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Application of Dissolved Noble Gas in Shallow Groundwater in Characterizing Deep Thermal State of Blind Geothermal System

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ABSTRACT

For areas without surface thermal displays (such as hot springs, fumaroles, mud pools, and geysers), i.e., blind geothermal systems, locating and characterizing deep geothermal resources is challenging, and drilling and exploration economics are high in the absence of target steering. In addition, the control depth and range are limited, most geophysical explorations are difficult to capture the motion process of deep geothermal fluids, and the detection results have multiple solutions. The development of research geochemical tools is very important for the limitation of deep thermal state. Noble gases hold three main characteristics: high volatility, chemical inertness, and significant differences between different endmembers, and are useful tools for deep geothermal characterization. In our study, we carried out a complete set of elemental content and isotopic ratio tests for noble gases (He, Ne, Ar, Kr, Xe) in the groundwater of Wudalianchi, and conducted source analysis (atmosphere, crust, mantle, etc.) and geological process analysis (recharge) of noble gases. Equilibrium, degassing equilibrium, diffusion, boiling vapor-liquid differentiation, etc.), and studied the ability and mechanism of shallow groundwater to capture deep thermal signals. This study holds scientific significance for expanding the application of noble gases in the field of geological fluid tracing and geothermal exploration, and can provide reference for other similar geothermal exploration in blind geothermal system areas.

1. INTRODUCTION

Geothermal energy is a new clean energy. In recent years, environmental protection is drawing more and more attention and traditional fossil energy is becoming increasingly scarce. The rational development and utilization of geothermal resources has become more and more popular. At the same time, geothermal energy has huge development potential. The utilization of geothermal energy has a very broad prospect of utilization.

In highly permeable formations, fluid upwelling of target aquifers along fault zones can leave characteristic signatures in shallow aquifers. The primary goal is to identify a suite of hydrological and isotopic system tracers that can point to deeper geothermal fluids or mantle heat sources, utilizing easily accessible shallow aquifers located above the target aquifer.

Noble gases have been recognized as tracer tools in hydrology for many years [1-5]. Their chemically inert nature, coupled with a clear distinction between different endmembers, can facilitate a good understanding of sinks and sources, making them powerful tools in earth and environmental sciences. Although radioactive isotopes of rare gases have many applications, mainly as dating tools for different age ranges [6], the main stable isotope system used in this study is the ^{3}He-^{4}He isotope system, expressed as the ^{3}He/^{4}He ratio. The exploration method based on hydro-geochemistry and rare gas geochemical isotope tracing is of great significance for geothermal exploration and genetic research related to mantle heat and mantle-derived magmatic heat, which can significantly reduce the cost of geothermal exploration dominated by geophysical and geological drilling.

Studies on natural earthquakes, geophysics, petro-geochemistry and other aspects show that there are a variety of data in Wudalianchi indicating upward migration of mantle materials [7-10], but the detection of dissolved rare gases in groundwater is still in a blank state. The samples collected in this study are shallow groundwater, and the test and study of dissolved rare gases in the groundwater not only fill the gap in the data of dissolved rare gases in the groundwater in the study area, but also confirm the phenomenon of upward migration of mantle materials in the region from the perspective of rare gas geochemistry.

In the past researches on rare gas isotopes in geothermal exploration, the drainage gas collection method was used to collect the gas escaping from hot springs for testing, which limited the sampling points to hot springs with gas escaping, which was not conducive to the layout of the best point for exploration. In this work, the content and isotope of dissolved rare gases in groundwater were detected and studied, and the sampling point selection range of rare gases in geothermal exploration was expanded.

2. STUDY AREA AND METHODS

Weishan is located in the northernmost part of Wudalianchi volcanic Group. Weishan basalt ($\beta q_2 w$), mid-Late Pleistocene Harbin Formation ($Q_{2\text{-}3}H$), early Holocene high floodplain accumulation (Q_4^1) and Late Holocene low floodplain accumulation (Q_4^2) are mainly exposed on the surface of Weishan area. The large thick Cambrian, Cretaceous and Quaternary strata constitute the main strata in the area (see Table 1). It has been revealed that the potential magma chamber is located at a depth of 7-13 km below the volcanic cone of Weishan, with a volume of at least 200 km^3 [8]. Based on previous seismic and MT studies [9], it is also possible that deeper magmatic distributions exist in which basaltic melts rise from sea level. The upper mantle passes through the Moho and the lower crust and heats the magma chamber in the shallow crust, where some of the material melts. There are two main groups of faults in the Weishan area, namely, the Machang-Weishan fault, which is developed in the Yanshanian granitic body, and the northeast end of the fault passes through the Weishan volcano. The fault tends to the southeast and is a compressive fault.

