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RESEARCH NOTE

Radon Monitoring as the Earthquake Precursor in Fault Line in Western Turkey

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Abstract
Variations in radon concentrations near the earth's surface can provide important information about seismic activities. Continuous monitoring of radon concentrations is one of the important steps in predicting earthquake mechanisms. This study monitored the radon concentration of an active tectonic zone in western Turkey. Four sampling stations in the seismic area, of the Tuzla fault line, were selected for radon monitoring. The online radon monitoring system was placed at Cumalı station. Concurrently, the radon concentrations in the soil gas were continuously measured using LR-115 nuclear track detectors and an online radon measurement system. Data obtained from Bogazici University Kandilli Observatory and Earthquake research Institute was incorporated in the analysis to correlate with the collected radon concentration. The radon concentrations were measured using solid-state nuclear track films (LR-115) in the soils of thermal water fields, which varied from 40 track cm^{-2} $week^{-1}$ to 1580 track cm^{-2} $week^{-1}$. Comparison of the radon concentration found using the above described techniques reveals that there is a linear correlation between the radon emission rate and the seismic activities in the area under investigation.
Keywords: Earthquake, LR-115 nuclear track detector, radon.

Batı Türkiye Fay Hattında Deprem İzleyicisi Olarak Radon Monitörü
Özet
Yüzeye yakın yerlerde radon konsantrasyonlarında meydana gelen değişimler sismik aktiviteler hakkında önemli bilgiler verebilmektedir. Sürekli radon monitörü, deprem mekanizması tahmininde önemli bir aşamadır. Bu çalışmada, Batı Türkiye'de aktif tektonik bir bölgede radon konsantrasyonu izlenmiştir. Tuzla fay hattı olarak bilinen sismik bölgede yapılan çalışmada dört istasyonda radon ölçümleri yapılmıştır. Cumalı istasyonuna sürekli radon ölçüm sistemi yerleştilmiştir. Ayrıca toprak gazında radon ölçümleri, sürekli olarak LR-115 nükleer iz dedektörü kullanılarak yapılmıştır.. Boğaziçi Üniversitesi Kandilli Rasathane ve Deprem Araştırma Enstitüsü'nden sağlanan deprem verileri kullanılarak deprem ve radon konsantrasyonu değişimleri arasındaki korelasyon incelenmiştir. LR-115 nükleer iz dedektörü kullanılarak yapılan radon ölçümlerinde termal suların bulunduğu topraklarda radon 40 $iz.cm^{-2}.hafta^{-1}week^{-1}$ ile 1580 $iz.cm^{-2}.hafta^{-1}$ arasında değiştiği gözlenmiştir. Yukarıda bahsedilen yöntemler ile ölçülen radon konsantrasyonlarının değerlendirilmesi sonucunda sismik aktivite ile radon konsantrasyonlarının değişimi arasında lineer bir korelasyon ortaya konmuştur.
Anahtar Kelimeler: Deprem, LR-115 nükleer iz dedektörü, radon.

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INTRODUCTION

Seismogeochemical algorithms can be used to define quantitative relations between seismic parameters and geochemical anomalies on the subsurface gas and groundwater (Walia et al. 2003). 222Radon is the most substantive contributor in soil gas concentration. A high radon emanation with active faults indicates that they have major paths for radon gas to seep out. At the same time, the outgassing process from the crust is not uniform and also controlled by the distribution and stress of the fractures. A relationship between the earthquake producing processes and radon emanation can provide significant information to use as a possible precursor of earthquake.

One of the widely used techniques to predict earthquakes is to monitor radon concentration within a seismo-active area (Igarashi and Wakita 1990, Pullinets et al. 1997, Zmazek et al. 2002). Furthermore, radon anomalies can be related to the

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upward migration of gas along fault zones. Particularly, variations in radon concentrations associated with thermal water and soil gas with earthquake activity had been proven earlier. For example, prior to the Tashkent earthquake of 1966, Ulomov and Mavashev observed that the radon concentration in water from a deep Russian well increased (Wattananikorn et al. 1998). During the past few decades, research efforts indicate that major geophysical events, such as earthquakes and volcanic eruptions, may create significant variations of the radon concentration in the soil. According to these research studies, radon concentration in soil can generate valuable information for the study of the tectonic activity of the earth's crust (Wakita 1996, Moussa and El Arabi 2003, Richon et al. 2003).

