Soil gas ^{222}Rn, He, and ^{220}Rn/^{222}Rn ratios at Cañadas caldera, Tenerife, Canary Islands, Spain

^{222}Rn, He y relaciones ^{220}Rn/^{222}Rn en gases de los suelos de la caldera de las cañadas, Tenerife, Islas Canarias, España

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ABSTRACT

Soil gas ^{222}Rn distribution suggest a close relationship with volcanic-geothermal features in and around Cañadas caldera according to both 1992 and 1995 soil gas surveys. Three transects were selected for soil gas ^{222}Rn, He and ^{220}Rn/^{222}Rn ratio measurements. Significant spatial variations were observed along those transects wich were designed to intersect fracture zones in the study area. Relatively high emission levels of ^{222}Rn and He as well as relatively high ^{220}Rn/^{222}Rn ratios seem to be related to significant diffuse degassing of deep-seated gases along these fracture systems.

RESUMEN

La distribución espacial de los niveles de emisión de ^{222}Rn en el ambiente superficial de la caldera de Las Cañadas refleja una estrecha relación con las características volcánico-geotermales de la misma según las campañas de gases en suelos realizadas en 1992 y 1995. Tres perfiles fueron selecionados para realizar medidas de ^{222}Rn, He y de relaciones isotópicas ^{220}Rn/^{222}Rn. Variaciones significativas fueron observadas a lo largo de los perfiles, los cuales se diseñaron para intersectar zonas de fractura en el área de estudio. Niveles de emisión relativamente altos de ^{222}Rn y he así como de las relaciones isotópicas ^{220}Rn/^{222}Rn parecen reflejar una importante desgasificación difusa de gases en profundidad que ascienden a lo largo del sistema de fracturas.

Key words: *Soil gas, ^{222}Rn, He, ^{220}Rn/^{222}Rn , Cañadas Caldera,Tenerife, Canary Islands.*

Geogaceta, 20 (3) (1996), 537-539
ISSN: 0213683X

Introduction

^{222}Rn (Radon) and ^{220}Rn (Thoron) are the only two radioactive isotopes of Radon which can be used in soil gas surveys because of their relatively long half-lifes, 3.8 days and 54.4 seconds, respectively. Both gases can diffuse through the soil and can be detected at very low concentrations (Tanner, 1964). Radon surveys have been successful in identifying uranium ore bodies in the subsurface (Fleischer *et al.*, 1980), correlating with earthquakes (King, 1980; Wakita, 1980), and detection of fault/fractures as well as high thermal gradients (Crenshaw *et al.*, 1982).

Helium -4 is produced by natural alpha-particle radioactive decay of U and Th. Helium is an excellent geochemical tracer in soil gas surveys because has unique chemical and physical properties. It is chemically inert, biogenically neither produced nor consumed, radioactively stable, highly diffusive, and has a low solubility in water. Most soil gas helium surveys have been performed in the search for oil and gas or uranium prospecting (Dyck, 1976; Reimer *et al.*, 1979). Soil gas helium surveys have also been succesfully conducted over high and low-temperature geothermal systems

