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GEOCHEMICAL SOUNDING OF TECTONIC FAULTS MEASUREMENT-BASED EXHALATION OF SOIL RADON

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Abstract

The scientific and methodological issues of geochemical sounding and localization of tectonic fault activity based on profile measurements of exhalation (volumetric activity) of soil radon (Rn 222),as well as emanation surveys on the territory of Ust-Kamenogorsk, carried out here in 2021-2023 in connection with seismic micro zoning (SMR) are outlined. It has been established that those geochemical methods of deep sounding of tectonic faults allow to reliably clarify the location and determine the activity of tectonic faults in the study area and provide new materials for seismic zoning of critical objects and determining seismic risk factors.

Keywords: geochemical sounding, fault activity, radon exhalation, soil radon, emanation survey, seismic risk, Irtysh shear zone

I. Introduction

In geological and tectonic terms, the city of Ust-Kamenogorsk in East Kazakhstan is located in the Irtysh shear zone (ISZ) and in seismic activity terms it is located in the area of possible earthquakes of magnitude 8. The main faults in the city have a northwestern strike and, in combination with transverse discontinuous faults, cause the folded-block nature of the Irtysh shear zone (ISS).

Geologists have been studying this zone since the beginning of the twentieth century. This tectonic structure is a deep fault zone with a width of 1.5 to 20 km, stretching across the territory of Russia, East Kazakhstan (Rubtsovsk, Ust-Kamenogorsk) to China (Fuyun) and further to Mongolia for more than 1000 km, in the form of a collage of heterogeneous blocks and scales, differing in the degree of deformation in the Paleozoic [1,2].

The objectives of the studies carried out at the ISS were: 1) to assess the radon activity of tectonic fault zones; 2) to work out the method of emanation survey for the conditions of the Irtysh shear zone and determine the limits of changes in the exhalation (volumetric activity) of radon in the subsoil air above the faults in the tectonic-active and passive areas of the study area.

To solve the tasks, several devices were used: "Ramon-Radon2" manufactured by the company "SOLO LTD" RK, radiometer-dosimeter "RKS-01-SOLO", designed for comprehensive radiation study of the study area. During the emanation survey, the Alfarad Plus instrument complex was used for express measuring and monitoring of OAR-222 and Toron-220 in the air

[3,4].

The city of Ust-Kamenogorsk is the regional center of East Kazakhstan (EKR), the largest industrial and transport hub of Rudny Altai. For sustainable development of non-ferrous metallurgy, mining and chemical industries, mechanical engineering and civil engineering, a comprehensive study of engineering-geological, hydrogeological, seismic and environmental conditions of the territory is necessary.

Until 1990, endogenous geological processes manifested themselves in the form of moderate earthquakes with an intensity of up to 6-7 points (MSK -64). However, the Zaisan earthquake that occurred on June 14, 1990, with an intensity of 8 points at the epicenter exceeded the existing estimate of seismic activity in this region (according to SNiP II-7-87) by 1 point. Since 2021, JEM and SMR have been carried out in East Kazakhstan region [5]. In this regard, geochemical studies were carried out here for the first time based on profile sounding, soil radon exhalation and emanation survey. It should be noted that in connection with the construction and installation works, such work was previously carried out in 2014-2015 on the territory of Almaty [6].

II. Methods

The natural radioactive gas radon (Rn^{222}) with a half-life of 3.82 days is the decay product of radium, which occurs as a result of the decay of uranium-238 [11].

It is known that among the three isotopes of radon (Radon-222, Thoron-220, Actinium-219), the first isotope with a half-life of 3.825 days is an optimal and reliable indicator in studies of seismic processes in large areas. High radon activity in fault localization sites has been noted in many studies [10, 11]. The mechanism of radon migration in the vertical direction has been described by many researchers [Koval, Udodov, Sankov et al., 2006; Akerbolm; Banwell,Parizek,1988; Hermansson, Cyssler; Moussa, ElArabi,2003; Wahita, Kumar, 2008] [10].

