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Helium Isotopic Ratios of Fluid Samples in I-Lan Plain, NE Taiwan and its Implication of Geothermal Energy Exploration

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ABSTRACT

The first comprehensive helium isotope survey of fluid samples in I-Lan Plain is reported here. We have sampled geothermal fluids thorough the whole plain. The results from representative sampling sites show that a mantle component is significant over all the studied area. The contributions of mantle components in the fluid samples can be up to 15% for both plain sites and mountain area. It implies that magmatic fluids might have invaded into the I-Lan Plain and indicate a heat source to elevate the geothermal gradient in this area. If it this is the case, the distribution of a potential geothermal energy reservoir will be much larger than previously expected. Meanwhile, it is worth noting that Ren-Tzer and Ten-Gou-Xi hot springs are characterized by different $^3He/^4He$ ratios with different percentage of mantle input, although they are only geographically divided by a river, Ten-Gou-Xi. It implies the existence of some fractures and/or faults as passageways for mantle featured fluids rising through and to the ground in this region.

1. INTRODUCTION

Geothermal resource is a sustainable resource of energy. It hardly produces any pollution, and we can get it from the resource area via proper means at any time, only depending on the condition of the geothermal area (Ngô and Natowitz, 2009).

Helium isotopes can be used to evaluate various kinds of geological or hydrological aspects. The unique signature of helium isotopes and other possible footprints characterizes a geothermal system. Due to the high temperature system, we can observe abnormal features on surface and its helium isotopes may indicate the mixing of different fluids (Roberts et al., 1975; Torgersen and Jenkins, 1982; Welhan et al., 1988a, b; Poreda and Arnorsson, 1992; Poreda et al., 1992; Hilton et al., 1993; Hilton, 1996; Hoke et al., 2000; Barry et al., 2009; Yokochi et al., 2013; Cinti et al., 2014; Koike et al., 2014).

The I-Lan plain, located at the northeastern part of Taiwan, is at the southern end of Okinawa Trough. Due to the opening of Okinawa Trough, there are more than 70 active submarine volcanoes detected and a higher geothermal gradient triggers on-land hot springs, which are well distributed around the I-Lan plain. The famous Ching-Suei Hot spring, which is the largest site producing geothermal energy, was already taken for producing geothermal energy, but was shut down in 1992 owing to technical problem such as scaling in or corrosion of well pipes (Yang et al., 2005; Lai et al., 2009). The importance of renewable energy resources is strongly emphasized during these years, and geothermal energy is expected to be a vital contributor of clean energy particularly in Taiwan. To investigate the geothermal fluids in the I-Lan plain, we use the special characteristics of helium isotopes to identify the gas source and reservoir of this area.

2. STUDY AREA

The I-Lan plain, at the northern part of Taiwan, is triangle-bounded in topography by the Hsuehshan Range and the northern part of Central Range. The I-Lan plain and Central Range are mainly divided by the Lishan Fault, a thrust fault which is extended to Okinawa Trough and the vertical depth of the Lishan Fault is less than 20 km (Tsai, 1975). Furthermore, from GPS data, the extension rate of the western boundary of the I-Lan plain is 126mm/yr, which may cause the subsidence of the I-Lan plain (Hsu et al., 1996; Yu et al., 1997; Lai et al., 2009). According to previous studies, the extension of the I-Lan plain might be related to the southwestern-toward extension of Okinawa Trough. Geophysical survey data also reveal the thickness of 1700 m sediments in the central part of the I-Lan, but debates about the lithology and stratigraphy deeper than the sediments is still ongoing based on further information.

3. SAMPLE COLLECTION AND MEASUREMENTS

Bubbling samples are from Su-Au (SA) cold springs, Ching-Suei (CS) hot springs, and Fan-Fan (FF) hot springs. Well water samples were collected from Jiao-Shi hot springs, Ren-Tzer (RZ) hot springs, and the San-xing borehole. Tu-chang (TGS) hot spring and Pai-Ku-Xi (PKS) hot spring were sampled from natural spring pools. Natural gases in Wu-Yuan (WY) were also collected. In contrast to most samples with CO_2 as major composition, WY gases are the only CH_4-dominant samples in this study (Fig. 1).

