Journal of Siberian Federal University. Biology 2019 12(2): 120-129
~ ~ ~

УДК 630.228.7:582.475.4(571.51)

Some Peculiarities of Foraminifera Species Distribution Associated with Concentrations of ^{226}Ra, ^{238}U, ^{232}Th in the Deryugin Basin (the Sea of Okhotsk)

Mikhail M. Domanov* and Tatyana A. Khusid
P.P. Shirshov Institute of Oceanology RAS
36 Nakhimovskiy, Moscow, 117997, Russia

Received 05.04.2016, received in revised form 23.06.2017, accepted 19.06.2018, published online 09.07.2018

An analysis of composition and quantitative distribution of foraminifera in bottom sediments collected in the Deryugin Basin (the Sea of Okhotsk) has demonstrated that specific foraminiferal assemblages at the depths of 691 to 1786 m are associated with distribution of natural radionuclides. A comparison of the percentage of Saccorhiza ramosa (Brady) as a dominant species in the community of benthic foraminifera and the concentrations of radionuclides in the sediments showed that the quantity of S. ramosa correlates with the concentrations of ^{238}U, ^{232}Th and ^{226}Ra in the sediments. The correlation coefficients for concentrations of ^{238}U, ^{232}Th and ^{226}Ra are 0.75, 0.83 and 0.86, respectively. Calcareous foraminifera abundance decreases with radioactivity growth and correlates with common radioactivity with the negative coefficient of -0.82.

Keywords: foraminifera, community of foraminifera, biocoenosis, radionuclides, ^{238}U, ^{232}Th, ^{226}Ra, sediment, abundance.

Citation: Domanov M.M., Khusid T.A. Some peculiarities of foraminifera species distribution associated with concentrations of ^{226}Ra, ^{238}U, ^{232}Th in the Deryugin Basin (the Sea of Okhotsk). J. Sib. Fed. Univ. Biol., 2019, 12(2), 120-129. DOI: 10.17516/1997-1389-0063.

* Corresponding author E-mail address: domanov@ocean.ru

Особенности распределения бентосных видов фораминифер и ^{226}Ra, ^{238}U, ^{232}Th в донных осадках впадины Дерюгина (Охотское море)

М.М. Доманов, Т.А. Хусид
Институт океанологии им. П.П. Ширшова РАН
Россия, 117997, Москва, пр. Нахимовский, 36

Анализ состава и количественного распределения фораминифер в донных осадках впадины Дерюгина (Охотское море) показал, что специфический комплекс фораминифер впадины Дерюгина на глубине от 691 до 1786 м связан с распределением природных радионуклидов. Сопоставление процентного содержания Saccorhiza ramosa (Brady), доминирующей в сообществе бентосных фораминифер, и концентрации радионуклидов в донных осадках показало, что количество фораминифер S. ramosa коррелирует с концентрацией в осадках ^{238}U, ^{232}Th и ^{226}Ra. Коэффициенты корреляции с концентрацией ^{238}U, ^{232}Th и ^{226}Ra равны 0,75, 0,83 и 0,86 соответственно. Обилие известковых фораминифер с ростом радиоактивности снижается и коррелирует с общей радиоактивностью с отрицательным коэффициентом –0,82.

Ключевые слова: фораминиферы, сообщество фораминифер, биоценоз, радионуклиды, ^{238}U, ^{232}Th, ^{226}Ra, морские осадки.

Introduction

Zones of increased natural radioactivity are of interest for research into evolutionary transformations in the history of the Earth biosphere (Odum, 1959; Neruchev, 1982). Benthic organisms living directly in the bottom sediments or on the sediment surface are mostly exposed to the influence of radiation from radionuclides concentrated in bottom sediments. Benthic organisms can accumulate radionuclides, which intensifies the effect of radiation. Xenophyophores, a group of protists of the benthic community, are able to concentrate naturally occurring radionuclides ^{238}U, ^{232}Th, ^{210}Po, ^{226}Ra, ^{210}Pb in the cytoplasm and the shell (Levin et al., 1986; Swinbanks, Shirayama, 1986; Lecrog et al., 2009). It was shown that concentrations of ^{226}Ra and ^{232}Th in these protists depend on the following: the species of the organism, the composition of the material utilized in agglutination, and the concentration of radionuclides in the environment (Domanov, 2015).