The essence of the phenomenon lies in the fact that the main isotope radon (Rn^{222}) is continuously generated in rocks in the process of radioactive decay, hence it is always present in any mountain range. The decrease in its concentration, both due to decay and due to migration from the massif into the air, is constantly compensated by the new generation of this gas. Therefore, the average radon content in the array is always constant and is determined by the concentration of uranium (radium) in this array. Radon migration to the mountain range and its release from the soil surface are determined by the diffusion coefficient, which depends on many factors. The most important of these are porosity, permeability and fracturing. Convective transport of radon with gas jets can be carried out from the upper part of the mountain range from depths up to 200m. World experience shows that radon (Rn^{222}), due to a number of its special geochemical properties in groundwater and surface-atmosphere, is an effective indicator of the geodynamic state of the Earth's crust [7,8,9].

It is also important to specify that, even though the radon presence in these fluxes is of negligible quantity, there are no problems with its registration due to its radioactivity. It is reliably recorded in the presence of approximately 30-50 decays per second in one cubic meter (m3), that is, radon activity is 30-50 Bq/m3 [3].

Radon anomalies over tectonic disturbances are very diverse in intensity and shape, as well as options for the location of the main shifter within them. The interpretation of the term "fault zone" includes not only the tectonics of the fault displacer but also significantly larger volumes of rocks in which plastic and discontinuous deformations genetically associated with its formation take place.

III. Results

As noted, in 2021-2023, the Institute of Seismology of the Ministry of Emergency Situations of the Republic of Kazakhstan in Ust-Kamenogorsk carried out work on geochemical sounding and emanation surveys to clarify the location and activity of tectonic faults based on profile measurement of the exhalation (volumetric activity) of soil radon (Rn^{222}).

During the summer periods of 2021-2022 in the eastern part of Ust-Kamenogorsk, 10 km from its western border, fieldwork was carried out on special profiles for measuring radon exhalation (Rn^{222}) to detect buried faults in increments of 50 m. In total, 5 profiles with a total length of 15.2 km were passed, through 5 fault zones (Fig. 1). The profiles passed across the strike of faults in a southeasterly direction. The distances between them ranged from 1.7 to 3.5 km., And the maximum length of a separate profile was 4 km.

Profile sounding was carried out by a complex of analyzers of the latest generation "Ramon-Radon2" and a radiometer-dosimeter "RKS-01-SOLO", manufactured by the company "SOLO LTD".

Fieldwork on emanation surveys was carried out from June to September 2021-2022, 46 profiles were passed, with a total length of 20,311 meters (Fig. 1).

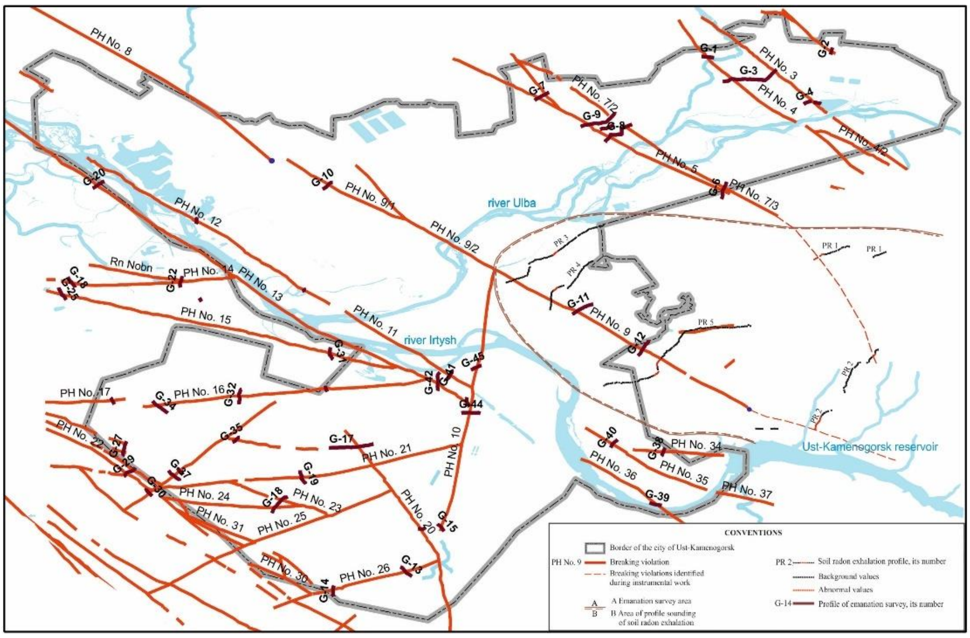

Fig. 1: *Map of field profile observations of soil radon exhalation in the territory of Ust-Kamenogorsk city*

In the course of the work, significant factual material for measuring the volumetric activity of Rn^{222} was collected. The emanation survey profiles were located across the strike of fault zones in those places where the main features of their structure were determined by the data of structural and geomorphological observations.