We used high vacuum and low permeability glass bottles with two evacuated stopcocks at both ends to collect the representative hot springs samples from the well and natural springs, and also the bubbling gas samples of springs for the measurement of gas compositions. Bubbling samples were collected by the method of water replacement using a funnel covering on the top of bubbling sites. All the gas samples were analyzed by a gas chromatography system, which is equipped with two thermal conductivity detectors and one flame ionic detector, for determining their gas compositions first. The analyzed samples were then sent for further helium isotopes measurement. $^3He/^4He$ and $^4He/^{20}Ne$ ratios have been measured with the Micromass 5400 noble-gas mass spectrometer. A 20 R_A pure helium gas standard (Matsuda et al., 2002) and air gas are used for the correction and calibration of helium isotopic ratio. Details of the measurements have been given by Yang (2000).

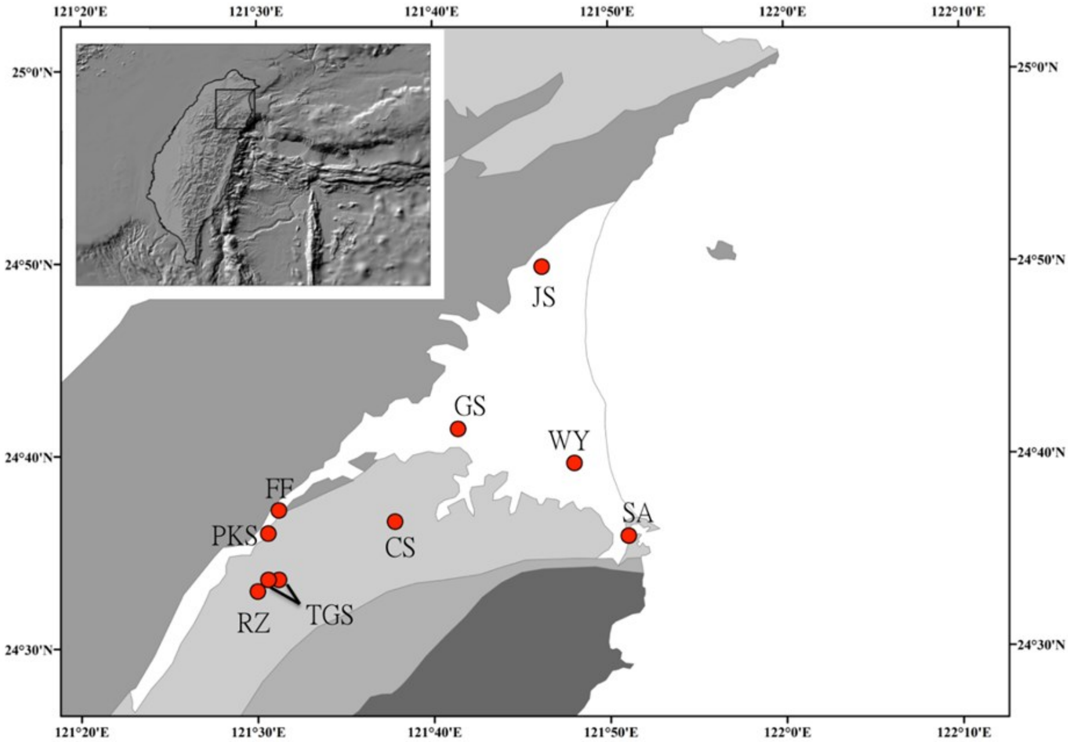

Figure 1: Study area, distribution of sampling sites in the I-Lan plain.

