

Assessment of Sensitivity Zone of Radon and Temperature Measurements in Study of Process of Tectonic Earthquakes Preparation

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Abstract—The results of the research of the behavior of radon (RVA - radon volumetric activity), released from the massif, are described. Radon migration and its emission from the massif depend on the porosity, permeability and fissility of the massif. A sharp change of the massif strength and a discharge of elastic stresses due to the external forces (earthquake) occur under certain changes in the structure of the massif, both during compression and tension of the massif. According to the results obtained from the reflection of changes in the geodynamic state of the geological environment during tectonic earthquakes preparation for areas with bending deformations, changes in RVA and temperature occur when the ratio of the magnitude to the logarithm of the epicenter distance is more than 2.5.

Keywords — *radon volumetric activity (RVA); dynamics of RVA change; critical state of the massif; external influence; discharge of the stress state; earthquake*

I. INTRODUCTION

While using various methods of studying the changes in the geodynamic state of the Earth's crust, which allow in some cases predicting seismic [1-16] and volcanic [17-22] events, the question of their long-range action or spatial sensitivity arises.

First works on radon precursors of earthquake were dated as early as 1966 and presented in the studies of G.A. Mavlyanov and V.I. Ulomov on radon variations in thermomineral waters. A significant increase in the radon content was found before the Tashkent earthquake ($M = 5.5$), as well as in connection with its aftershocks [23-26]. Since 1957, the content of radon in thermomineral water noticeably increased. By mid-1965, it had almost doubled. Then this process developed even faster, but in October 1965 stabilization began, which continued until April 26, 1966, when the earthquake in the magnitude of 8 occurred in Tashkent. Immediately after the earthquake, the radon concentration sharply fell, which attracted attention to this interesting phenomenon. All this confirms the regularity of the phenomena discovered then. Such data were later obtained in 1970 on Makhachkala, Przhhevskiy and other earthquakes.

Thermomineral waters of the artesian basin are located in the Tashkent region at a depth of 1300-2400 m. The water basin is replenished mainly due to atmospheric precipitation in the foothill parts of the Tashkent district and partly due to the migration of deeper waters. The intensity of their intake or the change in the content of radon in them determines the changes in the amount of inert gas in the thermomineral aquifer. The system of tectonic disturbances in the crystalline structure, a relatively high temperature of water (about 60° C) and weak

radioactivity suggest that radon waters are found in the zones of tectonic faults. Radon is inert gas and its penetration into the water occurs due to the diffusion from the rock "capillary", by emanation. As it has been found out, emanation is determined mainly by the structure of the rock, by the presence of passages in it, along which the radon released from radium enters the environment. Obviously, destruction of the crystal lattices of minerals and the development of an additional network of "capillary" in the rock (the possibility of "capillary" enrichment of the chemical and gas composition of mineral waters was suggested by academician V.I. Vernadsky) leads to the intensive release of radon. It is known that at some stages of geological development, the change in the composition of thermomineral waters proceeds very slowly, and it can be quite significant in the periods of intense geological processes.

A number of theoretical and experimental studies on assessment of the zone of influence or tension transmission were carried out for methods directly or indirectly related to changes in the tension of rocks [27-33]. In the most known and frequently quoted work of I.P. Dobrovolsky [34] the similar assessments of stress transfer in a homogeneous half-space have been made. A theoretical dependence for the radius of influence of the source of arisen tension during a tectonic earthquake preparation, depending on the ratio of the magnitude to the logarithm of the epicenter distance, is obtained. The conclusions arising from the solutions obtained by I.P. Dobrovolsky are quite well performed during measurements of a water level in wells. Our task was to check their applicability during measurements of temperature and radon volumetric activity (RAV) in different (in geological and seismic respect) regions. As it has been already mentioned, the area of change in the stress-strain state of rocks, covered by the process of earthquake preparation, will primarily depend on the ratio of the magnitude and the distance to the focus. Obtaining quantitative values of such dependence will allow forecasting the distance to the focus for a given magnitude or the magnitude of the event for a given distance. Considering that earthquakes, starting with a magnitude of 5.0, usually cause damage up to 6 points on the MSK-64 scale, one can calculate the spatial dimensions of the observation network, linking to a specific city or object for which the forecast of a possible event is important.

