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Original paper

Radiometric and seismic study of Chidvinskaya kimberlite pipe (Arkhangelsk diamondiferous province, North of the East European Craton, Russia)

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Resumen

Se realizaron cálculos geofísicos superficiales en el pasaje de diamante Chidvinskaya de la provincia productora de diamantes de Arkhangelsk (Norte del Craton de Europa Oriental, Rusia). Dichos cálculos incluyeron un estudio gamma-espectrométrico de alta precisión, una estudio de emanación de radón en el aire del suelo y un método de sondeo microsísmico. Se utilizáron cálculos radiométricos para encontrar anomalías de radiactividad de la capa superficial sobre el tubo de Chidvinskaya, el cual podría ser un resultado del impacto del cuerpo kimberlita en un medio huésped. Con la estructura profunda de la pasaje de kimberlita y el medio huésped se formó una imagen mediante el método de sondeo microsísmico. Los resultados indican que el tubo aparece como un cuerpo de alta velocidad. El medio huésped es de baja velocidad que es típico de las rocas con fisuras excesivas. Los valores aumentados de la radiación de rayos gamma total de la capa superficial cercana se observan dentro del contorno de la tubería y superan los valores de fondo de 2 a 4 veces. Se encontró emanación anómala de radón en el aire del suelo en los límites de las tuberías. De acuerdo con los datos de sondeo microsísmico, la zona de contacto cercano es una estructura permeable al gas con excesiva fisuración. Los resultados de los métodos utilizados concuerdan entre sí. El complejo de métodos propuesto ha permitido identificar la característica distintiva de la tubería.

Palabras clave: estudio gamma-espectrométrico, emanación del radón, microseísmo, tubería de Chidvinskaya, provincia diamantífera de Arkhangelsk.

Abstract

Surface geophysical measurements were carried out on Chidvinskaya diamond pipe of the Arkhangelsk diamondiferous province (North of the East European Craton, Russia). Geophysical measurements included a high-precision gamma-spectrometric survey, radon emanation survey in soil air, and microseismic sounding method. Radiometric measurements were used to found radioactivity anomalies of the surface layer over the Chidvinskaya pipe which could be a result of impact of the kimberlite body on a host medium. Deep structure of the kimberlite pipe and host medium was imaged by means of microseismic sounding method. Results indicate that the pipe appears as a high-velocity body. The host medium is low-velocity that is typical for rocks with excessive fissuring. Increased values of total gamma-ray radiation of near surface layer are observed within the pipe contour and exceeded the background values by 2-4 times. Anomalous radon emanation in the soil air was found at the pipe boundaries. According to the microseismic sounding data near-contact zone is a gas-penetrable structure with excessive fissuring. The results of the used methods are in good agreement with each other. The proposed complex of methods has allowed to identify the pipe distinctive feature.

Key words: gamma-spectrometric survey, radon emanation, microseisms, Chidvinskaya pipe, Arkhangelsk diamondiferous province.

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Introduction

Since the discovery of the first kimberlite pipe in the Arkhangelsk diamondiferous province (ADP) (North of the East European Craton, Russia) many traditional geophysical methods have been tested with the purpose to search new kimberlite bodies (Bezborodov *et al.,* 2003; Kontarovich & Babayants 2011). Aeromagnetic methods have shown the most effective (Mwenifumbo & Kjarsgaard 1999; Reed & Witherly 2007). However, at the present time crisis of the efficiency aeromagnetic survey to searching kimberlite bodies influences on the searches results increasingly. Thus, in the early eighties of the last century the efficiency verification magnetic anomalies was about 20 %; at the end of the eighties, 12.5 %; in the nineties it was already below 1 % (Stognij & Korotkov 2010). Today, this figure is less than 0.5% for the whole territory of the Arkhangelsk diamondiferous province. It is connected with a decrease of contrast magnetic anomalies which are tending to geological noise. Therefore, development of new approaches for exploration and prediction of kimberlite pipes are an important task.

