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Development of the Rehai (Hot Sea) Geothermal Field of Tengchong County, Yunnan Province, China

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ABSTRACT

This paper introduces the general situation of thermal springs in the Yunnan Province of China. The basic characteristics of the Rehai (Hot Sea) geothermal field in Tengchong County in the Baoshsn Prefecture of Western Yunnan is discussed. This is the sole geothermal system related to shallow, young intrusions in the Yunnan Province. The necessity and possibility of exploitation for constructing a geothermal power station in Rehai geothermal field are also discussed.

1. THERMAL SPRINGS IN YUNNAN PROVINCE

There are 815 thermal springs in the Yunnan Province, the highest concentration in China. A map showing the locations of these springs is given in Figure 1. The statistics of thermal springs in each prefecture or autonomous prefecture are given in Table 1.

Samples from 636 thermal springs (about 78% of total) were for analysis. Hydrochemical thermal springs in Yunnan have a dominant chemical composition of HCO_3-Na and HCO_3-CaMg, as shown in Table 2.

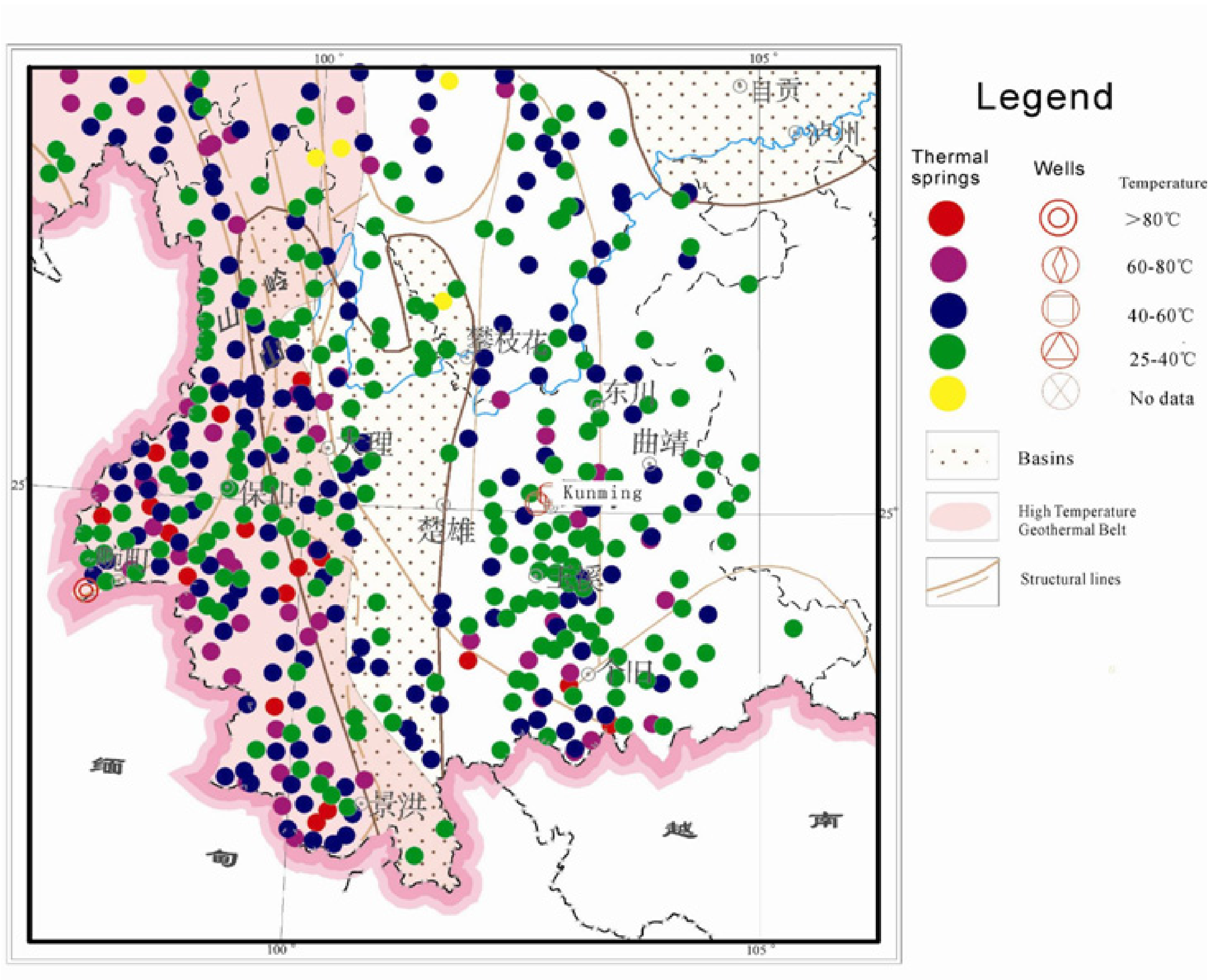

Figure 1: Thermal Springs in Yunan Province

Table 1. Statistics of Thermal Springs in Yunnan

Prefecture	Amount	Boiling Springs*.	Hot Springs**	Warm Springs***	Tepid Springs****
Kunming	37	0	6	8	23
Yuxi	45	0	9	12	24
Chuxiong	11	0	4	4	3
Honghe	77	1	25	18	33
Wenshan	20	0	2	5	13
Qujing	35	0	9	8	18
Dongchuan	8	0	0	1	7
Zaotong	19	0	7	5	7
Diqing	30	0	12	11	7
Nujiang	31	0	13	8	10
Dehong	71	4	37	23	7
Baoshan	140	4	76	35	25
Lijiang	19	0	6	5	8
Dali	81	1	34	25	21
Lincang	54	6	31	9	8
Puer	83	1	34	28	20
Xishuangbanna	54	3	29	16	6
Total	815	20	334	221	240
Percent (%)		2.45	40.98	27.12	29.45

Data From: Tong Wei, 1994; Wu Guangfan, 1999.

* Boiling Spring temperature is boiling point temperature or above boiling point;

** Hot spring temperature is 45°C to less than boiling point temperature;

*** Warm Spring Temperature is less than 35 to 35°C;

**** Tepid spring temperature is less than 35 to 25°C.

Table 2. Hydrochemical Types of thermal springs in Yunnan

Prefecture	Amount	Cl-Na type & derivation	HCO_3-Na type	HCO_3-Ca, HCO_3-Mg, HCO_3-Ca.Mg	HCO_3-Na.Ca HCO_3-Ca.Na	HCO_3-SO_4 type	SO_4-HCO_3 type	SO_4-Na.Ca, SO_4-CaNa
Kuming	16		1	12		1	1	1
Yuxi	26	1	1	20	1	2	1	
Chuxiong	3			3				
Honghe	57		13	28	4	5	1	6
Wenshan	13		4	9				
Qujing	16			14		2		
Dongchuan	12			6		1	4	1
Zhaotong	6			4		1	1	
Diqing	20	1	8	6		1	1	3
Nujiang	26		4	15		1	3	3
