Soil gas radon potential in two urban areas of central Portugal (*)(**)

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(ricevuto il 9 Giugno 1998; revisionato il 9 Febbraio 1999; approvato il 19 Gennaio 1999)

Summary. — Radon concentrations were measured (in quite similar conditions) in two regions of central Portugal with different geological settings. General conclusions are: the soil radon potential is mainly dependent on geological factors, specially lithology, uranium content and structure; in order to have a comprehensive understanding of radon distribution in soils, small-scale studies are needed.

PACS 91.65 – Geophysical aspects of geology, mineralogy, and petrology.
PACS 51.20 – Viscosity, diffusion, and thermal conductivity.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

In central Portugal two broad geological units have generally been considered: the Hesperian Massif, mostly made of hercynian granitoids and metamorphosed schists and graywackes, locally covered with thin Cretaceous to Tertiary detritic deposits; and the Meso-Cenozoic sedimentary Western Borderland, in most part of detritic and carbonate nature.

A number of occurrences of U-rich mineralizations have been discovered in the Massif, usually associated with granites. In the Western Borderland no U-mineralisations have been found; however, uranium concentrations of some tens of ppm, exceptionally of about three hundreds, at some areas in detritic sequences, were reported by Marques *et al.* (1979) and Marques *et al.* (1979a). Presumably, the uranium present in the Borderland rocks came from the Massif rocks, that were the main source of the Meso-Cenozoic sediments.

In this report two regions were selected for soil gas radon measurements. One of them (the Coimbra region in this report) extends over ca. 40 km^2 around the town of

(*) 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.

Coimbra and is located on the Western Borderland; the other (the Seia region in this report) is located on the Hesperian Massif and extends over ca. 8 km^2 around the town of Seia. Our main goal is to correlate the radon production in the two regions with the geological setting.

2. – Geological setting

Figure 1 presents simplified maps of the geology and regional setting of the studied areas. The Coimbra region is mainly composed of Triassic and Jurassic sedimentary rocks that cover strongly deformed Precambrian metamorphic rocks, which are mostly schists with a subvertical main foliation. Triassic rocks are of detritic nature and correspond to positive sequences with conglomerates and sandstones, locally clay-rich. The base of Jurassic is a sequence of sandstones and marly to dolomitic sandstones; this sequence evolved through Lower and Middle Jurassic to dolostones, dolomitic limestones, marls, marly limestones and limestones. Mesozoic formations are locally overlaid by Quaternary gravel and sand deposits, in most cases a few meters thick; however, in few places these young deposits are also clay-rich. More details on the geology of the region can be found in Soares *et al.* (1985).

Dominant rocks of the region of Seia are two-mica granites of hercynian age, which range from coarse- to fine-grained; the main type is a porphyritic, coarse-grained, biotite-muscovite granite. These granites intruded and metamorphosed Late Precambrian to Cambrian schists and graywackes. A Tertiary sequence of conglomerates, sandstones and claystones (sometimes in small nodules) locally overlays the granites of the Seia river valley; its thickness ranges from < 1 m to at least 10 m.

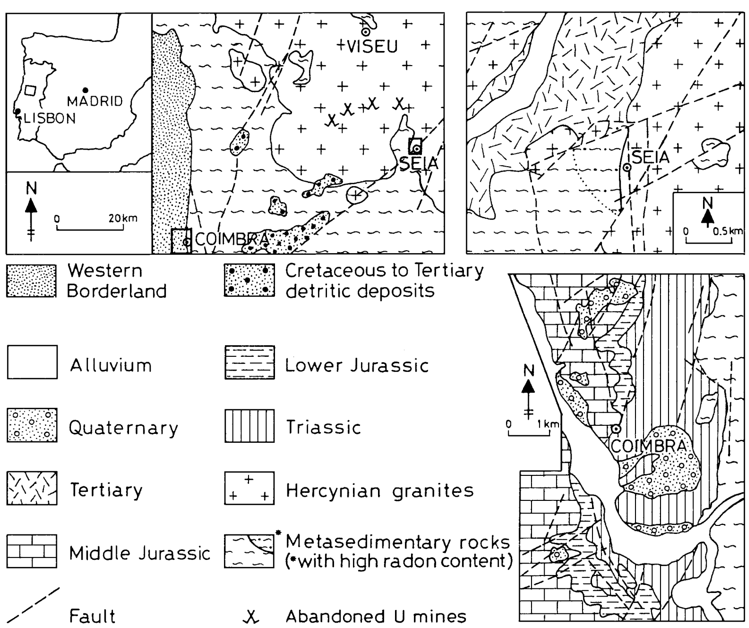

Fig. 1. – Localization maps and simplified geological maps of the Coimbra and Seia regions. The insert in the sketch of Portugal territory (top left corner) corresponds to the top left geological map.

