Proc. 1lth New Zealand Geothermal Workshop 1989

GEOTHERMAL ACTIVITY AND EARTHQUAKES IN SOUTHWEST CHINA

Liao Zhijie

Department of Geology, Peking University, The Peoples Republic of China

Abstract

This paper investigates the relationship between earthquakes and geothermal activity in southwest China. It consists of four parts. The first part describes the distribution of hot springs and earthquakes. The second discusses the depth of earthquake foci and geothermal reservoirs. Microearthquake activity in geothermal fields is discussed in the third part. Finally, the *link* between earthquakes and geothermal systems is discussed.

Introduction

Both geothermal systems and earthquakes release energy from the crust; hot fluids discharge heat energy while earthquakes release energy as elastic waves. Geothermal activity and earthquakes occur together in tectonically active zones of the earth's crust. These zones are associated with margins of tectonic plates. The relationship between earthquakes and geothermal activity in southwest China is discussed in this paper.

The distribution of hot springs and earthquakes

Hot springs are abundant in Tibet, Yunnan and Sichuan, and form the famous Tibet-Yunnan geothermal belt (Fig. 1). This belt extends from the Pamir Plateau to west Yunnan and includes the Yarlung Zangbo suture and the West Sichuan Plateau. Both the southern and northern boundaries of the geothermal belt are well defined. In the Tibetan Plateau, the southern border is the Himalayas while the northern one can be defined by a set of lakes in the Qiangtang Plateau. East of the West Sichuan Plateau, the hot springs along the northeastern side of Kangding fault suddenly decrease in number. About 1600 hot springs occur in the geothermal belt; there are 650 in Tibet, 600 in West Yunnan, and 350 in West Sichuan. There are geothermal manifestations of all kinds which are impressive and aesthetically attractive.

The distribution of the epicentres of earthquakes is different in each geothermal area. Over the southern slopes of the Himalayas, the epicentres are concentrated in a band. However, on the northern side of the Himalayas, the epicentres are spread over a wide area of the Tibetan Plateau (Fig. 2).

Garg et al. (1981) thought that "the major known hydrothermal systems are associated with seismically active regions with extensive faulting." What is the actual situation? The author has studied the relationship between high temperature hydrothermal systems and geological structure in West Yunnan and found that the hydrothermal systems are distributed along the following anticlinoriums: Tengchong-Gaoligonsan, Cangning-Lamcang and Ailaoshan-Diancangshan which are all metamorphic belts. The Baoshan synclinorium and the Simao-Lanping trough, which are located between the above-mentioned anticlinoriums, only have a small number of intermediate and low temperature hot springs (*Liao* Zhijie et al., 1986) (Fig. 3).

West Sichuan and Yunnan are the southern sectors of the north-south trending Seismic Belt in China. Earthquakes *axe* very frequent in this region. The epicentres of earthquakes (M4) during 1970-1977 appear to be controlled by major intersecting faults which are Oriented in NE and NW directions (Fig. 4). Some large earthquakes, for example, Tonghai (M 7.8), Ganzi (M *7.9)*. Simao (M6.6), Zhaotong (M7.1), Longling (M7.2), occurred at the node of NE and NW earthquake belts and nearby regions (Ding Guoyu et al., 1979). There is no relationship between these earthquake belts and surface structures.

For a comparison between Fig. 3 and Fig. 4, it should be noted that the Hengduan mountains are both seismic and geothermal regions. However, in the earthquake belt from Longling to Ningnang, there are no NE-trending faults.and in the high temperature belt over the Lincang granites, earthquakes are few and their magnitude is low.

The depth of earthquake foci and geothermal reservoirs

The crust is assumed to be a layered structure. The crust in Qinghai-Tibetan Plateau is about 70 km thick and consists of 5 seismic layers (Teng Jiwen et al., 1981) while in Sichuan and Yunnan, four seismic layers were noticed (Kan Rongju et al., 1986). The mineral assemblages, strength, temperature and stress conditions for each layer are different. When the continental crust is subjected to uniform stress, uniform deformation can be expected, but the actual deformation of each layer is uneven. The four layer crust in Sichuan and Yunnan can be divided into a surface layer, an upper layer (generally called the granitic layer), a middle level (its lower part contains a low velocity layer) and a basal layer (i.e. a basaltic layer). Viscous slippage occurs easily in the granitic layer where the seismic wave velocity is about 6 km/sec, and which is the main layer for storing elastic deformation.

