A Preliminary Study on the Chemical and Isotopic Characteristics of Geothermal Waters and Gases in Northern Thailand

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Hydrogen and oxygen isotopic compositions of hot spring waters and meteoric waters from San Kamphaeng, Fang, and their vicinity in northern Thailand were measured. Although most of the data fall on the global meteoric water line $\delta D = 8 \delta^{18}O + 10$, some meteoric waters exhibit high δD and $\delta^{18}O$ values which plot on a different line defined by $\delta D = 8 \delta^{18}O - 5$. The isotopic compositions of hot spring waters vary in the range defined by the above meteoric water lines with the δD variation between -50 and -62% . No large oxygen isotopic shift was observed for all geothermal waters collected in this survey, indicating that the geothermal waters originate from the local meteoric waters.

A distinct difference was observed in hydrogen concentrations of soil gases between San Kamphaeng and Fang geothermal areas. In Fang the high H_2 concentration areas are distributed around the hot spring zone and a closed fluorite mine which is a product of past hydrothermal activity. No such areas were found in the San Kamphaeng area, suggesting that geothermal activity may be higher in Fang than in San Kamphaeng.

The $^3He/^4He$ ratios of helium in hot spring gas samples from the Fang area are higher than those from the San Kamphaeng area, although these values are lower than 3×10^{-7} . The $\delta^{13}C$ values of CO_2 in these hot spring gas samples (-7 to -11%) are close to those for volcanic CO_2 . This suggests that the volcanic CO_2 is supplied from the deep seated geothermal system and a possibility that mantle He is diluted by a large amount of crustal He originated from abundant radioactive elements in granitic rocks widely distributed in northern Thailand.

1. Introduction

Many hot springs occur in the northern Thailand where no Quaternary volcanos are present. The hot spring waters are characterized by high temperature and low concentrations of dissolved chemical species.¹⁾ Mesozoic granitic rocks are widely distributed in the northern Thailand. It has been reported that high abundance of radioactive elements (U, Th, and K) in the granitic rocks contributes to the high heat flows observed in this area.²⁾

Therefore, the heat sources of the hot springs are considered to be non-volcanic.¹⁾ The origins of gases from the geothermal systems, however, have been rarely reported. Chemical and isotopic compositions of gases from geothermal systems are the useful indicators in evaluating the heat source of the volcanic geothermal systems^{3, 4)} and the geothermal activity.⁵⁾ Therefore, it is interesting to compare the chemical and isotopic signatures of fluids and gases from geothermal systems in the northern Thailand with those from vol-

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Fig. 1. Location of geothermal fields in northern Thailand. Squares show city, town, and village. Large solid circles are San Kamphaeng and Fang geothermal fields. Solid small circles indicate hot springs as follows; CR 4: Ban Pong Nam Ron, Mae Chan; CR 5: Ban Pong Pu Fueng, Mae Suai; CR 6: Ban Sop Pong, Wiang Pa Pao; LP 1: Ban Chae Son, Chae Hom; LP 3: Ban Pong Nam Ron, Ko Kha; PR 2: Mae Chok, Wang Chin.

canic ones in Japan. Based on these data, it should be concluded whether or not the heat sources of the hot springs are non-volcanic.

The difference in thermal activity between geothermal systems may be estimated by the combined survey on hydrogen concentration and carbon isotopic composition of CO_2 in soil gases.⁵⁾ The estimation of geothermal activity can be utilized not only in geothermal prospecting but also in surveying volcanic gases in the northern Thailand. If volcanic activity contributes to the heat flows in the geothermal systems, it can be considered that the higher the thermal activity of the geothermal system, the larger the contents of volcanic gases in geothermal ones.

