Soil radon pulses related to the initial phase of volcanic euruptions (*)(**)

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

Summary. — Soil radon behaviour related to the initial phase of volcanic eruptions is analysed from reported values related to the explosivity of four American stratovolcanoes: El Chichon (1982) and Popocatepetl (1994) in Mexico, Poas (1987-1990) in Costa Rica and Cerro Negro (1995) in Nicaragua. The measurements in the field were performed with solid-state nuclear track detectors and electrets. The ratio between the magnitudes of the radon in soil peaks generated when the eruptive period started and the average radon values corresponding to quiescence periods indicate a dependence on the Volcanic Eruptive Index for each one of the eruptive periods.

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

1. – Introduction

Soil radon determinations related to volcanic eruptions have been extensively reported since the Chirkov findings at the Karimsky volcano [1]. However, the complexity of the physical and chemical processes participating in a volcanic eruption results in a wide spectrum of radon fluctuation patterns having their own peculiarities for each active volcano. The American continent is characterized by subduction-related volcanic chains along the Pacific shore. Several volcanoes of the region have presented eruptive phases in the last decade and some of them have been monitored for soil radon and/or short- and long-lived radon daughters in ashes, fumaroles and plumes. The aim of the present paper is to review some common features observed during the initial phases of those volcanic eruptions that generated radon pulses. The analysis will be

(*) Paper presented at the "Fourth International Conference on Rare Gas Geochemistry", Rome, October 8-10, 1997.
(**) The authors of this paper have agreed to not receive the proofs for correction.

focused on two Mexican stratovocanoes, El Chichon, undergoing a catastrophic eruption in 1982, and the Popocatepetl that started a small eruptive crisis in 1994; and two Central American volcanoes, the Poas in Costa Rica (eruptive phase from 1987 to 1990), and the Cerro Negro in Nicaragua that presented a small volume intrusion in 1995.

2. – Radon monitoring results and discussion

On March 28, 1982, El Chichon volcano, Mexico (17.36 °N, 92.23 °W; 1060 m) erupted violently. Two major eruptions followed on April 3 and 4. The Volcanic Explosive Index (VEI) [2] of the eruption was estimated to be 5. After the first eruption, radon in soil monitoring started with LR-115 type-II, solid-state nuclear track detectors (SSNTD). The radon monitoring continued during 10 months at distant stations (15 to 25 km from the volcano) since the devastated area reached 20 km around the volcano. The soil radon response showed a radon pulse related with the initial phase of the eruption that was observed at all the monitoring stations located around the volcano. The level of this pulse was one order of magnitude higher than the background radon level of the region reached three months after the eruption (fig. 1A). Since all the radon stations were relatively far away from the crater, the soil radon concentration levels observed during the early stage of the explosive eruption indicated a sudden degassing associated to the magma intrusion, that induced the transport of gases through the volcanic cone, perturbing the flux pattern of underground fluids several km around. Short-lived radon and thoron daughters activities in ash-fall samples ejected from El Chichon volcano were also measured by gamma spectrometry. The observed values of ^{214}Pb, ^{214}Bi, ^{212}Pb and ^{212}Bi activities in the ashes permitted to estimate the volume of magma having degassed [3]. It is worth mentioning that two years before El Chichon eruption, the Mount St. Helens (Washington State, USA) had a catastrophic eruption with VEI. also estimated as 5. No radon measurements were performed in that occasion. However, Le Cloarec *et al.* [4], reported measurements of long-lived radon daughters ^{210}Po, ^{210}Bi and ^{210}Pb in filter samples from the plume. Those measurements, performed in September 1981, one year and four months after the Mount St. Helens climactic eruption on May 18, 1980, also permitted to estimate the volume of degassed magma.

In December 1994, an eruptive phase started at the Popocatepetl volcano, México (19.023N; 98.622W). The volcano (5465 m) is located within the central portion of the Trans Mexican Volcanic Belt and related to the oblique subduction of oceanic lithosphere. Its geographycal position, in an area where the largest population concentration in the country is settled, and the evidence of large eruptions in historical times, makes this volcano a high-risk one. The VEI estimated for the period 1995-1996 was < 2. Two years before the December 1994 eruption, radon in soil monitoring started at two monitoring stations with SSNTD (LR 115 type II) exchanged in the field in a monthly base [5]. Soil radon time series (fig. 1B) obtained at one of the stations located 5 km from the Popocatepetl summit showed fluctuations due to meteorological changes during the pre-eruptive period of two years 1993-1994. However, at the end of December 1994 and during almost three weeks of January 1995, a radon peak was observed in coincidence with the beginning of the eruptive period. The radon concentration decreased on February and then recuperated during March-April, when the volcano presented a complex seismic pattern. We can observe in the pre-eruptive period that radon peaks occurred also during January-March 1993 and March 1994.

