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Radioactivity measurements in volcano-tectonic area for geodynamic process study

D. Morelli[1,2,*], G. Immé[1,2], S. Cammisa[1], R. Catalano[1], G. Mangano[1], S. La Delfa[3] and G. Patanè[3]

[1] Dipartimento di Fisica e Astronomia, Università di Catania via S. Sofia, 64 I-95123 Catania, Italy
[2] INFN, Sezione di Catania - via S. Sofia, 64 I-95123 Catania, Italy
[3] Dipartimento di Scienze Geologiche, Università di Catania Corso Italia, 57 I-95100 Catania, Italy

Abstract

In the last ten years we carried out several radioactivity investigations in the aetnean area, a peculiar site characterized by both tectonic and volcanic features. In particular, continuous measurements in-soil radon gas carried out from 2001 until 2006 in the eastern flank of Mt. Etna, while several volcanic events occurred, showed a possible correlation between radon concentration and geodynamic activity, in particular magma uprising. We report in particular on the survey performed in order to determine vertical radon concentration profiles at different depths in sites near active faults in order to extract radon diffusion coefficients for the different sites. Moreover laboratory analysis allowed determining radionuclide contents (via γ-spectroscopy) and radon exhalation rate (via Can-technique) for different rock samples from the monitored sites. This study represents a contribution to better define the radon transport process through fractured media, in particular in volcanic area.

*E-mail: `daniela.morelli@ct.infn.it`

1. Introduction

Since some years, variations of in-soil radon concentration are considered a useful tool for geodynamical monitoring in active fault zones [1–5]; for surveillance in volcanic areas [1, 6–9] and for tracing neotectonic faults [10, 11].

Radon diffusion and transport through different media is a complex process and is affected by several factors [12–15]. Even if in the last years several radon measurements were done for geophysical investigations, origin and mechanism of the radon anomalies and their relationship to geodynamical events (seismic or volcanic ones) are, however, poorly understood.

According to proposed models [2, 4] radon anomalies are related to the mechanical opening of new cracks, widening or closing of old cracks or, alternatively, to compression mechanisms [16]. The diffusion coefficient of radon in the rocks changes significantly in these models, an is affected by several factors. Only a fraction of radon atoms can reach the Earth's surface and can exhale to atmosphere before decaying.

With the aim to better define the transport process of radon through fractured media, we reconstructed vertical profiles at different depths near active faults, determining in-soil radon diffusion coefficients in the Aetnean sites. Laboratory measurements were carried out on different rock samples in order to extract the exhalation rate.

2. Experimental procedure

The investigated area is located on Mt. Etna, a complex volcano (more than 3300 m high and 40 km in diameter) with four summit craters (SC), more than 300 lateral vents and cones on its flanks, and with several fault systems. Since the actual volcanic activity prevalently concerns the eastern flank and since our previous data [9, 17–21], continuously collected from 2001 to 2004 in the Etnean area, showed for the NE flank a possible correlation between the radon trend and eruptive events, we carried out an investigation of in-soil radon levels in the eastern region (see fig. 1), in particular near the villages of *Vena* (V) [NE, 825 m a.s.l.], *Cugno di Mezzo* (CM) [E, 1400 m a.s.l.], *Santa Venerina* (SV) [SE, 400 m a.s.l.].

All the three sites are located near fault systems that play an important role when an eruption is approaching. In particular, *Vena* is near the crossing point between the *Pernicana Fault* (PF) and the *Timpe della Naca Faults* (NF). *Cugno di Mezzo* is located on the southern edge of the eastern caldera named "*Valle del Bove*", characterized by very active faults. *S. Venerina*

