Proceedings World Geothermal Congress 2023
Beijing, China, April 17 – 21, 2023

Distribution characteristics of geothermal flow and types and distribution of favorable geothermal resources in Sichuan Basin

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Keywords: the Sichuan Basin; terrestrial heat flow; the type geothermal resources; resource advantage area

ABSTRACT

The terrestrial heat flow characteristics of sedimentary strata in Sichuan Basin include three types, namely, the Caledonian thermal structure controlled by the difference of basement lithology and low lithospheric tension, which is characterized by low terrestrial heat flow with stable thermal state and small difference in plane distribution; The Hercynian thermal structure controlled by basalt eruption and basin extension in Emei igneous province is mainly characterized by the distribution of abnormally high geothermal flow; The Mesozoic-Cenozoic thermal structure formed by the strong orogeny at the basin margin is mainly characterized by the high value distribution of the terrestrial heat flow at the basin margin. Three types of favorable geothermal resources and their distribution are proposed, including deep circulation geothermal resources in the fault zone of Sichuan Basin, geothermal resources in the fracture zone under the background of abnormal high temperature, and early buried geothermal resources.

1. INTRODUCTION

Sedimentary basin type geothermal resources are a kind of hidden geothermal resources, which are characterized by wide distribution area and rich resource potential. The scale of exploration and development of sedimentary basin-type geothermal resources in China is still small, and the utilization of medium-low temperature geothermal resources and deeper buried sedimentary basin-type geothermal resources is very small. The research of sedimentary basin geothermal resources in China is still in the exploration stage in both practice and theory. Sichuan Basin is a multi-cycle tectonic superimposed basin developed on the pre-Sinian basement. It has experienced two stages of early marine cratonic rifting and continental foreland basin evolution. The thickness of marine sedimentary strata is 4100-7000m, and the thickness of continental sedimentary strata is 3500-6000m. It has experienced multi-stage structural uplift, denudation, and subsidence processes. The structural evolution of the basin is complex, the burial depth of strata is large, and the lithologic association is significantly different. Sichuan Basin has a good background of geothermal resources and a variety of geothermal system types, with great potential for exploration and development of geothermal resources. The research on geothermal resources in Sichuan Basin is still in its infancy. The comprehensive and systematic research on geothermal resources has not been carried out in Sichuan Basin, and there is a lack of relevant research on the distribution, evolution, formation mechanism and evaluation of geothermal resources. This paper studies the distribution of geothermal flow, the analysis of main control factors, the type of thermal storage system, and the allocation and distribution of favorable geothermal resources in the Sichuan Basin, a concealed medium-low temperature sedimentary basin, hoping to play a positive role in the exploration and evaluation of geothermal resources in the Sichuan Basin.

Sichuan Basin is located in the west of Yangtze Block. The basin is bounded by the Mian-Lue suture zone in the north and the southern part of the Qinling orogenic belt, the Longmen Mountain in the west and the Songpan-Ganzi Plateau in the east, the Xuefeng Mountain structural belt in the front of the Yunnan-Guizhou-Chuan-Etai fold belt in the southeast, and the Kangdian Ancient Land and the Emeishan Ancient Uplift in the southwest. The basin is a diamond-shaped structure-sedimentary basin with an axial extension of NE, with an area of about 19.1 × 104km^2, the interior of the basin is mainly divided into six structural units: western Sichuan depression zone, northern Sichuan depression zone, central Sichuan uplift zone, eastern Sichuan high and steep structural zone, southeast Sichuan low and steep structural zone and southwest Sichuan gentle structural zone..

