

## On the diversity of microfossils in the Bazhenov Horizon of Western Siberia (Late Jurassic–Early Cretaceous)

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**Abstract.** Paleontological remains from the Bazhenovo Horizon of Western Siberia (Tithonian–Berriasian) are represented by macro- and microfossils. The Horizon had a marine genesis and the basis of ecosystem of this paleobasin composed of pelagic organisms-producers (phytoplankton: prasinophytes, coccolithophorids, dinoflagellates, as well as brown algae) and consumers (zooplankton: radiolarians, invertebrate larvae, crustaceans; and nekton: pelagic bony fish, ammonites, belemnites, paleosquids-teuthids and marine dinosaurs; and, in addition, benthic bivalves, foraminifera, and ostracods). Among microfossils, radiolarians are the leading importance, phytoplankton (dinoflagellates, coccolithophorids) and microbenthos (foraminifera, sponge spicules) are less common. Radiolarians, dinoflagellates, coccolithophorids, and foraminifera are used for biostratigraphic subdividing of sections and their correlation, and, in addition, together with sponge spicules, for reconstruction the paleoenvironments. In literature, a several paper indicated the presence of other siliceous microfossils in paleobiota of the Bazhenovo paleosea – diatoms, silicoflagellates, and acantharians. The article summarized data on radiolaria, coccolithophorids, dinophyta and critically reviewed reports of other microobjects. It is shown that the information about diatoms, silicoflagellates and acantharians from Bazhenovo Horizon and Bazhenovo Formation is probably unreliable.

**Keywords:** Radiolaria, coccolithophorids, dinoflagellates, Bazhenovo Horizon, Western Siberia, Late Jurassic, Tithonian, Early Cretaceous, Berriasian

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The vast marine basin that existed on the territory of Western Siberia during the period of the end of the Jurassic and early Cretaceous systems (Tithonian–Berriasian) was characterized by specific, sometimes unique features. The sediments of this basin formed the high-carbon Bazhenov regional lithological-stratigraphic horizon, which is an oil source and, at the same time, a regional screen for hydrocarbon deposits. At present, when oil production in traditional reservoirs in the West Siberian basin is decreasing, this stratum becomes an object of potential increase in reserves and oil production (Lobusev et al., 2011; Kontorovich et al., 2013; Kontorovich et al., 2014, and others). The representative literature is devoted to stratigraphy, paleogeography, paleobiology, and paleoecology of the basin (Zakharov, Saks, 1983; Braduchan et al., 1986; Zakharov, 2006, and others).

The biological productivity of the inner West Siberian Sea, which is associated with the Bazhenov naphthide genesis, was extremely high during the Volgian–Berriasian period (Kontorovich et al., 2013). The accumulation of huge masses of organic matter was due to the existence of a eutrophic pelagic ecosystem, the central link of which was plankton. The basis of the basin's ecosystem consisted of a variety of pelagic (Figs. 1, 2) producer organisms (phytoplankton: prasinophytes, coccolithophorids, dinoflagellates) and consumers (zooplankton: radiolarians, invertebrate larvae, crustaceans; as well as nekton: pelagic bony fish, ammonium paleocalamary-teuthids and sea lizards; besides them, benthic bivalves, foraminifers, and ostracods) (Zakharov, 2006). Note also that, in addition to unicellular planktonic algal flora, the water area and bottom of the basin could be inhabited by multicellular brown algae, which were also capable of creating a huge biomass (Kulikova et al., 2013).

Radiolarians, which sometimes played a significant role in the formation of paleobiota and sedimentation processes, were a very important element of the plankton of the West Siberian epicontinental Bazhenov basin

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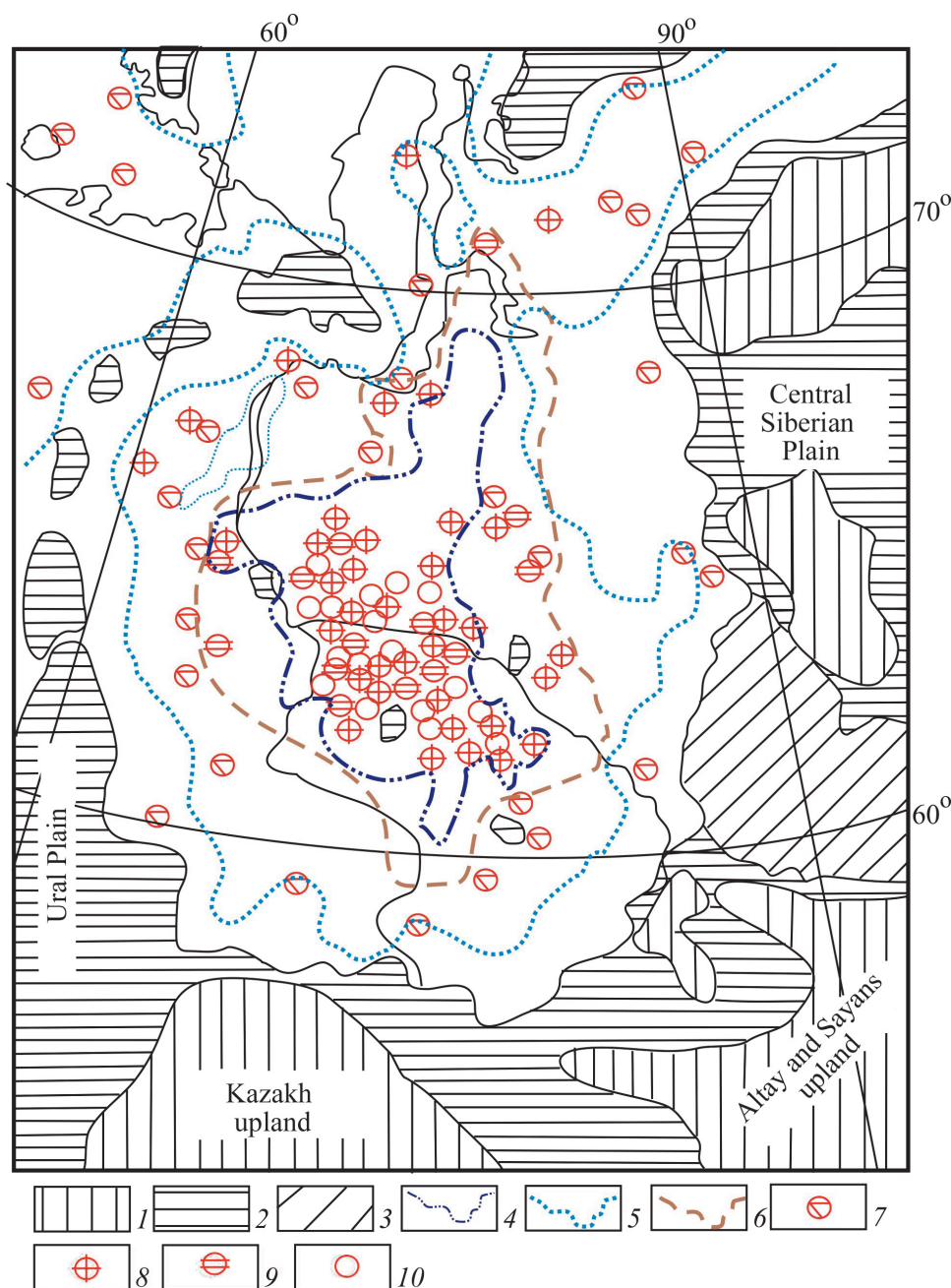


Fig. 1. Scheme of paleogeography of the West Siberian sea basin and the distribution of microfossils in the Bazhenov time (Tithonian–Berriasian) (Predtechenskaya, 2006; Panchenko et al., 2015; Vishnevskaya et al., 2020, with changes). 1 – plateau, mountainous areas; 2 – areas of denudation (hilly plateaus); 3 – lagoons, marshes, alluvial-lacustrine-bog plains; 4–6 – contours (boundaries) of areas of distribution: 4 – greatest depths (pseudoabyssal); 5 – relatively deep waters (middle and lower sublittoral); 6 – bituminous deposits; 7–10 – microfossils: 7 – foraminifera; 8 – radiolarians; 9 – coccolithophorids; 10 – calcareous cysts of dinoflagellates (calcispheres).