Swinbanks & Shirayama (1986) demonstrated that high levels of natural radiation occur in xenophyophores, as a result of presence of ^{226}Ra in intracellular barite crystals, and suggested that this radiation would induce numerous genetic mutations. Multidirectional influence of radioactivity on biodiversity and abundance of meiobenthos (particularly in the community of foraminifera) was noted in the Kara Sea (Alexeev, Galtsova, 2012). Thus, to assess the impact of various factors on functioning of benthic foraminiferal communities, radionuclides are to be taken into account.

One of the areas with high natural radioactivity of bottom sediments is the Deryugin Basin in the Sea of Okhotsk. The concentrations of ^{238}U, ^{232}Th are 2-3 times higher and ^{226}Ra concentration is 10-25 times higher in the central part of the Deryugin Basin than in the periphery (Domanov, 2009).

In this area, a particular community of benthos foraminifera with a small amount of species and a predominance of agglutinated foraminifera was discovered (Khusid et al., 2006, 2013).

The research was aimed to study a correlation between distribution of benthic foraminifera and radionuclides ^{238}U, ^{232}Th, and ^{226}Ra in the Deryugin Basin in order to identify a connection of dominant foraminifera species with the distribution of natural radionuclides in bottom sediments.

Materials and methods

The Deryugin Basin (Fig. 1) is bounded in the west by the northern Sakhalin continental slope and in the north by the Staretsky Trough and the Kashevarov Bank of the North Okhotsk margin.

The structure and composition of benthic foraminiferal communities from the Deryugin Basin were analyzed in 11 samples taken with the bottom grab "Okean" at the depths of 691 to 1786 m from the surface 0-2 cm sediment layer. Samples were collected during the 50th and 51st cruises of the R/V Professor Khromov. The location of the stations, their depths, and sediment description are given in Table 1. The majority of samples were collected in the deepest part of the Deryugin Basin at a small range of depths (from 1420 to 1786 m) (Fig. 2) and only one sample (St. 51-23) was taken at the southern edge of the basin, from the depth of 691 m.

Sediment samples (40–60 g) were washed and passed through a 0.05 mm mesh size sieve. Taxonomical identification of foraminifera was based on the accepted classification (Loeblich and Tappan, 1964, 1986, 1987). The planktonic and benthic foraminifers were studied under a Leica WILD M3C light microscope at x100 magnification. The taxonomic composition,

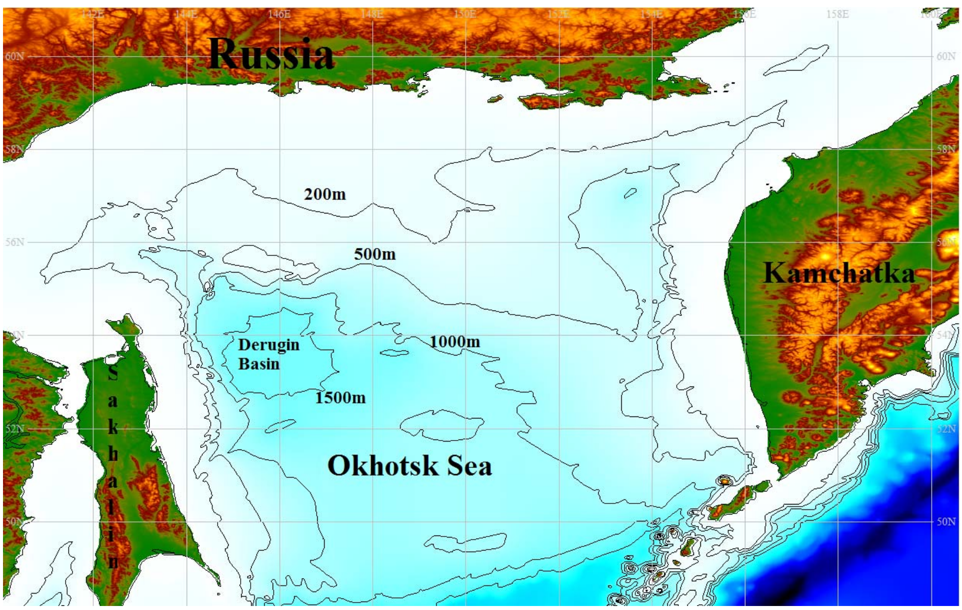

Fig. 1. Location of the study area

Table 1. Description of the bottom sediments and position of the stations in Deryugin Basin