3. – Methods and results

A total of 252 measurements of soil-gas radon concentration were carried out at a depth of 0.8 meters. In each case a small hole (2 cm in diameter) was drilled, and the soil gas manually pumped to a ZnS scintillation counter (Lucas cell); the accuracy of each measurement is approximately 10%. Calibration is achieved through the use of an internal standard provided by the manufacturer. In order to minimise the influence of meteorological factors on concentrations (see, *e.g.*, Ball *et al.*, 1991; Schumann *et al.*, 1992), all field work was carried out under similar conditions: during a brief period of time, at the beginning of the summer, and with stable weather and no rainfall.

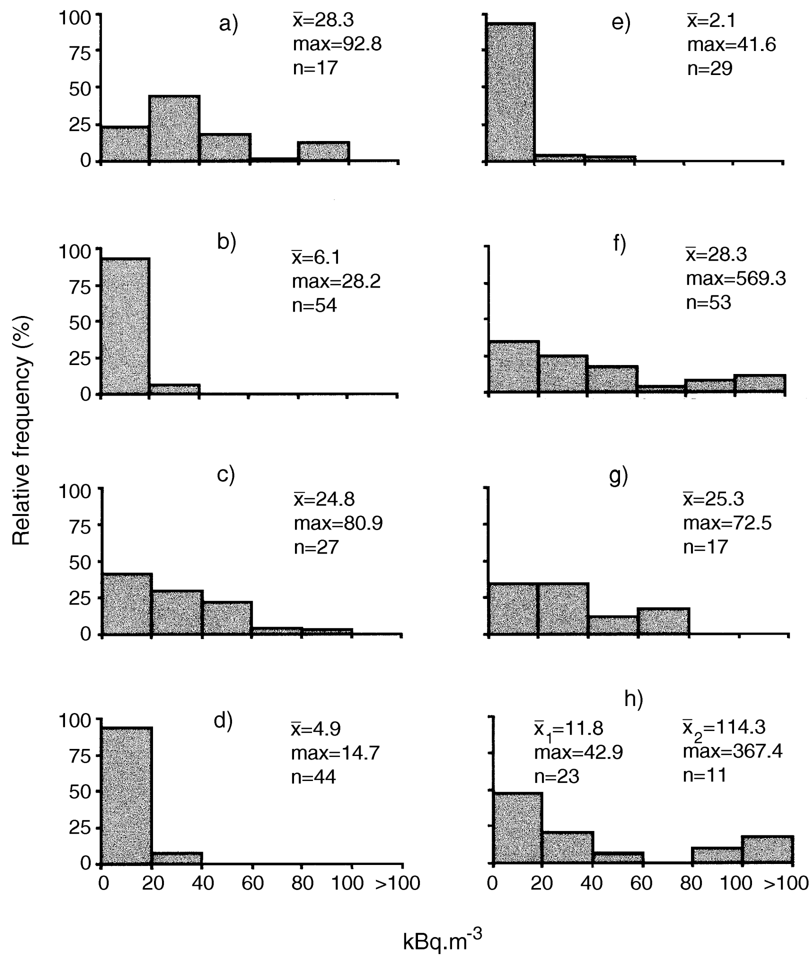

Fig. 2. – Radon concentration data on the Coimbra and Seia regions, grouped according to lithology. Coimbra region: Quaternary fine (a) and coarse (b) deposits; clay-rich fine-grained (c) and coarse-grained (d) Triassic rocks; Jurassic rocks (e). Seia region: Tertiary sediments (f), granites (g) and schists and graywackes (h). n is the number of measurements; max is the maximum value found; g is the geometric mean, which was preferred to the arithmetic mean because histograms are positively skewed as a rule.

The data obtained are summarised in fig. 2 (a-h); alluvium was not sampled because of its high moisture content, even during the dry season. Histograms are plotted for each geological unit mapped in the referred areas, with the following exceptions: 1) data for Triassic sandstones are grouped according to grain size, as results show that radon concentration is more dependent on this factor than on the position of the rock in the stratigraphic sequence; 2) the fine-grained Quaternary sediments, though not mapped, were separated from the Quaternary coarse ones; 3) Jurassic formations (mainly carbonate-rich) were grouped together, since their radon concentrations are quite similar.

4. – Discussion

The lowest radon concentrations were found in soils of the urban area of Coimbra which overlay carbonate-rich rocks from the Lower to Middle Jurassic (fig. 2e), in the coarse-grained detritic sediments from Triassic (fig. 2d), and in coarse Quaternary sediments (fig. 2b). Hercynian granites from Seia area emanate radon to soils at a moderate level (fig. 2g); however, concentrations as high as $72\,\mathrm{kBq\cdot m^{-3}}$ were observed, usually in relation with some of the faults that cut the granitic rocks. The radon content of the granites of the Seia region is similar to the radon content measured in fine-grained clay-rich detritic rocks (Triassic sandstones, fig. 2c; Quaternary deposits, fig. 2a).