One such approach is a complex use of surface geophysical methods such as a high-precision gamma-spectrometric survey, radon emanation survey in soil air and microseismic sounding. According to the microseismic sounding (MSM) method, kimberlite pipes appear as vertical zones with values of relative microseismic intensity lower than 5 dB. Kimberlite pipes are accompanied by faults with higher values of the relative intensity of MS (*Popov et al. 2014*). Gamma-spectrometric studies are used widely to search for uranium ore with high efficiency (IAEA, 2003; Babayants *et al.,* 2015; Killeen *et al.,* 2015). Also, radiometric studies have shown that total gamma-ray radiation and concentration of radioactive elements are increased in near surface layer. The boundaries of kimberlite pipes are accompanied by anomalous radon emanations.

Furthermore, as an example at Arkhangelskaya kimberlite pipe it was found that secular radioactive equilibrium of the even uranium isotopes is disturbed in enclosing rocks of the near-contact zone. Similarly, the radioactive elements concentrate inside that zone (Yakovlev *et al., 2016*).

The objective of the present work is to study Chidvinskaya pipe of the Chidvinsko-Izhmozerskoe kimberlite field of ADP. This pipe was selected because of its relatively large size and low overburden thickness that is important for radiometric measurements. The pipe’s dimensions exceeded the resolving power of the microseismic sounding method (MSM) and allowed to expect a more reliable determination of the deep structure.

General characteristics of the research object

Chidvinskaya pipe is part of the Chidvinsko-Izhmozerskoe kimberlite field, located 30 kilometers north-east from Arkhangelsk, and belonging to a membership of six pipes, constituting a chain with about 20 kilometers length to the North-North-East (Figure 1).

Chidvinskaya pipe is 1810x580 m. The pipe has low-grade ores without commercial value. However, a small amount of tests casts doubt on the accuracy of these estimates.

The complex overburden rock presented quaternary loose sediments, made mainly of sands, loams, peat and sand-pebble formations. Overburden thickness change from 1.5 to 35.3 m northern and southern part of the pipe. The average thickness of quaternary sediments is about 9.4 m.

The vertical section of Chidvinskaya pipe is two-root diatreme with a common trumpet in the surface portion. The upper part of the pipe is formed by rocks of crateral facies which are divided into two bench, the top and bottom bench with total capacity of about 123.5 m.

Top bench is composed of tuffaceous sedimentary rocks represented by coarse sandstones with an admixture of magmatic material, tuff-sandstones, tuffites and tuffs. Bottom bench is distributed in the northern part of the pipe and is made by tuffites with rare interlayers of tuffs and tuff-sandstones.

Diatreme facies is composed by autolit breccias, tuff breccias that form two ore pillars. The boundary between them is held in the middle bottleneck zone. Contacts between the diatreme rocks and the surrounding sedimentary deposits are quite clear.

Experimental

Surface geophysical measurements including high-precision gamma-spectrometric survey, radon emanation survey in soil air and microseismic sounding were used.

