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CENOZOIC VOLCANISM AND GEOTHERMAL ACTIVITY IN SOUTHWEST CHINA

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ABSTRACT

The westernmost part of southwest China, where many Cenozoic volcanoes and geothermal areas exist, lies, on geological and geophysical evidence, at the margin of two active plates: the Indian and Eurasian plates.

Volcanism, depending on chemical composition and mineral assemblage of the volcanic rocks, can be divided into two distinct belts: one belt starts in Kashmir, runs through southern Tibet, and bends southward to the Tengchonq–Burma arc; the other belt runs from Qiangtang Plateau to the Hengduan Mountains. These belts constitute an outer volcanic belt with calc-alkaline magmas and an inner belt with alkaline magmas, respectively.

Near the outer volcanic belt lies the Himalayan geothermal belt behind the Himalayan arc, and the Tengchong geothermal belt behind the Burma arc. The high-temperature hydrothermal systems of both geothermal belts discharge almost neutral-pH sodium chloride waters. However, the Tibetan waters are rich in boron, whereas the waters in Tengchong have low concentrations of boron. Near the inner volcanic belt, there is the Qiangtang-Hengduan geothermal belt where high-temperature hydrothermal systems with sodium bicarbonate waters occur, and which are not related to volcanism but are associated with convection of heated meteoric water along fault planes.

CENOZOIC VOLCANISM

Distribution

Cenozoic volcanism in Southwestern China occurs in two distinct belts:

Outer volcanic belt

Starting from Kashmir, it runs through Southern Tibet and bends southward into the Tengchong-Burma arc.

In southern Tibet, volcanic rocks belonging to the Cretaceous to Paleogene period erupted on the north slopes of the Gandise Mountains to the north of the Yarlung Zangbo River. The area covered by volcanic rocks is about 90000km^2, extending over some thousand kilometers. The rock types present include rhyolite, dacite, andesite, basalt, ignimbrite and other pyroclastics. The centres are without obvious cones. Most of the rocks belong to the calc-alkali series.

Behind the Burmese arc, the andesitic and basaltic volcanic arc (Pliocene to Pleistocene in age), extends from Tengchong in Western Yunnan to Burma. The volcanic rocks in Tengchong were formed during four eruptive phases: the first one produced andesites and alkaline dolerites in the Pliocene, the second one calc-alkali andesite-dacites of Early Pleistocene age, the third alkali basalts of Middle Pleistocene age, and the youngest one calc-alkali andesite-basalt of Late Pleistocene age (Liao, 1985). The alkalinity of volcanic rocks in Tengchong is higher than that in Burma, as Tengchong is far away from the subduction zone.

Inner volcanic belt

The inner volcanic belt runs from Qiangtang Plateau, which is an unpopulated area in the northern part of the Tibetan Plateau, to the Hengduan Mountains. On the Qiangtang Plateau, volcanic activity was limited and produced some cones which are separated from each other; these are clearly visible in aerial photographs.

The volcanic rocks of the inner belt are highly alkaline .and especially high in potassium. These rocks can be divided into two groups. In the nucleus of the Qiangtang Plateau - Bamao-Qiongzong area, hyperalkaline type of rocks occur, including leucitite, kenyite, shoshinite and trachyte. But to the north, a transitional alkali-line series can be found, including andelatite, two pyroxene andesite and (gebrite) dacite. Their effusive period was from Neogene to present. At Kardaxi No.1 cone in the Kunlun Ranges, a recent eruption occurred on 19 May 1952 (Tong et al., 1981). In eastern Tibet, the volcanism was by fissure extrusions, which occurred in the Neogene. In Western Yunnan, alkaline effusive rocks and some hypabyssal rocks occur at two places. From Jian-chuan to Fengyi along the Red Fault, Cenozoic alkaline rocks include alkali andesite, trachyte, basalt, lamprophyre, granite-porphyry and picrite. Trachytes of Miocene age are dominant. Olivine basalts of Pleistocene age at Puer can be divided into six flow units.

Volcanism and plate tectonics

The above-mentioned Cenozoic volcanic belts, both outer belt and inner belt, are controlled by the activity of the plates.

