$^3He/^4He$ ratios of fumaroles and bubbling gases of hot springs in Tatun Volcano Group, North Taiwan (*)

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(ricevuto il 9 Giugno 1998; approvato il 18 Novembre 1998)

Summary. — Eleven representative fumarolic gases and bubbling gases of hot springs have been collected from Tatun Volcano Group, North Taiwan for the helium isotope measurement. All the samples, except one, exhibit consistent corrected helium isotope ratios ($^3He/^4He$) with the mean value of 4.67 times of air ratios (R_A). The preliminary helium data show that more than 60% of helium composition comes from deep magmatic source in this area. It implies that a relic magma reservoir may still exist underneath North Taiwan.

PACS 91.25.Ey – Interactions between exterior sources and interior properties.
PACS 91.40 – Volcanology.
PACS 91.30.Tb – Volcano seismology.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

The Tatun Volcano Group, located in the northern-most part of Taiwan, consists mainly of andesite lavas and pyroclastics of Pleistocene epoch from different volcanoes overflowing the Miocene sedimentary terrains. It has been treated as the western extension of the Ryukyu arc, the products of Philippine Sea Plate subduction (fig. 1) (*e.g.*, [1, 2]). The eruption commenced ca. 2.5 My ago, and the activity reached its maximum ca. 0.7–0.2 My ago. It is believed that the last eruption occurred ca. 200 ky ago (*e.g.*, [3]) and thus the Tatun Volcano Group may be classified as dormant volcanoes, although the thermal activity is not uncommon. Teng and his co-workers [4, 5] further predicted that the magmatism might be extinct due to the westward propagating opening of the South Okinawa Trough and the extension collapse of the northern Taiwan mountain belt. Nevertheless, the fumaroles and hot springs are still very active, usually $> 90\,°C$ and some can reach up to $200\,°C$, and mainly along the Chinshan Fault zone (fig. 1).

(*) Paper presented at the "Fourth International Conference on Rare Gas Geochemistry", Rome, October 8-10, 1997.

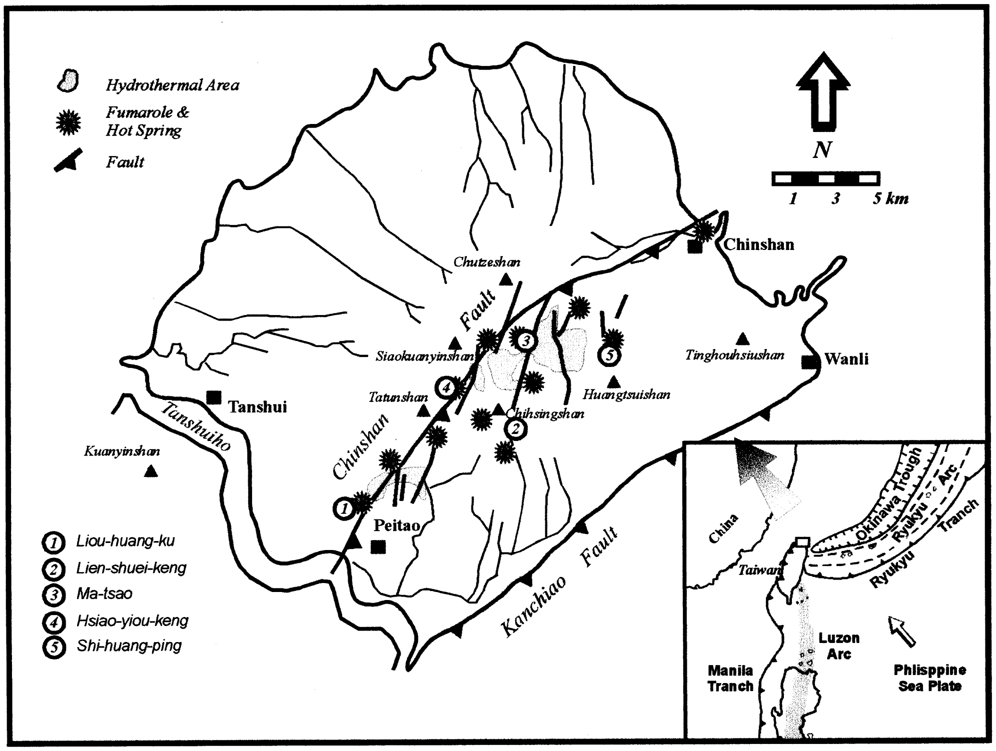

Fig. 1. – Sample locality and the distribution of hydrothermal activity of the Tatun Volcano Group; the tectonic setting around Taiwan is also shown in the inset.