The focal depths of earthquakes in Yunnan are generally about 5-20 km according to the earthquake central profile from Luxi to Ninglan (Fig. *5)* (Long Xiaofan et al., 1986). From the records of 660 shocks in Sichuan and Yunnan during 1965-1980, I found that 12.6% of the earthquakes originated at a depth of less than 5 km, nearly 12% occurred at depths between 5-10 km, 40.6% between 10-20 kms, 28.2% between 20-30 kms, 5.8% between 30-40 km, and only 0.1% at depths greater than 40 km. This means that earthquakes occur in the crust above the low velocity layer because the rigid (i.e. brittle) rocks above the plastic layer allow faults to release crustal stress as earthquakes.

Geothermal activity occurs in the upper part of the crust. In the Tibetan-Yunnan geothermal belt, the high-temperature hydrothermal systems were identified using chemical geothermometry. There are about 100 systems in this belt; more than 50 occur in Tibet, more than 30 occur in West Yunnan and about 10 in West Sichuan. The reservoir temperature for these high temperature hydrothermal systems is about 150-260°C; the depth of the reservoir is at least 2 km. If cooling magma were the heat source for these high temperature systems, they could extend to 10 km depth. If there is no magma heat source, the decay of radioactive elements in the granites are presumed to be the heat source which should be within 10 km of the surface. The deep hydrological structure of the terrestrial geothermal systems is controlled by the convective upflow of Cl water evolved by water/rock interaction and less likely by heat transfer from magma from depths between 6 and 10 kms. Therefore, these geothermal regions are present in the surface layer or in the upper part of the granitic layer. That is, the geothermal regions *are* mostly located near the top of the foci shown in Fig. *5.*

Microearthquakes in geothermal fields

According to the above discussion, areas with large seismicity and high temperature geothermal systems appear to be mutually exclusive although 1/4th of the earthquakes occurred within the shallow crust (<10 km) where many geothermal reservoirs are present. Abnormally high levels of seismicity and attenuation of seismic waves in geothermal areas have been noted during seismic surveys since the early days of geophysical prospecting for geothermal energy.

