ISSN 0145-8752, Moscow University Geology Bulletin, 2020, Vol. 75, No. 1, pp. 31–39.

"Conodont Pearls" from the Devonian Deposits of European Russia

V. M. Nazarova[a], * and Yu. A. Gatovsky[a], **

[a]*Department of Geology, Moscow State University, Moscow, 119234 Russia*
**e-mail: VM516@yandex.ru*
***e-mail: ustas62@bk.ru*

Received April 15, 2019; revised April 25, 2019; accepted April 25, 2019

Abstract—The study history and hypotheses of origin of unique phosphate microfossils, that is, "conodont pearls," are considered in the present paper. The material comes from the Middle and Upper Devonian deposits of the European Russia. The analysis of the chemical composition of these unique objects has shown their great similarity with other phosphate microfossils that belong to conodonts and types of fish that inhabit the same paleobasins. Based on their morphological features and chemical composition one can suggest that "conodont pearls" are the otoliths of conodonts.

Keywords: conodonts, "conodont pearls", otoliths, Devonian, European part of Russia

DOI: 10.3103/S014587522001010X

INTRODUCTION

"Conodont pearls" are microscopic phosphate spherules, which vary in color from yellowish and almost colorless to brown and black and in transparency from almost fully-transparent light varieties to absolutely opaque dark ones. On the surface of each sphere is a small hollow (basal dimple). Concentrically-arranged growth lines, which are similar to those in conodont elements, are visible in transmitted light. "Conodont pearls" occur together with conodonts in the same samples, but extremely rarely. In the history of the study of conodonts, findings of "conodont pearls" were mentioned in only approximately 20 works. The present paper is devoted to the analysis of these works and the consideration of the existing hypotheses on the origin of these phosphate spherules.

HISTORY OF STUDY AND INTERPRETATIONS

"Conodont pearls" were first described together with conodont taxa by C.R. Stauffer [1935] from the Ordovician deposits in Minnesota (United States) under the name of "egg cases (?)": "These little spherical bodies are composed of the same material as the teeth. They have no special characteristics except a circular or elliptical opening on one side. At one locality they were quite common and seemed of sufficient importance to illustrate. It is rather hesitatingly suggested that they may be egg cases, but there is no real substantiating evidence." Judging by the published images, these were opaque spherules. Later, Stauffer (1940) described "conodont pearls" from the Devonian deposits in Minnesota. The described spherules were transparent with visible growth lines. Although, Stauffer again called them "egg shells" he pointed out that "the exact nature of these bodies or their possible significance is still unknown, but their general appearance, composition, and occurrence with the conodonts suggests that may belong to these animals" (Stauffer, 1940, p. 434).

Later, "conodont pearls" were found mainly in the Devonian deposits (Bischoff, 1973; Clarkson, 1980; Glenister et al., 1976; Giles et al., 2002; Huang and Gong, 2014; Kemp, 2002; Levman, 2001; Leuteritz et al., 1972; Nazarova, 2013; Nazarova and Kononova, 2016; Nazarova et al., 2016; Wang and Chatterton, 1993; Youngquist and Miller, 1948), rarely Ordovician (Kemp, 2002) and Silurian (Glenister at al., 1976) deposits. Moreover, there are references to "conodont pearls" from the Lower Carboniferous deposits (Dumoulin et al., 2006; Krumhardt, 1994): in the former the age of these objects are in question, while in the latter doubts were expressed as to whether the spherules are "conodont pearls". There are no images and descriptions in these works.

As a result, it was established that there is no dependence between the presence of "conodont pearls" and the lithological features of a sample (Glenister et al., 1976; Levman, 2001), while these spherules always occur in association with conodont elements (Glenister et al., 1976; Huang and Gong, 2014; Levman, 2001; Nazarova, 2013; Nazarova and Kononova, 2016; Stauffer, 1935, 1940; Youngquist and Miller, 1948). The number of "conodont pearls" is directly proportional to a number of conodont elements, which are always more abundant (Youngquist and Miller, 1948). Chemical analysis has revealed the