Helium isotope ratio ($^3He/^4He$) measurements of fumarole and hot springs provide useful information on the magma activity [6-9]. Poreda and Craig [10], who measured $^3He/^4He$ ratios of volcanic gases from Circum-Pacific active volcanic arcs, showed that the dominant source of helium was the mantle wedge rather than subducted oceanic crust or sediment, both of which are rich in radiogenic ^4He. We will use this useful tracer to examine the possible sources of the fumarolic gases and bubbles of spring waters from the Tatun Volcano Group.

2. – Results

Eleven representative fluid samples have been collected with pre-vacuum helium impermeable glass bottles from Liou-huang-ku, Lien-shuei-keng, Hsiao-yiou-keng, Ma-tsao, Shi-huang-ping, respectively (fig. 1). We tried to collect both fumarolic gases and bubbling gases of hot springs from a single locality if available for comparison.

The measurement of $^3He/^4He$ and $^4He/^{20}Ne$ ratios have been carried out by the noble-gas mass spectrometer with dual collectors in Hiroshima University, Japan. The air was routinely run as standard for calibration. The total error of the ratios is $\sim 5\%$.

TABLE I. – *Helium isotope ratios of fluid samples from the Tatun Volcano Group, North Taiwan.*

Locality	Sample No.	Sample type	$^3He/^4He\,(\times 10^{-6})$	$^4He/^{20}Ne$	$R_c/R_A \pm 1\sigma$
Liou-huang-ku	LHG-2	fumarole	6.899	30.1	5.01 ± 0.25
	LHG-3	hot spring	6.819	6.14	5.19 ± 0.28
	LHG-4	hot spring	6.909	124	4.98 ± 0.25
Lien-shuei-keng	LSK-1	fumarole	5.254	1.10	4.92 ± 0.25
Hsiao-yiou-keng	SYK-1	fumarole	5.716	3.19	4.46 ± 0.22
	SYK-2	fumarole	3.389	0.41	7.55 ± 0.38
Ma-tsao	MT-1	fumarole	5.251	4.73	3.98 ± 0.20
	MT-3	hot spring	5.739	75.8	4.14 ± 0.23
	MT-4	hot spring	5.380	4.72	4.08 ± 0.20
Shi-huang-ping	SHP-1	hot spring	6.747	55.7	4.88 ± 0.24
	SHP-2	hot spring	6.712	7.18	5.01 ± 0.25

The measured helium isotope ratios range from 3.39×10^{-6} to 6.90×10^{-6} (table I). The $^3He/^4He$ ratio increases when the $^4He/^{20}Ne$ composition increases. It can be easily explained by the mixing between the magma and the air components (fig. 2). There are two samples, LSK-1 and SYK-2, with the He/Ne ratio lower than 1, which indicates that the air contamination may have occurred during gas collection. If we assume that all the ^{20}Ne concentration of the sample comes from the atmosphere, then we can correct its helium ratio for atmospheric He contamination by eq. (1) [10]:

$$
\text{(1)} \qquad \begin{cases} (^3He/^4He)_{cor} = [(^3He/^4He)_{obs} - (^3He/^4He) \times \mathbf{r}]/(1-\mathbf{r}), \\ \mathbf{r} = (^4He/^{20}Ne)_{air}/(^4He/^{20}Ne)_{obs}, \end{cases}
$$

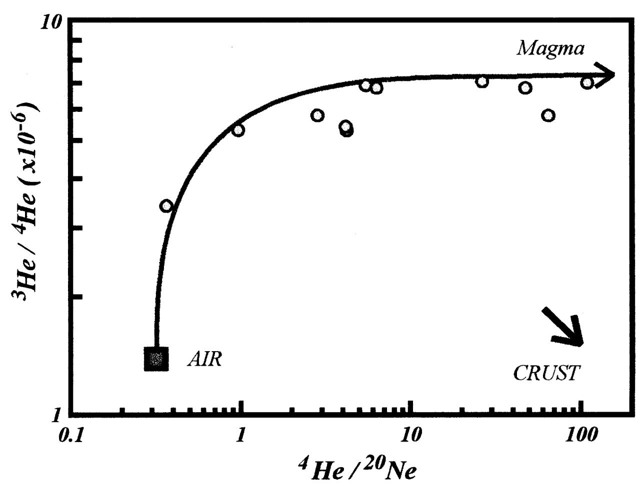

Fig. 2. – The analysis result of the fluid samples from the Tatun Volcano Group, North Taiwan in the plot of $^3He/^4He$ *vs.* $^4He/^{20}Ne$ ratios. The data show that the samples are the result of mixing between air and magma components.

where the subscript cor is the corrected value; obs is the observed value; air is the value of air.

All the samples exhibit coherent helium isotope ratios after correction, *i.e.*, 4.00–5.14 times of air ratios (R_A), except for the sample SYK-2. It would be due to serious air contamination indicating by the very low $^4He/^{20}Ne$ ratio (table I) and make it unable to do the correction for air contamination.

