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Source: Acta Palaeontologica Polonica, 57(4) : 773-790

Published By: Institute of Paleobiology, Polish Academy of Sciences

URL: https://doi.org/10.4202/app.2011.0040

Volgian and Santonian–Campanian radiolarian events of the Russian Arctic and Pacific Rim

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Vishnevskaya, V.S. and Kozlova, G.E. 2012. Volgian and Santonian–Campanian radiolarian events from the Russian Arctic and Pacific Rim. *Acta Palaeontologica Polonica* 57 (4): 773–790.

Radiolarians are widely distributed in two siliceous intervals that coincide with the Tithonian–Berriasian and Santonian–Campanian boundaries in the Mesozoic of the Russian Arctic and Pacific Rim. The first level is rich in organic matter and typical of Jurassic–Cretaceous boundary strata from the Russian North European Margin (Barents-Pechora, Volga-Urals, and Siberian hydrocarbon provinces, as well as western Kamchatka). Abundant and diverse representatives of the family Parvicingulidae provide a basis for establishing the new genus *Spinicingula* (uppermost Middle Volgian–Lower Berriasian); another new genus, *Quasicrolanium* (Upper Volgian–Upper Berriasian) is also described. A Santonian–Campanian siliceous interval with radiolarians is documented from the margins of northern Asia (eastern Polar Ural, Kara Basin, Kamchatka). The Boreal genus *Prunobrachium* makes its first appearance at the Santonian–Campanian boundary and reaches an acme in Campanian strata. Radiolarian data can be used for basin biostratigraphy and correlation, as well as palaeogeographical interpretation of these hydrocarbon-rich facies. The Arctic and northern Pacific rims are well correlated on the basis of parvicingulids, while in Sakhalin these are absent and calibrations are based on Unitary Associations zones of the Tethys. In addition to the two new genera noted above, five new species (*Parvicingula alata*, *Parvicingula papulata*, *Spinicingula ceratina*, *Lithostrobus borealis*, and *Spongurus arcticus*) are erected, while 60 radiolarian species typical of the Russian Arctic and Pacific rims are illustrated.

Key words: Radiolaria, events, new taxa, organic-rich cherts, Cretaceous, northern Russia.

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Received 9 July 2011, accepted 18 December 2011, available online 24 February 2012.

Introduction

There are four highly siliceous and organic-rich suites in Russia, which are unique and of great economic importance due to their high content of organic matter. The rocks of the Domanik (Upper Devonian), Bazhenovo (Upper Jurassic and Lower Cretaceous), Kuma (Paleogene) and Maikop (Neogene) suites are rich in siliceous tests of Radiolaria and sponge spicules. Studies of radiolarians of Bazhenovo suite have allowed the compilation of provincial zonal schemes and correlation with other regions. A good example and illustration of the use of radiolarians as a tool in evaluating stratigraphical and palaeoenvironmental aspects of hydrocarbon-rich sedimentary basins, is a special issue of *Micropaleontology* entitled "Radiolaria of giant and subgiant fields in Asia" which was published in 1993. In that volume, the emphasis was on the Asian part of the Eurasian continent; in consequence, the main oil and gas provinces of northern Europe were not included. Moreover, the generalised map of selected Eurasian basins (Blueford and Gonzales 1993) did not show any of the giant or subgiant fields of the Russian Arctic, exclusive of the western Siberian sedimentary basin, which is predominantly located in Siberia, but not in the Arctic. The North Sea, Norwegian Sea, and Barents Sea areas were not represented either.

Radiolarian biostratigraphy is vital for hydrocarbon exploration in these regions, because these biota often are the only fossils present. Because radiolarian assemblages are abundant and diverse, they can easily be used to constrain the age of core samples from drill sites in these hydrocarbon-rich successions. Recently, the Upper Jurassic and Lower Cretaceous Bazhenov oil-producing sequence of western Siberia and the Kimmeridgian and Volgian bituminous beds of northern Russia have attracted special attention (Hantzpergue et al. 1998; Zakharov 2006). Similar highly bituminous deposits are known along the Barents Sea margin and in the Volga-pre-Ural Basin, from Kara Sea, the Laptevs Sea margin and also from the Norwegian and North Seas. The origin

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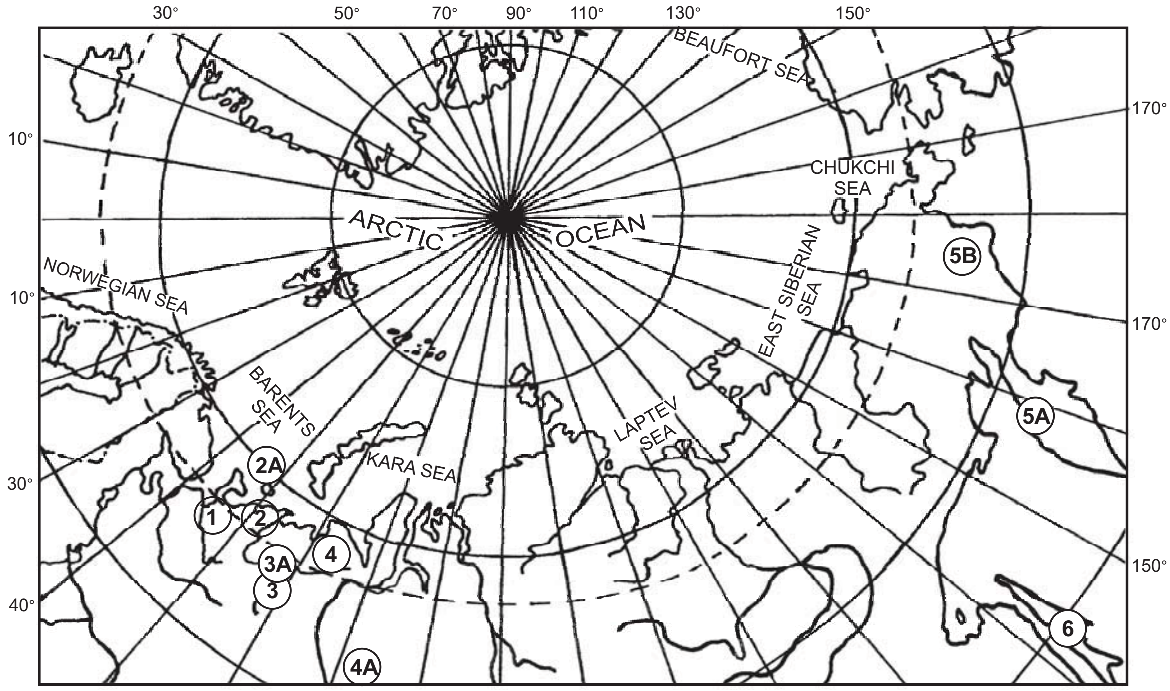

Fig. 1. Location of some radiolarian-bearing source rocks in the Russian Arctic and along the Pacific margins; localities A and B correspond to Fig. 2. 1, Mezen Basin, Pesha section. 2, southeastern Barents-Pechora Basin: 2, Narjan-Mar, borehole 5; 2A, Kolguev, borehole 140. 3. Volga-Pre-Ural Basin: 3, Shilovka section; 3A, Gorodicshe section, Uljanovsk region. 4, Northern and western Siberian basins: 4, Polar Ural, borehole 22; 4A, Upper Salym, borehole 17. 5, western Kamchatka and Chukotka: 5, Palana section; 5A, Omgon; 5B, Semiglawaya Mountains. 6, Sakhalin.

of the Volgian siliceous combustible shaly sequence is of great importance, so as is subject of constant discussions. Typically, these deposits, rich in organic matter, are non-calcareous, hydrophobic and distinguished by higher radioactivity among country rocks. Previously it has been shown that the Volgian combustible shaly sequences of the Bazhenov suite of western Siberia and the Norwegian continental shelf of the Barents Sea are essentially enriched relative to common clay rocks by organophilic elements which accompany sapropelic organic matter: V ten times higher than normal, Ni six times, Cu and Zn two to three times as much as the average of Recent oceans; 60% of U, Mo, As, Sb of their quantity in present-day oceans (Gavshin and Zakharov 1991). It has also been noted that deposits of that kind occur at different stratigraphic levels in the major oil and gas basins; within the Persian Gulf in the Callovian and Oxfordian, in the North Sea in the Kimmeridgian (Galimov 1986). For this reason, it is important to determine the chronostratigraphic position of these deposits as precisely as possible within the Volgian in the Boreal Realm, as well as to try to locate its equivalents in the Tethyan Realm. Radiolarian biostratigraphy offers the best means to make such important chronostratigraphic correlations, because these biota are common in these oil shale sequences. In addition, radiolarian biostratigraphy is well established for this time interval in the Tethyan Realm (Baumgartner et al. 1995; De Wever et al. 2001) as well as in the present day California (Pessagno 1977; Hull 1997; De Wever et al. 2001).

