

Geothermal distribution and their origin in Southwest China

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ABSTRACT

Based on geothermal spring data, including geothermal fluid quantity, spring water temperature and reservoir temperature, geothermal resources in Provinces of Sichuan, Yunnan, Tibet in southwest of China are classified to high-temperature geothermal system according to geological characteristics and their geothermal manifesting. Temperatures of geothermal reservoir for the hot spring in the area are mostly above 150°C, which formed a huge and ideal advantageous region of high-temperature geothermal in southwest China. Origin of the geothermal systems are also concluded that the systems may be formed in three different settings, for instance, related to cooling magma chamber in shallow the Earth's crust, such as the Hot Sea geothermal field in Tengchong of Yunnan Province; related to S-type granite of continent-continent collision, such as Yabajain geothermal field in Tibet; and related to tectono-activity and deep-cycled high heat flow setting, such as Ruili geothermal field in Yunnan Province. According to basic geological and geothermal data, considering resource condition, technology, market demanding, policy support, geothermal is predominated by high-temperature geothermal system in southwest China with a high market demanding that is favorable for power generation and room-heating.

1. INTRODUCTION

China is geologically encircled and affected by three major realms, such as Late Paleozoic Paleo-Asian realm to the north, Tethyan realm to the southwest evolved from Early Paleozoic to Cenozoic, and Circum-Pacific realm to the east respectively spreading from Mesozoic to now. Plate convergence and frequent tectono-thermal events trigger more hydrothermal activities, also called geothermal along the tectonic orogens between different terranes, blocks and cratons, for instance, geothermal in Himalaya orogenic belt, Lhasa-Gangdese terrane in the Tibetan Plateau is resulted from collision between Euro-Asia and India plates, and geothermal in South China orogenic belt and Taiwan orogenic belt in southeast China is formed by convergence between South China and Philippines plates. The purpose of this paper is to discuss geological features and geothermal distribution in southwest China base on previous geological data and our own studies on the area, their origins are concluded tentatively, and also, the utilization suggestions of the geothermal in the areas are proposed.

2. BACKGROUND

Orogenic belts created by continent-continent collision are perhaps the most dominant geologic features of the surface of the Earth (Dewey & Burke 1973). The youngest and arguably most spectacular of all the continent-continent collisional belts on the Earth is the Himalayan-Tibetan orogen, occupying the east-west trending, high-altitude Himalaya and Karakorum ranges in the south and the vast Tibetan plateau to the north. The orogen was largely triggered by the Indo-Asian collision over the past 70–50 Ma, and is part of the greater Himalayan-Alpine system that extends from the Mediterranean Sea in the west to the Sumatra arc of Indonesia in the east over a distance of more than 7000 km. This extraordinarily long and complexly amalgamated belt was developed by the closure of the Tethys oceans between two great land masses since the Paleozoic: Laurasia in the north and Gondwana in the south (Hsü et al. 1995, Sengör & Natal'in 1996, An Yin & T. Mark Harrison 2000).

Southwest China is occupied by Tibetan Plateau and Sanjiang strike-slip fold belt that divided geologically by the NE-trending sinistral strike-slip Altyn Tagh fault zone with Tarim craton to the northwest, by NE-trending Longmenshan thrust belt with Yangtze block to the east, and connected with India plate to the south. The area is proved to have undergone violent tectonic and magmatic events since Jurassic by geologic proofs, like Gangdese magmatic belt, the Yarlung Tsangpo suture belt, also called Yalu-Brahmaputra river suture zone, and western Yunnan Quaternary volcanos. Based on geological studies, Tibetan plateau is divided into several orogens or terranes separated by tectonic suture belts or large-scale strike-slip faults, for instance, Himalaya orogeny, Lhasa terrane, Qiangtang terrane, Songpan-ganzi terrane, eastern Kunlun-Qaidam terrane, Qilian Shan terrane, from south to north. The Himalaya orogen lies between the Indian shield to the south and the Yarlung Tsangpo suture to the north, consisting of three tectonic slices, the Greater (or High), the Lesser and the Tethyan Himalaya northwardly, bounded by three north-dipping Late Cenozoic fault systems: the Main Boundary Thrust, the Main Central Thrust, and the South Tibetan Detachment System.

