Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026

Hydrogeochemistry and subsurface temperature estimation of nitric geothermal waters in Western Jiangxi Province, SE-China

Zhanxue Sun[1]*, Gongxin Chen[1] , Xinhua Shi[1], Ximin Bai[2], Lu Li[1] and Zhichao Zhang[1]

1 East China University of Technology, Nanchang, 330013, Jiangxi, China

2 Jiangxi Survey Design Research Institute Co. Ltd., Nanchang Jiangxi Province, China

* zhxsun@ecut.edu.cn

Abstract : In order to assess the development potential of the geothermal resource and to identify their formation mechanism, the chemical and isotopic compositions of 15 nitric thermal waters including 11 thermal springs and 3 thermal waters from bore holes in western Jiangxi Province, SE-China, are analyzed. The thermal waters are of TDS ranging from 51 mg/L to 285 mg/L and pH values changing from 6.86 to 9.23. The chemical types of geothermal waters are mainly HCO_3-Na type and HCO_3-Ca type distributed near the major faults, and SO_4-HCO_3-Na type waters occurred in the magmatic rock area. Nitrogen is predominant gas in dissolved gases of the thermal waters accounting for 66.83% to 97.81%. The formation of the ultra-fresh nitric thermal waters is attributed to the dynamic equilibrium of precipitation-dissolution under conditions of strong and continuous water-rock interaction in geothermal systems. The geothermal reservoir temperature is estimated to be ranging from 70℃ to 135℃ and the residence time of geothermal waters is approximately ranging from 2400 years to 7600 years in the area. The researches revealed that the geothermal waters are low-medium temperature geothermal resources and suitable for non-electricity direct utilization.

Keywords: Hydrogeochemistry, water-rock interaction, subsurface temperature estimation, nitric geothermal waters

1 INTRODUCTION

For the past decade, geothermal development has been paid more and more attention to by the government and energy companies to achieve the dual carbon goals in China. 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 area, there are 95 thermal springs and more than 42 thermal water bore holes. A systematic compilation of thermal springs in the region was done by Li (1979), later by Sun (1988) and more recently by Bai (2023). The distribution of thermal springs in Jiangxi Province is mainly controlled by the NNE-NE, NW and EW trending deep faults. Thermal springs and geothermal 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).

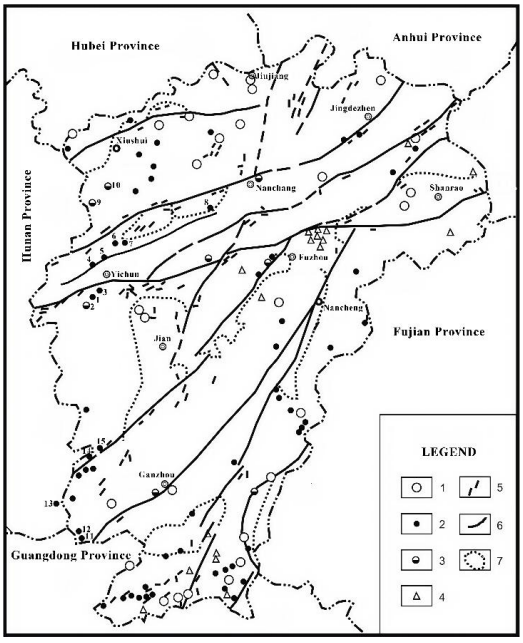


Figure 1. The distribution of geothermal waters in Jiangxi Province (1-epicenter; 2-hot spring; 3-thermal water bore hole; 4-meozoic crater; 5-intrusive rock; 6-active fault; 7-red basin.) (Modified after Sun et al., 2010)

Of the western part of the province, low TDS nitric thermal waters are widely found. Due to the relatively slow economic development in the western mountainous areas, there has been a lack of systematic studies on hydrogeochemistry and the temperatures of geothermal reservoirs. In order to determine their capacity to produce economically geothermal fluids for exploitation as inexpensively and rapidly as possible and to find out the mechanism of ultra-fresh nitric geothermal waters, the chemical and isotopic compositions of 15 nitric thermal waters including 11 thermal springs and 3 thermal waters from bore holes in Western Jiangxi Province are analyzed (Sample numbers are marked in Fig.1). The origin and formation conditions of the thermal springs are discussed.