Station	Latitude, N	Longitude, E	Depth, m	Comment
50-29	53°57.818	144°58.266	1420	Diatom sediment with sand inclusions
50-36	53°54.547	145°54.214	1650	Sediment with sand inclusions deep-brown, oxidated
50-37	53°30.936	146°05.599	1750	Diatom sediment with sand inclusions deep-brown, oxidated
50-38	53°18.158	146°33.756	1733	Sediment with sand inclusions, pelite
50-39	53°00.204	146 °04.462	1736	Diatom silt with path of sediment feeding
51-17	53°00.264	146 °24.356	1749	Sediment pelite deep-brown, oxidated
51-19	53°14.982	146 °06.600	1786	Sediment pelite deep-brown to black, oxidated
51-20	53°14.782	145°42.265	1731	Sediment with sand inclusions, pelite light gray, olive-green
51-21	53°30.928	146°05.658	1783	Sediment pelite deep-brown to black, oxidated
51-22	54°54.645	145°54.131	1648	Sediment pelite deep-brown to black, oxidated
51-23	52°30.001	144°49.995	691	Pelitic diatom ooze, greenish brown

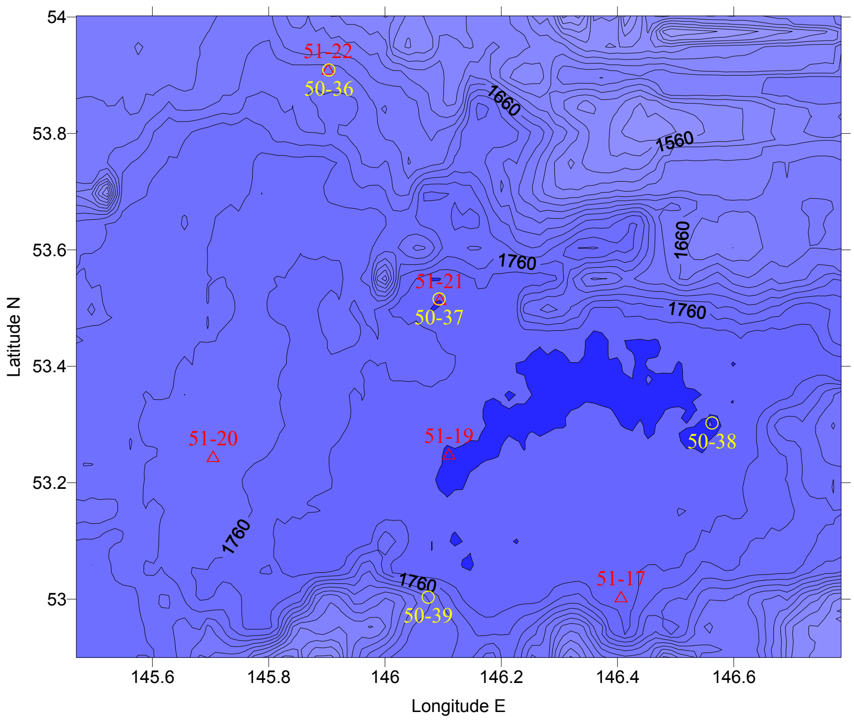

Fig. 2. Position of the stations in the deepest part of the Deryugin Basin

proportion of all foraminiferal species, and their total abundance (individuals per g dry sediment) were determined in each sample. The radioactivity analysis was performed in the Laboratory of Dosimetry and Environmental Radioactivity of the Chemistry Department of Moscow State University. The radioactivity of natural radionuclides (^{238}U, ^{232}Th and ^{226}Ra) in bottom sediments was measured on a gamma-spectrometer with a super pure germanium GC-3020 detector with a relative efficiency of 30% (Co-60 line – 1.332 Me) and a resolution of 1.8 Kev. The software GENIE-400 PC was used. The accuracy of measurements for Ra, Th and U was 5-7%, 10-15% and 15-20% respectively.