We had a chance to visit northern Thailand in July–August 1987 and collected

meteoric and thermal waters in there in order to know the origin of hot spring waters. The San Kamphaeng and Fang geothermal areas are the most promising candidates for geothermal exploration in the northern Thailand (Fig. 1). This paper reports the isotopic results of water samples as well as the difference in geothermal activities between San Kamphaeng and Fang geothermal areas deduced from Rn and H_2 concentrations and carbon isotopic ratios of CO_2 in soil gases. Five hot spring gases were collected from the San Kamphaeng and Fang hot springs to relate their $^3\text{He}/^4\text{He}$ and $^4\text{He}/^{20}\text{Ne}$ ratios and $^{13}\text{C}/^{12}\text{C}$ ratios of CO_2 to the origins or heat sources.

Fig. 2. Schematic diagram showing collection technique of soil gases.

2. Sampling and Analytical Methods

2.1. Isotopic compositions of water and gas samples

Hydrogen and oxygen isotopic compositions of water samples were measured using the following conventional methods. Water was converted to hydrogen gas through the reaction with uranium metal at 700°C. The D/H ratio of the hydrogen gas was measured with a mass spectrometer (MAT 250). The oxygen isotopic ratio was determined using the $\text{H}_2\text{O}-\text{CO}_2$ equilibration technique.⁶⁾

CO_2 in soil and hot spring gases were purified before isotope measurement. CO_2 and H_2O in a gas sample were separated from noncondensable gases by a trap work. CO_2 was purified from H_2O by fractional distillation at the acetone-dry ice temperature.

The hydrogen, oxygen, and carbon isotopic ratios are presented in the SMOW and PDB scales as follows,

$$\delta(\text{‰}) = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 10^3,$$

where $R = \text{D}/\text{H}$, $^{18}\text{O}/^{16}\text{O}$ or $^{13}\text{C}/^{12}\text{C}$ ratios of either sample or standard, respectively.

Noble gas isotopic and elemental compositions were determined using a mass spectrometer of a single focusing 90°

Table 1. δD and $\delta^{18}\text{O}$ Values of Meteoric and Hot Spring Waters from San Kamphaeng, Fang, and Their Vicinity

