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# General Characteristics of Geothermal Areas in China

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## ABSTRACT

There are more than 3000 natural geothermal outcrops in China. The two high temperature geothermal areas in China are the Taiwan geothermal zone and Himalayan geothermal zone. Low temperature geothermal areas are widely spread in the vast area of the Chinese mainland. The distribution of hot springs, geothermal wells and heat flow are controlled by geological structure. If the Ordos Basin and Sichuang Basin are considered to be located at the center, geothermal areas in China can be divided into three sections: the eastern, western, and middle geothermal areas.

## 1. THE TYPES OF THE GEOTHERMAL AREAS IN CHINA

### 1.1 Hot Springs and Geothermal Water Areas

There are more than 3000 natural geothermal outcrops in China with the temperatures above 25°C (Limin Wang, 1992). More than 90% of themare low temperature geothermal resources (< 80°C), as illustrated in Figure 1. The distribution of the hot springs shown in the Figure is controlled by geological structures. In early 1926, geologist Prof. Zhang Hongzhao pointed out that the distribution of hot springs is closely linked to the geological structures, just like the connection of the venation. Research on hot spring distribution is significant for revealing the nature of geological tectonics and supervising geothermal exploration.

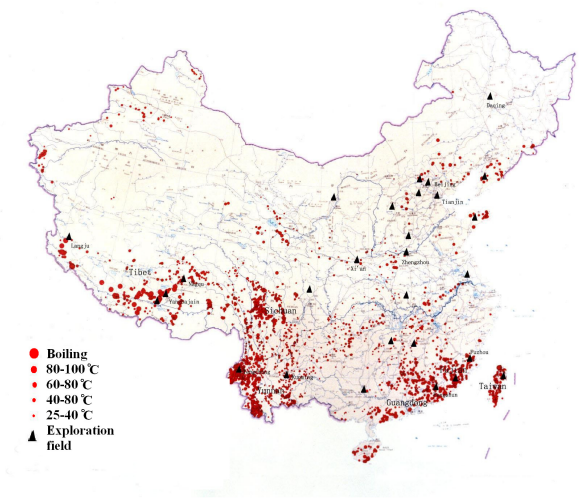


**Figure 1: Distribution map of hot springs in China (Huang , et al.,1983)**

Based on the distribution of various geothermal outcrops around the world, such as volcanoes, hot springs, fumaroles and boiling mud ponds, as well as the distribution of geothermal boreholes and geothermal fields, it is the consensus among geotectonic geologists that geothermal distribution on the surface of the Earth's crust is dominated by crustal tectonic movements and is characterized by linear distribution.

The geothermal areas in China can be divided into high and low temperature areas, with a dividing threshold wellhead temperature of 90°C.

### 1.2 High Temperature Geothermal Areas on the Plate Margin and Intraplate Low Temperature Geothermal Areas

Almost all of high temperature areas are distributed in post-Tertiary active volcanic regions around the world. There are more than 600 volcanoes in China, but few of them are active volcanoes. Therefore, the high temperature geothermal areas are under development in China, except Himalayan (from southern Tibet to western Sichuan and Yunnan) geothermal areas and geothermal areas in Taiwan. High temperature hot springs are densely covered in these regions. The Macao geothermal field in Taiwan is part of the Western Pacific island arc geothermal zone. The geothermal fields from southern Tibet to western Sichuan-Yunnan are an eastern extended part of the Mediterranean-Himalayan sutured geothermal belts, as shown in Figure 2. Therefore, the high temperature geothermal areas in China are located on the plate margin of the modern lithosphere.