Results

The bottom sediments from 1420 to 1786 m were represented by dark brown pelitic diatom silt. The sample from the depth of 691 m had an olive-brown colour and contained more diatoms (Table 1).

The abundance and species composition of benthic foraminiferal communities and the concentration of radionuclides in sediments are shown in Table 2. The composition of foraminiferal assemblages varied significantly. In most of the samples the abundance varied from 9 to 25 individuals per g, and the number of species was from 7-8 to 17. The sample from the depth of 691 m was characterized by the highest abundance 35 individuals per g and the highest number of species 30. The lowest number of species (7) and the lowest abundance of foraminifera (9–11 individuals/g) was observed in the samples from stations 36 and 17 located in the central part of the basin at the depths of 1650 and 1749 m, respectively.

The ratio of the main species is presented in Fig. 3. At all studied stations, except 51-23 (691 m), the fauna was generally represented by agglutinated species. *Saccorhiza ramosa* (Brady) was a dominant species making 47-92% of the total quantity of foraminifera. The largest percentage of *S. ramosa* (76-92%) was observed in the samples with the lowest number of species. In addition to *S. ramosa*, a significant number of representatives of other agglutinated species (*Cyclammina cancellata*, *C. bradyi*, *Recurvoides contortus*) were found.

Foraminiferal assemblages in some samples were characterized by clear dominance (82-99%) of agglutinated fauna. In other samples from central and peripheral parts of the basin the share of *S. ramosa* was much smaller (i.e. did not exceed 47-67%) and this species made only 5% at the depth of 691 m (Table 2). The shells of *S. ramosa* were composed of sand grains of different size glued with low quantities of secreted calcareous cement (Fig. 4).

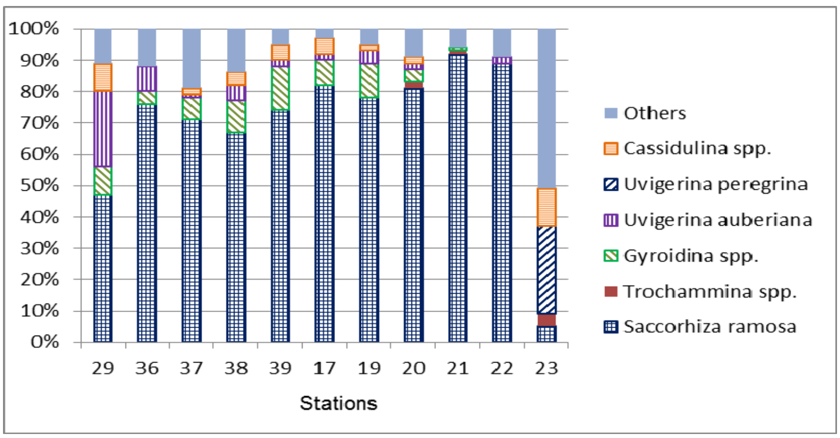

Fig. 3. Species composition of the foraminiferal assemblages (others: *Cyclammina cancellata* Brady, *C. brady* Cushman, *Recurvoides contortus* Earland, *Globobulimina auriculata* (Bailey), *Alabaminella weddellensis* (Earland), *Valvulineria sadonica* Asano, *Nonionella labradorica* (Dawson), *Elphidium* sp.)

Table 2. Abundance and species composition of benthic foraminifera community and concentration of the natural radionuclides in sediments.

