Proceedings World Geothermal Congress 2023
Beijing, China, April 17 – 21, 2023

Hydrogeochemistry of hot springs in Western Jiangxi Province, SE-China

Sun Zhanxue[1, 2], Chen Gongxin[1, 2], Li lu[2]

1. State Key Laboratory of Nuclear Resources and Environment, East China University of Technology, Nanchang, 330013, Jiangxi, China

2. East China University of Technology, Nanchang, 330013, Jiangxi, China

zhxsun@ecut.edu.cn

Key words: hot spring, hydrogeochemistry, isotopes, subsurface temperature evaluation of geothermal reservoirs, Jiangxi Province

ABSTRACT

In order to assess the potential of geothermal development, hydrogeochemistry of ten selected hot springs from Western Jiangxi Province, SE-China are studied. Based on field investigation and sample analysis, the chemical composition and isotopic characteristics of the hot springs and the evaluation of subsurface temperatures of geothermal reservoirs in this area are discussed. The hydrochemical types of hot springs in the area mainly belong to HCO_3-Na and HCO_3-Ca types distributed in southern part, and SO_4-HCO_3-Na type exposed in the northern part. Most hot springs are neutral or weak alkaline nitrogen-containing waters.

Isotopic compositions of hydrogen and oxygen indicated that the thermal waters are of meteoric origin. The geothermal water is formed by deep circulation of precipitation through the faults and fractures. The recharge altitudes of the hot springs of HCO_3-Na type and SO_4-HCO_3-Na type are estimated to be about 900-1700m, and the recharge altitude of the hot springs of HCO_3-Ca type ranges from 200-700m. The ^{14}C ages of SO_4-HCO_3-Na hot springs are greater than 6000a, much older than that (about 2000a) of HCO_3-Na type hot springs.

Using quartz and chalcedony geothermometers, the temperatures of the geothermal reservoirs are calculated as about 80-100℃ for HCO_3-Na type hot springs, 40-60℃ for HCO_3-Ca type hot springs and 90-120℃ for SO_4-HCO_3-Na type hot springs respectively. The geothermal waters are low-mid geothermal resources and suitable for direct uses.

INTRODUCTION

Jiangxi province is one of the most abundant geothermal resource regions of China, which is located in the south plate of the middle reaches of the Yangtze River and in the low mountains and hills and the plain area of Poyang Lake. The region belongs to the southeast coastal geothermal belt, where low temperature thermal water are widely distributed. According to early investigations, there are 96 hot springs and 22 boreholes discovered in the province, as total of 118 thermal waters. However, a great number of geothermal waters recovered by boreholes in recent years, as the potential for development and utilization of geothermal resource is also increasing. As we all known, chemical composition of underground thermal water depends on various geological movements, which is closely related to regional groundwater systems, geothermal conditions and rock properties. Therefore, the study of hydrogeochemistry of hot spring in this province is of great significance to the sustainable exploitation and utilization of geothermal resources.

Yichun area as one of most famous tourist regions for there are several well-known hot springs occurring in area of this province, among which, Wentang Hot spring, JiuxianTang Hot spring, Tangli Hot spring and others. In addition, there are also some hot springs who are less studied, including Xintian hot spring in Yuanzhou District, Lutang Hot Spring in Wanzhi County, Hantang Hot Spring in Shanggao County, etc. There were also lack of systematic studies on hydrogeochemistry of hot springs in this area. In early studies, scholars were mainly focused on hydrochemistry, neglecting isotopes and gases. They only carried out detailed research on some key hot springs, such as Wentang hot springs, neglecting other important hot springs such as Tangli Hot spring in Tonggu County.

In order to assess the potential of geothermal development, hydrogeochemistry of ten selected hot springs from Western Jiangxi Province, SE-China are studied. Based on field investigation and sample analysis, the chemical composition and isotopic characteristics of the hot springs and the evaluation of subsurface temperatures of geothermal reservoirs in this area are discussed.

GEOLOGICAL SETTINGS

The distribution of hot springs in Jiangxi Province is mainly controlled by the NNE-NE, NW and EW trending deep faults. The hot springs are mainly outcrops along the Jiuling-Huaiyu Mountain, Nanling Mountain, Jiuling-Zhuguangshan Mountain and Wuyi Mountain. There are 18 deep and large faults preliminarily identified in the area, most of which developed in the late period of basement fold. After many activities, the depth and area of the deep and large faults increased, which gradually dominated the volcanic and magmatic activities in the province, controlled the formation of the red basins, and affected the hydrothermal activities and geothermal background in the region. Jiangxi Province is located in southeast China, on the southern bank of the middle reaches of the Yangtze River. The province is roughly bounded by the Zhejiang-Jiangxi Railway: the northwestern part of the Yangtze River lies in the southeastern edge of the Yangtze Huaihe platform; the central and southern regions are located in the northeast of South China fold system. In the province, there are a series of dense folds and faults mainly in Northeastward and northeastward directions, but there are also folds and faults in other directions.