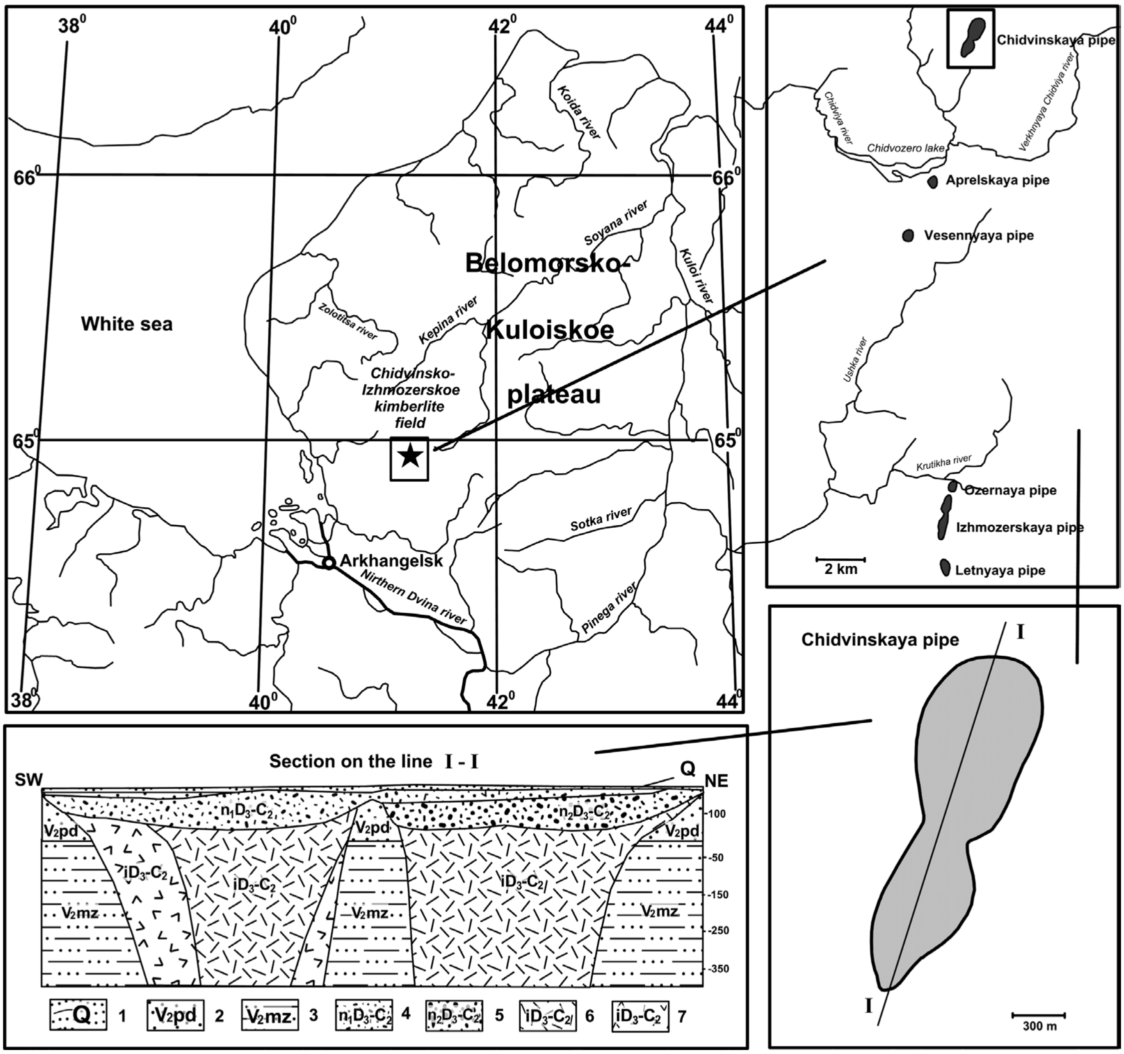

Figure 1. Location of the pipes of Chidvinsko-Izhmozerskoe kimberlite field and structure of the Chidvinskaya pipe (section by Eremenko (2004).

1.- quaternary deposits (sandy loams, loams, sands, clays); 2.– padun suite of vendian system (sandstones, argillites, siltstones); 3.– mezen suite of vendian system (siltstones, argillites, sandstones); 4.– top bench of crateral facies (tuffaceous sandstones with interlayers tuffs and tuffites); 5.– bottom bench of crateral facies (tuffites with interlayers tuffs); 6.– autolith breccias of diatreme facies; 7.– tuff breccias of diatreme facies.

Gamma-spectrometric survey

During the opening of the first diamond-bearing pipes of ADP gamma-spectrometric survey was used in combination with traditional geophysical methods, but it didn't receive further development, although it has been shown that kimberlite bodies were accompanied by radiation field anomalies in well landscape and geological setting (Babayants *et al.,* 2015). Kimberlite pipes of Yakut diamondiferous province were characterized by increased concentrations of thorium according to the airborne gamma-spectrometric measurements (Tsyganov *et al.,* 2004). Diamond deposits of tuffizit type were characterized by high-radioactivity in areas with low thickness of covering deposits (Rybalchenko *et al.,* 2011).

Surface gamma-spectrometric studies in the area of Chidvinskaya pipe were performed in pedestrian options using high-precision mobile scintillation gamma spectrometric complex RS-700 (Canada). Complex RS-700 is an advanced high resolution (1024 channels) digital spectrometer (ADS) allowing real-time to perform measurements of total radioactivity (Bq m^{-3}), as well as a separate measurement of the concentration of total uranium (μg/g), thorium (μg/g) and potassium in percentages

(%). The complex is equipped with an integrated GPS-receiver, enabling precise measurement of each binding. Complex RAD Assist software is used, that may directly conduct processing of the data in the field.

