Studies of geothermal waters in Jiangxi Province using isotope techniques

SUN Zhanxue (孙占学) & LI Xueli (李学礼)

East China Geological Institute, Linchuan, Jiangxi 344000, China

Received November 3, 2000

Abstract Isotope hydrogeological studies of thermal waters conducted in the Lushan hotspring area, northern Jiangxi Province, the Maanping hotspring area, central Jiangxi, and the Henjing hotspring area, southern Jiangxi Province show that the local meteoric water line of Jiangxi Province is similar to the Craig line. The δD and δ^{18}O values of geothermal waters in the province are roughly in accord with the local meteoric line, which implies that the thermal waters are of meteoric origin. Variations of isotopic composition of natural waters in the study areas reveal that the recharge areas of the geothermal fields are the adjacent mountains. The ages of geothermal waters measured by different dating methods, such as Ra/Rn dating and tritium dating, range from several decades to several hundred years in the Province which suggests that the geothermal waters are undergoing active circulation. The ^{3}He/^{4}He ratios of gases from the hotsprings in the Hengjing hotspring area show that the hotspring gases originate from the depth, and probably partly from the mantle source.

Keywords: geothermal water, isotope, Jiangxi Province.

1 Determination of genetic type of geothermal waters

1.1 The Lushan hotspring area

The Lushan hotspring area is located at the southeastern foothill of Mt. Lushan, 40 km south of Jiujiang city. The hotspring has a long history of utilization, and now has been developed into a famous sanatorium. In order to find out the recharge area of the hot spring, water samples were taken from cold springs, wells, hotsprings and surface water bodies in the area. The isotopic data of the samples are reported in Table 1.

Based on the isotopic composition of shallow groundwaters, the local meteoric water line of the Lushan area is obtained as follows:

$$\delta D = 7.16\,\delta^{18}O + 8.88, \quad (\gamma = 0.98). \tag{1}$$

Equation (1) and the isotopic data points are shown in Figure 1. It is clear from Figure 1 that the omposition of the Lushan hotspring is close to the global meteoric water line ($\delta D = 8\delta^{18}O + 10$) proposed by Craig[1] and the local meteoric water line, which indicates that the thermal water is of meteoric origin. The research on the geology of Mt. Lushan made by Li et al.[2] showed that geological structural conditions in the area are favorable for the deep circulation of rain water to form the hot groundwater.

Table 1 Isotopic composition of natural waters in the Lushan hotspring area

No.	Sample	T_{water} /℃	$\delta^{18}O$/‰	δD/‰	^3H/TU	Sampling altitude H/m
CK-1	Hot water(drill hole)	71	−8.06	−52.9	<1	40
S1-2	Lushan hotspring	65	−7.98	−49.6	<1	40
CK-6	Cold water(drill hole)	19	−6.37	−38.8	37	40
L-10	Guizong Temple well	20	−6.24	−36.1	16	60
L-11	Clever spring	19	−6.82	−34.6	<1	60
L-12	Haihui Temple spring	23	−7.20	−42.6	20	330
L-13	The sixth spring	19	−7.07	−42.8	13	130
L-14	Jade creek spring	19	−7.24	−43.6	23	145
L-15	Yulian spring	19	−6.94	−38.7	—	240
L-16	Dragon pool	19	−6.56	−40.5	—	70
L-17	Poyang lake	21	−5.85	−35.2	17	20
L-18	Jade stream	20	−7.38	−41.2	—	140
L-19	Pine spring	18	−7.36	−42.9	22	5417
L-20	spring	17	−7.71	−45.2	12	1304
L-21	TV Tower well	18	−7.96	−44.9	17	1320
L-22	Botanical garden spring	18	−7.88	−48.1	28	1111
L-23	Sweet spring	19	−7.66	−46.6	33	980
L-24	Small heavenly pool	18	−7.44	−41.6	—	1210
L-25	Lushan sanatorium well	20	−7.68	−43.2	—	
L-26	Black drogen pool	19	−7.43	−43.2	—	870

1.2 The Maanping hotspring area

The Maanping hotspring area is located in the Maanping village, Chongren County. The hotsprings occur along the Jinshui-Dexing deep-great fault. The hotsprings discharge a carbonate type thermal water with the temperature of about 41℃, and a free CO_2 concentration of around 1200 mg/L.