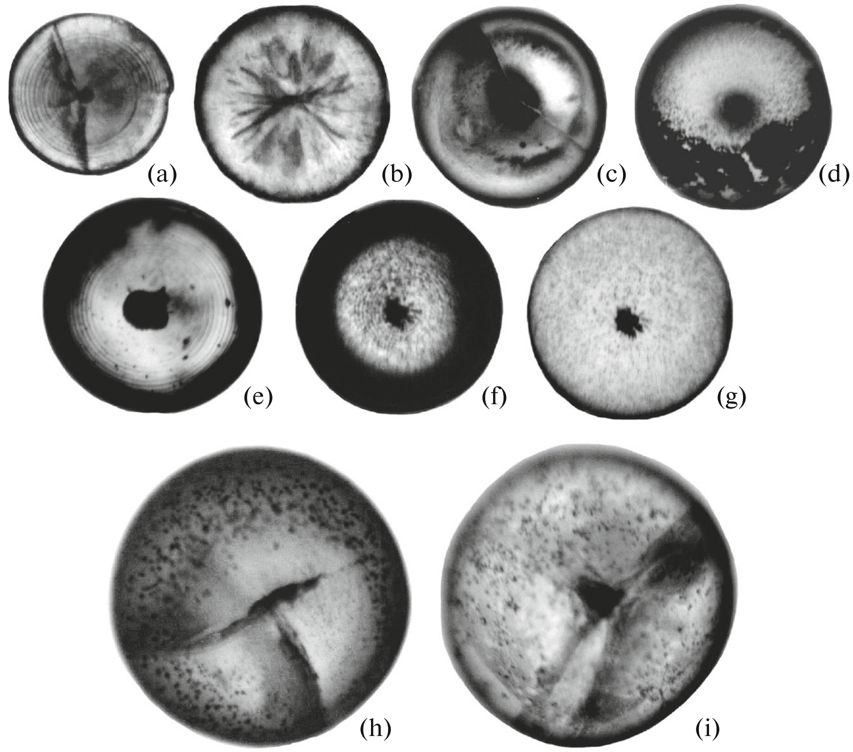

Fig. 1. The structural elements of the "conodont pearls" visible under the transmitted light microscope; In all cases magnification 140 x. a, growth lines and radial fractures, spec. 364/9, Frasnian Stage, Mendymian regional stage, Bashkiria, outcrop on the Sikaza R., sample 2-6; b, secondary alterations along radial fractures, spec. 364/10, the same locality and age, sample 1-13; c, radial fractures and concentrically-arranged secondary alterations, spec. 364/6, Eifelian Stage, Mosolovian Regional Stage, Kursk Region, Shchigry-19 borehole, depth int. 180.0–184.9 m, sample Shch-19/185; d, surface secondary alterations, spec. 364/5, the same sample; e, concentrically-arranged growth lines, spec. 364/4, the same locality and age, depth int. 189.8–194.7 m, sample Shch-19/203; f, concentrically-arranged growth lines and short radial fractures in the central part, spec. 364/1, the same age, Kursk Region, Shchigry-16 borehole, depth int. 184.35–189.25 m, sample Shch-16/206; g, short radial fractures in the central part and surface secondary alterations, the same spec.; h, large radial fractures and surface secondary alterations, spec. 364/8, Eifelian (?) Stage, Cherny Yarian regional stage, Voronezh Region, Novokhoperskaya 8750/1 borehole, depth int. 296.6–301.3 m, sample NKh 568; i, large radial fractures and surface secondary alterations, spec. 364/11, Frasnian Stage, Mendymian regional stage, Bashkiria, outcrop on the Sikaza R., sample 1-13.

phosphate composition of the "conodont pearls" (Giles et al., 2002; Glenister et al., 1976; Huang and Gong, 2014; Leuteritz et al., 1972; Levman, 2001; Nazarova et al., 2016; Wang and Chatterton, 1993; Youngquist and Miller, 1948). It was noted that spherules consist of radial crystallites, arranged as concentric bands around a core (Giles et al., 2002; Leuteritz et al., 1972). At times, there were radial rays in the central part of a globule (Glenister et al., 1976; Leuteritz et al., 1972; Nazarova, 2013; Wang and Chatterton, 1993).

Researchers were not able to distinguish any taxa among "conodont pearls" due to their too simple morphology. Therefore, all these publications are devoted to discussion of hypotheses of their origin.

Leuteritz et al. (1972) stated his opinion that living organisms were not involved into the formation of these phosphate microspheres. Short rays radiating from cores are visible on some cross sections of some spherules. They were interpreted as outgrowths forming around processes of dinocysts. Occasionally, such rays occur in outgrowths described in (Glenister et al., 1976; Wang and Chatterton, 1993) and in those from our samples (Figs. 1b, 1f, 1g). However, they are much longer and, due to this, it is difficult to interpret them as elements of microfossils. It is evident that these are later radial microfractures. The presence of a basal dimple in each of spherules first of all does not support the inorganic hypothesis of their origin. In addition, they are found in different kinds of rocks, which mean that their origin does not depend on the formation conditions of these rocks.

Bischoff (1973) interpreted phosphate spherules as statoliths of conulats, that is, a group of jellyfish fossils, whose skeletons contain calcium phosphate. Apart from conodont elements and pearls this author recognized numerous diverse phosphate ridges and plates in samples. Imprints of conodont animals were unknown at that time and Bischoff tried to reconstruct a jellyfish skeleton from all the phosphate objects he had found. He suggested distinguishing a new Conulariida class with two subclasses: proper conulats and conodonts. Within the framework of this idea, “conodont pearls” were interpreted as statoliths of medusae. Despite their diverse chemical composition, statoliths of modern medusae usually occur as single crystallites are characterized by a less complex microstructure (*Zoologiya*..., 2008). It is currently accepted that conodonts have no genetic link with medusae because of the imprints that have been found (Barskov, 1985).

In fact, Glenister et al. (1976) were first to use the term “conodont pearls.” These authors generalized all previous findings and suggested that conodonts, like mollusks, secreted pearls in response to mechanical or organic stimuli. However, in the case of stimulation of the tissues that produce conodont elements, it would be more likely to assume the formation of pathologically altered elements, but not smooth spherical spherules. Incidentally, this situation is often recorded in the fossil record (Nazarova and Kononova, 2018). Even pearls produced by mollusks are rarely of the proper shape. Therefore, not every researcher has supported this hypothesis, but the use of term “conodont pearls” for these spherules has become common in any case. The terms “microspherules” (Giles et al., 2002; Huang and Gong, 2014; Wang and Chatterton, 1993) and “calciumphosphat-sphären” (Leuteritz et al., 1972) found in the literature can be applied to the description of other objects (for example, concretions and tektites). The term “conodont pearls” refers to specific objects without taking their genesis into account.