The first site to measure radon gas concentration in the soil to study the correlation with eartquakes, was installed in 1974 by Birchfard and Libby. (Zmamek 2002). One remarkably study was accomplished by Igarashi and Wakita (1990). They have observed several radon anomalies in Eastern Japan. Most of these anomalies were found to be associated with large earthquakes in the vicinity of the Eastern Japan (Igarashi and Wakita 1990). Another significant study on radon anomalies at 12 monitoring stations in Japan (Tokai region, Izu-Oshima region, Kamakura and the eastern part of Fukushima Prefecture) indicates that observations can provide valuable information on the earthquake formation process. These results made very important contributions in terms of understanding the mechanism of eartquakes (Wakita 1996). For example, in measurements carried out in the Hyogo Prefecture (Kobe), the changes of ground water radon concentration within 3 months, the earthquake increased about fourfold. A nine days before the earthquake, they observed that the radon concentration reached its peak value. After this increase, they recorded a decrease in the radon concentration. These anomalies support the assumption that radon is likely to be the precursor of an earthquake (Igarashi and et al. 1995). Since then, both, soil and ground-water radon concentration variation have been considered as potential precursors for earthquakes (Zmazek et al. 2003). A study on the radon concentration in several thermal stations in Slovenia describes the relationship between change in radon concentration and tide effects as a possible symptom of an earthquake (Zmazek et al. 2002). These studies generally focus on earthquake magnitudes greater than 4 on the Richter scale, although there are some other correlations reported for smaller magnitudes (Zmazek et al. 2002). For example, Inan et al. (2008) systematically monitored the physical and chemical properties of spring waters and soil radon gas at several locations in the Marmara Region of Turkey. In that study, soil radon gas activity was also continuously monitored. They indicated that radon was found to be more responsive to seismic activity and to earthquakes of $M>4$, which were preceded by a positive anomaly. In addition, they said that the time variations of soil radon that could be related to seismic activity typically includes three stages as build-up, high level, and then decrease to background level, depending on the epicentral distance of the impending earthquake to the station. Finally, they emphasized that the highest radon peak was occured about three weeks before the earthquake.

Western Anatolia Region of Turkey is an important region to study throughout the year because of the frequency of earthquakes. A new seismicity map of Turkey shows that the western Anatolia has a different stipulation than the activities on the other parts of Turkey. This difference comes from the seismogenic characteristics of the region. Western Anatolia exhibites a tectonics where graben groups and faults take place. Recently, results obtained from the seismic moment tensor show that earthquakes in the region are tensile based (Utku 2000).

According to the results of a previous study carried out in the same region, the radon concentrations measured increased for two standard deviations (2σ) or more over their average value before the earthquake occurred in October 2005 (Sac et al. 2006).

The present study deals with radon data obtained from short term measurements of radon in thermal waters that are located in Seferihisar which is well known for its high seismic activities.

MATERIAL AND METHOD

Before continuous radon measurement station was installed in the fault region, the radon measurements in soils were performed by using LR-115 nuclear track detectors located (Cumali, Karakoc, Doganbey 1 and Doganbey 2) at 50 cm depths throughout fault line. Measurements were

carried out from October 2006 to December 2007. According to the LR-115 nuclear track detectors measurement results, it was decided to install an online radon measurement system in place where the Cumali site because it gave the best relationship between the magnitudes of earthquake and radon anomalies

Geological Settlement of Study Area

Turkey can be divided into four main geothermal regions along the magmatic belts of western, eastern and central Anatolia and along the north Anatolian fault zone. The Buyuk Menderes and Gediz grabens of western Anatolia tend to be important features from the geothermal viewpoint, with many hot water springs located along the fault zones of these grabens (Fig. 1). The Seferihisar geothermal area located SW of İzmir is in the southwestern part of the NE-SW trending Cubukludag graben which is thought to have formed at the beginning of the Tertiary Period. The main faults bounding the graben strike generally run NE-SW and are crossed by younger NW-SE and W-E faults. The main tectonic features of the Seferihisar geothermal site, ascribed to the Alpine orogeny, are NE-SW trending strike-slip faults and fracture systems. Hot water springs which were observed around Tuzla, Cumalı, Doğanbey and Karakoç, appear along the faults. (Fig. 2). The Cumalı, Tuzla and Doganbey faults are part of the Orhanlı fault zone. This approximately 40 km-long zone extends from Buca district in the south-eastern part of the Bay of 'Izmir to Doganbey district in the north-western part of Kuşadası Bay. Geothermal activity in the southwestern part of the Cubukludag graben can be observed along the fault zones inside secondary grabens located between the Seferihisar, Doganbey and Karakoc¸ horsts (Fig. 1) (Drahor and Berge 2006).

