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# Soil gas Radon concentrations in three study areas of Calabria (Southern Italy)

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## INTRODUCTION

Radon is a naturally occurring radioactive gas, colorless, odorless, practically chemically inert; it is present in only trace concentrations in the atmosphere. It is one of the products of the natural decay of uranium, which is ubiquitous in rocks and soils, though variable in concentration according to the specific mineralogy (TANNER, 1964; CLAMP & PRITCHARD, 1998, SEGOVIA *et al.*, 2007; SINGH *et al.*, 2011).

The World Health Organization (WHO), through the International Agency for Research on Cancer (IARC), has classified, since 1988, radon in Group 1 (which lists 95 substances classified as carcinogenic to humans). Radon would be the second most important cause of lung cancer after cigarette smoking. Therefore, knowledge of the levels of radon in the soil gas and underground water or in the dwelling's atmosphere is necessary to protect populations from the consequences of excessive exposure to radiation (NERO, 1990).

Radon tends to migrate from its source mainly upwards. Its rate of migration and soil-gas concentration are controlled by a large number of factors, such as: the distribution of uranium in the soil and bedrock, soil porosity, permeability and humidity, degree of fracturing of rocks, micro-cracks of the bedrock, granulation, rainfall, air temperature, barometric pressure, surface winds, and so on (NISHIMURA & KATSURA, 1990; AL-TAMIMI & ABUMURAD, 2001; PLANINIĆ *et al.*, 2001). As a result, the ease with which Radon moves in pore spaces or fractures affects how much radon reaches the Earth's surface at any given location. Anomalously high concentrations are often found in soils above highly fractured rocks, such as those associated with geologic faults, active volcanoes and geothermal sources.

Radon spatial information is commonly obtained at specific sampling points. Geostatistical methods (MATHERON, 1971; BADR *et al.*, 1993) provide a valuable tool to study the spatial structure of radon concentrations. The interpolation technique of the variable at unsampled locations, known as kriging, provides the "best", unbiased, linear estimate of a regionalized variable in an unsampled location - where "best" is defined in a least-square sense (CHILÈS & DELFINER, 1999).

This study is aimed at defining the relationships between geological features, seismicity and soil-gas Radon concentrations in three study areas of Calabria (Crati Graben, northern border of the Sila massif, and "Stretta di Catanzaro" – cf. Fig. 1).

## $^{222}$RN: SOURCES AND DISTRIBUTION

Radon has 86 protons and may have a variable number of neutrons in its atomic nucleus, depending on the parent radionuclide of the decay series. The three primary sources for natural Radon are the parent isotopes of the two uranium series ($^{238}U$ and $^{235}U$) and of the thorium series ($^{232}Th$) (MUDD, 2008). Approximately, Radon has a 3.2 days half-life. Although there are 33 radon isotopes known with 110–142 neutrons (EKSTRÖM & FIRESTONE, 2008), only Radon ($^{222}Rn$), Actinon ($^{219}Rn$) and Thoron ($^{220}Rn$) are relevant in natural or industrial contexts.

The concentration of radon in air and in soil is expressed in Becquerel per cubic meter (Bq $m^{-3}$) in SI. As for the geographical distribution of Radon levels in the world, useful data can be found in AL-TAJ *et al.* (2004), FONT *et al.* (2008), KEMSKI *et al.* (2009), NERI *et al.* (2011), PEREIRA *et al.* (2010).

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## ENVIRONMENTAL SETTING

The study areas (Fig. 1) are located in the Central-Northern sector of the Calabrian Arc (CA), an arc-shaped structure of the circum-Mediterranean orogenic belt, representing an accretionary wedge of crustal terranes originated by the Africa-Europe collision (TORTORICI, 1982).

The CA consists of a series of ophiolite-bearing tectonic units and of overlying basement nappes, which are considered to be a remnant of the Cretaceous–Paleogene Europe-verging Eo-Alpine Chain, involved in the construction of the Apennine orogenic belt during Oligocene-Early. Since Middle Miocene, overthrusting - combined with the progressive eastward migration of the CA - was associated with the opening of the Tyrrhenian basin (DE CANDIA *et al.*, 1998). The migration occurred along a NW-SE trending regional strike-slip fault system, which dissected the thrust assemblage of the Arc.

