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Soil gas measurements as an indicator of volcanic activity at Popocatépetl, México (*)

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Summary. — It is well known that anomalously high levels of soil gases such as radon, carbon dioxide and helium can be measured over faults or fractures. This type of measurement is a useful tool to determine the structure of many types of geological environment, including volcanic edifices. It is important that other controlling factors are considered, principally changes in the meteorological conditions, since they can have a strong influence on the concentrations measured. In the case of volcanoes, additional information can be obtained on mass gas movement and magmatic resurgence. A temporal variation in the concentration of soil gases has been observed as a precursor to both earthquakes and volcanic activity. However, few long-term studies have been carried out. In the case of volcanoes, measurements are taken at a distance from the active crater, making it a much less hazardous form of monitoring than the direct sampling of fumaroles. Recently Popocatépetl has commenced a new active phase with several explosive events producing ash falls at large distances from the volcano. Measurements of SO_2 and CO_2 flux have shown a large variation. For a better understanding of the processes occurring within the volcano, as well as its structure, further data of different types is required. This study will include an extensive program of soil gas measurements, including radon, carbon dioxide, methane and helium. A comparison will be made with seismic and groundwater and ash geochemical data. One goal will be an improved understanding of the mechanism whereby seismic events influence the concentration of soil gases, which is not currently well understood. Here the preliminary results are presented.

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1. – Introduction

The concentration of various gas species in the soil has been used for some time for locating faults or fractures and in the search for buried ore deposits (McCarthy &

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Reimer, 1986; Varley & Flowers, 1993). Much research has also been done in the search for precursors to earthquakes (King, 1986). However, in the field of volcanology, the potential use of soil gases is a relatively new topic. The main goal has been to identify anomalously high readings as precursors to eruptive activity. In some cases this has been achieved, but the relationships are still far from clear. To monitor temporal changes in degassing processes, ideally, fumarolic gas discharges would be measured. However, for continuous monitoring there can be problems of access and some volcanoes are too potentially hazardous.

Various gaseous species can be measured; the principal ones being carbon dioxide, radon, and helium. The transport of soil gases is largely controlled by pressure-driven flow within fracture systems. CO_2 represents the most abundant species after water vapour in volcanic gases. However, it is only recently that the significance of non-eruptive degassing of CO_2 has been realised (Gerlach, 1991). Rn represents an easy gas in the soil to measure due to its alpha-emission, but its concentration can vary greatly with climatic changes (Varley & Flowers, 1992). Much of this can be explained by temperature-sensitive partitioning between the gaseous and aqueous phases (Washington & Rose, 1990). Changes in atmospheric pressure can also influence the soil gas concentration. Much of the factors controlling the emanation of radon is discussed in Ball *et al.* (1991).

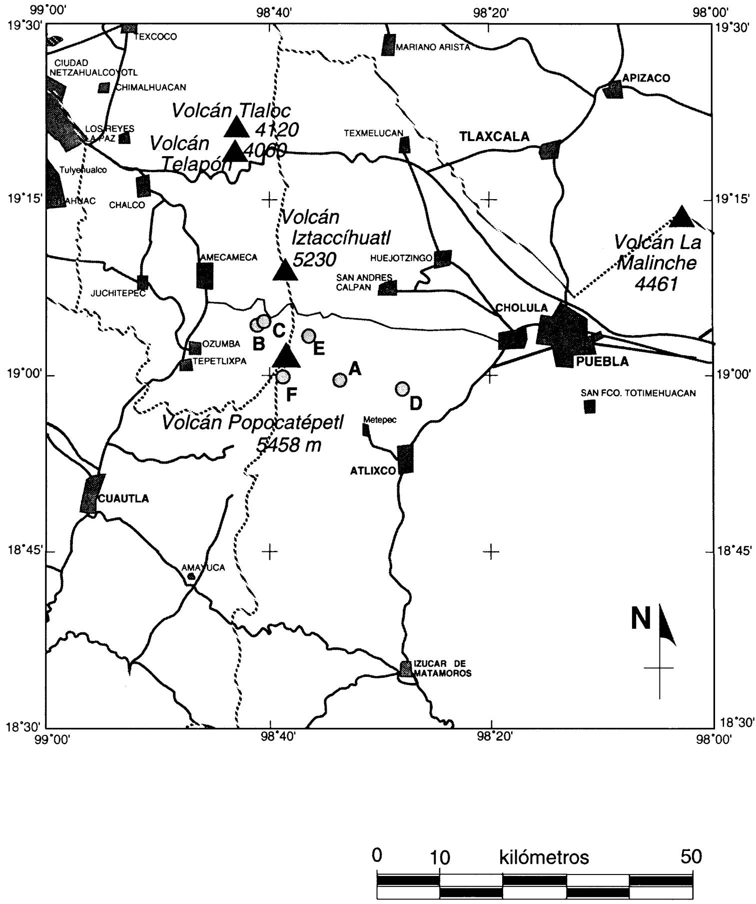
Radon has two useful isotopes that can be measured in soil gas. High concentrations of the shorter-lived isotope ^{220}Rn indicate very rapid transport and hence very permeable fractures. Few studies have considered this isotope. Helium has also been extensively used in geochemical exploration and for fault location. ^{3}He has a primordial signature and hence can provide information on tectonic controls and the relative importance of the different components within mantle-derived melts. The ratio ^{3}He/^{4}He can be used to determine the amount of magmatic gas in a sample.