The traverse survey was carried out at a relatively uniform network with increments of 50 - 100 m. The measurements were made at 1.2 m above the ground. In total more than 16800 measurements, were performed using the gamma-spectrometric complex RS-700.

Radon emanation survey

^{222}Rn is a member of the ^{238}U radioactive series (Abumurad & Al-Tamimi 2001). Radon in the earth's surface depends on the characteristics of geological structure of the territory: development of plutonic rocks, permeable zones (faults), groundwater dynamics, presence of hydrocarbon accumulations, etc. (Bossew 2003). Heightened concentrations of radon are associated with tectonic faults, where it enters on the system of joints and tiny fractures and with fracturing persilicic intrusive mass (King, 1980). Zone crushing rocks surrounding these faults are feeders for radon (Kikaja *et al.,* 2016). Fractured rocks can increase the *in situ* local radon concentration, hence increasing the radon signal.

Measurements of radon emanation in soil air above Chidvinskaya pipe were conducted on the profile that crosses the north pole of the pipe in north-west – south-east direction using an automatic radium emanation radiometer RRA-01M-03 (Figure 2).

For the measurement of radon in soil air, drilling of pits to 0.5 m depth and 0.2 m diameter using soil portable drilling rig were conducted. The gas collector was placed to pit, then gas was pumped out from soil into the ionization chamber of the radiometer. After that radon measurement was conducted. The values of radon emanation were obtained for the 16 observation points.

Microseismic sounding method

The microseismic sounding method (MSM) was implemented on the assumption that the vertical component microseisms are determined mainly by the contribution of the fundamental mode of Rayleigh waves (Bath 1979). According to the results, two regularities were noted (Gorbatikov & Tsukhanov 2011; Gorbatikov *et al.,* 2013):

1) power spectrum amplitudes of Rayleigh waves increases when passing through low-velocity heterogeneities and decreases when passing through high-velocity heterogeneities;

2) the greatest change in intensity is observed for wavelengths twice the size of the cover thickness of the heterogeneity. This can be explained by the fact that a shear stress zone of Rayleigh wave is located at a depth equal to half of the length of a wave. As this takes place, the shift zone is located closer to surface.

The first statement on a qualitative level was predicted theoretically by Savarenskii and Kirnos, (1955). The close conclusions were reached at independent research of Rayleigh waves amplifications (Lin*, et al.,* 2012; Eddy and Ekström, 2014)

In the MSM it is necessary to define an indicative spectrum of microseisms for each point of measuring. For this purpose microseisms are accumulated during the period of stationarity equal to 1.5 hours duration (Gorbatikov & Stepanova, 2008).

Processing of the data starts with the construction of power spectra. Next, each frequency is studied individually. The relative intensity (I_i) of microseisms between the reference and mobile stations is calculated as

$$I_i = 20 \cdot log_{10} \frac{A_{ip}}{A_{ip}} \qquad (1)$$

where A_{ip} and A_{io} are the spectral amplitudes for recordings at the i^{th} point of the mobile and reference stations at the considered frequency.

The next step is the determination of the depth to be sounded which is equal to a half of the wavelength. The wavelength is determined based on the most probable velocity model of the investigated object.

The result of this processing is a distribution diagram of relative intensity of microseisms along the profile by depth. Zones with a higher relative microseism intensity represent an area with relatively reduced velocity properties, and vice versa.

Due to the fact that the microseismic sounding method is aimed at the vertical and near-vertical boundaries, it can be used for the allocation of various geological objects, including faults and kimberlite pipe.

The microseismic sounding method was successfully tested on a number of tubes of the kimberlite pipes (Gorbatikov *et al.,* 2009; Popov *et al.,* 2014)

Microseisms were measured along the profile that crosses the northern block of the pipe Chervinskaya. The central part of the profile of (MSM) coincided with the route of radon emanation survey (Figure 2). Microseisms were measured by the seismic equipment of production Guralp (Great Britain).

Records of microseisms were processed in a complex DAK program (*Popov et al. 2014*).