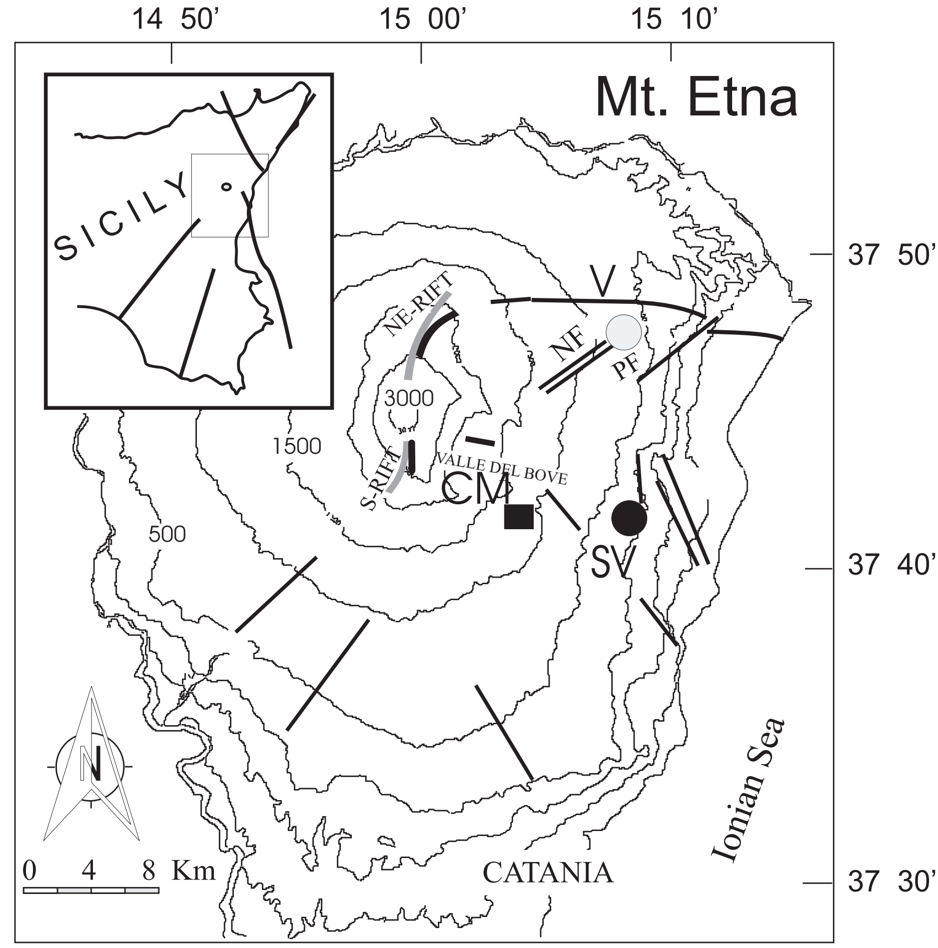

Figure 1: Etna map and location of investigation sites: *Vena* (white circle); *Santa Venerina* (black circle); *Cugno di Mezzo* (square). NF = *Naca Faults*; PF = *Pernicana* Faults; TFS = *Timpe Faults System*; STF = *Santa Tecla Faults*; TF = *Tremestieri Faults.*

is located close to two systems, the *Timpe Faults System* (TFS) and the *S. Tecla Fault* (STF).

The three sites were simultaneously investigated for a long time under the same meteorological conditions, in order to extract vertical radon profiles and the diffusion coefficient.

Gamma-ray spectroscopy in laboratory and exhalation rate analysis on rock samples collected in the investigated sites were performed, too.

2.1 Radon diffusion coefficient

In order to determine the vertical profile of the radon concentration at different depths, in-soil measurements were carried out using nuclear track detectors (SSNTD-CR39). The detectors (active area: $25 \times 25\,\text{mm}^2$) were placed inside a diffusion chamber that allows only ^{222}Rn entry. At each measurement point detectors were vertically allocated, in 20 cm distance intervals, from 20 to 100 cm of depth, inside a closed PVC tube ($l = 100\,\text{cm}$, $\phi = 6.3\,\text{cm}$), uniformly pierced along all its length in order to allow the radon entry. In order to avoid saturation effects the CR-39 detectors were replaced every two weeks.