Here we consider two siliceous intervals: the Volgian and the Campanian. Because siliceous bituminous rocks of the Russian Arctic and along the Ural margin are part of the concept of the Volgian Stage (i.e., the Bazhenovo productive horizon and others), the stratigraphic correlation of the Boreal Volgian Stage with its counterpart in the Tethyan province needs to be considered. Based on the views accepted by the Interdepartmental Stratigraphic Committee of Russia (Zhamoida and Prozorovskaya 1997), the Upper Volgian Substage corresponds to the lower Berriasian (Lower Cretaceous), while the Middle Volgian Substage equates with the Tithonian (Upper Jurassic). Thus, the Volgian siliceous interval is the highest interest with regard to the position of the Jurassic–Cretaceous boundary, which is situated between the Middle and Upper Volgian.

Institutional abbreviations.—GIN, Geological Institute, Moscow, Russia; VNIGRI, All-Russia Petroleum Research Exploration Institute, Sankt-Peterburg, Russia.

Historical background

The Mesozoic radiolarians of the Russian Arctic Margin were first studied by Kozlova and Gorbovetz (1966) and Kozlova (1971, 1983, 1994b). Three different radiolarian assemblages were introduced for the Jurassic (Lower Kimmeridgian, Middle Volgian and Upper Volgian) of the Timan-Pechora region (Kozlova 1971, 1994b) and the Middle Vol-

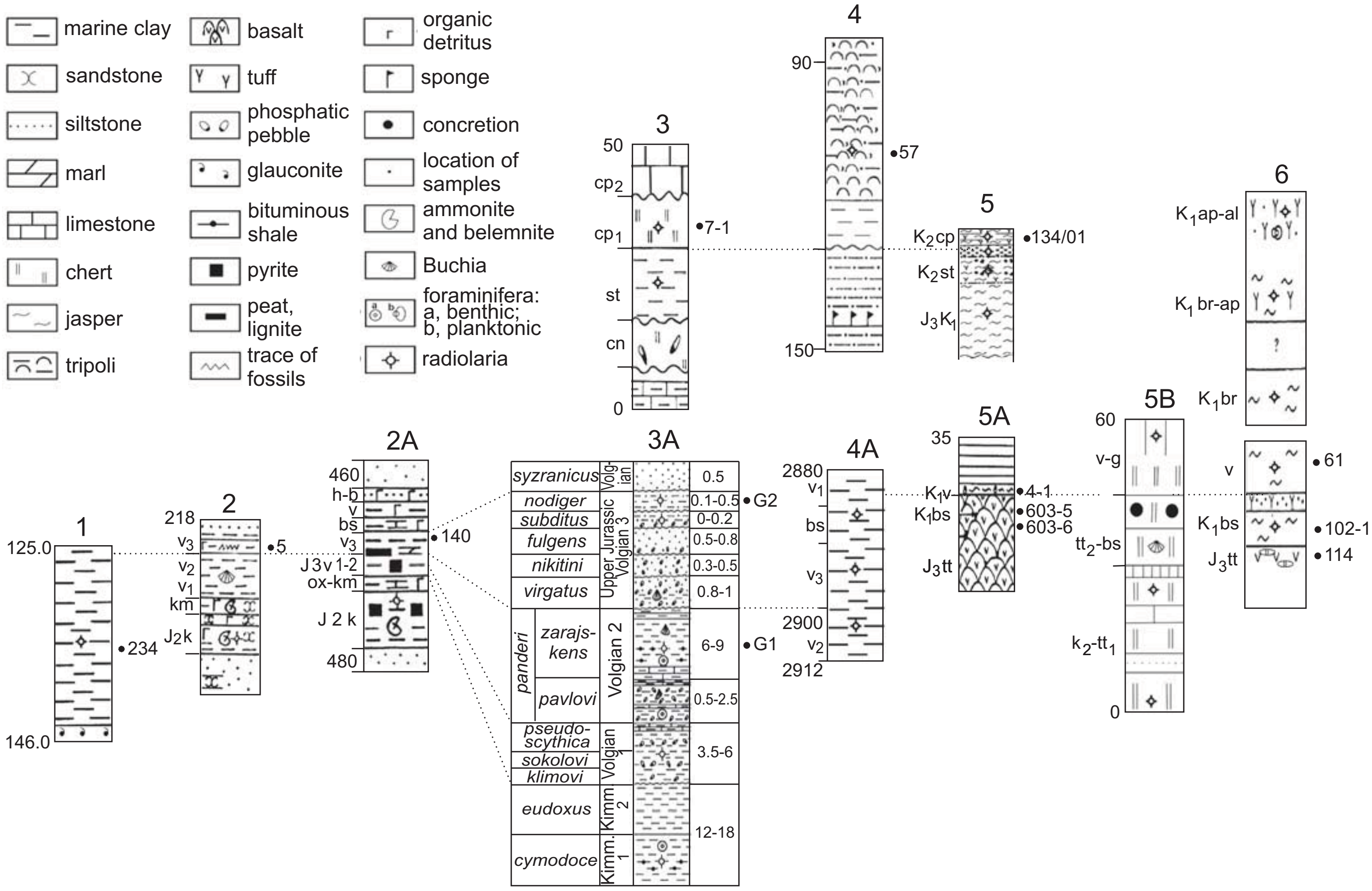

Fig. 2. Correlation of Upper Jurassic and Cretaceous sequences from the Barents-Pechora region of the Arctic to Sakhalin in the far east of the Pacific Margin. Localities: 1, Mezen Basin, Pesha section. 2, southeastern Barents-Pechora Basin: 2, Narjan-Mar, borehole 5; 2A, Kolguev, borehole 140. 3, Volga-Pre-Ural Basin: 3, Shilovka section; 3A, Gorodicshe section, Uljanovsk region. 4, Northern and western Siberian basins: 4, Polar Ural, borehole 22; 4A, Upper Salym, borehole 17. 5, western Kamchatka and Chukotka: 5, Palana section; 5A, Omgon; 5B, Semiglawaya Mountains. 6, Sakhalin. Abbreviations for Jurassic: k, Callovian; km, Kimmeridgian; ox, Oxfordian; tt, Tithonian; v, Volgian regional stage. Abbreviations for Cretaceous: al, Albian; ap, Aptian; br, Barremian; bs, Berriasian; cn, Coniacian; cp, Campanian stage; h, Hauterivian; st, Santonian; t, Turonian; v, Valanginian.

gian, Middle/Upper Volgian, and Upper Volgian of Siberia (Kozlova 1983), as well as the Lower and Upper Campanian of Siberia (Kozlova and Gorbovetz 1966). All radiolarians of the Timan-Pechora region studied (Kozlova 1971, 1994b) were collected from soft clays and illustrated exclusively by line drawings (Kozlova 1971, 1983). Only the 1994a paper by Kozlova contains scanning electron micrographs, but in turn the descriptions are missing. The Late Jurassic to Early Cretaceous radiolarians of Siberia were studied in thin sections and no images of species are available (Kozlova 1983; Lipnizkaya 2006). The Late Cretaceous radiolarians of Siberia were illustrated in line drawings (Kozlova and Gorbovetz 1966). Moreover, the 1994b paper by Kozlova and two abstracts of papers presented at international conferences (Kozlova 1994a, c), and some other key contributions (Braduchan et al. 1984; Repin et al. 1999) listed several names of new genera and species, among them *Colgus* (Kozlova 1994c), *Pseudocrolanium* (Kozlova 1994a), *Quasicrolanium* (Repin et al. 1999), *Excingula*, *Spinicingula*, *Parvicingula alata*, *Parvicingula papulata*, *Parvicingula simplicima* (Kozlova 1994b) and others, which, to this date, were never formally introduced remaining merely nomina nuda. A new family was erected by Bragin (2009) for material from Arctic Siberia. Some new radiolarian species were also described from the Pechora Basin (Vishnevskaya 1998) and the Polar Ural (Vishnevskaya 2011). The Mesozoic radiolarians of the Russian Pacific margin have been studied both in thin sections by Lipman and Zhamoida (Vishnevskaya 2001) and by means of the SEM (Vishnevskaya et al. 2005).