3. – Discussion

3·1. *Flux from the magmatic component.* – Interestingly the helium isotope ratios of both fumarolic and bubble gases from the same locality are almost identical after correction (table I), indicating rather homogeneous helium degassing source for each locality. It is worth noting that the average helium ratio ($4.07 \times R_A$) of Ma-tsao is lower than the average values of other places ($4.46–6.03 \times R_A$). It indicates that there may be more crustal and/or surface components contaminated with its source helium composition near this area. Nevertheless, we can use the average helium isotope ratio to estimate the approximate helium flux degassing from the magma component. Unfortunately, there is no direct helium measurement of phenocrysts to represent the magma component of the helium isotope ratio for this area. However, we can reasonably assume that the highest value of fluid samples which has been reported in this area, *i.e.*, $6.4 \times R_A$ [10], can be treated as the magmatic component in North Taiwan. It can be easily calculated that more than 60% of the helium composition of the fumarolic gases and bubbling gases of hot springs in the Tatun Volcano Group derives from the deep magmatic source by a simple mixing model between the magmatic

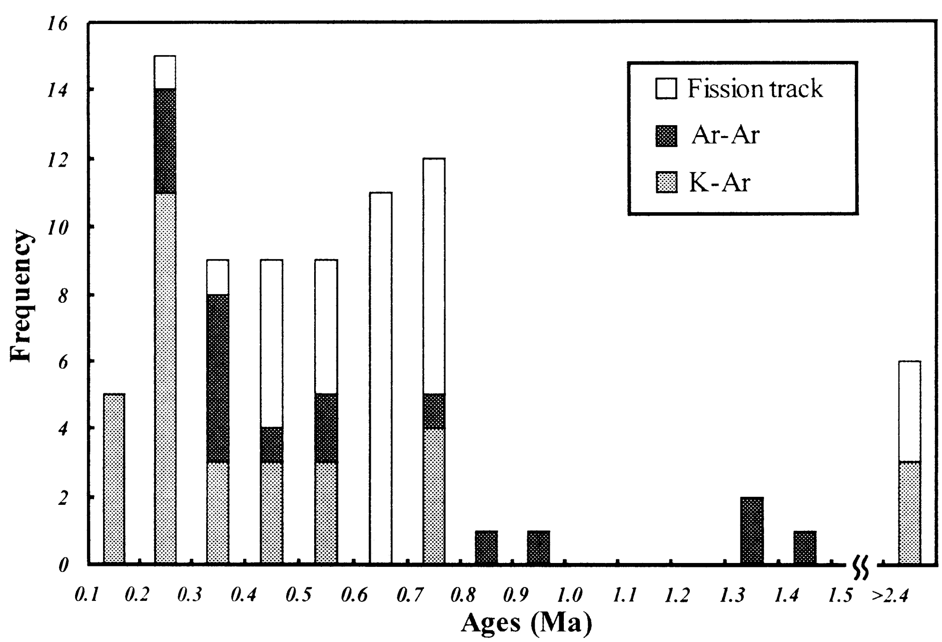

Fig. 3. – The magmatic activity of the Tatun Volcano Group; the ages are compiled from the published data [1, 11-13, 15-16].

component ($6.4R_A$) and the air component. There would be much more helium composition derived from the magmatic component if the crustal component ($< 0.1R_A$) instead of the air component ($1R_A$) were used in the mixing model calculation.

3·2. *Magma activity of the Tatun Volcano Group.* – Traditionally local geologists believed that the Tatun Volcano Group belongs to the product of southern part of the Ryukyu arc system (*e.g.,* [1, 2, 11-13]). According to the compiled published age data, hence, it was proposed that the arc magmatism in North Taiwan might have been demised due to the opening of South Okinawa Trough [4, 5]. Most recently, however, another argument was proposed, according to which the northern Taiwan volcanic zone (NTVZ) might not be the southern extension part of the Ryukyu arc system [14]. The available age dating [1, 11-13, 15-16] results show that the magma activity is continuous from ca. 0.7 My to very recently (fig. 3). Wang *et al.* [17] further interpreted that NTVZ is the product of post-collisional magnatism under extensional tectonic setting. It implies that the magmatism may be going to be active but not extinct in this area. Such extremely different tectonic model alerts people to re-evaluate the potential eruption of Tatun Volcano Group. The helium data in this study show that more than 60% of the helium composition derives from the deep magmatic source and imply that a magma reservoir may still exist underneath North Taiwan. However, degassing from a cooling relic "still hot" rock body is also an alternative possibility. Under this circumstance, long-term surveillance is necessary to monitor the magma activity in this area.

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The senior author wishes to thank Mrs. Y.-L. CHEN and T. NAOTO for their help in collecting samples and isotopic measurement. Thanks are also due to Dr. T. F. YUI of Academia Sinica for the valuable discussion and comment. This research was supported by National Science Council of Taiwan (NSC86-2116-M-002-009; NSC87-2110-M-002-001/TFY).

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