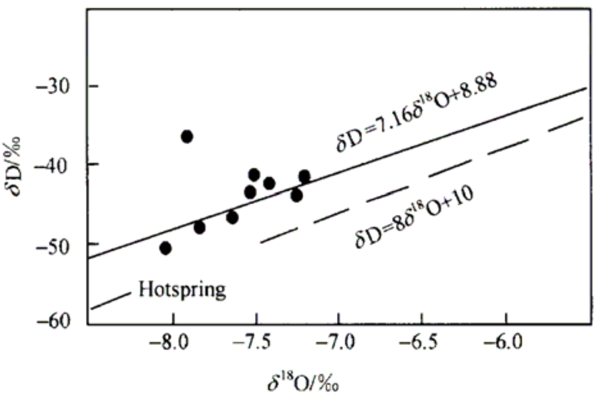

Fig. 1. The δD and $\delta^{18}O$ relation of natural waters in the Lushan hotspring area.

The isotopic composition of natural waters from hotsprings, cold springs, wells and water reservoir is given in Table 2. Based on the data of shallow groundwaters from the area, the correlation line between δD and $\delta^{18}O$ in Maanping area, central Jiangxi is:

$$\delta D = 8.31\ \delta^{18}O + 11.06, \quad (\gamma = 0.97). \qquad (2)$$

The $\delta^{18}O$ and δD values of the thermal water in the area are roughly in accord with the local meteoric water line (Fig. 2), which indicates that the thermal waters are of meteoric origin.

Table 2 Isotopic composition of natural waters in the Maanping hotspring area

No.	Sample	T_{water}/℃	δD/‰	δ^{18}O/‰	^{3}H/TU
M02	Well	22	−35.4	−5.60	40
M03	Well	19	−29.8	−5.15	_
M04	Cold spring	18	−37.4	−5.93	_
M05	Surface water	21	−22.3	−3.97	_
M06	Cold spring	19	−37.6	−5.57	_
M07	Cold spring	20	−35.6	−5.78	44
M08	Well	20	−42.3	−6.30	33
M09	Cold spring	18	−36.9	−5.70	_
M010	Hot spring	41.5	−44.1	−7.23	<1.0
M011	Hot spring	41	−45.4	−6.84	2
M012	Cold spring	20	−34.3	−5.46	333

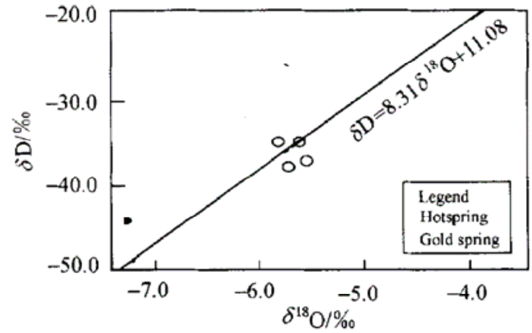

Fig. 2. The δD and δ^{18}O relation of natural waters in the Maanping hotspring area.

1.3 The Hengjing hotspring area

The Hengjing hotspring area is located in the southern end of the Wuyi Uplifted Zone in the South China Fold System, and along the Xunwu-Ruijin deep-great fault. In the area, there are two groups of fault: one is NW-trending faults, another is EW-trending faults. All the fault are active ones along which earth quakes have occurred for many times in the last decade. The terrestrial heat flow of the region is from 67.2 to 75.6 mW/m^2 which is higher than the average value for Jiangxi Province.

The results of isotopic composition of the water samples of the area are given in Table 3. Based on the data in Table 3, the local meteoric water line is obtained:

Table 3 Isotopic composition of natural waters in the Hengjing hotspring area

No.	Sample	T_{water}/℃	δD/‰	δ^{18}O/‰	^{3}H/TU
1	Cold spring	20	−55	−7.4	13
2	Hot spring	25	−57	−7.2	4
3	Hot spring	48	−53	−6.9	2
4	Hot spring	40	−49	−6.7	1
5	Hot spring	37	−53	−7.2	2
6	Hot spring	73	−47	−6.1	3
7	Cold spring	18	−46	−6.5	—
8	Cold spring	21	−39	−5.6	4
9	Hotspring	26.8	−48	−5.9	1
10	Cold spring	22.2	−49	−7.0	—
11	Hot spring	48	−48	−5.9	2
12	Hot spring	44	−49	−7.0	2
13	Cold spring	20	−48	−6.9	3
14	Cold spring	19	−45	−6.6	—

$$\delta D = 8.33\ \delta^{18}O + 8.52, \quad (\gamma = 0.97). \tag{3}$$

The isotopic data points of hotsprins in the area are plotted in Figure 3, which indicate that the data points of thermal waters are close to the local meteoric water line. It is obvious that the thermal water came from the deep circulation of local precipitation.