(Figs. 3, 4, 5). In this communication, some features of the paleobionomy of radiolarians are considered, since they are not fully covered in the literature (Braduchan et al., 1986; Zakharov, 2006, and others). Biostratigraphic aspects of the distribution of radiolarians in the Bazhenov horizon and the composition of their fossil assemblages were analyzed earlier (Braduchan et al., 1986; Amon et al., 2011; Vishnevskaya, 2013; Panchenko et al., 2015; Vishnevskaya et al., 2018a, b, 2020).

In addition, new data on coccolithophorids and dinoflagellates are presented, and reports on diatoms,

silicoflagellates, and acantharia from the Bazhenov horizon, known in the literature, are critically revised.

Thus, in the proposed review and analytical work, our new data on radiolarians, dinophytes, coccolithophorids, palynomorphs, micro-spicules, obtained in recent years, are presented in a concise form, and information on other microfossils is subjected to critical analysis, which makes a new contribution to the knowledge of the features of the Bazhenov formation.

The original stone material, which served as the basis for this study and numbering several thousand samples,

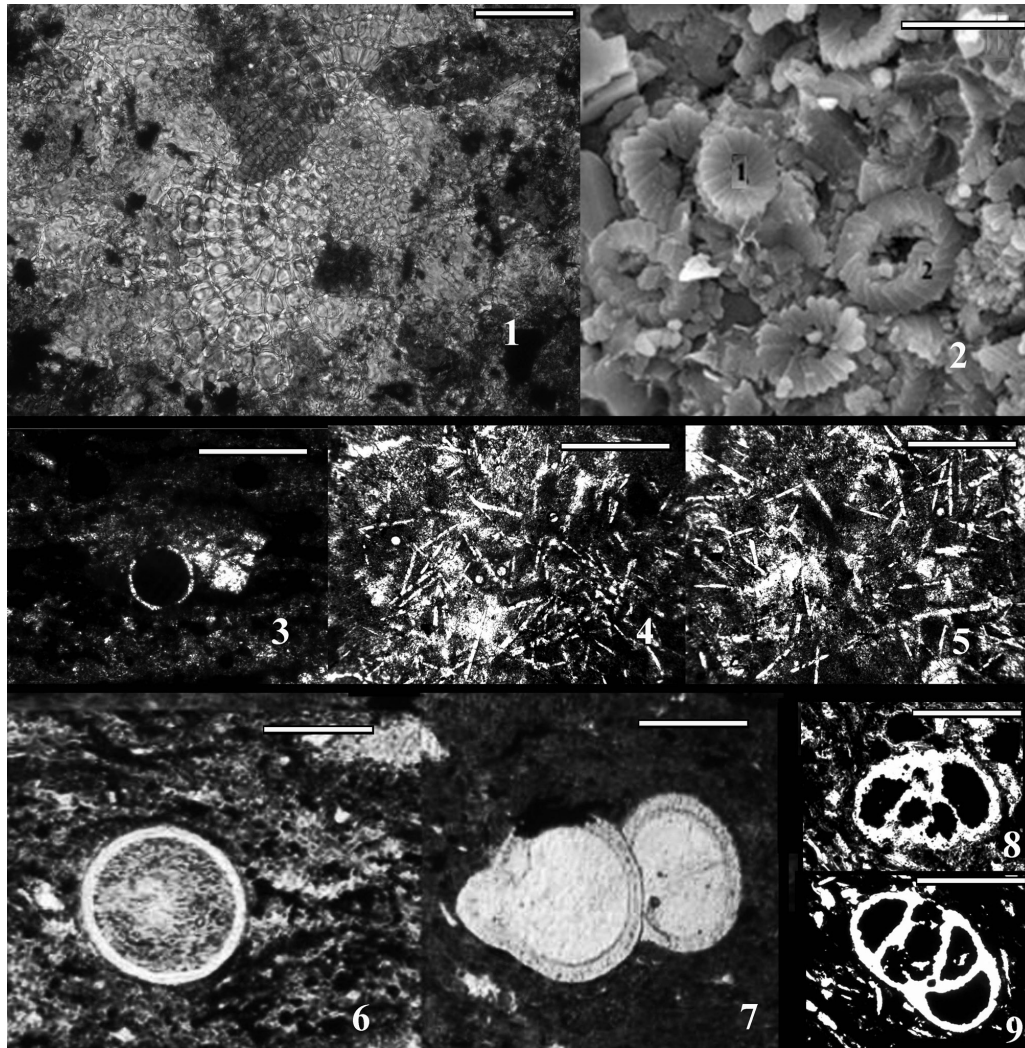


Fig. 2. Microfossils of the Bazhenov horizon, 1, 3–9 – optical photographs in transmitted light, 2 – photograph in a scanning electron microscope. 1 – biomorphic structure of radiolarite, in the foreground is a fragment of radiolarian from fam. Spongidiscidae, North Emangalskaya area, Middle Volga substage; 2 – nanoplankton with monorodic composition of complexes, dominated by *Watznaueria* spp. (photo by N.S. Balushkina, definitions by M.A. Ustinova), Emangalskaya area, Middle Volga substage; 3 – calcareous dinocysts, West Unlorskaya area, middle Volga substage; 4, 5 – sponge spicules at the top of the Bazhenov Formation, Aprelskaya area, Upper Volga substage; 6–9 – sections through foraminifera shells, middle Volga substage: 6, 7 – Severo-Konitlorskaya area, 8 – Nizhne-Yanlotskaya area, 9 – Sredne-Pomutskaya area. The length of the scale bar: 1, 3–9 – 50, 2 – 5 microns.

was obtained during the study of wells drilled in more than three dozen exploration areas in Western Siberia and on its Arctic periphery on the Yamal Peninsula (areas of South Tambeyskaya, Gubkinskaya, Imilorskaya, Novoortyagunskaya, Pravdinskaya, Aprilskaya, Sredne-Shapkinskaya, Molodezhnaya, Nizhne-Yanlotskaya, Verkhne-Salymyskaya, Radonezhskaya, Malobalykskaya, etc.) (Fig. 1, Table 1) (Kozlova, 1983; Amon, 2011; Panchenko et al., 2015; Vishnevskaya, 2013, 2017; Vishnevskaya et al., 2018a, 2018b, 2020; Vishnevskaya, Kozlova, 2012).

The stone material was processed using standard methods, including the preparation of petrographic thin sections, chemical disintegration, and preparation using  $\text{CH}_3\text{COOH}$ , HF and HCl. Microfossils (skeletons of radiolarians, etc.) were studied using optical and scanning electron microscopes, as well as using a new

method of X-ray computed tomography (Vishnevskaya, 2017; Vishnevskaya et al., 2018a).