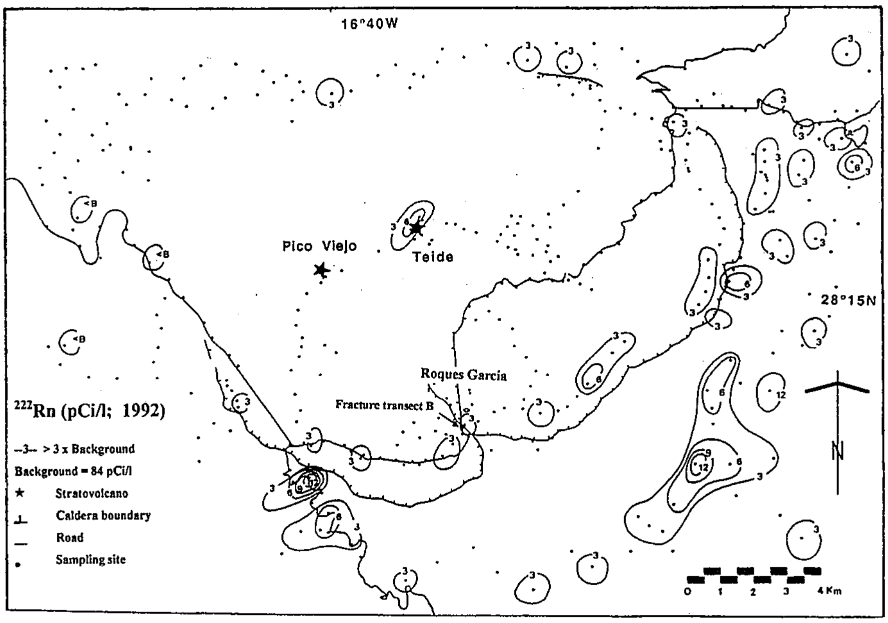

Fig. 1.-Soil gas ^{222}Rn distribution at Cañadas caldera, Tenerife, Canary Islands (1992 survey).

Fig. 1.- Distribución de gas ^{222}Rn en los suelos de la caldera de las cañadas, Tenerife, Islas Canarias (Estudio de 1992).

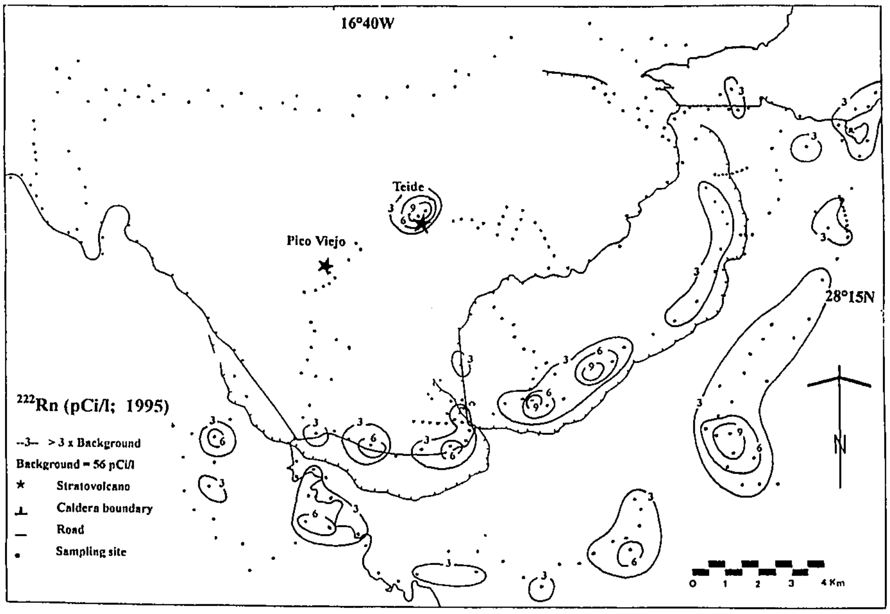

Fig. 2.-Soil gas ^{222}Rn distribution at Cañadas caldera, Tenerife, Canary Islands (1995 survey).

Fig. 2.- Distribución de gas ^{222}Rn en los suelos de la caldera de las cañadas, Tenerife, Islas Canarias (Estudio 1995).