Dehong	71		50	13	6		1	1
Baoshan	138	2	71	38	13	13		1
Lijiang	14	1	3	5	1	4		
Dali	77	8	24	11	7	13	7	7
Lincang	44		20	16		7	1	
Puer	55	9	29	9	1	2	3	2
Xishuang Banna	42	3	35		1	3		
Total	636	25	263	209	34	56	24	25

The 263 HCO_3-Na springs and 34 HCO_3-Na.Ca or HCO_3-Ca.Na springs total 297, which make up 46.7% of the total and are discharged in the granite region of West Yunnan. However, there are 207 HCO_3-Ca.Mg springs (including a few HCO_3-Ca and HCO_3-Mg), which account for 33% of the total and are discharged from the carbonate terrain of East Yunnan. With respect to the cause of formation, NaCl water can be divided into two categories: one related to shallow young silicic intrusion, and the other is related to Cl ions stemming from magmatic gas. The deep phreatic water migrated upward and mixed with cold waters to form Cl.HCO_3-Na type or HCO_3.Cl-Na type waters. These waters were generally discharged to the surface. They are imbued with high temperatures and mostly formed boiling springs or fumaroles. These waters were called volcanic water by D.E. White (1975). Another NaCl type water emerged from a saline-gypsiferous horizon. Due to the increase in the content of gypsm in the formation, a corresponding increase in the sulfate ion concentration in the water has occurred. The temperatures of these springs are fairly low.

2. THE REHAI (HOT SEA) GEOTHERMAL FIELD

Convective geothermal systems can be subdivided into the following two categories according to their geological environments and heat transfer regimes (Muffler, 1976):

a) Hydrothermal systems in high porosity/permeability environments related to shallow, young silicic intrusion;
b) Circulation systems in low porosity-fracture permeability environments in areas of high to normal regional heat flow.

According to investigations of thermal springs in Yunnan by the authors since 1973, they all belong to convective geothermal systems, but only one system, the Rehai (Hot Sea), belongs to a category related to shallow, young intrusion. All the remaining faults are related to circulation systems. The evidence and basic characteristics of the Rehai field are as follows (Liao et al., 1998).

1) Tengchong County is a famous Cenozoic Era volcanic region. Volcanism began in the Pliocene or the Miocene and reached its peak by the Lower Pleistocene (1 Ma), and lasted for the whole Pleistocene. Occasional explosions still

occur in the Holocene (about 7 ka±). This long period of volcanism has undoubtedly fueled the geological setting of strong geothermal activity in Tengchong County.

