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

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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 $^{238}\text{U}$, $^{232}\text{Th}$ and $^{226}\text{Ra}$ in the sediments. The correlation coefficients for concentrations of $^{238}\text{U}$, $^{232}\text{Th}$ and $^{226}\text{Ra}$ 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, $^{238}\text{U}$, $^{232}\text{Th}$, $^{226}\text{Ra}$, sediment, abundance.

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Особенности распределения бентосных видов фораминифер и 226Ра, 238У, 232Th в донных осадках впадины Дерюгина (Охотское море)

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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 238У, 232Th и 226Ra. Коэффициенты корреляции с концентрацией 238У, 232Th и 226Ra 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, 238У, 232Th, 226Ra, 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 238U, 232Th, 210Po, 226Ra, 210Pb in the cytoplasm and the shell (Levin et al., 1986; Swinbanks, Shirayama, 1986; Lecrog et al., 2009). It was shown that concentrations of 226Ra and 232Th 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 226Ra 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 foraminifers) 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 $^{238}\text{U}$, $^{232}\text{Th}$ are 2-3 times higher and $^{226}\text{Ra}$ 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 $^{238}\text{U}$, $^{232}\text{Th}$, and $^{226}\text{Ra}$ 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,
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).
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 | S. ramosa | Other agglutinated | S. ramosa | Concentration of radionuclides in sediments, Bq/kg |
|-------------|------------------|-------------------|------------------|-----------------------------------------------|---------|-------------------|---------|-----------------------------------------------|
|             |                  |                   |                  |                                               |         |                   |         | 232Th | 238U | 226Ra |
| 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                | 19      | 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 |
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...
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 $S. \text{ ramosa}$ abundance and radioactivity. $S. \text{ ramosa}$ 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 $S. \text{ ramosa}$ in the community of benthic foraminifera and the concentrations of radionuclides in sediments showed that domination of $S. \text{ ramosa}$ in the community increases with the increase of $^{238}\text{U}$, $^{232}\text{Th}$ and $^{226}\text{Ra}$ concentration and common radioactivity in sediments. The coefficients of correlation for $^{238}\text{U}$, $^{232}\text{Th}$ and $^{226}\text{Ra}$ 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 $S. \text{ ramosa}$ 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.

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