4. ANALYTICAL RESULTS

4.1 Dissolved gases

The compositions of dissolved gases of hot spring water are shown in Table 1. In addition to Wu-Yuan where the major dissolved gas is methane, carbon dioxide plays an important component of all proportion in most samples. Compared to hot spring bubble, the main part of dissolved gas of samples from the well in CS is nitrogen, possibly due to the continuous introduction of well water to the cooling tank so that the air occupies a significant proportion of dissolved gas (Table 2). The main gas of samples obtained from other drilling wells is also carbon dioxide.

Table 1: Gas compositions of dissolved gases in hot springs

Date	Site	Ar (%)	N_2 (%)	O_2 (%)	CH_4 (%)	CO_2 (%)	He (ppm)
110228	TGS	1.23	45.39	5.12	0.51	47.75	4.20
110301	WY	0.66	16.34	3.12	78.08	1.79	2.87
110616	GS	B.D.L.	19.48	12.55	1.08	65.26	1.41
110704	CS	0.85	73.67	20.68	B.D.L.	4.77	1.93
110705	CS	0.97	72.10	19.73	B.D.L.	7.19	5.73
110804	SA	0.01	3.12	0.36	B.D.L.	96.51	7.97
110804	JS	0.47	66.63	12.69	B.D.L.	20.22	9.61
110818	PKS	0.29	20.02	1.02	B.D.L.	78.67	6.11
111121	RZ	1.12	78.96	6.87	0.39	11.53	5.03
111207	TGS	0.22	91.55	7.29	0.58	0.36	0.48

4.2 Bubbling gas

There are four hot springs bubbling sites outcropping in this area (Table 2). The bubbling site in CS is close to the borehole, and the main composition is carbon dioxide gas. Methane bubbles dominate Wu-Yuan. Fan-Fan also has a major component of carbon dioxide in bubbles.

4.3 Helium isotopes

Helium isotope ratios, the study area will be expanded to the entire Ilan integrate previous studies (Yang et al., 2005) and the program analyzes the data in the table below (Table 3).

Table 2: Gas compositions of bubble gases in hot springs

Date	Site	Ar(%)	N_2(%)	O_2(%)	CH_4(%)	CO_2(%)	He (ppm)
100707	CS	0.08	3.91	0.45	B.D.L.	95.06	0.55
100804	CS	0.02	3.34	0.57	B.D.L.	96.03	0.59
100910	WY	0.15	8.62	0.05	90.78	0.38	6.77
111121	FF	0.38	27.68	1.18	4.36	66.37	13.83

Table 3: Helium isotopic ratio and mantle input percentages of bubble and dissolved gases in hot springs