Sichuan Basin is a multi-cycle tectonic superimposed basin developed on the basis of the pre-sinian metamorphic rocks. The formation and evolution of the Sichuan Basin can be divided into two stages: the first stage is the cratonic basin stage, where huge thick Sinian-Middle Triassic marine carbonate rocks were deposited on the pre-sinian metamorphic rock basement, which was mainly affected by two large-scale transgressions of the Caledonian and Hercynian movements; The second stage is the basin finalization stage dominated by the evolution of the foreland basin. The Indosinian movement since the late Triassic uplifted the Sichuan basin, and the sea water gradually withdrew from the basin from east to west, ending the history of transgression. After the succession and development of the Yanshan movement and the strong transformation of the Himalayan movement, the orogenic belt around the basin continued to rise, resulting in several major faults, such as the Longmenshan fault in the west and the Huayingshan fault in the east. After the Himalayan movement, the Sichuan basin was shaped into the current basin structure.

2. THERMAL STRUCTURE OF SEDIMENTARY STRATA IN SICHUAN BASIN

2.1 Thermal structure of sedimentary strata in Sichuan Basin

Geothermal reservoirs in sedimentary basins are characterized by multi-layer and areal distribution, and their evolution is closely related to tectonic activity and geological age. The evolution has obvious stages. The average heat generation rate of early carbonate sedimentary strata is less than 0.8 μ W/m^3, the average heat generation rate of continental foreland basin is much higher than that of marine craton basin, and the average heat generation rate is greater than 1 μ W/m^3, the average heat generation rate decreases rapidly with the increase of layer depth. The Sichuan Basin shows the difference between the "cold basin" of the early craton and the "warm basin" of the late foreland basin. The heat generation rate represents the sum of the heat generated by the sedimentary strata, and represents the heat generation capacity of the sedimentary strata themselves. The heat generation capacity of the continental strata is higher than that of the marine strata. However, from the perspective of current formation temperature, the average temperature of Jurassic strata is 74.78 ℃, and the average temperature of Sinian strata is 154.55 ℃. The temperature increases with the increase of burial depth. There is an obvious linear relationship between temperature and burial depth, reflecting that heat conduction is the main heat transfer mode of sedimentary strata in Sichuan Basin. The terrestrial heat flow in Sichuan Basin is generally between 50-80 mW/m^2. The thermal state before the Caledonian movement is relatively stable and the heat flow value is low. The peak value of the average terrestrial heat flow occurred in the Permian-Early-Middle Triassic of Hercynian, and the heat flow continued to decline until now, and gradually entered a relatively stable stage. According to the evolution process of the terrestrial heat flow, the sedimentary strata in Sichuan Basin can be divided into three thermal structures: the Caledonian thermal structure of the early cratonic low terrestrial heat flow.

