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Investigation of the relationship between rock strain and radon concentration in the tidal frequency-range

Gyula Mentes

Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, Csatkai E. u. 6-8., H-9400 Sopron, Hungary

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ABSTRACT

Changes in the radon gas concentration can precede geodynamic processes associated with tectonic, volcanic activities and earthquakes. For this reason the relationship between rock strain and radon concentration is an important scientific issue to be answered. According to the complexity of the radon emanation process influenced by environmental effects, the interpretation of radon concentration variation as a possible precursor of geodynamic processes is not yet resolved unambiguously. The Sopronbánfalva Geodynamic Observatory in Hungary is one of the few places where radon concentration and rock strain variations are simultaneously monitored. The object of this study is to investigate the connection between indoor radon concentration and rock strain in the tidal frequency-range on the basis of seven-year long data series measured in years from 2009 till 2015. The relationship between rock deformation and radon concentration was investigated together with the temperature and barometric pressure effects. It was found that the strain induced radon concentration variations are in the order of 10–100 Bq nstr^{-1}, while the concentration variations bear more considerable similarity and relation to the temperature and barometric variations. The theoretical tide at the location of the measurement site and tidal components computed from strain, radon concentration, barometric pressure and temperature data were compared with each other. Spectral and tidal analysis of data demonstrated that only the thermally induced solar components S1 and S2 are present in the radon concentration but their amplitudes hardly exceed the spectral noise level. The principal lunar semidiurnal M2 and diurnal O1 tidal waves cause the largest rock strain variations. The lack of the O1 and M2 constituents in the radon concentration confirms the fact that the detected S1 and S2 tidal components appear due to the barometric tide and the daily variations of the temperature and barometric pressure.

1. Introduction

Radon 222 is an inert, omnipresent radioactive gas which is continuously produced in the rocks and migrates into the air (Steinitz and Piatibratova, 2010; Szabó et al., 2013). Thus the amount of radon exhalation depends on the properties of the rock (elasticity, porosity, permeability, homogeneity, fragmentation, etc.) and on the fractures and hydrologic and geodynamic processes in the rock (Holub and Brady, 1981; Kies et al., 2002, 2005; Millich et al., 1998; Papp et al., 2008). The fact that geodynamic processes also change the properties of rocks, inspires to study geodynamic processes by investigation of radon emanation and concentration. This is why radon concentration variations were observed during volcanic (Toutain and Baubron, 1999; Viñas et al., 2007) and tectonic (Aumento, 2002; Garavaglia et al., 1998, 2000; Mahajan et al., 2010; Omori et al., 2007; Utkin and Yurkov, 2010) activities. Several papers deal with the investigation of the relationship between Earth tides and radon concentration variations measured in underground caves and dwellings (Alekseenko et al., 2010; Barnet et al., 1997a, 1997b; Groves-Kirkby et al., 2004; Kies et al., 1999). Richon et al. (2009) studied the connection between radon concentrations and barometric tides. Since the Earth tide induced local strain in the rock is much smaller than the strain caused by earthquakes, volcanic activity (Viñas et al., 2007) or by large tectonic movements it is difficult to detect the interaction of tidal strain and radon emanations. Furthermore, the amount of radon emanation strongly depends on the temperature and barometric pressure (Barnet et al., 1997a, 1997b; Gregorič et al., 2011; Mentes and Eper-Pápai, 2015; Pinault and Baubron, 1996; William and Wilkening, 1974). The problem is worsened by the fact that the temperature and the barometric pressure short-term variations coincide with some diurnal and semidiurnal tidal frequencies. In addition, both the temperature and barometric pressure have also an indirect effect, as their changes induce stress in the rock (Mentes, 2000). Until now, the verification of the role of the tidal effect in the radon emanation from rocks and soils has not been reassuringly unambiguous due to the above mentioned problems. Barnet et al. (1997a, 1997b) graphically compared short radon data series with the theoretical tidal components. The short data series and the varying phase shift between

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E-mail address: mentes@ggki.hu.

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the plots questioned the effect of the tidal phenomena. Crockett et al. (2006) calculated the correlation between theoretical tidal signals and radon concentrations but they got very low correlation coefficients (< 0.3). Many authors used FFT (Alekseenko et al., 2010), and additional frequency analysis methods, as spectral-decomposition techniques (Crockett and Gillmore, 2010), Empirical Mode Decomposition, Singular Spectrum Analysis (Crockett et al., 2010), etc. but they came to various results, which can be attributed to different measurement locations and methods. According to our knowledge the relationship between radon concentration and rock strain variations has not yet been investigated using tidal evaluation.

In the Sopronbánfalva Geodynamic Observatory (SGO) simultaneous strain and radon concentration measurements have been carried out by means of a quartz-tube extensometer and an AlphaGUARD™ radon concentration recorder since 2009. It provides a good opportunity to investigate the relationships between strain and radon concentration data. In this paper the relation of radon concentration to rock deformation caused by tidal effects is studied by spectral and Earth tide analysis on the basis of radon concentration, strain, indoor and outdoor temperature and barometric pressure data measured between 2009 and 2015.

2. Observation site and measuring methods

2.1. Observation site

Sopronbánfalva (SGO) is located in the Sopron Mountains near to the Hungarian-Austrian border (see lower right corner in Fig. 1). This territory belongs to the eastern foothills of the Alps represented by crystalline rocks and is characterized by their outcrops in this Alpokalja (Lower Alps) region. The Sopron Mountains are made of metamorphic rocks of Palaeozoic age such as gneiss and different mica schists which formed from granitic and clastic sedimentary rocks (Kisházi and Ivancsics, 1985, 1987, 1989; Fülöp, 1990; Haas, 2001). The reason for the high radon concentration in the SGO is the high uranium and radium concentration in the rocks on this area (Freiler et al., 2015, 2016).