Meteoric waters		No.	Date	δD (‰)	$\delta^{18}\text{O}$ (‰)	pH	Temp. (°C)
(Fang and Chiang Rai area)							
Mae Chai river (Dam) near Fang	72804	Jul. 28	-55.4	-8.21	-	-	
	81601	Aug. 16	-56.6	-8.34	-	-	
Mae Kok river at Tha Ton	72806	Jul. 28	-47.9	-6.98	-	-	
	73007	Jul. 30	-45.2	-6.25	-	-	
	81801	Aug. 18	-63.5	-9.11	-	-	
River near CR 4 (Mae Chan)	73005	Jul. 30	-48.6	-6.76	-	-	
Mae Khong river at Chiang Saen	73006	-	-81.0	-11.27	-	-	
Mae Lao river near Mae Suai	73009	-	-32.7	-3.93	-	-	
(San Kamphaeng and Chae Hom area)							
River near CR 6 (Wang Pa Pao)	73010	Jul. 30	-46.8	-6.68	-	-	
Mae Mon river 1 near LP 1 (Chae Hom)	80106	Aug. 1	-53.1	-7.84	-	-	
Mae Mon river 2 near LP 1 ()	80108	-	-52.1	-7.55	-	-	
Mae Ping river near Chiang Dao	82201	Aug. 22	-52.1	-7.71	-	-	
Mae Taeng river near Mae Taeng	82202	-	-56.6	-8.49	-	-	
Mae Kao river near Chiangmai	82205	-	-81.3	-11.15	-	-	
(Lampang area)							
River near Lampang	73101	Jul. 31	-25.9	-2.40	-	-	
River near PR 2	73102	-	-31.3	-3.33	-	-	
Mae Yom river near PR 2 (Wang Chin)	73106	-	-31.3	-3.37	-	-	
Mae Kae river	80102	Aug. 1	-15.9	-1.75	-	-	
Mae Wang river	80103	-	-22.5	-2.23	-	-	
Hot spring and geothermal waters							
Sample name	No.	Date	δD (‰)	$\delta^{18}\text{O}$ (‰)	pH	Temp. (°C)	
(Fang)							
Natural hot spring 1	72701	Jul. 27	-58.5	-7.62	9.5	98	
	82101	Aug. 21	-60.9	-8.04	8.8	98	
Natural hot spring 2	72703	Jul. 27	-61.5	-8.20	9.0	92	
	82102	Aug. 21	-60.1	-8.09	8.6	94	
Natural hot spring 3	72704	Jul. 27	-60.8	-8.22	8.9	98	
	82103	Aug. 21	-58.8	-8.26	9.0	98	
Natural hot spring 4	72705	Jul. 27	-61.9	-8.39	9.2	92	
	82104	Aug. 21	-61.6	-8.24	9.1	94	
FGTE-7	72702	Jul. 27	-60.5	-8.44	9.0	96	
FGTE-3 (GEYSER)	72801	Jul. 28	-60.3	-8.44	9.2	99	
FGTE-14	72802	-	-60.9	-8.35	9.2	99	
FGTE-12	72803	-	-61.4	-8.58	9.2	98	
FGTE-360	72805	-	-58.8	-7.96	9.2	94	
(CR 4 : Ban Pong Nam Ron, Mae Chan)							
Natural hot spring 1	73001	Jul. 30	-57.2	-7.78	8.0	92	
Natural hot spring 2	73002	-	-56.8	-7.83	8.0	98.5	
Natural hot spring 3	73003	-	-56.2	-7.74	8.0	96	
Natural hot spring 4	73004	-	-55.8	-7.34	8.0	98	
(CR 5 : Ban Pong Pu Fueng, Mae Suai)							
Natural hot spring	73008	Jul. 30	-56.5	-8.22	8.0	74	
(CR 6 : Ban Sop Pong, Wang Pa Pao)							
Natural hot spring 1	72901	Jul. 29	-58.2	-7.91	8.3	84.5	
Natural hot spring 2	72902	-	-57.9	-8.15	8.3	92.5	
Natural hot spring 3	72903	-	-57.2	-8.01	8.0	80	
Natural hot spring 4	72904	-	-57.2	-8.05	8.0	91.5	
(San Kamphaeng)							
Geyser	80701	Aug. 7	-50.9	-6.80	8.4	98	
	81301	Aug. 13	-51.9	-6.82	-	-	
Natural hot spring, Chamlong I	80301	Aug. 3	-52.6	-7.37	9.2	99	
Natural hot spring, Chamlong II	80302	-	-52.7	-7.35	9.2	98	
Natural hot spring, SP-1A	80501	Aug. 5	-51.4	-6.84	8.1	93	
Natural hot spring, SP-1B	80502	-	-53.9	-7.49	8.3	94	
Natural hot spring, SP-1C	80503	-	-52.5	-7.25	8.1	91.5	
Natural hot spring, SP-4	81401	Aug. 14	-50.4	-6.87	-	98.5	
Natural hot spring, SP-4/2	81402	-	-51.3	-6.94	-	85	
GTE-6	82203	Aug. 22	-52.7	-7.54	8.8	98.5	
GTE-2	82204	-	-52.1	-7.89	8.4	74	
	81302	Aug. 13	-54.0	-7.73	8.3	74	
EGAT-2	80702	Aug. 7	-50.9	-6.83	8.4	72	
(LP 1 : Ban Chae Son, Chae Hom)							
Natural hot spring 1	80104	Aug. 1	-56.4	-7.93	7.8	81	
Natural hot spring 2	80105	-	-56.8	-7.89	7.8	78.5	
Natural hot spring 3	80107	-	-56.1	-7.76	7.8	81	
(LP 3 : Ban Pong Nam Ron, Ko Kha)							
Natural hot spring, LP 3	80101	Aug. 1	-51.4	-7.10	7.7	65	
(PR 2 : Mae Chok, Wang Chin)							
WGTE-1	73103	Jul. 31	-54.5	-7.61	7.6	76	
Natural hot spring 1	73104	-	-52.7	-7.65	7.6	62	
Natural hot spring 2	73105	-	-51.4	-7.08	7.6	57	
... not measured							