Sun and Chen, or Li et al.

The development and evolution of Jiangxi's geological structure has obvious imbalance. In general, the geosynclinals fold return or continental crust accretion in Jiangxi province and its adjacent areas generally advance from north to south. In the west or northwest, fold action is dominant, accompanied by magma intrusion, while in the east or southeast, fault depression and fault uplift are dominant, accompanied by strong volcanic eruption.

Yichun area is rich in hot spring resources, among which Wentang, Jiuxian Tang, Tangli and other hot springs are well known throughout the province. In addition, there are Xintian hot spring in Yuanzhou District, Lutang Hot Spring in Wanzhi County, Hantang Hot Spring in Shanggao County, etc., which are less developed. Due to the relatively slow economic development in some mountainous areas of Yichun, Jiangxi Province, there has been a lack of systematic studies on hydrogeochemistry of hot springs in this area. Early studies mainly focused on hydrochemistry, without isotope and gas work, and only relatively more studies were conducted on the famous Wentang hot springs. Others, such as Tangli Hot spring in Tonggu County, have not been studied before.

2 SAMPLING AND ANALYSIS METHODS

2.1 Sample collection and analysis

Ten hot springs in Yichun area are collected in this study. Those springs (NO1 and NO2) are located in Anfu County within the jurisdiction of Ji 'an City. Four gas samples of hot spring (NO3, NO4, NO6 and NO8) in Yichun area were collected also. The gas sample was sampled with drainage and collecting air with an aluminum-plastic bag. 12 cold waters and 10 thermal water samples were collected for analysis of δD and $\delta^{18}O$.

Figure 1: Samples site

2.3 Analysis methods

The water samples were first filtered by microporous filter membrane, and then loaded into polyethylene sampling bottles soaked in 10% superior pure nitric acid for 24h and cleaned with distilled water before drying. According to the laboratory analysis requirements, 500mL volume of water samples are for cationic, trace elements and anions respectively. The hot spring water sample is used to test cationic and trace elements by adding superior pure nitric acid on site to keep pH at 2. Thermal water samples for anions analysis use raw water. After sampling, the hot spring water sample is sealed to prevent the water sample from external contamination.

Some parameters, such as dissolved oxygen in water, pH, conductivity, Eh, SiO_2 content and alkalinity and other variable water chemical components, were analyzed on site using portable thermometer, dissolved oxygen meter, multifunctional parameter tester, Hash water quality analyzer.

The stable water chemical components, such as major cations and trace elements, were sent to lab to analyze by ion chromatography, atomic absorption spectrometer, inductively coupled plasma mass spectrometer and other instruments at the Analysis and Testing Research Center of East China University of Technology.

The gas in hot spring samples, such as CH_4, C_2H_6, C_3H_8, H_2, N_2, O_2, CO_2, Ar, He and other components, were analyzed by MAT271 mass spectrometer in Lanzhou Petroleum Research Center, Northwest Institute of Eco-Environment, Chinese Academy of Sciences which can get high resolution.

δD and $\delta^{18}O$ in water samples were determined by Stable isotope ratio Mass spectrometer (MAT-253) at the State Key Laboratory of Nuclear Resources and Environment, East China University of Technology. The ^{14}C and ^{13}C were determined by Beta Laboratory in the United States using accelerator mass spectrometry (AMS).

3 RESULT AND DISCUSSION

3.1 Chemical characteristics of hot spring water

The hydrochemical characteristics of thermal water are the result of the interaction between water and rock, which is determined by the hydrogeological conditions during the movement of thermal water and the composition of surrounding rock in contact. In order to systematically study the water chemical characteristics of typical hot springs in Yichun area, 10 hot spring water samples collected in this research institute were sent to the Analysis and test Center of East China University of Technology for full analysis and testing.

Sun and Chen, or Li et al.

The test result of thermal spring chemical analysis was plotted in a Piper diagram (Figure 2). Ten hot spring water samples were classified according to the Kalev water chemical classification method. The thermal water in Yichun area can be divided into three groups: NO1, NO2 and NO3 hot springs are HCO_3-Na type water; NO4, NO5, NO6, NO7 and NO8 hot springs are HCO_3-Ca type water. NO9 and NO10 hot springs are SO_4-HCO_3 -Na type water.