To assess the degree of permeability of the mountain range along the extended profiles, the analysis of digital elevation models was carried out with the allocation of ledges of straightened valleys and linear-erosion forms, which reflect the position of active faults in the study area. To measure the radon flux density from the soil surface and measure the volumetric activity of radon in soil air samples, the measuring complex for monitoring radon, thoron and their daughter products "Alfarad Plus" was chosen, designed for rapid measurements and continuous monitoring of the volumetric activity of radon-222, as well as the equivalent volumetric activity (EROA) of radon and thoron-220 in the air.

Geomorphologically, the areas of radon surveying are hilly terrain, represented by a combination of individual hills, massifs and inter-hill depressions, composed of loams from the surface and complicated by outcrops of Paleozoic rocks in the form of ridges, manes, cliffs, individual hills, with relative exceedances of up to 100 m.

Geologically, the described territory is part of the Irtysh structural-formational zone, stretching in a narrow strip in the northwest direction between the Kalba-Narym and Rudno-Altai zones.

In geological and petrological terms, the ISS is the Irtysh-Zaisan structural-formational zone, with a length of more than 500 km. with highly compressed and dislocated horst-anticlinorium. It is this feature that determines its modern high Seismo-dynamic activity here.

Profile No. 1: located on the northern outskirts of the village of Ushanov. It has a northeast direction and passes across the strike of the deep Irtysh fault. The length of the profile is about 1.5 km. 30 measurements were made on the profile every 50 meters, with the determination of coordinates and altitude values and data from the readings of other devices. In the identified areas with increased radon exhalation, the distance between the points of the profile was reduced to 20 m and control measurements were carried out. The average value for exhalation radon is 83 mBq/s*m^2. Between points 2 and 7, there was an increased exhalation of radon up to 17 0 mBq/s*m^2 with a section length of 250 m, which exceeds the background radon release by two times (Fig. 2). When measured on this profile with the Ramon-Radon2 device and the RKS-01 radiometer-dosimeter, a complete coincidence of anomalous areas is noted.

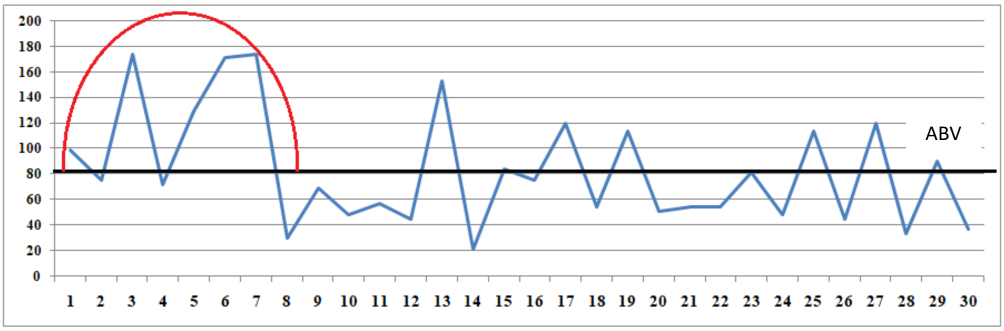

Fig. 2: *Profile 1. Exhalation of radon alpha particles (mBq/s*m2)*
ABV – average background value of radon

Profile No. 2: located to the east, 10 km from Ust-Kamenogorsk, along the Ust-Kamenogorsk-Zyryanovsk highway. The profile runs along the ridge to the Irtysh River at the cross of the ISS strike.

In the course of fieldwork, 54 measurements were made every 50 m, with the determination of coordinates, altitude values and instrument readings. The average background value of radon exhalation is 66 mBq/s*m^2, the maximum is 177 mBq/s*m^2, and the minimum is 12 mBq/s*m^2, (Fig. 3).

As can be seen from the graph, four areas of sharply increased radon exhalation are identified on this profile. The length of the first section is 150 m, and the remaining sections are respectively 200 m and 120 m. On average, radon exhalation exceeds the background content by 2-3 times, reaching a maximum value of 177 mBq/s*m^2.