The Gandise volcanic belt in southern Tibet was formed by subduction of the Indian Plate beneath the Eurasian Plate. During convergence, subducted oceanic crust was partially molten. At a later period of subduction, as subduction rates increased, the dip of the Benioff Zone became steeper, leading to an injection of heat into the crust beneath the Gandise Ranges, and causing partial melting of the crust. Thus a mixed andesitic and dacitic magna was formed. A definite crustal contamination can be assigned to these volcanic rocks, because of the high initial $^{87}Sr/^{86}Sr$ value of 0.708 (Tu Guang-Zhi et al., 1981).

There is a different situation in the Burma arc, where Eocene to Miocene volcanic rocks are sparse.. This implies that there was no subduction, or that subduction was very slow, or that some oceanic crust was subducted; as tectonic emplacement of oceanic crust occurred in the Indo-Burma Ranges (Mitchell, 1975).

Strictly speaking, volcanism in Tengchong, of which the oldest is of Pliocene age, was not caused by subduction, because the convergence between Indian Plate and Eurasian Plate occurred during Oligocene.

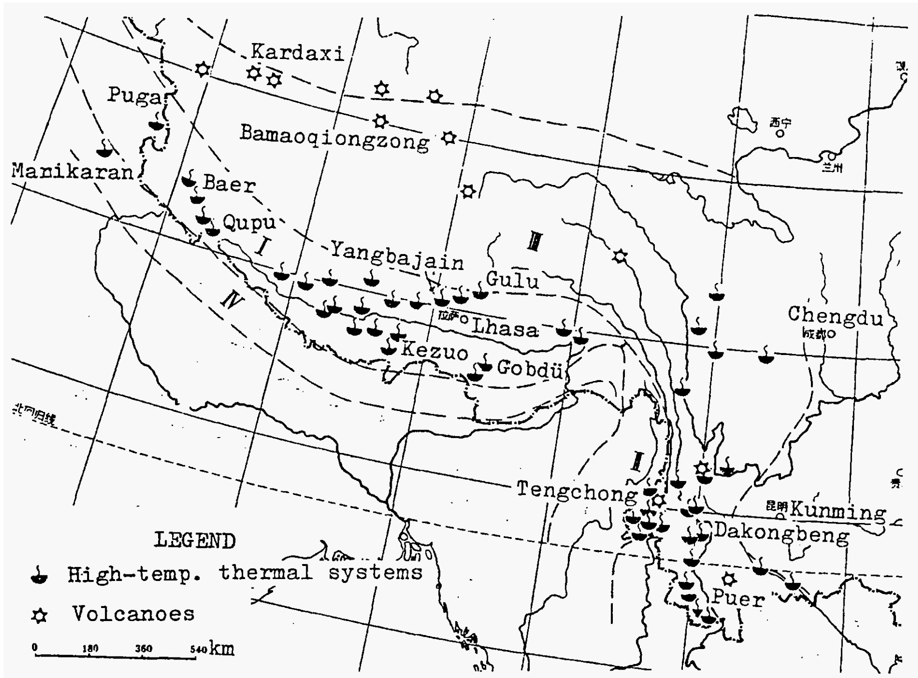

Figure 1:

Sketch map showing the geothermal belts and Neogene–Pleistocene volcanoes of South–western China.

I. Himalayan geo–thermal belt

II. Tengchong geo–thermal belt

III. Qiangtang–Hengduǎn geothernal belt

IV. Himalayan South slope geothermal belt.

After the collision, the crust movement was still very intense, causing the northwestward upthrust of the Indo–Burma Ranges. When Tengchong and the sur–rounding area were in tension, the magma caused by partial melts of upper mantle rocks, rose along faults to form alkaline volcanic rocks. When the area was in compression, the magma suffered contamination by crustal material to form the calc–alkali dacite–andesite with high Sr isotope values (0.706–0.715) (Mu et al., 1985).

In the centre of Qiangtang Plateau, volcanic rocks have high potassium values. The proto magma was not directly associated with the upthrust of the Tibetan crust but originated from partial melting of upper mantle rocks. These erupted along re–activated faults and formed alkali volcanic rocks.

PRESENT HYDROTHERMAL ACTIVITY

Outline of geothermal belts

There are about 1600 thermal areas of different size in southwestern China near both the Outer and the Inner volcanic belts. These thermal areas can be grouped into four geothermal belts where thermal ares have a common geological setting and exhibit similar chemistry (Fig. 1).

