$^3He/^4He$ ratios in and around Teide volcano, Tenerife, Canary Islands, Spain

Relaciones isotópicas ^3He / ^4He del sistema volcánico Teide, Tenerife, Islas Canarias, España

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ABSTRACT

Helium-3 emission spatial distribution in and around Teide volcano, Tenerife, Canary Islands, has a quite different pattern from other stratovolcanoes which show usually a decreased trend for the $^3He/^4He$ with respect to distance from the summit crater. This finding might be related to the volcano-tectonic setting differences between subduction-type and oceanic island-type statrovolcanoes. Radiogenic helium production is a quite significant process for the dilution of uprising deep-mantle fluids in and around subduction-type stratovolcanoes while it can be almost negligible for polygenetic volcanoes at oceanic islands.

RESUMEN

La distribucion geográfica de los niveles de emisión de helio-3 en los alrededores del volcán Teide, Tenerife, Islas Canarias, presenta un modelo muy diferente al observado en otros estratovolcanes que normalmente reflejen una tendencia decreciente en las relaciones isotópicas $^3He/^4He$ respecto a la distancia con la zona sumital. Esta observación pudiera estar relacionada con las diferencias que claramente existen en el ambiente volcánico-tectónico de stratovolcanes formados en zonas de subducción y aquellos en islas volcánicas oceánicas. La producción de helio radiogénico es el proceso que juega un mayor papel en la dilución de fluidos magmáticos durante su ascenso hacia la superficie, mientras que este proceso puede ser muy poco significativo para estratovolcanes asentados en islas oceánicas.

Key words: *Helium, Isotopes, Fluids, Teide volcano, Canary Islands, Spain*

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Introduction

Helium isotope systematics in natural fluids is a potential tool for detecting deep-seated mantle degassing (Sano and Wakita, 1985; Sano *et al.*, 1986; Wakita *et al.*, 1987). Previous studies on helium-3 spatial distribution in and around polygenetic volcanic structures such as stratovolcanoes reflected a decreased trend of $^3He/^4He$ ratios with respect to distance from the summit crater (Sano *et al.*, 1984; Williams *et al.*, 1987; Marty *et al.*, 1989; Sano *et al.*, 1990; Sakamoto *et al.*, 1992). Radiogenic helium production as well as degree of tortuosity (θ) in the subsurface are the most important mechanism and geological feature, respectively, to play a significant role in the dilution of uprising deep-seated mantle helium. Therefore, this dilution process is mainly responsible for the decreased trend of $^3He/^4He$ ratios in and around stratovolcanoes.

Teide stratovolcano (3716 m elevation) is located in the intersection of three rift zones at Tenerife which is the largest island of the Canarian archipelago. Most obvious geothermal features in the subaerial environment of Tenerife Island is detected at the summit crater of Teide volcano while there is not evidences of fumarolic degassing along the rift zones. Previous studies related to geochemical and geothermal investigations at Tenerife Island revealed that temperature and chemical anomalies of the ground water system reflects some degree of volcanic-geothermal activity beside the fumarolic field at summit crater of Teide volcano (Valentín *et al.*, 1990; Albert-Bertrán *et al.*, 1990).

The aim of this study is to evaluate helium-3 spatial distribution in and around Teide volcano since most of previous studies were carried out in stratovolcanoes related to subduction-volcanism.

Sampling and analytical methods

Sampling sites are shown in Figure 1. Gas and water samples were collected in lead-glass containers fitted with high-vacuum stopcocks at both ends. Gas samples were collected from the fumarolic discharges (85°C) at summit crater of Teide volcano and Aguas del Valle's gallery, a horizontal drilling for ground water exploitation. All water samples were collected from galleries which reach Tenerife's volcanic aquifer at different depths and elevations.