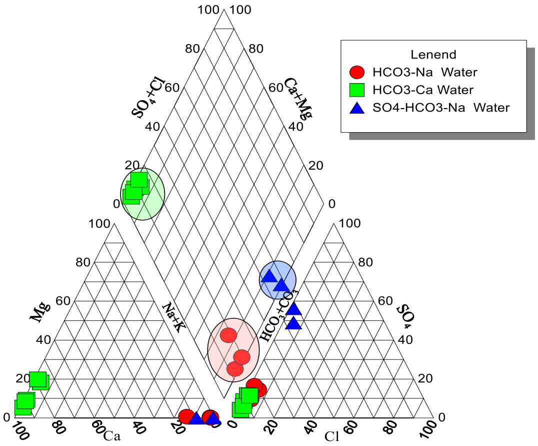


Figure 2: Hot Spring Piper diagram

3.2 Gas Geochemical characteristics

The main component of the four hot spring gases is N_2, and the content (volume) of N_2 gas ranges from 66.83% to 94.07%, with an average of 84.90%. Other gas components were founded in these hotspring waters, O_2 4.49% ~ 7.25%, Ar 0.8% ~ 1.17%, CO_2 0.27% ~ 2.11%, however, other components such as H_2, He, C_2H_6, H_2S, C_3H_8, C_4H_{10} and othes were not founded. NO3 hot spring water does not contain CH_4 gas. NO6 hot spring and NO8 hot spring were with low CH_4, 1.42% and 1.08% respectively, but NO4 hot spring has a high CH_4 content of 23.87%.The main N_2 component of the typical hot spring gas in Yichun area accounts for 66.83% ~ 94.07% of the total gas, indicating that the hot spring gas in Yichun area belongs to nitrogen type.

N_2 is the main hot spring gas in the study area, and N_2 is one of the main chemical components in the exhaled gas of the atmosphere and solid earth. N_2/Ar was calculated for four hot springs. N_2/Ar of NO3 hot spring is 80.4 and NO4 hot spring is 83.5. N_2/Ar coefficient is between 38 and 84.4. It can be roughly determined that nitrogen in NO3 and NO4 hot spring is the atmospheric source. However, N_2/Ar of hot spring NO6 was 86.6, and N_2/Ar of hot spring NO8 was 90.4, slightly higher than 84.4, indicating that N_2 was added from other sources. This study could not confirm whether it was from biological sources, magma sources, mantle sources or a variety of mixed processes. The CH_4 content of NO4 hot spring was higher, reaching 23.87%. Due to the lack of correlation analysis of gas isotopes in this study, the exact source of CH_4 in the hot spring is not yet clear. However, the field investigation found that the NO4 hot spring was located near the middle and small stream of the village, with fish growing and moss growing near the hot spring, and there was no oil or natural gas reservoir in the study area. Therefore, the CH_4 of hot Spring NO4 May be derived from the biochemical reactions of the shallow crust, the metamorphism of the deep crust, or the combination of the two.

The percentage of H_2 in the geothermal water underground can be used to preliminarily judge that the geothermal system in the study area belongs to the high-temperature or medium-low temperature geothermal system. The H_2 percentage in the hot spring gas in Yichun area in this study is near 0%, which indicates that the geothermal system in the study area may be medium-low temperature. This is good correlated with the earlier analysis results of the heat flow data obtained by East China University of Technology and Chinese Academy of Sciences.

3.3 Isotopic geochemistry

3.3.1 Hydrogen and oxygen isotope characteristics

The stable isotopes of waters in study area were shown in Table 1. Among them, 12 cold waters were obtained from the foot to peak ended in Jinding of the Wugong Mountain, the highest peak mountain in Jiangxi. 10 thermal water samples were obtained from the 10 typical hot spring locations in Yichun area.

Table 1: Basic information of natural water sampling points and hydrogen and oxygen isotope compositions

No.	Type	elevation(m)	δD（‰）	δ^{18}O（‰）
1C	Cold spring	1714	-46.9	-7.2
2C	Cold spring	1913	-45.4	-7
3C	Cold spring	1545	-44.3	-6.8
4C	Cold spring	1480	-44.8	-7.2
5C	Cold spring	1485	-44.2	-7.1
6C	Cold spring	1360	-44.6	-7.4
7C	Cold spring	1153	-43.9	-7.2
8C	Cold spring	893	-39.5	-6.7
9C	Rain water	562	-33.2	-5.7

Sun and Chen, or Li et al.

10C	Cold spring	382	-33.6	-5.8
11C	Cold spring	374	-35.7	-6
12C	Cold spring	207	-35.6	-6.2
NO1	Hot spring	382	-67.6	-7.8
NO2	Borehole water	219	-61.8	-7.2
NO3	Hot spring	174	-55.2	-6
NO4	Hot spring	110	-50.2	-5.5
NO5	Hot spring	110	-51.4	-5.8
NO6	Hot spring	92	-53.1	-6.7
NO7	Hot spring	108	-43.6	-6
NO8	Hot spring	61	-46.1	-5.9
NO9	Borehole water	233	-59.4	-7.8
NO10	Borehole water	264	-53.5	-7.5

In addition, samples for ^{14}C and ^{13}C were collected from NO2 Chijiang Hot spring, NO3 Wentang Hot Spring, NO9 Hongqi Hot Spring and NO10 Guqiao Hot Spring.