McConnel and Ward (1978) compared “conodont pearls” with uroliths of modern nautiloids, which have a spherical shape and phosphate composition. They are characterized by concentrically-arranged growth lines and variations in color when heated, like conodont elements. However, as seen in images, uroliths are irregular in shape and often grow together. In addition, the conodont elements change in color from amber to brown and black, but not from pink to gray. It is also unclear why uroliths of nautiloids have not been found at other stratigraphic levels, (for example, in the Mesozoic).

Giles et al. (2002) believed that “conodont pearls” are otoliths of acanthopterigians, because the results of studying the chemical composition of the material showed their greater similarity with fish teeth than with conodont elements. However, otoliths of modern and fossil kinds of fish have a complex morphology and are calcareous in the chemical composition. They are sensitive to variations in the chemical composition of marine water, but these variations, as a rule, do not affect the amount of phosphorus in their composition without changes in the contents of calcium and sodium (Pavlova and Pavlov, 2006). According to other researchers, the chemical composition of “conodont pearls” is closer to that of conodont elements rather than ichthyolites (Wang and Chatterton, 1993). Having studied amino acids from different phosphate microfossils, A. Kemp (2002) also tended to believe that “conodont pearls” were secreted by the conodont-bearing animals. In this case, “conodont pearls” were a normal component of an animal and they did not grow around a stimulus.

Most scientists have tended to believe that “conodont pearls” are related to conodonts (Bischoff, 1973; Donoghue, 1998; Glenister et al., 1976; Levman, 2001; Stauffer, 1935, 1940; Youngquist and Miller, 1948). Both “pearls” and conodont elements are similar in chemical composition, color, and microstructure, and they are found together. However, it is impossible to imagine “conodont pearls” as a part of dentition. Moreover, they bear no traces of abrasion or intravital damage.

Youngquist and Miller (1948) were the first to suggest that phosphate spherules may be otoliths of conodonts. This opinion was supported by other researchers (Donoghue, 1998; Huang and Gong, 2014). The organs of balance, known as statocysts, in different groups of animals are very diverse. They differ in their location in the body, shape, quantity, their origin during ontogenesis, mechanism of action, the morphology of statoliths, and their chemical composition. This diversity can be manifested within the same type and even lower taxonomic subdivisions. In other words, organs of balance in different (albeit similar) evolutionary branches often developed independently and they were formed using those structures that were most developed in animals (tentacles, limbs, rows of cilia, head, etc.).

The only mineralized parts of conodonts are conodont tooth-like elements. One can assume that otoliths of these animals are of the same origin.

The presence of otoliths with a complex microstructure in conodonts indicates the high level of their development compared with invertebrates and, possibly, the presence of a vestibular apparatus. It is considered that conodonts were not disturbed by their position in space and were probably able to control it. This confirms the traditional view of the nektonic way of life of conodonts (Barskov, 1985).

The purpose of the basal dimple has not been discussed in the literature; only its presence was mentioned in some works (Glenister et al., 1976; Huang and Gong, 2014; Nazarova, 2013; Stauffer, 1935; Wang and Chatterton, 1993). We believe that the basal dimple is the junction of “conodont pearls” with a soft body. The dark matter, a small amount of which is sometimes preserved in a basal dimple, can be considered as a analogue of the basal callus of conodont elements. Such an interpretation is in an agreement with the hypothesis that “conodont pearls” are otoliths of conodonts. Fish otoliths, for example, are also connected with cilia of the sensitive epithelium (Dzerzhinsky, 2005).

“Conodont pearls” are not found in deposits younger than Devonian (Early Carboniferous?), although conodonts existed until the end of the Triassic. This is perhaps due to the fact that conodonts were forced to restructure the vestibular apparatus due to stressful changes in the environment or their otoliths became so small that they were missed during the study of samples.

MATERIALS AND METHODS

The authors of the present paper described the findings of the "conodont pearls" in Russia for the first time (Nazarova, 2013; Nazarova and Kononova, 2016; Nazarova et al., 2016). While the problem of "conodont pearls" are briefly discussed in the first publications (Nazarova, 2013; Nazarova et al., 2016), the "pearls" were already included in the general lists of conodont elements from the Mosolovian regional stage of the Voronezh Anteclise in the last publication (Nazarova and Kononova, 2016).

The collection of "conodont pearls" includes 153 specimens (Table 1). They come from the Middle–Upper Devonian deposits of the Voronezh Anteclise, exposed by boreholes: Kursk Region (Shchigry-16 (Niahnekrasnoe) and Shchigry-19 (Osinovka) boreholes), Bryansk Region (Prosvet-2P borehole), Orel Region (Naryshkino-4177 borehole), Voronezh Region (Novokhoperskaya-8750/1 borehole), and Lipetsk Region (Zadonskaya ZDOL-1 borehole). The location schemes of boreholes and their sections, as well as the data on faunal composition of deposits, were previously published (Nazarova and Kononova, 2016).

Similar spherules were also found in deposits of the Mendymian regional stage (Upper Devonian) exposed in the Sikaza River basin, Bashkiria (see the description of the section in (Kononova, 1979)), deposits of the Sirachoyian regional stage (Upper Devonian) exposed by the Khosedayusskaya Yuzhnaya 1 borehole, the Nenets Autonomous Okrug (see the description of the section in (Kiryukhina et al., 2015)), as well as in the Frasnian deposits exposed by Devonskaya-3 borehole, Astrakhan Region (see the borehole section in (*Astrakhanskii*..., 2008)). Samples were processed to extract conodont elements following the standard procedure (dissolution in 10% acetic acid). The CamScan, Tescan, and Zeiss Evo50 scanning electron microscopes were used to take images at the Russian Academy of Sciences, as well as a Levenhuk 595 microscope equipped with a Levenhuk C310 digital camera. The studied collection no. 364 of "conodont pearls" is stored at the Department of Paleontology (Faculty of Geology, Lomonosov Moscow State University).