In the laboratory, a glass container with the water sample was connected to another container, and the dissolved gas was extracted by shaking both glass containers in order to

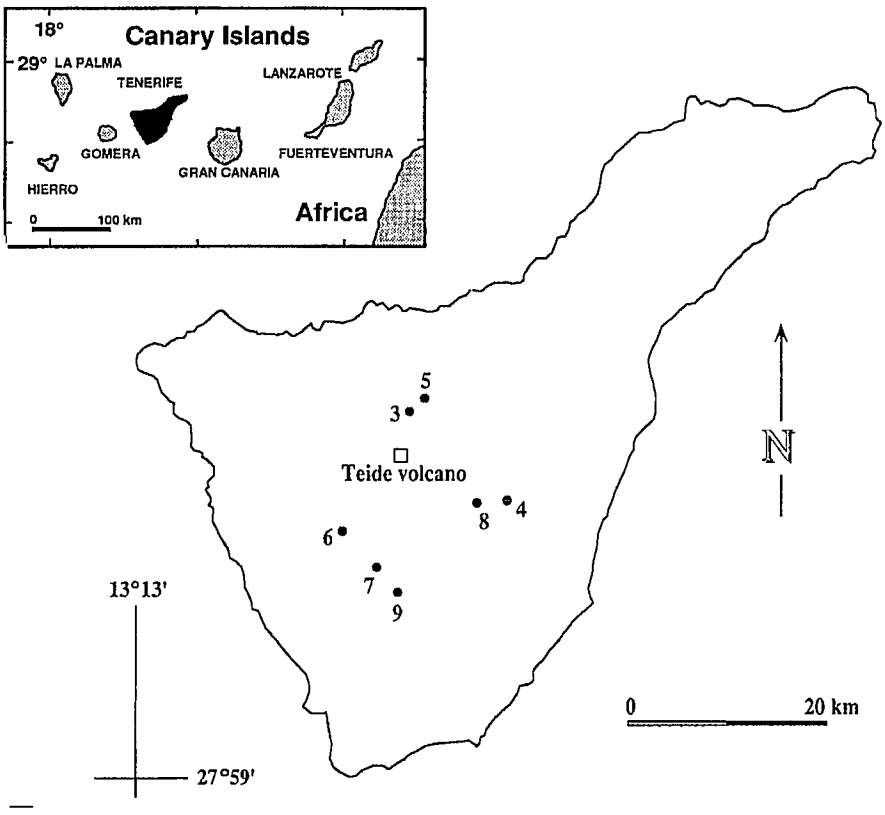

Fig.1.- Sampling sites and summit crater of Teide volcano locations.

Fig. 1.- Localización de los puntos de toma de muestra y del crater sumital del Teide.

