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Radon Concentration in Thermal Water as an Indicator of Seismic Activity

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A B S T R A C T

Radon concentration in thermal springs at Hotavlje and Bled has been measured from October 2005 to June 2008 and from October 2005 to September 2007, respectively. At both locations several anomalies in radon concentration were observed, that might have been caused by seismic events. In this study all earthquakes with ratio (D/R) between strain radius (D) and distance to the epicenter (R) greater than 0.5 were taken into account. Five earthquakes occurred in the vicinity of Bled in this period, the strongest at a distance of 17 km with the magnitude M_L=3.8 and four radon anomalies were observed. At Hotavlje fourteen earthquakes occurred in the vicinity with D/R ratio from 0.5 to 2.9. During this period three radon anomalies were observed.

Key words: *radon, anomalous radon level, thermal water, earthquakes*

Introduction

Earthquakes cause severe human disasters in many parts of the world. The large amount of energy released by an earthquake can lead to great loss of life and property, especially if the earthquake is located near big cities[1]. The greatest worldwide seismic hazard is the ground shaking and the greatest risk is the structural damage that results from this ground motion. On the other hand, secondary effects, such as landslides and tsunamis triggered by the ground motion, may even cause far greater loss of life and property. Therefore, earthquake precursors have been intensively sought in order to forecast increasing seismic activity – one of the precursors is radon.

Radon (^{222}Rn) can be transported effectively from deep layers of the Earth to the surface by carrier gases and by water[2–3]. This transport is affected by phenomena accompanying seismic events[4–6]. If radon in a thermal water spring is monitored for a long period, shortly before, during or after an earthquake, a radon anomaly may be observed[7–9], i.e. a sudden either increase or decrease in radon activity concentration. Radon concentrations of two standard deviations (2σ) above or below average value are considered as an anomaly. Thermal springs and ground waters in Slovenia have therefore been systematically surveyed for radon[10–12].

It is well known that a gas such as ^{222}Rn can be released by rock micro fracturing[13]. Small strains could have major effects on the generation of anomalies at pre-existing fractures and faults[14]. Toutain and Baubron[5] observed that gas transfer within the upper crust is affected by strains less than 10^{-7}, much smaller than those causing earthquakes. Anomalies in water temperature, radon concentration and gas composition are related to both hydrometeorological data and seismic events. For our purpose the radius, D, of the effective precursor manifestation zone in km (also called the »strain radius«) was calculated using Dobrovolsky's equation[15]:

$$D=10^{0.43M} \qquad (1)$$

for an earthquake of magnitude M, corresponding to a deformation of 10^{-8}. In this study all earthquakes with ratio $D/R>0.5$ were taken into account, where D is strain radius calculated from equation (1), R is the distance between our measurement site and the epicenter. All earthquakes were detected by the Office of Seismology at the Environmental Agency of the Republic of Slovenia.

The work presented here is a continuation of our previous radon monitoring related to seismic activity carried out on weekly analyses during 1981–82 in thermal waters of the Ljubljana basin[11]. In 1998, measurements

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Fig. 1. Map of Slovenia.

were resumed and extended to the tectonically active region close to the Soča (Isonzo) river (north-west Slovenia) (Figure 1). Radon content, electrical conductivity and temperature were measured continuously[12] at Bled and Zatolmin, as well as at Podplat near Rogaška Slatina as a reference point. In 2003, radon measurements were started at Hotavlje village, some 30 km to the south of Bled. In this paper, we focus on radon anomalies in thermal springs at Hotavlje and Bled in the period from October 2005 to June 2008 and from October 2005 to September 2007, respectively.

Geologic setting

There are only a few thermal springs in the seismically active area along the Soča River, the closest and most easily accessible ones being at Bled and Hotavlje. In contrast, there are many thermal springs in east Slovenia, but this area exhibits lower seismic activity.

The recent geotectonic setting in Slovenia is a cumulative result of Tethyan evolution, where recent dynamics are determined by the closure of the Tethys and the collision of several lithospheric units. Slovenia lies at the junction of three tectonic plates (European, Adriatic and Tiszian), which were amalgamated during the Tertiary period[16].

The thermal spring at Bled wells on the Bled fault on the eastern side of Lake Bled (46.37N, 14.11E) which belongs to Southern Alps. Water springs from a deep Triassic carbonate reservoir and rises through Oligocene clay and shallower Quaternary Lake and glacial sediment. Thermal water is used in the swimming pool of the Toplice Hotel and is characterized by a constant temperature of 21.82 ± 0.01 °C and by active bubbling[17].