(1) Thermal water origin

By analyzing the relationship between δD and $\delta^{18}O$ in cold spring water and atmospheric precipitation, the local atmospheric meteoric water line (LMWL) in Yichun area was obtained as the following equation:

$$\delta D = 8.06\delta^{18}O + 12.93 \quad (r^2=0.91) \tag{1}$$

The local atmospheric meteoric water line $\delta D=8.06\delta^{18}O+12.93$ in Yichun area, and the relationship between δD-$\delta^{18}O$ is shown in Figure 2. As seen from Figure 2, hot springs from NO1 to NO10 in this study are distributed near the meteoric water line in Yichun area, and the isotopic composition of hot springs is very close to LMWL, which indicated that hot springs were recharged from atmospheric precipitation.

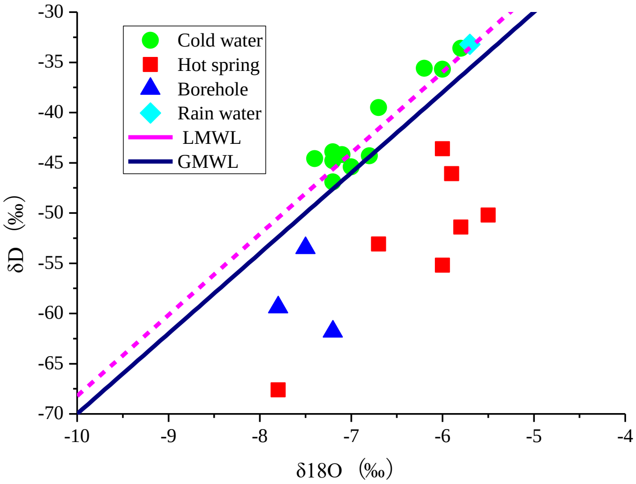


Figure 2: The δD-$\delta^{18}O$ **relationship of hot springs in the study area**

Generally, the water-rock interaction occurs under the condition of underground high temperature (higher than 80°C), and the phenomenon of "oxygen drift" is relatively obvious. As shown in Figure 2, oxygen drift occurs obviously and water-rock interacted strongly in the thermal water field in Yichun area. It suggested that the thermal water and the rock have isotopic exchange under the condition of high temperature. However the speculation is not supported by the subsurface temperatures of the geothermal reservoirs in the area being quite low as discussed in Section 3.4. Probably the oxygen shift could be caused by long time water-rock interactions in low-mid temperature geothermal systems.

(2) Thermal water recharge attitude

The source of hot spring is atmospheric precipitation, so the height of origin area can be calculated with δD and $\delta^{18}O$ values. The formula of δD, $\delta^{18}O$ content and local altitude is followings:

$$H = \frac{\delta S - \delta P}{k} + h \tag{2}$$

Sun and Chen, or Li et al.

Where, H is the origin attitude of hot spring, m; δS is δD or $\delta^{18}O$ value of water sample; δP is δD or $\delta^{18}O$ value of atmospheric precipitation; h for the attitude of the sampling point, m; k is the gradient of hydrogen or oxygen isotope of atmospheric precipitation, n ‰/100m.

The recharge attitude of thermal water in Yichun area was calculated according to Formula 2. As Isotope exchange reaction has little accuring on δD, so δD is generally used to calculate the attitude of recharge area. δD is -41‰ of the atmospheric precipitation in Yichun area (SMOW). The gradient of δD in southwest of China is -2.5‰/100m. Gradient of Yichun area is lower than that of southwest area, taken as -2‰/100m. Combined with local hydrogeological data, it can be seen that hot springs are fed by atmospheric precipitation, among which typical HCO_3-Na hot springs of 1-3 type and typical SO_4-HCO_3-Na hot springs of 9-10 type have higher recharge attitude, ranging from 884m to 1712m and 889m to 1153m, respectively. Typical HCO_3-Ca type 4-8 hot spring recharge attitude is relatively low, ranging from 238m to 697m.

3.3.2 Carbon isotope characteristics

(1) Sources of carbon in underground thermal water

According to $\delta^{13}C$ values of the samples, the origin can be roughly determined. In this study, four water samples were collected for the test of $\delta^{13}C$ value as shown in Table 2.