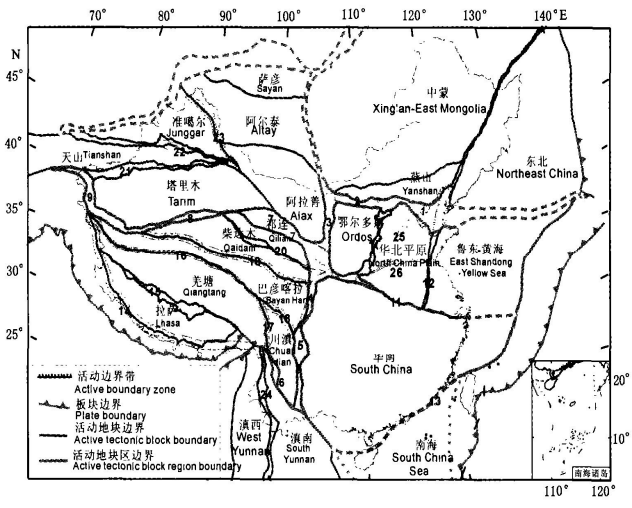


**Figure 2: Distribution of active tectonic blocks and their boundaries (Zhang et al., 2005). 1-26: the serial number of the active blocks. (1: Yan Mountai-Bohai Sea, 2: Yinshan Montain, 3: Helan Mountain, 4: Minshan-Longmen Mountain, 5: -Anning River-Xiaojiang Riber, 6: Honghe River, 7: Haiyuan-Qilian, 8: Aerjin, 9: West Kunlun, 10-Fen-Wei River, 11: Qinling-Dabieshan Mountain, 12: Tanlu, 13: Southeast coast, 14: Himalayan, 15: Karakorum-Jiali, 16: Mani-Yushu, 17: Source region of three rivers(Yellow river, Jinsha river**

**and Lanchang river),18:Xianshui River,19: East Kunlun, 20:Wesat Qinling-Delingha, 21: Sounthern Tianshan,22: Northern Tianshan, 23: Fuyun, 24: Lancang River, 25: Huabei Plain, 26: Anyang-Heze-Linyi)**

Low temperature geothermal areas are distributed in the China plate. Some of them belong to the fold system, especially in the active tectonic zones of the late Cenozoic, where outcrops of hot springs are dense. Others belong to the basins among the fold systems, especially the active blocks between the active structural zones. The underground geothermal water is abundant there. Borehole data shows that the temperatures normally reach 30-50°C at a depth of 1000 m and 55 – 80°C at a depth of 2000 m. Few of them reach 90-100°C. It is obvious that the basin geothermal zones are mainly characterized by low temperature.

### 1.3 Brief characteristics of three types of geothermal zones

Geothermal zones in China can be divided into three types: high temperature geothermal zones in plate margins related to volcanic and recent magmatic activity, hot spring zones in fold systems related to active structural zones within the plate or in the block margins, and geothermal water zones in basins related to the active blocks within the plate.

#### 1.3.1 Plate Marginal High Temperature Zones

High temperature zones in plate margins are located along the junction zone of the plate collision, viz. the Western Pacific island arc geothermal zone and Mediterranean-Himalayan sutured geothermal zone in the global geothermal belt. Because volcanic and magmatic heat sources exist in the shallow part of the earth's crust, local geothermal anomalies of high heat flow can be observed. Hot springs of this type are common on the ground surface, and most have temperatures higher than 90°C. Also, some high temperature geothermal activity can be found, such as hydrothermal explosion, geysers and boiling springs. Usually, the temperature of a geothermal field is higher than the local boiling point, most of them above 200-300°C. Under the influence of volcano-magma activities and the control of local geochemical conditions, the geothermal fluid is mainly acidic water of Cl-Na type and low mineralization. It contains silicic acid, metasilicate, arsenic acid, carbon dioxide, sulfur dioxide, hydrogen sulfide, hydrochloride gas, fluoride prussic acid gas, etc. These geothermal resources are abundant. Its isotopic components are close to precipitation in recharge areas and belong to the modern cycling meteoric water type.

