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Characterization of radon levels in soil and groundwater in the North Maladeta Fault area (Central Pyrenees) and their effects on indoor radon concentration in a thermal spa

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ABSTRACT

Radon levels in the soil and groundwater in the North Maladeta Fault area (located in the Aran Valley sector, Central Pyrenees) are analysed from both geological and radiation protection perspectives. This area is characterized by the presence of two important normal faults: the North Maladeta fault (NMF) and the Tredós Fault (TF). Two primary aspects make this study interesting: (i) the NMF shows geomorphic evidence of neotectonic activity and (ii) the presence of a thermal spa, Banhs de Tredós, which exploits one of the several natural springs of the area and needs to be evaluated for radiation dosing from radon according to the European regulation on basic safety standards for protection against ionizing radiation. The average soil radon and thoron concentrations along a profile perpendicular to the two normal faults — 22 ± 3 kBq·m^{-3} and 34 ± 3 kBq·m^{-3}, respectively — are not high and can be compared to the radionuclide content of the granitic rocks of the area, 25 ± 4 Bq·kg^{-1} for ^{226}Ra and 38 ± 2 Bq·kg^{-1} for ^{224}Ra. However, the hypothesis that the normal faults are still active is supported by the presence of anomalies in both the soil radon and thoron levels that are unlikely to be of local origin together with the presence of similar anomalies in CO_2 fluxes and the fact that the highest groundwater radon values are located close to the normal faults. Additionally, groundwater ^{222}Rn data have complemented the hydrochemistry data, enabling researchers to better distinguish between water pathways in the granitic and non-granitic aquifers. Indoor radon levels in the spa vary within a wide range, [7–1664] Bq·m^{-3} because the groundwater used in the treatment rooms is the primary source of radon in the air. Tap water radon levels inside the spa present an average value of 50 ± 8 kBq·m^{-3}, which does not exceed the level stipulated by the Spanish Nuclear Safety Council (CSN) of 100 kBq·m^{-3} for water used for human consumption. This finding implies that even relatively low radon concentration values in water can constitute a relevant indoor radon source when the transfer from water to indoor air is efficient. The estimated effective dose range of values for a spa worker due to radon inhalation is [1–9] mSv·y^{-1}. The use of annual averaged radon concentration values may significantly underestimate the dose in these situations; therefore, a detailed dynamic study must be performed by considering the time that the workers spend in the spa.

1. Introduction

Radon is a radioactive noble gas that results from disintegration of uranium and thorium, which are present in almost all rock and soil types. There are three natural isotopes of radon: ^{222}Rn (hereafter referred as radon), ^{220}Rn (hereafter referred as thoron), and ^{219}Rn, with half-lives of 3.82 days, 55.6 s and 3.96 s and are derived from the ^{238}U, ^{232}Th and ^{235}U decay series, respectively. Radon can move rather freely through porous media such as soil or fragmented rock, can be incorporated into groundwater flows because it is soluble in water, can migrate over significant distances within the earth and the atmosphere as well as enter into dwellings and accumulate indoors. The concentration of thoron indoors is of lesser importance due to its shorter half-life, whereas ^{219}Rn is normally ignored. Indoor radon levels and their temporal variations in a given room are the consequence of a complex balance of different processes involving geological parameters, weather, the structural characteristics of the dwellings, and the habits of the occupants (Font and Baixeras, 2003).

There are a large number of studies on the applications of radon as a tracer, covering almost all applications in geology, geophysics and

