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Hydrogeochemistry and Direct Use of Hot Springs in Jiangxi Province, SE-China

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ABSTRACT

In Jiangxi Province, SE-China, there are 96 hot springs and more than 30 thermal water bore holes. The hot springs occur in rocks of different types and ages all over the region, and have very close relations with geological structures. Most of them are located along NE- and NNE-trending faults. The intersection locations between NE-trending faults and NW-trending faults are very favorable for the formation of the thermal springs. The temperatures of the thermal waters range from 25℃ to 88℃ at the out flow from boreholes or springs. Based on hydrochemical and isotopic studies, the origin and the subsurface temperature of the hot springs in the area are evaluated. The geothermal direct uses such as aquaculture, agriculture, sanatoriums and spas are discussed.

1. INTRODUCTION

Jiangxi Province is located in the Southeastern China Active Geothermal Zone, and is one of the provinces in which thermal waters distribute most widely in the country. In this Province, 96 hot springs and more than 30 thermal water bore holes have been found. A systematic compilation of hot springs in the region was done by Li (1979), later by Sun (1988).

Faults are well developed in the Province and can be classified into four groups: the nearly EW-trending group, the NE-NEE trending group, the NNE-SN trending group and the NW trending group. These faults control the hot springs distributions and regional geothermal regime (Zhou et al., 1996).

The hydrochemical and isotopic composition of natural waters in geothermal areas has been studied since 1988 (Sun, 1988; Sun et al., 1992, 2006; Li et al., 1993; Sun & Li, 2001). Direct use of hot springs has been paid more and more attention to for the past two decades due to the rapid development of economy in the Province. This paper summaries the hydrogeochemistry and the direct use of the hot springs in the Province.

2. DISTRIBUTIONS OF HOT SPRINGS AND BOREHOLE THERMAL WATERS

Hot springs and thermal waters from boreholes occur in different types of rocks with different ages all over the Province. Usually, geothermal waters distribute along the active faults (Fig.1).

2.1 Temperature

Geothermal waters in Jiangxi Province have temperatures ranging from 25℃ to 88℃ at the outflow from boreholes or springs. Among them, more than 80% are in the range of 25 ℃ to 60 ℃ (Table 1).

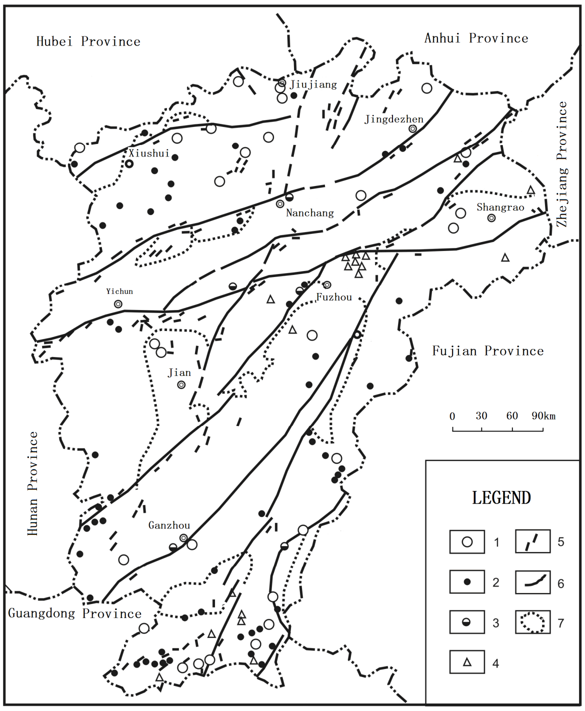

Figure 1: The distribution of geothermal waters in Jiangxi Province (1-epicenter; 2-hot spring; 3-thermal water bore hole; 4-meozoic crater; 5-intrusive rock; 6-active fault; 7-red basin.)

Table 1: Temperature of geothermal waters in Jiangxi Province

Temp. /℃	25-40	40-60	60-88	>80
Numbers of thermal waters	66	36	13	3
%	56	30.5	11	2.5

2.2 Rate of Discharge

The outflow of hot springs and borehole thermal waters in the Province ranges from lower than 1 L/s to higher than 30L/s. Around 80% of them is in the range of 1L/s to 3L/s.

