Radon measurements in Vadetetős Cave, Mecsek Mountains, Hungary

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Abstract: Radon transport processes were investigated in Vadetetős Cave in the Mecsek Mountains, Hungary, for several years. DATAQUA monitoring devices were used for recording the radon concentration, the pressure and the temperature of cave air. Apart from studying the convectional laws of the cave, our primary intention was to detect any significant changes during the nearly five-year-long measurement period. Samples of cave sediment and rock were collected in order to investigate the possible sources of radon. During the measurement period remarkable concentration variations were detected concerning the radon levels of cave air. Besides, with the help of radon transport measurements turning points were discovered regarding the direction of airflow.

Keywords: radon, air convection, Vadetetős Cave, Mecsek Mountains, Hungary

Introduction

Radon concentration monitoring of cave air provides an excellent opportunity to study the convectional laws of cave atmospheres since radon is an excellent tracer of underground airflow (HAKL, 1997, DEZSŐ & MOLNÁR, 2001). Due to the fact that radon (^{222}Rn) is an inert gas and has a 3.8-day half-life, it can move far away from its parent substance. The primary factors governing this migration are temperature, humidity and rock porosity whereas air movements caused by temperature differences or rapid atmospheric pressure changes can have a secondary influence on it as well (PAPP et al. 2004).

As the analysis of radon transport processes can contribute to the exploration of undiscovered passages (HAKL, et al, 1997), several small caves were monitored in Western Mecsek Mountains between 1995 and 2007 (ZALÁN, 1998, KOLTAI, et al. 2010). The investigations inside Vadetetős Cave started in November 2003. The cavity was only 6 metres long at that time (ZALÁN, 2004), since then three explorations have proven the results of the first radon concentration measurements that suggested the presence of more extended passages.

Apart from studying the convectional laws of the cave atmosphere our primary intention was to detect any significant changes during the measurement period as well as to define the main governing factors of radon level variations by using different statistical analyses. DEZSŐ et al., (2001) has claimed that the primary source of radon in caves is clay deposits, which fill in the passages, therefore samples of clay deposits and rock were gathered to seek for the possible source of radon.

Material and methods

The study area

The geological structure of Western Mecsek is characterized by an anticlinal with an eastern-western line of strike. The rocks of the anticlinal are particularly stressed, fragmented and moved by faults (BARTA & TARNAI, 1999). In Western Mecsek karstic rocks geologically belong to one single block, however, on the surface they can be found in three different zones. Vadetetős Cave is situated within the largest block, located between the Abaliget-Mecsekrákos fracture and Misina, in a 40 km^2 territory. The area is divided by the drainage basins of eight efflux caves; Vadetetős Cave is hydrologically connected to Abaligeti Spring Cave. The investigated cave is now 180.5 metres long with a depth of 37.5 metres (Fig. 1).

Data and methods

Both single-and multi-parameter DATAQUA detectors were used for data collection. Apart from radon concentration the multi-parameter device recorded the temperature and the atmospheric pressure of cave air. The studied parameters were documented in 60-minutes intervals. The measurement periods usually lasted for 4-6 months, the first detector was placed at the entrance zone of the cave at -7 metres depth in 2003 in order to investigate how the direction of airflow changes inside the cave. Radon concentration was measured in two different locations inside the cave for 1.5 years when an additional logger was deployed at the end of the known passages in 2007 (Fig. 2).