1. The Himalayan geothermal belt covers the narrow region, including the north ,of the High Hima–layas and the south of Qiangtang Plateau, where intense Late Mesozoic intermediate to acidic intrusions, Paleogene volcanism and odd Neogene acidic intrusions occur. Geothermal manifest–ations are very impressive. The deep thermal waters from high temperature hydrothermal systems contain sodium chloride and are rich in boric acid.

2. The Tengchong geothermal belt is located between,, the Nujiang Fault and the Indo–Burma Ranges, and is associated with intense Mesozoic intrusions, Paleogene metamorphism, Pliocene to Pleistocene volcanism as well as frequent earthquakes. The thermal manifestations are also impressive. Some high–temperature hydrothermal systems discharge sodium chloride waters but have low concentrations of boron.

3. The Oiangtang–Hengduan geothermal belt covers the Qiangtang Plateau and the Hengduanshan Mountains, where the neotectonic movements were very strong; faulting developed, Pliocene to recent volcanoes occur now and then, and earthquakes are frequent. Most thermal waters contain HCO_3-Na and HCO_3-Ca with low boron.

4. The Himalayan Southern slope geothermal belt occupies the narrow region between the High Himalayas and the Main Boundary Fault crossing India, Nepal, Bhutan, Sikkim and China. In this area, tectonic novement is very strong and shallow earthquakes are close together, but geothermal activities are much weaker. The deeper thermal waters are also of the HCO_3-Na type with low boron.

Types of high temperature water

Using Na–K–Ca geothermometers corrected for Mg and SiO_2 conductive cooling to estimate minimum reservoir temperatures, a large number of high temperature geothermal systems are indicated. More than 30 of them occur in the Himalayan belt, 9 in the Tengchong belt, and 30 in the Qiangtang–Hengduanshan belt.

The chemistry of water found in high–temperature hydrothermal systems in southwestern China can be classified as follows:

(a) Sodium chloride waters issue in the Himalayan belt and the Tengchong belt. These change into HCO_3-Cl-Na waters when hot water is diluted with surface cold water. This type of water has been called volcanic water or magmatic water by D.E. White (1957). According to the content of HBO_2, the sodium chloride waters can be Classified into two subtypes. All Cl–Na waters with high boron only emerge from thermal systems in the Himalayan belt. The content of HBO_2 may amount to 200-500ppm; the highest value found was 1965 ppm. Another subtype is Cl–Na water with low boron, which emerges from some thermal systems in the Tengchong belt. The HBO_2 content here is less than 20 ppm.

(b) HCO_3-Na waters appear mainly in thermal systems in the Qiangtang–Hengduan belt. The content of Ca and Mg increases with decreasing temperature. The Cl-content is very low, being 40–70 ppm in West Sichuan and less than 10 ppm in West Yunnan. The water is also low in HBO_2 (>20 ppm) and in TDS (<1g/ℓ). There is no significant difference in chemical constituents between HOC_3-Na thermal water and groundwater. Of course, the bicarbonate content of these thermal waters is higher than that of cold water.

High-temperature hydrothermal systems and Cenozoic magmatism

HCO_3-Na waters emerge in the Qiangtang–Hengduan belt where the volcanoes are young, i.e. from Miocene to Present. The volcanic rocks belong to an alkali or alkali–lime series with a high potassium content, which implies that the magmatic source is deep in the Upper Mantle. The volcanoes are distributed along major faults. When the magma ascended along the faults, contamination of magma with crustal rocks did not occur and the magma did not intrude into the shallow crust to become the heat source of geothermal systems. Volcanism in the Qiangtang–Hengduanshah belt appears not to be associated with deep geothermal systems. The hot springs discharging HCO_3-Na type water are distributed along major faults, and can be maintained by groundwater circulation along fault planes. High temperatures between 150 and 200°C can occur between *4* and 5 km depth beneath these high–temperature hydrothemal systems, which are associated with boiling springs on the surface; the active area, however, is small. For example, the Dakongbeng thermal area with fumaroles covers only 1–2 km^2.

Most of the high temperature HCO_3-Na waters cccur in West Yunnan. Their distribution is controlled by an anticlinorium of metamorphic **rocks** and granites. Younger metamorphism could produce CO_2 to enrich these waters in HCO_3. Granites with a high heat–generating capacity can produce the heat for the deeply cycling waters.