Radon Measurements in Soils

The Solid State Nuclear Track Detector Method (SSNTD) Long term determination of radon in soil, has been systematically performed with LR-115 film detector. Films were cut into squares of 15x15 mm2 dimensions. They were placed in plastic bottles whose bottom were opened and placed into the cylindrical holes of 50 cm depth in soil. Films recovered from the soil were firstly developed in 10% NaOH bath solution for 110 minutes at 60°C. At the end of the bath, films were washed with de-ionised water (Tarcan and Gemici 2003). The films

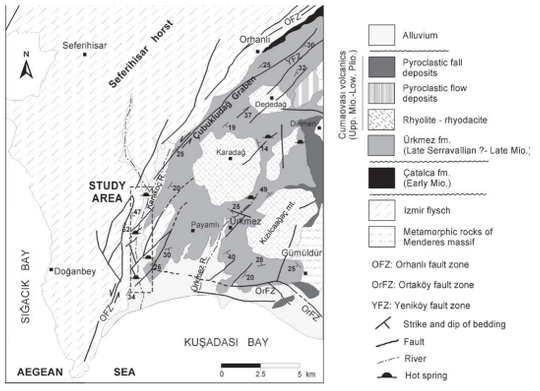


Fig. 1. Geology map of Seferihisar in western Turkey (Drahor, 2006).

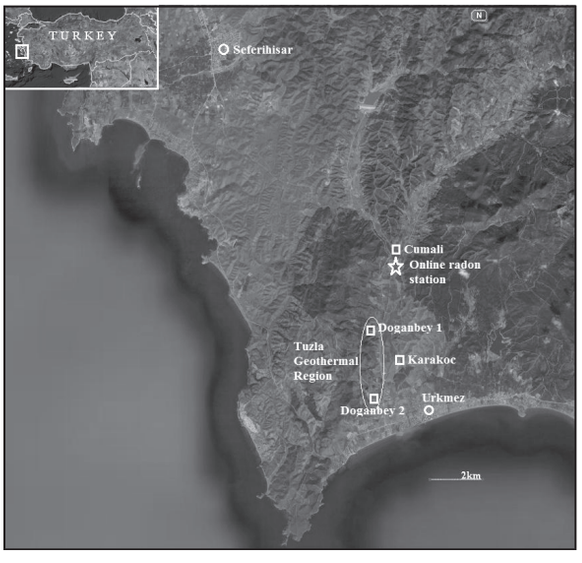


Fig. 2. Digital image of Seferihisar region showing the sampling areas (from digital mapping software of google.earth).

in 15x15 mm2 were viewed using a digital microscope and tracks were counted via software.

Online Radon Monitoring System

The radon monitoring system used in the present study was situated in a thermal water area at a latitude 38° 07´ 29.24´´ N and longitude 26° 54´ 43.42´´ E about 80 km SW of the city of İzmir, Turkey. According to the results of another study in this region, we installed the automatic measurement system of soil-gas 222Rn in the Cumali thermal water source vicinity. (Sac et al., 2006). The online radon measurement system is made up of detector unit (Alpha-Meter 611 manufactured by AlphaNuclear Corporation, Canada), datalogger, power supply unit and GSM modem. The detector is covered by waterproof polymeric material that

allows the alpha particle penetrate. Radon measurements are stored at 15 min. intervals in the internal memory of the system. The detector unit composed the steel cylindrical tube having a diameter of 5 cm and an overall length of 40 cm. was installed at depth of 80 cm in the soil (Fig. 3).

Figure 3.

The steel cylindrical tube contained the Si-photodiode detector together with the integrated amplifier circuits. The datalogger based on microcontroller and power supply unit have been located in an external box above of 150 cm from the ground. The detector unit also called the pulse processing unit made up from pulse shaping, amplifier and counting circuits. The data logger accumulates the number of events every second and stores it in the internal memory. The collected data are downloaded via GSM modem periodically from the data logger to the host computer. The power supply unit also contains battery charge circuit. The battery can provide a required voltage to the detector and can be safely operated in the field for two months.

RESULTS AND DISCUSSION

The radon concentrations in the soils around the thermal waters change significantly with time. Figure 4 shows the variation of monthly integrated and online soil gas radon values. LR-115 values were obtained by averaging integrated radon values from 3 measuring devices at each depth. These values varied from 40 track $cm^{-2}.week^{-1}$ to 1580 track. $cm^{-2}.week^{-1}$. From Fig.4 and Fig 5, changes of radon data measured using the online radon monitoring system and nuclear track films (LR115) can be clearly seen in pre-seismic activities. These two anomalies correspond well with two earthquakes of magnitudes 3.0 and 4.2 which occurred on June 04th and November 11th, 2007.

The results also showed that, in some cases, radon concentration increased notably, exceeding the upper limit of the estimated range of normal radon fluctuations. As seen in Figure 4, it can be stated that there were anomalies in radon concentration between April 2007 and June 2007.