3. HYDROGEOCHEMISTRY OF GEOTHERMAL WATERS

3.1 Sampling and Analysis

Samples were taken from cold springs, wells, hot springs and surface water in the geothermal areas of the Province. Field parameters were measured for data supporting such as pH value, SiO_2 concentration and temperature.

The chemical analyses were mainly conducted by chemical methods and partly by the 4500i type Ion Chromatography. The oxygen and hydrogen isotopic composition of the waters was determined by Mat-253 mass spectrometer, and the tritium concentration for the samples was determined using LSC_LBI type low background liquid scintillation counter.

3.2 Water Chemistry and Isotopes

Three areas in which hot springs are very typical in terms of hydrochemistry for the province are selected for the study. The first is the Lushan Hot Spring Area in the north, the second is Maanping-Linchuan Hot Spring Area in the central, and the third is the Hengjing Hot Spring Area in the south of the Province.

3.2.1 The Lushan Hot Spring Area

The temperatures of thermal waters in the Lushan Hot Spring Area range from 65℃ to 71℃. The water chemistry of natural waters in the area is given in Table 2. It can be seen from Table 2 that the hydrochemical types are HCO_3-Na for thermal waters and HCO_3-Na, HCO_3-Ca-Na-Ma, Cl-SO_4-HCO_3, HCO_3-Ca and SO_4-Ca for cold groundwaters. The thermal waters are characterized by low TDS, alkaline to neutral pH values. The silica and fluorine concentrations of the thermal water are much higher than those of local cold groundwaters, which mainly depend upon the circulation distance and the water temperatures.

The δ D and δ ^{18}O values of the thermal waters range from -49.6‰ to -52.9‰ , and from -7.98‰ to -8.06‰ (SMOW) respectively. The ^{3}H values of the thermal waters are around 1TU, which demonstrates that the thermal water was recharged several tens of years ago. Based on the local meteoric water line of the Lushan area δ D=7.16δ ^{18}O +8.88 (Sun & Li, 2001), the stable isotopic data points are plotted in Figure 2 which indicates that the thermal water is of meteoric origin.

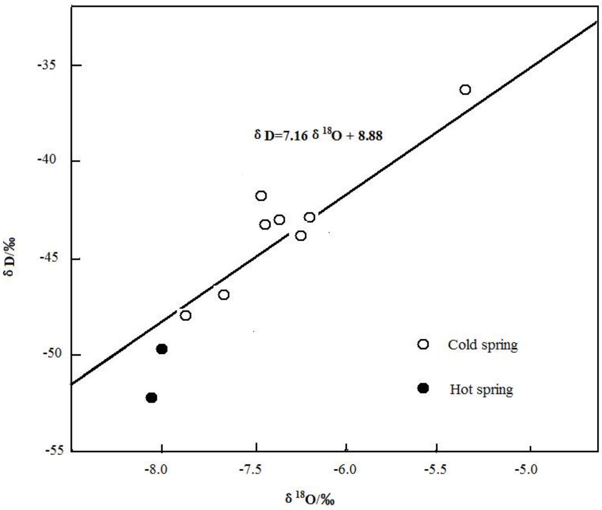

Figure 2: The δ D and δ 18O relations of natural waters in the Lushan Hot Spring Area.

Using the silica geothermometer (Fournier, 1973), the subsurface temperatures are estimated to be from 110℃ to 130℃. The maximum circulation depth of the thermal water is estimated to be around 4000m based on the geothermal gradient in the area being about 29℃/km.

3.2.2 The Maanping-Linchuan Hot Spring Area

The hydrochemical compositions of natural waters in the Maanping-Linchuan Hot Spring Area are presented in Table 3.