Table 1: Brief strata information in Weishan area

Rock stratigraphic unit	Age	Code	Thickness /m	Rock type
Low river floodplain accumulation layer	Holocene	Q_4^2	4.8	Grit and silt
Gaohe floodplain accumulation layer	Holocene	Q_4^1	6.8	Silt, gravel, coarse gravel, silty silty clay and silty clay
Harbin formation	Middle Pleistocene to Holocene	$Q_{2\text{-}3}h$	18.35	Sandy silty clay and silty clay
Weishan basalt	Middle Pleistocene	$\beta Q_2 w$	77.77	Pumice boulders, volcanoes, volcanic slag, fused breccia aggregates and basalt
Beikuanhe formation	Lower Cambrian	$Pt\in_1 b$	244.82	Silty slate, carbonaceous slate, biotite schist, diorite schist

We collected 11 groundwater samples for this study and test the contents and isotopic ratios for dissolved noble gases. When sampling well water for noble gas testing, the well should be pumped for about an hour and then the water is allowed to flow through copper tubing through a stainless steel hose. When the pH value and water temperature are stable, check that there are no bubbles and clamp both ends of the copper pipe. For spring water samples, a small peristaltic pump is used to pump water into a copper pipe through a plastic hose. To avoid air pollution, draw water as close to the spring as possible. For spring escape gas, a plastic funnel connected to a length of hose is placed above the bubbling gas for sampling purposes.

3. RESULTS AND DISCUSSION

3.1 Geophysical hypothesis for the existence of a magma sac in Weishan

Both P-wave and S-wave velocity characteristics of seismic waves can reflect the differences of geological structure attributes inside the crust. But compared with the P wave, dense array imaging method provided by the underground three dimensional S wave velocity structure, for underground rock is more sensitive to factors such as temperature, fluid, partial melting, can better reflect the rheological state and thermal structure of the earth's interior medium, especially similar fluid and partial melting of the existence of lava sac, often can cause S waves of low speed significantly abnormal, It is easy to be detected by dense array imaging.

Based on the dense array imaging method, Li Zhiwei et al. set up a dense array of 43 seismometers in Wudalianchi volcanic area in 2014, and found that there was an upper crust magma cyst under Wudalianchi Weishan volcano. Although the dense array in 2014 only covered the core area of Wudalianchi volcano centered on Weishan, based on the dense array surface wave imaging, it was found that a magma sac with a volume of about 200 km3 existed 6-13 km below Weishan volcano [8]. This result was also confirmed by magnetotelluric imaging [9].

At the same time, geophysical results show that there is a shallow barrier layer at the depth of 1-3 km in the shallow part of Weishan, which plays an insulating role for the magma reservoir.

3.2 Sections of Your Paper

The study of rare gases in Weishan area provides geochemical evidence for the existence of magma pockets in the crust of Weishan area. The measured He isotope in groundwater can be expressed as:

$$R = \frac{^3He_s}{^4He_s} = \frac{^3He_{eq} + {}^3He_{ea} + {}^3He_{cis} + {}^3He_{cn} + {}^3He_m + {}^3He_{trit}}{^4He_{eq} + {}^4He_{ea} + {}^4He_{cis} + {}^4He_{cn} + {}^4He_m} \quad (1)$$

$$He_{noea} = He_s - He_{ea} \quad (2)$$

$$He_{exc} = He_s - He_{eq} - He_{ea} \quad (3)$$

Each subscript represents: s, sample; eq, equilibrium dissolved air (saturated water); ea, excess air; cis, crustal input generated in situ; cn, crustal input generated ex situ; m, mantle source input; Trit, ^3H undergoes beta decay; noea, the measured concentration of the component without ea; exc, the measured concentration minus the ASW (air saturated water) and ea components.

According to the discrimination of He isotopes, there is no mantle source signal in the groundwater in the northern part of the two Weishan faults. After the groundwater flows through the faults from north to south, there is an obvious mantle source signal in the groundwater in the southern part of the faults. The ratio of rare gas sampling sites and helium isotope R_{exc}/R_a is shown in figure 1. It indicates that the fault connects mantle-derived magmatic gas and shallow groundwater.

The potential magma sac and gas channel provide better conditions for mantle-derived gas to enter the shallow groundwater. The groundwater containing mantle-derived gas is mixed in both basalt and sandstone water in Weishan area. The NE and NW trending faults in Weishan area constitute a channel for upper mantle magma to penetrate and mantle-derived gas to rise, and the flow direction of groundwater is north to south. When passing through the fault area, deep groundwater containing mantle-derived components is mixed, so the rare gases of samples from south part of the fault have obvious mantle-derived signals (Figure 1). Combined with the geophysical results mentioned in the previous section, it can be shown that there is an uncondensed mantle-derived magma sac in the shallow crust of Weishan, and the signal analysis of rare gases in the shallow groundwater of Weishan area is shown in figure 2.