Fig. 1 shows the experimental dependencies (obtained by different authors) of the ratio of the magnitude to the distance, when changes in the values of the measured hydrogeological effects appear [35]. Seismic events occurred during the period from 2006 to 2010 on the territory with a radius of 1500 km are plotted on this graph. Red circles indicate events appeared in hydrogeological effects. Characteristic radon changes appeared in all events except the Tohoku earthquake. It is obvious that the display of temperature and radon effects correspond to the ratio obtained by King from the results of observations of changes in the water level in wells in central Japan. That is, if the value of the ratio of the magnitude to the logarithm of the distance is more than 2.5, then this event will be reflected with a high degree of probability in the curves of temperature and radon volumetric activity changes and for the South Kuril region.

The threshold value of the ratio of the magnitude to the logarithm of a distance equal to 2.5 is obtained for the geological and geodynamic conditions of the subduction zone, where the pattern of interaction of tectonic plates is identical for both Japan and the South Kuril Islands. The subduction zone is characterized by the presence of bending deformations on the edge of the continental plate and the appearance of an extension zone. As an example of the reflection of tectonic events in the RVA field, Fig. 2 shows the changes in the radon volumetric activity at the Yuzhno-Kurilsk station in November 2006. The ratio of the magnitude of events to the logarithm of the distances for the events of 11/15 and 11/24 is equal to 2.9 and 2.6 respectively, which exceeds the criterion of 2.5.

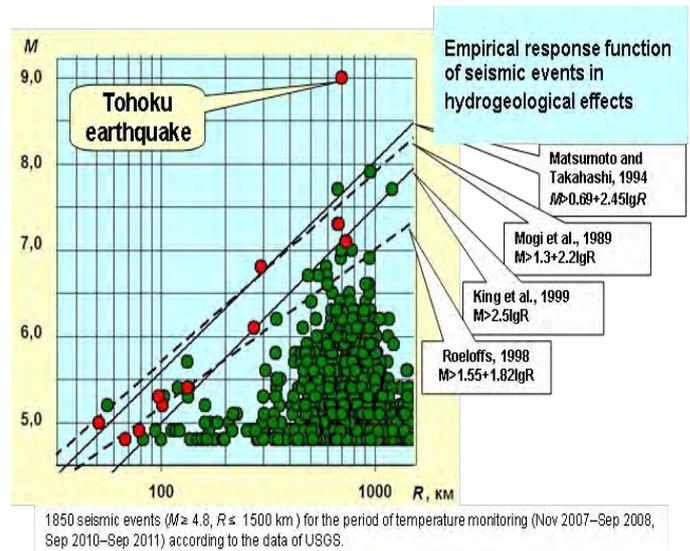


Fig.1. The response of seismic events in temperature and radon fields according to different authors

We will consider the validity of the application of the criterion 2.5 for other regions by the examples of the Northern Tien Shan, the North Caucasus and the Urals. At different times, monitoring observations of temperature and radon volumetric activity were carried out in these areas.

II. NORTHERN TIEN SHAN

In 2002-2004 in the Northern Tien Shan, radon monitoring was carried out for 2.5 years at 8 stations located from Bishkek to Karakol. Unfortunately, the number of seismic events during the observation period was insignificant, and not all of them occurred in the sensitivity zone (by the criterion of 2.5) of radon stations.

Fig. 3 shows a fragment of the recording of the volumetric activity of radon and thoron at Ala-Archa station before the event of December 4, 2002 [36, 37]. The geodynamic scheme of the crustal blocks movement for the Northern Tien Shan also supposes a thrust of the modern orogen over the Kazakhstan plate.

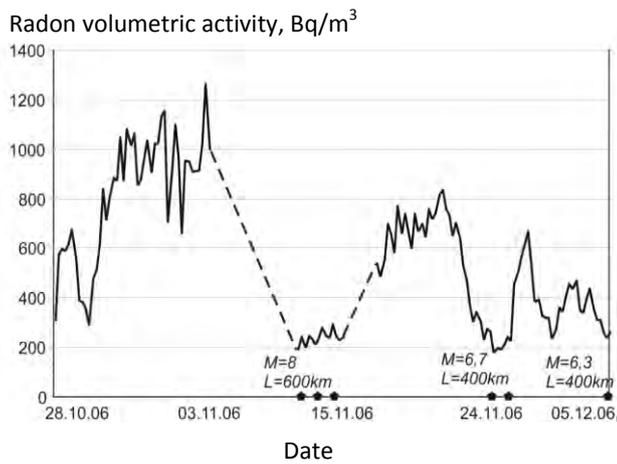


Fig.2 Reflection of the process of earthquakes preparation in the RVA at the Yuzhno-Kurilsk radon station.