2) The surface manifestations in the Rehai have two very strong phases including boiling springs, fumaroles, steaming grand, etc. The temperature of spring waters range from 42 to 96°C (boiling point temperature at local altitude). The area of the field is about 20 km^2, and the natural heat flow is greater than 180 MW.

3) Hydrothermal alteration in the field is very strong. Kaolinlisation can be found all over the field, and alunitization emerged in the center of field along the Liuhuangtang-Huangguaqing fault with a north-south trend. Sulfur is constantly crystallizing around the orifices of the fumaroles due to the oxidation of H_2S. Intermediate temperature alteration minerals, such as Illite-Semectite mixed layer minerals, occur at the surface of some sites. Montmorillonite and calcite appear at the western boundary of the field. The homogenization temperatures of the quartz inclusions range from 166 to 300°C. The oldest ages of silica sinter or the silica cap are 380 ka, as established by uranium series dating. Most dates are about 23 to 80 ka.

4) The waters discharged from boiling springs are of the Cl-HCO_3-Na type, which could be derived from deep fluid of the NaCl type. Low magnesium content is a distinguishing characteristic of this deep fluid. The HCO_3.Cl-Na type water is discharged from hot or warm springs. It is a mixture of geothermal fluid and cold water. The SO_4-Na type water is found in springs on the steaming ground, and it is heated by steam. Obviously, the Rehai field is a hot-water system rich in chloride, whose subsurface boiling zone is close to the surface. Cation geothermometers indicate reservoir temperatures in the range 230 to 275°C.

5) According to the composition of gases, two types of steam can be distinguished. The first type was sampled in sites with higher elevations. It is rich in CO_2 and H_2S and has a relatively high CH_4/H_2S ratio. It could come directly from the steam cap or condensation zone. The second type has lower CO_2 and H_2S and a lower CH_4/H_2S ratio. It is believed to be released from the thermal water reservoir. It has a $^3He/^4He$ ratio in the range from 3.08 to 4.22 Ra, indicating the presence of mantle-derived helium with of from 27% to 52% in the Rehai.

6) Short microearthquake observations have been performed twice during the 1980-1982 period. The results show that many minor earthquakes and microseismic events occurred around the geothermal field and released energy. The Rehai field is located in a seismic free zone. The mean velocities of P and S waves in this area are only 4.62 and 2.88 km/s, respectively, which is less than that in the Asian granitic layer (5.6km/s and 3.4km/s, respectively). The Poisson's ratio in the Rehai is only 0.18, which is less than the normal value of 0.25 for common elastic solids and approaches the level of The Geysers and Coso geothermal fields.

7) Magnetotelluric (MT) soundings were performed at 11 stations along a 13 km profile, which crosses the Rehai field along the only road in an almost E-W direction perpendicular to the regional tectonic trend. The resistivity profile of a deep section produced by a 2-D inversion algorithm using TM-mode and TE-mode is shown in Figure 2. Anomalously conductive structures with 5-10Ωm exist in the upper crust from 6 to 25 km depths below the thermal area, perhaps representing a partially molten magma chamber that is the heat source for the Rehai geothermal system. The lower resistivity anomaly appears to increase below 25 km depths. The cooling magmatic body came from the upper mantle along some.