After the exposure the CR-39 detectors were chemically etched and read by an optical microscope (connected to a CCD camera and a personal com-

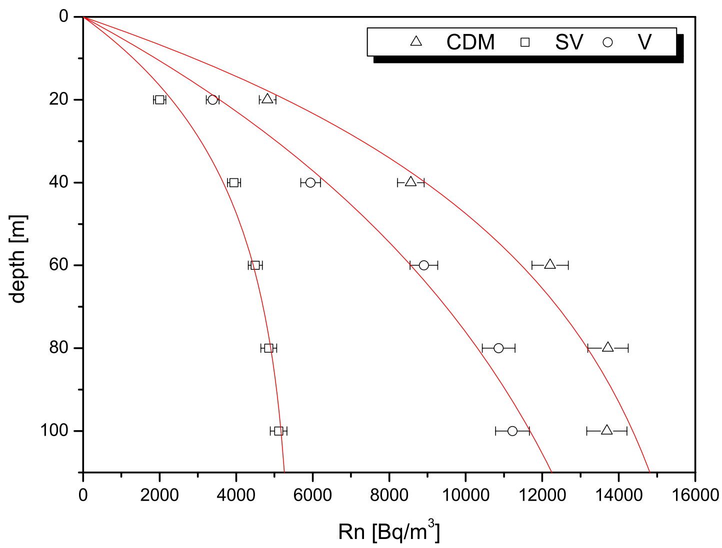

Figure 2: Vertical radon concentration profiles in the *Vena, Cugno di Mezzo* and *Santa Venerina* sites.

Table 1: In soil average Rn concentration at one meter depth; the diffusion coefficient D is extracted from the fit, for the three sites (V, CM, SV) (see text).

Site Code	Rn [kBq m^{-3}]	D [10^{-3} cm^2 s^{-1}]
V	11 ± 3	14.3 ± 0.1
CM	14 ± 2	16.0 ± 0.3
SV	4 ± 1	3.50 ± 0.01

puter) by means of a semiautomatic procedure for discriminating the tracks according to minor and major axis and area.

The vertical profile of the radon concentration was determined by fitting the measured values to an exponential relation [22]:

$$C(z) = C_\infty \left[1 - \exp\left(-z \cdot \sqrt{\frac{\lambda}{D}}\right)\right], \tag{1}$$

where C_∞ is the radon concentration at profound depth, D is the diffusion coefficient, λ the radon decay constant and z the depth.

In figure 2 the radon concentration vertical profiles, obtained in the investigated sites, are plotted. Data refer to average values of in-soil radon concentration at each depth over the investigation period. In table 1 the values of the diffusion coefficient D obtained by data fit are reported.

2.2 Radionuclide amount

Rock samples collected from the investigated sites and together with other rock samples (sedimentary and metamorphic) were radiometrically characterized by means of γ-ray spectroscopy, performed using a high-purity germanium (HPGe) detector with a relative efficiency of 30%.

In table 2 is reported the radionuclide concentration. The specific activity concentration of ^{238}U was determined using the gamma line of ^{214}Bi at 609 keV and 1120 keV. For ^{232}Th, the specific activity was calculated using the gamma line of ^{228}Ac at 911 keV. The specific activity concentration of ^{40}K was estimated directly by its gamma line at 1461 keV [23].

The radionuclide distribution for different kinds of rock is shown in fig. 3. Higher uranium and thorium concentration is observed in magmatic rocks.

Table 2: Radionuclides concentration for different kinds of rock: Sedimentary rock (from sample C01 to C05); Metamorphic rock (C06) and Magmatic rock (C07 *Vena*; C08 *Cugno di Mezzo*; C09 *Santa Venerina*).

Site Code	^{238}U [Bq kg^{-1}]	^{232}Th [Bq kg^{-1}]	^{40}K [Bq kg^{-1}]
C01	5 ± 1	9 ± 2	89 ± 6
C02	7 ± 1	2 ± 1	78 ± 5
C03	31 ± 3	14 ± 1	95 ± 6
C04	19 ± 3	11 ± 1	89 ± 7
C05	41 ± 5	8 ± 1	250 ± 15
C06	31 ± 4	108 ± 10	100 ± 8
C07	56 ± 7	49 ± 7	110 ± 10
C08	80 ± 9	50 ± 7	180 ± 12
C09	40 ± 6	72 ± 8	85 ± 9

2.3 Radon exhalation rate

The radon exhalation rate was determined by means of the Can Technique [24] using CR39 detectors. The rock samples, dried at 80 °C and reduced to about 300 g mass, were allocated in sealed cylindrical cans ($\phi = 8.6$ cm; $h = 10.5$ cm). A CR-39 detector was fixed, inside its diffusion chamber, on the top inside each can and exposed for detecting alpha particles from the decay of radon exhaled from the sample in the remaining volume of the can. After three months exposure the detectors were etched and read for track counting.