Sample	^{4}He (ppb)	ΔHe (ppb)	^{222}Rn (pCi/l)	^{220}Rn/^{222}Rn
A02	5250	10	4.2	-
A03	5290	50	163.3	-
A04	5259	19	74.4	-
A05	5270	30	13.5	-
A06	5250	10	55.8	-
A07	5310	70	53.1	-
A08	5310	70	18.0	-
A09	5290	50	203.5	-
A10	5300	60	119.4	-
A11	5270	30	89.4	-
A12	5280	40	82.2	-
A13	5310	70	186.1	-
B01	5310	70	232.9	-
B02	5330	90	115.8	-
B03	5320	80	88.8	-
B04	5310	70	69.6	-
B05	5280	40	48.0	-
B06	5330	90	48.0	-
B07	5310	70	31.2	-
B08	5290	50	196.3	8.2
B09	5330	90	159.7	9.8
B10	5440	220	131.5	26.4
B11	5310	70	73.2	9.2
B12	5280	40	31.2	6.4
B13	5260	20	30.0	-
B14	5280	40	30.6	-
B15	5290	50	23.4	-
B16	5310	70	58.2	-
C01	5300	60	2.4	-
C02	5310	70	11.4	-
C03	5300	60	7.2	-
C04	5310	70	15.6	-
C05	5300	60	27.0	-
C06	5290	50	147.7	-
C07	5290	50	87.0	-
C08	5300	60	63.3	-
C09	5260	20	26.4	-
C10	5350	110	32.4	-

not analyzed

Table 1. Soil gas He, ^{222}Rn, and ^{220}Rn/^{222}Rn ratios at Cañadas caldera, Tenerife.

Tabla 1.- He, ^{222}Rn y relaciones ^{220}Rn/^{222}Rn en gases de los suelos de la caldera de las Cañadas, Tenerife.

(Hinkle *et al.*, 1978; McCarthy *et al.*, 1982; Baldi *et al.*, 1984). These surveys have effectively delineated the margins of the fields and also identified fault/fracture zones where gas-flow occurs. This observation is quite important to evaluate in active volcanic areas where active fault/fractures can be pathways of magma uprising to the surface. Previous helium soil gas studies have been performed in several volcanic areas such as Kilauea, Hawaii (Hinkle *et al.*, 1978; Reimer, 1985), Campi Flegrei, Italy (Lombardi *et al.*, 1984), and Long Valley caldera, California (Hinkle and Kilburn, 1980; Green, 1984) providing significant insights on the dynamics of these volcanic systems.

Sampling and analysis

Soil gas ^{222}Rn surveys were carried out by using emanometry and Track-etch measurement techniques in the summer of 1995 and 1992, respectively. Sample sites were generally chosen near roads and trails after careful consideration of the local geology and structure. For the 1992 soil gas ^{222}Rn survey of approximately 400 sample sites, environmental commercial detectors were buried at 40 cm depth and recovered after 30 days to minimize short-term meteorological variations. In 1995, soil gas ^{222}Rn measurements were also performed at 40 cm depth, but alpha scintillation counters were used to measure Rn activities in 311 sample sites. ^{220}Rn/^{222}Rn ratios were also measured by using alfa scintillation counter fitted with a Lucas cell.

Soil gases for He measurements were collected by pounding an 8-mm-diameter hollow steel probe into the soil to a depth of 0.5 m. A septum-containing cap was placed on the probe to create an air-tight seal and the gas was slowly withdrawn through the system by hypodermic syringe. The probe nominally contains a dead volume of 10 cm^3 and was first purged by withdrawning and discharging 10 cm^3. A sample of 10 cm^3 was then withdrawn into the syringe and transfered to a pre-evacuated stainless steel container of 6 cm^3 internal volume for shipment to the laboratory for analysis. The container is overpressurized with the sample and sealed with a single valve on one end with a septum in series through which the sample is injected. Soil gas helium was analyzed by using a small leak-detector mass spectrometer tuned specifically for helium mass-to-charge ratio of 4+ (Reimer *et al.*, 1979). Analytical precision for helium is ±10 ppb. A total of 38 soil gas samples were collected and analyzed. Three transect (A, B, and C) were selected for soil gas Rn and He analysis in the study area.