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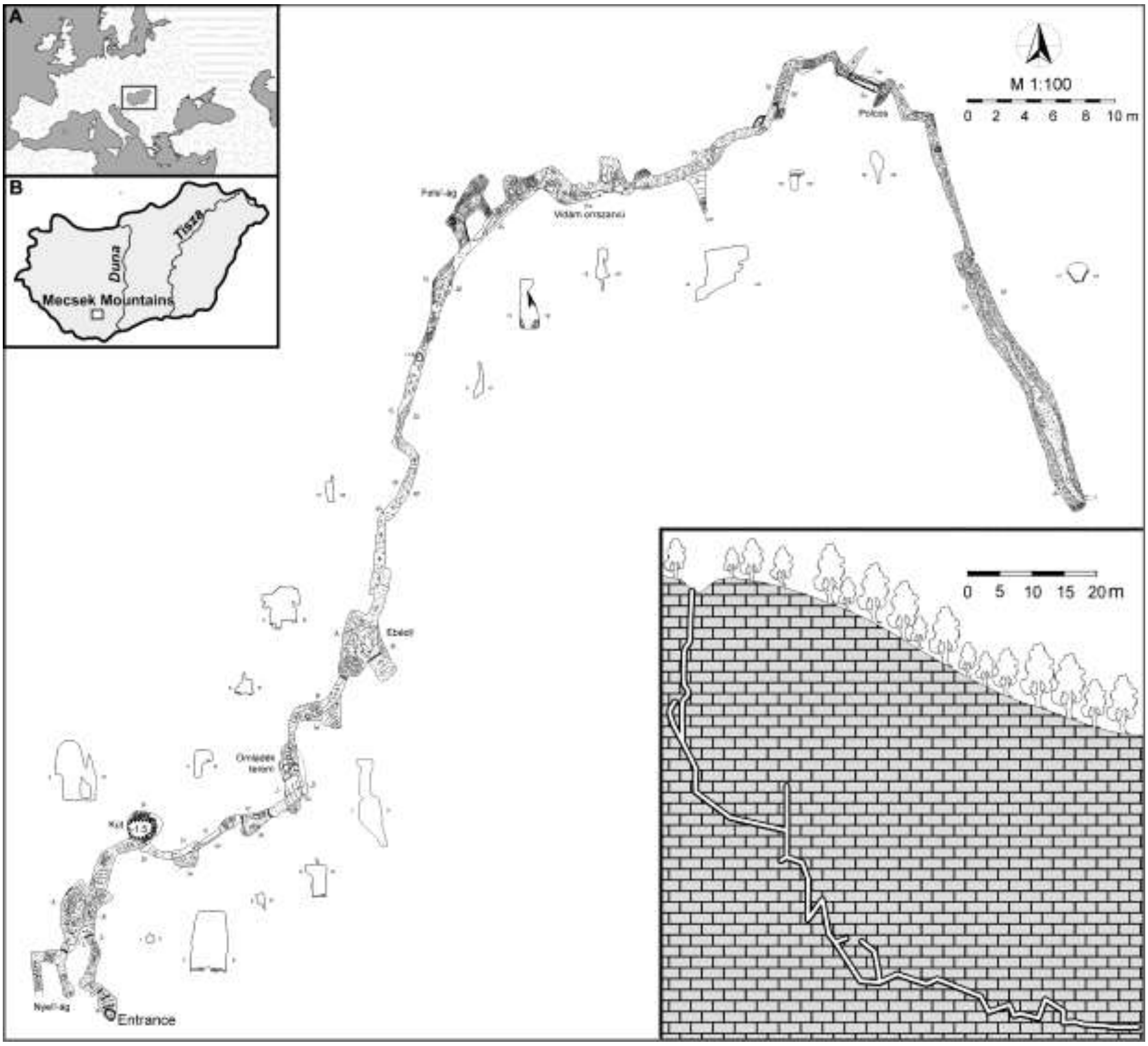

Fig. 1: The map and the longitudinal profile of Vadetetős Cave.

The underground data were comprehensively analysed and graphed in relation to external temperature and atmospheric pressure[4]. To provide an answer for the question of the extent to which the different factors influence the variation of radon concentration a factor analysis with special transformation was applied. Factor analysis provides an opportunity to identify any linear relationships among subsets of examined variables while reducing the dimensionality of the initial database without substantial loss of information (Makra et al., 2012). After performing factor analysis, a special transformation of the retained factors was done in order to discover how strongly the explanatory variables affect the resultant variable (Jahn & Vahle, 1968). Furthermore, Pearson correlation was used to describe the strength of the linear relationship between the investigated parameters.

Rock and clay samples were collected at 3 places in the cave. Our aim was to collect different kinds of clay deposits in order to locate the possible source of high radon levels. Clay deposit measurements have been performed using an ORTEC HPGe gamma-spectrometer (35 % relative efficiency, 1.4 keV resolution at $E\gamma$ = 661.6 keV) in a low background shielding. The system was calibrated for a 100 cm^3 flat metal pot geometry using international standard rock samples of known activity for the primordial nuclides (U- and Th-series isotopes). Since gamma-spectrometry allows the parallel measurement of many isotopes in the sample, the activity concentrations of ^{232}Th (through ^{212}Pb, ^{208}Tl and ^{228}Ac, assuming secular equilibrium) have also been determined. Sample masses varied around 140 g and measurement times were over 100’000 s to ensure a few percent counting uncertainty. All radioactivity measurements were made on air-dried samples.