CONCLUSION

In this study, it was found that the anomalous irregularities observed in the data is more likely associated with the seismic activities preceding and accompanying the earthquake events. The mechanism of the stress-induced radon emission

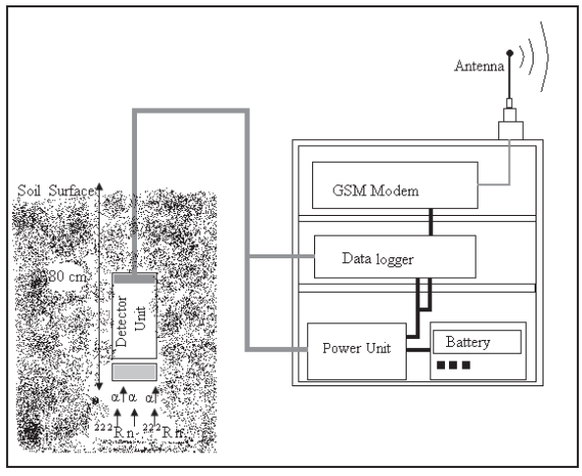


Fig. 3. Schematic diagram of online radon measurement system placed in Cumali Station.

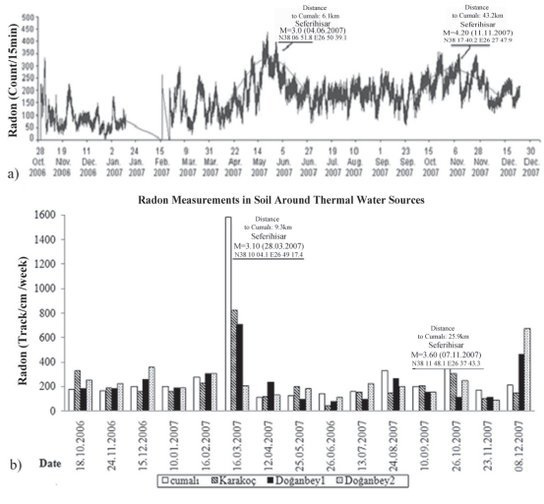


Fig. 4. Schematic diagram of online radon measurementsa and collector methodb results for Cumali Station.

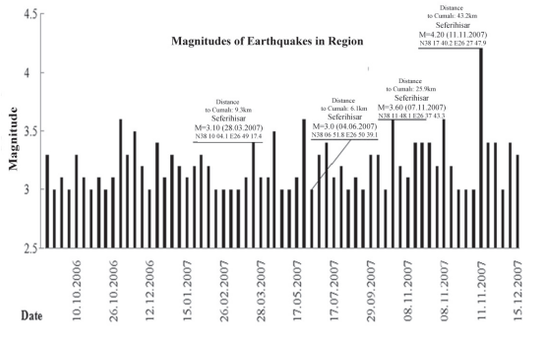


Fig. 5. Temporal magnitudes of earthquakes in study region (www.koeriboun.edu.tr).

depends on the geological conditions of the region to a large extent. This geological formation can be used effectively in the sensitivity of the online radon monitoring station. In this study, our radon stations were chosen according to the geological conditions which might help the monitoring of the radon fluctuations that changes because of the stress. Before continuous radon measurement station was installed in the fault region, the radon measurements in soils were performed by using the LR-115 nuclear track detectors throughout fault line. According to those results, we decided to install an online radon measurement system. The Cumali site gave the best relationship between magnitudes of earthquake and radon anomalies. The results also showed that, in some cases, radon concentration has increased notably, exceeding the upper limit of the estimated range of normal radon fluctuations. As seen in Figure 4, it can be stated that there was anomalities in radon concentration associated with some seismic activities between March 2007 and June 2007. The radon concentration reached the peak value 10 days before the Seferihisar earthquake (M. 3, June 4, 2007, 35 km from the radon monitoring station). A few days after the earthquake, a significant decreases recorded in radon concentration. This rising and falling in the radon seem to be a precursor for the Seferihisar earthquake. In Figure 4, there is a sharp rise and significantly decrease in LR-115 measurements before the Seferihisar earthquake (M 3.1, March 28, 2007). After that, the radon concentration has sharply dropped and back to levels before the earthquake. These anomalies corresponded very well with earthquakes of magnitudes: 3-3.5 which occurred about 32 km from the Cumali station. According to the chemical and physical measurement results of the thermal waters, it cannot be clearly justified that there is a relation between the parameters considered and the seismic activities. On the other hand, it was found that the radon parameter was increased before the earthquake. Therefore, this parameter can be observed continuously in further studies. These uncommon increases may provide evidence of possible radon response to earthquake activity in the region, and thereby it may indicate the possible application of radon measurements as a useful predictive tool for monitoring the tectonic behaviour of the concerned seismogenic fault.

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