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Measurements of soil radon in South Russia for seismological application: Some results

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ABSTRACT

Results of soil radon concentration measurements at the surface in Northern Caucasus (Krasnodar territory) in different geological features are shown. Measurements were made in mud volcanoes, faults, mineral deposits and landslips. The data were compared to seismicity. Before earthquakes, the changes in the concentration of radon appear as "humps" or "splashes" of various durations. Monthly, daily and hourly changes of the concentration of soil radon during the earthquakes are shown for each zone of researches. The simultaneous measurement of radon in the big area has shown the movement of the increased concentration of radon to the epicenter several days prior to the earthquake.

1. Introduction

Environmental radiation measurements during strong geophysical processes (e.g., earthquakes) are important for South Russia. Variations in the background gamma radiation levels in various galleries and caves in the Caucasus have been investigated since 1987 (e.g., Tsvetkova et al., 2001), while large-scale measurements of soil radon at the Earth's surface in the Krasnodar region began later. Preliminarily, we have solved some methodological questions. As a result, soil radon detectors with photodiodes or ZnS scintillators were applied, and measurements of alpha-activity in the soil were performed continuously. The data were recorded in the "memory" of the device every hour (for photodiodes) or every 5 min (for ZnS scintillator), and radon detectors were placed in dry cellars with stable temperatures. Fortunately, there were buildings with cellars located near most of the geological features studied (e.g., faults, mud volcanoes and landslips) in the Krasnodar region. The cellars used in this study maintained stable temperatures around the detectors and were not penetrated by atmospheric precipitation.

The influence of meteorological factors (change of air temperature, humidity, atmospheric precipitations and pressure) on radon data when compared with seismic processes was therefore minimal. This was confirmed by long-term measurements in the Krasnodar region.

The main task of this study was to measure the range of radon variations during earthquakes. Possible changes in radon concentrations before an earthquake have been described in a number of studies; the greatest volume of research has examined various hydrogeological features (e.g., prospecting boreholes, mineral springs, and wells). The results of soil radon measurements, however, have been studied less frequently. In one review study (Dubinchuk, 1993), markedly different results were obtained:

- Changes in radon were observed in distances ranging from several tens of kilometers to hundreds of kilometers from the epicenter of an earthquake;
- Anomalies occur both before and after an earthquake or do not occur at all;
- The time of outstripping varied from several hours to several months;
- The dependence of radon anomalies on the force and distance of the earthquake differs between cases.

It is therefore necessary to continue researching variations in radon concentrations, particularly in connection with the prediction of earthquakes. The results of changes in soil radon concentrations during earthquakes in the Northern Caucasus (Krasnodar region) are discussed in this paper.

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2. Region of research

The primary seismic zones are located in the southern part of the Krasnodar region. The southern area was therefore chosen to research changes in soil radon concentration during earthquakes. Rn-probes were placed in different geological features in the Krasnodar region (e.g., faults, mud volcanoes, and mineral deposits). The study area in the Krasnodar region and the locations of radon measurements are shown in Fig. 1.

Measurements of radon were performed in the faults of the central and southern parts of the Krasnodar region: the western fault, "Bugazsky"; the southern fault near the settlement of Dzhubga and the city of Tuapse in the coast of the Black Sea; and the fault zone in the city of Krasnodar and the settlement of Kholmsky.

Mud volcanoes in the Krasnodar region are generally located in the territory of the Taman peninsula. Examples of mud volcanoes used in this study are described in Tsvetkova et al. (2004). All mud volcanoes are connected with zones of tectonic infringements penetrating through sedimentary units. Most mud volcanoes share a common structural-tectonic environment with the oilfields of the Taman peninsula. The majority of measurements were performed in the volcanoes "Miska" (the city of Temrjuk), "Shugo", and "Shapshugsky".

Additionally, radon measurements were performed in the territory of the oil-and-gas and mercury deposits of the Abinsk district. These mineral deposits are located in the area of the settlement of Kholmsky. The mercury ore-bearing zone is composed of clays and sandstones that are intensively crumpled and hydrothermally processed. This zone crosses the meridian fault, Kholmsky, as well as the faults of the central Caucasian orientation.

Oil boreholes exploit oilfields in sandstones of the Palaeocene deposits. The oilfields also extend down to the ancient meridian fault, Kholmsky, and penetrate through the entire sedimentary unit up to metamorphic and magmatic rocks of Paleozoic origin. The increased concentrations of iodine, bromine and chlorine are revealed in the accompanying waters.

Fig. 1. Map of the Rn observation station in the Western Caucasus. Black squares show points in the faults; white squares show points in mineral deposits; triangles designate mud volcanoes; points of the Rn-network are shown by black ellipses. The large circles show seismically active zones. The region of study is shown by a circle on the map of Russia.

Rn-probes with photodiodes were placed in all the faults, volcanoes and mineral deposits. Measurements were collected continuously. Data in the "memory" of devices were recorded each hour.

In addition to measurements taken at faults, volcanoes and deposits, radon measurements were also performed in regions without any geological peculiarities. There is clearly tectonic damage of different extent (e.g., cracks and small faults) in any terrestrial surface; regions with minimal tectonic cracks (according to the geological data) and with approximately identical geological conditions were therefore chosen. The network of Rn-stations for the investigation of Rn behavior in the area was created from such places (Fig. 1). An optimal step with a distance between points of 50 km was chosen. This step pattern managed to locate the majority of points of the network in areas without large faults. The initial step (distance) and location of points for Rn-probes were chosen for practical reasons, namely, an opportunity for fast data acquisition from the detectors and their control. Subsequent measurements demonstrated the validity of the 50-km spacing and the locations of the detectors. In this network, all scintillation detectors were located in the cellars and equipped with devices to register the soil temperature.

This analysis was based on the seismic catalog of the Central Experimental Expedition (CEE) of the Geophysical Service of the Russian Academy of Sciences (GS RAS).

3. Results

Tsvetkova et al. (2005) have shown monthly, daily and hourly changes of soil radon concentration in galleries and caves. Changes in the monthly data exceeded the changes in regional seismicity for 3–4 months. The daily concentration of soil radon in galleries and caves increased several days prior to the earthquakes. The concentration of radon began to decrease after the earthquakes had occurred. Similarly, hour-long "splashes" of the underground gamma radiation (Tsvetkova et al., 2003) were measured, and infringements of the daily Fourier harmonic in Rn-data for 9 ± 1 days before the earthquakes were detected.

Rn-data obtained on the surface of the Earth were analyzed similarly to the underground data. Monthly, daily and hourly variations were compared with seismicity.

3.1. Rn in the faults

Identical observations were obtained in all researched faults and the results obtained in the Krasnodar fault are shown as an example in Fig. 2.

3.1.1. Monthly changes

The radon concentration (Fig. 2a) varied widely from month to month. Frequently, the concentration of radon was higher in the autumn than in the winter, but in some years (e.g., 2004), this trend was not observed. The activity of radon in February was consistently the lowest. A comparison with seismicity shows the following results: The factor of correlation, K_{kor}, of the monthly activity of radon with the monthly number of earthquakes within a radius of 1000 km (black vertical columns in Fig. 2a) around the radon detector was equal to 40%. When the radius increased to 2000 km (the number of earthquakes shown by the white columns in Fig. 2a), K_{kor} increased to 67%. Similarly to Tsvetkova et al. (2005), the earthquake quantity data (for research forecasting the