The lack of proper descriptions of the above-mentioned genera and species hampers correlations. Therefore, the objectives of the present paper are threefold. First, to erect formally some endemic genera and species from organic-rich shales along the Russian Arctic Margin; secondly, to re-examine the radiolarian assemblages of the Volgian, Berriasian/Valanginian and Campanian intervals of the Russian Arctic and Pacific Margin and to supply images and descriptions of the characteristic species; and lastly, to compare and correlate the Tithonian–Berriasian and Santonian–Campanian boundaries of the Russian Boreal province on the basis of radiolarians.

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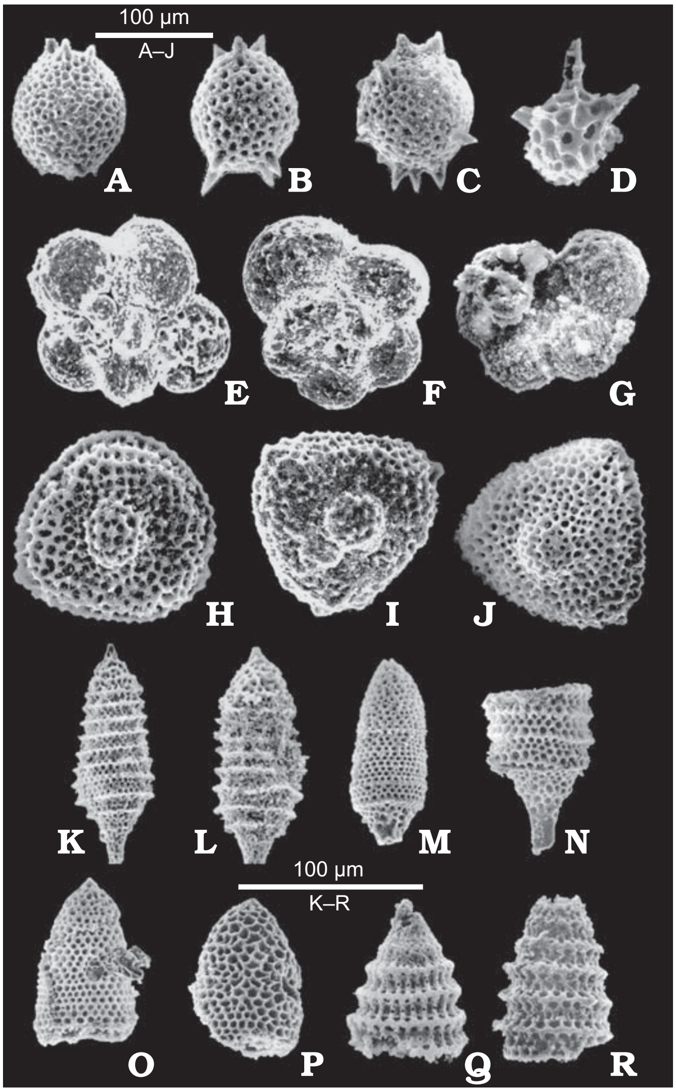

Fig. 3. Types of microfaunas from Kamchatka. A–J. Palana Section: Campanian spumellarians (A–D), Santonian foraminifera (E–G), Santonian radiolarians (H–J). K–R. Omgon section: Tithonian parvicingulids (K–N), Jurassic nassellarians (O–R). **A**–**C**. *Lithomespilus mendosa* (Krasheninnikov, 1960). **A**. GIN 76a. **B**. GIN 76b. **C**. GIN 76c. **D**. *Amphisphaera goruna* (Sanfilippo and Riedel, 1973), GIN 76/v. **E**. *Archeoglobigerina bosqiensis* Pessagno, 1967, GIN N 173/99/F1. **F**. *Hedbergella holmdelensis* Olsson, 1964, GIN N 173/99/F2. **G**. *Hedbergella delrioensis* (Carsey, 1926), GIN N 159/99. **H**. *Pseudoaulophacus venadoensis* Pessagno, 1976, GIN N 202/01/1. **I**, **J**. *Pseudoaulophacus floresensis* Pessagno, 1963. **I**. GIN N 202/01/2. **J**. GIN N 202/ 01/3. **K**–**N**. *Parvicingula omgoniensis* Vishnevskaya, 1998. **K**. GIN N 604/3k. **L**. GIN N 604/3l. **M**. GIN N 604/3m. **N**. GIN N 604/3n. **O**–**R**. *Parvicingula* sp. **O**. GIN N 603/5/7. **P**. GIN N 603/5/2. **Q**. GIN N 603/5/5. **R**. GIN N 603/5/1.

Geological setting

In the section below, radiolarian events are reviewed for six areas of the Russian Arctic: Mezen, southeastern Barents-Pechora, Volga-pre-Ural, northern and western Siberia, western Kamchatka, and Chukotka, and Sakhalin (Fig. 1, Table 1). A provisional calibration of the various radiolarian Boreal zonations for these areas with the Mesozoic time scale and other zonations is shown in Tables 1 and 2.

The Mezen Basin.—This basin is the northwestern segment of the East European Craton. Its rift origin was documented by deep seismic, wide-angle reflection, refraction, and profiling studies carried out by the GEON Centre in 1985 and by Spetsgeofizica in 2001–2002 (Kostyuchenko et al. 2006). The seismic data from these two basins have been used to identify several tectonic units within the basement, related to rifting and a weakly reflected sedimentary cover. Within the Middle–Upper Volgian sequences, highly bituminous shale is widely distributed in this area.

Abundant Middle Volgian radiolarians were recovered from borehole 234 (Fig. 2: locality 1) in the central part of the Pesha Depression in the Chekh-Gulf of Barents Sea (Fig. 1). The Volgian radiolarian-bearing deposits are represented by 20 m of bituminous shale and clay. The emphasis was on the Middle Volgian (= Late Tithonian) *Parvicingula haeckeli* Zone (Fig. 4). The coeval radiolarian association is widely distributed, having been documented also from borehole of 61 on the left bank of the Pesha River (Sysola River Basin) and borehole 6406/6-1 in the Norwegian Sea (Kozlova 1994b).

The Middle Volgian radiolarian assemblage of sample 234 from borehole 234 (Fig. 2: locality 1) is represented by *Orbiculiforma iniqua* Blome, 1984; *Orbiculiforma mclaughlini* Pessagno, 1977; *Orbiculiforma retuza* (Kozlova, 1971); *Hagiastrum* cf. *plenum* Rüst, 1885; *Pentalastrum* sp. 1; *Tetraditruma* aff. *emilei* Hull, 1997; *Caneta blomei* (Yang, 1993); *Pseudoeucyrtis* aff. *paskentaensis* Pessagno, 1977; *Stichomitra* sp. A sensu Kiessling, 1999; *Parvicingula alata* Kozlova and Vishnevskaya sp. nov.; *Parvicingula grantensis* Pessagno and Whalen, 1982; *Parvicingula haeckeli* (Pantanelli, 1880); *Parvicingula* cf. *jonesi* Pessagno, 1977; *Parvicingula* cf. *blowi* Pessagno, 1977; *Parvicingula* cf. *obstinata* Hull, 1995; *Parvicingula* cf. *rothwelli* Pessagno, 1977; *Praeparvicingula* aff. *sencilla* Hull, 1995; *Praeparvicingula* cf. *rotunda* Hull, 1995; *Praeparvicingula holdsworthi* (Yang, 1993); and *Zhamoidellum boehmi* Kiessling, 1999 (Fig. 4).

The radiolarian faunas are characterised by low diversity, but high abundance of *Parvicingula* and spongy spumellarians and nassellarians, and the complete absence of Tethyan species and genera (Baumgartner et al. 1995), such as *Tritrabs*, *Andromeda*, *Mirifusus*, *Podobursa*, and *Tethysetta*. Foraminifera co-occur with radiolarians in some samples, including the benthic species *Lenticulina ponderosa* Mjatluk, 1939; *Saracenaria pravoslavlevi* Fursenko and Polenova, 1950; *Geinitzinita nodulosa* (Fursenko and Polenova, 1950); *Kutsevella labythnangensis* (Dain, 1972); and others (Fig. 5). They belong to the *Lenticulina ponderosa* assemblage, which corresponds to the *Dorsoplanites panderi*–*Virgatitus virgatus* ammonite zones (Lyrov and Vishnevskaya 2000). Samples also contain numerous sponge spicules, ostracods, and algal debris (Fig. 5).