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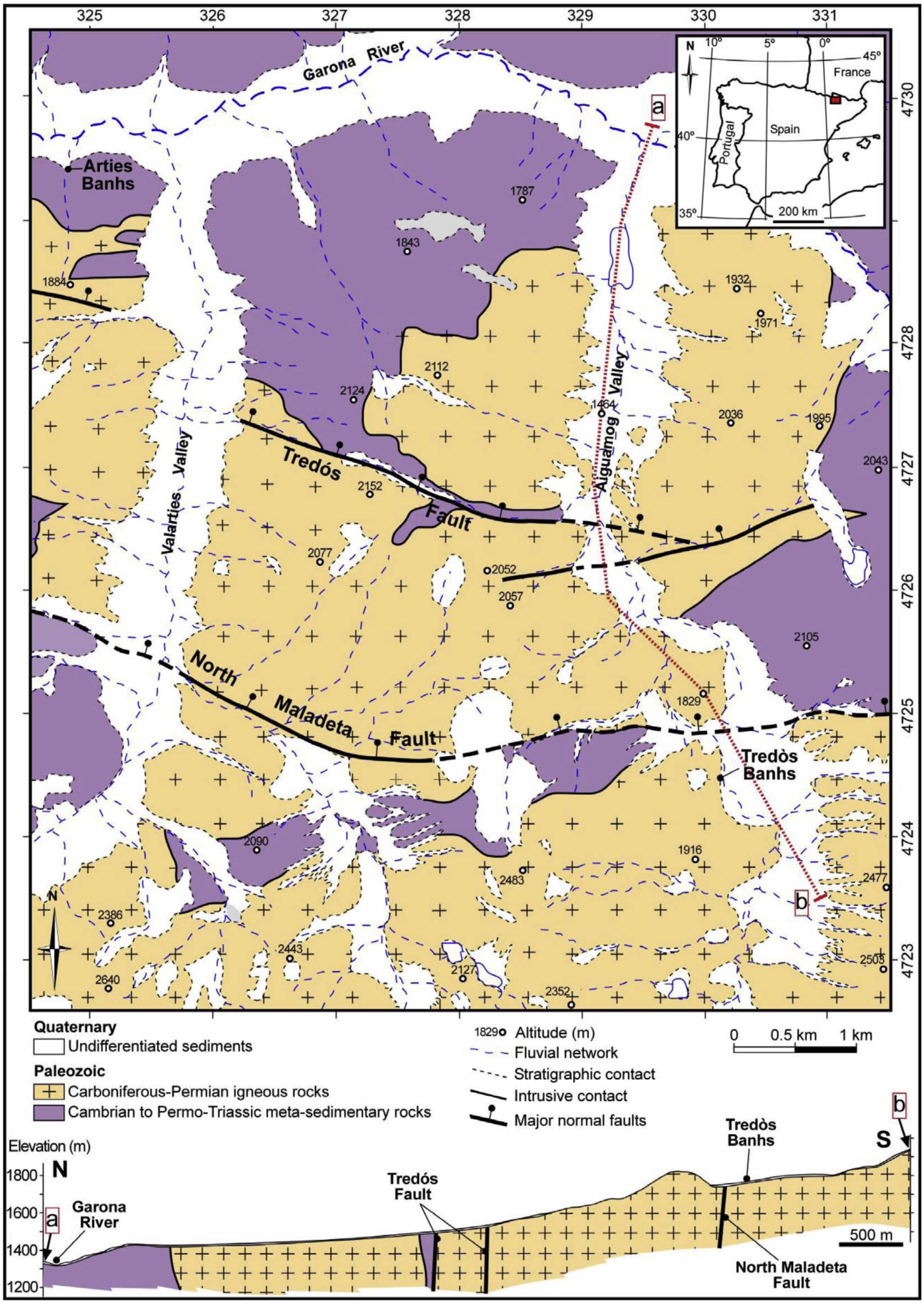

Fig. 1. Main geological and geomorphological features of the study area.

geochemistry, including oceanography and atmospheric sciences (Baskaran, 2016) for two reasons: i) it can be measured with accuracy in soil, water, and air, and ii) its half-life allows it to trace environmental processes of several days of duration. In particular, radon has been used by the scientific community to characterize and study the activity of fault areas and volcanic regions around the world, finding radon anomalies in soil, groundwater, and buildings (King, 1978, 1996; Baubron et al., 2002; Ioannides et al., 2003; Hernández et al., 2004; Erees et al., 2006; Papastefanou, 2010; Walia et al., 2010; Neri et al., 2011,2016; Appleton, 2013; Martin-Luis et al., 2015; Ye et al., 2015; Yuce et al., 2017). In the Iberian Peninsula, some volcanic and fault areas have already been studied with radon measurements (González-Díez et al., 2009; Künze et al., 2012). The studies performed in the volcanic region of La Garrotxa (Baixeras et al., 2005; Moreno et al., 2008, 2009; 2014) and the Amer fault zone (Font et al., 2008a; Zarroca et al., 2012; Moreno et al., 2016) are especially detailed. In several volcanic, faulty or geothermal environments, ^{222}Rn anomalies have been correlated with the strong degassing of other trace gases as carbon