### Radiolaria

Radiolarians are most common in the rocks of the Bazhenov horizon and, as a rule, are rock-forming (Figs. 3, 4, 5). We have proposed and characterized a new version of the scheme of biostratigraphic subdivision and correlation of sections of the Bazhenov horizon by radiolarians (Panchenko, 2015; Vishnevskaya et al., 2018a, 2018b, 2020; Vishnevskaya, 2017; Vishnevskaya et al., 2019a, 2019b).

Radiolarians (protists with an internal siliceous skeleton) were widespread in the ecosystem and in sediments of the Bazhenov Sea of West Siberia. They are typical representatives of pelagic plankton; inhabited and still live in the depth interval 0–1500 m with a noticeable

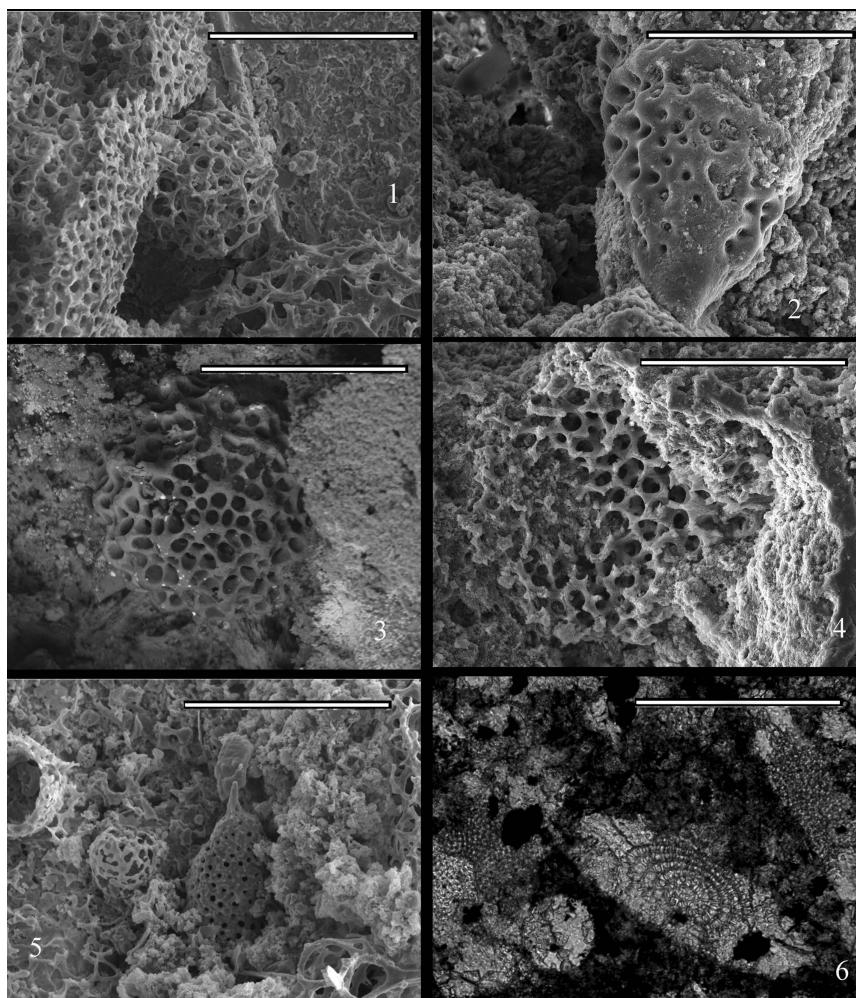


Fig. 3. Rock-forming significance of microfossils in the Bazhenov horizon, radiolarian skeletons make up both the base and the matrix of the rock, 1–5 – photographs in a scanning electron microscope, 6 – optical photography in transmitted light. 1 – representatives of *Spumellaria*, in the center a small spherical shape, at the bottom right of a large sphere, a long needle of which divides the image into two parts, on the left a destroyed skeleton of a large spongy shape, specimen. GIN No. 170/1-Y3-005, South Tambeyskaya area, lower Volga substage; 2 – a representative of *Nassellaria*, the vertex region is well discernible, specimen. GIN No. 170-TRI-90, South-Tambeyskaya area, lower Volga substage; 3 – a representative of *Praeconocaryomma* from the order *Spumellaria* with a characteristic knobby external sculpture, specimen. GIN No. 170-STI-4, South-Tambeyskaya area, lower Volga substage; 4 – the arrangement of pores in staggered rows on the shell wall indicates that the fragment belongs to *Nassellaria*, specimen. GIN No. 170-TRI-54, South Tambeyskaya area, lower Volga substage; 5 – juvenile forms from different orders of radiolarians among decayed skeletal elements, in the lower right corner are fragments of lattice skeletons of the family. *Poulpidae* and peripheral rings of *Saturnalidae* (?), specimen. GIN No. 170/1-Y3-004, South-Tambeyskaya area, lower Volga substage; 6 – cellular structure of skeletons in the center and on the right, an abundance of spheres and discs on the left, specimen. GIN No. CE-98-28-20x-15, Severo-Emangalskaya area, Middle Volga substage. The length of the scale bar for all objects is 100  $\mu\text{m}$ .

preference for the upper water horizon to depths of 10–75–150–500 m. In the Arctic, living radiolarians are found in the depth interval 15–1000 m (Ikenoue et al., 2015, 2019). At the same time, the maximum abundance of individuals (living and dead forms) is confined to the interval of 15–300 m. In particular, according to D.N. Zasko, K.N. Kosobokova, live individuals of the species *Actinomma boreale* Cleve, 1899 were found in the Arctic in the Canadian Basin in the 50–500 m layer with a maximum abundance in the 50–100 m layer. But skeletons of this species, i.e. dead individuals, were found up to the maximum fished depths (3000 m).

The same species in the Makarov basin is vertically distributed as follows: live individuals inhabited the layer 25–1000 m with a maximum at depths of 50–100 m, and skeletons were also found up to the maximum fished depths and had the highest abundance in the layer 2000–3000 m. In the Amundsen basin, live individuals of this species were found only in the 25–300 m layer; their maximum concentrations were confined to the 200–300 m layer (Zasko, Kosobokova, 2014). Since the Late Jurassic West Siberian basin was boreal, and in Western Siberia, radiolarians of the Volgian age were found in the core of many wells in the latitude band from

approximately 58°N to 66°N, the cautious analogies with the modern Arctic can be extended to Siberian material – radiolarians here, probably lived in the depth interval 25–300 m, forming a maximum abundance in the interval 50–100 m.

Recall that paleobatimetric analysis showed that the Bazhenov Sea of West Siberia was relatively deep, most researchers estimated its depth at 200–500 m (Zakharov, Saks, 1983; Braduchan et al., 1986, and others), possibly deeper, up to 700–750 m in the deepest parts (Bochkarev et al., 2008). At the same time, the near-bottom anoxia environments with hydrogen sulfide contamination, developed in the West Siberian Sea, hindering the development of benthic epi- and infauna, did not have a noticeable negative effect on the habitat of radiolarians in the upper horizons of the water column. However, there is another point of view that high-carbon black shale rocks of the Bazhenov formation accumulated on a relative uplift – a shallow hilly plateau (Stafeev et al., 2019, and others).

Radiolarians are classical heterotrophs and symbiotrophs; they were and are consumers of the first level in pasture-type food chains, consuming organic matter produced by primary producers: phyto- (dinophytes, coccolithophores, prasinophytes) and bacterioplankton. At the same time, accumulating significant biomass, radiolarians were a secondary producer in food webs for consumers of a higher level, mainly for juvenile stages of development of various crustaceans, cephalopods, planktophagous fish, etc.