(- : not measured)

Fig. 3. Diagram of δD vs. $\delta^{18}O$ for the meteoric and thermal waters from San Kamphaeng, Fang, and their vicinity.

sector type with 30 cm radius of ion curvature. Pipetted atmospheric noble gases and an artificially prepared $^3\text{He}/^4\text{He}$ standard gas were used to estimate the sensitivity and mass discrimination during measurement.

2.2. Sampling methods of soil- and hot spring gases

The soil gases were collected in the following way. A 60 cm deep hole with a diameter of 4.5 cm were made by driving a steel pipe into the ground. The Rn concentrations in soil gases were measured by circulating the soil gas through a cell of a portable scintillation counter (Model RD 200 made by EDA) immediately after removing the steel pipe. After the measurement of Rn concentration, the soil gas was confined in the hole using a bentonite seal (Fig. 2). After a storage for about 24 hours, the gas was sampled into a evacuated small glass tube (5 ml) by a syringe and analyzed for chemical composition. The remaining gas was transferred to an evacuated glass tube (about 150 ml) for the carbon isotopic measurement of CO_2 . The concentrations of CO_2 in soil

gases were measured in the field by gas detection tubes (Gastec). Bubble gas in hot springs was collected by the conventional water replacement method. The chemical analyses of soil and bubble gases were done by a gas chromatograph.

3. Results and Discussion

3.1. Isotopic compositions of geothermal and meteoric waters

Table 1 shows hydrogen and oxygen isotopic ratios of geothermal and meteoric waters in northern Thailand. The relationship between δD and $\delta^{18}O$ of meteoric waters from San Kamphaeng, Fang, and the vicinity were shown in Fig. 3. The relationship between δD and $\delta^{18}O$ of the local meteoric waters is close to that of the global meteoric water line, $\delta D = 8\delta^{18}O + 10$,⁷⁾ excluding samples from the Lampang area. The Lampang meteoric waters show high δD and $\delta^{18}O$ values which lie on a line, $\delta D = 8\delta^{18}O - 5$. Furthermore, it was found that the δD and $\delta^{18}O$ values of Mae Kok river waters collected three times within two weeks fluctuate drastically in the range between -64 to -45‰ and -9.1 to

Fig. 4. Sampling locations of soil gases in the San Kamphaeng area and the concentrations of Rn. Solid line shows road. A-A': Huai Ang fault, B-B': sub-fault perpendicular to the Huai Ang fault (after Chuaviroj *et al.*⁹⁾).

–6.3‰, respectively, along the global meteoric water line. Takashima and Jarach⁸⁾ reported that the isotopic compositions of meteoric and thermal waters were confined in the area defined by the equations of $\delta D = 8\delta^{18}O + 2.6$ and $\delta D = 8\delta^{18}O - 1.4$, and the δD values of –55 and –68‰, assuming that the slope is 8 for precipitations. In this survey, it was found that the slope of local meteoric water line in northern Thailand also is 8 and isotopic compositions of meteoric waters fluctuate dras-

tically over normal range.