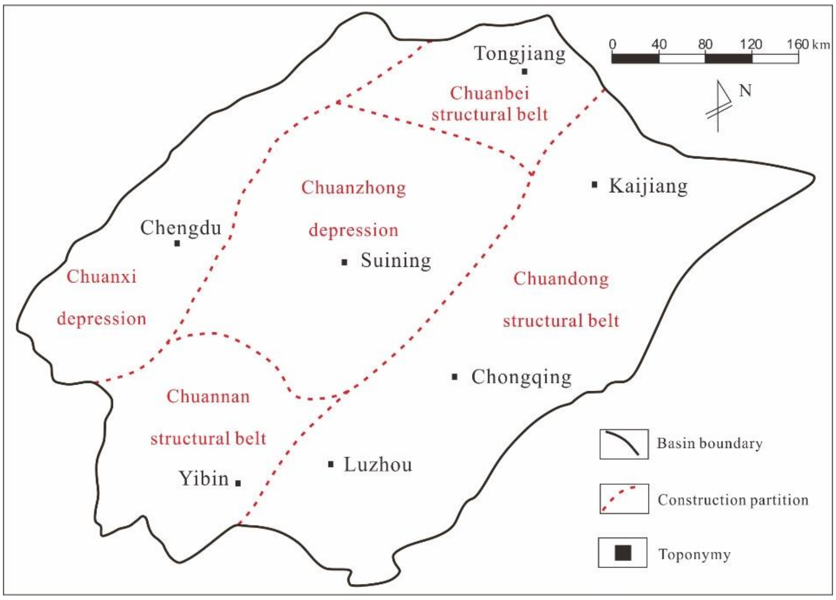

Fig. 1 Tectonic division and distribution of bedrock strata in sichuan basin

2.2 Distribution of terrestrial heat flow in sedimentary strata of sichuan basin

Geothermal flow is a comprehensive thermal parameter that represents the regional geothermal state. The distribution of terrestrial heat flow in the three stages of the Sichuan Basin has obvious differences. In addition to the high value of abnormal earth heat flow formed by volcanic activities in Emei Great Igneous Province, the average value of the whole basin's earth heat flow is 58.21mW/m^2, which is slightly lower than the national average value of the earth heat flow of 63mW/m^2 , which is equivalent to the earth heat flow value of 60W/m^2 in the lower Yangtze platform, and is higher than the earth heat flow value of 52.3mW/m^2 in the Jianghan Basin in the middle Yangtze and 23.4-53.7W/m^2 in the Jungar Basin.The Indian plate drifted northward and collided with the Eurasian plate, and subducted to its lower part, causing the lower edge of the Eurasian plate to be heated and melted, and floated up along the tectonic weak zone of the upper plate, providing geotectonic and thermal source conditions for the formation of colorful geothermal activities in the Tibetan Plateau [6]. Tibet has become the most favorable region for the formation of high-temperature geothermal conditions in China.

The thermal structure of the Caledonian movement in the Sichuan Basin has a small difference in the terrestrial heat flow, and the thermal state is stable. The distribution of the terrestrial heat flow value is mainly distributed between 55-60 mW/m^2. The plane distribution is obviously affected by the ancient rift trough, and the terrestrial heat flow value in the rift trough is low, and the high parts on both sides of the tension trough present high values. During the Caledonian movement, the western part of Sichuan Basin was located in the Mianyang-Changning rift trough, and the northeast part was located in the ancient rift trough of western Hubei, forming a high geothermal flow value area on both sides of the rift trough. The terrestrial heat flow at this stage has the characteristics of "cold basin" with small difference and low terrestrial heat flow on the plane.

During the Hercynian period, the Emei large igneous province was strongly active, and the volcanic activity at this stage was characterized by difference, multiple stages and large eruption scale. In space, it was strong in the west and weak in the east, strong in the south and weak in the north, and early in the west and late in the east, and early in the south and late in the north. The volcanic eruption caused by the strong rise of the mantle plume in the southern part of the Sichuan Basin during the Late Permian-Middle and Late Triassic period uplifted the crust, and the volcanic eruptions in the western and eastern parts of Sichuan during the same period produced continuous tension, which made the geothermal flow in this period reach the peak value of the geothermal flow evolution in the Sichuan Basin. The earth heat flow at this stage is between 75-103 mW/m^2. The high value of the earth heat flow is mainly distributed in the southwest of Sichuan and the north of the eastern Sichuan tectonic belt.

The terrestrial heat flow value of the continental clastic rock sedimentary stage since the Indosinian movement is significantly higher than the thermal structure of the Caledonian movement. The large geothermal flow value of continental clastic rocks is distributed between 40-80 mW/m^2. At this stage, the distribution of terrestrial heat flow in Sichuan Basin is quite different. The distribution of terrestrial heat flow is closely related to the strong orogeny at the edge of Sichuan Basin since the Indosinian movement. The high value of terrestrial heat flow is mainly distributed in the Longmenshan fault zone, Micang-Dabashan fault zone and Huayingshan fault zone.