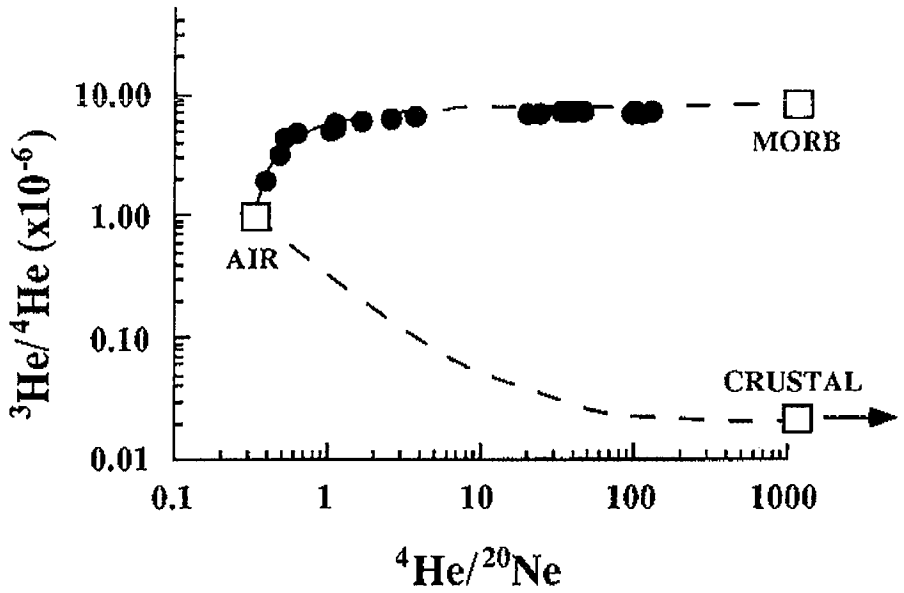

Fig.2.- Correlation between the $^3He/^4He$ and $^4He/^{20}Ne$ ratios in gas and ground water samples in Tenerife, Canary Islands. Dashed lines represent the mixing lines between MORB-type He, atmospheric He, and crustal-type He.

Fig. 2.- Correlación entre las relaciones isotópicas $^4He/^{20}Ne$ en muestras de gases y aguas de Tenerife, I. Canarias. Las líneas discontinuas representan líneas de mezcla entre He-MORB, He-Plume, y He-Atmosferico

achieve equilibrium between gas and water. A sample of about 0.5 cm^3 STP was admitted to the purification vacuum line. Purification and separation of helium and neon from other components such as water, carbon dioxide, and nitrogen were carried out by using a hot Ti-Zr getter held at 550°C, a SAES getter at room temperature, and three charcoal traps held a 77K. The $^4He/^{20}Ne$ ratios were measured by a quadropole mass spectrometer (QMG 112, Blazers) using atmospheric air as standard. Errors for $^4He/^{20}Ne$ ratio are estimated about 10%. Helium was completely separated from neon by a cryogenic charcoal trap held at 40K and transfer to a high-precision gas mass spectrometer (VG5400, VG Isotopes). The helium isotope measurements were carried out under static conditions. Ion beams of ^3He and ^4He were detected simultaneously with a double collector system. Resolving power of about 550 at 5% peak height was attained for complete separation of $^3He^+$ from those of H_3^+ and HD^+. Atmospheric helium was used as a running standard. Uncertainty for R/Ra ratios is about 1%. All helium measurements were carried out at the Laboratory for Earthquake Chemistry of the University of Tokyo. A detailed procedure of the helium isotopic ratio measurement has been described elsewhere (Sano and Wakita, 1988)

Results and discussion

Observed $^3He/^4He$ and $^4He/^{20}Ne$ ratios of gas and water samples are listed in Table 1. The elevation of the sampling site, distance from the summit crater of Teide volcano, sample type and date of collection are also shown. Errors related to $^3He/^4He$ measurements are one standard deviation.

The $^3He/^4He$ and $^4He/^{20}Ne$ ratios vary from 3.19 Ra (where Ra is the atmospheric $^3He/^4He$ ratio = 1.4×10^{-6}) to 7.21 Ra, and from 0.49 to 117.0, respectively. The highest $^3He/^4He$ ratio of 7.21 is observed in the fumarolic discharges at the top of Teide volcano. The lowest observed $^3He/^4He$ ratio of 3.19 was detected in the ground water discharge at Salto del Topo's gallery, and it can be attributed to significant atmospheric contamination. Relatively high $^4He/^{20}Ne$ ratios are found at the summit crater of Teide volcano as well as at Cabezón and Aguas del Valle galleries, suggesting high emanation of deep magmatic-fluids in those sites. On the contrary, low ratios were observed for the rest of the samples, and it reflects a significant atmospheric component. All gas and water samples lie on a mixing line between typical MORB and atmospheric values suggesting that crustal helium is negligible (Fig.2).