The isotopic compositions of hot spring waters from the San Kamphaeng area are systematically higher than those from the Fang areas (Table 1). This can be explained by the difference in the altitude between the two areas. Although the range overlaps, the hydrogen isotopic compositions of hot spring waters of this study are consistently higher than those reported by Takashima and Jarach.⁸⁾ This suggests that the isotopic compositions of

Fig. 5. $\delta^{13}\text{C}$ values (‰) of CO_2 of soil gases in the San Kamphaeng area. The dotted area indicates the high $\delta^{13}\text{C}_{\text{CO}_2}$ zone (≥ -16 ‰). B-B': sub-fault perpendicular to the Huai Ang fault.

geothermal waters may fluctuate in the range defined by the equations, $\delta\text{D} = 8\delta^{18}\text{O} + 10$ and $\delta\text{D} = 8\delta^{18}\text{O} - 1.4$, and δD values of -50 and -68 ‰ (Fig. 3). Furthermore, it should be noted that no oxygen shift was observed. Therefore, the origin of these geothermal waters can be concluded to be local meteoric waters. Furthermore, fluctuation of isotopic ratios of the hot spring waters may be ascribed to intermittent incorporation of the local meteoric water having extremely high isotopic ratios.

3.2. Chemical and isotopic compositions of soil gases

3.2.1. San Kamphaeng geothermal area

Figure 4 shows sampling locations of soil gases. The Rn concentrations range from 1 to 1032 counts/3 min. These concentrations are higher than those (7 to 591 counts/3 min.) in the North Kirishima geothermal field in Japan. Hereafter, we will compare our data at northern Thailand with those at North Kirishima, because

North Kirishima is the only geothermal field where soil gas survey has been extensively made.⁵⁾ The sites with high Rn concentration distribute along the Huai Ang fault. Chuaviroj *et al.*⁹⁾ have reported a similar distribution of Rn concentrations in soil gases of this area. However, the CO₂ anomaly zones (the concentration of mainly 0.5 to 4%, higher than those from the North Kirishima area that range from 0.1 to 0.6%) were not observed.

Kita and Taguchi⁵⁾ reported that the $\delta^{13}\text{C}$ mapping of soil CO_2 is more useful than the CO_2 concentration mapping for the geothermal prospecting. The $\delta^{13}\text{C}$ values of CO_2 in San Kamphaeng soil gases range from -12 to -26% . The high $\delta^{13}\text{C}$ sites (higher than -16%) are distributed not along the Huai Ang fault but mainly along the sub-fault (Fig. 5). Although there is a large difference in CO_2 concentrations between the San Kamphaeng and North Kirishima geothermal areas, the $\delta^{13}\text{C}$ values of CO_2 are roughly in the same range between -12 and -25% . In general, the $\delta^{13}\text{C}$ values of sedimentary carbon are from -40 to -20% including petroleum and coal, whereas the mean $\delta^{13}\text{C}$ values of CO_2 from geothermal areas vary between -3 to -5% .¹⁰⁾ The $\delta^{13}\text{C}$ value of marine limestone fluctuated between -1 and 4% during Phanerozoic time.¹¹⁾ Taking the above variations in $\delta^{13}\text{C}$ of various carbon reservoirs, soil gases in the San Kamphaeng area contain CO_2 of mainly organic origin (with $\delta^{13}\text{C}$ values less than -20%). However, soil gas CO_2 with $\delta^{13}\text{C}$ values higher than -20% along the sub-fault (Fig. 5) suggests a gas migration from the deep seated geothermal system. On the other hand, the sites of high H_2 and CH_4 concentrations were not found out in the San Kamphaeng geothermal field. This is inconsistent

Fig. 6. Sampling locations of soil gases in the Fang area and the concentrations of Rn. Solid line shows load.

with what Kita and Taguchi⁵⁾ found in the North Kirishima geothermal area, Japan: positive spatial correlation between the area of high temperature geothermal waters and high H_2 - and high $\delta^{13}C_{CO_2}$ anomalies of soil gases. The fact that the San Kamphaeng soils do not show the H_2 anomaly but the $\delta^{13}C_{CO_2}$ anomaly along the sub-fault suggests that temperature of the geothermal waters underneath the sub-fault may be relatively low. In other words, the geothermal activity of the San Kamphaeng area is lower than that of the North Kirishima area. Our estimation is consistent with the fact that no high tem-