[4] *Meteorological data were collected at a weather station located 1.5 kilometres from the entrance of Vadetetős Cave. Surface parameters were documented at ten minutes frequency.*

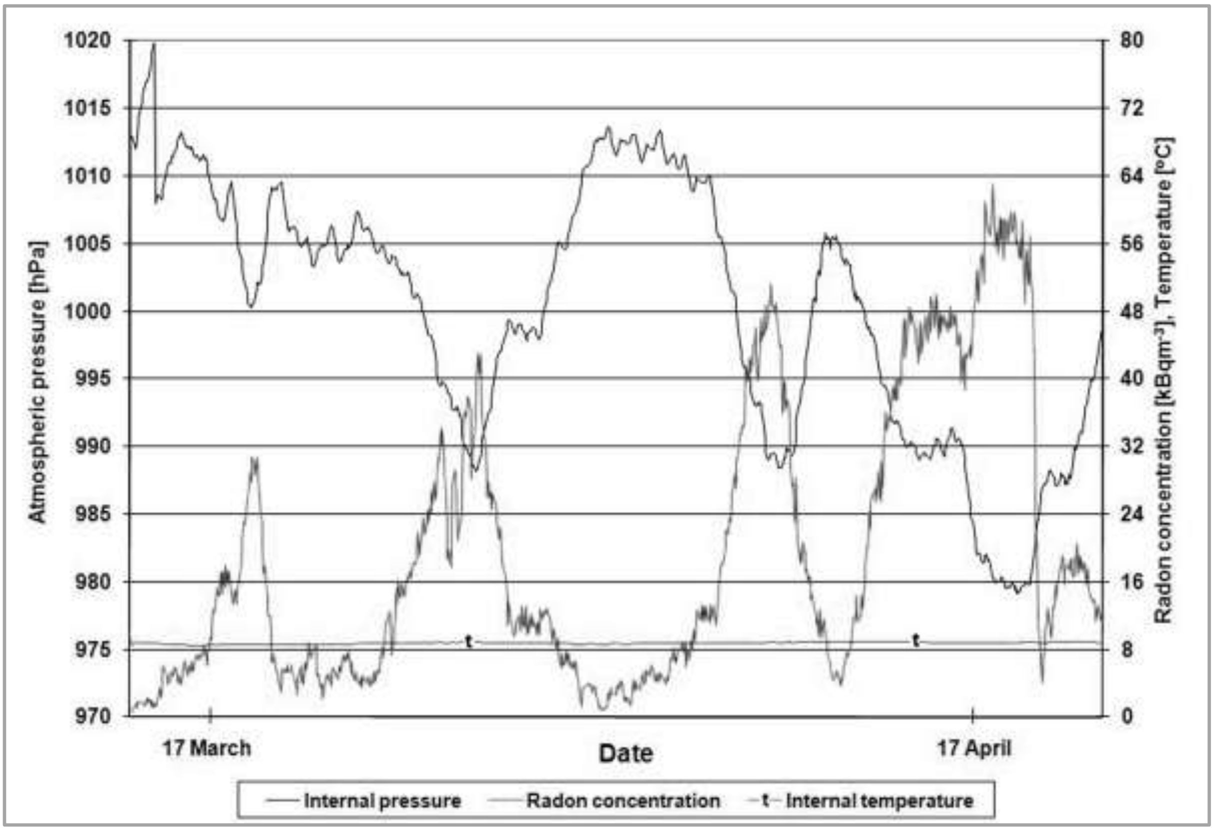

Fig. 2: Radon concentration changes in the entrance zone of Vadetetős Cave, 2005.

Results and discussion

During the measurement periods that altogether lasted nearly five years two interesting turning points can be detected when considering the air circulation model of the cave. The first one occurred at the end of 2005 and the second one a year later. Before November 2005 and after 2006 the cave was characterized by high winter (e.g.16.53 kBq m^{-3} between 01.12.2003 and 29.02.2004) and low summer (e.g. 3.55 kBq m^{-3} between 01.06.2004 and 22.08.2004) radon values while in-between summer maxima and winter minima were recorded. The first anomalies were detected in November 2005, which implied the "momentary" inverse functioning of the air convection system in Vadetetős Cave. However, this inverse operation became persistent from November 2005 until the end of 2006. Both statistical methods (factor analyses with special transformation and correlation) have demonstrated a significant change in the sign of surface temperature (Table 1).

As already mentioned, before November 2005 Vadetetős Cave was characterized by remarkable differences between low summer and high winter periods. Since then the difference between summertime and wintertime is less significant. The mean value of summer data was 3.6 kBq m^{-3} in 2004 and 2.3 kBq m^{-3} in 2005, while the winter period of 2003-04 was characterized by 16.5 kBq m^{-3} and in the following year by 15.1 kBq m^{-3}. The mean value of the recorded data in winter 2005-2006 remained on a surprisingly low level (2.9 kBq m^{-3}) despite the fact that the radon concentration reached 44.2 kBq m^{-3} once and exceeded 15 kBq m^{-3} twice between December 1st 2005 and February 28th 2006. Unfortunately, there was no monitoring during the next winter.