2 SAMPLING AND ANALYSIS

Samples were taken from cold springs, wells, hot springs and surface water in the geothermal areas of the study site. All the water samples were filtered through a 0.22 μm membrane and acidified to pH <2 with 65 % HNO_3 for cation and trace element analysis. Field parameters for data supporting such as dissolved oxygen in water, pH, Eh, conductivity, silica content, alkalinity and other variable water chemical components were analyzed on site using portable thermometer, dissolved oxygen meter, multifunctional parameter tester and HACH water quality analyzer. The cations, anions, trace elements were analyzed 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 oxygen and hydrogen isotopic compositions of the waters were determined by Mat-253 mass spectrometer at the State Key Laboratory of Nuclear Resources and Environment of East China University of Technology, carbon-13 and carbon-14 isotopes were determined at the Beta Laboratory in the United States and the Third Institute of Oceanography, Ministry of Natural Resources by using Stable isotope mass spectrometer (Delta V Advantage, America, ±0.2‰) and accelerator mass spectrometer (1.5SDH-1, America, ±0.4 %), respectively. Gas composition (including CH_4, CO_2, N_2 and H_2) was analyzed by gas chromatograph (Agilent 6850, America and Trace GC Ultra, America) with an accuracy <0.01 cm-1. The concentrations of carbonate and bicarbonate ions were detected at the sampling locations by HACH digital titrator with a precision of 1 %.

3 HYDROGEOCHEMISTRY OF THERMAL WATERS

3.1 Water chemistry and gas composition

The hydrochemistry of thermal waters is the result of water-rock interactions during the formation processes of the thermal springs. The water chemistry and gas composition of geothermal fluids have proved very effective in evaluating subsurface temperature, determining water origin, predicting scaling and some other aspects. In Western Jiangxi Province, SE-China, 15 selected thermal spring samples were collected and analyzed. Water chemistry is plotted in a Piper diagram (Figure 2a) and a Na-K-Ca triangle diagram (Figure 2b). From Figure 2a, you can see that the thermal waters in the study area can be divided into three groups: Thermal waters 1-3,11-12 and 15 are HCO_3-Na Type water, Thermal springs 4-8 are HCO_3-Ca Type water, and Thermal Waters 9-10 and 13 are SO_4-HCO_3-Na Type water. Figure 2b will be discussed late in Section 4.

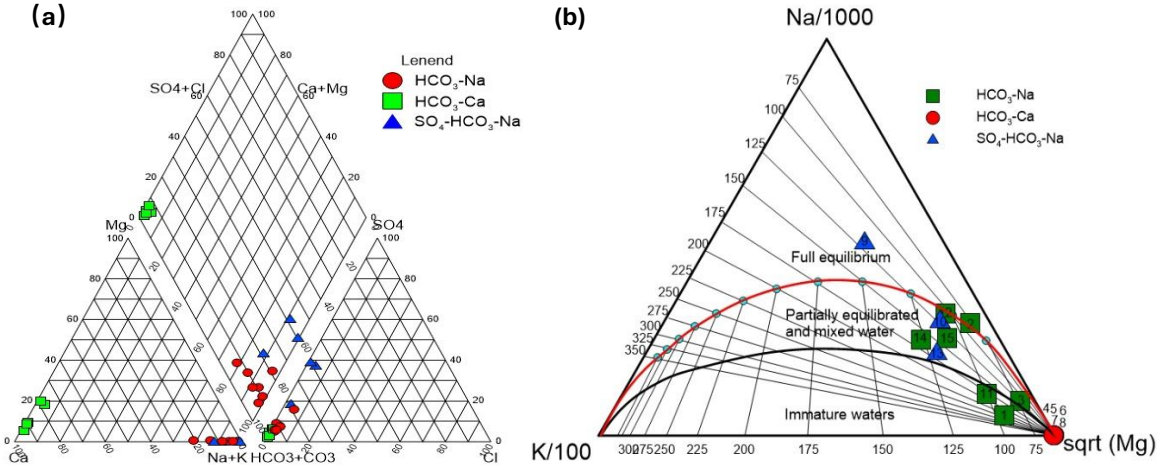


Figure 2. Piper diagram (a) and Na-K-Ca triangle diagram (b) of geothermal waters in Western Jiangxi Province,