Results and discussion

Statistical-graphical analysis of soil gas ^{222}Rn in the surface environment at Cañadas caldera showed four overlapping populations in both 1992 (Pérez *et al.*, 1993; Hernández *et al.*, 1994) and 1994 surveys. Spatial distribution of the anomalous soil gas ^{222}Rn is quite similar in both soil gas surveys (Fig. 1 and Fig. 2). The background means are slightly similar for 1992 (84 pCi/l) and 1995 (56 pCi/l) surveys, respectively. On the contrary a significant difference was observed in the dimensions of the background population which did represent 47% and 79.4% of the total data for the 1992 and 1995 surveys, respectively. Peak groups showed quite different mean values (1992: 1100 pCi/l, and 1995: 570 pCi/l), but they had a similar percentage of the total data for these anomalous population (1992: 1%, and 1995: 1.4%). The observed differences might be related to the effects of short-term meteorological effects which can affect our data from the 1995 survey, but they can be also related to volcanological effects since higher levels of anomalous soil gas ^{222}Rn were not only observed but also lower size of the background population for the 1992 survey which include a similar distribution and number of sampling points. A new soil gas ^{222}Rn survey using one of the above techniques as well as the same distribution ans number of sampling sites will provide us with additional insight about this observation.

The distribution of the helium concentration was fairly uniform with the exception of the data along the transect B. The average helium concentration at Cañadas caldera is 5298 ppb and is quite similar to the observed average value for soil gas helium at Kilauea volcano, 5248 ppb. Soil gas He results are shown in Table 1. The δHe is the difference in helium from the atmospheric concentration which nominally contains 5240 ppb and is a remarkably constant reservoir (Glueckauf, 1949; Oliver *et al.*, 1984).

Concentrations of helium greater than the atmospheric content (5420 ppb of He) must be related to a subsurface source. $^3He/^4He$ ratios from actual volcanic hydrothermal discharges in the Canary Islands suggest that the lower and upper mantle are the main subsurface sources of helium (Pérez *et al.*, 1994; 1995). Soil gas helium concentrations at Cañadas caldera are similar to that found in other regional surveys such those in the Powder River Basin of Wyoming (Reimer *et al.*, 1980), and the Basin and Range Province of Utah and Nevada (Reimer and Bowles, 1983). This observation is consistent with relatively low concentrations of U and Th which can contribute to a high helium background at Cañadas caldera.

Spatial variations of soil gas ^{222}Rn, He and $^{220}Rn/^{222}Rn$ ratios showed that transect B presents the best signatures and it was designed to intersect one of the most significant geological features of Cañadas caldera, Roques García (Fig. 3). Relatively high soil gas He and ^{222}Rn as well $^{220}Rn/^{222}Rn$ ratios were observed across this transect B and close to the intersection of the fracture zone where deep-seated gases might be uprising towards the surface environment. These $^{220}Rn/^{222}Rn$ values are much higher than those observed in the fumarolic degassing of Teide volcano (Hernández *et al.*, 1994; Pérez *et al.*, 1996). A very good agreement seems to exist between relatively high levels of soil gas He and $^{220}Rn/^{222}Rn$ ratios in transect B. This observation might suggest that $^{220}Rn/^{222}Rn$ ratios might be a better geochemical tracer than Rn to delineate active degassing sites.

Conclusions

Soil gas ^{222}Rn, He and $^{220}Rn/^{222}Rn$ ratio spatial distribution analysis is a quite useful tool to have a better understanding of the dynamics of diffuse degassing mechanism of active volcanic structures such as Cañadas caldera. $^{220}Rn/^{222}Rn$ ratios seems to show a better agreement with soil gas He than soil gas ^{222}Rn; therefore, temporal and spatial variations of $^{220}Rn/^{222}Rn$ ratios can become a quite important geochemical parameter for volcanic-seismic surveillance programs.