The thermal spring at Hotavlje (46.12N, 14.08E) is situated at the bank of a small stream near the Hotavlje village. Water temperature is constant at 20.22 ± 0.04 °C and wells on the fault in Main dolomite oriented along the valley of Kopačnica. The water is of meteoric origin. Meteoric water trickles through the rocks to deeper layrs, where it accumulates and warms up and is then raised again with convective flow through fault zones[18].

Materials and Methods

Radon activity concentration (shortly concentration, C_{Rn} in Bq m^{-3}) in water was measured with the Barasol probe (MC-450, ALGADE, France)[19]. The probe gives C_{Rn} based on alpha spectrometry of radon decay products in the energy range of 1.5–6 MeV, using an implanted silicon detector. The sensitivity is 50 Bq m^{-3} and sampling frequency once per hour. In addition to radon concentration, the probe also records temperature and barometric pressure. Values of all measured parameters are stored in the inner memory and later transferred to a PC for evaluation. Instruments are regularly checked using AlphaGuard radon monitor (Genitron, Germany) as a reference instrument.

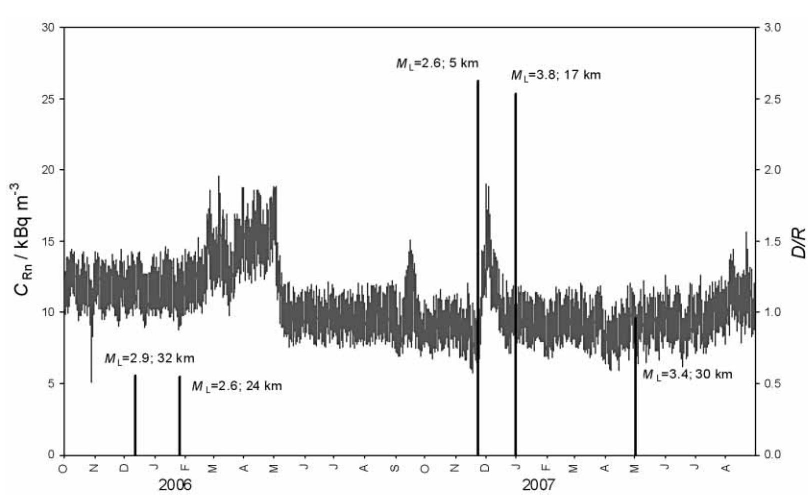

Fig. 2. Radon concentration (C_{Rn}) in thermal water at Bled and D/R ratio (ratio between the strain radius and the distance to the epicenter) for the local earthquakes during the period from October 2005 to September 2007; vertical bars present earthquakes, for which magnitude M_L and the distance between our measurement site and the epicenter are indicated.

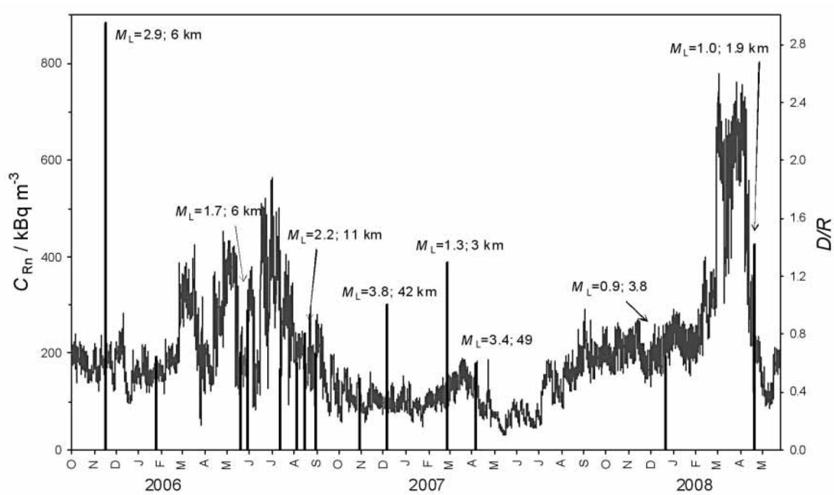

Fig. 3. Radon concentration (C_{Rn}) in thermal water at Hotavlje and D/R ratio (ratio between the strain radius and the distance to the epicenter) for the local earthquakes during the period from October 2005 to June 2008; vertical bars present earthquakes, for which magnitude M_L and the distance between our measurement site and the epicenter are indicated.