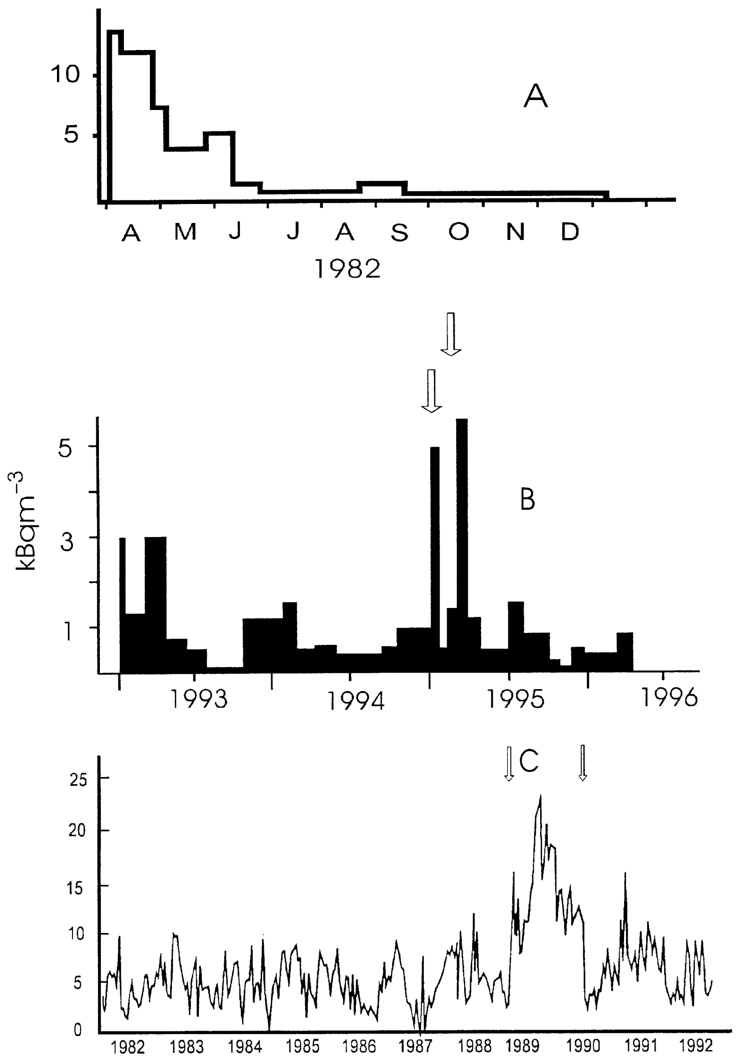

Fig. 1. – Radon in soil behaviour related to the eruptive phases of three American volcanoes: A) El Chichon, Mexico [3]. The arrow indicate the main eruption occured on March-April, 1982. B) Popocatepetl, Mexico [5]. The arrow indicate the activity initiation in December 1994. C) Poas, Costa Rica [6]. The arrows indicate the periods of disappearance of the crater lake.

However, the intensity of the radon signal obtained in January and March 1995 was higher than $X + 2\sigma$ (2.8 kBq/m^3) obtained during the pre-eruptive period.

The Poas volcano (10.20 °N, 84.23 °W) is one of the main active volcanoes of Costa Rica rising up to 2708 m altitude. The volcano has had several eruptive periods during the present century. Between 1979 and 1987 a quiescence period occurred followed by a new eruptive period starting with phreatic eruptions in June 1987. A moderate activity continued during 1988. In April 1989 the activity intensified with the formation of a dome in the crater. The crater lake disappeared at the end of April 1989 and again in

TABLE I. – *Radon activity ratios between values corresponding to the eruptive initial phase peaks and the mean quiescence values as reported at the* 4 *American volcanoes undergoing different* VEI *eruptive periods.*

Volcano	VEI	Peak value/mean quiescence value
El Chichon	5	13.5/0.6 = 22.6
Popocatepetl	< 2	4.9/1.2 = 4.08
Poas	< 2	24/6 = 4
Cerro Negro	< 2	1665/348 = 4.78

April 1990. The VEI estimated during the period 1987-1990 was around 2. A soil radon network was installed in 1982, consisting of 7 SSNTD (LR 115 type II) operated monitoring stations located from the crater edge to several km down the flank [6]. Figure 1C) indicate the response of soil radon at the station of the edge of the crater. The pre-eruptive period, 1982-1987, indicates fluctuations representative of external meteorological effects. The radon increase observed in 1989, coincides with phreatic activity, and sediments and gas columns ejections. In the particular case of the Poas, the radon in soil increase elapsed during almost one year with sporadic fluctuations. The average radon value during the pre-eruptive quiescence period 1981-1988 was 6 kBq/m^3, while the peak value in 1989 reached 24 kBq/m^3.

The Cerro Negro (12.506N; 86.702W), Nicaragua, is a small-volume (675 m) basaltic cinder cone that has erupted 22 times since its formation in 1850. In 1995 the activity started with seismic swarms on May 24th, followed by explosive eruptions on May 28 that continued until August 16. In early June the activity consisted of discrete explosions producing convective ash columns that commonly reached 200 m height. The soil radon was monitored with electrets (E-perm) at stations located up to 1 km from the crater. Connor *et al.* [7] reported radon monitoring one year before the eruption, May-June 1994, and during the eruption, June 1995. The sample geometric mean values obtained by the cited authors at 27 and 23 radon stations were 1665 and 348 Bq/m^3, respectively, for the reported periods. An increase of the radon levels by a factor of 5 was observed in June 1995 as compared with data from 1994.

In table I the ratio between the radon pulse values obtained in connection with the initial phase of the eruptions and the mean value of the radon data corresponding to the quiescence periods of the four volcanoes are shown, indicating a dependence of this ratio on the VEI for each one of the eruptive periods.

3. – Conclusions

For the four studied eruptive periods, even if differences between the eruptions occurred, the soil radon behaviour indicated that radon was produced in the degasing of the magma and forced at an early stage of the eruptive period to circulate following the movement of the fluids through the volcanic building. The examples shown in this paper indicate that pulses of soil radon can be expected in connection with the initiation of the eruption and the activity ratios between the climax and the quiescence periods are related to the VEI.

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The authors acknowledge finantial support from CONACYT, Mexico, Project 3791 P-T, and IAEA Research Contract 8361.2.

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