Fig. 7. $\delta^{13}\text{C}$ values (‰) of CO_2 and H_2 concentration (in parentheses, ppm) of soil gases in Fang area.

perature geothermal waters were obtained from the exploration wells in the San Kamphaeng area drilled to 150 m (GTE-3), about 500 m (GTE-1, 2, 4, 5, and 6) and 1227 m (GTE-7) (Fig. 5).¹²⁾

3.2.2. Fang geothermal area

Figure 6 shows the sampling locations of soil gases. The Rn concentrations range from 0 to 2311 counts/3 min. The Rn concentrations around the hot spring zone are clearly higher than those in the San Kamphaeng area. Granitic rocks are widely distributed in the Fang area. The

altered granitic rocks are also exposed in the hot spring zone. Distribution of soil gases with high Rn concentrations seems to be consistent with the existence of granitic rocks which are rich in U and Th.

The Fang soil gases are characterized by high H_2 concentration of 4 to 8700 ppm, especially around the closed fluorite mine (Fig. 7). CO_2 concentrations are also high in the range from 2 to 9% (which is higher than those in the San Kamphaeng area). The $\delta^{13}\text{C}_{\text{CO}_2}$ values are in the range from -11 to -26 ‰ (Fig. 7), being almost the same as those from the San Kamphaeng area and North Kirishima in Japan, despite of the large difference in CO_2 concentrations in soil gases between these areas. This fact indicates that the CO_2 originates mostly from organic materials. On the other hand, CO_2 of soil gases in and around the hot spring zone including the closed fluorite mine shows the high $\delta^{13}\text{C}$ values indicating that the CO_2 are migrated from the deep seated geothermal system. The high $\delta^{13}\text{C}_{\text{CO}_2}$ values are coupled with the significantly high H_2 concentrations in soil gases around the closed mine. The zones with the significantly high concentrations of H_2 may suggest the existence of high temperature geothermal waters underneath.⁵⁾ A distinct difference was observed in hydrogen concentrations of soil gases between San Kamphaeng and Fang areas. Therefore, the geothermal activity at the Fang area can be considered to be higher than that at San Kamphaeng area.

3.3. $^3\text{He}/^4\text{He}$ and $^4\text{He}/^{20}\text{Ne}$ ratios and $\delta^{13}\text{C}$ values of CO_2 in hot spring gases

The $^3\text{He}/^4\text{He}$ ratios and $\delta^{13}\text{C}$ values of CO_2 in hot spring gases are good geochemical parameters to estimate the heat source of geothermal manifestations. The

Fig. 8. Plots of $^3\text{He}/^4\text{He}$ vs. $^4\text{He}/^{20}\text{Ne}$ in hot spring gases from the San Kamphaeng and Fang geothermal fields. SP and FP are from San Kamphaeng and Fang hot springs, respectively. a, c, and m represent atmospheric, crustal, and mantle He, respectively. Downward arrows mean that the values of $^3\text{He}/^4\text{He}$ are equal to or less than ones shown in the Figure.

Table 2. $^3\text{He}/^4\text{He}$ Ratios, $\delta^{13}\text{C}$ of CO_2 and CO_2/CH_4 Ratios of Hot Spring Gases from San Kamphaeng and Fang Areas

Sample name	Temp. ($^{\circ}\text{C}$)	CO_2 (%)	CH_4 (%)	CO_2/CH_4	$\delta^{13}\text{C}$ of CO_2 (‰)	$^3\text{He}/^4\text{He}$ ($\times 10^{-7}$)	$^4\text{He}/^{20}\text{Ne}$
San Kamphaeng							
SP-1	93	0.14	4.5	0.03	-11.2	≤ 1	48
SP-4	96	-	-	-	-	≤ 1	15
SP-4/2	85	14.1	2.5	5.6	-7.1	≤ 1	45
Fang							
FP-7	72	24.4	11.5	2.1	-7.1	3	60
FP-7N	89	42.7	4.4	9.7	-7.6	≤ 2	33

