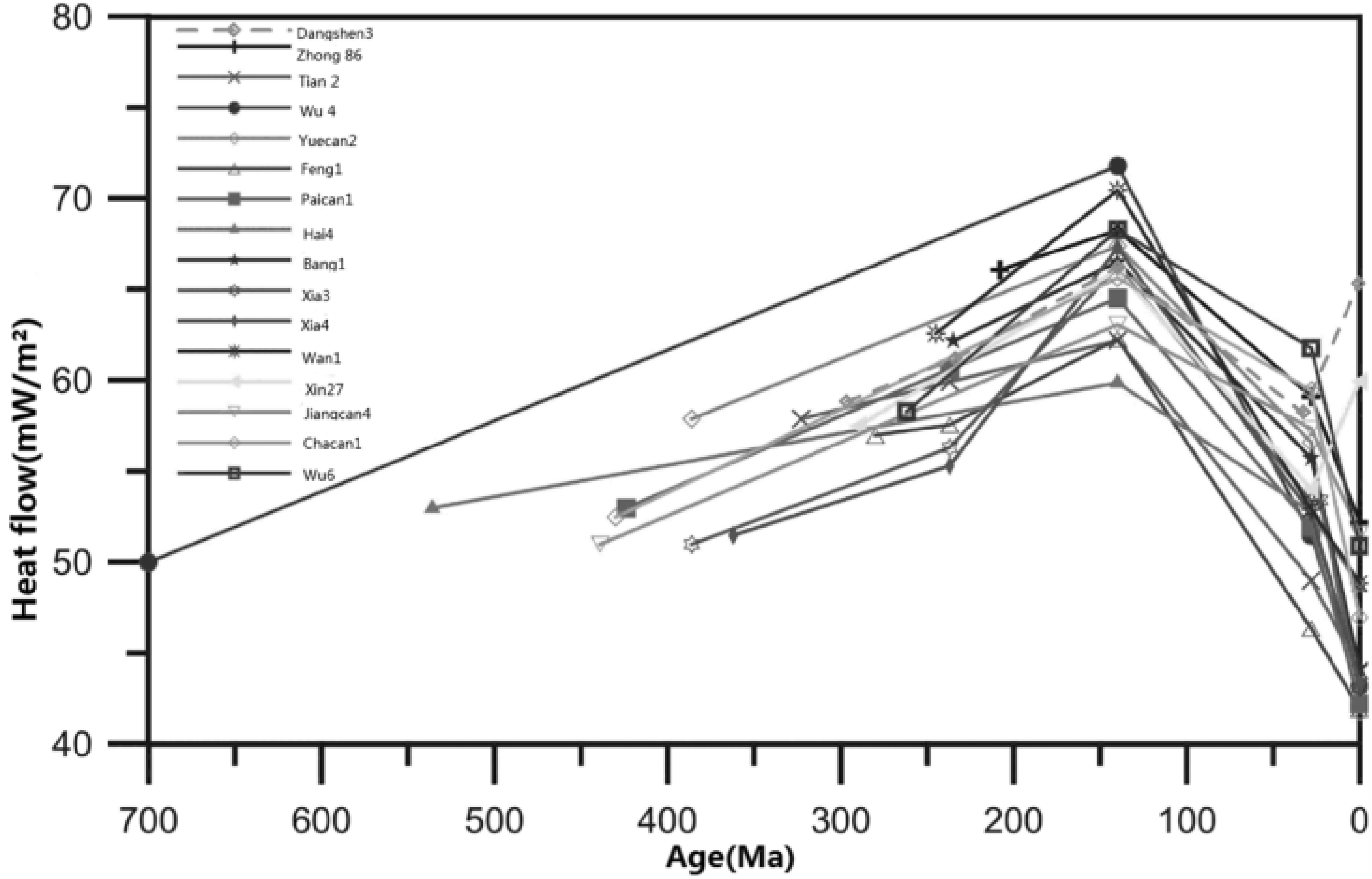

Figure 5. Heat flow history of research boreholes in the Jianghan basin.