The mass exhalation rate ε_M was determined by the expression [25]:

$$\varepsilon_M = \frac{CV\lambda t}{M[t + 1/\lambda(e^{-\lambda t} - 1)]}\,, \tag{2}$$

where C is the radon concentration measured by the track detector [Bq m^{-3}], V is the free volume of the can, λ is the radon decay constant; t is the exposure time, M is the sample mass.

The obtained values of the exhalation rates, for the rock samples, are shown in fig. 4. Generally, for volcanic rocks a correlation is found between ^{238}U concentration and exhalation rate.

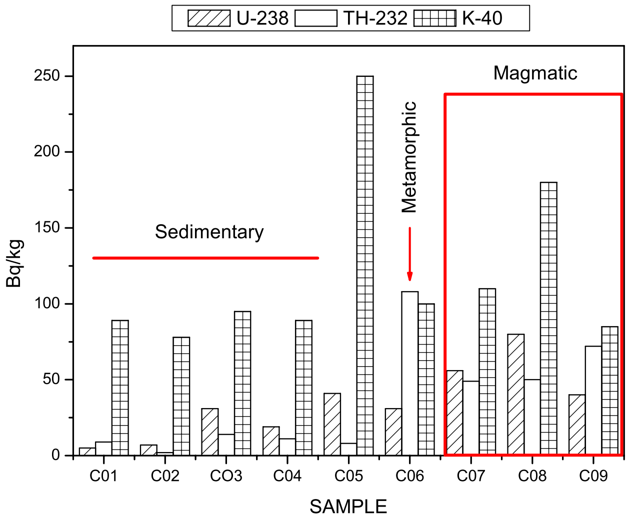

Figure 3: Radionuclide distribution obtained via γ-spectroscopy for different kinds of rock: Sedimentary rock (from sample C01 to C05); Metamorphic rock (C06) and Magmatic rock (C07 *Vena*; C08 *Cugno di Mezzo*; C09 *Santa Venerina*).

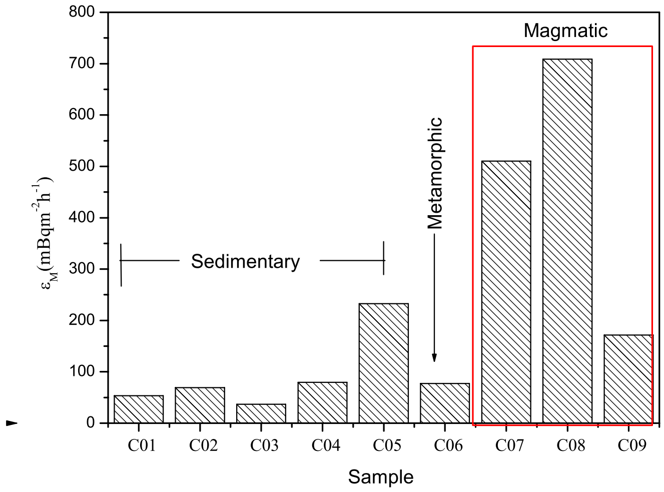

Figure 4: Exhalation rate for kinds of different: Sedimentary rock (from sample C01 to C05); Metamorphic rock (C06) and Magmatic rock (C07 *Vena*; C08 *Cugno di Mezzo*; C09 *Santa Venerina*).

3. Conclusions

In order to better define the radon transport process through fractured media, an investigation was performed in sites located in the geodynamically active area on the eastern flank of Mt. Etna.

The survey was performed using different methodologies for both short and long-term measurements, and for reconstructing vertical radon profiles at different depths near active faults, in order to determine the diffusivity of radon.

Moreover, laboratory measurements on rock samples, collected from the investigated sites, allowed to extract the radon exhalation rate under controlled physical conditions.

The comparison with results obtained using sedimentary and metamorphic sample rocks has shown that magmatic rocks have higher radionuclide amounts and higher exhalation rate.

By comparing in-soil Radon concentration values, the Radon diffusion coefficient, the amount of uranium, and the exhalation rate a good correlation was found, representing a further contribution to define radon transport process, allowing in particular to shed light on the role of radon as precursor of volcanic activity.

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