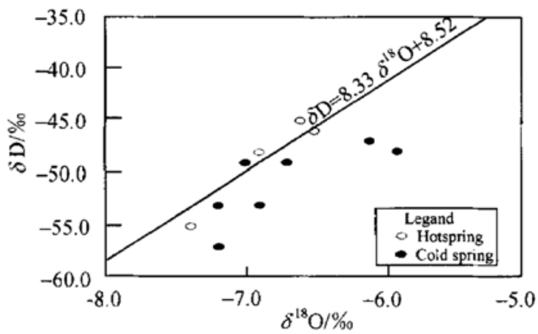

Fig. 3. The δD and $\delta^{18}O$ relation of natural waters in the Hengjing hotspring area.

The emerging temperatures of geothermal waters in Jiangxi Province are all below 90℃. In all cases, no obvious oxygen shift has been found. This suggests that the temperatures of deep geothermal reservoir are not high. The geothermal reservoir in the province belongs to the deep circulation type and low enthalpy geothermal resources.

2 The altitude of recharge areas of the hot springs

The oxygen-18 and deuterium isotopic composition in precipitation depends upon average temperatures of air. Air temperature decreases with increasing elevation. The higher the elevation is, the lower the D and O values of precipition are. That is altitude effect.

2.1 The Lushan hotspring area

The recharge area altitude of geothermal waters in Jiangxi province has been studied by means of isotopic altitude effect. Based on the data in Table 1, the dependence of altitude upon the isotopic composition of oxygen and hydrogen in the Lushan area, northern Jiangxi are expressed as follows:

$$-\delta D = 35.34 + 0.0138H, \quad (\gamma = 0.72). \tag{4}$$

$$-\delta^{18}O = 6.33 + 0.0018H, \quad (\gamma = 0.61). \tag{5}$$

where, H is altitude expressed in meters.

The δD and $\delta^{18}O$ values of Lushan hotspring are –49.6‰ and –7.98‰ respectively. The recharge area altitude of the hotspring has been calculated to be about 1100 meters by equations (4) and (5). The planation surface of Mt. Lushan ranges from 850 to 1100 meters above sea-level. The analysis of the geological, hydrogeological and physicogeographical conditions of the area shows that the recharge area of Lushan hotspring should be the planation surface whose area is about 75 km^2. From the recharge area, rain water penetrate into the depth along faults and fractures to recharge hot springs.

2.2 The Maanping hotspring area

The altitude-isotopic composition correlation lines of natural waters in Maanping area, Central Jiangxi are calculated as follows from the data in Table 4:

Table 4 Isotopic composition and recharge altitude of shallow cold waters in the Maanping hotspring area[a)]

No.	Sample	δD/‰	δ^{18}O/‰	Recharge altitude H/m
1	M09	−5.70	−36.9	250
2	M04	−5.93	−37.4	350
3	M03	−5.15	−29.8	110
4	M06	−5.57	−35.8	220
5	M07	−5.78	−35.6	280

a) data from Sun et al., 1992.

$$-\delta D = 25.11 + 0.047H, \quad (6)$$

$$-\delta^{18}O = 4.82 + 0.0032H, \quad (7)$$

where the δD and δ^{18}O values are expressed in permill versus the SMOW; H means altitude in meters.

According to the isotopic composition of hydrogen and oxygen ($\delta D = -45‰$, $\delta^{18}O = -6.84‰$), the altitude of recharge area of Maanping hot spring has been obtained by equations (6) and (7). The altitude is about 500 meters and similar to the altitude obtained by traditional hydrogeologic condition analysis[3].

2.3 The Hengjing hot spring area

Due to complex of geography in the area, it is very difficult to determine the recharge altitude of shallow groundwaters. For this reason, no altitude effect equation can be got from the isotopic data for cold waters. In order to identify the recharge altitude of the geothermal waters in the area, the equation (6) and (7) are also used here. The recharge altitude of hotspring waters in the area is calculated to be from 350 m to 700 m. The inference is supported by the result obtained by hydrogeological survey[3] which indicate the recharge area is the mountainous whose altitude ranging from 300 m to 800 m.

3 The ages of the geothermal waters

In order to study the properties and formation process of geothermal waters in Jiangxi province, their tritium, radium and radon concentrations have been measured. Some results are reported in Table 5. The tritium content of geothermal waters is commonly much lower than that of shallow cold groundwaters. The tritium value is less than 1 TU in most geothermal waters of Jiangxi. The low tritium values show that the thermal waters were recharged by meteoric waters before the beginning of thermonuclear tests.