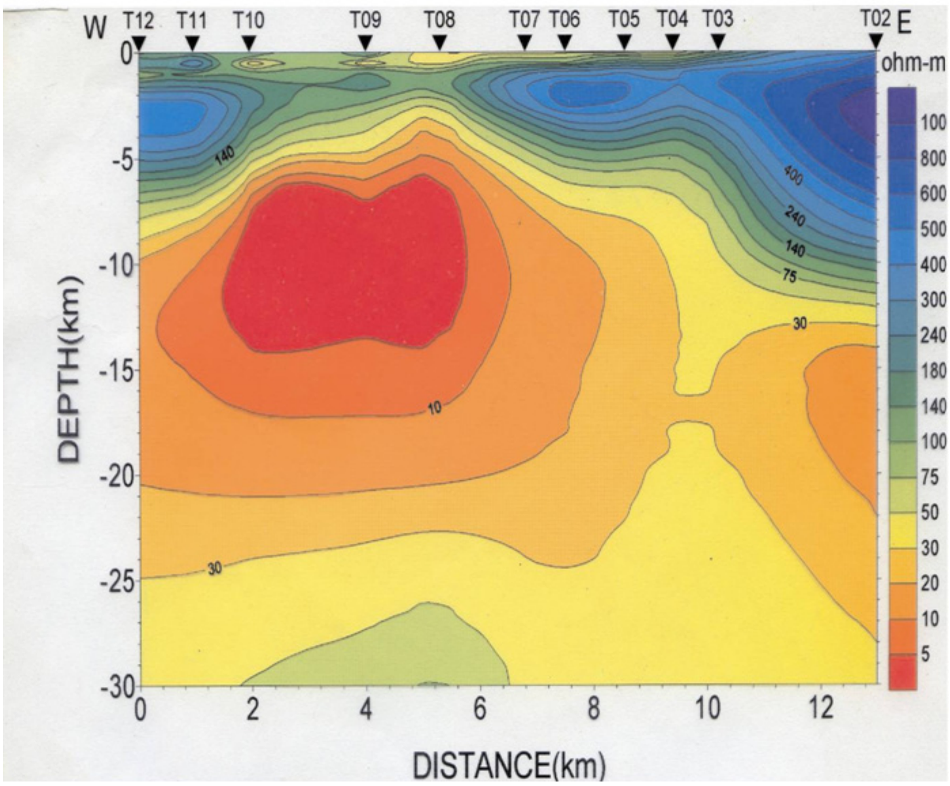

Figure 2: 2-D Resistivity Image of The Tengchong Thermal Field

3. ADVANTAGES AND DISADVANTAGES OF EXPLOITATION OF THE REHAI

The decision to develop a geothermal field depends on necessity and possibility. The Rehai field is rich in geothermal energy that could be used in a geothermal power station to produce secondary energy. As early as 1973, The Geothermal Research Section of the Geology Department of Peking University investigated this field and identified a long-range capacity of 100 MW. The Geothermal Exploration Team of the Bureau of Geology and Mineral Resources of Yunnan submitted the “Report Of Reconnaissance of the Rehai Geothermal Field of Tengchong County of Yunnan Province” in 1987, and reported a reservoir capacity of 2.4234 EJ. Tong Wei and Zhang Mingtao wrote a book called ”Geothermics in Tengchong”, which was published in 1989, and estimated the geothermal resource in Liuhuangtang-Huangguaqing of the Rehai to be 9.21 EJ. Further they concluded that 233.5 MW of electricity could be produced from this reserve for 30 years after Monte Carlo analysis. Since the 1980s, many geothermal experts from different countries have visited the Rehai field and stated that it is entirely possible to construct several 10 MW geothermal power stations similarly to geothermal fields in their countries. The current problem is the necessity to construct a geothermal power station in Tengchong.

A small hydropower station in Tengchong had a great reputation for a long time due to little investment and low risk. But since 1990’s, all mini hydropower stations less than 1 MW (they have been called thunder power station) stopped running. According to the electricity plan of local government, the hydroenergy resource of the Longchuangjiang and Binlangjiang Rivers will be developed. The Longchuangjiang River is a tributary of the Irrawaddy River with theoretical hydroelectric resource of 230 MW, which has been planned for the site of construction of five step power stations. The total installed capacity could be 175 MW. Two step power stations have been completed and sell electric power to Myanmar. The theoretical hydropower reserves of the Longchuanjiang River (a first class tributary of the Irrawaddy River) is 1170 MW. A tentative idea for Yunnan is to construct seven step power stations with a total installed capacity of 601 MW. At one time, 220 kV electrified wire netting stretched from Manwang hydropower station on the Langcangjiang River all the way to Tengchong. Thus, it is greatly beneficial to produce electric power in Tengchong.

Geothermal electricity production in the Rehai field has been abandoned for a long time, but the real start was in 1997. The plan was to drill three exploratory wells construct 10 MW pilot stations to the west of the field at Reshuitang with transportation facilities. The first well was completed to a depth of 1640 m in 1998 at Reshuitang, but it was a great disappointment due to low temperature (143.5°C) and permeability. Owing to the failure of the first well, the plan ended without any positive results. The “Recommendation of Construction Project of Geothermal Power Station in Tengchong” was submitted in 2004 by Yunnan Geothermal Corporation jointly owned by Yunnan Company and Israel’s Ormat Company, and a full proof of experts was given. The new plan was to construct a 48.8 MW geothermal power station with no discharging by making an investment of 99 million US dollar. The plan is subject to ratification by the State Development and Reform Committee.

The hesitancy of exploitation with a geothermal power station in Tengchong is a result of misunderstanding. Many believe geothermal exploitation conflicts with environmental protection due to a perception of geothermal and volcanoes as a peculiar tourist attraction. If a geothermal power station is built in the Rehai field to pump enormous amounts hot water from the reservoir, the geothermal manifestations of the Rehai would be wiped out, causing a loss of the tourist and medical resources. Contrary to this belief, exploitation can be achieved in tandem with environmental protection. If recharging measures are used in a geothermal power station to achieve zero discharge of geothermal fluid, renewable geothermal energy could be produced without damaging the enchantingly beautiful scenery. A new geothermal power station would stand like a giant on the Rehai as a tourist point as well as an energy resource to steadily produce electricity for Tengchong.

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