#### 1.3.2 Hot Spring Zones in Fold System

Artesian hot springs are exposed at the low-lying, structurally fractured zone of the uplifted mountain and small type intermountain basin. The flow rate of a single spring usually is 20-200 $m^3$/day, and a few of them can reach more than 1000 $m^3$/day. The meteoric water comes from a primary recharge source and circulates to the deep crust along the tectonic fractures. The heat source comes from the natural geothermal gradient, and only one or two high temperature areas are related to modern volcanic or magmatic residual heat. Geothermal water is mainly fracture-vein water of unstable water quality and flow rate, with temperatures less than 80°C, except for a few geothermal anomaly areas. The temperature increment is not evident along the depth. These hot springs are $HCO_3$-Na type water and have weak alkalinity and lower mineralization, which usually less than 2 g/L. The Cl-Na type water exists along coastal areas, and its TDS values can reach 10 g/L. This water has a high content of $CO_2$ (nearly hundreds of mg/l). Hot springs often contain Sr, Ra, Al, F, B, and $SiO_2$. $H_2SiO_3$, $H_4SiO_4$, $F^-$ and Rn are also typical elements in this kind of hot springs.

#### 1.3.3 Geothermal Water Zones in the Basin

Geothermal water is rich in the inner zone of the large scale artesian basin, where the runoff circulation is low or stagnant. The reservoir lithology contains clastic rock, carbonate rock and crystalline rock. There is a lack of natural outcroppings of springs. However, the boreholes often have super high pressure. The heat source comes from the natural geothermal gradient. The temperature and flow rate are relatively stable. The temperature lies on the geothermal gradient, gradually increasing with depth. It can reach 30-50°C at a depth of 1000 m and 50-90°C at a depth of 2000 m. The flowrates of some wells range from 100-500$m^3$/day, while those of others range from 1000-2000 $m^3$/day individually. Geothermal water in the basin can be classified into 2 types according to the formation conditions: circulation system geothermal water and closed or sealed system geothermal water. The former type is mainly derived from precipitation since the Late Pleistocene. Waters of this type have lower TDS values (most of them are 1-2 g/L, and only few are more than 30g/L). The origin of the latter type is comparatively complicated, and could be related to the ancient meteoric water or ancient sea water on different degrees. It could also be related to water-rock interaction, diagenesis, and other geological processes. The hydro-chemical types of these geothermal waters are mainly Cl-Na and Cl-Na-Ca. Compared to modern meteoric water, the isotopic composition is poor in $^2H$. But the chemical composition is richer in $Ca^{2+}$ than modern sea water. Some of them accompanied by salt mineral deposit have TDS values of more than 50-320 g/L and are rich in $H_2S$ gas, B, Li, K, Rb, Sr, etc. Some of them accompanied by hydrocarbon mineral deposits have TDS values more than 50-150 g/L and are rich in methane, Br and I.

## 2. DISTRIBUTION OF THE GEOTHERMAL AREAS IN CHINA

### 2.1 Trisection Pattern of the Geothermal Areas in China

Chinese geothermal exploration has shown that the hot spring zones in fold systems and the geothermal water zones in the basin are controlled by linear geological tectonics, such as the foreland pediment, basin boundary or inner deep tensional fracture, the fracture zone at the anticline axis, and the boundary of graben structure. All of these are called "heat-controlling structures". Geothermal features usually develop very well at the compound positions or intersection points of two groups of heat-controlling structures. Taking Ordos Basin and Sichuang Basin as the center, the geothermal areas in China can be divided into three sections according the strike of the geothermal zone, as illustrated in Figure 3:

(1) Eastern geothermal area

(2) Middle geothermal area

(3) Western geothermal area

The structural strike in the eastern geothermal area is mainly in the NE and NNE longitudinal direction, followed by the NW and EW transverse direction. In the western area, it is mainly in the NW and EW transverse direction, and secondly in the NE and NNE longitudinal direction. In the middle area, it is mainly in the SN longitudinal direction, and secondly in the EW transverse direction. Thus, the

distribution of geothermal areas in China is said to have a "trisection pattern".