The Lhasa terrane is bounded by the Yarlung Tsangpo and the Bangong-Nujiang sutures (Chang & Zheng 1973, Allègre et al 1984, Dewey et al 1988, Pierce & Deng 1988). Sedimentary strata in the Lhasa terrane consist of a sequence of Ordovician and Carboniferous to Triassic shallow marine clastic sediments (Yu & Zheng 1979, Wang et al 1983, Yin et al 1988). Basement is believed to be Mesoproterozoic to early Cambrian in age, as represented by the Amdo gneiss along the Golmud-Lhasa road in the northern Lhasa terrane (Xu et al 1985, Harris et al 1988, Dewey et al 1988). The volcanoclastic sediments of Late Carboniferous to Early Permian strata are interpreted to have resulted from back-arc extension (Pierce & Mei 1988, Leeder et al 1988), which are mostly restricted to the northern part of the Lhasa terrane and were deposited after rifting related to the inferred back-arc extension. Late Triassic strata are

mostly restricted in the southeastern Lhasa terrane, and consist of volcanoclastic sediments with abundant basalts, which sequence is interpreted as being a consequence of rifting (Pierce & Mei 1988), possibly related to its separation from India plate. The Jurassic strata exposed in northern the Lhasa terrane are mostly of turbidites interlayered with volcanic flows and tuffs (Yu & Zheng 1979), and are generally folded with locally well-developed slaty cleavage. Cretaceous limestone and marine deposits are widespread in the Lhasa terrane except the locally-distributed Late Cretaceous strata (Yin et al 1988), which has been attributed to the development of a foreland basin during continuing convergence along the suture between the Qiangtang and Lhasa terranes in the Late Cretaceous (Yin et al 1994; Murphy et al 1997). Along its southern margin, the Paleozoic and Mesozoic sequences of the Lhasa terrane are intruded by the dominantly Cretaceous to Tertiary Gangdese batholith belt, being related to north-dipping subduction of a plate carrying India (Chang & Zheng 1973, Allègre et al 1984), while the Jurassic granitoids in northern Lhasa may have been related to southward subduction of the oceanic material between the Lhasa and Qiangtang terranes (Coulon et al 1986). South of the Gangdese batholith is the Cretaceous to early Tertiary Xigaze forearc basin, one of the best-exposed forearc sequences in the world (Durr 1996). This basin was underthrust along the north-dipping Oligo-Miocene Gangdese thrust at the southwestern and southeastern margins of the Lhasa terrane (Yin et al 1994, 1999). The southern boundary of the Xigaze forearc basin is the Yarlung Tsangpo suture, which is strongly modified by the development of a major south-dipping late Tertiary thrust system, the Great Counter Thrust (Heim & Gansser 1939, Yin et al 1999). Besides these, one of the most striking geologic relationships in the Lhasa terrane, particularly well-exposed in its southern part, is that the Late Paleocene-Early Eocene (~65–40 Ma) volcanic sequence (Allègre et al 1984, Coulon et al 1986, Leeder et al 1988) is essentially flat-lying (Yu & Zheng 1979, Wang et al 1983, Liu 1988), implying that the Lhasa terrane has experienced no significant Cenozoic north-south shortening in the upper crust (An Yin & T. Mark Harrison 2000). The complex and frequent tectono-magma thermal events occurred from Mesozoic to Cenozoic in the Lhasa terrane provide favorable setting for formation of the geothermal resources (Fig.1).