The studies of water chemistry showed that the thermal waters in the area are neutral or alkaline with pH values ranging from 6.86 to 9.23 and with extremely low TDS ranging from 51 mg/L to 285 mg/L. Silica concentrations of

geothermal waters in the study site are ranging from 57mg/L to 122mg/L, which is quite high compared with their low TDS values. The HCO_3-Na type and HCO_3-Ca type geothermal waters distributed in the vicinity of major faults in southern part of the study area, and the SO_4-HCO_3-Na type ones exposed in the northern magmatic rock region.

Why are the nitric geothermal waters so fresh? The interaction of thermal waters with aluminosilicate minerals continued throughout their occurrence in rocks during both filtration down to the geological profile and ascent to the surface. Chemical elements that accumulated in the solution because of endogenous mineral dissolution were continuously assimilated into secondary minerals: Ca into calcite, montmorillonite, zeolites, and other aluminosilicates; Mg into glaucophane, talc, chlorite, and zeolites; Na into albite and zeolites; K into illite, muscovite, microcline, biotite, phlogopite, etc.; Fe into siderite and Fe-aluminosilicates; and F into fluorite and micas. Thus, the system could reach both chemical and dynamic equilibrium and establish a balance between the amounts of elements, which enter into and precipitate from the solution. However, these secondary minerals were not formed simultaneously, instead they were formed sequentially in accordance with dissolution laws: minerals with low solubility are formed first, followed by highly soluble minerals (Shvartssev et al., 2008, 2018).

Nitrogen is predominant gas in dissolved gases of the geothermal waters accounting for 66.83% to 97.81%. There is small amount of CO_2, He, Ar and H_2. It is noted that helium content of thermal spring No.12-No.15 is ranging from 0.25% to 0.84% which is higher than industrial grade of 0.1% for exploitation in China. These thermal springs are distributed in granite area and helium are mainly radiogenic which is supported by the helium isotopic evidence (the ratio of helium-3/Helium-4 ranges from 0.06Ra to 0.13 Ra), and nitrogen mostly come from atmosphere and minorly from the crust (Sun et al., 2014).

3.2 Isotopic composition

3.2.1 Hydrogen and oxygen isotopic composition

Hydrogen and oxygen isotopic compositions of rain water, cold springs, hot springs, and thermal water from boreholes are shown in Figure 3. In the region, the local meteoric water line(LMWL) is (Sun et al., 2023):

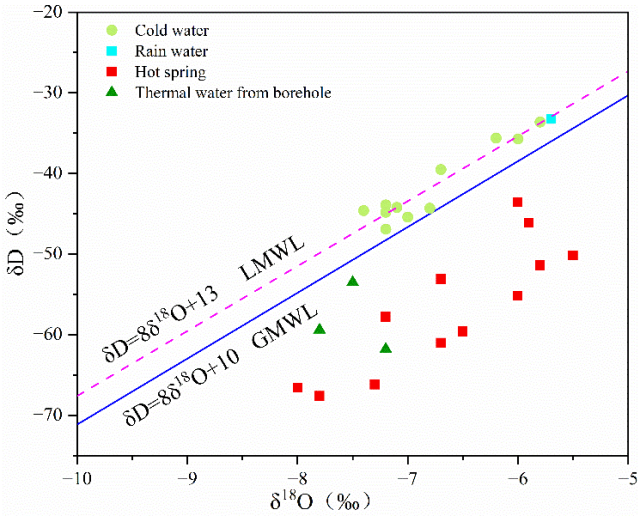


Figure 3. The δD and $\delta^{18}O$ relationship of natural waters in Western Jiangxi Province.