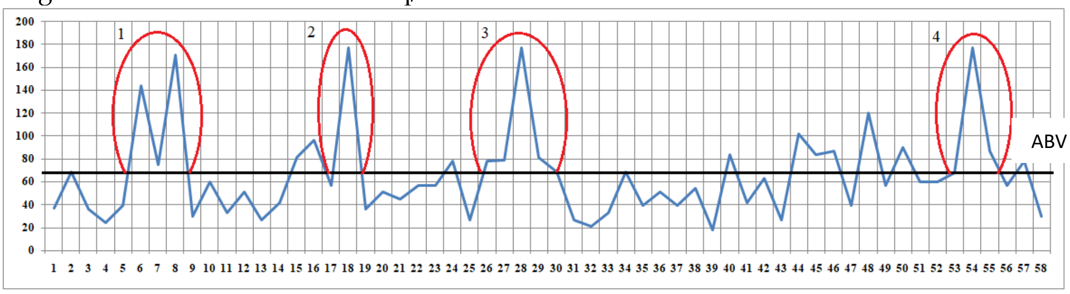

Fig. 3: *Profile 2. Exhalation of radon alpha particles (Bq/s*m^2)*
ABV – average background value of soil radon exhalation

Profile No. 3: passed on the eastern outskirts of the city of Ust-Kamenogorsk, on the left bank of the Ulba River, on a gentle slope of the ridge. The profile runs in the middle part of the slope of the eastern exposure with a direction to the northeast, across the strike of the ISS.

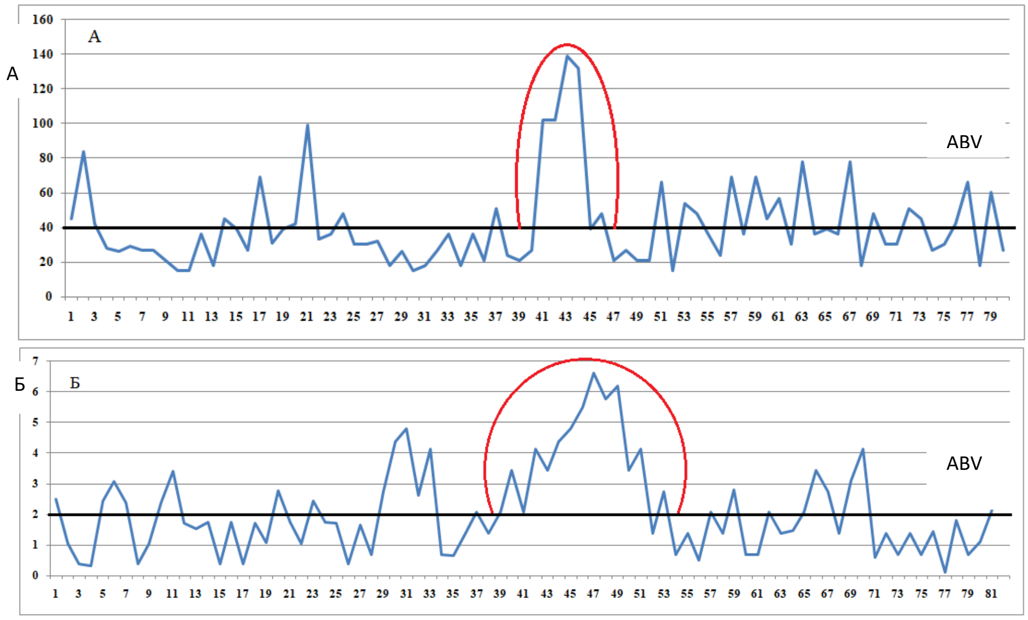

Fig. 4: *Profile 3. A - exhalation of radon alpha particles (mBq/s*m2) and B - beta particle dosimeter (part/min * cm²), ABV - average background value of radon*

The length of the profile is 4.0 km. In the process of fieldwork, 80 measurements were made every 50 meters, with the determination of the readings of all devices. In the identified areas with increased radon exhalation, the distance between the profile points was reduced to 20 m and control measurements were carried out.