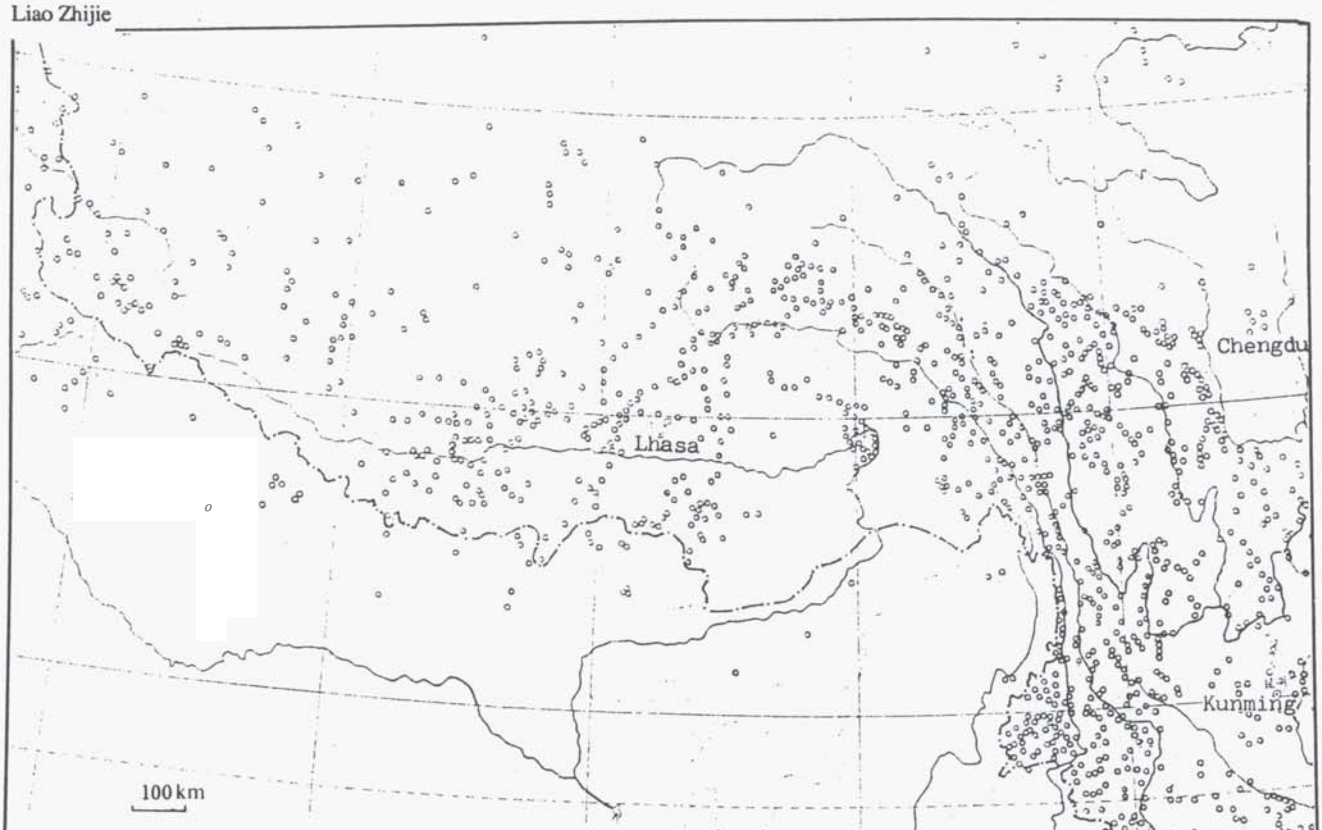

Fig. 1. The distribution of hot springs in Southwest China. Data are taken mainly from the Geothermal Research Section of the Department of Geology, Peking University.

Fig. 2. The distribution of the epicentres in the Himalayas and Tibet.

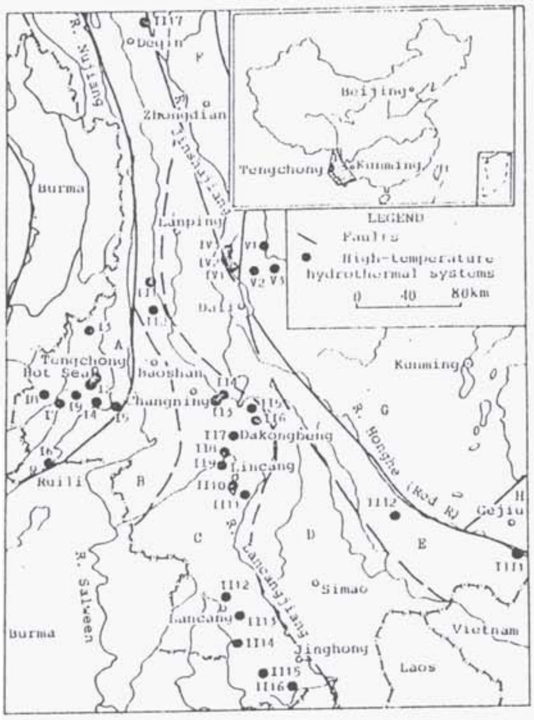

Fig. 3
West
B. Ba
belt;
platfor

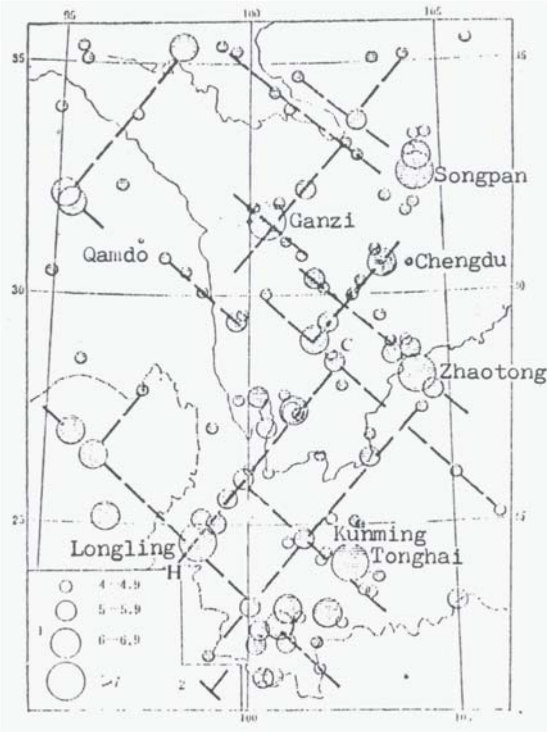

Fig. 4. A net-like distribution of the centres of earthquakes (M≥4) in Sichuan and Yunnan during 1970-1977. 1. centres and magnitude; 2. network (after Ding Guoyu et al., 1979).