Furthermore, according to the equation $t = -1/\lambda \ln (1-NR_a/R_n)$ proposed by Cherdyntsev[4], the estimated ages of thermal waters in the province are ranging from several decades to several hundred years. For instance, the ages of Lushan hot spring (northern Jiangxi), Linchuan hot spring and Maanping hot spring (central Jiangxi) are 82 years, 200 years and 80 years respectively. These results are demonstrated by the hydrogeochemical characteristics of the thermal waters. The geothermal waters are mainly HCO_3-Na and HCO_3-Na-Ca type of waters with low salinity. These characteristics indicate that the geothermal waters are of meteoric origin and do not have long

Table 5 The tritium, radium and radon concentration of some natural waters in Jiangxi Province

Sampling location	Sample	^3H/TU	R_a/Bq • L^{-1}	R_n/Bq • L^{-1}	R_a-R_n age/a
Linchuan, Central Jiangxi	Hot spring	0.33	2.533	52.15	116.8
	Cold spring	9.50	0.0444	407.00	2.5
	Cold spring	12.13	0.0112	58.09	0.5
Chongren, Central Jiangxi	Hot spring	1.9-7.5	0.685	20.40	79.0
	Cold spring	33.30	0.0189	185.00	0.2
	Well	39.77			
Lushan, Northern Jiangxi	Hot spring	1.0	0.259	7.40	82.9
	Cold springh	12.7	0.0167	122.1	0.3
	Cold springh	23.4	0.0059	248.6	0.1
Xunwu, Southern Jiangxi	Hot spring		0.198	8.51	55.0
	Cold springh		0.067	296.74	0.5

residence time.

The number of the hot springs with gas manifestations makes up about one third of the total number of the hotsprings in Jiangxi Province. Of all the hot springs, those in the Hengjing hot spring area have the strongest gas manifestation. The major gas component from the hot springs in the area is carbon dioxide which takes from 96.7% to 99.8% of the total gases. Noble gas helium is also found in the hot spring gases. The concentration of helium in the gases from the hot springs is from 0.0047% to 0.0137% (Table 6). Free CO_2 are more than 250 mg/L or even reaches 1000 mg/L or more in the most hot spring waters in the area.

Table 6 Gas composition and $^3He/^4He$ ratios of hot springs in the Hengjing hotspring area[a)]

Sample No.	Gas composition Φ_B/%					$\delta^{13}C$/‰ (PDB)	$\delta^{13}C_{CO_2}$ /‰ (PDB)	Helium isotopic composition	
	N_2	CO_2	CH_4	Ar	He			$^3He/^4He$	R/R_a
2		99.84	0.04	0.115	0.0047	−27.69	−4.96	$(1.90\pm0.06)\times10^{-6}$	1.36
3		97.96	1.86	0.117	0.0016	−34.86	−4.43	$(2.74\pm0.12)\times10^{-6}$	1.96
9	2.01	96.47	1.28	0.211	0.0234	−59.31	−5.50	$(2.95\pm0.10)\times10^{-6}$	2.11
11	1.91	97.92	0.06	0.095	0.0137	−45.30	−5.06	$(2.30\pm0.08)\times10^{-6}$	1.64

a) R is the ratio of $^3He/^4He$ for samples, Rais the ratio of $^3He/^4He$for air which is equal to1.4×10^{-6}.

The $^3He/^4He$ ratios of the hot spring gases are measured and reported in Table 6. The ratios vary from 1.9×10^{-6} to 2.95×10^{-6}, which indicate that the gases came from the depth and probably partly from the mantle source.

4 Conclusions

Based on discussions above, the following conclusions can be reached:

(1) The geothermal waters are of meteoric origin and are formed by deep circulation of local precipitation along faults and fractures in Jiangxi Province.

(2) The geothermal waters were recharged before the thermonuclear test, and the age of the thermal waters are from several decades to some hundred years. The altitude difference between

the recharge area and the location of hotsprings is usually several hundred meters or more.

(3) The sources of the geothermal waters and the gases in thermal water are different. Carbon dioxide and some other gases in the thermal waters came from the depth and are from the mantle source.

References

1. Craig H., Isotopic variation in meteoric waters, Science, 1961, 133: 436—468.
2. Li Xueli, Shi Weijun, Yang Zhongyao, The formation condition and genesis of the Lushan hotsprings, Journal of East China geological Institute. 1992, 15(3): 229—233.
3. Sun Zhanxue, Li Xueli, Shi Weijun, et al., The hydrogeochemistry of the Henjing hotsprins, southern Jiangxi Province. Proceedings of the 4th National Symposium on Geothermal Resources, Beijing: Geological Press, 1994: 105—109.
4. Cherdyntsev, V. V., Uranium-234, Moskva: Atomizdat, 1969.