Station no.	Station depth, m	Abundance, ind./g	Number of species	Agglutinated foraminifera, % of total abundance		Calcareous foraminifera	Concentration of radionuclides in sediments, Bq/kg		
				S. ramosa	Other agglutinated		^{232}Th	^{238}U	^{226}Ra
29	1420	14	17	47	4	49	11.90	35.30	603.10
36	1650	9	7	76	12	12	13.70	89.30	910.20
37	1750	16	14	71	19	10	14.80	64.10	884.30
38	1733	21	13	67	13	20	14.00	5.40	1069.30
39	1736	10	12	74	2	24	16.50	94.70	880.60
17	1749	11	7	82	0	18	17.50	133.00	1417.10
19	1786	16	14	78	2	20	21.10	92.30	1047.10
20	1731	23	16	81	9	10	23.90	111.60	1439.30
21	1783	25	8	92	7	1	20.80	152.80	2057.20
22	1648	12	8	89	7	4	19.90	122.80	1639.10
23	691	35	30	5	7	88	23.50	77.60	139.50

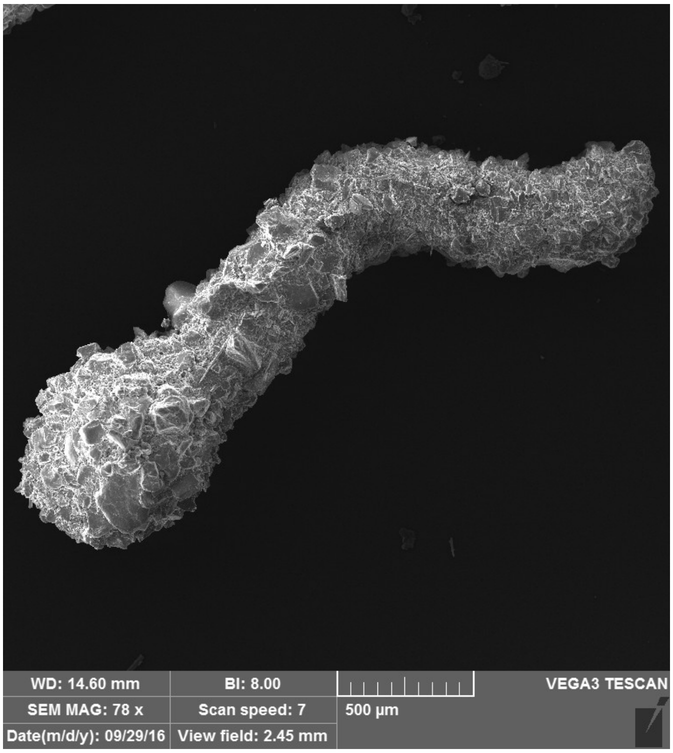

Fig. 4. Agglutinated foraminifera *Saccorhiza ramosa* (Brady)

Among calcareous species, *Uvigerina auberiana* d'Orbigny (Fig. 5) and *Gyroidina orbicularis* d'Orbigny were the most common in the associations of the basin; these species are known as ubiquitous (able to exist in very different environmental conditions).

Calcareous species including *Uvigerina peregrina* Cushman and *Cassidulina* spp. predominated in the assemblages from the upper Sakhalin slope (station 51-23) (Fig. 3). The species *U. peregrina* is considered to be an indicator of highly productive regions but it was missing from the Deryugin Basin.

Common radioactivity of key elements in uranium-thorium families (^{238}U, ^{232}Th and ^{226}Ra) in the bottom sediments of the Deryugin Basin varied from 650 to 2231 Bq/kg. Major contribution to radioactivity was made by ^{226}Ra (89-93%) (Table 2). A comparison of the percentage of *S. ramosa* in the community of benthic foraminifera and concentration of radionuclides in the sediments showed that the quantity of *S. ramosa* correlated with the concentration of ^{238}U, ^{232}Th and ^{226}Ra in the sediments. The correlation coefficients for ^{232}Th, ^{238}U, and ^{226}Ra concentration were equal to 0.75, 0.83 and 0.86, respectively (Table 3).