- : not measured

$^3\text{He}/^4\text{He}$ ratios of He on the earth vary widely in the range from about 1×10^{-8} to 1×10^{-5} and the variation can be explained by the mixing of He originated from three sources; the atmosphere, crust, and mantle.³¹ Figure 8 plots $^3\text{He}/^4\text{He}$ and $^4\text{He}/^{20}\text{Ne}$ ratios in hot spring gases. Relative contribution of atmospheric, crustal, and mantle He to a sample gas can be evaluated using the various mixing curves

shown in Fig. 8. The $^3\text{He}/^4\text{He}$ ratios of volcanic and hot spring gases in Japan are generally higher than the atmospheric ratio (1.4×10^{-6}) and the gases can be considered to be a mixture between atmospheric and mantle He.^{3,4)} The amounts of ^3He in hot spring gases from the San Kamphaeng and Fang areas were so low that the precise measurements of $^3\text{He}/^4\text{He}$ ratios were difficult. This was due to very

high radiogenic He concentrations of total He (about 150 to 950 ppm). The $^3\text{He}/^4\text{He}$ and $^4\text{He}/^{20}\text{Ne}$ ratios of the San Kamphaeng and Fang hot spring gases plot on the mixing lines of atmospheric and mostly crustal He (Fig. 8), reflecting high U and Th contents in Mesozoic granitic rocks ($\text{U}=7$ to 25 ppm and $\text{Th}=15$ to 42 ppm) of San Kamphaeng and Fang areas.²⁾ This indicates that mantle He is greatly diluted by the crustal He in the hot spring gases. However, it is noted that ^3He was present sufficiently enough to be measured exactly in a sample (FP-7) from the Fang area where the geothermal activity seems to be higher than that at San Kamphaeng area. A trace amount of mantle He may be present in the Fang hot spring gases.

Table 2 shows the $\delta^{13}\text{C}$ values of CO_2 in bubble gases from San Kamphaeng and Fang areas. $\delta^{13}\text{C}$ values of CO_2 in these bubble gases are significantly higher than those of soil gases and close to the $\delta^{13}\text{C}$ values of typical volcanic CO_2 .

In the San Kamphaeng area, Permian limestone formation distributes. According to Holser *et al.*,¹¹⁾ CO_2 originated from this limestone would have a high $\delta^{13}\text{C}$ value (-1‰ to 4‰). On the other hand, the Fang area is widely covered by exposed granitic rocks. Regardless of the difference in the geology between the Fang and San Kamphaeng areas, the same $\delta^{13}\text{C}_{\text{CO}_2}$ values of -7‰ are obtained in both geothermal areas. This fact may suggest that the CO_2 is volcanic.

These bubble gases contain considerable amounts of CH_4 . Therefore, it is conceivable that the $\delta^{13}\text{C}$ values of CO_2 may be affected by carbon isotopic equilibration between CO_2 and CH_4 under the high temperature conditions. Large carbon isotopic fractionation between

CO_2 and CH_4 would increase the $\delta^{13}\text{C}$ values of CO_2 and might have made them accidentally close to that of volcanic CO_2 . However, judging from the difference in thermal activity between the San Kamphaeng and Fang geothermal areas, carbon isotopic equilibration between CO_2 and CH_4 also may be achieved at different temperatures between two geothermal areas. Furthermore, CO_2/CH_4 ratios of these bubble gases range from 0.03 to 9.7 (Table 2). Nevertheless, almost constant $\delta^{13}\text{C}$ values of CO_2 seem to indicate that $\delta^{13}\text{C}$ values of CO_2 are not controlled by the isotopic equilibration between CO_2 and CH_4 . Therefore, it may be inferred that the volcanic CO_2 is supplied from the deep-seated intrusives, although the isotopic signature of magmatic He has been almost erased by overwhelming addition of crustal He.

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Keywords

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