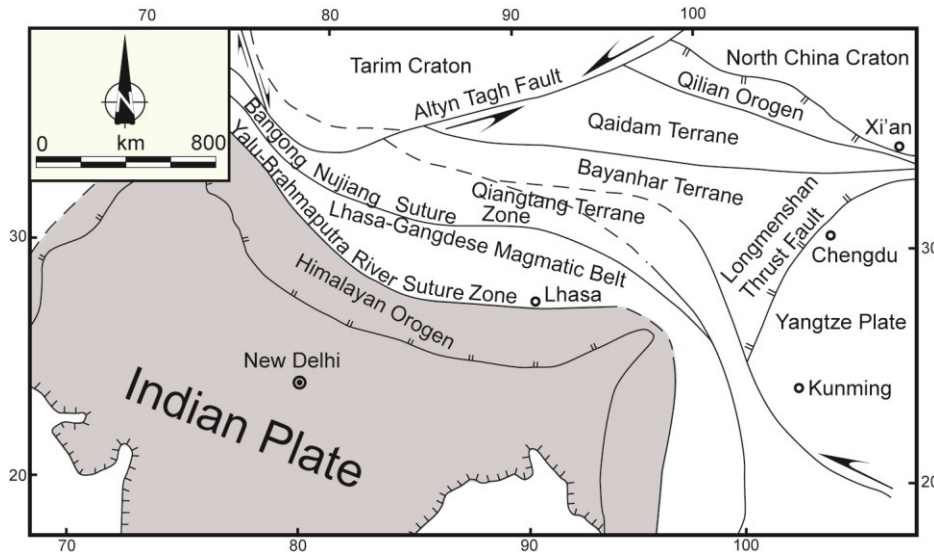


Figure 1: Sketch map of the southwest China

3. GEOTHERMAL FEATURE IN SOUTHWEST CHINA

As Southwest China gestating the most advantageous geological condition for geothermal system in China, the high-quality geothermal resources are distributed in the area majorly, and the high-temperature geothermal systems are studied as a standard geothermal region. Thus we collected hot spring temperatures and their reservoir temperatures of high-temperature geothermal display areas for basal data, from which we try to summarize some regularities and origin.

3.1 Geothermal system distribution

Southwest China consists of Tibet autonomous region, Yunnan Province and Sichuan Province in regionalism of China, and is mostly covered by rifted mountains that develop dramatic middle- to high-temperature geothermal systems. According to international customs rules, geothermal system is divided into types of low-temperature, middle-temperature and high-temperature by temperature of geothermal reservoir, for instance, lower than 90 °C, 90 °C-150 °C, higher than 150 °C respectively. Iceland is an exception, however, that set 150 °C for lower limit of geothermal system resulted from its much higher geothermal system. In order to evaluate temperatures of geothermal reservoirs, average temperature is counted from geothermal thermometer of SiO₂, Na-K, Na-K-Ca and K-Mg, based on the hot spring data collected in the area. To be identified as a high-temperature geothermal system, the temperature of geothermal reservoir should satisfy some conditions. For instance, the arithmetic mean value of the four geothermal thermometers must be higher than 150 °C.

According to accounting results, there are 129 hot springs are classified into high-temperature geothermal system with their average temperature of geothermal reservoir higher than 150 °C in Tibet from 150 °C to 245 °C. Frequency statistics show that, 12 hot springs in Tibet with their temperature of geothermal reservoir higher than 200 °C, such as Qulong, Labulang, Semi, Kawu, Chabu, and so on; 28 hot springs with temperature between 180 °C and 200 °C, like Suoduo, Qiwugongba, Qupu, Yamenzha, Tuohepingcuo, Rujiao, Dajia, Buluoba, and so on; and the other 90 hot springs have the lower temperature between 150 °C and 180 °C. The geothermal fields

developed in Tibet are mostly concentrated in Lhasa block and Tethyan Himalayan terrain, where the Cenozoic volcano-clastic outcropped in a large scale, such as the Linzizong Formation that constitutes the major geothermal reservoir, and Quaternary loosed sand and gravel bed covered on the reservoir is the ideal caprocks.

In Sichuan Province, actually the western area, 38 hydrothermal active areas are identified with their temperature of geothermal reservoir higher than 150°C, 34 areas of which are distributed in Ganzi autonomous state of Zang nationality, and the other 4 areas are in Liangshan autonomous state of Yi nationality. Among the areas, Ganyinguo vaporized spring in Ganzi County is the only hydrothermal active area that has a highest temperature of geothermal reservoir more than 200°C, the temperature between 190°C and 200°C is Qukailongwa vaporized spring, the temperatures between 180°C and 189°C are 5 springs of Chaluo, Zhangke, Huoqu in Xiangcheng of Batang County, the temperatures between 170°C~179°C and 160°C~169°C are 5 and 15 springs respectively, and the temperatures below 160°C are the remaining 11 areas. The geothermal fields are mainly limited in faults and fractures of the area western the Sichuan Province that featured by strong tectonism and less magmatism. The geothermal reservoir is formed in broken strata and fault belt that filled with geothermal liquid. The caprocks in the area are Cenozoic sandstone and siltstone.