RESULTS AND DISCUSSION

"Conodont pearls" are always found together with conodont elements in the studied samples. Spherules are smooth, bright, slightly flattened, 90–300 μm in diameter (150–200 μm, on average). It should be noted that it is hardly possible to find microfossils of less than 100 μm in diameter in the studied samples following the extraction protocol of conodonts (in particular, the sieving of washed powder through fabric mill gas). Spherules range from semi-transparent to opaque and from yellowish to brown and black.

On the surface there is a small hollow, a basal dimple (Plate 1, 1–16), sometimes filled with dark matter. At times, there are two closely located basal dimples (Plate 1, 3–4, 12). At a distance from a basal dimple (dimples) a "pearl" is surrounded by a thin rim (Plate 1, 1–2, 5–10), which is sometimes hardly distinguishable. Despite the fact that such a rim has not been described in the literature, it is noticeable in some images (Huang and Gong, 2014, figs. 3b, 3e, 3g–3i). Concentrically arranged growth lines (Figs. 1a, 1e, 1f), similar to those of conodont elements, are visible in transmitted light. These are also visible on cleavage surfaces (Plate 2, figs. 1, 2b, 3a, 3b). Radially arranged thin apatite crystals, similar to those in conodont elements (Donoghue, 1998) are found between growth lines (Plate 2, figs. 4a–4c). The core of a "conodont pearls" includes a hollow sphere with smooth walls 10 μm or less in diameter (Plate 2, figs. 2b, 3c).

There are frequent fractures (Figs. 1a, 1c, 1h, 1i), signs of secondary damage and changes both inside a "conodont pearls" (Figs. 1b, 1c) and on its surface (Figs. 1d, 1g–1i). The co-occurrence of "conodont pearls" with any particular genera of conodont-bear-

Plate 1. In all cases magnification is 140×. (1) Spec. 364/12, Eifelian Stage, Mosolovian Regional Stage, Lipetsk Region, Zadonskaya 1 borehole, a depth, 336.0 m, sample ZDOL-1/336; (2) spec. 272/772, the same age, Kursk Region, Shchigry-16 borehole, depth int. 189.25–194.15 m, sample Shch-16/219; 3, spec. 364/14, Frasnian Stage, Sirachoyian regional stage, Nenets Autonomous Okrug, Khosedayuskaya Yuzhnaya 1 borehole, depth int. 3682.0–3696.0 m, sample 38; (4) spec. 364/15, the same locality and age; (5) spec. 364/13, Eifelian Stage, Mosolovian Regional Stage, Lipetsk Region, Zadonskaya-1 borehole, a depth, 330.0 m, sample ZDOL-1/329; (6) spec. 364/3, the same age, Kursk Region, Shchigry-19 borehole, depth int. 180.0–184.9 m, sample Shch-19/190; (7) spec. 364/16, Frasnian Stage, Sirachoyian regional stage, Nenets Autonomous Okrug, Khosedayuskaya Yuzhnaya 1 borehole, depth int. 3682.0–3696.0 m, sample 38; (8) spec. 364/17, the same locality and age; (9) spec. 364/18, the same locality and age; (10) spec. 364/2, Eifelian Stage, Mosolovian regional stage, Kursk Region, Shchigry-16 borehole, depth int. 189.25–194.15 m, sample Shch-16/222; (11) spec. 364/21, Frasnian Stage, Astrakhan Region, Devonskaya-3 borehole, depth int. 5051.17–5057.76 m, sample 8; (12) spec. 364/19, Frasnian Stage, Sirachoyian regional stage, Nenets Autonomous Okrug, Khosedayuskaya Yuzhnaya 1 borehole, depth int. 3682.0–3696.0 m, sample 38; (13) spec. 364/7, Eifelian Stage, Mosolovian regional stage, Kursk Region, Shchigry-19 borehole, depth int. 180.0–184.9 m, sample Shch-19/190; (14) spec. 364/22, Frasnian Stage, Astrakhan Region, Devonskaya-3 borehole, depth int. 5051.17–5057.76 m, sample 8; (15) spec. 364/23, the same locality and age; (16) spec. 364/20, Frasnian Stage, Sirachoyian regional stage, Nenets Autonomous Okrug, Khosedayuskaya Yuzhnaya 1 borehole, depth int. 3682.0–3696.0 m, sample 38.