The average background value of radon exhalation is 41 Bq/s*m², the maximum is-139 mBq/s*m² min.–15mBq/s*m². According to the profile, the area (between points 39-46) with increased radon exhalation, exceeding the background value by two times with the length of the anomalous zone of 400 mis defined. Processing of field survey materials with the Ramon-Radon2 device and the RKS-01 radiometer-dosimeter shows the complete coincidence of anomalous areas (Fig. 4 A and B).

Profile No. 4: passed on the eastern outskirts of the city of Ust-Kamenogorsk, in a valley bounded from the east and west by ridges of hills. The route runs along the slope of the western exposure. The direction of the profile is to the northeast, across the strike of the Irtysh shear zone.

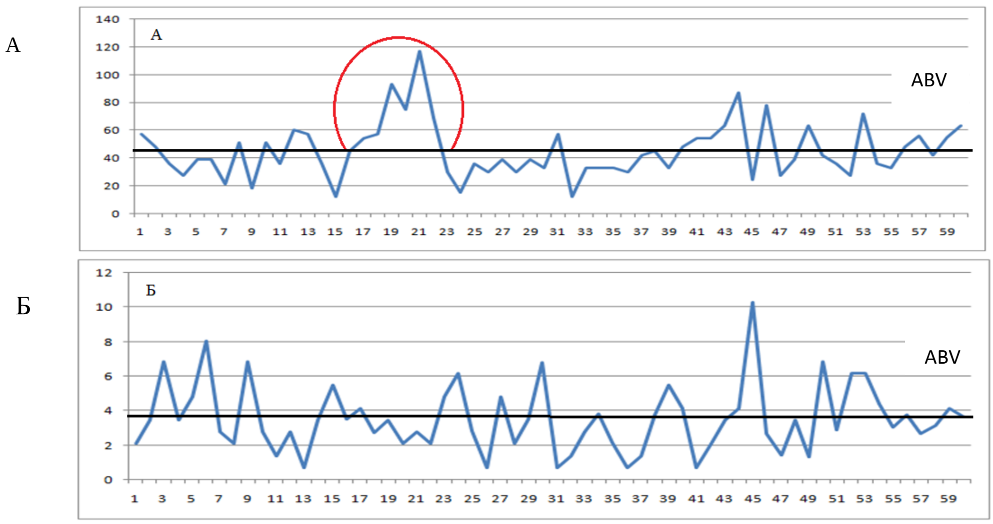

Fig. 5: *Profile 4. A is the exhalation of radon alpha particles (mBq/s*m²) and B - beta particle dosimeter (part/min * cm²), ABV - average background value of radon*

The length of the profile is 3.0 km. 60 measurements were made every 50 meters, with the determination of the readings of all instruments. In the identified areas with increased radon exhalation, the distance between the profile points was reduced to 20 m and control measurements were carried out.

The average background value of radon exhalation is 45 mBq/s*m², the maximum is 117 mBq/s*m2, and the minimum is -1 2mBq/s*m². According to the profile, an area (between points 15 - 23) with increased radon exhalation exceeding the background value by 2 times, with a length of the anomalous zone of 450 m was defined (Fig. 5).

Profile No. 5: located on the right bank of the Irtysh River, on the eastern outskirts of Ust-Kamenogorsk, along Vatutin Street, (Fig. 6). The direction of the profile is to the northeast, across the strike of the ISS.