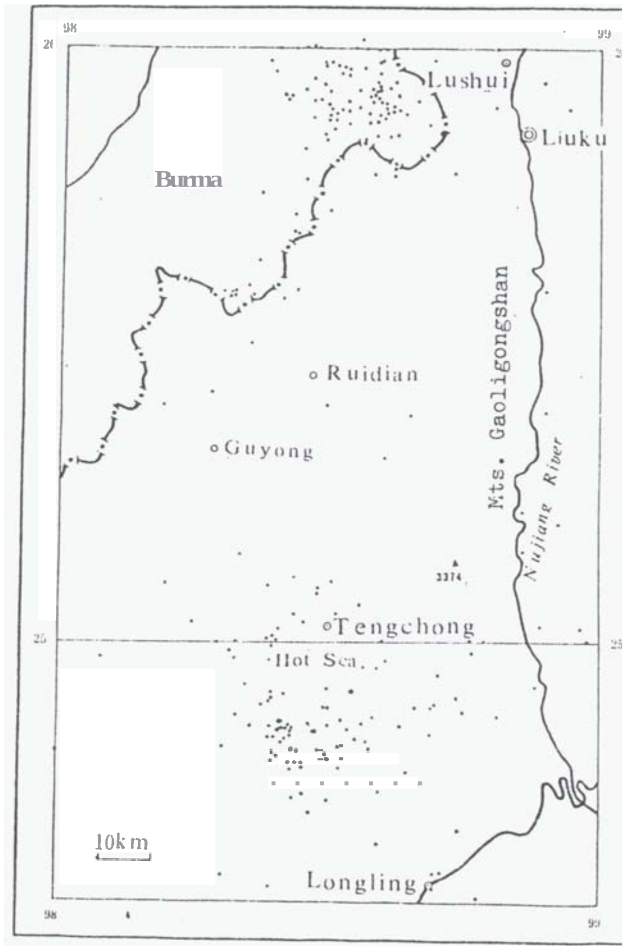

Fig. 6. Sketch map showing the distribution of earthquakes in Tengchong and the surrounding area from 1965 to 1975. The data are taken from Yunnan Seismic Bureau (after Liao Zhijie et al., 1985).

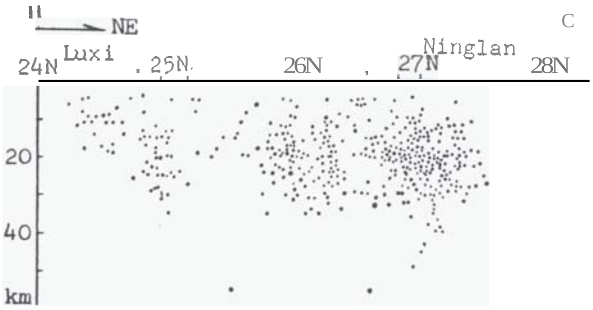

Fig. 5. The section of focal depth from Luxi to Ninglan (after Long Xiaofan et al., 1986).

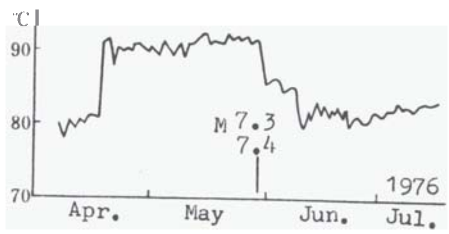

Fig. 7. The graph of the temperature change in Banazhang hot spring during the large Longling earthquakes in 1976 (after Cheng Lide et al., 1979).

Many microearthquakes occur around some high temperature thermal areas; their energy is usually released during earthquake swarms. Following the collection of earthquake data during 1965-1975 in Tengchong and the surrounding area, a map of earthquake centres was compiled and shows that microearthquakes are very common around the Hot Sea thermal field (Fig. 6). Large earthquakes have not occurred within a 200 km^2 radius of the Hot Sea prospect (Liao Zhijie et al., 1985). A similar situation occurs at Tengchong (Liu Baocheng et al., 1986) and at Cerro Rieto (Mexico). Lumb (1981) thought that microearthquakes are generally associated with small movement during fracturing of rocks at depth. Changes within the heat source which cause uneven heat and fluid flow and changes in fluid pressure might trigger earthquakes.

The attenuation of seismic waves often occurs when they pass through a geothermal area. The means of P and S velocities for the granitic layer in Tengchong area are 4.62 km/sec and 2.88 km/sec respectively, which are much less than that of the Asian continent (5.6 and 3.4 km/sec respectively). The lower S wave velocity also means that the shear modulus is small (Liu Baocheng et al., 1986). The observed teleseismic P wave delays associated with geothermal areas occur for the same reason (Lumb, 1981).