Table 2: Water chemistry of natural waters in the Lushan Hot Spring Area (Concentration in mg/L)

No.	T/℃	pH	K^+	Na^+	Ca^{2+}	Mg^{2+}	HCO_3^-	SO_4^{2-}	Cl^-	SiO_2	F^-	TDS
1	71	8.60		110.1	1.723	0	185.56	14.4	5.50	80	15	239.50
2	65	8.78		96.0	2.71	0.69	173.85	13	5.14	90	15	219.47
3	65	8.62		110.0	1.88	0	185.56	11.4	5.36	70	15	236.42
4	23	6.65		3.3	1.10	0.097	8.12	2.8	0.78	8	0.8	12.94
5	69	8.61	1.70	87.0	2.10	0.15	174.00	13	5.00	70	14	209.95
L-11	19	5.90		10.1	4.05	0.0	27.09	3.5	3.83	33	0.1	35.13
L-15	19	6.79		3.0	1.26	0.097	8.12	2.6	0.64	9	0	11.66

Table 3: Water chemistry of thermal waters in the Maanping Hot spring Area (Concentration in mg/L)

No.	T/℃	pH	K^+	Na^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	SiO_2	HCO_3^-	TDS
MN1	41.5	6.13	97.5	145	109	4.88	30	9.23	60	835.7	813.46
MN21	43	6.1	120.7	167.8	117.3	11.9	42	10.98	60	940.3	940.83
MN22	41	6.19	97.5	147.5	96.4	9.9	30	8.88	50	835.7	808.03
MN23	41	6.4	92	120	102.9	8.7	28	8.93	50	837.6	779.33

Table 4: Silica geothermometry results of the Maanping and Linchuan thermal waters

Sample No.	Measured temperature (°C)	Quartz temperature (Tqz) (°C)	Chalcedony temperature (Tch-1) (°C)	Chalcedony temperature Tch-2 (°C)
1	42	111	81	82
2	41	102	72	73
L1	41	118	90	90
L2	39	111	81	82
L3	59	124	97	97

Note: T_{qz}, T_{ch-1} and T_{ch-2} equations are from Fournier and Potter (1982), Fournier (1977) and Arnorsson, et al. (1983) respectively.

All the data are plotted in the triangular diagram (Figure 3) as relative concentrations. The waters in the area can be classified into three types: 1) Mg-HCO3 type: includes one cold water sample numbered 9; 2) Ca-HCO_3 type: includes cold water samples numbered 4, 6 and 7 and hot water samples numbered L1, L2, L3; 3) Na+K-HCO_3 type: the rest of the samples. Clearly, the difference in the chemical composition of hot springs in the area is quite significant.

All the data points are also plotted in Giggenbach's (1988) Na-K-Mg triangular diagram (Figure 4). It shows that all the waters in the area are immature ones for which the application of cation geothermometers is not suitable.

As discussed above, all the thermal waters in the area are immature waters, so cation geothermometers such as Na-K and Na-K-Ca geothermometers are not applicable for these hot waters. The only option is to use silica geothermometers. The results are given in Table 4.

It is clear from Table 4 that the estimated subsurface temperatures range from 72 °C to 124 °C for the hot spring area. Results of drilling show that the temperatures of thermal waters from wells above 1000 meters deep are not higher than 100 °C in the Province. So the chalcedony geothermometer temperatures, which are about 70-100°C, are probably closer to the reservoir temperature than the quartz ones.

The δD and $\delta^{18}O$ values of the thermal waters in the area are from -38.4 to 52.0‰, and from -6.57 to -7.23‰ (SMOW) respectively. The data points are in accordance with the local meteoric water line of the area $\delta D=8.31\delta^{18}O + 11.08$ (Sun & Li, 2001), which suggests that the thermal water is of meteoric origin. The ^3H values of the thermal waters vary from less than 1 TU to around 2TU, which shows that the thermal water has undergone subsurface circulation for several decades.