$$\delta D = 8.1\delta^{18}O + 13(\gamma^2 = 0.91) \quad (1)$$

The LMWL is similar to the Global Meteoric Water Line (Craig, 1961). The geothermal waters in this area distribute near the two lines, which reveals that all the geothermal waters are of meteoric origin. However they all show obvious oxygen isotope shift, which actually reflects the noticeable water-rock interaction in the geothermal systems in this area, that is, the evident oxygen isotope exchange reaction between water and rock. Generally, geothermal system temperatures need to reach at least 70-80°C for the kinetic rate of water-rock isotope exchange to be significant enough to produce observable oxygen shift over a reasonable geological time. The temperatures of the geothermal reservoirs in this study area range from 70 °C to 135°C which will be discussed late. Although they are low-medium geothermal systems, the subsurface temperatures are mostly higher than 70°C, and its residence time is mostly more than 2,000 years which will be also discussed late, and the surrounding rocks of the reservoirs are mostly silicate-rich crystalline rocks (such as granite, gneiss) or volcanic rocks (such as rhyolite and andesite). These rocks are ideal mediums for oxygen isotope exchange. The above factors lead to obvious oxygen shift of geothermal water in this area as indicated in Figure 3.

3.2.2 Estimation of recharge altitudes for geothermal waters

Based on altitude effect of precipitation and using Equation 2, recharge altitudes of geothermal waters can be estimated according to hydrogen isotopic composition due to no hydrogen isotopic shift in geothermal systems in most cases.

$$H = \frac{\delta S - \delta P}{k} + h \quad (2)$$

Where, H is the recharge altitude of hot spring (m); δS is the δD value of water sample and δP is the δD value of local atmospheric precipitation, respectively; h is the altitude of the sampling point (m); k is the δD altitude gradient of atmospheric precipitation, n ‰/100m.

In southern China, altitude gradient for δD is -2‰/100m (Yuan, 2013) and is applied here for recharge altitude calculation. The recharge altitude is ranging from 884m to 1712m for the HCO_3-Na type thermal waters, from 821m to 1153m for the SO_4-HCO_3-Na type ones and from 238m to 697m for the HCO_3-Ca type ones, respectively. Usually the HCO_3-Ca type thermal waters were recharged at relatively lower altitude areas and their residence time is relatively smaller too.

3.2.3 Dating of geothermal waters

According to previous studies, the corrected ages of carbon-14 dating for geothermal waters in the study area using Person Model are approximately ranging from 2400 years to 7600 years (Li, 2018, Sun et al., 2023). The ^{14}C age of SO_4-HCO_3-Na thermal waters occurred in magmatic rock areas are greater than 6000a, much higher than that (about 2000a) of HCO_3-Na type distributed near faults. This indicated that the geothermal waters' recharge path in magmatic rock areas is relatively longer and groundwater runoff is relatively slower.

4 EVALUATION OF SUBSURFACE TEMPERATURES IN GEOTHERMAL RESERVOIRS

The Na-K-Mg triangle diagram created by Giggenbach (1988) can be applied to assess the water-mineral equilibrium. The concentrations of Na, K and Mg in geothermal waters in the study area were plotted in Figure 2(b). It shows that all thermal spring samples are distributed in the partial equilibrium or immature zone, indicating that the waters have not in the water-rock equilibrium state, which may be caused by the geothermal water mixing with shallow groundwater to some extend during their rising movement. The thermal waters from boreholes numbered 2, 9 and 10 are close to the complete equilibrium line, indicating that these three thermal waters are closer to the water-rock equilibrium state. The three points reveal that the subsurface temperatures of geothermal reservoirs vary from 75°C to 125°C. The rest thermal waters are immature or partial equilibrium state and not suitable to use Na-K, Na-K-Ca, K-Mg and other cationic geothermometers to estimate subsurface temperatures.