Popocatépetl is a volcano with an altitude of 5458 m, and is situated in central Mexico close to the two large urban centres of Mexico City and Puebla. In December 1994 a new eruptive phase began which has been characterised by ash emission and some lava (GVB, 1997). Recently a lava dome has been forming in the crater, which had a volume of 13 million m^3 up to the eruption of 1 January 1998 (De la Cruz-Reyna, 1998). Much effort has been put into monitoring since the onset of this new phase. SO_2 and CO_2 in the plume are being measured using COSPEC and an infrared analyser (Gerlach *et al.*, 1997). Very high fluxes have been measured of both gases (currently the highest recorded from any volcano (Delgado, 1998)), with some large variations. A possible explanation of the variation is that the activity has been characterised by periods of open degassing, followed by the sealing of the conduit. The explosive events could be coinciding with the conduit reopening.

However, the number of soil gas surveys is limited. The major study has concentrated on only two locations, and since 1993, ^{222}Rn has been measured using track-etch detectors. An anomaly was identified which was thought to be related to emissive events (Segovia *et al.*, 1997). However, concentrations were only measured to be up to 5 kBq m^{-3}. More recently solid-state detectors have also been installed.

2. – Method

Soil gas was sampled using a stainless-steel probe, sampling being performed at a depth of about 0.6 m. Radon was measured using an alpha scintillation counter, whilst samples were taken in glass tubes and returned to the laboratory, where gas chromatography was used to measure the concentration of CO_2. Figure 1 shows Popocatépetl and some of the locations where measurements have been carried out. Traverses have been carried out to try and locate spatial anomalies, several of which have been identified. These are now being studied in an attempt to identify temporal variations in the characteristics of the soil gas. Later isotopic analysis will be performed on C and He to verify the origin of the gases. Efforts will be made to identify correlations between temporal variations in soil gas concentrations with other data such as seismic, or plume emissions.



○	A	Barranca Xalteluco	D	San Baltazar Atlimiyaya
	B	Cañada Palo Rechino	E	Barranca Tlamacas
	C	Cañada Atlamaya	F	Flanco sur de Popo

Fig. 1. – Popocatépetl and its surroundings.

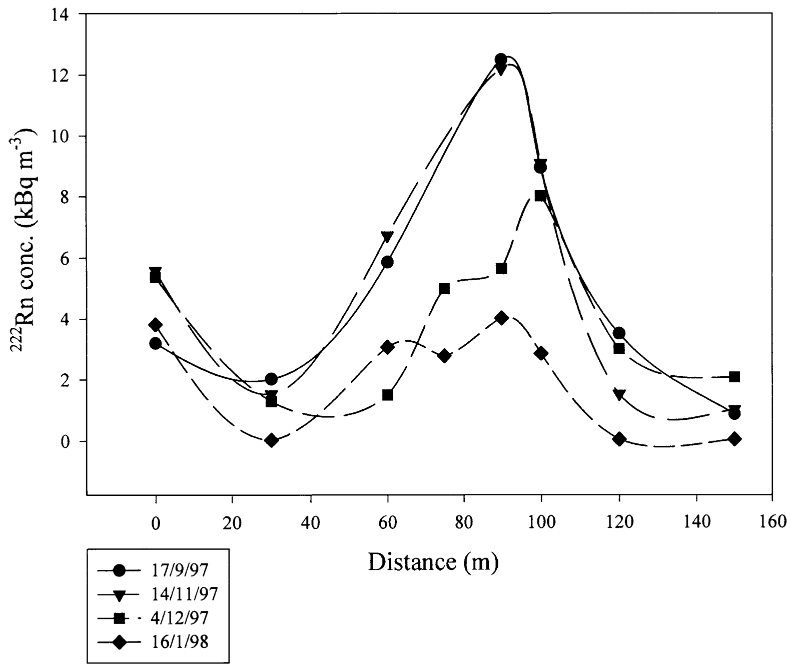


Fig. 2. – Variation of ^{222}Rn at Palo Rechino over a 4-month period.