Assuming that the $^4He/^{20}Ne$ ratios of magmatic and crustal components are

significant higher than that of air, it is possible to correct atmospheric helium contamination as follows:

(1)

$$(^3He/^4He)_{cor} = [(^3He/^4He)_{obs} - r] / (1-r)$$

(2)

$$r = (^4He/^{20}Ne)_{air} / (^4He/^{20}Ne)_{obs}$$

where $(^3He/^4He)_{cor}$ and $(^3He/^4He)_{obs}$ indicate the corrected and observed $^3He/^4He$ ratios, and $(^4He/^{20}Ne)_{air}$ and $(^4He/^{20}Ne)_{obs}$ are the atmospheric $(^4He/^{20}Ne)$ ratio = 0.318, and observed $(^4He/^{20}Ne)$ ratio, respectively. In the case of a water sample, the $(^4He/^{20}Ne)$ ratio value is assumed to be 0.274, based on the data related to noble gas abundance in fresh water of air saturation at 25°C (Ozima and Podosek, 1983). This method is similar in principle to that reported by Craig *et al.* (1978). The corrected $^3He/^4He$ ratios are also listed in Table 1. Since $^4He/^{20}Ne$ ratio measurement has a 10% error, corrected $^3He/^4He$ ratios were also estimated according to this analytical error.

$(^3He/^4He)_{cor}$ shows a range from 5.97 to 8.06 Ra. Taking in consideration a 10% error for the analytical determination of $^4He/^{20}Ne$ ratios, upper limits of $(^3He/^4He)_{cor}$ reflect a range of values from 6.78 to 9.06 Ra while lower limits of $(^3He/^4He)_{cor}$ indicate a range from 5.45 to 7.41 Ra. Samples which do not reflect a high degree of atmospheric contamination has $^3He/^4He$ ratios equivalent to MORB ($^3He/^4He = 8 \pm 1$ Ra; Craig and Lupton, 1976; Kurz and Jenkins, 1981; Lupton, 1983), and they are just lower than those helium isotope ratios observed in La Palma Island ($^3He/^4He = 9.68$ Ra), one of the most westernmost islands of the Canarian archipelago (Pérez *et al.*, 1994). Higher $^3He/^4He$ ratios than those observed at Tenerife Island had been also detected in geothermal fluids from other oceanic volcanic islands such as Reunion and Hawaii (Marty *et al.*, 1993)

Following the assumption that crustal helium does not significantly contribute to the observed $^3He/^4He$ ratios in gas and water samples from Tenerife Island and the evidences of a hot spot origin for the Canarian volcanism (Schmincke 1973, 1976; Hoernle and Schmincke, 1993; Pérez, *et al.*, 1994), $^3He/^4He$ ratios from Tenerife Island can be explained by a mixing model of atmospheric, MORB-type, and plume-type helium. This model proposed by Sano *et al.* (1985), in the case of geothermal fluids from Iceland, can estimate the helium's fractions from each geochemical reservoir using the following equations:

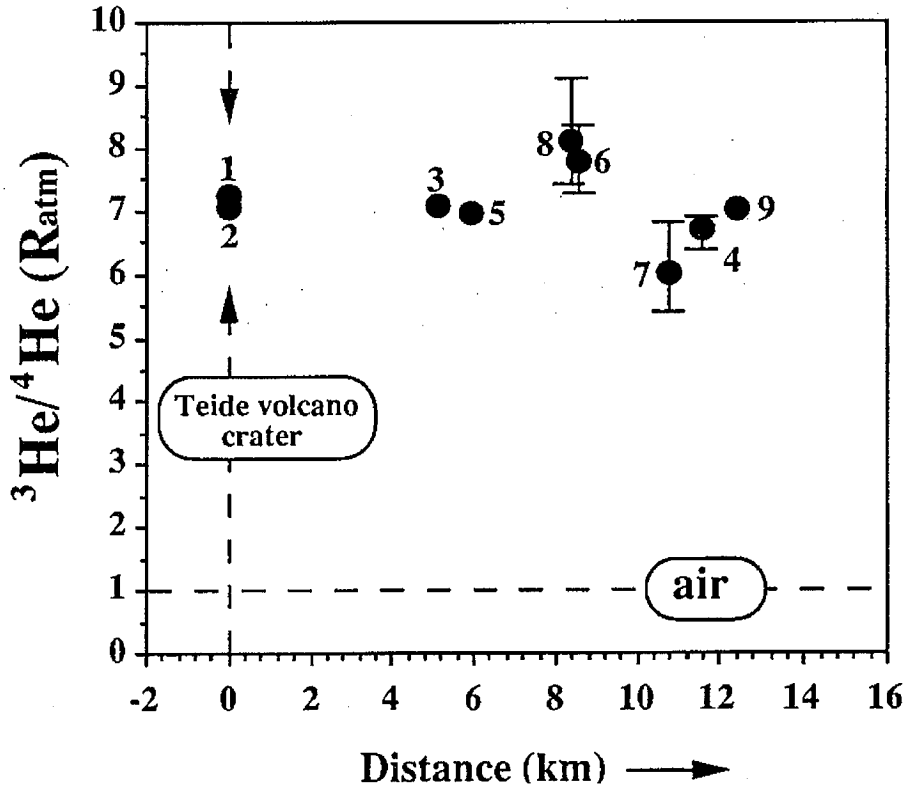

Fig.3.- The relationship between $^3He/^4He$ ratios and distance of the sampling site from summit crater of Teide volcano, Tenerife, Canary Islands. Error bars are related to the uncertainty of $^4He/^{20}Ne$ measurement.

Fig. 3.- La relación entre $^3He/^4He$ y la distancia respecto a la zona sumital del Teide, Tenerife, Islas Canarias. Los errores se relacionan con las medidas de $^4He/^{20}Ne$.

(3)

$$(^3He/^4He)_s = (^3He/^4He)_a \times A + (^3He/^4He)_m \times M + (^3He/^4He)_p \times P$$

(4)

$$1/(^4He/^{20}Ne)_s = A/(^4He/^{20}Ne)_a + M/(^4He/^{20}Ne)_m + P/(^4He/^{20}Ne)_p$$

(5)

$$A + M + P = 1$$

where subscripts s, a, m, and p stand for sample, atmospheric, MORB-type, and plume-type, respectively, and A, M and P are the fractions of atmospheric, MORB-type, and plume-type helium, respectively. Taking values for $(^3He/^4He)_a = 1.4 \times 10^{-6}$, $(^3He/^4He)_m = 11 \times 10^{-6}$, $(^3He/^4He)_p = 50 \times 10^{-6}$, $(^4He/^{20}Ne)_a = 0.318$ (0.274 for water samples), $(^4He/^{20}Ne)_m = 1000$, and $(^4He/^{20}Ne)_p = 1000$ (Sano 1983, Sano and Wakita, 1985), helium's fractions of Tenerife samples can be estimated (Table 2).

Sple.	Location	Type	Elevation (m)	Distance (km)	T. (°C)	$^3He/^4He$ ($\times 10^{-6}$)	$(^3He/^4He)_{obs}$ (Ra)	$^4He/^{20}Ne$	$(^3He/^4He)_{cor}$ (Ra)	Date
1	Teide	F	3716	0	85	10.09	7.21	117	7.23	06/91
2	Teide	F	3716	0	84	9.74	6.96	24	7.06	06/94
3	Vergara	GW	1320	5.1	15	9.25	6.61	3.7	7.14	01/94
4	San Isisdro	GW	1320	11.6	-	7.25	5.18	1.1	6.57	05/94
5	Cabezón	GW	1455	5.9	-	9.72	6.94	110	6.95	05/94
6	Lomo de Quicio	GW	1140	8.6	-	6.73	4.81	0.63	7.74	04/94
7	Salto del Topo	GW	835	10.8	27	4.46	3.19	0.49	5.97	12/94
8	Risco Atravesado	GW	1075	8.4	32	6.07	4.34	0.52	8.06	12/93
9	Aguas del Valle	G	470	12.4	-	9.73	6.95	95.68	6.97	07/93

F: Fumarolic gases; GW: Ground water; G: Hydrothermal gases

Table 1.- Observed $^3He/^4He$, $^4He/^{20}Ne$, and corrected $^3He/^4He$ ratios of waters and gases in and around Teide volcano, Canary Islands.