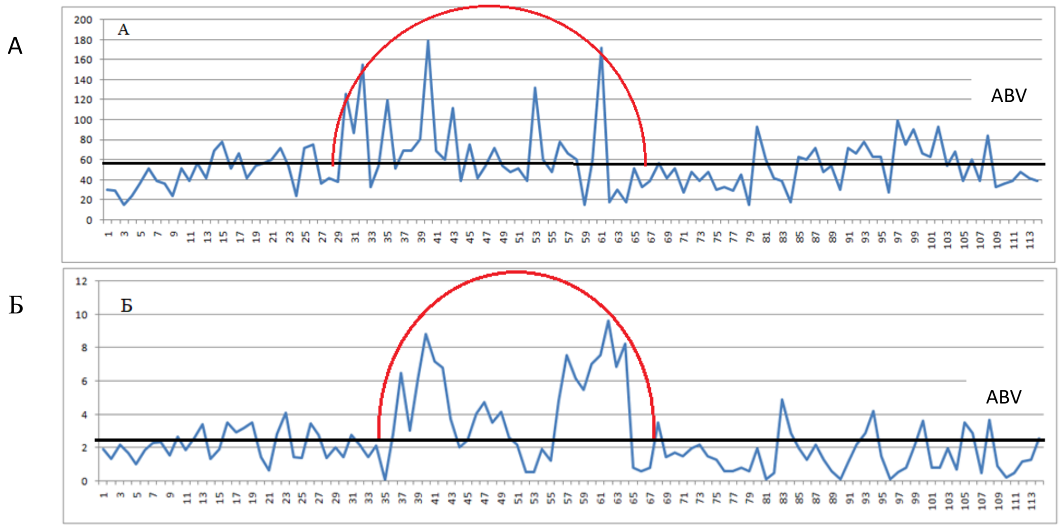

Fig. 6: *Profile 5. A – exhalation of radon alpha particles (mBq/s*m2) and B - beta particle dosimeter (part/min * cm²), SPZ - the average background value of radon*

The length of the profile is about 4.0 km. 114 complex measurements were performed every 50 meters, with the determination of coordinates and altitude values. In areas of increased radon exhalation, the distance between the points was reduced to 20 m.

The average background value of radon exhalation is 56.7 mBq/s*m², the maximum is 17.9 mBq/s*m², and the minimum is -1.5 mBq/s*m². According to the profile, an anomalous area (between points 29-65) was identified with a background value 2-3 times higher, with a length of 1.300 m. According to the radiation of beta particles, the anomalous zone is marked between points 35 - 65, with a length of 1200 m.

Emanation shooting.

The main task of the fieldwork in 2022 was to conduct an emanation survey on the territory of Ust-Kamenogorsk in connection with the construction and installation work, where faults are buried under a large cover of Quaternary sediments. During the period of fieldwork in the city, 46 profiles were passed, with a total length of 20311.1 m.

The profiles of the emanation survey were located crosswise along the strike of fault zones in those places where the main features of their structure were determined by the data of structural and geomorphological observations.

The profiles crossed differently oriented parts of discontinuous faults with distances between sampling points from 15 to 100 m.To compare faults by radon activity, the relative indicator was used: K = Qmax/Qmin, where Qmax is the maximum value of the Q parameterwithin the profile (anomaly intensity), and Qmin is the minimum value of the Q parameterin rocks outside the fault zone. Examples of such registration are shown in Table 1.

Table 1: *Quantitative parameters of profiles obtained from emanation survey data*

Profile Number	The length of the profile, m	Breaking Violation Number	Q max	Q min	Q cp	To
G-1	258,1	PH No. 1	520	89	291.30	5.84
G-2	303,3	PH No. 2	507	102	259.14	4.97
G-3	1480.6	PH No. 3,4	1940	120	605.63	16.17
G-6	635.3	PH No. 7/3, 5	1309	120	616.58	10.91
G-11	614	PH No. 9	2053	110	657.94	18.66
G-12	619	PH No. 9	2677	190	1231.95	14.09
G-13	441	PH No. 26	845	179	448.33	4.72
G-14	400	PH No. 26	804	90	323.58	8.93
G-19	542	PH No. 21	656	40	223.72	16.40
G-21	252	PH No. 12	2482	239	866.44	10.38
G-22	378	PH No. 14	1158	347	629.40	3.34
G-27	538	Rn Nobn	1903	95	632.33	20.03
G-31	461	PH No. 15	950	413	693.18	2.30
G-33	212	PH No. 16	736	144	419.00	5.11

In the simplest cases, the area of anomalous values of the Q parameter has one maximum in cross-section with a gradual or stepwise decrease in the concentration of soil radon to the periphery (Fig. 7). However, in most of the situations studied, the radon anomaly is more complex, usually discontinuous, which is associated with the heterogeneous structure of the fault zone. The largest of the discontinuities are manifested in the form of local extremes of Q values: maxima when filling the zone of the shifter with permeable fault breccias and minima if the tectonics were subjected to intense weathering or are represented by friction clay.

Anomalies of soil radon over discontinuous disturbances are characterized by spatial heterogeneity, which is apparently due to the permeability of the rupture substrate.

As a result of geological routes and remote sensing analysis, a catalogue of the main discontinuous disturbances was compiled, where Table 2 shows examples of such registration in the study area with the main characteristics, as well as the resulting data on the azimuth of the strike, azimuth of incidence and angle of incidence. The main azimuthally direction of discontinuous faults is northwestern. Most of the discontinuous faults have a steep vertical angle of inclination of the mixer, and the azimuths of the fall mainly have a southeastern strike.