Site	Type	$^4He/^{20}Ne$	$^3He/^4He$	$[R/R_A]^1$	$[R_c/R_A]^2 \pm 1\sigma$	He (ppm)	$X_M{}^3$	Ref.
Wu-Yuan natural gas								
110301-WY	Well	6.11	2.10×10^{-6}	1.51	1.54 ± 0.02	4.34	19%	5
50309-WY-1	Bubble	4.55	1.93×10^{-6}	1.39	1.42 ± 0.03	7.14	17%	4
50403-WY-2	Bubble	5.59	1.94×10^{-6}	1.4	1.42 ± 0.02	6.34	17%	4
Su-Au cold springs								
110804-SA	Well	6.92	1.57 × 10-6	1.13	1.14 ± 0.02	7.97	14%	5
90728-SA-2-2	Bubble	3.59	1.61 × 10-6	1.16	1.17 ± 0.03	27.7	14%	5
20223-SA-2-1	Bubble	7.33	1.77 × 10-6	1.27	1.29 ± 0.03	33.4	16%	4
20710-SA-1-1	Bubble	4.32	1.60 × 10-6	1.15	1.17 ± 0.03	64.7	14%	4
30227-SA-1	Bubble	14.8	1.70 × 10-6	1.22	1.23 ± 0.04	36.7	15%	4
30314-SA-1	Bubble	11.5	1.80 × 10-6	1.29	1.30 ± 0.04	38.0	16%	4
30404-SA-1	Bubble	15.5	1.71 × 10-6	1.23	1.23 ± 0.03	42.1	15%	4
Jiao-Shi hot springs								
110804-JS	Well	6.77	0.56×10^{-6}	0.40	0.37 ± 0.01	9.61	4%	5
90625-JS	Well	2.00	0.70×10^{-6}	0.51	0.41 ± 0.01	13.2	5%	5
90408-JS-2	Well	7.75	0.56×10^{-6}	0.41	0.39 ± 0.01	—	4%	5
30221-JS-2	Well	8.73	0.54×10^{-6}	0.39	0.37 ± 0.01	61.8	4%	4
30404-JS-2	Well	5.09	0.57×10^{-6}	0.41	0.37 ± 0.01	41.2	4%	4
30418-JS-1	Well	9.94	0.54×10^{-6}	0.39	0.37 ± 0.01	39.4	4%	4
Yuan-Shan hot springs								
090710-YS	Well	1.60	0.71×10^{-6}	0.51	0.39 ± 0.01	0.81	4%	5
30213-YS-2	Bubble	0.69	0.93×10^{-6}	0.67	0.39 ± 0.01	11.4	4%	4
30519-YS-2	Bubble	0.63	1.02×10^{-6}	0.73	0.45 ± 0.01	11.5	5%	4
30811-YS-2	Bubble	0.68	0.94×10^{-6}	0.67	0.39 ± 0.01	11.3	4%	4
31009-YS-2	Bubble	0.82	0.92×10^{-6}	0.66	0.44 ± 0.01	17.2	5%	4
Ching-Suei hot springs								
100707-CS	Bubble	0.68	1.54×10^{-6}	1.12	1.20 ± 0.07	0.55	14%	5
20223-CS-2	Bubble	0.73	1.82×10^{-6}	1.31	1.55 ± 0.04	2.27	19%	4
20710-CS-2	Bubble	0.64	1.54×10^{-6}	1.11	1.22 ± 0.31	1.50	15%	4
Fan-Fan hot springs								
111121-FF-2	Bubble	2.26	0.21×10^{-6}	0.15	0.02 ± 0.00	13.8	<1%	5
30206-FF-1	Bubble	2.65	0.31×10^{-6}	0.22	0.12 ± 0.00	8.17	<1%	4
Ren-Tzer hot springs								
111121-RZ-1	Well	0.43	1.08×10^{-6}	0.77	—	5.03	—	6
00819-RZ-2-1	Bubble	4.34	0.22×10^{-6}	0.16	0.09 ± 0.01	6.34	<1%	4
00828-RZ-2-2	Bubble	3.74	0.27×10^{-6}	0.2	0.12 ± 0.03	1.86	<1%	4
Tu-chang hot spring								
111207-TGS-4	Natural	0.98	1.57×10^{-6}	1.13	1.18 ± 0.03	0.48	14%	5
110228-TGS	Natural	0.85	1.18×10^{-6}	0.85	0.75 ± 0.01	4.20	9%	5
090716-TGS	Natural	0.64	1.24×10^{-6}	0.89	0.78 ± 0.02	1.08	9%	5
Pai-Ku-Xi hot spring								
110818-PKS	Bubble	1.88	0.44×10^{-6}	0.32	0.18 ± 0.00	1.52	2%	5
San-xing drilling well								
110616-GS	Well	0.76	0.74×10^{-6}	0.54	0.19 ± 0.00	1.41	2%	5

[1] R: $^3He/^4He$ ratio of measured samples; R_A: $^3He/^4He$ ratio of air (=1.39×10^{-6}).
[2] R_C：air corrected helium isotopic ratio, assuming all the Ne derived from the air (Poreda and Craig, 1989).
[3] X_M：percent of mantle component based on the calculation of $R_C = 8.0 \times X_M + 0.05 \times (1 - X_M)$.
[4] Data from Yang et al. [15].
[5] Data from this study.
[6] Failed to determine X_M. Data from this study.