Tertiary sediments of the Seia region display a broad range of radon concentrations, with values ranging from 1 to $569\,\mathrm{kBq\cdot m^{-3}}$ (fig. 2f); the highest radon content can be correlated with the most fine-grained clay-rich levels and with faults in the underlying bedrock. Schists and graywackes of this region display a complex distribution where two modes can be recognised (fig. 2h). The higher radon concentrations were found to be restricted to a small portion of the outcropping area (ca. $0.5\,\mathrm{km^2}$), which is partially surrounded by granitic rocks; concentrations close to $370\,\mathrm{kBq\cdot m^{-3}}$ were measured in it.

To sum up, radon concentrations are considerably higher in soils derived from granites and fine-grained clay-rich sedimentary rocks; carbonates and coarse-grained sediments have the lowest radon contents. This is in good agreement with other geological information collected in the areas under study. Pereira *et al.* (1996) and Costa *et al.* (1996) analysed the uranium content in 65 samples taken from all the geological units outcropping in the Coimbra and Seia regions; in general, the U content in the rocks correlates well with radon concentrations of the overlaying soils; the exception is the very high radon content locally observed in the schists and graywackes, and also in the Tertiary sediments of the Seia area; in both cases the U content of the rocks could not explain the content of radon in soils. For the metasediments, a deep source for radon is assumed, probably consisting of uranium ores located in fractures or disseminated in the subsurface rocks; several uranium mines showing a similar geological setting are known in central Portugal. In the Tertiary sediments highly radioactive clay-rich nodules (centimeter sized) were observed in significant amounts. The U content of these nodules can be as high as 425 ppm, which can explain some of the high radon measurements obtained. Because the thickness of the formation is locally very thin (less than 1 meter), a strong influence from the underlying bedrock on the radon content cannot be overruled.

5. – Radon potential

Combining the results on radon with permeability data, it is possible to assess the radon potential of each geological unit (*e.g.*, Åkerblom, 1994). At the moment quantitative data on the permeability of the rocks of Coimbra and Seia regions are not available; however, a qualitative assessment can be made on the basis of the available geological information. In both areas soil thickness is frequently less than 2 meters; thus, the nature of the bedrock must also be taken into account to assess the permeability of each geological unit.

Granites and metasedimentary rocks have, in general, low permeability, unless fractured or deeply weathered. In the Seia region these rocks are cross-cut by a dense fracture network; thus, an increase in the permeability is locally expected. In the case of the metasediments occurring in Coimbra and Seia areas, the main foliation is subvertical, a factor which can afford an increase in permeability. In face of the measured radon concentrations, and taking into account the several radon risk classifications proposed (Åkerblom, 1987; 1994; Barnet, 1991; Gunderson *et al.*, 1992; Appleton and Ball, 1995), a high radon potential is predictable for part of the metasediments mapped in the Seia region (see fig. 1), as well as for restricted faulted areas in the granites. The remainder area occupied by the metasediments, including those outcropping in the Coimbra region, and the granites would have a low and a moderate radon potential, respectively.

As far as the sedimentary rocks are concerned, the high radon concentrations are related to fine-grained sediments, often very clay-rich, found in the Triassic (Coimbra), Tertiary (Seia) and Quaternary (Coimbra) deposits. In many cases these deposits have low permeability, to which also a nearly horizontal bedding contributes; thus, these geological units should be regarded as having, in average, only a moderate radon potential. However, in situations where the radon concentrations in soils are greater than ca. $100\ \mathrm{kBq \cdot m^{-3}}$, a high radon potential is also predictable. This situation occur at times in the Tertiary sediments of the Seia area. Considering their low radon content, carbonates, marls, and coarse-grained sediments have a low radon potential, in spite of their locally high permeability.

6. – Conclusions

In the studied areas soil radon concentration is mainly dependent on nature, uranium content and structure of the rocks. Higher concentrations were found in granites and fine-grained sediments; coarse-grained sediments, carbonates and marls are radon-poor. Radon concentration and rock permeability are, in both regions, the main factors to be taken into consideration in assessing radon potential; this potential is clearly enhanced by faulting, which implies that small-scale geological studies are needed for radon potential assessment.

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The authors acknowledge the financial support by the Portuguese Foundation for Science and Tchnology (FCT), through the Project Praxis XXI/2/2.1/CTA/399/94 and the Geosciences Center of Coimbra University.

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