This discovery of assemblages in eastern Europe that are dominated by *Parvicingula* sensu lato, which is indicative of

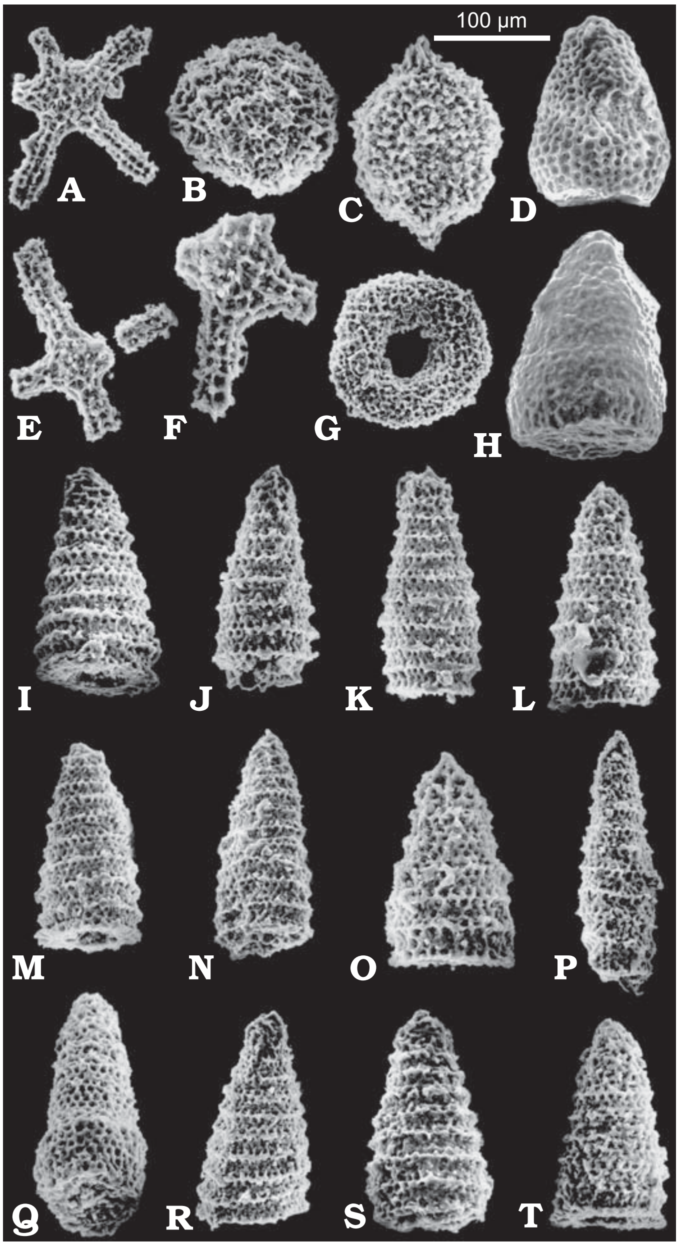

Fig. 4. Scanning electron micrographs of Late Jurassic radiolarians from siliceous clay rocks in northern Russia, Barents offshore. Sample 234, Middle Volgian (*Dorsoplanites panderi* Ammonite Zone) of the Pesha River Basin, borehole 234 (A–C, E–G, I–T). Sample G2, Late Volgian (*Craspedites subditus* Ammonite Zone) of the Uljanovsk Volga Basin, species from siliceous clay rocks in northern Russia, section Gorogische (D, H). **A**. *Pentalastrum* sp., GIN N 234-R-15. **B**. *Praeconocaryomma hexagona* (Rüst, 1898), GIN N 234-R10. **C**. *Stylartus* sp., GIN N 234-R12. **D**. *Stichocapsa devorata arctica* Vishnevskaya and Murchey, 2002, GIN N G-2-R1-3. **E**, **F**. Hagiastridae. **E**. GIN N 234-R11a. **F**. GIN N 234-R11b. **G**. *Orbiculiforma*? *retuza* (Kozlova, 1971), GIN N 234-R13. **H**. *Spinicingula ceratina* Kozlova and Vishnevskaya sp. nov., GIN N G-2-R1-5b. **I**. *Praeparvicingula* aff. *sencilla* Hull, 1995, GIN N 234-R21. **J**, **M**. *Parvicingula* cf. *jonesi* Pessagno, 1977. **J**. GIN N 234-R18b. **M**. GIN N 234-R18c. **K**. *Parvicingula jonesi* Pessagno, 1977, GIN N 234-R18a. **L**. *Parvicingula blowi* Pessagno, 1977, GIN N 234-R16. **N**. *Parvicingula* cf. *grantensis* Pessagno and Whalen, 1982, GIN N 234-R19b. **O**. *Praeparvicingula holdsworthi* (Yang, 1993), GIN N 234-R17. **P**. *Parvicingula* cf. *obstinata* Hull, 1995, GIN N 234-R23b. **Q**. *Stichocapsa* sp., GIN N 234-R27. **R**. *Parvicingula rothwelli* Pessago, 1977, GIN N 234-R24. **S**. *Praeparvicingula rotunda* Hull, 1995, GIN N 234-R25. **T**. *Parvicingula alata* Kozlova and Vishnevskaya sp. nov., GIN N 234-R1-2.

the Northern Boreal Province, is very important in light of the good age control from other fossils. Majority of the previously described *Parvicingula*-rich faunas are derived from Pacific Rim sequences (Chukotka, western Kamchatka) in which tectonic positions are uncertain (Vishnevskaya 1993, 1997; Filatova and Vishnevskaya 1997; Vishnevskaya and Filatova 1996, 2008; Vishnevskaya and Murchey 2002), as well as the North American Pacific Rim (Hull 1997; Pessagno et al. 2000).

The southeastern Barents-Pechora Basin.—This basin, and the Volga-pre-Ural Basin, are located in the foreland of the northern parts of the Ural Orogen. The southeastern Barents-Pechora Basin is situated in the northeastern segment of the East European Craton known as the Pechora-Kolva Aulacogen. It is the axial suture of the Barents-Pechora Basin and the spreading rift zone is located in the northern part of the Timan-Pechora Basin. Measured in a regional deep seismic survey throughout the southeastern Barents Basin, the Moho reaches 36–40 km in its western part; 38–42 km in its central portion and 34–36 km in its northeastern part (Kostyuchenko 1993). The Kimmeridgian–Volgian phase of active rifting of this sedimentary basin (Table 1) has been traced to the north into the Barents, Norwegian, and North Seas (Dyer and Copestake 1989) and to the south into the Volga-Ural or Volga-pre-Ural basins (Vishnevskaya and Baraboshkin 2001; Vishnevskaya 2001).

The tectonic setting which governs the distribution of the Volgian–Lower Cretaceous bituminous formations within the southeastern Barents-Pechora and Volga-Ural basins (Fig. 2: localities 2, 2A, 3A) is similar to that in the North Sea, where rifting probably caused rapid subsidence, which outpaced sedimentation to create basinal troughs or grabens responsible for the formation of oil (Dyer and Copestake 1989).

The Volgian sequences in the southeastern Barents-Pechora Basin (Fig. 2: localities 2, 2A) clearly show a transgressive depositional system starting with Middle Jurassic sands and deepening upwards to the accumulation of the higher-grade source rocks in the Volgian and Early Cretaceous. The Jurassic sequences, starting in the Kimmeridgian and continuing to the Volgian, include highly bituminous horizons which occasionally contain well-preserved radiolarians (Kozlova 1971, 1994b), among them *Parvicingula papulata* Kozlova and Vishnevskaya sp. nov. (Fig. 6). It is very important to emphasise that the early Kimmeridgian radiolarian assemblages of the Pechora Basin (Ukhta Section) are similar to the ones from borehole 7018/5-4 in the Norwegian Sea (Kozlova 1994b), but contain Tethyan elements, including Pantanelliidae (*Pantanellium tierrablankaense* Pessagno and McLeod, 1987; *Pantanellium lanceolata* [Parona, 1890]; and *Vallupus* sp.). Late Jurassic representatives of the family Pantanellidae were also recorded by Bragin (1997) from the Moscow Basin. The presence of pantanelliids and some ammonites indicate a Tethyan influence, which is probably related to the input of warm water. This is confirmed by palaeotemperature data (Riboulleau et al. 1998). The Middle Volgian

http://dx.doi.org/10.4202/app.2011.0040

Table 1. The main characteristics of Russian Arctic and Pacific Margin radiolarian-bearing basins.