5. DISCUSSIONS AND CONCLUSIONS

By the analysis of the data, the percentage of mantle component (X_M) of all sampling sites and Yang et al. (2005) can be matched, which means that the gas composition of Springs in the I-Lan is fairly stable, with little change over time. By the data marked on the map, we can detect the mantle component throughout the I-Lan plain. Over the southern part of the I-Lan plain, such as the Su-ao Cold Spring, Wu-Yuan and other regions, a mantle component as a percentage of 15% or more can be found (Table 3 and Fig. 2), implying here there may be characteristics of mantle as heat source added.

Meanwhile, it is worth noting that Ren-Tzer and Ten-Gou-Xi hot springs are characterized by different $^3He/^4He$ ratios with different percentages of mantle input, although they are only geographically divided by a river, Ten-Gou-Xi. It implies the existence of some fractures and/or faults as passageways for mantle featured fluids rising through and to the ground in this region. In Fan-Fan and other sites, there is still mantle source provided as gas component, but the proportion is small, about 5% or less.

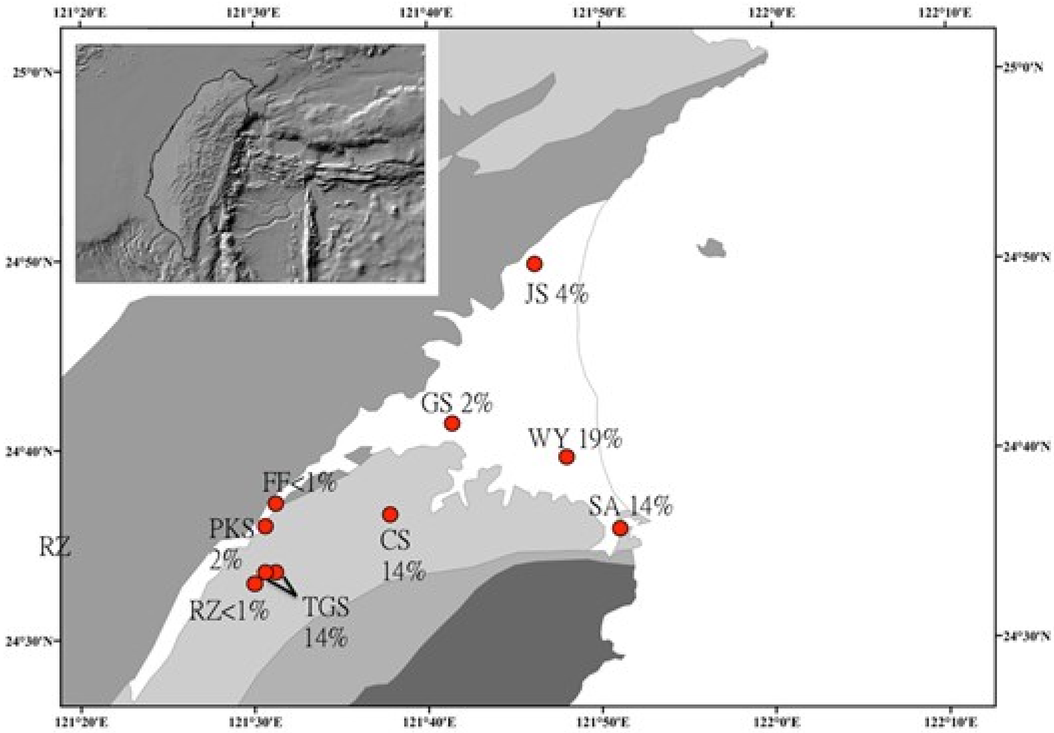

Figure 2: Estimated contribution of mantle component based on helium isotopic data in studied area.

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