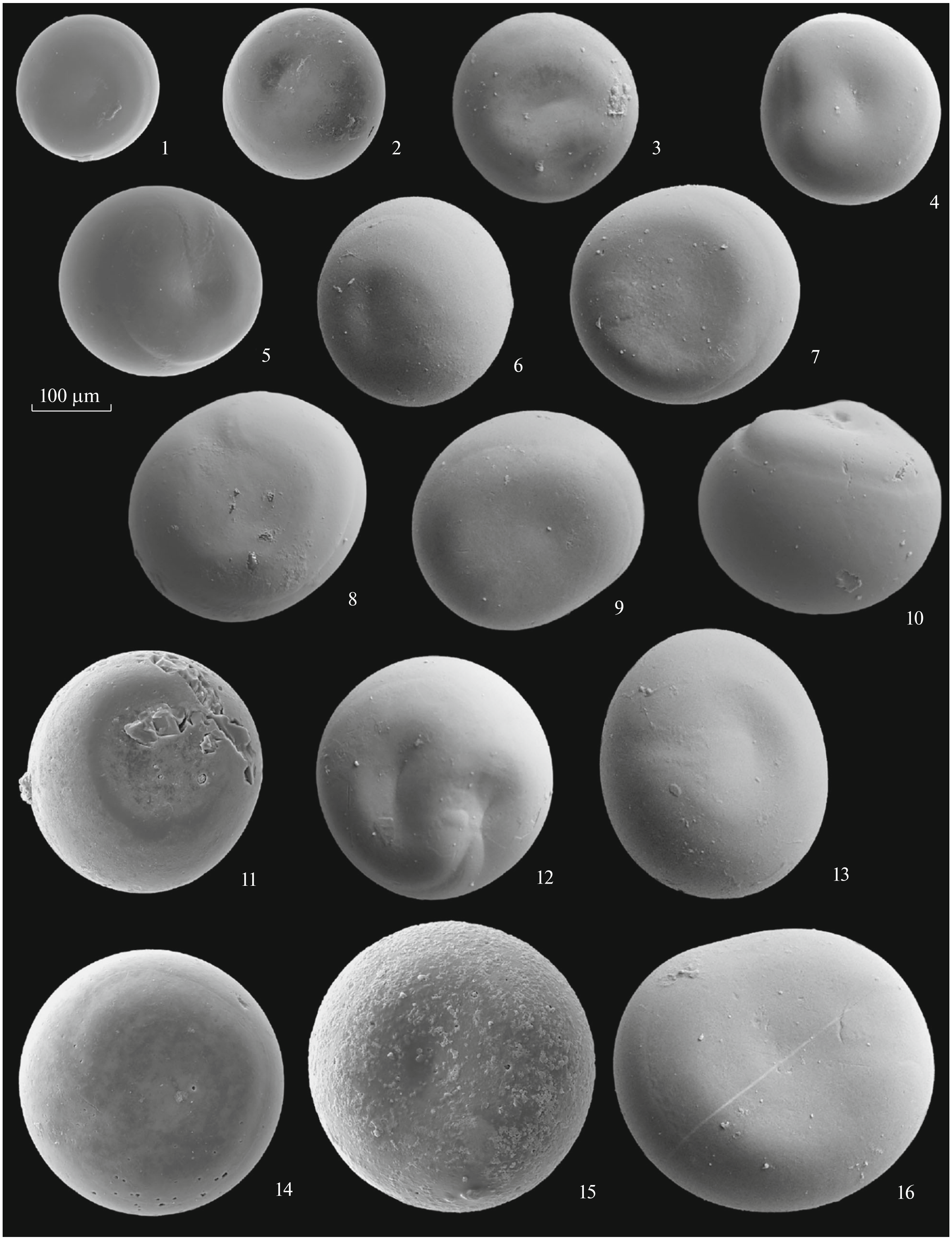
1
2
3
4
5
6
7
100 μm
8
9
10
11
12
13
14
15
16

Table 1. Sites and levels of findings of "conodont pearls"

Stage, regional stage/ conodont zone	Borehole, outcrop	Depth int., m	Sample no.	Number of specimens
Famennian, Eletskian/rhomboidea	Zadonskaya-1	31.0	ZDOL-1/29A	1
Frasnian, Sirachoyian/lower rhenana	Khosedayuskaya Yuzhnaya 1 borehole	3682.0–3696.0	Samples 38, 40	46
Frasnian	Devonskaya-3, Astrakhan Dome Borehole	5051.17–5057.76	Sample 8	15
Frasnian, Mendymian/lower rhenana	Sikaza	–	Sikaza-1-13	7
			Sikaza-2-6	2
Frasnian, Sargaevian/upper falsiovalis – transitans	Shchigry-16	110.85–120.65	Shch-16/84,	1
			Shch-16/210a	1
Givetian, Stary Oskolian/varcus	Shchigry-16	179.45–184.35	Shch-16/196	1
Givetian, Cherny Yarian/upper ensensis	Novokhoperskaya -8750/1	296.6–301.3	NKh-568	7
Eifelian, Mosolovian/kockelianus – lower ensensis	Naryshkino-4177	346.4	Nar-161	2
		346.9	Nar-162	2
	Prosvet-2P	319.8	2P-50	1
		321.5	2P-47	3
	Shchigry-19	180.0–184.9	Shch-19/185	2
			Shch-19/190	16
		189.8–194.7	Shch-19/203	5
	Shchigry-16	184.35–189.25	Shch-16/206	1
			Shch-16/216	2
		189.25–194.15	Shch-16/219	6
			Shch-16/222	7
			Shch-16/223	7
			Shch-16/225	2
	Zadonskaya ZDOL-1	324.5	ZDOL-1/324	4
		327.5	ZDOL-1/327	1
		328.5	ZDOL-1/328	1
		330.0	ZDOL-1/329	2
		334.8	ZDOL-1/334	2
		335.3	ZDOL-1/335	4
		336.0	ZDOL-1/336	1
		336.8	ZDOL-1/337	1

ing animals has not been revealed. Most samples with conodont elements do not contain "pearls."