Key sections	Mesen Basin, borehole 234	Southeastern Barents-Pechora Basin	Volga-pre-Ural Basin	Northern and western Siberian Basin	Western Kamchatka-Chukotka	Sakhalin
Age of basins	Volgian	Kimmeridgian–Early Valanginian	Kimmeridgian–Volgian	Late Cretaceous; Kimmeridgian–Early Valanginian	Middle Jurassic–Cretaceous	Middle Jurassic–Early Cretaceous
Age and lithology of radiolarian-bearing sediments	Middle Volgian: organic-rich shale	Early Kimmeridgian: clay; Volgian–EarlyValanginian: organic-rich clay	Kimmeridgian–Volgian: organic-rich clay	Campanian: siliceous clay; Kimmeridgian–Early Valanginian: organic-rich clay	Late Jurassic, Berriasian–Valanginian: chert and jasper	Late Tithonian, Berriasian–Valanginian: chert
Type of other fossils	*Lenticulina ponderosa* benthic foraminiferal assemblage, *Dorsoplanites panderi-Virgatitus virgatus* ammonite zones	Berriasian: ammonite *Bojarkia mesezhnikovi* Schulgina. Late Volgian ammonite: *Craspedites* cf. *ocensis* (d' Orbigny), buchiid *Buchia unschensis* (Pavlow). *Middle Volgian: Dorsoplanites panderi* and *Virgatites virgatus* ammonite zones, *Buchia mosquensis* (von Buch), benthic foraminifera *Doratia tortosa* Dain and Komissarenko. Kimmeridgian: *Amoeboceras kitchini* ammonite Zone, *Buchia bronni* (Roill).	Late Volgian: *Craspedites subditus* ammonite Zone; benthic foraminifera. Middle Volgian: *Dorsoplanites panderi* ammonite Zone. Early Volgian: *Ilowaiskya klimovi* ammonite Zone.	Late Berriasian–Valanginian: *Hectoroceras kochi* and *Bojarkia mesezhnikovi* ammonite zones. Late Volgian ammonite: *Craspedites okensis* (d'Orbigny). Middle Volgian: *Dorsoplanites groenlandicus*	Buchiids Foraminifera	
Tectonic regime	Decompensated subsidence, rifting				Volcanic activity	
Character of sedimentation	Anoxic				Oxic	

Parvicingula haeckeli Assemblage Zone from the Pechora River Basin (Vishnevskaya and Murchey 2002) also includes *Parvicingula alata* Kozlova and Vishnevskaya sp. nov., *Parvicingula papulata* Kozlova and Vishnevskaya sp. nov., and other species (Fig. 6). The Middle Volgian (= Late Tithonian) age is supported by the supplementary marker taxon *Zhamoidellum boehmi* (Yang 1993; Kiessling 1999). Other fossils include ammonites of the *Dorsoplanites panderi* and *Virgatites virgatus* zones, the buchiid bivalve *Buchia mosquensis* (von Buch, 1818) and the benthic foram *Doratia tortosa* Dain and Komissarenko, 1972 (Kozlova 1994b; Vishnevskaya 2001).

The Middle Volgian radiolarians assemblages are very similar in taxonomic composition to coeval ones from the Pesha sequences (Fig. 4). Analyses of radiolarian biodiversity have shown that radiolarian endemism increased between the Kimmeridgian and Middle/Late Volgian, in a period when the radiolarian diversity decreased.

Abundant endemic (or typical of the Boreal province) Parvicingulidae with external cephalic spines and apophyses (Fig. 6) first appear (e.g., sample 5 of borehole Narjan-Mar) in the uppermost Middle Volgian and lowest Upper Volgian (Fig. 2: locality 2). This type of parvicingulid often makes up 50%, or more, of the Late Volgian radiolarian fauna.

The Late Volgian *Stichocapsa devorata arctica* assemblage (Vishnevskaya and Murchey 2002) of the Pechora River Basin (sample 5 of borehole Narjan-Mar) and Kolguev Island (sample 140 of borehole Kolguev) contains (see Fig. 6) the index-species, *Spinicingula ceratina* Kozlova and Vishnevskaya sp. nov. and the first representatives of *Quasicrolanium planocephala* (Kozlova, 1976). The Late Volgian (= Early Berriasian) age is indicated by the first appearance of *Quasicrolanium planocephala* and the last occurrence of *Spinicingula ceratina* sp. nov. in the uppermost Upper Volgian (Kozlova 1994b). Macrofaunas of the same organic-rich clay strata include the ammonite *Craspedites* cf. *ocensis* (d'Orbigny, 1845) and the buchiid *Buchia unschensis* (Pavlow, 1907) (Kozlova 1994b; Vishnevskaya 2001). The *Quasicrolanium planocephala* acme event occurs near the top of the Upper Volgian (Fig. 6A). It is distinguished by trihedral-pyramidal forms with longitudinal ribs. *Quasicrolanium* appears to be characteristic of the Boreal Realm. The latest Middle Volgian representatives of *Parvicingula papulata* Kozlova and Vishnevskaya sp. nov. from depths between 227 and 234 m (Kozlova 1994b) have visible external circumferential ridges, while the Late Volgian *Spinicingula ceratina* Kozlova and Vishnevskaya sp. nov. from depths between 218 and 223 m (borehole 5, Narjan-Mar, sample 5) and the Volga Basin lack ridges (Fig. 6).

The Late Jurassic in the northern East European Platform was a critical period; following a prolonged continental regime, marine sedimentation started. The sequences studied are shown in Figs. 1, 2. Several hypotheses have been proposed to explain the co-existence within these deposits of ammonites and members of other faunal groups that belong to exotic palaeozoogeographic provinces. The most plausible hypotheses are those which postulate the existence of "sea straits" between the Boreal and Tethyan realms or the existence of "cold streams" between western and eastern provinces (Gavshin and Zakharov 1991).

The Jurassic marine deposits in the northern part of the East European Platform reach thicknesses between 10–30 and 80–150 m. The lowest values are reported for Central Russia (0–50 m), whilst the thickest sequences are found to the northeast, in the Pechora Basin (>150 m).

The late Berriasian–Valanginian *Parvicingula khabakovi* assemblage (Vishnevskaya and Murchey 2002), containing small individuals of *Parvicingula* aff. *boesii* (Parona, 1890), *Parvicingula khabakovi* (Zhamoida, 1963), and *Williriedellum salymicum* (Kozlova, 1983), was traced in the Pechora and Siberia basins (Kozlova 1983). It differs from the Late Volgian *Stichocapsa devorata arctica* assemblage in yielding abundant cryptocephalic representatives of the genus *Williriedellum*. The Berriasian age is confirmed by the co-occurring ammonite *Bojarkia mesezhnikovi* Schulgina, 1969 in the Izhma River Basin (Kozlova 1994c). Thus, two new genera, *Spinicingula* and *Quasicrolanium*, make their first appearance near or just above the Jurassic–Cretaceous boundary.

Volga-pre-Ural Basin.—This basin is located to the west of the Urals and is considered to be an ancient passive margin with foredeep slope, where Kimmeridgian–Volgian hydrocarbon-rich facies (Fig. 2: locality 3A) contain numerous organic shale beds yielding radiolarians (Vishnevskaya 1998). Radiolaria from Kimmeridgian–Volgian organic shale horizons have been described previously by Vishnevskaya (1998) and Vishnevskaya and Baraboshkin (2001). Data from those studies are used herein for comparative analysis.

The most complete section of Kimmeridgian–Volgian strata in the Volga-Ural basins is exposed 10 km upstream from Gorodishce, where the lectostratotype of the Volgian Stage has been established (Fig. 2: locality 3A). These Kimmeridgian strata also bear Tethyan elements in the ammonite assemblage. However, the overlying Volgian succession is distinguished by its Boreal assemblage (Vishnevskaya and Baraboshkin 2001). The radiolarian assemblages of the Early Volgian *Parvicingula jonesi* Zone in the Gorodishce section are equivalent to the *Ilowaiskya klimovi* Ammonite Zone and the Middle Volgian *Parvicingula haeckeli* Zone is coeval with the *Dorsoplanites panderi* Ammonite Zone. Both assemblages show a predominance of *Parvicingula* sensu lato. A wide range of morphotypes is represented, with most specimens possessing regular hexagonal frame pore frames. Moreover, Tethyan genera such as *Andromeda*, *Tethysetta*, *Bernoullius*, *Mirifusus*, and *Podobursa* are altogether absent. Only several individuals of *Pantanellium* (*P. tierrablankaense* Pessagno and MacLeod, 1987) have been recorded.