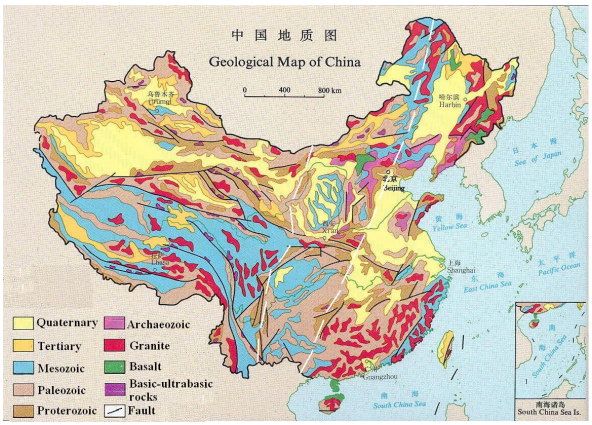


**Figure 3: Geological map of the Chinese mainland (original map downloaded from China Geology Survey). (Two white lines indicate the boundary of trisection pattern of the geothermal areas in China. The eastern line: Big Xinganling Mountain-Taihang Mountain-Wuling Mountain. The western line: Helan Mountain-Longmen Mountain-Tectonic Zone from north to south)**

### 2.2. Heat Flow Distribution of the Boundary and the Inland in China2.2.1 Heat flow distribution of the boundary in China

The average terrestrial heat flow in China is 63±16mW/m$^2$ (Chen et al., 1994), which is similar to the global continental statistic value. The southeast boundary of the Chinese mainland is close to the plate boundary of the Philippine Sea and the Pacific Ocean. Meanwhile, the India plate has intensive effects on southwestern China. Thus, China's southern boundary has a higher heat flow than the northern boundary, as shown in Figure 6.

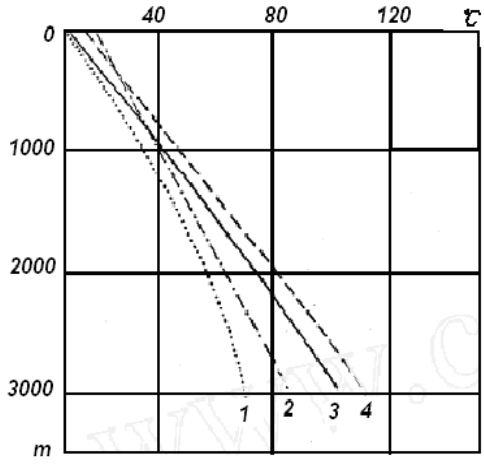


**Figure 4: Relationship between the hot water temperature and depth in the main basins of China:1-Junggar Basin, Tarim Basin and Jiuquan Basin; 2- Sichuan Basin; 3-Qaidam Basin, Ordos Basin; 4-Jianghan Basin, Huabei Basin, Subei Basin and Songliao Basin**

The high heat flow values on the southern boundary are 80-120 mW/M$^2$ in Taiwan Island, 75-80m W/m$^2$ on the southeastern seaboard, 85-118mW/m$^2$ in Tengchong in the Yunnan Province, and 100-319 mW/m$^2$ in southern Tibet (from Bangong Lake to the Shouthern part of the Nujiang Fracture). The low values on the northern boundary are < 40mW/m$^2$ at Xinganling Mountain and < 45mW/m$^2$ in the Juggar Basin.

#### 2.2.2 Trisection Pattern of Heat Flow Distribution in the Inland

Except for the incidence of two high heat flow areas, the heat flow distribution in the inland is similar to the trisection pattern of geothermal areas. Heat flow values decline from east to west. The eastern area has the highest heat flow values. The average value is 62±13mW/m$^2$ in the entire Huabei Mesozoic-Cenozoic fault basin, including the Xialiaohe Basin. The heat flow is 78±14mW/m$^2$ in the basement convex area and 51±8mW /m$^2$ in the basement depression area. The distribution and changes in heat flow can reflect the basement tectonic features and the tectonic pattern of alternate uplifts and depressions. The average value is 52±12mW/m$^2$ in the middle area and 43±8mW/m$^2$ in the western area. Figure 4 shows that the temperature of the hot water decreases from east to west in sedimentation basins, which is consistent with the trisection pattern of the heat flow changes.