Table 2: $\delta^{13}C$ values of hot springs in the study area

number	Type	$\delta^{13}C$（PDB,‰）
NO2	Borehole water	-19.7
NO3	Hot spring	-14.1
NO9	Borehole water	-17.3
NO10	Borehole water	-17.1

Generally, the $\delta^{13}C$ values range from 2‰ to -2‰ for carbon of carbonate metamorphism origin, from -8‰ to -4‰ for carbon from upper mantle, from -10‰ to -35‰ for carbon of organic sources, and from -22‰ to -25‰ for biogenic carbon respectively. The $\delta^{13}C$ values of the thermal waters in Yichun area range from -14.1‰ to -19.7‰, with an average value of -17.05‰, indicating that the carbon in the thermal water may be derived from organic carbon.

(2) Age of thermal water

Based on the decay principle of radioisotopes, ^{14}C is widely used to estimate the age of groundwater. In this study, a total of 4 water samples were collected for ^{14}C test, measured by accelerator mass spectrometer (AMS) in Beta Laboratory according to radiocarbon dating method as shown in Table 3.

Table 3: ^{14}C of thermal water in the study area

number	Type of water source	^{14}C （PMC， %）	$\delta^{13}C$ （PDB, ‰）	Apparent age	Person correction age (years)
NO2	Borehole water	58.50	-19.7	4008	2393
NO3	Hot spring	91.10	-14.1	347	--
NO9	Borehole water	31.20	-17.3	9205	6400
NO10	Borehole water	26.60	-17.1	10524	7588

The radioactivity ratio at the closing time of the system is the same as that of CO_2 in the atmosphere at the same time. ^{14}C can be used to determine the age of the thermal water. The Person method is used to correct the age of ^{14}C. See Table 3 for details. According to the sampling calculation results, hot springs NO9 and NO10 are older than hot springs NO2 and NO3, more than 6000 years old. Hot springs NO9 and NO10 are exposed in the granite area, while hot springs NO2 and NO3 are exposed near the fault zone.

3.4 Evaluation of subsurface temperature in geothermal reservoirs

3.4.1 Na-K-Mg triangle diagram

The Giggenbach's Na-K-Mg triangle diagram can be applied to evaluate the water-mineral equilibrium. The contents of Na, K and Mg in the groundwater thermal water collected in Yichun were plotted in the Na-K-Mg triangle diagram as shown in Figure 4.

Figure4 shows that most spring samples are located in the partially equilibrated and mixed water, that is, below the Full equilibrium line, indicating that those spring point thermal water has not in the water-rock equilibrium state, which may be caused by the geothermal water mixing with shallow groundwater to some extend during the migration to the surface. The water samples of NO2, NO9 and NO10 hot springs are located the the Full equilibrium or near the equilibrium line, indicating that these three hot springs are in the water-rock equilibrium state and they are mature water or less affected by cold water mixing. For the mature waters NO9 and NO10 (HCO3-Na type water), the estimated discharge temperature is around 120 ℃. For the mature waters NO2 (HCO3-Na type water), the estimated discharge temperature is around 80℃. These water are closer to the thermal water of deep reservoir. As can be seen from the figure, hot springs NO3 NO4, NO5, NO6, NO7 and NO8 are all clustered in the lower part of the equilibrium zone, that is, farther away from the water-rock equilibrium state than other springs. The Mg^{2+} content of water samples in these places is relatively high, ranging from 3.55 to 13.5mg/L, with an average value of 7.9mg/L. This indicates that the typical HCO_3-Ca type hot spring in Yichun area is still in the initial stage of water-rock interaction, and the cationic geothermal scale is not suitable for the evaluation of reservoir temperature of this kind of geothermal water. Therefore, the most hot springs, expect NO2, NO9 and NO10, in the study area have not reached the full equilibrium state, and it is not suitable to use Na-K, Na-K-Ca, K-Mg and other cationic geothermometers to calculate the geothermal reservoir temperature in those thermal waters.

Sun and Chen, or Li et al.