Kiessling (1999) documented the pantanelliid abundance in Antarctica and noted that the main characteristics of the North Boreal Province were low diversity, and a marked predominance of *Parvicingula* sensu lato, as based on personal observations of Vishnevskaya's materials. Antarctic radiolarian faunas described by Kiessling (1999) are characterised by an abundant, albeit poorly diversified, pantanelliid assemblage (including Vallupinae). Bragin (1997) showed that Pantanelliidae occurred and were represented by several species in the southern part of the Boreal Province. The same holds true for material from Scotland and the North Sea (John Gregory, personal communication 1997).

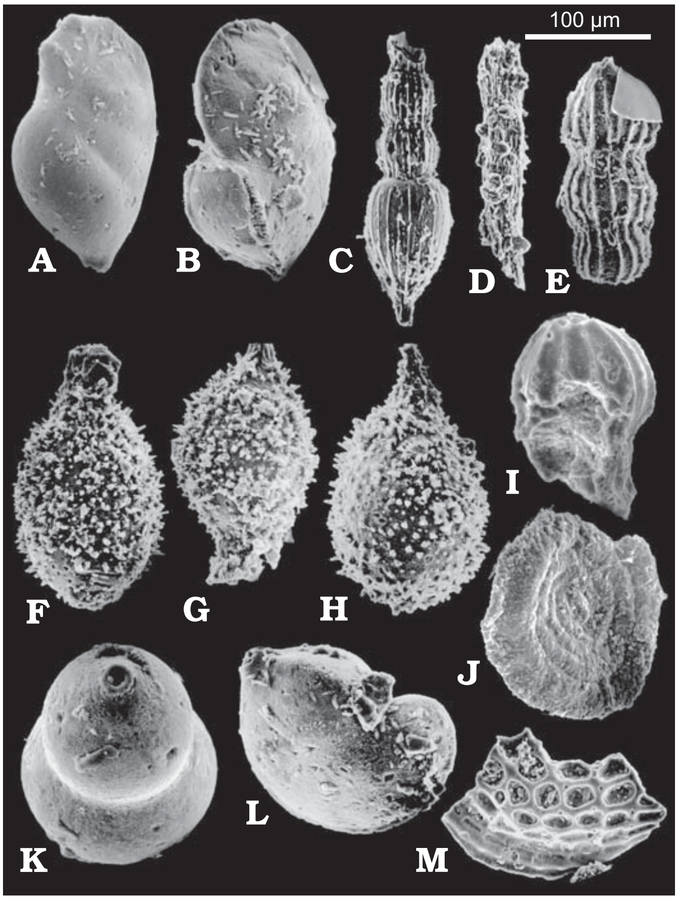

Fig. 5. Scanning electron micrographs of Volgian foraminifera and ostracods from siliceous clay rocks in northern Russia, Barents offshore; sample 234, Middle Volgian (*Dorsoplanites panderi* Zone) of Pesha River Basin, borehole 234. **A**, **B**. *Astacolus*? *suspectus* Basov, 1967. **A**. GIN N 234-F1-1. **B**. GIN N 234-F2. **C**. *Nodosaria tubifera* Reuss, 1863, GIN N 234-F3. **D**. *Citharina*? *angustissima* (Reuss), 1863, GIN N 234-F4-2. **E**. *Marginulinita* cf. *pyramidalis* (Koch, 1851), GIN N 234-F5-3. **F**–**H**. *Ramulina nodosarioides* Dain, 1972. **F**. GIN N 234-F6-1. **G**. GIN N 234-F6-2. **H**. GIN N 234-F6-3. **I**. *Pseudonodosaria*? *multicostata* (Bornemann, 1854), GIN N 234-F7-2. **J**. *Ammodiscus veteranus* Kosyreva, 1972, GIN N 234-F8. **K**, **L**. *Lenticulina* sp.? **K**. GIN N 234-F9-1. **L**. GIN N 234-F9-2. **M**. Indeterminate ostracod, GIN N 234-F10.

Middle Volgian specimens of Parvicingulidae from the *Dorsoplanites panderi* Ammonite Zone and Kimmeridgian *Parvicingula* display well-developed circumferential ridges with three rows of very large pores (Fig. 6H), while Late Volgian ones have weakly developed circumferential ridges, irregular hexagonal frameworks with small pores and a spindle-like test form; the proximal part of the tests tends to be bulbous (Fig. 6D, E). Characteristic species of the *Parvi-*

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Table 2. Correlation of radiolarian zonations proposed for the Russian Arctic Margin.

Age	Pechora Basin (Kozlova 1994)	Siberia (Kozlova 1983)	Boreal province (Repin et al. 1999)	Siberia (Lipnizkaya 2006)	Arctic Margin (Vishnevskaya and Murchey 2002)
Early Valanginian–Berriasian		*Williriedelum salymicum*	*Hemicryptocapsa salymica*	*Hemicryptocapsa salymica*	*Parvicingula khabakovi*
Late Volgian	*Pseudocrolanium planocephala*	*Stichocapsa dolium*	*Quasicrolanium planocephala*	*Quasicrolanium planocephala* *Parvicingula* cf. *seria*	*Stichocapsa devorata*
Middle Volgian	*Parvicingula papulata*	*Parvicingula* cf. *seria* *Parvicingula* cf. *multipora*		*Parvicingula* cf. *multipora*	*Parvicingula haeckeli*
Early Volgian–Kimmeridgian					*Parvicingula jonesi*
Early Kimmeridgian	*Crucella crassa*				*Parvicingula elegans*

cingula haeckeli assemblage Zone of the Middle Volgian are *Parvicingula alata* Kozlova and Vishnevskaya sp. nov. and *Parvicingula papulata* Kozlova and Vishnevskaya sp. nov. (sample G-1). Species of *Parvicingula* are dominant.

Specimens of *Parvicingula* from the Late Volgian (= Berriasian) *Stichocapsa devorata arctica* Assemblage Zone (sample G-2) are very small in size, possess small pore frames and have post-abdominal chambers with weakly developed circumferential ridges or almost none (Fig. 6). The degree of endemism is high, on account of the great abundance of *Parvicingula*-like morphotypes with external cephalic spines (Fig. 6) and apophyses (Kozlova 1994b; Vishnevskaya 1998, 2001). Also, a decrease in the number of chambers was documented in Late Volgian representatives of the genera *Parvicingula* and *Stichocapsa* above the Gorodishce section. The commonest taxa within the *Craspedites subditus* Ammonite Zone (sample G-2) are *Stichocapsa devorata arctica* Vishnevskaya and Murchey, 2002; *Parvicingula alata* Kozlova and Vishnevskaya sp. nov.; and *Spinicingula* gen. nov. (Fig. 6). Associated foraminifera include *Ammodiscus veteranus* Kosyreva, 1972; *Kutsevella labythnangensis* (Dain, 1972); *Lenticulina pseudoarctica* Ivanova, 1970; *Marginulina transmutata* Basov, 1967; *Marginulina glabroides Gerke* (Basov, 1967); *Recurvoides obskiensis* Romanova, 1960; and *Bullopora vivejae* Jkovleva, 1974. *Stichocapsa devorata arctica* Vishnevskaya and Murchey, 2002 (Fig. 6) is a highly characteristic species of Berriasian assemblages of the North Arctic basins of Russia (Vishnevskaya and Murchey 2002). Thus, a change from the *Parvicingula*-rich assemblage to the *Stichocapsa*- and *Spinicingula*-rich one occurs at the Jurassic–Cretaceous boundary. This shift was probably caused by sea level changes and cooling (Kozlova 1994b; Riboulleau et al. 1998).

Assessments of the biodiversity of fossil radiolarian assemblages have made it possible to trace different evolutionary rates of siliceous microfossils (Vishnevskaya 1993, 1997, 2009) and to define the intervals of minimum biodiversity. Low diversities in Phanerozoic radiolarians and relatively small numbers have commonly been recorded for intervals associated with anoxic events, which are linked with the occurrence of endemic species in the Boreal realm. In view of the fact that the Volgian contains abundant organic-rich intervals and extinction horizons, the lectostratotype of the Volgian Stage (i.e., the Gorodishce section) has been studied in detail. Middle Volgian faunal assemblages were collected from the *Dorsoplanites panderi* Ammonite Zone, the lithology of which suggests anoxic sedimentary conditions. This zone spans an interval represented by rhythmically bedded, alternating carbonate clays and non-calcareous, organic-rich shale. A horizon of reworking and dissolution was recorded at the base, whereas black bitumen shales occur in the upper part, and the amount of organic matter increases from 1–1,5% at the base to 22% in the upper shales. The bituminous beds contain an abundance of small juvenile forms of the benthic foraminifera *Loropes fischerianus* and *Scurria maeotis* and non-pionic young ammonites which suggest a strong anoxia during shale formation. Only a few benthic foraminiferal species (*Evolutinella emeljancevi* [Schliefer, 1966]; *Kutsevella labythnangensis* [Dain, 1972]; *Dorothia tortuosa* Dain and Komisarenko, 1972; *Lenticulina infravolgaensis* Fursenko and Polenova, 1950; *Marginulina robusta* Reuss, 1863; *Marginulina striatocostata* Reuss, 1863; and *Pseudolamarckina zatonica* Mjatluk, 1939) have been recorded.