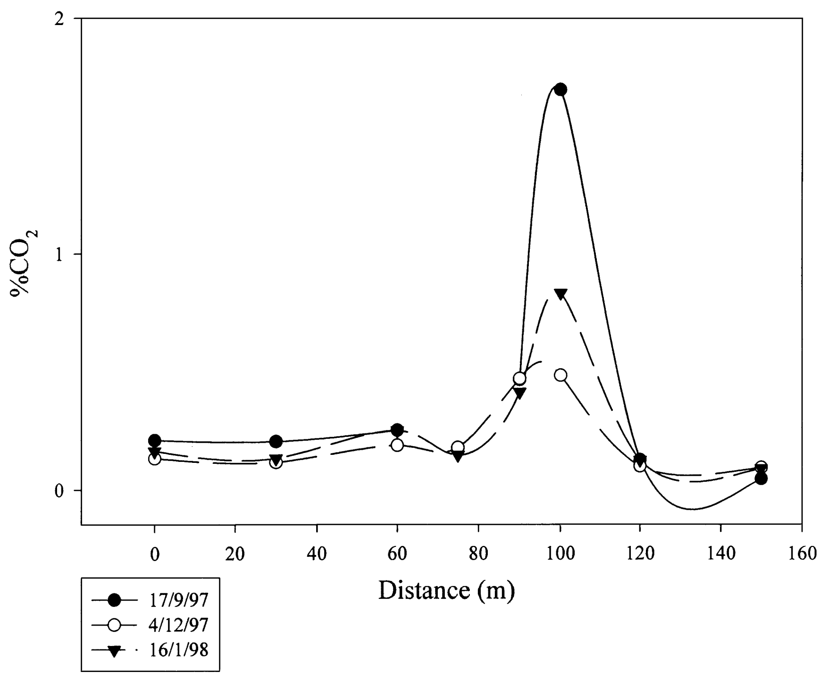


Fig. 3. – Variation of CO_2 at Palo Rechino over a 4-month period (no data for November).

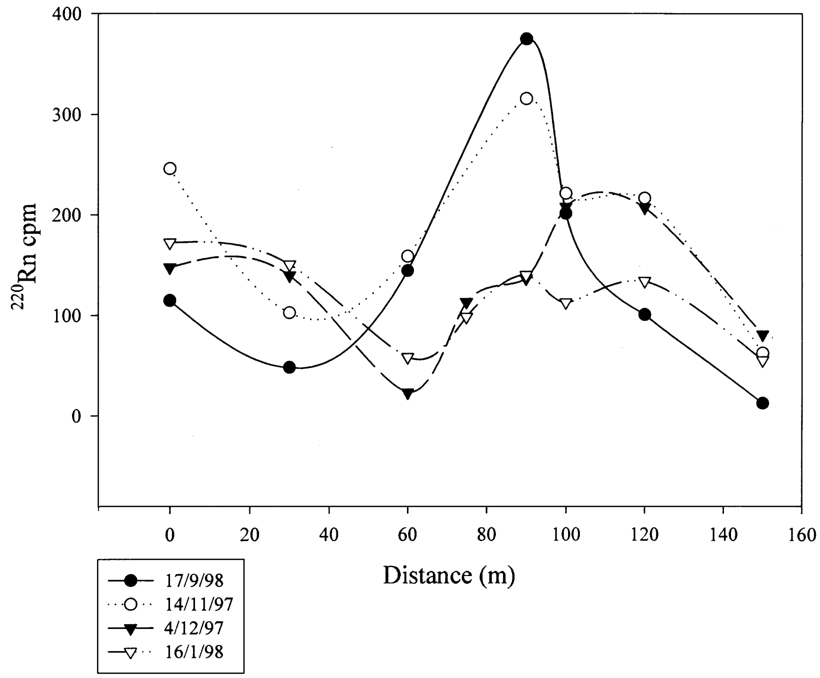


Fig. 4. – Variation of ^{220}Rn at Palo Rechino over a 4-month period.

3. – Results and discussion

In fig. 2 and 3 the results of measurements of ^{222}Rn and CO_2 at one location are shown. The traverse was repeated on five occasions between September 1997 and January 1998. It can be seen that there is a positive anomaly of ^{222}Rn and CO_2 in the centre which corresponds to the bottom of a small valley. It is likely that this represents a fault which is acting as a pathway for deep gases. As time progressed the concentration of both gases was seen to decrease. All measurements were taken during the dry season, so soil moisture is unlikely to have greatly influenced the results. This period of the year is also characterised by stable atmospheric pressure conditions. As shown in fig. 4, ^{220}Rn showed a similar pattern, however, some movement in the position of the anomaly is apparent.

The decrease could be explained by either dynamics of the fault system reducing the local mass gas transport to the surface, or a reduction in the degassing of the magma. Other data does not support the second hypothesis, so it seems likely that the pathway for the gases has undergone some form of contraction.

4. – Conclusions

At this stage of the project few conclusions can be made. However, locations with anomalies of both Rn and CO_2 have been identified and some temporal variation observed. Soil gas measurements can be used to successfully identify the location of fault systems on Popocatépetl. Data of this kind can make a useful contribution to the overall knowledge of the structure of this volcano and, in combination with other data, may help to predict increases of volcanic activity.

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