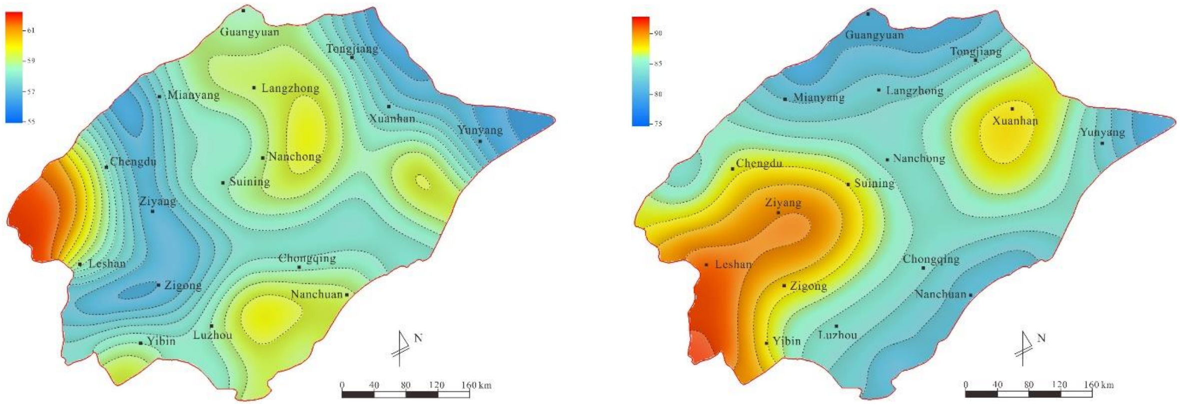

Fig. 2 Distribution of terrestrial heat flow in the sedimentary period of craton basin(The left figure shows the distribution of terrestrial heat flow during the Caledonian period; The right figure shows the distribution of terrestrial heat flow in Hercynian period)