In Yunnan Province, mostly the western area, 88 hydrothermal active areas are classified into high-temperature geothermal system with their average temperature of geothermal reservoir higher than 150°C from 150°C to 229°C, among which areas, 4 areas have the higher temperatures above 200°C, such as 229°C for Tengchong Hot Sea, 208°C for Dakongbeng of Yun County, 206°C for Xiaoshuitang of Yunlong Caojian area, and 201°C Hulukou of Changning County. Besides the 4 higher systems, the temperatures between 190°C and 199°C are 4 areas of Mengman of Menghai area, Xingfu of Yun County, Bangnazhang of Longling area, Xiaotanghe of Lancang area with their temperature of 199°C, 195°C, 192°C, 190°C in order, and the temperatures from 180°C to 189°C are 6 areas of Lapihanhe of Luxi area, Shangmangjiao of Lincang area, Laobandeng of Lancang area, Daxing of Fengqing area, Choushui of Lijiang Luxi area, and Malutianba of Yunxian County with their temperatures of 188°C, 188°C, 186°C, 183°C, 183°C, 182°C orderly. For a lower temperature system, the temperatures between 170°C~179°C, 160°C~169°C, 150°C~159°C are 9, 30, 35 springs respectively (Fig.2). The geothermal fields in western Yunnan Province are represented by Tengchong Cenozoic volcanic enrichment region with a high heat flow value that provides heat source for formation of the geothermal fields. Similar with the geothermal fields in Sichuan and Tibet, the reservoirs in Yunnan are also characterized by broken strata and fault belt that filled with geothermal liquid, and the caprocks are Quaternary sandstone and siltstone.