A comparison of data on diversity dynamics of radiolarians and ammonites in the Late Jurassic shows that episodes of significant decrease in taxonomic diversity in both groups (i.e., the Late Volgian Crisis) were synchronous. This crisis coincided with significant changes in ammonoid morphotypes and radiolarian skeletons. Mass explosions of radiolarians are correlated with anoxic episodes, whereas no such correlation is established for ammonites. Wide-ranging extinction of radiolarians and ammonites at the end of the Jurassic began in the Volgian, and most likely resulted from a marine regression and climatic cooling. This was confirmed by a predominance of cold-water representatives of the genus *Parvicingula* in radiolarian associations and the Boreal ammonite family Craspeditidae at that time in the Central Russian, Timan-Petchora and western Siberian seas (Mitta and Vishnevskaya 2006). The rapid evolution of Radiolaria and a bloom of morphological diversity of *Parvicingula* with the development of numerous abnormal skeletons may have been caused by stressed conditions. Probably, only the more generalist and primitive forms of *Parvicingula* and *Stichocapsa* survived, in order to give rise to new evolutionary trends.

In the Upper Cretaceous of the Volga Basin (Uljanovsk region, Shilovka section; Fig. 2: locality 3; sample 7-1), the siliceous horizon separated into the *Prunobrachium articulatum* Beds containing many representatives of the genus *Prunobrachium* (Fig. 7), together with *Afens liriodes* Riedel and Sanfilippo, 1974 and *Amphymenium sibiricum* Lipman, 1960 correspond to the Campanian interval. The interval of deposits with *Prunobrachium articulatum* is well recognised in sections of the Russian platform, western Siberia and the Subpolar Urals (Fig. 2: locality 4), being a perfect biostratigraphic marker for the Campanian due to an acme of index species (Hollis 1997).

Northern and western Siberian basins.—These basins extend beneath the Kara and Laptevs seas; they form the largest sedimentary basin, and represent a system of intracontinental rift basins. The well-known Volgian–Berriasian or Volgian–Valanginian Bazhenovo Formation bears radiolarians (Fig. 2: locality 4A) and contains the richest productive horizon (Braduchan et al. 1984). A second siliceous Radiolaria-bearing interval (Fig. 2: locality 4) is Campanian in age.

The Bazhenovo Formation is developed over a huge area of more than 1 million square kilometres with an average thickness of about 30 m. In comparison, this formation is 20 m thick in the western and central parts of the western Siberian Basin to 160 m in the southeastern part. The shallow-water (= pseudo-abyssal) palaeo-area has been located in northwestern and Recent Kara Sea territories (Zakharov 2006).

Autochthonous planktonic organic matter accumulated in the marine basin (normal salinity) during Volgian time and continued into the Berriasian. The organic-rich bazhenovites are about 30 m thick and comprise, from the bottom to the top, twelve ammonite zones, which correspond to 10–12 myr. Slow warping of the basin floor was not compensated under the conditions of minimum supply of terrigenous material, and palaeodepth could reach 500–700 m (Gavshin and Zakharov 1991).

The rocks predominating this formation are very typical by their detritus. Originally, they were described as black and brownish-black mudstone, often platy, bituminous, with lots of fish remains, crushed buchiid shells, ammonites and belemnite rostra. However, it became clear later that the name "mudstone" was not at all adequate to describe their composition which varied within wide limits, due to a varying content of three basic components: clayey material, sapropelic organic matter and biogenic silica. The term "bazhenovites" has been proposed for these rocks; workers abroad would undoubtedly refer to them as "oil shale" or "organic-rich shale" (Gavshin and Zakharov 1991).

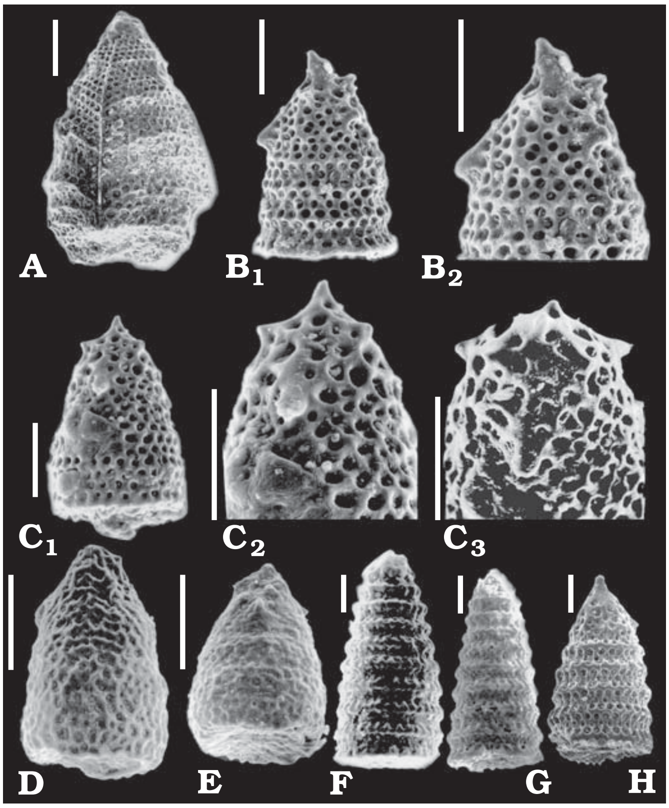

Fig. 6. Scanning electron photomicrographs of Late Jurassic radiolarians from siliceous clay rocks in northern Russia, Barents Sea region. A–F from Kozlova (1994b). **A**. *Quasicrolanium planocephala* (Kozlova, 1976), uppermost Volgian, Kolguev offshore, borehole 140, sample 140, VNIGRI N 140-667/41a. **B**–**E**. *Spinicingula ceratina* Kozlova and Vishnevskaya sp. nov. **B**, **C**. From Narjan-Mar, borehole 5, Upper Volgian, sample 5. **B**. Holotype, VNIGRI N 667/66. **C**. VNIGRI N 667/66-1. **D**, **E**. From Upper Volgian, Gorodishce section (*Craspedites subditus* ammonite Zone) of Uljanovsk Volga Basin, sample G2. **D**. GIN N G-R1-1. **E**. GIN N G-R1-2. **F**, **G**. *Parvicingula alata* Kozlova and Vishnevskaya sp. nov., Middle Volgian, Gorodishce section (*Dorsoplanites panderi* Ammonite Zone) of Uljanovsk Volga Basin, sample G1. **F**. Holotype, GIN N G-1-2Ka. **G**. GIN N G-1-3K. **H**. *Parvicingula papulata* Kozlova and Vishnevskaya sp. nov., holotype, GIN N P-1K. Pechora Basin, Ukhta section, sample P, Lower Kimmeridgian. Scale bars 50 μm.