The resource food base for radiolarians in the Bazhenov basin was practically inexhaustible. Phytoplankton could produce at least two seasonal outbreaks of increased bioproductivity (flowering) during the year: spring (coccoliths) and summer-autumn (dinophytes).

Optimal hydrological (relatively high temperature, standard density, calm dynamics, transparency of waters), hydrochemical (normal salinity, high content of biophilic elements and dissolved silicon (dSi), saturation with dissolved gases, primarily oxygen) and ecotopic (eutrophicity, high trophic status) environmental factors and the presence of free ecological niches contributed to the rapid development of the radiolarian fauna in the Bazhenov basin at several stages.

The results of the vital activity of radiolarians were so high that they were one of the essential factors of sedimentogenesis, and the rock-forming role of radiolarians (Fig. 2) is very clearly seen during studies in scanning electron and optical microscopes.

The Upper Jurassic-Lower Cretaceous radiolarians of Western Siberia have been known for more than half a century and are now one of the most important tools for stratigraphic subdivision and correlation of sections of the region (Kozlova, 1983; Braduchan et al., 1986;

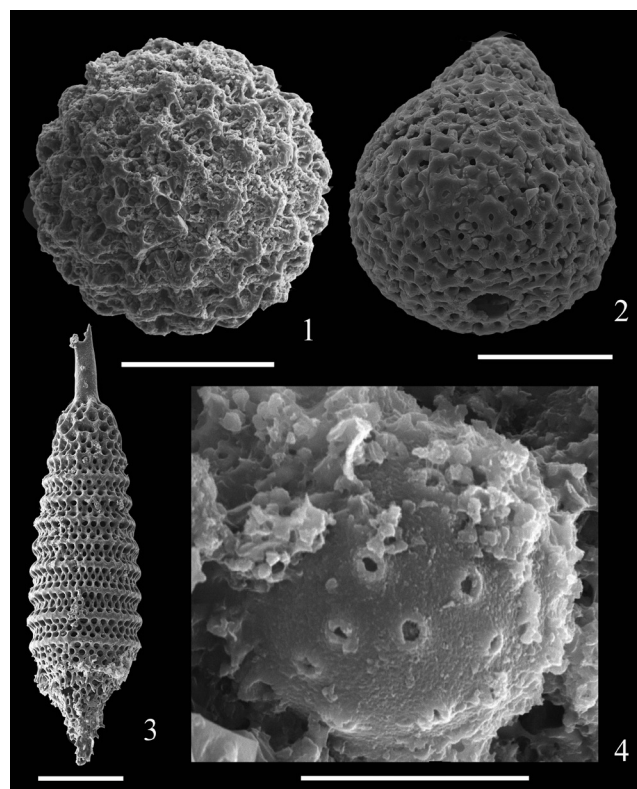


Fig. 4. Individual representatives of the radiolarians of the Bazhenov horizon, photographs in a scanning electron microscope. 1 – *Praeconocaryomma hexagonata* (Rüst), specimen. GIN No. 651/2-048, Gubkinskaya area, middle Volga substage; 2– *Williriedellum salyicum* (Kozlova), specimen. GIN RAS No. 651/5-4-067 (1), Gubkinskaya square, Berrias; 3 – *Parvicingula blowi* Pessagno, specimen. GIN No. 170/1-018, South-Tambeyskaya area, lower Volga substage; 4 – *Siphonosphaera* sp., Specimen. GIN No. 170/1-TRI-90, South-Tambeyskaya area, lower Volga substage. The length of the scale bar: 1.2 – 100, 3 – 50, 4 – 10 microns.

Amon et al., 2011; Vishnevskaya, 2013; Panchenko et al., 2015; Vishnevskaya et al., 2018a, 2018b, 2020). At the same time, there are still many unclear aspects and incomprehensible features of their paleogeographic distribution and paleobionomy that require further study. In particular, attention should be paid to the relationship of various types of skeletal structures, the ratio of morphotypes and the dominance of certain forms, depending on the specific living conditions. Thus, in the Lower Volga deposits, radiolarians are represented by all typical morphological groups: spheroid group (Fig. 5, obj. 2, 3, 5, 15), discoid (Fig. 5, obj. 1, 4, 6–14, 21, 29), prunoid (Fig. 5, obj. 30), cyrtoid (Fig. 5, obj. 16–20, 22–28). For the Middle Volgian deposits, according to preliminary observations, it can be concluded that cyrtoid morphotypes dominate, spheroidal morphotypes are numerous, and discoid and prunoidal ones are less represented, which definitely indicates normal marine pelagic settings in the region. As a rule, the sharp predominance of cirtoid forms may indicate the existence of stable upwelling currents such as upwelling.