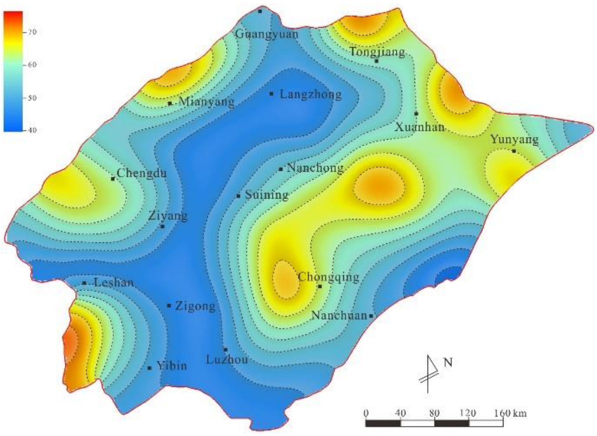

Fig. 3 Distribution of heat flow in the mesozoic and cenozoic zone

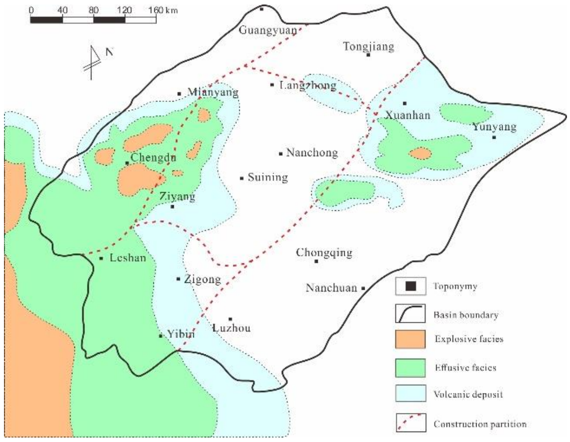

Fig. 4 Distribution of Hercynian volcanic rocks in Sichuan Basin

3 Favorable regional distribution of geothermal resources in sedimentary strata of sichuan basin

According to the distribution of terrestrial heat flow and thermal storage system, three types of favorable geothermal resources in Sichuan Basin are proposed. The first type is the deep circulation geothermal resources in the fault zone, mainly distributed in the structural belt of southwest Sichuan. Under the influence of strong fracture and fault-folding, the deep and large fault deepens the basement, and the deep high-temperature strata are reactivated, forming a good thermal cycle and thermal convection channel. A large amount of surface water supplies cold water to the thermal storage system through the fracture fracture zone and the ancient land contact zone, and forms geothermal resources after circulating heating. The second is the geothermal resources in the fracture zone under the background of abnormal high temperature, mainly distributed in the Huayingshan fault zone and Micang-Daba fault zone in eastern Sichuan. Emei large igneous province provides an abnormally high temperature background, strong tension provides a large number of rock fracture development zones, structural joint zones and karst distribution zones of carbonate rocks, and the Mesozoic-Cenozoic orogeny forms a complex fault system, which is conducive to the runoff, heat exchange and storage of groundwater, and some deep and large faults will communicate with the surface to form volcanic hot springs. The third category is the early buried geothermal resources. Due to the large burial depth, the formation temperature is generally above 140 ℃, forming a high temperature background. The difference in the plane distribution of the earth heat flow in the early thermal storage system of the Sichuan Basin is small, which is manifested as a stratified thermal storage. The thermal storage is formed in a relatively closed environment. The sealing conditions are generally good, but the connection with surface water and atmospheric precipitation is small, and the groundwater circulation is weak, The dominant geothermal resources of this type are mainly concentrated in the relatively high part of the stratigraphic anticline in southwest and southeast Sichuan.

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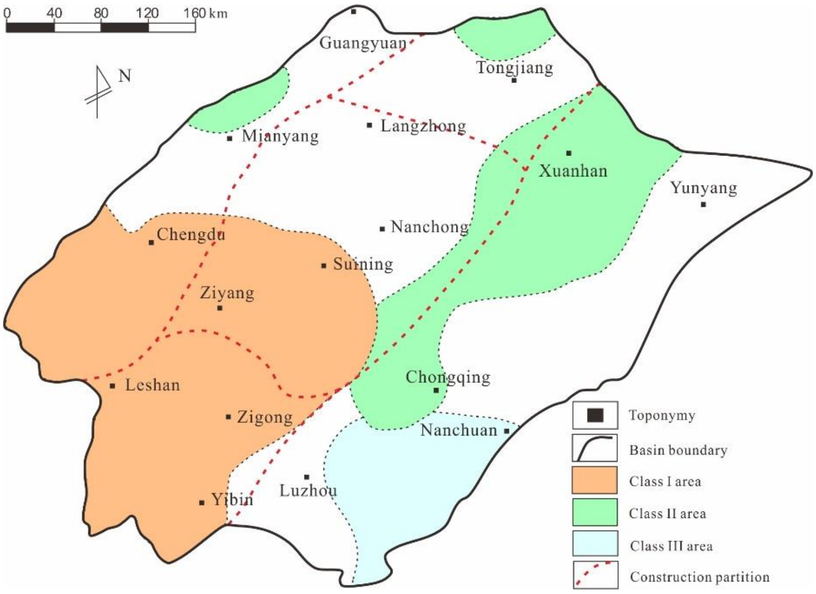

Fig. 5 Classification and evaluation distribution map of sedimentary geothermal resources in Sichuan Basin

4 CONCLUSION

Geothermal reservoirs in sedimentary basins are characterized by multi-layer and areal distribution, and their evolution has obvious stages. According to the spatiotemporal difference of the evolution of the terrestrial heat flow, the Sichuan basin is divided into three thermal stages: the early Caledonian movement stage of the craton basin, the distribution difference of the terrestrial heat flow is small, the thermal state is stable (the average terrestrial heat flow is 58mW/m^2), and has the obvious characteristics of low terrestrial heat flow "cold basin". At the stage of the eruption of the Emei large igneous province in the Hercynian period, the mantle plume upwelling was accompanied by strong basin tension, and the earth heat flow increased sharply, forming the high temperature background of the Sichuan basin (the average earth heat flow was 83 mW/m^2). In the basin-range transition and foreland basin formation stage since the Indosinian, the supersaturated filling of clastic rock deposits, the uplift of basin margin folds and the large-scale denudation in the late stage, the earth heat flow continued to decline and gradually stabilized under the high temperature background of the Hercynian (the average earth heat flow was 62mW/m^2). Favorable geothermal resources in Sichuan Basin include deep circulation geothermal resources in fault zone, fracture zone geothermal resources under abnormal high temperature background and early buried geothermal resources..

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