RESULTS OF CHEMICAL ANALYSIS

The chemical composition of "conodont pearls", as well as accompanying phosphate microfossils (conodont elements, teeth of sarcopterygian and cartilaginous kinds of fish, scales of acanthodians and acanthopterigians) from two paleobasins was studied with a Zeiss Evo50 scanning electron microscope equipped with an Inca Oxford 350 microanalyzer (20 kV). In total, 17 specimens from deposits of the Mosolovian regional stage (Late Eifelian, Middle Devonian) of the Voronezh Anteclise (Shchigry-16 and -19 boreholes) and 46 specimens from deposits of the Sirachoyian regional stage (Upper Frasnian, Upper Devonian) of the Timan–Pechora province (Khosedayuskaya Yuzhnaya 1 borehole).

The samples were coated with gold. Contents expressed in wt % were used for calculations. The pre-

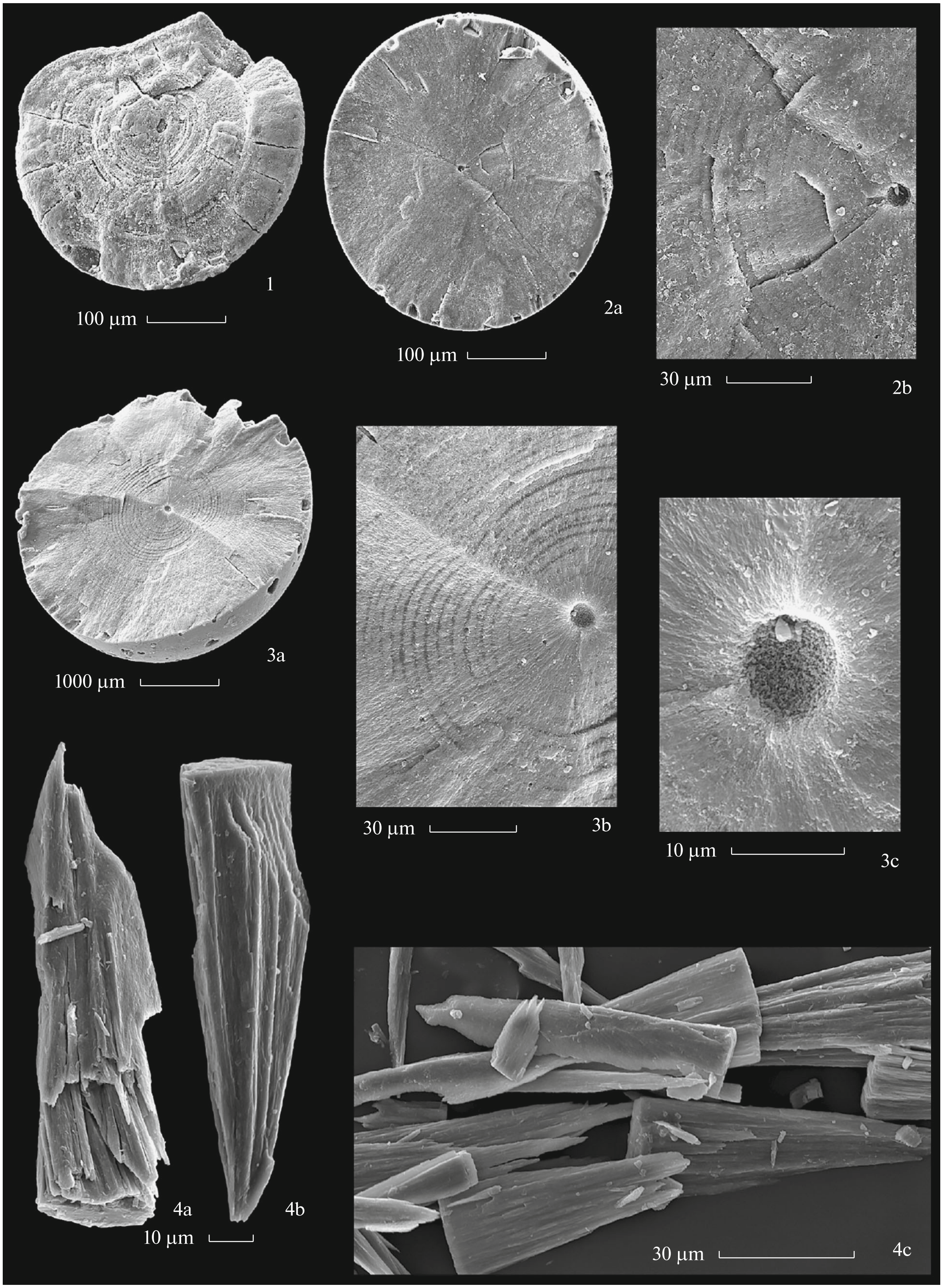

Plate 2. (1) Spec. 364/24, transverse shear, Frasnian Stage, Astrakhan Region, Devonskaya 3 borehole, depth int. 5051.17–5057.76 m, sample 8, 140×; (2) spec. 364/25 (a, transverse shear, 140×; b, central part, 500×), the same locality and age; (3) spec. 364/26 (a, transverse shear, 140 x; b, central part, 500×, c, core, 2000×), the same locality and age; (4) spec. 364/27; a, b, c, sheared fragments, Eifelian Stage, Mosolovian regional stage, Lipetsk Region, Zadonskaya 1 borehole, depth, 336.8 m, sample ZDOL-1/337, 800×.