Discussion

With the increase of common radioactivity in the sediments, the percentage of *S. ramosa* in the community increased from 47 to 92%. The correlation coefficient was equal to 0.84 (Table 3). The abundance of calcareous foraminifera with the growth of common radioactivity decreased and had a negative correlation coefficient of -0.82. Thus, radionuclides ^{238}U, ^{232}Th and ^{226}Ra may have a depressing effect on calcareous foraminifera. Radioactivity of natural radionuclides has an impact on the functioning

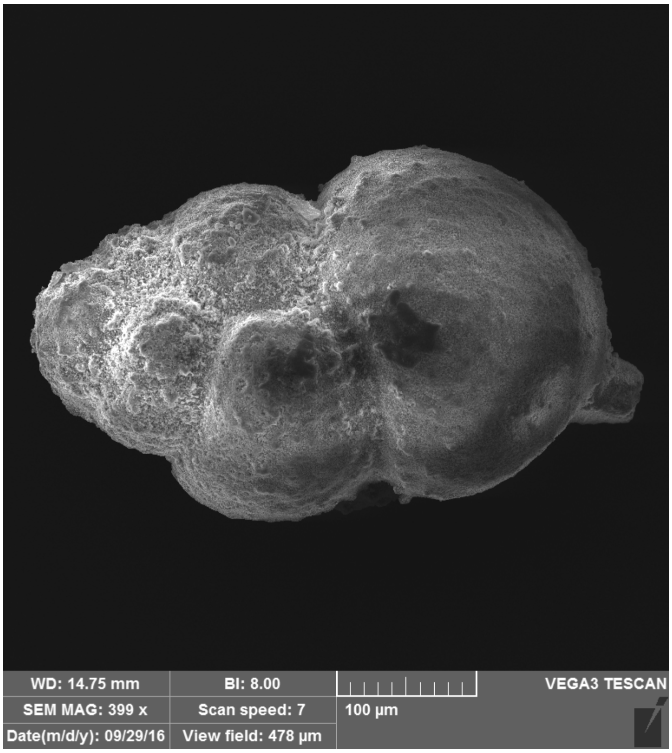

Fig. 5. Calcareous foraminifera *Uvigerina auberiana* d'Orbigny

Table 3. Correlation matrix for benthic foraminifers (% of total abundance) and concentration of natural radionuclides in sediments (Bq/kg) (correlation is significant at $p< 0.05$)

	^{232}Th	^{238}U	^{226}Ra	Common radioactivity
S. ramosa	0.75	0.83	0.86	0.84
Calcareous	-	-	-0.84	-0.82

- not identified

of the benthic community. Both the positive effect (radiation hormesis) (Kuzin, 1991), and the depressing effect depend on the internal factors of an organism (age, state of cells, resistance of an organism). These vary in different species of the benthic community (in this case in foraminifera species). Stimulation of development of *S. ramosa* may be more pronounced than a negative effect of radiation on it, which may lead to domination of this species.

A stimulating influence of radioactive ^{226}Ra contained in natural sea barite on the development of heterotrophic bacteria from the Barents Sea was described in the previous paper (Domanov et al., 2015). Earlier, multidirectional influence of artificial radioactivity on biodiversity and abundance of meiobenthos in the Russian Arctic shelf was noted in the paper by Alexeev and Galtsova (2012). However, for a number of meiobenthic organisms, the effect of radioactivity changed from positive to negative. The taxonomic diversity of meiobenthic communities increased and the population density decreased with the growth of concentration of ^{137}Cs. It was suggested that meiobenthic communities can react very quickly to deterioration of environmental radioactivity by changing their taxonomic composition and quantitative characteristics (Galtsova et al., 2004).

Radionuclide concentration in organisms can vary depending on the species, their feeding habits, physiological processes, body size and seasonal changes (Alam, Mohamed, 2011).

The way of feeding may also be a factor which determines the correlation between *S. ramosa* abundance and radioactivity. *S. ramosa* feeds on detritus in the surface sediment layer and in comparison with the species feeding on seston is more subjected to the influence of both external and internal radiation.

Conclusion

A correlation analysis between the percentage of *S. ramosa* in the community of benthic foraminifera and the concentrations of radionuclides in sediments showed that domination of *S. ramosa* in the community increases with the increase of ^{238}U, ^{232}Th and ^{226}Ra concentration and common radioactivity in sediments. The coefficients of correlation for ^{238}U, ^{232}Th and ^{226}Ra equal 0.75, 0.83 and 0.86, respectively. It may be a result of the influence of raised radioactivity on a natural benthic foraminiferal community and is connected with the structural reorganization of community dominants in which *S. ramosa* is probably the most resistant species. The revealed changes in the structure of benthic foraminifera may also be caused by other factors. Thus, it is necessary to examine if the radioactivity is the dominating factor or these changes are the summative result of a number of causes. Such study is a part of a multi-stressor approach which helps to improve our understanding of the influence of the environment on the fauna.