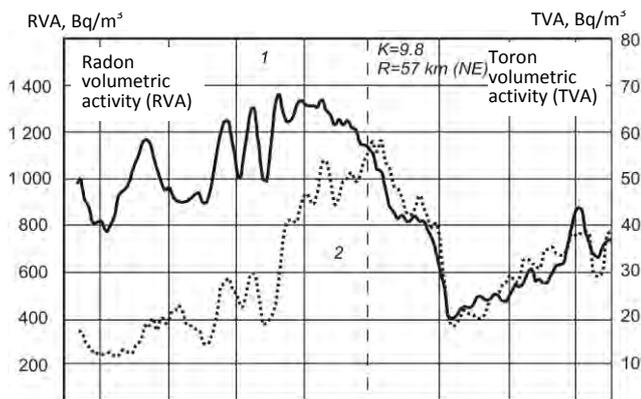


Fig.3. Fragment of the recording of the volumetric activity of radon and thoron at Ala-Archa station for the period from 11/27 to 12/11/2002

III. NORTH CAUCASUS

It can be assumed that in the North Caucasus there are also conditions for horizontal movement of the earth's crust blocks and bending deformations. Geophysical and geochemical monitoring is performed here, including radon measurements [38-41]. In terms of the applicability of the criterion 2.5, let us analyze the obtained series of the RVA. Fig. 4 shows a fragment of the RVA observation record for the period from 10/27/2018 to 07/18/2018 at the radon station installed at the

end of 2017 in Vladikavkaz. There are 3 areas on the curves of RVA changes that can be associated with the process of earthquakes preparation during the observation period. These are the periods from 12/25/2017 to 01/01/2018; from 05/02/2018 to 05/10/2018 and from 05/31 to 06/06/2018. The process of the event preparation on 06/05/2018 in Azerbaijan with a magnitude of 5.3 and at a distance of about 180 km from Vladikavkaz is clearly distinguished on the obtained curve of RVA change (Fig. 5). The calculated ratio of the magnitude to the logarithm of the distance is 2.4, which suggests the applicability of the criterion 2.5 for the territory of the North Caucasus. The subsequent earthquake on 06/29/2018 in Georgia, approximately at the same distance, was not so clearly reflected in the changes of radon volumetric activity. The ratio of the magnitude to the logarithm of the distance for this event is less than 2. Before the event of 01/01/2018 the characteristic changes in the radon volumetric activity were observed for the earthquake preparation process; however, King's criterion could not be calculated due to the lack of data about the distance to the epicenter.

In 2015, quite unexpectedly, an earthquake with a magnitude of about 4.5 occurred in the Middle Urals, near the Sabik settlement. At the radon station installed at the Kourovka Observatory, it was possible to obtain the data on the changes in the radon volumetric activity. Figure 5 shows a fragment of the change in radon volumetric activity [42]. Despite the fact that the ratio of the magnitude to the logarithm of the distance was 2.4, the preparation of this event was not reflected in the changes of radon volumetric activity.

A specific nature of the reflection of this event in the changes of radon volumetric activity was that it manifested itself two days after the event. Also the absence of aftershock activity can be considered as a distinctive feature of this event. Such behavior is characteristic for a change in the radon volumetric activity during career explosions whether this is a feature of the preparation of events in the Urals or the nature of this event is not associated with bending deformations. After this event, 3 years later on 09/04/2018 in Ust-Katav district of Chelyabinsk region, the strongest earthquake occurred during the period of observations in the Urals with a magnitude of 5.4. At radon stations in Yekaterinburg and Kourovka, this event was not reflected in the curves of radon volumetric activity (the ratio of the magnitude to the logarithm of the distance is 2.2). This event is characterized by intense aftershock activity. A number of subsequent shocks corresponded to magnitudes 4.5-4.7.