Table 2. The average chemical composition (wt %) of phosphate microfossils from the Mosolovian regional stage, Kursk Region (Shchigry-16 and Shchigry-19 boreholes) based on the data from 17 specimens

Composition	Conodont pearls	Conodont elements	Ichthyolites
Na_2O	–	0.15	0.15
MgO	–	–	–
Al_2O_3	–	0.42	0.40
SiO_2	–	0.24	0.15
P_2O_5	**19.21**	**17.29**	**17.45**
SO_3	–	–	–
CaO	**23.20**	**17.40**	**21.48**
FeO	–	–	*2.16*
F	–	–	–
Cl	–	0.07	–

The frequency of occurrence of a chemical element/oxide in the studied pearls: light-face, <25%, italics, 25–50%, bold italics, 50–75%, bold, 75–100%.

Table 3. The average chemical composition (wt %) of phosphate microfossils of the Sirachoyian regional stage in the Nenets Autonomous Okrug (Khosedayuskaya Yuzhnaya 1 borehole): data from 46 specimens

Composition	Conodont pearls	Conodont elements	Ichtyolites
Na_2O	0.52	0.59	*0.35*
MgO	0.02	0.10	0.05
Al_2O_3	–	–	–
SiO_2	–	–	–
P_2O_5	**23.16**	**20.40**	**16.72**
SO_3	*0.30*	–	*2.2*
CaO	**29.69**	**28.88**	**21.39**
FeO	0.05	–	*0.96*
F	**2.95**	**3.99**	**3.50**
Cl	0.03	*0.17*	*0.06*

* See notes to Table 2.

liminary results were reported at the "Lomonosov's Readings–2016" conference (Nazarova et al., 2016).

Ca, P, and C were found in all studied microfossils, (Tables 2, 3). Carbon was excluded from consideration, since its occurrence in samples can be determined by not only its possible content in apatite, the presence of organic matter in remains and the possible admixture from enclosing carbonate rocks, but also the analytical procedure: the specimens were placed on a working table with an organic glue and the working table was mounted on a microscope with scotch tape.

The chemical analysis revealed that the difference in the chemical composition between "conodont pearls" from the different paleobasins under consideration is greater than that between "pearls" from the same basin. When comparing different groups of microfossils from the same paleobasin, it was noted that "conodont pearls" consist of clearer apatite. In most cases, the composition of "conodont pearls" includes only Ca and P, less often F and Na, and rarely Mg, S, Cl, and Fe. As well, it was established that there is no dependence of the chemical composition of "conodont pearls" on color, morphology, or dimension. The fish remains include a maximum amount of admixtures of calcite, aluminosilicates, pyrite, etc. In this aspect, conodont elements occupy an intermediate position.

It is likely that the presence and the volume of admixtures depend on the character of the surface of the "conodont pearls" (a smaller number of admixtures on a smoother surface) and the degree of porosity (more porous "pearls" contain a higher level of impurities), but not on the primary chemical composition. In addition, most ichthyolites contain a noticeable amount of iron, which was also revealed when studying other material (Nazarova and Zaitseva, 2018). The rest of the microfossils contain minor amounts of iron.

CONCLUSIONS

Having examined the history of the study of "conodont pearls" and analyzed different hypotheses on their origin we have come to the conclusion that these objects could not belong to any of the organisms discussed above (conulats, fish, etc.). Their chemical composition, color, microstructure, and co-occurrence indicate that "conodont pearls" belong to conodonts. It is most likely that these phosphate microspherules in the body of a conodont could play the role of an otolith, which as a part of the organ of balance allowed the animals to navigate and move freely in the marine environment. It should be noted that findings of these specific "pearls" in Russia are described in the present paper for the first time.

ACKNOWLEDGMENTS

We are deeply grateful to L.I. Kononova for providing the material and assistance in its processing, valuable advices and comprehensive support, L.V. Zaitseva for assistance in conducting chemical analyzes, E.A. Zhegallo and R.A. Rakitov for taking the images of "conodont pearls," as well as S.V. Moloshnikov, Yu.V. Rostovtseva, and T.V. Filimonova for valuable comments and constructive criticism.

REFERENCES

Astrakhanskii karbonatnyi massiv: Stroenie i neftegazonosnost' (Astrakhan Carbonate Massif: Structure and Petroleum Potential), Volozh, Yu.A. and Parasyny, V.S., Eds., Moscow: Nauchn. Mir, 2008.

Barskov, I.S., Conodonts in modern geology, in *Itogi nauki i tekhniki. Ser. Obshch. geol. T. 19* (Achievements in Science and Technology. Ser. General Geol.), Moscow: VINITI, 1985, vol. 19, pp. 93–221.

Bischoff, G.C.O., On the nature of the conodont animal, *Geol. Palaeontol.*, 1973, vol. 7, pp. 147–174.

Clarkson, G.R., Devonian conodont biostratigraphy in the subsurface of Mason county, West Virginia. *Submitted to the Graduate School West Virginia University in Partial Fulfillment of the Requirements for the Degree of Master of Science*, Morgantown, 1980.

Donoghue, P.C.J., Growth and patterning in the conodont skeleton, *Phil. Trans. R. Soc. London*, 1998, vol. 353, pp. 633–666.

Dumoulin, J.A., Harris, A.G., Blome, Ch.D., and Young, L.E., Conodont and radiolarian data from the De Long Mountains Quadrangle and adjacent areas, Northern Alaska, *Open-File Rep.*, 2006-1068, 2006.

Dzerzhinskii, F.Ya., *Sravnitel'naya anatomiya pozvonochnykh zhivotnykh* (Comparative Anatomy of Vertebrates), Moscow: Aspekt-Press, 2005.