Results and discussion

Gamma-spectrometric studies

Figure 2 shows the map of total gamma-ray distribution of near surface layer above Chidvinskaya pipe. The total radioactivity of rocks varies widely from 172 to 1585 Bq m^{-3}. The distribution of high gamma-field has a slightly wide configuration than the pipe contour. The most contrast and the biggest area of increased gamma-ray values is confined to the northern part of the pipe and localized within the north pole, where thickness overburden of quaternary sediments is minimal and is about 1.5 m. Value of total radioactivity reached 1500 Bq m^{-3}.

Spatial distribution of high values of total gamma-ray radiation of near surface layer above Chidvinskaya pipe forms a linear anomaly of northeast trending which goes beyond contour of the pipe. Average values of radioactivity are about 800-900 Bq m^{-3} outside this area.

Concentration of thorium in Chidvinskaya pipe area varies within 0.5 - 14.0 µg/g. The maximum values of thorium are localized at small areas and are arranged substantially within the contour of the pipe. The potassium content ranges from 0.3 to less than 3.8%. The spatial distribution picture of potassium content in general is identical to the index of total gamma-ray radiation and forms an area of high values within pipe contour, especially in the northern part of the pipe where thickness overburden of quaternary sediments is minimal. Uranium concentration ranges from less than 0.4 to 4.6 µg/g. Distribution picture of uranium isn't unambiguous. Explicit spatial confinement to the contour of the pipe wasn't observed.

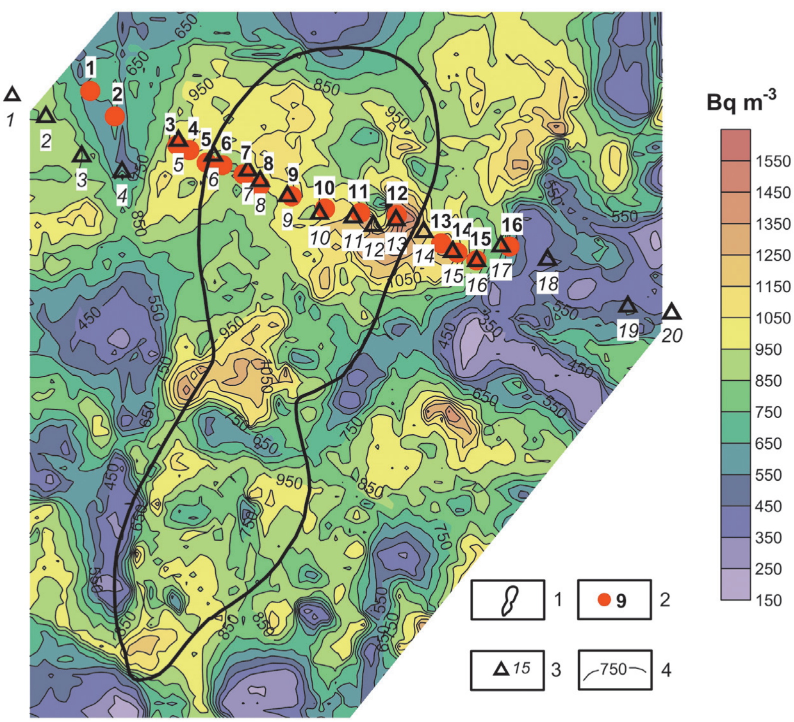

Figure 2. Distribution of total gamma-ray radiation above Chidvinskaya pipe.
1.- Chidvinskaya pipe contour; 2.- point measurement of radon emanation in the soil air; 3.– MSM measuring points; 4.- contour lines of gamma-ray radiation intensity.

In general, it can be noted that Chidvinskaya pipe have increased values of gamma radiation, as well as potassium. Distribution of thorium and uranium concentration doesn't have areal disposition that apparently is a consequence of erosional feature of top bench craterial facies Chidvinskaya pipe.

Radon emanation results

Traverse of radon method included 16 observation points. Points of observation are shown in Fig. 2. The results are shown in Table 1.

Radon radioactivity in the soil air ranges from 114 to 1312 Bq/m^3 on the profile that crosses the north pole of Chidvinskaya pipe. Variation of values radon emanation are insignificant within the contour of the pipe from 185 to 312 Bq/m^3. Anomalous increase of radon concentrations was observed at the boundaries of Chidvinskaya pipe.