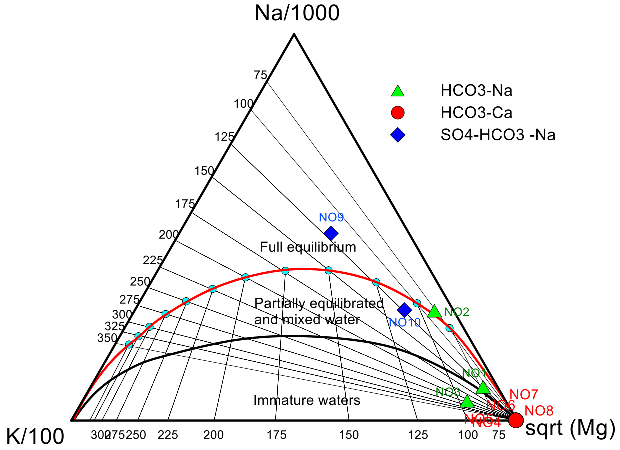
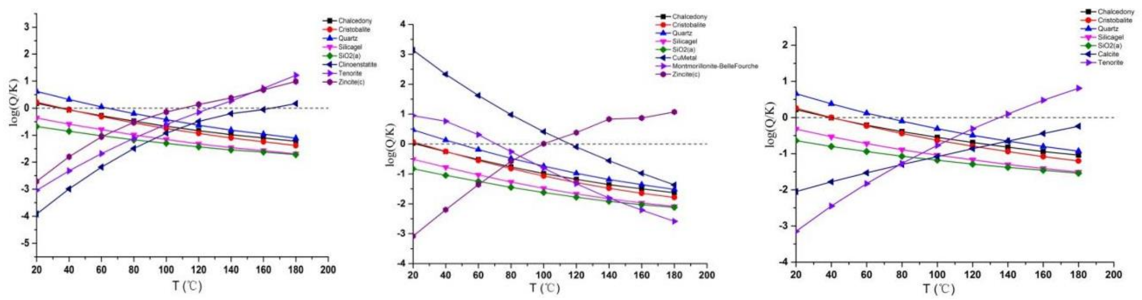


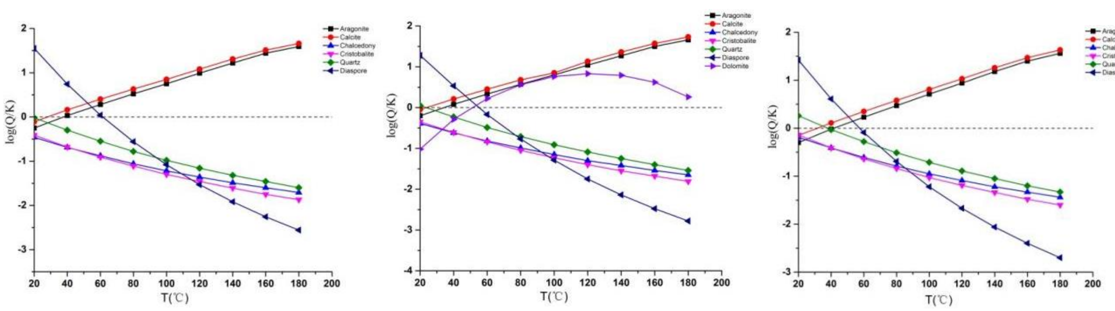
Figure 4: Na-K-Mg equilibrium diagram for Arnórsson (2000)

6. 2. 2 Log(Q/K)-T diagrams

All thermal waters were plotted log(Q/K)-T diagrams according mineral equilibrium calculation. As shown in figure5(a), it can be estimated that geothermal reservoirs temperature in NO1 thermal water are from 90℃ to 110℃. The estimated geothermal reservoirs temperature in NO2 thermal water are from 70℃ to 100℃(Figure5 b). The estimated geothermal reservoirs temperature in NO3 thermal water are from 80℃ to 120℃(Figure5 c). The estimated geothermal reservoirs temperature in NO4 thermal water are from 40℃ to 60℃(Figure5 d).The estimated geothermal reservoirs temperature in NO5 thermal water are from 60℃ to 55℃ (Figure5 e). The estimated geothermal reservoirs temperature in NO6 thermal water are from 40℃ to 60℃(Figure5 f). The estimated geothermal reservoirs temperature in NO7 thermal water are from 40℃ to 55℃(Figure5 g). The estimated geothermal reservoirs temperature in NO8 thermal water are from 40℃to 60℃(Figure5 h). The estimated geothermal reservoirs temperature in NO9 thermal water are from 100℃ to 130℃(Figure5 j). The estimated geothermal reservoirs temperature in NO10 thermal water are from 100℃ to 135℃(Figure5 k).

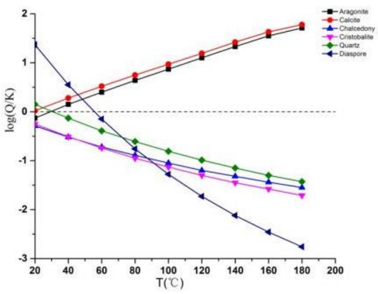


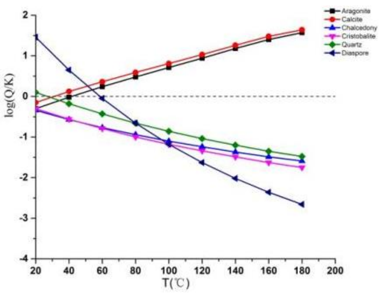
(a) **(b)** **(c)**

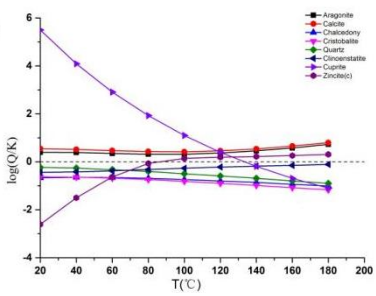


(d) **(e)** **(f)**

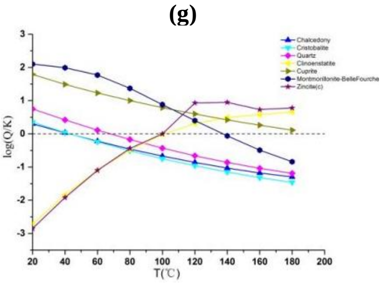
Sun and Chen, or Li et al.