Results

The average radon concentration in thermal water at Bled in the period from October 2005 to September 2007 was 10.5 ± 2.1 kBq m^{-3} (Figure 2). Five earthquakes occurred in the vicinity in this period, with D/R ratio from 0.6 to 2.6. The strongest one at a distance of 17 km with M_L=3.8 and D/R=2.5 occurred on January 1, 2007, and the nearest one at a distance of 5 km with M_L=2.6 and D/R=2.6 on November 24, 2006. Four anomalies in radon concentration were observed.

At Hotavlje (Figure 3), the average radon concentration in water in the period from October 2005 to June 2008 was 197 ± 121 kBq m^{-3}. In this period fourteen earthquakes occurred in the vicinity, with D/R ratio from 0.5 to 2.9. The strongest one with M_L=3.8 at a distance of 42 km and D/R=1.0 occurred on January 1, 2007, and the nearest one at a distance of 1.9 km with M_L=1.0 and D/R=1.4, on May 17, 2008. The earthquake with the highest D/R ratio (D/R=2.9) occurred on December 12, 2005, only 45 days after measurements were started. In this period three radon anomalies were observed.

Discussion

The first radon anomaly at Bled was observed immediately after measurements were started, at the end of October 2005. In three days, radon concentration decreased from 11.7 to 5.2 kBq m^{-3}, being about 2.5σ below the average value. This was 45 days before the first of two earthquakes with magnitudes from 2.6 to 2.9 and epicenter distances from 24 to 32 km. A longer anomaly (about 3σ above the average value) followed from the end of February to the beginning of May 2006. The last two anomalies were observed, first one (about 2σ above the average value) in September, two months before earthquake M_L=2.6, and the second (about 3σ over the average value) in December 2006, one month before the strongest earthquake.

At Hotavlje three radon anomalies were observed from October 2005 to June 2008, as mentioned in the previous chapter. There were no anomalies in radon concentration during the short period before the first earthquake on December 12, 2005. Radon concentration raised for the first time in April 2006, however it did not exceed 2σ above the average value. The first radon anomaly was observed in June 2006. Six earthquakes followed in the period from June to September. The second anomaly (2.5σ above the average value) was observed in July 2006, five months before the strongest earthquake. After this anomaly radon concentration remained below the average value. The highest radon anomaly was observed in April 2008 (more than 4σ above the average value). Earthquake with D/R ratio 1.4 occurred on May 17, 2008 in the vicinity of Hotavlje, only few days after radon concentration dropped to the average value.

As in our previous study[19], these data will be further analyzed using machine learning statistical methods, such as decision trees and neuron networks, in order to identify anomalies that cannot be ascribed to environmental parameters, but are probably caused by seismic events.

Conclusion

Although no strong earthquakes have occurred in the period of this study, some radon anomalies were identified that might have been caused by earthquakes. At Bled, an anomaly was observed 3.5 months before the strongest earthquake with M_L=3.8. Five months before the same earthquake an anomaly was also observed at Hotavlje.

These preliminary results are based on simple statistics. Further analysis will be performed, applying decision trees and neuron networks of the machine learning approach. For that purpose, the time series of radon concentration of the whole period of measurements will be considered and not only the period limited in this paper.

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KONCENTRACIJA RADONA U TERMALNIM VODAMA KAO INDIKATOR SEIZMIČKE AKTIVNOSTI

SAŽETAK

Koncentracija radona u termalnim izvorima mjerena je na lokacijama Hotavlje i Bled (Slovenija) u razdoblju od listopada 2005.g. do lipnja 2008.g., odnosno od listopada 2005.g. do rujna 2007.g. Na objema lokacijama opaženo je nekoliko odstupanja u koncentraciji radona, koje bi mogle biti uzrokovane seizmičkom aktivnošću. U ovom istraživanju uzeti su u obzir svi potresi u kojima je omjer udaljenosti od epicentra (D) i radijusa područja deformacije (R), D/R veći od 0,5. Pet potresa pojavilo se u okolici Bleda u navedenom periodu, najjači s udaljenošću od epicentra od 17 km, magnitude M_L=3,8, a opažene su četiri anomalije u koncentraciji radona. U okolici područja Hotavlje dogodilo se 14 potresa s omjerom D/R od 0,5 do 2,9, a tijekom ovog razdoblja opažena su tri odstupanja u koncentraciji radona.