Maxima of radon radioactivity in soil air were obsewrved at the north-western and south-eastern borders of the profile, 1156 Bq/m^3 and 1312 Bq/m^3, respectively. ^{222}Rn radioactivity falls sharply and decreases to a minimum beyond the boundaries of the pipe.

Revealed regularities of radon changes on the profile can be elucidated by the fact that the contacts of kimberlite pipe with the enclosing rocks are fractured faults zones with high permeability.

Microseismic sounding results

The results of MSM are shown in Figure 3 were the high-velocity tube body is allocated at observation points 6 - 15. The border dividing the western and eastern blocks of a pipe has an inclination of about 45 degrees at depths up to 400 m. Deeper than 400 m all borders remain almost vertical. Eastern block is traced up to the depths more than 1000 m despite the small sizes in deep part of a section. The pipe differ from environment in 2-7 dB by relative microseism intensity. The western and east blocks of pipe differ from each over about 2-5 dB by relative microseism intensity. According to (Gorbatikov & Tsukhanov 2011) these relative microseism intensity changes correspond to velocity properties changes in 1.5-2 times and 1.2-1.5 times.

The allocated pipe is limited by contrast linear, vertical low-velocity zones from the West and the East. These zones are likely caused by faults in endocontact rock. These faults are traced at the depths of 200-1000 m under points 5 from the West and 15-16 from the East. Also, the vertical low-velocity zones can be traced for 300-400 m off pipe to the west and east.

Table 1. Radioactivity ^{222}Rn in soil air above Chidvinskaya pipe.

Number of measuring points	Coordinates of measuring points N	E	Radioactivity ^{222}Rn, Bq/m^3 (± absolute error)
1	64.95030	41.11813	114±20
2	64.94983	41.11915	682±115
3	64.94927	41.12177	1156±184
4	64.94917	41.12228	545±98
5	64.94893	41.12300	238±49
6	64.94888	41.12367	195±42
7	64.94870	41.12455	185±42
8	64.94848	41.12522	248±52
9	64.94827	41.12657	300±57
10	64.94803	41.12798	312±58
11	64.94793	41.12948	201±42
12	64.94787	41.13103	254±53
13	64.94733	41.13288	254±53
14	64.94715	41.13357	857±145
15	64.94700	41.13437	1312±209
16	64.94723	41.13580	212±44

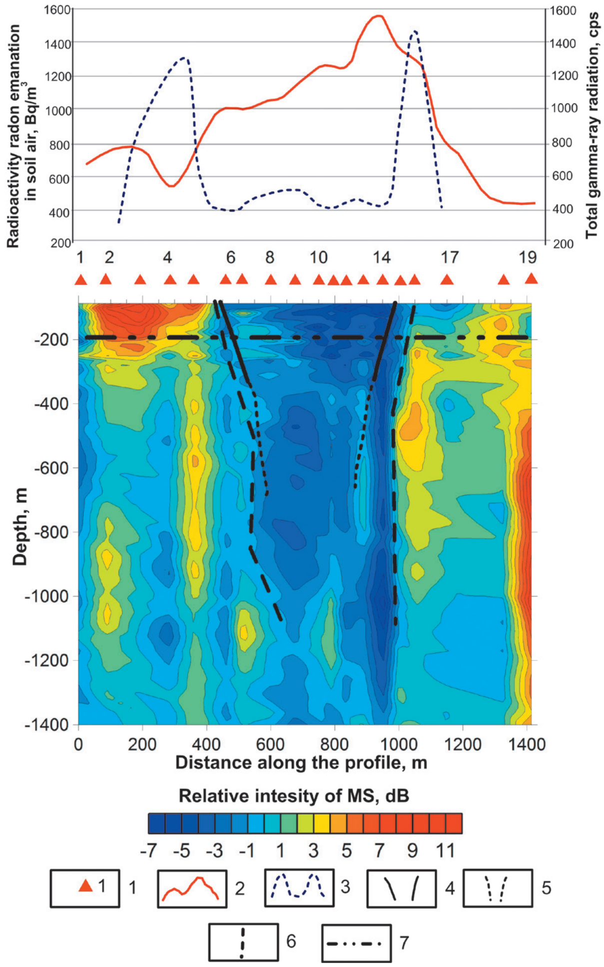

Figure 3. The depth section of relative intensity distributions of microseisms and radiometric parameters along the profile crossing Chidvinskaya pipe. 1.- point measurements of MS; 2.- curve of change the total intensity of the gamma-ray radiation, Bq m^{-3}; 3.- curve of change of radon emanation in soil air, Bq/m^3; 4.- Chidvinskaya pipe border for geological exploration data; 5.- proposed structure of diatreme facies; 6.- side pipe body according to MSM; 7.- border Padun and Mezen suites of Vendian.