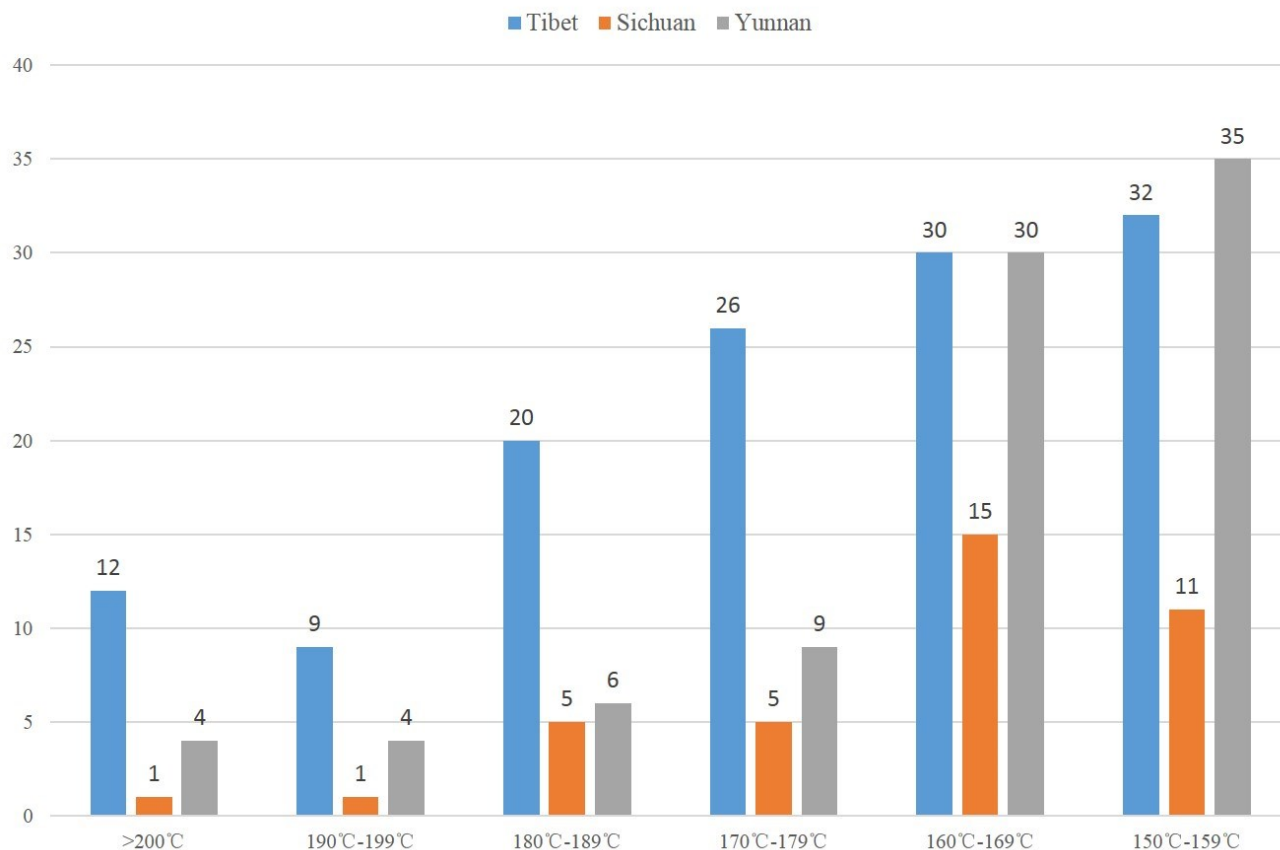


Figure 2: Histogram for temperature frequency distribution of geothermal reservoir in southwest China

According to the distribution of the high-temperature geothermal system, we believe that the geothermal are developed along the major tectono-thermal active belts, such as southern the nearly east-west-trend Lhasa-Gangdese magmatic belt, and also limited in the crossed regional faults that cut each other geologically.

3.2 Origin for the geothermal system

The 255 high-temperature geothermal systems in southwest China are divided into three different origins.

3.2.1 Related to cooling magma chamber in shallow the Earth's crust

This origin type is defined as a geothermal system related to shallow juvenile acid intruded magmatism that appears in a geological setting with high porosity and permeability, including almost all the high-temperature geothermal system used for commercial electricity generation worldwide. The magma chambers are developed in special geological settings, for instance, continental rift, subduction zone, intra-plate hot-spot, oceanic ridge, and transform fault, and consist of acid or mid-acid magma originated from partial-melting of upper mantle that contaminated with material in continental crust when ascending upward. The age of magma intruding should be no older than Pliocene, particularly later than Miocene-Pliocene. In the study area, the Hot Sea geothermal field in Tengchong of Yunnan Province is the only system that can be classified to this type. The geothermal fields in the U.S. like Hawaii and The Geysers belong to intra-plate hot-spot and transform fault respectively. The geothermal fields in Iceland are all formed in a setting of oceanic ridge, which develop the high-quantity geothermal resources in the world.

3.2.2 Related to S-type granite of continent-continent collision

This origin type is much usual in southern Tibet, such as Yabajain geothermal field, which is under the setting of continent-continent collision between India and Euro-Asia plates since Cenozoic, which resulted in partial-melting that triggered magma intrusion of S-type granite. The S-type granite is the main hot source of the system. The Paleogene Linzizong volcanic sequence and its associated youngest phases of the Gangdese plutons form an east-west linear belt along the southern margin of the Lhasa terrane. The Linzizong rocks are dominantly andesites and ignimbrites that have an calc-alkaline geochemical characteristics of an Andean continental margin, representing the plates collision.

3.2.3 Related to tectono-activity and deep-cycled high heat flow setting

This geothermal convection system is formed in an active tectonic belt without magmatic hot source in a fault belt with high heat flow setting through deep-cycled process. Temperature of geothermal reservoir of the system depends on regional background of heat flow and cycled depth of geothermal liquid. The system based on hydrothermal convection may form a high-, middle-, even a low-temperature geothermal system. For instance, Ruili geothermal field is a high-temperature geothermal convection system without Cenozoic magmatic hot source under a geological setting of high heat flow (Fig.3).