### 2.3. Trisection Pattern of the Character of the Geothermal Water

#### 2.3.1 Low Mineralization and Deep Circulation Hot Water in the Eastern Geothermal Area

The large scale Mesozoic-Cenozoic basins developed in the east geothermal area, such as the Huabei Basin (upper Tertiary) and Songliao Basin (upper Cretaceous). All of them are sand-clay inter-beds filled with open deposits of river-lake facies. Because of the huge thickness (hundreds of meters to 2000 m) and the high ratio of sand to clay in the layer, they are nice clastic rock reservoirs.

In Huabei Basin, the fracture and cavity is widely spread and developed in the carbonate rock reservoir beneath the upper Tertiary. In the local extension stress tectonic environment, tensional fractures and a series of graben structures of alternate uplifts and depressions developed in the dual-structure reservoir. Thus, the heat transfer properties of the rock are distinctly different. After the reallocation of the heat flow during the transfer process, the local heat anomaly was formed in the cap-rock of the uplift area, in which the temperature gradient is higher than 4°C/100 m and the heat flow is more than 65 mW/m$^2$. The cap-rock is composed of the shallow reservoir and its super stratum Quaternary sediments. The geothermal water is different from the groundwater in the shallow aquifer and the basin foreland. The latter is modern cycling meteoric water. Geothermal water has a deep cycle and is continuously recharged by ancient meteoric water originating since the latest glacial period. The low mineralization and deep cycle are the main characteristics of the abundant geothermal water in the eastern geothermal area.

#### 2.3.2 The Low Temperature and Sealed-Up Fresh Brine in the Western Geothermal Area

The multi-layer hydrocarbon mine and the low temperature fresh brine developed in the western geothermal area. Based on hydro-geochemical and isotopic research, the origin of the brine is ancient sea water, sediment pore water from diagenesis, and huge amounts of crystallization water that emerged from the transformation of gypsum into anhydrite. The fresh brine is sealed-up hot brine. Chronology studies of the rare gas indicate that the contact time of the brine and its surrounding rock is close to the age of the surrounding rock.

2.3.3 Low Temperature and Highly Concentrated Hot Brine in Middle Geothermal Area

In middle geothermal area, there are several kinds of low temperature and highly concentrated hot brines. For example, the Sichuan Basin formed in a compressional environment; brines are widely distributed in gas fields of the Sichuan Basin from the Sinian period layer to the Cretaceous layer but have different concentrations and geneses. The primary brine is the multi-type low temperature concentrated and highly concentrated hot brines in salt deposits, and the secondary type is low temperature fresh brine and highly concentrated calcium chloride (CaCl) brine in hydrocarbon deposits.

## 3. CONCLUSION

1 There are two high temperature geothermal areas in China: the Taiwan geothermal zone and the Himalayan geothermal zone, which belong to global geothermal belts.

2. Low temperature geothermal areas are widely spread in the vast area of the Chinese mainland. The distributions of hot springs, geothermal wells and heat flow are controlled by geological structures. Strong geothermal activity occurs in the surrounding areas of the high temperature geothermal area.

3. Taking the Ordos Basin and the Sichuan Basin as the center, the geothermal areas in China can be divided into three sections:

(1) Eastern geothermal area: the strike of the geothermal zone is mainly north-east in direction. The local crustal stress field is extensional. The heat flow is higher, and the cycling low temperature hot water exists in eastern geothermal areas.

(2) Western geothermal area: The strike of this geothermal zone is mainly north-west in direction. The local crustal stress field has extrusional nature. The heat flow is lower in most areas, except for the Himalayan high temperature geothermal zone. The low temperature fresh brine in the hydrocarbon mine and the low mineralization water occurs in it.

(3) Middle geothermal area: the strike of this geothermal zone is mainly north-south in direction. The local crustal stress field has extrusional nature. The low temperature and highly concentrated hot brine occurs in it.

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