In near-surface area the most contrast low-velocity body is observed under points 2-5 at depths from 40 to 200 m and has a cone-shaped structure. According to (Gorbatikov & Tsukhanov 2011). this contrast approximately correspond to velocity decreasing of 2-3 times. Also vertical low-speed zones are traced on removal from a pipe body on 300-400 m to the West and the East.

The changes in the configuration consistent with the changes in the intensity of the allocated zones allow to place the layer in the crust at about 200 m depth, and corresponds to boundary of Padun and Mezen suites of the top of Vend.

When comparing the results we observe an increase of the total gamma gamma-ray radiation consistent with MSM, that corresponds to a high-velocity anomaly. Intensity of gamma radiation on the high-speed anomaly is greater than 2-4 times for background values of enclosing rocks. At the same time, there is a decrease of total gamma radiation from western to eastern blocks of the pipe body. Such a significant change of the gamma radiation level and high-speed characteristics may indicate different material composition of the Western and Eastern pipe blocs. This difference can indicate either different implementation phases, or that data block was subjected to various (physical, metamorphic, erosive) processes after the formation of the tube.

Anomalous radon concentrations at the boundaries of Chidvinskaya pipe are appropriate contrasting linear low-velocity zones. As a dedicated fault structures, there is a possible influx of radon and other gases. High-velocity nature of the pipe body indicates a consolidated structure and a minimum influx of ^{222}Rn. High velocity nature of the pipe body can be explained by the sharply different composition of the pipe and enclosing medium.

The proposed set of methods can be used in further studies, since the methods showed a good convergence of results.

Conclusions

The results of the radiometric and seismic studies including high-precision gamma-spectrometric survey, radon emanation survey in soil air and microseismic sounding method in the area of Chidvinskaya pipe of the Chidvinsko-Izhmozerskoe kimberlite field ADP are as follows:

1. The method of surface gamma-ray spectrometric survey showed that Chidvinskaya pipe against the backdrop of the deposits are allocated increased values of gamma-field, as well as potassium, especially in the northern part with minimum thickness overburden quaternary sediments.

2. Anomalous radon has fixed on lips of the pipe. Probably, it is linked with excessive fissuring of host sediments which appear in the form of contrasting high-velocity zones on MSM data.

3. The method of MSM was conducted clarifying the deep structure of the pipe and enclosing environment. Chidvinskaya pipe manifests as a high- velocity body.

4. The consistency of the results with each other and with the known geological and geophysical information indicates the validity of the data.

References

Abumurad K., Al-Tamimi M., 2001, Emanation power of radon and its concentration in soil and rocks. *Radiat. Meas.*, 34, 423–426.

Babayants P.S., Kertsman V.M., Levin F.D., Trusov A.A., 2015, Special features of the state-of-the-art airborne gamma-spectrometry. *Prospect of mineral resources*, 12, 10-15.

Bath M., 1979, Spectral Analysis in Geophysics, *Elsevier Scientific Publ. Co., Amsterdam, Oxford, New York*, 539.

Bezborodov S.M., Verzhak V.V., Gerasimchuck A.V., 2003, Diamond exploration and mining in north-west of Russia: 4th Fennoscandian exploration and mining. Final Program and Event Document. - Rovaniemi, 279-304.

Bossew P., 2003, The radon emanation power of building materials, soils and rocks. *Appl. Radiat. Isot.*, 59, 389–392.

Eremenko A.V., 2004, Osobennosti sostava khromshpinelidov trubok vzryva Izhmozjorskogo polya Arhangel'skoj almazonosnoj provintsyi kak otrazhenie geodinamiki ikh formirovaniya // *Vestnik Voronezhskogo universiteta, Geologiya*, 1, 84-92.