The temperatures of geothermal reservoirs are evaluated by various methods such as quartz and chalcedony geothermometers, and (log Q/K)-T plot. Integrated with previous study (Zhang, 2016), the subsurface temperatures are estimated as from 70°C to 135°C, which indicates the geothermal waters are categorized as low-medium temperature geothermal resources. They are suitable for direct uses.

5 CONCLUSIONS

The geothermal waters in Western Jiangxi Province are nitric waters with extremely low TDS ranging from 51 mg/L to 285 mg/L and with neutral-alkaline pH from 6.86 to 9.23. The chemical types of geothermal waters are mainly HCO_3-Na type and HCO_3-Ca type distributed near the major faults, and SO_4-HCO_3-Na type waters occurred in the magmatic rock area. Nitrogen is predominant gas in the geothermal waters accounting for 66.83% to 97.81% which mostly come from atmosphere and minorly from the crust. The formation of nitric geothermal waters is attributed to the dynamic equilibrium of precipitation-dissolution under conditions of strong and continuous water-rock interaction in geothermal systems.

Stable hydrogen and oxygen isotopic compositions showed that the thermal waters in the study area are of meteoric origin and radiocarbon dating indicated that the residence time of geothermal waters is approximately ranging from 2400 years to 7600 years in the area. The subsurface temperatures of geothermal reservoirs are estimated as from 70°C to 135°C, which reveals the geothermal waters are low-medium temperature geothermal resources and suitable for non-electricity direct utilization.

Acknowledgements

This research was supported by the Scientific Development Fund of East China University of Technology (No. 2211001000) and the National Natural Science Foundation of China (No. 41511130031).

REFERENCES

Bai, X.M., Ye, H.L., Fan, B.H., Deng, J.J., Zhou, L., Xu, L., Yu, S.P.: Research Report on Characteristics and Metallogenic Regularity of Geothermal Water Resources in Jiangxi Province. Department of Natural Resources of Jiangxi Province, Nanchang. China (2023).

Craig, H.: Isotopic variations in meteoric waters. *Science,* 133, (1961), 1702–1703.

Giggenbach, W.F. Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators. *Geochim. Cosmochim. Acta* 52(1988), 2749–2765.

Li, L.: Hydrogeochemistry of typical hot springs in Yichun area of Jiangxi Province. *Master's Thesis. East China University of Technology*, Nanchang, China (2018).

Li X.L.: The relationship between distribution of thermal waters and uranium mineralization in Jiangxi. *Journal of East China Geological Institute*, 2(1979), 21-29.

Shvartsev,S.L.: Geochemistry of fresh groundwater in the main landscape zone of the Earth. *Geochemistry International*, 46(13), (2008), 1285–1398.

Shvartsev, S.L., Sun, Z.X., Borzenko, S.V., Gao, B., Tokarenko, O.G., Zippa, E.V.: Geochemistry of the thermal waters in Jiangxi Province, China. *Applied Geochemistry,* 96, (2018) , 113–130.

Sun, Z.X., Gao, B., Zhang, Z.S.: Isotopic and geochemical evidences for origin of geothermal gases from hot springs in southern Jiangxi Province, SE-China, Chinese Journal of Geology, 49(3), (2014): 791-798.

Sun Z.X.: The formation conditions of hot springs in Jiangxi Province, SE-China. *MSc. thesis of East China Geological Institute*, Fuzhou China (1988), 50pp.

Sun Z.X., Chen G.X., Li L.,2023: Hydrogeochemistry of hot springs in Western Jiangxi Province, SE-China. *Proceedings World Geothermal Congress 2023*, Beijing, China (2023).

Yuan, J.: Hydrogeochemistry of geothermal systems in Guangdong coastal area. *Doctor's Dissertation. China University of Geosciences*, Wuhan, China (2013).

Zhang, Z.C.: Hydrogeochemistry of nitric hot springs in southern Jiangxi Province, *Master's Thesis. East China University of Technology*, Nanchang, China (2016).