References

Alam L., Mohamed C.A.R. (2011) A mini review on bioaccumulation of ^{210}Po by marine organisms. *International Food Research Journal*, 18: 1-10

Alexeev D.K., Galtsova V.V. (2012) Effect of radioactive pollution on the biodiversity of marine benthic ecosystems of the Russian Arctic shelf. *Polar Science*, 6: 183-195

Domanov M.M. (2009) Speciation of ^{226}Ra in seabed sediments formed in hydrothermal cold fluid zones (Deryugin Deep, Sea of Okhotsk). *Radiochemistry*, 51(1): 85-90

Domanov M.M. (2015) Natural ^{226}Ra and ^{232}Th radionuclides in xenophyophores of the Pacific Ocean. *Geochemistry International*, 53(7): 664-669

Domanov M.M., Moskvina M.I., Ilinskiy V.V. (2015) Development of populations of marine heterotrophic bacteria irradiated with 226Ra contained in natural barite. *Proceedings of the International Scientific Conference "Radiobiology: "Mayak", Chernobyl, Fukushima" (Gomel, September 24–25, 2015)*. Gomel, Institute of Radiology, p. 76-80 (in Russian)

Galtsova V.V., Kulangieva L.V., Pogrebov V.B. (2004) Meiobenthos of the former nuclear test area and nuclear waste disposal grounds around the Novaya Zemlya Archipelago (Barents and Kara Seas). *Russian Journal of Marine Biology*, 30 (4): 231-240

Khusid T.A., Belyaeva N.V., Demina L.L., Domanov M.M., Chekhovskaya M.P. (2013) Changes of planktonic and benthic foraminiferal assemblages in upper quaternaru sediments of the Deryugin Basin, Sea of Okhotsk. *Stratigraphy and Geological Correlation*, 21(2): 237-248

Khusid T.A., Domanov M.M., Svininnikov A.M. (2006) Species composition and distribution of foraminifers in the Deryugin Basin (Sea of Okhotsk). *Biology Bulletin*, 33(2): 172-178

Kuzin A.M. (1991) *Natural radioactive background and its significance for Earth's Biosphere*. Moscow, Nauka, 116 p. (in Russian)

Levin L.A., DeMaster D.J., McCann L.D., Thomas C.L. (1986) Effects of giant protozoans (class: Xenophyophorea) on deep-seamount benthos. *Marine Ecology Progress Series*, 29: 99–104

Lecroq B., Gooday A.J., Tsuchiya M., Pawlowski J. (2009) A new genus of xenophyophores (Foraminifera) from Japan Trench: morphological description, molecular phylogeny and elemental analysis. *Zoological Journal of the Linnean Society*, 156: 455-464

Loeblich A.R., Tappan H. (1964) *Sarcodina, chiefly "Thecamoebians" and Foraminiferida. Treatise on invertebrate paleontology. Part C. Protista 2 (2 volumes).* Moore R.C. (ed.) University of Kansas Press, 900 p.

Loeblich A.R., Tappan H. (1986) Some new and revised genera and families of hyaline calcareous Foraminiferida (Protozoa). *Transactions of the American Microscopical Society*, 105: 239-265

Loeblich A.R., Tappan H. (1987) *Foraminiferal genera and their classification*. New York, Van Nostrand Rienhold Co., 970 p.

Neruchev S.G. (1982) *Uranium and life in Earth's history*. Leningrad, Nauka Press, 208 p. (in Russian)

Odum E.P. (1959) *Fundamentals of Ecology. 2nd Edition*. Philadelphia, W.B. Saunders, 384 p.

Swinbanks D.D., Shirayama Y. (1986) High levels of natural radionuclides in a deep-sea infaunal xenophyophore. *Nature*, 320: 354–358