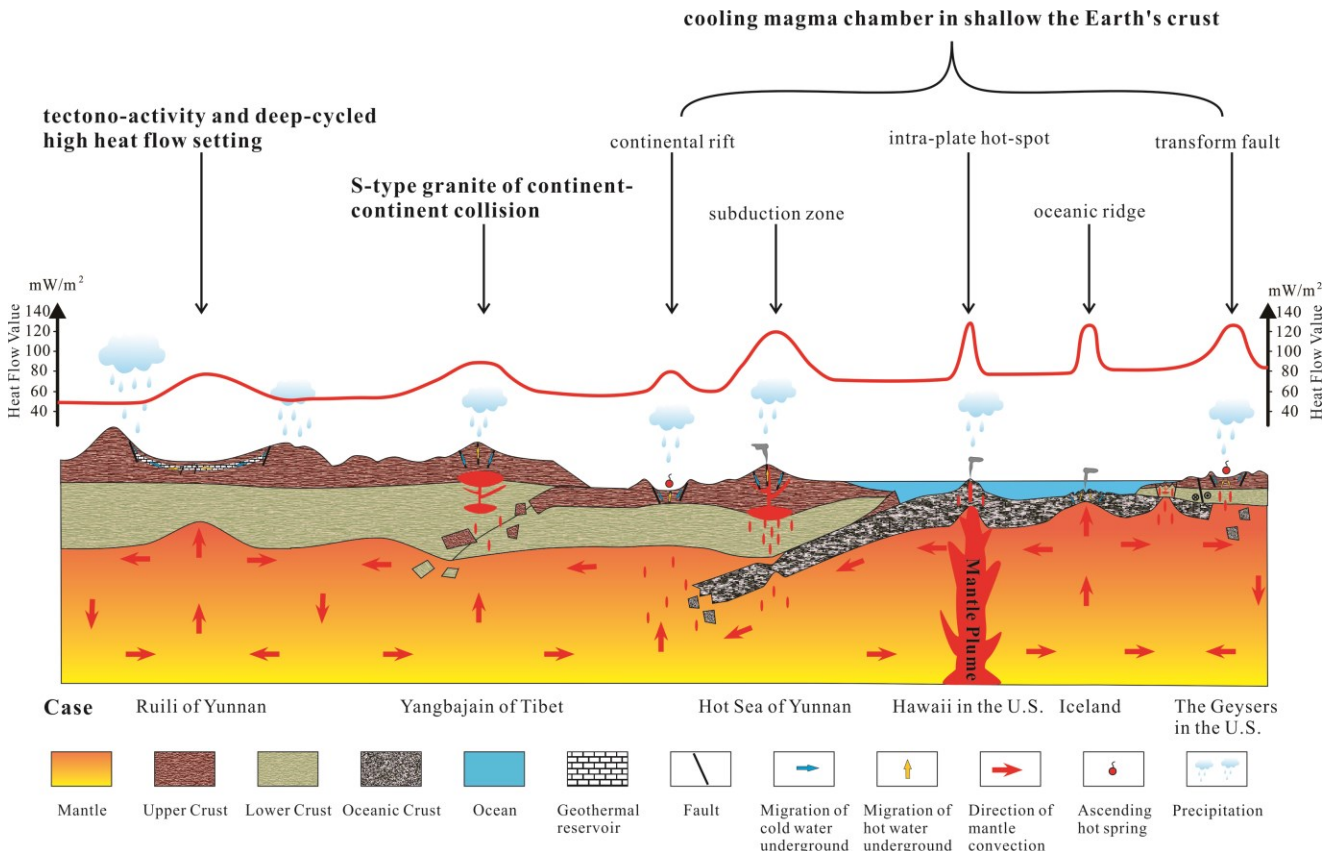


Figure 3: Model of geologic setting for origin of high-temperature geothermal systems in China and other countries**3.3 Geothermal utilization**

Southwest China is an economic less-developed area that with less population and industry, where tourism is prosperous since the Reform and Open of China that stimulates large deficiency in energy consumption, strongly supporting by government and energy companies. And winter is so long and so cold in the area that needs room-heating for a long time. Therefore, according to basic geological and geothermal data, considering resource condition, technology, market demanding, policy support, geothermal is predominated by high-middle temperature in southwest China with a high market demanding that is favorable for geothermal electricity power generation and room-heating commercially.

4. CONCLUSIONS

Some conclusions are drawn as follows.

- (1) Geothermal resources in Provinces of Sichuan, Yunnan, Tibet in southwest of China are classified to high-temperature geothermal system.
- (2) Temperatures of geothermal reservoir for the hot spring in the area are mostly above 150°C, which formed a huge and ideal advantageous region of high-temperature geothermal in southwest China.
- (3) The geothermal systems may be formed in three different settings, for instance, related to cooling magma chamber in shallow the Earth's crust; related to S-type granite of continent-continent collision; and related to tectono-activity and deep-cycled high heat flow setting.
- (4) High-temperature geothermal system in southwest China is favorable for geothermal electricity power generation and room-heating.

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