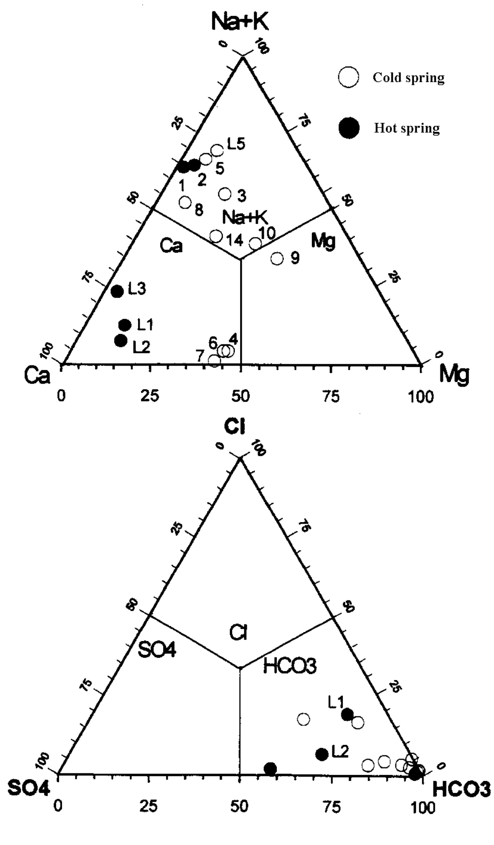

Figure 3: Triangular diagrams of relative component concentrations, in equivalents, for the Maanping - Linchuan waters.

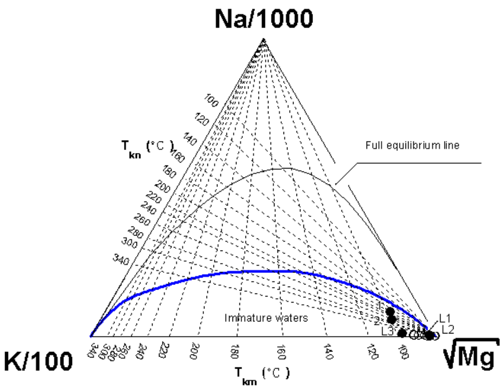

Figure 4: Na-K-Mg triangular diagram for the Maanping-Linchuan waters.

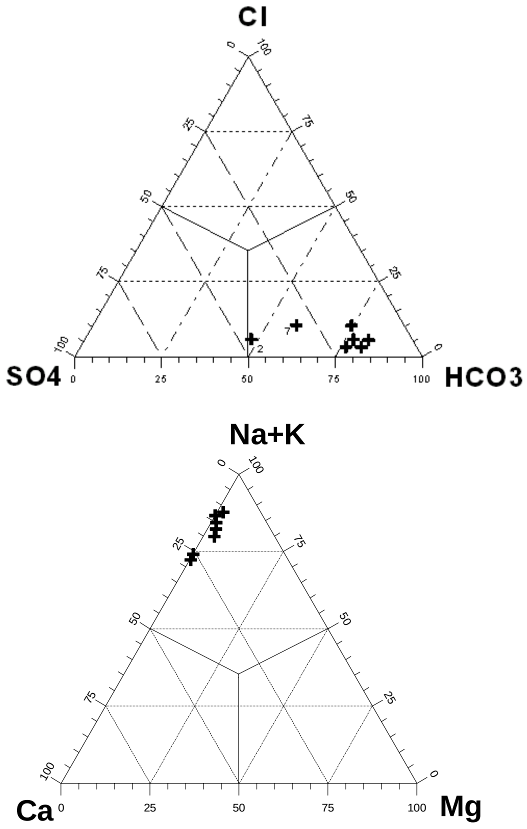

Figure 5: Triangular diagrams of relative component concentrations, in equivalents, for the Hengjing waters.

<u>3.2.3 The Hengjing Hot Spring Area</u>

The water chemistry of hot springs in the area is reported in Table 5 and is plotted in Figure 5. It is clear from Table 5 and Figure 5 that the waters belong to Na-HCO_3 type with higher concentrations of TDS, Fluorine and silica compared with the thermal waters in the rest areas of the Province.

The carbon dioxide concentration of the hot springs in the area ranges from 250 mg/L to 1263 mg/L. The hot springs belong to CO_2-type thermal mineral waters.