Giles, K.A., McMillan, N.J., and McCarson, B.L., Geochemical analysis and paleoecological implications of phosphatic microspherules (otoliths?) from Frasnian–Famennian boundary strata in the Great Basin, USA, *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 2002, vol. 181, pp. 111–125.

Glenister, B.F., Klapper, G., and Chauff, K.M., Conodont pearls? *Science*, 1976, vol. 193, pp. 571–573.

Huang, Ch. and Gong, Y.M., Phosphatic microspherules and their geobiological implications from the Frasnian-Famennian transition at the Yangdi section, Guilin, South China, *Sci. China. Earth Sci.*, 2014, vol. 57, pp. 943–956.

Kemp, A., Amino acid residues in conodont elements, *J. Paleontol.*, 2002, vol. 76, no. 3, pp. 518–528.

Kiryukhina, T.A., Bol'shakova, M.A., Stupakova, A.V., et al., Lithological and geochemical characteristics of Domanik deposits of Timan–Pechora Basin, *Georesources*, 2015, vol. 2, no. 61, pp. 87–100.

Kononova, L.I., Upper Frasnian and Tournaisian Conodonts of the Sikaza river section (Southern Urals), *Serv. Geol. Belg. Prof. Pap.*, 1979, vol. 161, pp. 71–86.

Krumhardt, A.P., Conodont analyses from the Arctic National Wildlife refuge, Northeast brooks range, Alaska 1990–1993, *Divis. Geol. Geophys. Surv.*, 1994.

Leuteritz, K., Pietzner, H., Vahl, J., and Ziegler, W., Aufbau, zusammensetzung und entstehung von calcium-phosphat-sphären in paläozoischen kalken, *Geol. Palaeontol.*, 1972, vol. 6, pp. 111–137.

Levman, B.G., The Frasnian/Famennian (mid-late Devonian) boundary in the Long Rapids formation, James Bay Lowlands, Northern Ontario, Canada. *A Thesis Submitted in Conformity with the Requirements for the Degree of Master of Science Graduate Department of Geology University of Toronto*, 2001.

McConnell, D. and Ward, P., Nautiloid uroliths composed of phosphatic hydrogel, *Science*, 1978, vol. 199, no. 4325, pp. 208–209.

Nazarova, V.M., On the origin of "conodont pearl", in *"Lomonosovskie chteniya-2013. Tez. Dokl. Moskva, aprel 2013 g.* (Proc. Conf. "Lomonosov's Readings-2013", Moscow, April 2013). http://geo.web.ru/pubd//2013/11/24/ 0001187290/pdf/nazarova_2013.pdf.

Nazarova, V.M. and Kononova, L.I., Conodont-based stratigraphy of the Mosolovian Regional Stage (Eifelian, Middle Devonian) of the Voronezh Anteclise, *Stratigr. Geol. Correl.*, 2016, vol. 24, no. 4, pp. 339–363.

Nazarova, V.M. and Kononova, L.I., Pathology of Devonian conodont elements of the Voronezh Anteclise, in *Tr. XVII Vseross. Mikropaleont. soveshch. "Sovremennaya mikropaleontologiya - problemy i perspektivy". Kazan', 24–28 sentyabrya 2018 g.* (Proc. XVII All-Russ. Micropaleontol. Conf. "Modern Micropaleontology – Problems and Perspectives" (Kazan, September 24–29, 2018)), Moscow: GEOS, 2018, pp. 329–333.

Nazarova, V.M. and Zaitseva, L.V., Chemical composition of Late Devonian phosphate microfossils from the East European Platform, *Byull. Mosk. O–va Ispyt. Prir.*, *Otd. Geol.*, 2018, vol. 93, no. 2,pp. 42–53.

Nazarova, V.M., Gatovskii, Yu.A., and Zaitseva, L.V., The EDS study of phospate microfossils from the Devonian deposits of the Russian Plate, in *"Lomonosovskie chteniya-2016. Tez. Dokl. Moskva, 13–22 aprelya 2016 g.* (Proc. Conf. "Lomonosov's Readings-2016", Moscow, April 13–22, 2013). http://www1.geol.msu.ru/deps/paleont/conference/ Nazarova_et_al_ 2016.pdf.

Pavlova, L.A. and Pavlov, S.M., Features of RsmA of fish otoliths as a perspective environmental monitoring tool, *Metody Ob"ekty Khim. Analiza*, 2006, vol. 1, no. 1, pp. 48–53.

Stauffer, C.R., The conodont fauna of the Decorah shale (Ordovician), *J. Paleontol.*, 1935, vol. 9, no. 7, pp. 596–620.

Stauffer, C.R., Conodonts from the Devonian and associated clays of Minnesota, *J. Paleontol.*, 1940, vol. 14, no. 5, pp. 417–435.

Wang, K. and Chatterton, B.D.E., Microspherules in Devonian sediments: origins, geological significance, and contamination problems, *Can. J. Earth Sci.*, 1993, vol. 30, no. 8, pp. 1660–1667.

Youngquist, W. and Miller, A.K., Additional conodonts from the Sweet land Creek Shale of Iowa, *J. Paleontol.*, 1948, vol. 22, no. 4, pp. 440–450.

Zoologiya bespozvonochnykh. V 2-kh t. (Zoology of Invertebrates (in 2 vols.)), Vestkhaide, V. and Riger, R., Eds., Moscow: Tov-vo Nauchn. Izd. KMK, 2008.

Translated by D. Voroshchuk