(g) (h) (i)



(j)

Figure 5: Mineral equilibrium diagram (a: NO1 thermal water; b:NO2 thermal water; c:NO3 thermal water; d: NO4 thermal water; e: NO5 thermal water; f: NO6 thermal water; g: NO7 thermal water; h: NO8 thermal water; i: NO9 thermal water; j: NO10 thermal water;

3.4.3 Silica geothermometers

Silica geothermometers are given below:

Quartz-no steam loss geothermometers, 0 ~ 250℃,

$$t^0C = \frac{1309}{5.19 - \log C} - 273 \quad (3)$$

Chalcedony geothermometers, 0 ~ 250℃,

$$t^0C = \frac{1032}{4.69 - \log C} - 273 \quad (4)$$

α-quartzite geothermometers, 0 ~ 250℃,

$$t^0C = \frac{1000}{4.78 - \log C} - 273 \quad \textbf{(5)}$$

Table 4: Geothermometers and circulation depth in the study area

Hot spring number	SiO_2 (mg/L)	Formula3 (℃)	Formula 4 (℃)	Formula 5 (℃)	(logQ/K)- T (℃)	Circulation depth (m)
NO1	5.7	22.1	-10.8	-24.6	90-110	2386
NO2	35	85.9*	54.9*	35.9*	70—100	1963
NO3	49.2	101.1*	71.1*	50.7*	80-120	2397
NO4	8.9	35.5*	2.7	-12.1	40-60	523
NO5	13.3	48.8*	16.2	0.4	40-55	903
NO6	18.1	59.7*	27.5	10.8	40-60	1214
NO7	16.1	55.5*	23.1	6.7	40-55	1094
NO8	14.3	51.3*	18.8	2.7	40-60	974
NO9	78.3	124.0*	95.9*	73.3*	100—130	2249

Sun and Chen, or Li et al.

NO10	85.5	128.6*	101.0*	78.0*	100—135	2394

* Thermal waters which is suitable to use the silicon dioxide geothermometers to calculate the subsurface temperatures of geothermal reservoirs.

Comparative analysis of the subsurface temperatures calculation results (as shown in table 4) indicated that the estimated temperature of geothermal reservoirs by quartz and chalcedony geothermometers were more in line with the geological conditions to form the thermal water. All in all, the temperature of HCO3– Na type thermal water ranges from 80-100℃, HCO3-Ca type thermal water from 40-60℃, and SO4-HCO3– Na type thermal water from 90-120℃, respectively.

4 SUMMARY

The thermal water in Yichun area is neutral or weakly alkaline. The hydrochemical types mainly HCO_3-Na type and HCO_3-Ca type distributed near the big fault in the south of Yichun, and SO_4-HCO_3-Na type waters were located in the northern magmatic rock area. Most thermal water have long residence time and their main ions content are positively correlated with temperature. The water-rock interaction of geothermal system has a strong influence on the concentration of ions in thermal water. The analysis results of hot spring gas components show that the hot spring gas in Yichun area belongs to nitrogen type hot spring, which mainly originates from the infiltration of atmospheric water.

Studies on hydrogen and oxygen isotopic compositions show that the thermal water in the study area is of meteoric origin, which is formed by the interaction between precipitation water and rocks. HCO_3-Na type hot springs and SO_4-HCO_3-Na type hot springs recharge elevation are higher, from 900m to 1700m, HCO_3-Ca type hot springs recharge elevation is relatively lower, from 200m to 700m. Radiocarbon dating shows that the age of SO_4-HCO_3-Na hot springs in the magmatic area is more than 6000a, much longer than that of HCO_3-Na hot springs near the fault (about 2000a), which indicates that the thermal water flow path in the magmatic area is relatively longer and groundwater runoff is slower.