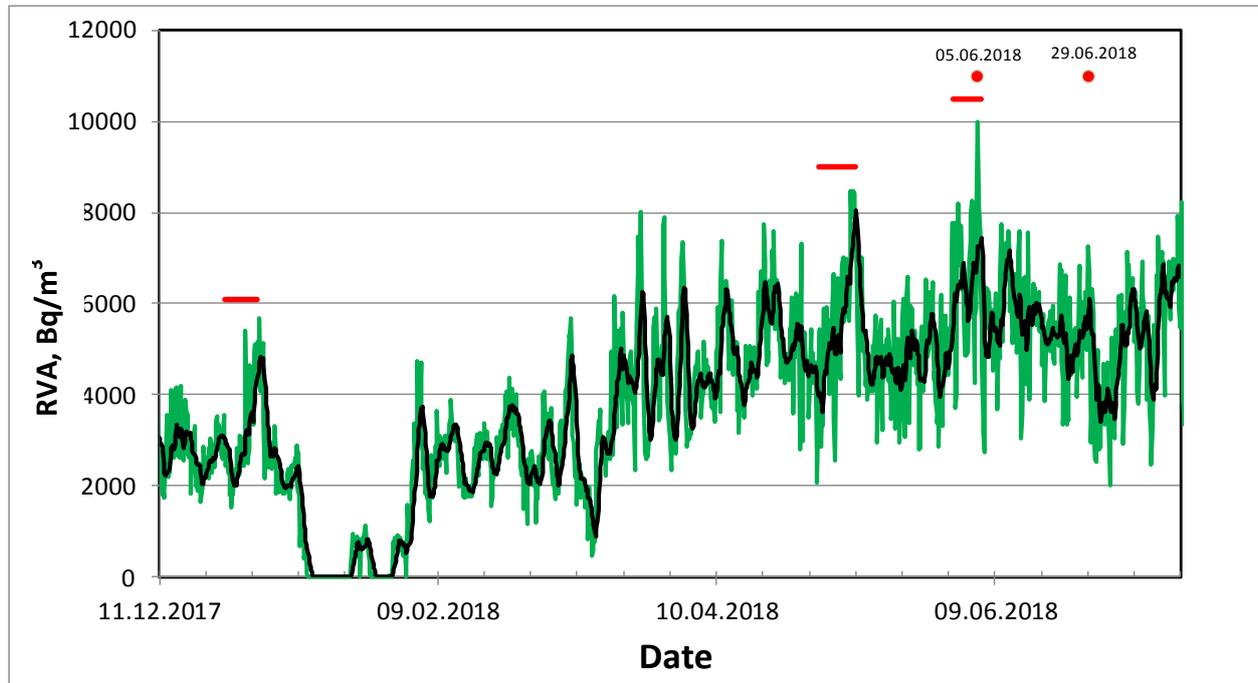


Fig. 4. A fragment of the record of radon volumetric activity at the station “Vladikavkaz” from 10/27/2018 to 07/18/2018; smoothing by 10 points, the areas associated with the preparation of earthquakes and earthquakes are marked

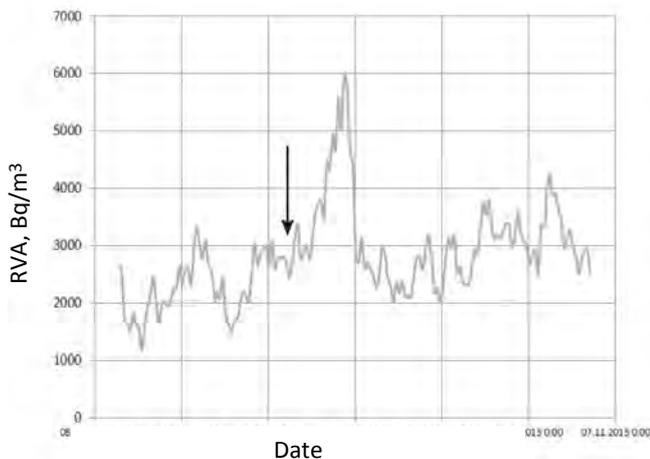


Fig. 5. Changes in the volumetric activity of soil radon at the Kourovka Observatory from 10/08/2015 to 11/07/2015.

IV. CONCLUSION

According to the results obtained from the reflection of changes in the geodynamic state of the geological environment in preparation of tectonic earthquakes for areas with exposure of bending deformations, the changes in volumetric activity of radon and temperature occur when the ratio of the magnitude to the logarithm of the distance to the epicenter is more than 2.5.

Using this dependence, it is possible to plan the location of radon and temperature stations when organizing the monitoring of cities and hazardous objects.

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