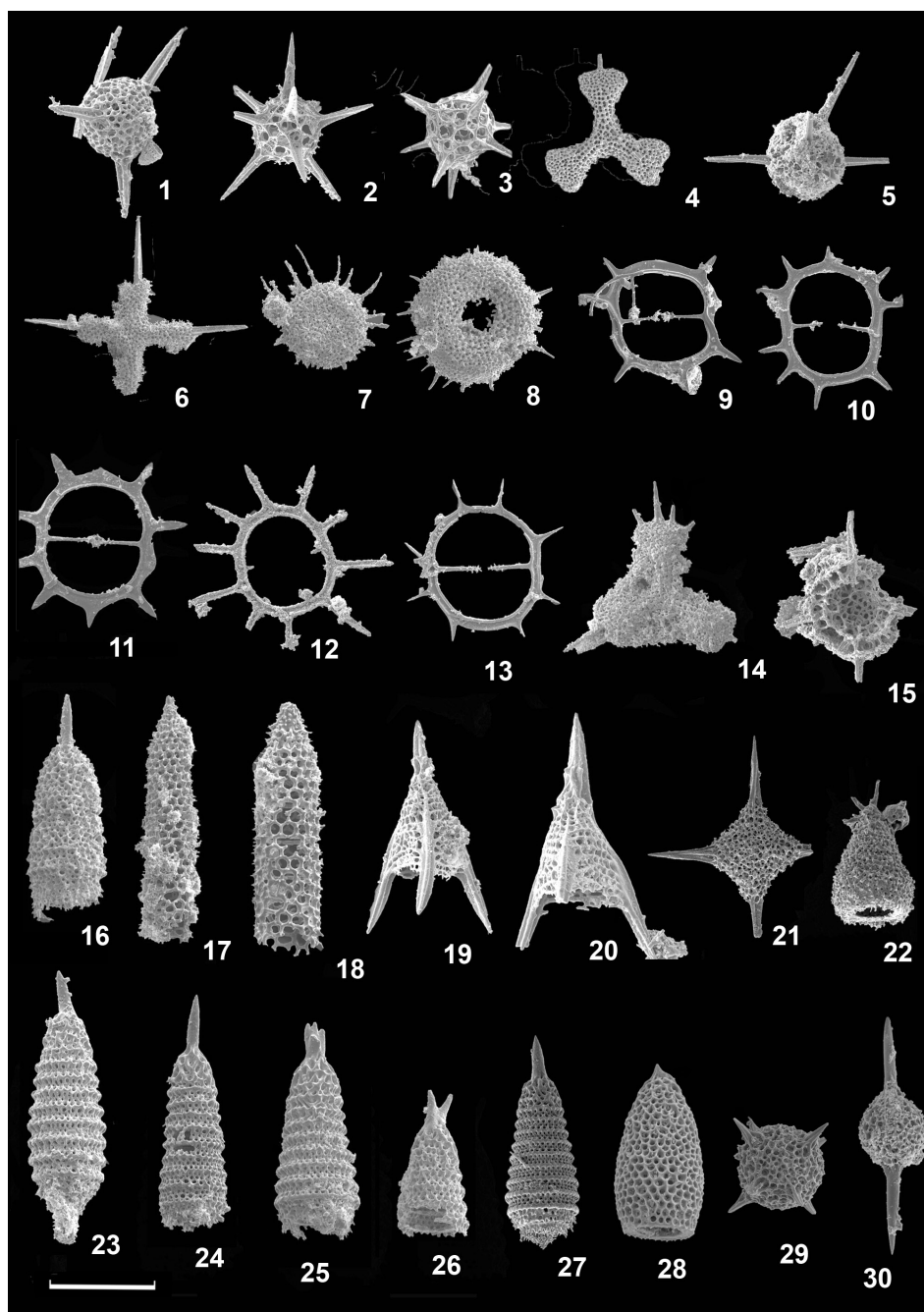


Fig. 5. Morphological groups of radiolarians of the Bazhenov horizon, South Tambeyskaya area, Lower Volga substage: 1, 4, 6–14, 21, 29 – discoid; 2, 3, 5, 15 – spheroid group; 16–20, 22–28 – cirtoid; 30 – prunoid; photographs in a scanning electron microscope. 1 – *Tripocyclia trigonum* Rüst; 2, 3 – *Actinomma frigida* Kiessling; 4 – *Santonaella* cf. *obesa* Yang; 5, 15 – *Centrocupidae* (?) Gen. et sp. indet.; 6 – *Higumastra inflata* Baumgartner gr.; 7, 8 – *Orbiculiforma* cf. *teres* Hull; 9–11 – *Acanthocircus* cf. *minispineus* Yang; 12 – *Acanthocircus* cf. *yaoi* Yang; 13 – *Acanthocircus* aff. *breviaculeatus* Donofrio et Mostler; 14 – *Homoeoparonaella* cf. *barbata* Hull; 16 – *Parvicingula gorda* Hull; 17, 18 – *Triversus* cf. *fastigatus* Hull; 19, 20 – *Napora* aff. *cruda* Yang; 21, 29 – *Spongostaurus* sp.; 22 – *Arctocapsula* cf. *devorata arctica* (Vishnevskaya et Murchey); 23, 25, 27 – *Parvicingula blowi* Pessagno; 24 – *P. jonesi* Pessagno s.l.; 26 – *Parvicingula* sp. A; 28 – *Parvicingula* sp.; 30 – *Archaeospongoprunum* sp. The length of the scale bar is 100  $\mu$ m.

With the radiolarian necromass, a significant gross amount of organic matter came to the bottom of the basin, and in the form of its most valuable part – lipids. Therefore, radiolarians can be considered as a group of planktonic microorganisms capable, under certain conditions, of serving as an important source of organic matter that could contribute to the formation of oil

(Amon, 2011). This correlates with the previously stated considerations that: “The most favorable for the formation of oil deposits are types ... and classes ... of sections with members of high-resistivity siliceous, carbonate and siliceous-carbonate sapropelic-clayey rocks confined to depressions and slopes of uplifts” (Polyakova et al., 2001, p. 70).

System	Stage/ substage		Zones of radiolarians (Vishnevskaya et al., 2020)	Exploration areas		
				Nannoplankton	Calcisphaera	Calcarea
Cretaceous	Berriasian – Valanginian		Williriedellum		Aprelskaya, Vostochno-Panlorskaya, Zapadno-Unlorskaya, Zapadno-Tashinskaya, Vatieganskaya, Emangalskaya, Novoortyagunskaya, Em-Egovskaya	
	Berriasian	Upper	Parvicingula khabakovi – Williriedellum salymicum	Aprelskaya, Emangalskaya, Yuzhno-Yagunskaya		Aprelskaya, Emangalskaya, Molodezhnaya, Radonezhskaya
Parvicingula rotunda – P. alata			Emangalskaya, Verkhnesalymyskaya, Severo-Nivagal'skaya	Molodezhnaya, Galiyanovskaya, Sredne-Shapkinskaya, Nizhne-Yanlotskaya	Emangalskaya, Molodezhnaya	
Parvicingula jonesi – P. excelsa						
Jurassic	Tithonian	Lower	Parvicingula antoshkinae – P. blowi			Gubkinskaya, Em-Egovskaya, Yuzhno-Tambeyskaya

Tab. 1. Biostratigraphic units of the Bazhenov formation along radiolarians and the distribution of microfossils in the sections of the Bazhenov formation of exploration areas

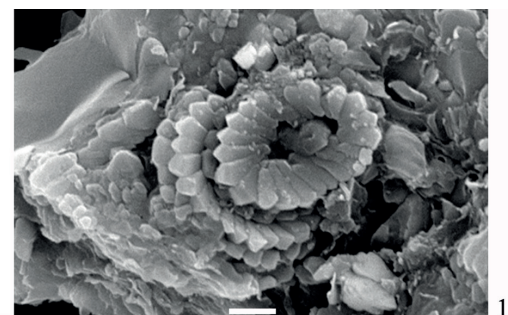
### Coccolithophorids

For nanoplanktonic coccolithophorids (coccolithin), formally attributed to the golden algae Chrysophyta (otherwise haptophytes, primnesiophytes, Haptophyta, Prymnesiophyta), it is characteristic that the maximum concentration of their modern living individuals is observed near the coast (Korchemkina, Lee, 2015). However, during periods of anomalous blooms of these microalgae, apparently caused by winter convection inflows of deep waters and wind mixing, blooms begin (start) in deep-water zones and quickly (within 2–3 weeks) cover the shelf and coastal waters (Yasakova, Stanichny, 2012).

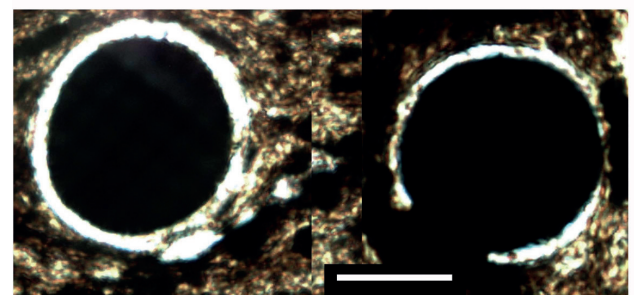
This is typical for both the Black Sea (southern closed water body) and the Norwegian Sea (northern open water body). The normal habitat depth is limited by the photosynthetic zone and does not exceed 100 m, despite the fact that they can inhabit above areas of different depths, up to the abyssal. These representatives of nanoplankton are known for their ability to multiply rapidly, causing algal bloom in huge water areas.

In Western Siberia, finds of coccolithophorids are mainly confined to the upper Bazhenov horizon, and these micro-fossil algae are most often very poorly preserved and are represented by the so-called “relics of coccolithins” (Fig. 6, obj. 1) (Panchenko et al., 2015; Vishnevskaya et al., 2018b; Eder et al., 2019). In some cases, the species definitions of forms belonging mainly to the genus *Watznaueria* are possible – these are massive coccoliths, more resistant to dissolution. Among them, *Watznaueria barnesae* (Black), *W. fossacincta* Black, and *Watznaueria* sp. indet. (Ustinova et al., 2014, Vishnevskaya et al., 2019b). In addition to *Watznaueria fossacincta*, *W. barnesae*, *W.?* *britannica* Stradner, *W.* sp.