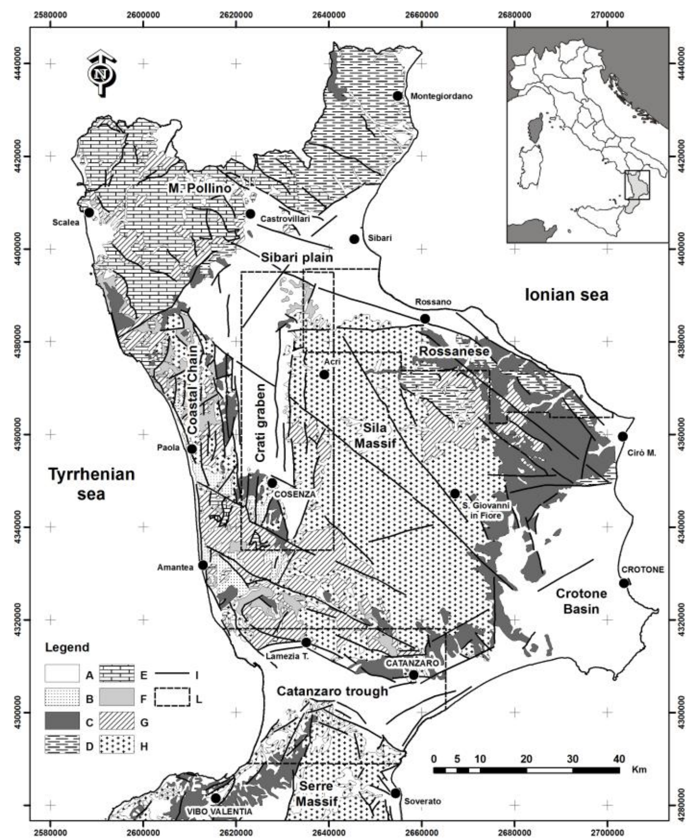


*Fig. 1* – Geological sketch of Central-Northern Calabria (after SORRISO-VALVO & TANSI, 1996, mod.), and location of the study areas. Key: A) loose deposits; B) detrital coherent deposits; C) detrital argillaceous deposits ; D) flysch; E) limestone and dolostone; F) middle-high grade ophiolitic metamorphic rocks; G) low grade metamorphic rocks; H) middle-high grade metamorphic rocks and plutonites; I) main fault; L) study areas.

During Middle Miocene-Middle Pleistocene, the NW-SE system affected the northern portion of the CA, assuming the characters of a crustal oblique transpressional shear zone (mainly dipping toward NE), characterised by left-reverse movements (VAN DIJK *et al.*, 2000).

## METHOD

In the study area, the survey of Radon soil-gas concentrations has been carried out through a portable monitor, (AB-5 PYLON), a trace environmental level gas detector (which detects radon levels as low as 11 Bq $m^{-3}$), and a data acquisition unit (instantaneous measurements).

The soil gas has been pulled off at opened holes of 75 cm depth, through a vacuum soil probe by a vacuum hand pump - as shown in Fig. 2.

Measured soil gas radon data were modelled as an intrinsic stationary process (CHILÈS & DELFINER, 1999) and interpolated using a geostatistical approach called multi-Gaussian ordinary kriging. It is based on a multi-Gaussian model and requires a prior Gaussian transformation of the initial attribute into a Gaussian-shaped variable with zero mean and unit variance.

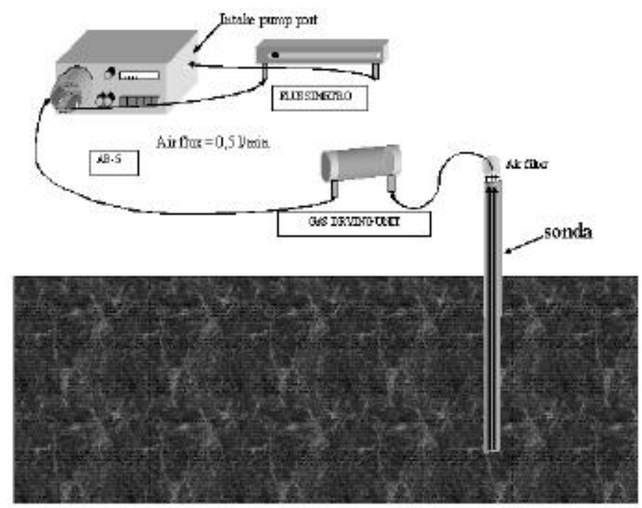


*Fig. 2* – Sampling method of soil gas radon.

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