Data also showed that radon concentration levels frequently exceeded 40 kBq m^{-3} between 2003 and 2006, but it rarely exceeded 30 kBq m^{-3} since February 2006. Between the middle of March and end of April 2005, while external temperature was permanently low, radon concentration exceeded 30 kBq m^{-3} five times: reaching 40 kBq m^{-3} once, 50 kBq m^{-3} twice and 64 kBq m^{-3} once (Fig. 2). Air pressure variations were the major control parameter of radon level changes with negative correlations of r^2=0.739 concerning cave air pressure and r^2=0.735 regarding ambient atmospheric pressure.

In 2007 a second detector was deployed at the end of the known passages. Because it was less affected by inflow of external air, the second measurement point was characterized by higher radon concentration (Fig. 3). In winters the mean value of radon concentration was 17 kBq m^{-3}, while in summer it was only 7.8 kBq m^{-3}. As Table 1 shows there was a strong connection between the two radon levels: they correlated with each other significantly.

GÉCZY et al. (1988) observed that in the case of narrow-entrance vertical caves radon concentration changes are mainly controlled by atmospheric pressure. The effect of temperature variations on radon levels was usually less significant in Vadetetős Cave than atmospheric pressure fluctuations. The reasons for the previously described change in cave atmosphere between November 2005 and the end of 2006 could be some digging of cave passage or the opening of a breakdown. Though the cave is relatively small, its convectional system is complex. Regarding the relationship of external temperature and internal radon concentration, smaller turning points can be observed, too. These draught changes might be caused by an air connection with another cave, which has an upper position and opens up for shorter or longer periods. A small passage or a siphon might unfold and close again.

Year	Variables	Weight	Rank	Threshold of significance
2005	**radon concentration (entrance zone)**	***-0,95188***	**-**	*$X_{0.01}$= 0.060* $X_{0.05}$=0.46
	internal pressure	*0,87976*	1	
	internal temperature	0,05886	4	
	external temperature	***0,10128***	***3***	
	external pressure	*0,20133*	2	
2006	**radon concentration (entrance zone)**	***0,97038***	**-**	*$X_{0.01}$= 0.060*
	internal temperature	*-0,13140*	3	
	external temperature	***0,27421***	**2**	
	external pressure	*-0,65070*	1	
2007	**radon concentration (entrance zone)**	***-0,89755***	**-**	*$X_{0.01}$= 0.067*
	external temperature	*0,81344*	1	
	external pressure	*0,23719*	4	
	radon concentration (end zone)	-0,78882	2	
	internal temperature	***0,68318***	***3***	
2007	**radon concentration (end zone)**	***-0,96612***	**-**	*$X_{0.01}$= 0.067*
	external temperature	*0,37414*	3	
	external pressure	*0,29324*	2	
	radon concentration (entrance zone)	*-0,73284*	2	
	internal temperature	***0,93088***	1	

Table 1: The effect of the explanatory variables (first row in each section) on radon concentrations as resultant variable and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable.

The radon concentration of the caves situated in Mecsek Mountains is generally high. During our research in these Mountains, the highest radon levels were detected in Vadetetős Cave. Radon has only a short half-life, therefore, the extremely high Rn-concentrations observed in Vadetetős Cave suggested that the source of Rn might be somewhere within the cave itself. Clay deposits and rock samples were therefore collected at three different places for further analysis (Fig. 4).

So far, the assay of primordial radioactivity for two clayey cave deposit specimens has been completed. The results obtained are (42.5 ±0.4) and (39.5 ±0.3) Bq/kg ^{226}Ra for the “Drill-bit” and clayey samples, respectively. These data fit well within the range found elsewhere in the country for clayey soils and sediments. The results for ^{232}Th are somewhat higher: 57.6 ±0.3 and 54.3 ±0.3) Bq/kg, respectively. The small difference in the respective values between the samples (6-7%) might be caused by a difference in their water content.