(small), *Cyclagelosphaera tubulata* Grün et Zweili, *C. margerelii* Noël, *Biscutum* sp. (large), *Zeughrabdodus erectus* (Deflandre) (Vishnevskaya et al., 2018b). This is a very poor complex, and the reason for the depletion



1



2

Fig. 6. Separate representatives of coccolithophores and dinophytes of the Bazhenov Horizon. 1 – shell of coccolithophorids in a siliceous-carbonate rock; Upper Salym mega-wall, Upper Volga substage, sample no. 72/3003, photograph in a scanning electron microscope (photo by N.S. Balushkina). The length of the scale bar is 1 μm. 2 – calcareous dinocysts, left *Colomisphaera(?) fortis* Rehánek, specimen. 11-23, right *Stomiosphaerina cf. proxima* Rehánek, specimen. 11-23-1, April Square, Berriasian (Vishnevskaya, 2017, Fig. 13C and Fig. 12, respectively), optical photography in transmitted light. The length of the scale bar is 15 microns.

of the nanoplankton complex of the Bazhenov formation is, possibly, the relatively large depth of the basin and remoteness from the coastline.

Yu.N. Zanin and colleagues (Zanin et al., 2012) identified *Ellipsagelosphaera keftalrempti* Grun, *E. bazhenovi* Zanin, *E. ovata* Bukry, *Cyclagelosphaera*. All these species have a wide age interval and are not suitable for accurate determination of the age of the enclosing strata, but are important for fixing the stable existence of food chains and deciphering paleogeography.

The role of prasinophyte picoplankton representatives (class Prasinophyceae of the Green algae division) in the general ecology of the sea has been little studied due to their very small size.

### Palynomorphs and dinocysts

Microfossils of the Bazhenov horizon are also represented by palynomorphs and dinophytes. If palpine residues are not *sensu stricto* plankton, then dinoflagellates (dinophytes) belonging to a peculiar group of phytoplankton are characterized by the fact that they can form populations of significant density, forming from 30 to 54 % of the species composition of phytoplankton and up to 89 % of its biomass in summer-autumn season. It is believed that the nutritional value of biomass (the ratio of organic matter to dry ash residue) formed by dinophytes is very important, significantly exceeding that of other phytoplankton representatives.

According to the results of palynological studies, a large number of palynomorphs can be traced in the roof part of the Bazhenov formation and in the lower reaches of the Achimov formation. These are pollen of *Podocarpidites* sp., *Piceapollenites* spp., *Classopollis*, *Cycadopites* spp., *Quaraeculina limbata*, *Callialosporites dampieri*, *Sciadopityspollenites macroverrucosus*, *S. multiverrucosus*; spores *Leiotriletes* spp., *Gleicheniidites*, *Osmundacidites* spp., *Cyathidites* spp., *Ebora ciatorosa*, *E. granulosa*, *Contignisporites problematicus*, *Lycopodium sporites* sp., *Neoraistrickia truncata*, *Densoisporites velatites pseudosporosis* microphytoplankton – prasinophytes *Tasmanites* spp., *Pterospermella* spp. and acritarchs *Micrhystridium* sp., *Fromea amphora* (Panchenko et al., 2015).

Among the organ-walled dinocysts, *Hystrichodinium pulchrum*, *Circulodinium* sp., *Sirmiodinium grossi*, *Systematosphora* sp., *Cassiculosphaeridia magna*, *Batioladinium radiculatum*, *B. jaegeri*, *B. varigranosum*, *Bourkidinium granulatum*, *Giocilentina*. Unfortunately, no comprehensive paleontological and stratigraphic characteristics have been provided, and no age estimate has been given for this pollen spectrum and the dinocyst assemblage (Panchenko et al., 2015, p. 21).

At the top of the Bazhenov formation, calcareous dinocysts were found (Vishnevskaya, 2017; Vishnevskaya

et al., 2018b) (Fig. 3, obj. 3., Fig. 6, obj. 2), which have not been studied or described here until now. Previously, such micro-objects were designated as “calcispheres”, “calcispherides”, and recently there have been publications indicating their belonging to cysts of calcareous dinoflagellates (Vishnevskaya, 2018; Vishnevskaya, 2017; Kietzmann, Scasso, 2019). Note that the use of calcareous dinocysts for stratigraphy has great potential, since a representative spectrum of these microfossils has been found in many sections of the Bazhenov formation.

In the sections of the Bazhenov formation in Western Siberia, an association of dinoflagellate calcareous cysts has been established, which contains typical calcispheres of the Tithonian–Berriasian, such as *Stomiosphaerina proxima* Rehánek, *S. wanneri* (Borza), *Colomisphaera fortis* Rehánek, *C. tenuis* (Nagy), *C. conferta* Ch. volgeri (Borza), *Stomiosphaera? alpine* Leisnerch, *Cadosina semiradiata olzae* Nowak, *Colomisphaera lapidosa* (Vogler) (Vishnevskaya et al., 2018a, 2018b; Vishnevskaya, 2017; Vishnevskaya et al., 2019a, 2018b). The Bazhenov association of calcispheres is in many ways similar to the Antarctic, where the Tethyan zones *Carpistomiosphaera borzai*, *Carpistomiosphaera malmica*, *Parastomiosphaera malmica*, *Colomisphaera tenuis*, *Colomisphaera*.

It is interesting that calcareous dinocysts were found in the biohorizons *Parvicingula haeckeli* and *P. khabakovi* of the Latitudinal Ob region (Vishnevskaya et al., 2018a, 2018b), where, together with radiolarians, numerous *Stomiosphaerina proxima* Rehánek, *S. wanneri* (Borza), *Colomis tenuis* (Nagy) (Vishnevskaya et al., 2018a, 2018b; Vishnevskaya, 2017; Vishnevskaya et al., 2019a, 2018b), comparable to the forms of the northern periphery of the Tethyan belt (Reháková, 2000; Michalík et al., 2016).

### Other micro-objects

*Spicules of flint sponges.* In the Bazhenov formation, we and other researchers (Karnyushina, 2003 and others) also found numerous microspicules (elements of the mineral skeleton) of flint sponges (Fig. 2, obj. 4, 5). Flint sponges are the only group of benthic organisms that concentrate silica to form large needles (or spicules) of macrosclera, as well as thin, often very complex microsclera (Vishnevskaya et al., 2009). At the top of the Bazhenov Formation, microlayers of spongolites, composed of microspicules of flint sponges, predominantly uniaxial, are encountered. All spicules are straight, have even and smooth rays, gradually thinning towards the ends. The spicules are distinguished by a high degree of symmetry and correct geometric shape, which indicates the normal salinity of the reservoir. The length of the spicules varies from 0.5 to 3 mm. The diameter of the spicules, respectively, varies from 0.01



to 0.1, sometimes to 0.2 mm, and the cross section of the axial channel, from 0.001 to 0.01 mm.

It is known that flint sponges, being colonial or solitary benthic organisms and belonging to passive filter feeders, can exist on the bottom areas with constant movement of bottom highly productive water layers (Koltun, 1964, 1966). In addition, all flint sponges can develop only in waters of normal salinity. Spicules of sponges from an abnormal salinity environment have an irregular geometric shape, curved and distorted. Most flint sponges are cold-loving, and flint sponges are thermophilic. All these factors (high content of nutrients, the presence of bottom currents supplying new portions of suspended matter, salinity, temperature) predetermine the places of settlement of sponges and the depth of their distribution.