The Na-K-Mg diagrams, silica geothermometers and log(Q/K)-T diagrams are used to evaluate the reservoir temperature of typical hot springs in Yichun area. The results show that most of the thermal water has not reached the full equilibrium state, and it is not suitable to use the cation geothermometers such as Na-K, Na-K-Ca and K-Mg to calculate the heat reservoir temperature. Quartz geothermometers and chalcedony geothermometers are suitable for the calculation of reservoir temperature in the study area. The results show that the subsurface temperatures are from 80℃ to 100℃for the HCO_3-Na type hot springs, from 40℃ to 60℃ for the HCO_3-Ca type hot springs， and from 90℃-120℃ for the SO_4-HCO_3-Na type hot springs. The circulation depth for HCO_3-Na type and SO_4-HCO_3-Na type waters is about 2000m， and is relatively shallow, about 1000m for HCO_3-Ca type hot springs .

REFERENCES

Arnórsson, S., 2000: Isotopic and chemical techniques in geothermal exploration, development and use. Sampling methods, data handling, and interpretation. International Atomic Energy Agency, Vienna, 49-57.

Árnason, B., Groundwater systems in Iceland traced by deuterium[J]. Soc.Sci. Islandica, 1976(42): 236.

Bodvarsson G．Exploration and exploitation of natural heat in Iceland．Bull. Volcanol., 1960, 2: 241-250．

Craig H. Isotopic Variations in Meteoric Waters[J]. Science, 1961, 133(3465):1702.

Fournier R.O., and Rowe J.J．Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells．Am.J.Sci., 1966, 26: 685-697．

Giggenbach W.F. Geothenmal solute equilibrium. Derivation of Na-K-Mg-Ca geoindieatiors.Geochimica Cosmochimica Acta[J].1988 (52), 2749-2756.

Guo Qinghai, Wang Yanxin. Significance of hydrogeochemical information on the characteristics of karst groundwater flow system: A case study of Shentou Spring in Shanxi Province[J]. Geological and scientific information, 2006, 25(3):85-88.

Hu Shengbiao,Xiong Liangping,Wang Jiyang,et al. The first batch of measured geothermal flow data reports in Jiangxi Province[J].Scientific bulletin.1992.37（19）：1791-1793.

Klaus J S, Hansen B T, Buapeng S. 87 Sr/ 86 Sr ratio: a natural tracer to monitor groundwater flow paths during artificial recharge in the Bangkok area, Thailand[J]. Hydrogeology Journal, 2007, 15(4):745-758.

Liu Bangxiu,Li Yongming,ZUO Zufa. Analysis of mineralization geological background of different structural units in Jiangxi［J］．Journal of East China Institute of Technology，2006．29(z) : 45-50．

Mahon W.A.J．Silica in thermal water discharged from drillholes at Wairakei．New Zealand, J.Sci., 1966, 9: 135-144．

Norman M D, Gagan M K. Climatic significance of seasonal trace element and stable isotope variations in a modern freshwater tufa[J]. Geochimica Et Cosmochimica Acta, 2003, 67(13):2341-2357.

Pang Zhonghe,Fan Zhicheng,Wang Jiyang. Isotopic evidence of the genesis of underground thermal water mixed with seawater in Zhangzhou Basin. geochemistry，1990(4)：296-302．

Song Yan,Dai Jinxing. A preliminary study on the combination types and causes of hot spring gas in eastern China. Natural Gas Geoscience，1991(5)：199-208．

Sun and Chen, or Li et al.

Sun Wenjie. Hydrogeochemical study of hot springs in Jiangxi Province. Master's thesis, East China University of Technology. 2008.6

Sun Zhanxue, Gao Bai, Zhang Zhanshi. Isotopes and geochemical evidence of the origin of geothermal gases in Gannan. geological sciences, , 2014, 49(3):791-798

Sun Zhanxue,WU Hongmei. Judgment of mineral-fluid chemical equilibrium and estimation of thermal storage temperature in geothermal system. Acta Geologica Sinica, 1999, 20 (Suppl.)）： 595-598 .

Sun Zhanxue. Formation characteristics of medium and low temperature underground thermal water in Jiangxi-A case study of Chongren Maanping Hot Spring. Master's thesis of East China Institute of Geology，1988 .

Sun Zhanxue . Geothermometry and Chemical Equilibria of Geothermal fluids from Hveragerdi，SE-Iceland，and Selected hot Springs Jiangxi Province . SE-CHINA, UNU, 1998 .

WERNER F.GIGGENBACH. Geothermal solute equilibria.Derivation of Na-K-Ca geoindicators . Geochimica-Cosmochimica Acta.1988,Vol,52,pp.2749-2765.

Yang Yan, Yuan Daoxian, Cheng Hai, et al. Study on ICP-MS230Th dating of older stalagmites in Dongge Cave, Libo, Guizhou and its paleoclimatic application[J]. Journal of Stratigraphy, 2008, 32(2):201-206.

Zhang Weimin . Origin analysis of geothermal water and evaluation of geothermal reservoir temperature in the Henjing area, south Jiangxi province, China . Geotectonica et Metallogenia, 1999, 23(2): 155-165 .