Graph of changes in the volumetric activity of soil radon Q along the profile G11, G33.

It should be noted that according to the data of the emanation survey and the primary analysis of materials, a heterogeneous distribution of the concentration of soil radon along and across the strike of fault zones is traced, and at the same time, a clear tracing of discontinuous violations is recorded.

The leading role in the distribution of radon concentration over fault zones is played by the structural and geodynamic factors. Radon anomalies over faults are characterized by spatial heterogeneity, which is associated with variability in the permeability of the fault zone. We emphasize that the indicator of radon activity of the fault - KQ represents the ratio of the intensity of the near-fault emanation anomaly (Qmax) to the minimum value of the volumetric activity of radon beyond its limits. This relative parameter is less than Qmax and depends on the thickness of the overlying sediments and the radioactivity of the rocks at the fault.

The areal distribution of the UAR on the territory of Ust-Kamenogorsk is shown in 3D measurements according to the statistical processing of data from 46 profiles (Fig. 8). Here we see that the fault zone is represented by several pick-shaped or hump-shaped maximum values (Qmax) with a gradual decrease in the concentration of the OAR, turning into calm "dead" segments, which characterize the inactive sections of the fault. It can be assumed that the current activity of the faults according to the radon indicator, is not homogeneous in strike, because there are inactive (passive) segments of faults in the modern era, which can stretch for several hundred meters or km in length. This situation is extremely important in the seismic micro zoning of the city.

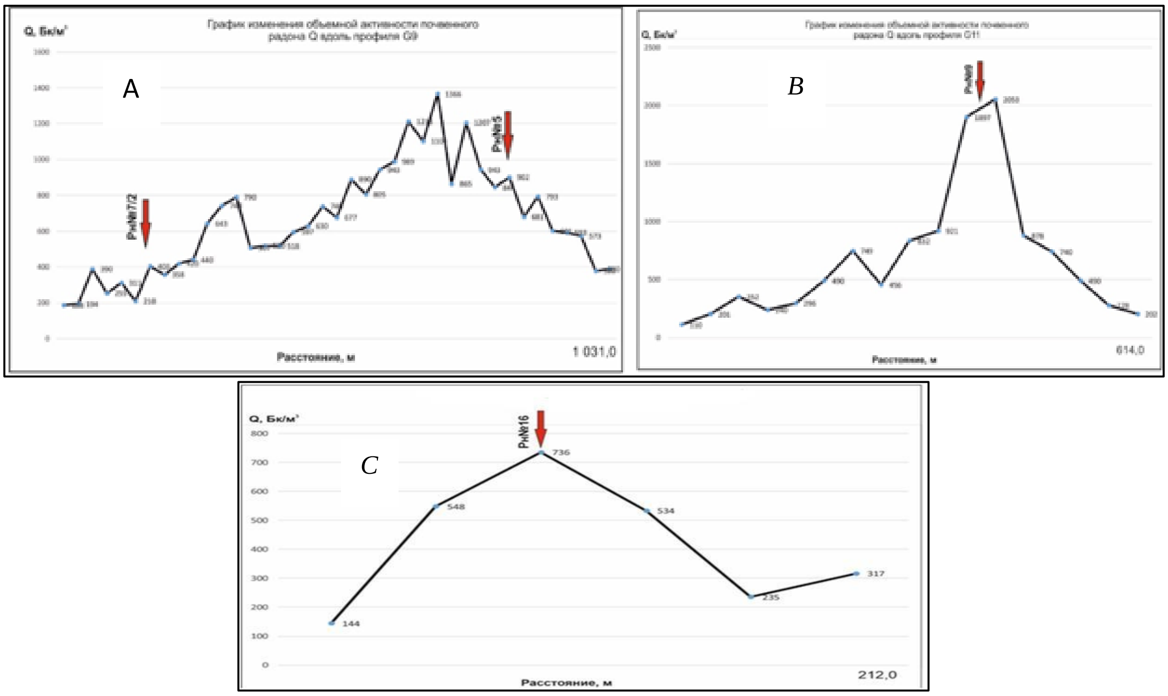

Fig. 7: *(A, B, C) - examples of typical distribution curves volumetric concentration of soil radon*