The SGO is an artificial gallery driven horizontally into gneiss in the Nádormagaslat open quarry. The coordinates of the observatory are: latitude 47°40′55″ N, longitude 16°33′32″ E, and the altitude is 280 m a.s.l. The overlay above the gallery is about 60 m. The gallery where the instruments are placed is thermally insulated but not hermetically sealed. There is a slow air transport via the conduit for the electric cables of the instruments. This ventilation does not change the temperature in the gallery but it ensures that the indoor and outdoor barometric pressures are the same. The yearly mean value of the temperature is 10.4 °C and the yearly and daily temperature variations are <0.5 °C and 0.05 °C, respectively. The relative humidity of the air is 90% and its variation is negligible. The quarry is not working and there is no human activity in the observatory and in its surroundings. The instruments in the observatory are controlled via Internet.

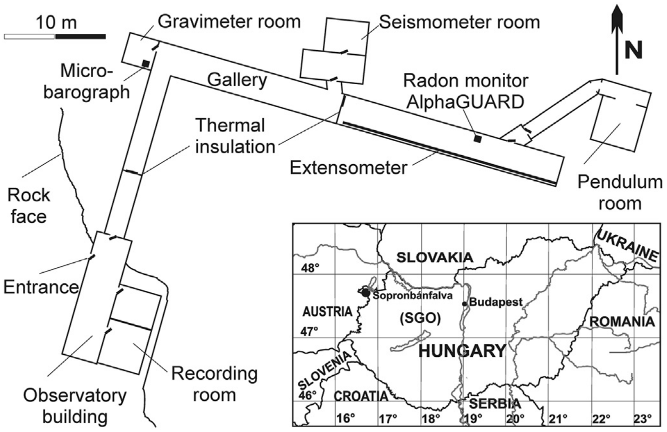

Fig. 1. Ground plan and the location of the Sopronbánfalva Geodynamic Observatory (SGO) in Hungary (lower right corner).

2.2. Measuring methods

In 1990, a quartz-tube extensometer was installed in the observatory for recording Earth tides and local tectonic movements (Mentes, 1991). Fig. 1 shows the ground plan of the observatory and the location of the extensometer in the gallery. The extensometer is about 30 m from the entrance and it is thermally insulated by three doors. The azimuth of the extensometer is 116° and its scale factor is 2.093 ± 0.032 nm mV^{-1}. Construction of the extensometer and its calibration are described by Mentes (2010) in detail.

In autumn 2008, a radon monitor (AlphaGUARD™ PQ2000PRO) was placed near the extensometer (Fig. 1) to measure radon concentrations. The AlphaGUARD™ is able to continuously determine the radon and radon progeny concentrations as well as to register barometric pressure and temperature (http://www.saphymo.com/radiation-measurement/environmental-radiation-monitoring-systems/alphaguard/154.htm, last access: 20.10.2016). AlphaGUARD™ incorporates a pulse-counting ionization chamber (alpha spectroscopy). This instrument is able to measure radon concentrations between 2 Bq m^{-3} and 2 MBq m^{-3}. Its sensitivity is 5 cpm (counts per minute) at 100 Bq m^{-3}. It has a stable long-term calibration factor. The measurements are carried out in diffuse mode. The radon concentration, temperature and barometric pressure data are measured hourly by the radon monitor and are stored in its own memory.

The analogue output signal of the extensometer, the microbarograph, the outdoor temperature and barometric pressure data are sampled and digitized hourly by means of a PREMA 24 bit A/D converter. Radon concentration, strain, outdoor temperature and outdoor barometric pressure data were subjected to data processing, as the indoor temperature was practically constant (10.4 °C) and the indoor and outdoor barometric pressures did not differ significantly.

3. General overview of the measured data

Fig. 2 shows the hourly measured data from 1 January 2009 till 31 December 2015. The radon concentration (Rn c.) strongly depends on the outdoor temperature (Temp.) and the measured strain (Strain) also displays a seasonal variation due to temperature variations, while the barometric pressure (Bar. p.) does not have an obvious seasonal character. At first sight, it is apparent that the character of the radon

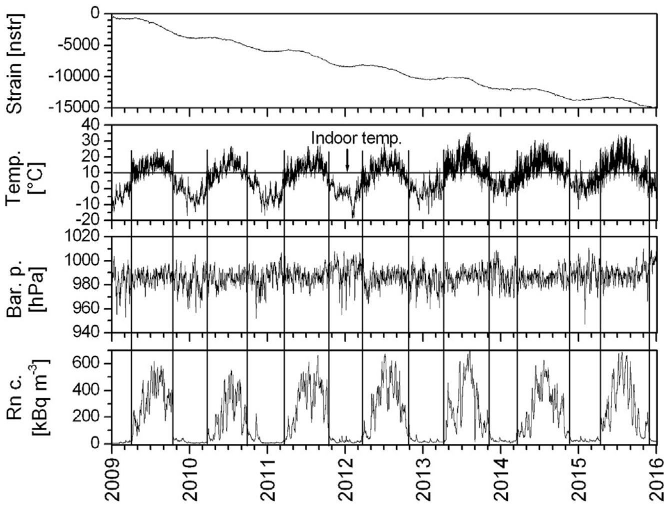

Fig. 2. Strain measured by the extensometer (Strain), outdoor temperature (Temp.), barometric pressure (Bar. p.) and radon concentration (Rn c.) measured between 1 January 2009 and 31 December 2015.