Acknowledgements

We are very grateful to ICONA, Teleférico Pico Teide S.A., Instituto de Productos Naturales y Agrobiología - CSIC, Terranostra Research Institute, USGS, ENUSA, Cabildo Insular de Tenerife, and the laboratory for Earthquake Chemistry at the University of Tokyo for their assistance and logistic support. We thank Eugenio M. González, Jose M. Salazar, Francisco J. Hernández, Caroline Whitehill, and Christen Clarke for their assistance during the field work. This research was supported by grants from Cabildo Insular de Tenerife (P.A.H.), NATO (C.E.A. & N.C.S.), and EU-STF Programme in Japan (N.M.P.).

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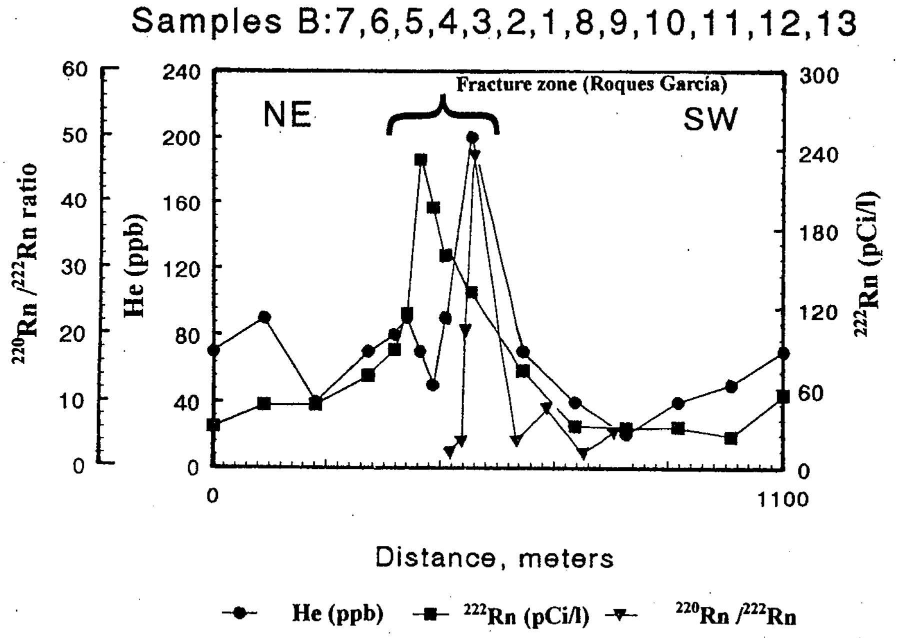

Fig. 3.- Soil gas ^{222}Rn, He and $^{220}Rn/^{222}Rn$ ratios for fracture transect B (Roques García).

Fig. 3.- Valores de ^{222}Rn/He correspondientes al transecto B (fractura Roques García)

Sample	$\delta^{13}C$ (CO_2) / ‰	$\delta^{13}C$ (CH_4) / ‰
3	-31.65	-72.77
21	-33.63	-69.92
28	-34.99	-70.34
65	-25.47	-63.25
67	-30.82	--
78	-33.96	-69.76
88	-36.92	-75.70
97	-22.87	--
99	-25.34	--
130	-38.00	-70.38
143	-18.77	--
147	-34.05	-75.33
158	-30.71	-69.55
164	-29.84	-68.17
168	-30.23	-73.28
179	-27.84	-68.53
194	--	-70.25
201	-25.79	-68.42
217	-33.85	-67.70
225	-26.72	-70.46
226	-17.98	-66.42
256	-33.34	-70.33
270	-30.26	-70.08
276	-23.48	-69.42
293	-30.14	-68.85
300	-26.43	--
311	-20.89	-65.14
354	-36.04	-69.23
361	-32.97	-69.94
372	-34.33	-67.79
Teide 1	-12.91	-70.35
Teide 2	-8.290	-70.25

-- not detected

Table 2.- Carbon isotopic data for soil gas samples of Cañadas caldera.

Tabla 2.- Composición isotópica de carbono en gases de los suelos de la caldera de Las Cañadas.