Table 2: *Characteristics of discontinuous disorders within the study area*

№	Name	Length Km	Type	Options			Classification according to the angle of inclination of the mixer
				Azimuth of stretch	The azimuth of the fall	Angle of incidence	
1	PH No. 1	6355.19	shift	315	135	70	steep
6	PH No. 5	9991.42	shift	290	82	80	steep
11	PH No. 7/3	1690.31	shift	210	86	71	steep
16	PH No. 10	9385.80	shift	190	30	62	steep
23	PH No. 17	1698.71	shift	220	160	71	steep
31	PH No. 24	3184.84	shift	260	175	58	steep
40	PH No. 33	1827.70	shift	290	160	80	steep

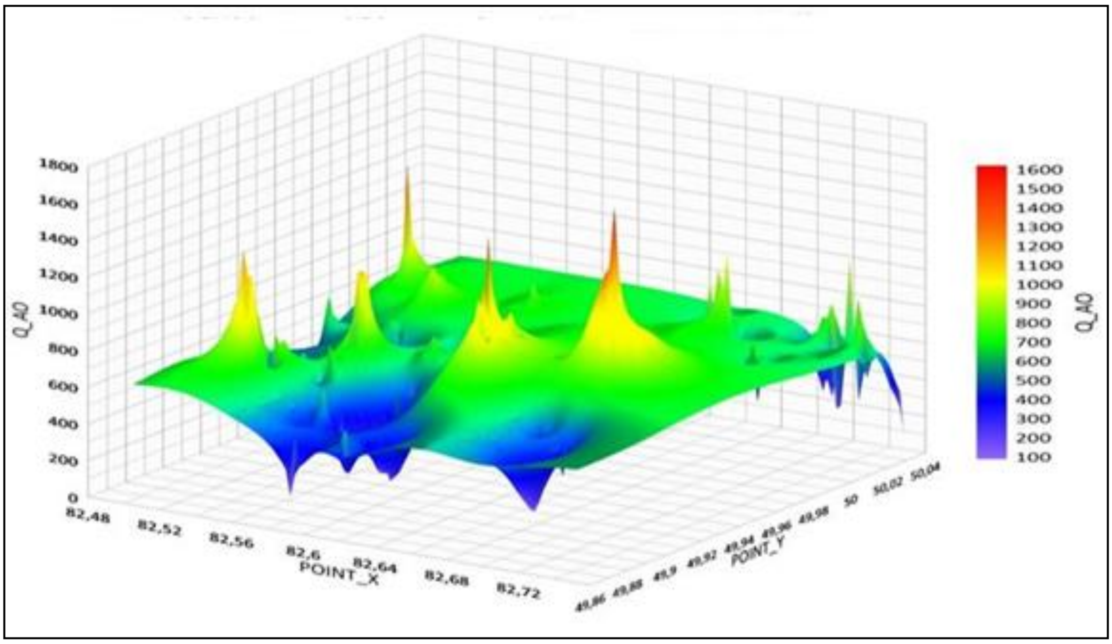

Fig. 8: *Areal distribution of radon volumetric activity (Rn^{222})*

IV. Discussion

For the first time, geochemical field studies were carried out within the Irtysh shear zone to clarify the position of discontinuous disturbances and their activity using profile measurements of the volumetric activity of soil radon Rn^{222}.

As a result of geochemical sounding in the area of Ust-Kamenogorsk, tectonic fault zones have been identified, which characterize modern tectonic activity in the study area, and make it possible to trace buried faults.

On geochemical profiles, anomalous zones of increased radon exhalation differ from the background values of radon on the ground by exceeding the concentration of UAR by 3–4 times. Such anomalous zones show the existence of tectonic faults in the area of Ust-Kamenogorsk, which are active in the modern era both as a whole and in their segments.

This is evidenced by the tomography of radon convictions obtained during emanation surveying in the territory of Ust-Kamenogorsk (Fig. 8). Here, fault zones along the strike are marked by hump-shaped extreme values, which in some segments "fail" over considerable distances, inactive sections of these faults.

These facts indicate that fault zones marked by radon anomalies appear to be characterized by a high degree of fragmentation of individual areas, as well as significant convection of radioactive gases from these zones into the surface atmosphere.

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