Conclusions

Although Vadetetős Cave is small, its air convection system is rather complex. By studying radon transport processes turning points were detected concerning the direction of airflow. These variations were also demonstrated by the different statistical methods. Factor analysis with special transformation showed that radon level fluctuations were governed by the variables considered in the analysis (internal and external pressures and temperatures). Nevertheless, the weighting of these variables noticeably changed with time. The investigated case is a narrow-entrance vertical cave, and the principal controlling factor was atmospheric pressure. Significant correlations were found between radon concentrations of the entrance part and of the end zone of the cave in 2007 and 2008 suggesting that radon exhales from the same source. Clay deposits and rock samples have been collected in the cave in order to define the possible sources of extremely high radon concentrations. So far, two clayey cave deposit samples have been measured and showed usual levels of ^{226}Ra and ^{232}Th contents. Further research is needed in order to locate the source of the high radon concentration levels.

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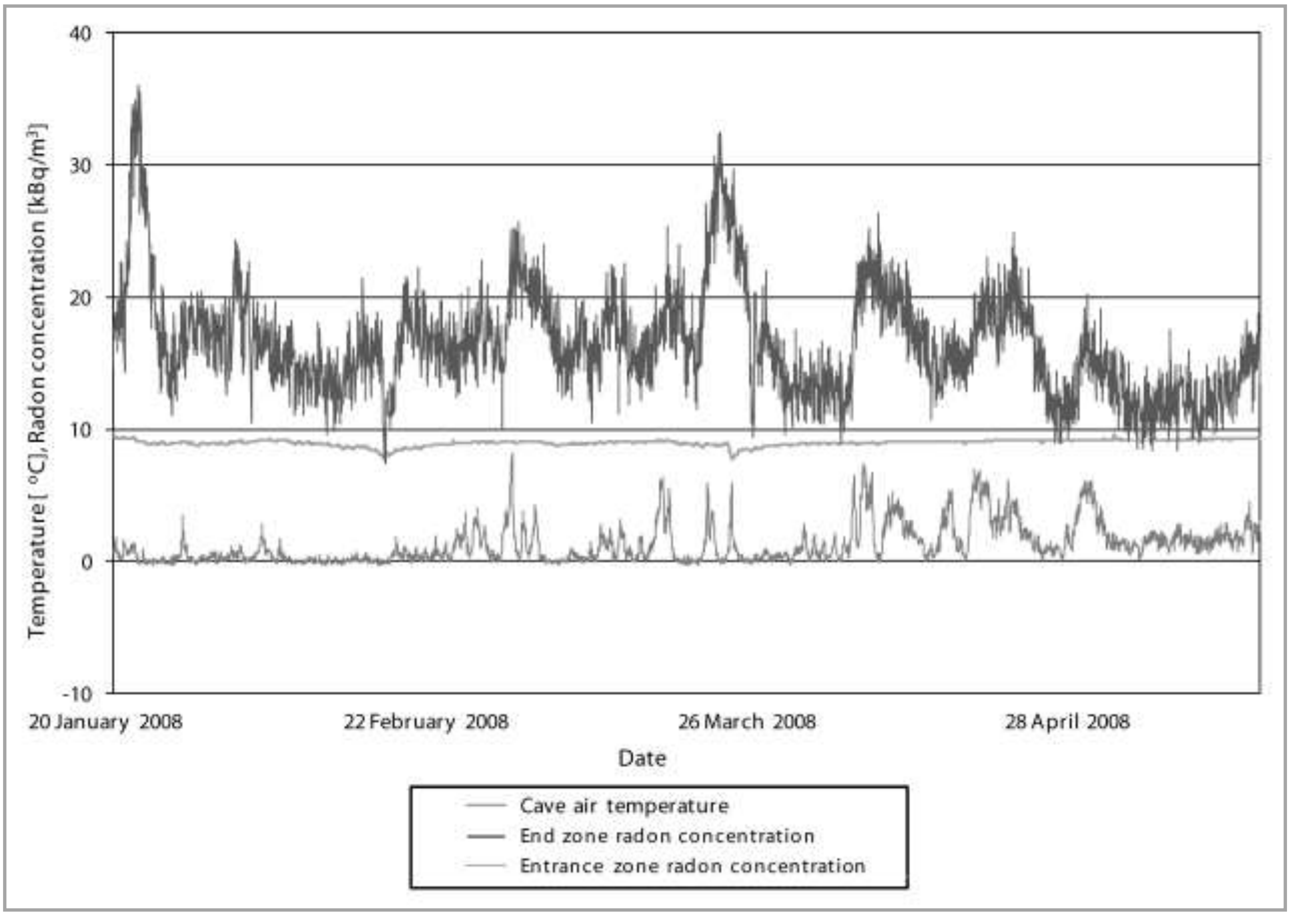

Fig. 3: Radon concentration changes in the entrance and end zones of Vadetetős Cave, 2008.

Fig. 4: Clay sample collection. (Photo: G. Koltai).

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