Gorbatikov A.V., Stepanova M.J., 2008, Statistical characteristics and stationarity properties of low-frequency seismic signals. Izvestiya, *Physics of the Solid Earth,* 1, 50-59. DOI: 10.1007/s11486-008-1007-0.

Gorbatikov A.V., Tsukanov A.A., 2011, Simulation of the Rayleigh waves in the proximity of the scattering velocity inhomogeneities. Exploring the capabilities of the microseismic sounding method. *Izvestiya, Physics of the Earth,* 4, 354-369. DOI: 10.1134/S1069351311030013

Gorbatikov A.V., Larin N.V., Moiseev E.I., Belyashov A.V., 2009, The microseismic sounding method: Application for the study of the buried diatreme structure. *Doklady Earth Sciences,* 1, 1222-1226. DOI: 10.1134/S1028334X0907040X.

Gorbatikov A.V., Montesinos F.G., Arnoso J., Stepanova M.Yu, Benavent M., Tsukanov A.A., 2013, New Features in the Subsurface Structure Model of El Hierro Island (Canaries) from Low-Frequency Microseismic Sounding: An Insight into the 2011 Seismo-Volcanic Crisis. *Surveys in Geophysics,* 34, 463–489. DOI: 10.1007/s10712-013-9240-4.

IAEA-TECDOC-1363. Guidelines for Radioelement Mapping Using Gamma Ray Spectrometry Data, Vienna: 2003.

Kikaja D., Jeranb Z., Bahtijaric M., Stegnara P., 2016, Radon in soil gas in Kosovo. *Journal of Environmental Radioactivity*, 164, 245–252.

Killeen P.G., Mwenifumbo C.J., Ford K.L., 2015, Tools and Techniques: Radiometric Methods. *Treatise on Geophysics (Second Edition)*, 11, 447–524.

King Chi-Yu, 1980, Episodic radon changes in subsurface soil gas along active faults and possible relation to earthquakes*. J. of Geophys. Res.*, 6, 3065–3078.

Kontarovich R.S., Babayants, P.S., 2011, Problems of modern advanced geophysical support for prediction and exploration operations. *Prospect of mineral resources.* 7, 18-22.

Lin F.C., Tsai V.C., Ritzwoller M.H., 2012, The local amplification of surface waves: A new observable to constrain elastic velocities, density, and anelastic attenuation, *J. Geophys. Res*., 117, B06302, doi:10.1029/2012JB009208.

Mwenifumbo C.J., Kjarsgaard B.A., 1999, Gamma-ray logging and radioelement distribution in the Fort à la Corne kimberlite pipe 169. *Exploration and Mining Geology*, 8, 12, 137–147.

Popov D.V., Danilov K.D., Zhostkov R.A., Dudarov Z.I., Ivanova E.V., 2014, Processing the digital microseism recordings using the Data Analysis Kit (DAK) software package. Seismic Instruments, 50, 75-83. DOI: 10.3103/S074792391401006X.

Reed L.E., Witherly K.E., 2007, 50 Years of Kimberlite Geophysics, A Review.

Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration" edited by B. Milkereit. 679-689.

Rybalchenko A.Ya., Rybalchenko T.M., Silaev V.I., 2011, Theoretical basis for forecasting and exploration of primary diamonds deposits of tuffizit type. *Proceedings of the Komi Science Centre,* 1, 5*,* 54-66.

Stogniy V.V., Korotkov Yu.V., 2010, The Search of the Kimberlite Bodies by Transients. *Malotirazhnaya tipografiya 2D, Novosibirsk*, 121.

Tsyganov V.A., Kontarovich R.S., Mogilevskij V.E., Golubkov V.V., Kercman V.M., 2004, Sovremennye aérogeofizicheskie tehnologii – kak osnova geologicheskikh i prognozno-mineragenicheskikh kart novogo pokoleniya. In *Sbornik nauchnyh trudov «Kongress vypusknikov geologicheskogo fakul'teta MGU 26 maya 2004».* pp. 151-158. MGU, Moskva.

Yakovlev E.Y., Kiselev G.P., Druzhinin S.V., 2016, Non-equilibrium uranium in kimberlites and host rocks Pionerskaya pipe of the M.V. Lomonosov deposit. *Vestnik of Northern (Arctic) Federal University*, 1, 19-28.