A massive amount of flint sponges and their spicules were found at depths of 500–600 m, while off the coasts of Australia and Africa, the content of spicules was found above 10 spicule units per 1 cm<sup>2</sup>, and at the very coasts of Antarctica – up to 100–300 spicule units and more in the bottom water layers (Koltun, 1966). The distribution of spicules in the sediment is different: in the area of the slope of the continental step (“transitional area”), spicules of relatively shallow-water sponges inhabiting the shelf form their own sediments at a depth of 1000–3000 m and even enrich oceanic sediments at depths of up to 4000 m (Koltun, 1966). The drift of spicular material to the slope and foot of the continental step of the Antarctic continent is in direct proportion to the bottom currents. Spicules in significant numbers are transported over a distance of over 700 km from the place of their production or initial location. The intensity of drift is so great that in a number of cases there are much more spicules in sediments on the slope and in the coastal abyssal than in the adjacent areas of the shelf. Individual fragments of spicules were found in the surface layers of water (1–6 pieces per 1 L of water) (Koltun, 1966). In general, flint sponge spicules are good indicators of salinity, temperature, basin depth, and hydrodynamic conditions.

Based on these data, it is possible to assume that in the Bazhenov basin, flint sponges lived near the edge of the shelf, as well as on separate elevations of the over-deepened shelf, in the upper part of the continental slope, and on the underwater basements of the islands located in the place of the modern Urals. The settlements of flint sponges were characterized by linear or spotty island distribution, since spongolites do not form large continuous areas. Modern settlements of flint sponges are known not only on the shelf of Antarctica in areas of the bottom with high mobility of bottom waters, but also in the southwestern part of the Barents Sea, in the Sea of Japan, Okhotsk, and Bering seas, along the Pacific coast of the Kuril Islands (Petelin, 1954).

*Benthic foraminifera.* In rare cases, single shells of benthic foraminifera were found in thin sections (Fig. 3, obj. 6–9). At the base of the Bazhenov bituminous silty mudstones, there are single redeposited fragments of foraminiferal shells from the JF42 *Tolypammina virgula* – *Planularia pressula* foraminiferal zone complex (Upper Kimmeridgian–Lower Tithonian). Above, isolated secretory benthic foraminifera were recorded, belonging to the foraminiferal zone JF45 *Spiroplectamina vicinalis*–*Dorothia tortuosa* (Middle Volgian substage) (Amon, 2011).

### **Problematic microfossils: diatoms, silicoflagellates and acantaria**

The main rock-forming components of the Bazhenov Formation are represented by organic, siliceous, clayey, carbonate substances and sulfides. Bituminous deposits are characterized by a high content of authigenic silica of biogenic origin, and its accumulation was associated with the development of microorganisms with an opal skeleton in the basin, among which radiolarians, as well as diatoms and silicoflagellates, were named in the literature. But if the remains of radiolarians in the rocks of the Bazhenov formation have been reliably established for quite a long time (starting with the explorations of R.Kh. Lipman in 1948–1959), they are well confirmed by studies in a scanning electron microscope (Vishnevskaya et al., 2018a, 2018b, 2020), then, there is still no complete clarity about the silica-skeletal phytoplankton.

In respected publications on lithology, stratigraphy, paleogeography, and paleobionomy of the Bazhenov basin, diatom microalgae with an opal shell were either not mentioned at all (Zakharov, 2006; Eder et al., 2017, and others), or they were carefully discussed with a question mark (Yasovich, Poplavskaya, 1975; Zakharov, Saks, 1983; Braduchan et al., 1986), or, on the contrary, they spoke quite confidently (Karnyushina, 2003) and emphasized their great importance as a necessary component of the paleobiota (Ushatinsky, 1981, 1984). The presence of remains of diatoms in the Upper Jurassic of Western Siberia was noted by various researchers, for example, V.N. Vekshina in the articles of 1960 and 1962; R.A. Konysheva and R.S. Sakhibgareev in 1976; I.N. Ushatinsky in 1979. According to Ushatinsky (1981, 1984), the main source of biogenic silica in the sediments of the Bazhenov formation was diatoms, therefore, they also served as the main source of organic matter, and the contribution of other organisms is subordinate.

The presence of diatoms was sometimes spoken of to a presumptive degree: “Probably, along with radiolarians, siliceous phytoplankton — diatoms — coexist in the water column” (Eder et al., 2015, p. 26). F.G. Gurari spoke emotionally about the diatoms in the rocks of the Bazhenov strata: “And how many remains of organisms

were not noticed by researchers or died in the processes of sedimentation, secondary transformations of rocks, and even were simply destroyed during drilling! Almost nothing is known, for example, about a very numerous group of planktonic organisms, which are diatoms. The fact is that these organisms usually accumulate in abundance, but their shells are very fragile and easily destroyed ... If diatoms really did not inhabit the pelagic zone of the Bazhenov Sea, then the reason could be too high water temperatures” (Gurari et al., 1983, p. 8).

In a number of publications (Nemova, 2012; Danko, 2015, and others), a rather widespread and repeated from publication to publication point of view is stated that “The source of biogenic silica in the sediments of the Bazhenov basin is mainly the remains of radiolarian shells, less often of diatoms, silicoflagellates and silicon sponges” (Predtechenskaya et al., 2006, pp. 136–137; Vazhenina, 2010, p. 162), which admits the reality of the existence of diatoms and silicoflagellates in the pelagic zone of the Bazhenov Sea.

At the same time, such a point of view, in our opinion, is debatable, since there is no real evidence of the presence of remains of diatom shells and silicoflagellate skeletons in the rocks of the Bazhenov formation in the cited works, and this information is questionable. In particular, photos of pseudomorphisms of secondary carbonates (!) based on the remains of “shells of radiolarians, diatoms, and siliceous algae” were cited as evidence (Predtechenskaya et al., 2006, p. 139, Figs. 3, 4). However, these micro-objects (for example, Predtechenskaya et al., 2006, Fig. 4) prove little, since they are some amorphous formations in which any details of the structure of frustules and diatom belts or silicoflagellate skeletons are indistinguishable. Similarly, in the characteristics and in the photograph of the Bazhenov biomorphic silicite, which is called diatom-radiolarian (Predtechenskaya, Zlobina, 2017: 115, Fig. 1a, b), the remains of diatoms (?) and small radiolarians are completely replaced by carbonate and pyrite, which does not allow to speak with confidence about diatoms.

Our main doubt about the reality of the finds of diatom remains in the Bazhenov strata is that the very existence of diatoms in the Late Jurassic is debatable and raises serious objections. Back in 1974 N.I. Strelnikova noted that “Jurassic diatoms have not been reliably found. Those, until now belonged to the Jurassic diatoms has now undergone revision” (Strelnikova, 1974, p. 101).

Over the past decades, the situation, in comparison with the one described by N.I. Strelnikova, has changed little: as before, when they talk about the initial stages of the evolution of diatoms, they refer to what was published in 1896 and 1900. a report by A. Rothpletz about the discovery of the diatoms *Pyxidicula* from Leias Württemberg (northwestern Germany). However, this

message is recognized as very dubious and unverifiable (Katz et al., 2004; Sims et al., 2006; Kooistra et al., 2007).

If we do not take into account such paleontological fiction as reports on the discovery of diatoms in the Precambrian and Paleozoic (Siemińska, 2000; Kwiecińska, 2000; Siemińska and Kwiecińska, 2002), then the documented data on pre-Cretaceous diatoms are negligible. The only factual evidence of Jurassic diatoms was provided by D.M. Harwood with colleagues, who described the *Calyptosporium* diatoms from the Upper Jurassic–Lower Cretaceous continental (!) deposits of South Korea (Harwood et al., 2004; Sims et al., 2006; Kooistra et al., 2007). And the oldest well-preserved fossil remains of marine diatoms were recorded in the Cretaceous Aptian-Albian samples of the deep-sea drilling program in the Weddell Sea of the Atlantic sector of the South Ocean (ODP, Leg 113, Site 693, Weddell Sea) (Harwood, Gersonde, 1990; Sims et al., 2006).