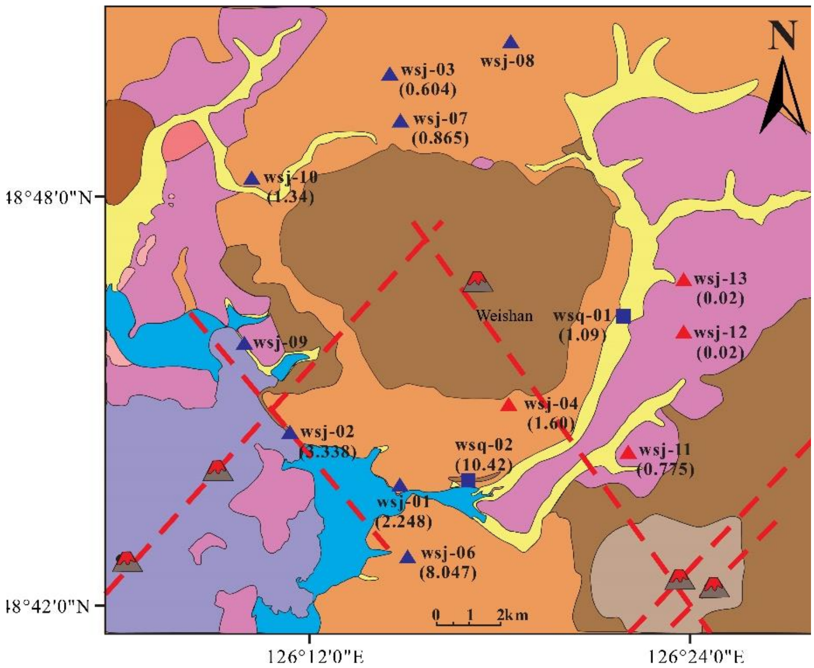

Figure 1: R_{exc}/R_a distribution pattern of helium in shallow groundwater of Weishan area.

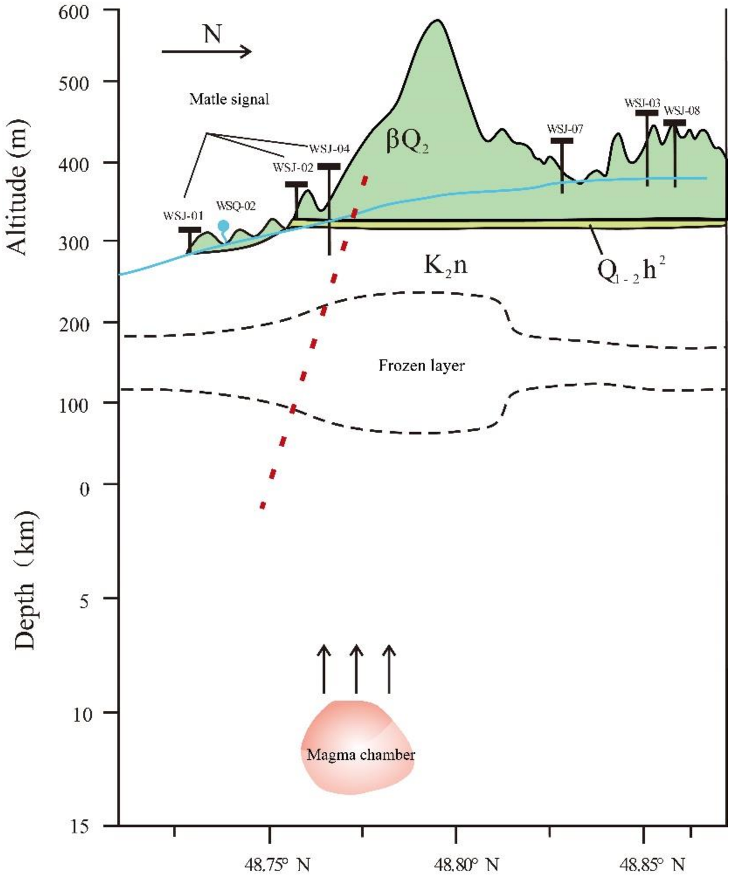

Figure 2: Schematic diagram of signal analysis of rare gases in shallow groundwater of Weishan area.

4.CONCLUSIONS

The NE and NW faults in Weishan area constitute the upper mantle magma and gas channels. The potential magma sac and gas channel provide a good condition for mantle-derived gas intrusion, and the aquifer near the fault area is obviously input by mantle-derived components of rare gas and hydrochemical components. In Wudalianchi Weishan area, geophysical and rare gas geochemical evidences indicate the existence of mantle-derived magma pockets in the crust and high temperature geothermal in the shallow crust. Weishan area can be used as a favorable area for dry hot rock geothermal geological survey and dry hot rock drilling project.

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According to this study, dissolved Noble Gas in Shallow Groundwater could be used in Characterizing thermal state of blind geothermal system.

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