Thermal Cl–Na water with **low** HE02 emerges from two areas in the Tengchong belt: the Hot Sea Field and the Langpu Hot pool area. Both areas are situated in a circular structure with an area of 200km^2, around and within which there are Pleistocene volcanoes. In the vicinity of the circular structure, earthquakes are very frequent. Althougn numerous micro-earthquakes occur around the circular structure, there is a non–seismic zone inside (Fig. 2). This could imply that this field is related to magmatism. As stated above, the proto magma of the Tengchong volcanoes probably originated from the upper mantle. Under compression, magma did not ascend freely and might have intruded into the shallow crust to form the heat source.

The Cl-Na waters with high boron content only emerge from thermal systems in the Himalayan Geothermal belt. The content of HBO_2 in thermal waters from this belt is about 500 ppm. Outside the belt, the content of HBO_2 decreases. This also applies to systems in India; the content of B is 116–145 ppm in **Puga**, but is only 1 ppm in Manikaran (Gupta, 1974).

We believe that the Cl-Na thermal waters in the Himalayan Belt which are rich in boron are a distinct product caused by the continent–continent collision:.' After the Indian continental crust collided with the Eurasian Continent in the Eocene, the plate convergence continued to create a thick crust and many large thrusts. This produced intrusive granites in South Tibet and which then brought about further heating of the Tibetan crust. These granites contain a high B_2O_3 component of 2200 to *6400* ppm (Gansser, 1964). The hot, boron–bearing, buried granites are probably the heat source for geothermal activity in this belt.

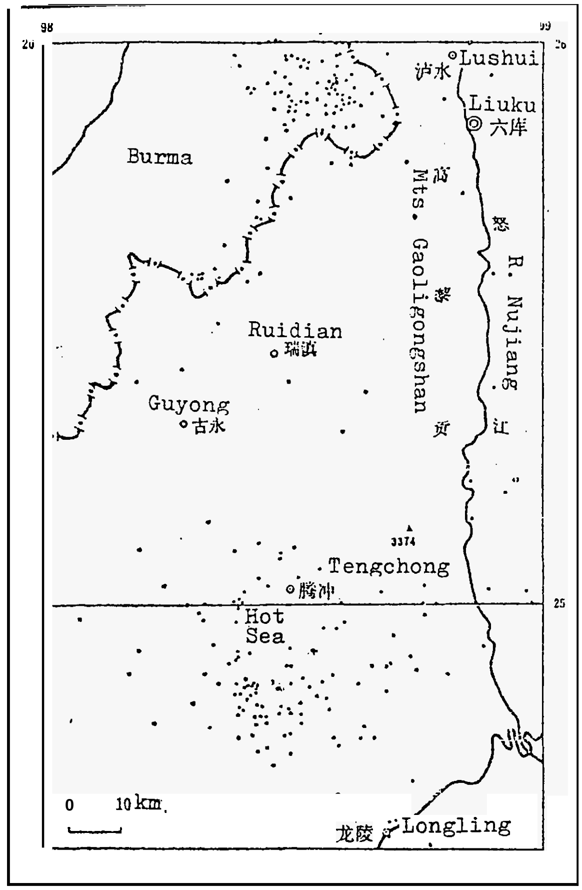

Fig. 2: Sketch map showing the distribution of earthquakes in Tengchong and surrounding region from 1965 to 1975. (Data from Yunnan Seismic Bureau.)

SUMMARY

Cenozoic volcanism and geothermal activities in southwest China are caused by the collision between the Eurasian Plate and the Indian Plate.

Behind the Himalayan arc there is the Himalayan geothermal belt discharging Cl-Na thermal waters rich in boron. The likely heat sources for these systems are hot, boron–bearing, buried Neogene granitic intrusions; geothermal activity appears to be independent of Paleogene volcanism. Behind the Burmese arc there is the Tengchong geothermal belt where Cl-Na waters are issued which are low in boron, and where the heat source of high temperature hydrothermal systems is probably concealed, contaminated, andesitic intrusions.

Far beyond the suture lies the Qiangtang–Hengduan geothermal belt, with Neogene to Present alkali volcanism. The HCO_3-Na waters discharged from high–temperature hydrothermal systems have no magmatic heat, but are associated with convection of heated meteoric water moving along fault planes.

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