There is also very little data on ancient Lower Cretaceous diatoms. R. Gersonde and D. Harwood provided an excellent review and revision of all published data, which in one way or another highlight the Early Cretaceous diatoms (Gersonde, Harwood, 1990). A little more than a dozen literary sources with reports of localities in Europe in the regions of Germany, the Polish Carpathians, the Ligurian Alps, Stavropol, Penza are named; in Canada, Northeast Alberta; Queensland in Australia, and the Weddell Sea in the South Ocean. At the same time, the shells of diatoms are very poorly preserved and pyritized, which often casts doubt on the definitions themselves.

It is noteworthy that Gersonde and Harwood analyzed the famous monograph by G. Rüst on the Jurassic radiolarians of Europe (Rüst, 1885), and found that among the siliceous microfossils (radiolarians, sponge spicules) extracted by Rüst from the so-called “coprolites” (in fact – from phosphorite nodules) in iron ore deposits (the layers are dated by Rüst Upper Lias – an Early Dogger based on the finds of two ammonites) in the Ilsede region (near Pein in Lower Saxony, Germany), six specimens of well-preserved diatoms are depicted (Rüst, 1885, Taf. 44, Figs. 1–6). These diatoms are very similar to those from the Aptian – Albian sediments of the Weddell Sea, and it is important that the age of the phosphorite nodules (= Rüst’s coprolites) is Albian, not Jurassic, and the ammonites are redeposited in Lower Cretaceous sediments (Kemper, 1973). The study of diatoms from the Ilsede locality showed that they are of Albian (Holt) age (Forti, Schulz, 1932; Gersonde, Harwood, 1990; Sims et al., 2006).

Some researchers believed, based on biogeochemistry data, that the evolution of planktonic diatoms began, according to biochemical markers (in particular, according to 24-nordiacholestanes) from the Late

Jurassic (Moldowan, Jacobson, 2000; Katz et al., 2004). It is also possible that, according to molecular phylogeny, this event can be attributed to the Early Jurassic, but possibly to the Middle Triassic (Kooistra et al., 2007; Cermeño, 2016; Medlin, 2016). However, it should be noted that this “virtual” data has not yet been supported by any paleontological evidence.

Earlier, in the Late Jurassic–Early Cretaceous cherts of the Lesser Caucasus, single microobjects similar to the shells of diatoms 0.05–0.15 mm in size were noted in thin sections, and it was suggested that they belong to the class *Centrophicea* (Vishnevskaya, 1984). But poor preservation and large size, in the absence of photographic images, cast doubt on the fact that this is a find of diatoms.

Summarizing the above, we can conclude that until now there is no possibility to speak with confidence about the real existence of diatoms in the pre-Cretaceous epoch. Therefore, the literature data on the diatoms of the Bazhenov formation are, most likely, unreliable.

The situation is somewhat different with silicoflagellates, which are also mentioned in the literature on the Bazhenov horizon (Predtechenskaya et al., 2006; Vazhenina, 2010). The opinion is quite typical that “Among the remains of organisms with a siliceous skeleton, radiolarians predominate in the rocks of the Bazhenov horizon. Less common are silicoflagellates, diatoms, and siliceous sponges” (Predtechenskaya et al., 2012, p. 134), however, no evidence was provided for the presence of silicoflagellates.

Among our material, in one of the samples from the South Tambeyskaya area in Yamal (Lower Volga substage), fragments of fossilized siliceous microbial objects were found (Fig. 3, obj. 5 in the lower right corner), consisting of openwork ligature of beams and needles. They are unloaded fragments of lattice chambers of forms from the family Poulpidae and peripheral rings of some Saturnalidae, so characteristic of the Tithonian of southern Germany (Dumitrica and Zügel, 2008) and recently found in the Lower Volga substage (Vishnevskaya et al., 2020). These fragments partly resemble fragments of silicoflagellate skeletons, also consisting of crossbeams (Glezer, 1966), and, possibly, similar formations served as the basis for judgments about the presence of silicoflagellates in the Bazhenov horizon. Of course, such finds require more close attention and serious study, but it should be emphasized that silicoflagellates are not typical of the Jurassic. Recall that earlier on the eastern slope of the Urals and in Western Siberia, based on materials from boreholes and natural outcrops, the most ancient silicoflagellates were found in the Upper Cretaceous (Santonian–Campanian) sediments. The complexes of these flint flagellated microalgae, in addition to Cretaceous, are characterized here in the Paleocene,

Eocene, and Oligocene, with silicoflagellates, as a rule, accompanying and subordinate to diatoms (Glezer, 1966).

In general, the most ancient, reliably documented finds of silicoflagellates are confined only to the Late Cretaceous (Santonian–Campanian), and their early evolution begins from this epoch (McCartney et al., 2010; Van Tol et al., 2012). Though, the first information about the finds of silicoflagellate (?) fragments appeared in the older Albian sediments of the Weddell Sea (McCartney et al., 2014) and the Southern Basin of Argentina (Pérez-Panera, 2015), but they still require rechecking.

In addition to the above-mentioned siliceous microfossils, others were also mentioned in the literature. An opinion was expressed (Zlobin et al., 2016), with reference to the finds in samples from the Golchikha formation of the Gydan facies region of Western Siberia, that the northeastern periphery of the Bazhenov Sea was inhabited by red algae, ascidians, and acantharians. These researchers attributed acantharians to radiolarians and indicated that: “some taxa of radiolarians used barium compounds of the  $Ba[Pt(CN)_4]$  type in the encrustation of the shell to create a protective mechanism against radioactive radiation” (Zlobin et al., 2016, p. 29). Moreover, “the ecosystem of the sea basin may have used acantharians, which glow under radiation exposure, as an indicator of an unfavorable habitat for many other organisms. Planktonic and nektonic accumulations of radiolarians, bioluminescent in yellow-green tones, scared off representatives of marine biota from dangerous areas, thereby preserving the gene pool of the biocenosis” (Zlobin et al., 2016, p. 38). We leave this statement of the cited authors about the fantastic role of “radiolarians” as “scarers” and “guardians of the gene pool” without a detailed commentary, noting only that radiolarians and acantharians are two different groups in the rank of types in the kingdom of the rhizarians, and in the more than 160-year history of the study of acantharians (since 1865), not a single(!) find of them in a fossil state has been recorded.

## Conclusion

The microfossils of the Bazhenov marine basin of Western Siberia known to date are represented by the remains of zooplankton (radiolarians) and phytoplankton (dinoflagellates, coccolithophorids), as well as, more rarely, microbenthos (benthic foraminifers and sponge spicules). Radiolarians, dinoflagellates, coccolithophorids, and foraminifera are used for biostratigraphic dissection of sections and their correlation, and, in addition, together with sponge spicules, to reconstruct the parameters and settings of the paleoenvironment. During the flourishing of the radiolarian fauna, the bioorganism produced by

radiolaria, and primarily lipids, was so large that this necromass, which enriched the silt bottom sapropels, could become one of the possible sources of oil.

A number of literary sources reported that, in addition to radiolarians, diatoms and silicoflagellates were the source of biogenic silica in the Bazhenov formation. However, the analysis showed that until now it is not possible to assert with confidence the existence of diatoms and silicoflagellates in the pre-Cretaceous epoch. Therefore, information about these microfossils in the Bazhenov formation is most likely unreliable.

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