The surface temperatures of these springs are in the range 26°C to 73°C. They are grouped in two types of water: Na-HCO_3 and Ca-HCO_3. The quartz geothermometer and silica-enthalpy diagram indicate the reservoir temperature in the range 80 to 155ºC. The evidences show that the geothermal waters are from the low to moderate temperature geothermal reservoirs (Sun & Zhang, 2005).

The δD and $\delta^{18}O$ values of the thermal waters range from -47‰ to -57‰, and from -5.9‰ to -7.4‰ (SMOW) respectively. The isotopic data points are close to the local meteoric water line of the area $\delta D=8.33\delta^{18}O+8.52$ (Sun & Li, 2001), which means that the thermal water is of meteoric origin. The ^3H values of the hot springs are from 2TU to 4 TU, which suggests that the thermal water was recharged several decades ago.

4. DIRECT USE OF GEOTHERMAL WATERS

4.1 Heat Pumps and Direct Use of Geothermal Energy

For the past decade, the use of geothermal energy, involving heat pump technology or the direct use of low-enthalpy geothermal energy for heating and/or cooling, has increased steadily throughout Jiangxi Province. The development is usually in small units, providing heat and/or cooling to commercial buildings, local government or university buildings and some private houses. Due to high cost for electricity and fossil fuel in the province, the development has proven to be economically attractive. This kind of use of geothermal energy will be paid more and more attention to by estate companies and various investors because of the government's favorable policies such as reducing or remitting taxation to support the utilization of renewable energy.

4.2 Recreation Use

Developers continue to be interested in geothermal resources for recreational and therapeutic use in resorts in the province. Many drilling projects testing for geothermal waters for these applications have been carried out and more than 10 hot spring resort hotels have been built in the geothermal areas for the past ten years in the province. One of the most famous hot spring resorts in the province is the Lushan Tianmu Hot Spring Resort which is located in the Lushan Hot Spring Area of the northern Jiangxi Province. In the hot spring resort, the numerous fascinating hot spas and swimming ponds have attracted millions of visitors every year from all over the country (Figure 6).

4.3 Agriculture and Aquaculture

Vegetables, flowers and fruits from greenhouses heated by geothermal waters have become more and more popular in the market of the province. Aquaculture use of geothermal energy has been also increased for the past decade. Tilapia, salmon, trout, shrimp or prawns and eels are the most common fish raised in the province.

5. CONCLUSIONS

The thermal waters in Jiangxi Province have temperatures between 25℃ and 88℃ and are mostly Na-HCO_3, Na-Ca-HCO_3 and Ca-HCO_3 type with SiO2 contents ranging from 50 to 135 mg/L. The subsurface temperatures of the geothermal systems vary between 70℃ and 155℃. The geothermal waters are meteoric origin and generally belong to low-enthalpy type geothermal resources. They can be used for direct uses such as space heating, fish farming, agriculture and recreation.

ACKNOWLEGEMENTS

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Table 5: Water chemistry of thermal waters in the Hengjing Hot spring Area (Concentration in mg/L)

No.	T/℃	pH	TDS	SiO_2	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}	HCO_3^-	F^-
1	25.00	6.52	2289.22	99.00	138.50	15.37	84.60	698.60	81.18	325.00	1,886.10	2.92
2	48.00	6.67	2216.11	94.00	117.10	10.95	71.79	679.10	70.19	764.88	1,004.20	2.85
3	37.00	6.74	270.75	78.00	29.12	0.09	4.42	93.63	8.51	26.50	216.95	1.73
4	73.00	7.30	163.08	81.00	9.85	0.09	3.09	71.47	8.51	17.00	106.14	1.59
5	26.80	6.50	2696.33	43.00	106.90	10.42	81.97	969.80	50.69	350.00	2,253.10	3.60
6	48.00	6.77	1918.06	135.00	107.80	6.74	43.17	711.20	35.10	300.00	1428.10	3.24
7	44.00	6.63	495.96	82.00	52.25	0.33	6.85	154.40	28.71	115.00	276.83	1.87

Figure 6: Some hot spas in the Lushan Hot Spring Area, South Jiangxi Province, SE-China.

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