The relationship between earthquakes and geothermal activity

The majority of natural earthquakes are caused by sudden movement generally along faults; these are tectonic earthquakes. Large magnitude earthquakes are more difficult to interpret in terms of changes of heat transfer - high temperature fluids do not trigger earthquakes. The most important cause of earthquakes in the shallow crust (<20 km) is the large strike-slip along a fault plane (Brace et al., 1966, 1970).

Many hot springs rise in temperature before an earthquake. For example, the Banazhang hot spring in Longling seismic region (Fig. 7); an earthquake (M=7.6) occurred here in May 1976 - its epicentre was 10 km away. Temperature monitoring of this spring began on 6th April, 1976. Normally, the temperature of the Banazhang spring is about 81°C but on 18th April, it suddenly rose to 91°C and maintained a temperature of 91-93°C until the earthquake occurred. After the two main shocks (M=7.6 on 29th May), the temperature of the hot spring decreased. Following an aftershock (M=6) on 9th June, the temperature of the spring returned to 81°C (Fig. 7) (Chen Lide et al., 1979). Although these temperature changes might reflect changes in the fracture permeability of the reservoir, the effect of heat input by frictional heating cannot be discarded. The focal depths of both main earthquakes in Longling are 21 km and 24 km respectively. When the earthquakes occurred, some energy may have been transformed into heat thus raising the temperature of the rocks in the seismic focal planes.

1. Earthquakes and hot springs release energy in seismically active areas. Large earthquakes and high temperature hydrothermal systems do not occur together in the same region.

2. The large shocks are tectonic earthquakes whose energy can be transformed into some heat energy

3. The cause of microearthquakes in geothermal areas might be related to changes in heat transfer and thermal stresses produced by local changes in temperature.

Note by the Editor: Although papers in the Proceedings of the NZ Geothermal Workshop by non-NZ authors are only edited with respect to the use of english language, an additional reference is made here to the seismicity pattern shown in Fig. 2 of the paper. This pattern can be explained by the concept of "collision tectonics" where the Indian plate acts as an "indenter" upon the Asian plate as was already proposed by Tapponier and Molnar (1976). Heating of the crust by plastic shear deformation will be a maximum in the slipline field. MPH.

References

Brace, W.F. and Byerlee, J.D. 1966. Stick-slip as a mechanism for earthquakes. Science, 153: 990-992.

Brace, W.F. and Byerlee, J.D. 1970. California earthquakes: why only shallow focus? Science 168: 1573-1575.

Chen Lide and Zhao Weicheng. 1979. Longling large earthquakes in 1976. Seism Press.

Ding Guoyu and Li Yongshan. 1979. Seismicity and the recent fracturing pattern of the earths crust in China. Acta Geologica Sinica 53(1): 22-34.

Garg, S.K. and Kassoy D.R. 1981. Convective heat and mass transfer in hydrothermal systems. In L. Rybach and L.J.P. Muffler (eds) Geothermal Systems: Principles and Case Histories. J. Wiley and Sons. pp. 37-76

Kan Rongju and Liu Zhongyang. 1986. A preliminary study on crustal and upper mantle structure in Yunnan. Earthquake research in China. 2(4):50-61

Liao Zhijie, Tong Wei, and Zhang Baoshan. 1985. Cenozoic volcanism and geothermal activity in southwest China. Proc. 7th N.Z. Geothermal Workshop. pp. 197-200.

Liao Zhijie, Tong Wei, Liu Shibin and Zhao Fengsan. 1986. High temperature hydro-systems in west Yunnan province, China. Geothermics 15: 627-631.

Liu Baocheng, Tong Wei, Zhang Baoshan, Zhang Limin, and Zhang Zhaoxing. 1986. Microseismic observation in Tengchong volcano-geothermal region. Acta Geophysics Sinica. 29(6): 556-565.

Long Xiaofan and Wang Shaojin. 1986. A preliminary discussion on distribution characteristics of focal depth and S-P velocity in Yunnan region. J Seismological Research. 9(6): 631-642.

Lumb, J.T. 1981. Prospecting for geothermal resources. In L. Rybach and L.J.P. Muffler (eds) Geothermal Systems: Principles and Case Histories. J. Wiley and Sons. pp 77-108.

Tapponier, P. and Molnar, P. 1976. Slipline field theory and large scale continental tectonics. Nature 264: 319-324.

Teng Jiwen. 1981. Characteristics of the geophysical field and plate tectonics of the Qinghai-Xizang (Tibet) Plateau and its neighbouring regions. In Proceedings of symposium on Qinghai-Xizang (Tibet) Plateau (Beijing, China). pp 633-650.