Tabla 1.- Relaciones isotópicas de $^3He/^4He$ observando, $^4He/^{20}Ne$, $^3He/^4He$ corregido en gases y aguas subterraneas en el volcan Teide y sus alrededores, Islas Canarias.

Sample	Location	He (%) MORB	He (%) atm.	He (%) plume
1	Teide	99.76	0.24	0.00
2	Teide	98.71	1.29	0.00
3	Vergara	92.70	7.30	0.00
4	San Isidro	75.10	24.90	0.00
5	Cabezón	99.78	0.22	0.00
6	Lomo de Quicio	56.53	43.47	0.00
7	Salto del Topo	47.33	52.67	0.00
8	Risco Atravesado	44.10	55.90	0.00
9	Aguas del Valle	99.75	0.25	0.00

Table. 2.- Estimated Helium Fractions (%) of MORB, plume and atmospheric componentes.

Tabla 2.- Estimaciones sobre las fracciones (%) de He de orígen MORB, plume y atmosférico.

One of the most significant observation of these helium isotope data from Tenerife Island is the relation between the $^3He/^4He$ ratios and distance of the sample locations from the summit crater of Teide volcano where occurs the most obvious geothermal features in Tenerife Island (Fig.3). Previous studies on helium-3 spatial distribution in and around stratovolcanoes located in many different volcanic regions showed a clear decreased trend of $^3He/^4He$ ratios with distance from the summit craters (Sano *et al.*, 1984; Williams *et al.*, 1987; Marty *et al.*, 1989, Sano *et al.*, 1990; and Sakamoto *et al.*, 1992) reflecting a dilution process of uprising deep magmatic-gases by crustal fluids which are rich in radiogenic helium. On the contrary, fluids from Tenerife Island show that $^3He/^4He$ ratios is quite uniform and did not show any relation with distance. Samples collected as far as 13 km from Teide volcano showed $^3He/^4He$ ratios equivalent to those observed at the summit crater of Teide volcano suggesting that deep-mantle degassing occurs also far away from the summit of stratovolcanoes in active volcanic regions. The main difference between these results is that previous studies were carried out on stratovolcanoes related to subduction-type volcanism, while this study was carried out in a different tectonic setting, oceanic volcanic island. Polygenetic volcanic edificies such as stratovolcanoes in oceanic islands are frequently built up at the intersection of rift zones which are the most important volcanological features in the formation of oceanic volcanic islands (Walker, 1992; Carracedo, 1994). Our results suggest that high levels of mantle degassing can occur along these structures even though there are not clear evidences of geothermal activity. Subsurface gas ^{222}Rn transects in the inner atmosphere of some horizontal drillings from Tenerife Island show an exponential enrichment of ^{222}Rn degassing closer to the rift zones (Soler *et al.*, 1992). This results on ^{222}Rn outgassing suggest clearly that an important advection component is responsible for the uprising of deep-seated gases along these structures.

Conclusions

High $^3He/^4He$ ratios have been detected far away from summit crater of Teide stratovolcano. This high helium-3 emission occurs mainly through the rift zones, which are the most important geological feature in the formation of oceanic volcanic islands, reflecting the uprising of deep-seated fluids. Spatial distribution of the $^3He/^4He$ ratios does not show any relationship with respect to distance from the summit crater like it had been observed in other volcanic scenarios. This feature should be related to differences related to the volcanic-tectonic settings of the stratovolcanoes which had been investigated.

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