The Volgian–Berriasian radiolarians of the Bazhenovo Formation and Campanian taxa from siliceous intervals have previously been documented exclusively by drawings (Kozlova and Gorbovetz 1966; Braduchan et al. 1984). Here, we supply scanning electron micrographs (Fig. 7) and descriptions of new Campanian radiolarians (compare Vishnevskaya and Alekseev 2008; Vishnevskaya 2011). The Santonian radiolarian fauna from western Siberia is very poor and dominated by discoidal spongy spumellarians; an assemblage with Discoidea and single Prunoidea (Kozlova and Gorbovetz 1966). Just above the Santonian–Campanian boundary, a siliceous interval with abundant radiolarians has been recognised (Fig. 2: locality 4). The Campanian radiolarian assemblages (sample 57) of the Siberian Arctic (Vishnevskaya 2011) are

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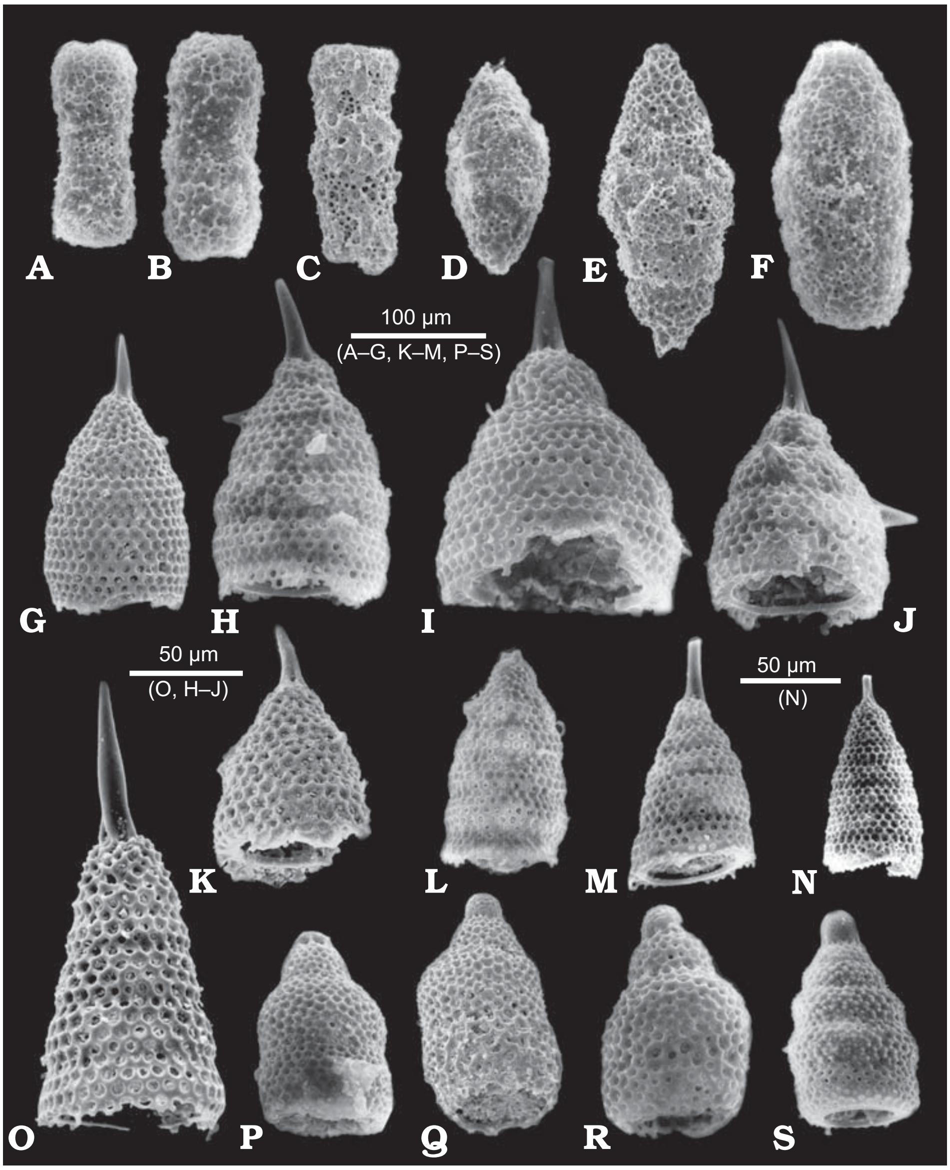

Fig. 7. Scanning electron micrographs of Late Cretaceous (Early Campanian) radiolarians from siliceous rocks of the Russian Arctic Margin (western Siberia, borehole 22, Ust-Manja, sample 57), except for D which is from the Volga Basin, Uljanovsk region, Shilovka section, sample 7-1. **A**–**C**. *Spongurus arcticus* Kozlova and Vishnevskaya sp. nov. **A**. Holotype, GIN N K22-2-57. **B**. GIN N K22-2a-57. **C**. GIN N K22-2b-57. **D**–**F**. *Prunobrachium articulatum* (Lipman, 1952). **D**. GIN N K22-15a-57. **E**. GIN N K22-15b-57. **F**. GIN N K22-15c-57. **G**, **K**–**N**. *Lithostrobus* ex gr. *rostovzevi* Lipman, 1960. **G**. GIN N K22-1a-57/1. **K**. GIN N K22-1b-57/1. **L**. GIN N K22-1c-57/2. **M**. GIN N K22-1c-57. **N**. GIN N K22-1d-57. **H**–**J**. *Lithostrobus borealis* Kozlova and Vishnevskaya sp. nov. **H**. GIN N K22-1a-57. **I**. GIN N K22-1b-57. **J**. Holotype, GIN N K22-1-57. **O**. *Lithostrobus longus* Grigorieva, 1975; GIN N K22-11-57. **P**–**R**. *Immersothorax marinae* (Gorbovets, 1966). **P**. GIN N K22-12-57. **Q**. GIN N K22-12a-57. **R**. GIN N K22-12b-57. **S**. *Amphipyndax stocki* (Campbell and Clark, 1944), GIN N K22-13-57.

dominated by several genera, such as *Orbiculiforma* (4 species), *Prunobrachium* (6 species), *Pseudobrachium* (2 species), *Spinibrachium* (1 species), *Spongurus* (*S. arcticus* Kozlova and Vishnevskaya sp. nov.), *Dictyomitra* (2 species), *Lithostrobus* (2 species), and *Amphipyndax* (3 species). Total diversity is low, but the predominance of *Prunobrachium* and Lithostrobus (*L. rostovzevi* Lipman, 1960; *L. borealis* Kozlova and Vishnevskaya sp. nov.) can be seen in most samples (Fig. 7). Upsection, diversity is higher (Sarkisova 2007).

A comparative analysis of Jurassic radiolarian assemblages from bituminous sediments, characterised as immature potential source rocks, in the Barents Sea region (Kozlova 1994b; Vishnevskaya 2001; Vishnevskaya and Murchey 2002), the North Sea (Dyer and Copestake 1989), as well as the Norwegian Sea (Bob Goll, personal communication 1991) has demonstrated the presence of similar radiolarian events (Table 2) within the coeval latest Jurassic–earliest Cretaceous radiolarian associations of the Laptevs Sea shore north of Siberia (Vishnevskaya and Malinovsky 1995; Bragin 2009) and western Siberia (Braduchan et al. 1984; Lipnizkaya 2006). There are four radiolarian assemblages in the Bazhenovo Formation (Braduchan et al. 1984), as based on borehole 17 of the Upper Salym (Fig. 2: locality 4A). The Middle Volgian *Parvicingula* cf. *multipora* Beds (interval 2901–2912 m) (Braduchan et al. 1984; Kozlova 1994b) or Zone (Lipnizkaya 2006) include an assemblage with *Parvicingula jonesi* Pessagno, 1977; *Parvicingula* cf. *multipora* (Khudyaev, 1931); *Parvicingula papulata* Kozlova and Vishnevskaya sp. nov.; and *P. santabarbarensis* Pessagno, 1977. The age is confirmed by *Dorsoplanites maximus* and other ammonites (Braduchan et al. 1984). This interval is approximately equivalent to the *Parvicingula jonesi* assemblage Zone. The Middle to Late Volgian *Parvicingula* cf. *seria* Beds (interval 2896–2901 m) (Braduchan et al. 1984; Kozlova 1994b) or Zone (Lipnizkaya 2006) include an assemblage with *Parvicingula crassitestata* (Rüst, 1885), *Parvicingula rostrata* (Khabakov, 1937), *Parvicingula conica* (Khabakov, 1937), and *Parvicingula haeckeli* (Pantanelli, 1880). The Volgian age is supported by the ammonite *Dorsoplanites groenlandicus* (Braduchan et al. 1984). These strata can be correlated with the *Parvicingula haeckeli* Zone on the basis of the consistent presence of index species, *Parvicingula haeckeli* (Vishnevskaya 2001). The Late Volgian *Quasicrolanium planocephala* Beds (interval 2891–2895 m) (Braduchan et al. 1984; Kozlova 1994b) or Zone (Lipnizkaya 2006) contain an assemblage with *Spinicingula ceratina* Kozlova and Vishnevskaya sp. nov., *Quasicrolanium planocephala* (Kozlova, 1976), and *Stichocapsa devorata arctica* Vishnevskaya and Murchey, 2002. The Late Volgian age is corroborated by the first appearance of the ammonite *Craspedites okensis* (d'Orbigny, 1845) (see Kozlova 1994b). These strata are coeval with the *Stichocapsa devorata arctica* Zone, on account of the co-occurrence of the characteristic species *Quasicrolanium planocephala* and *Stichocapsa devorata arctica*.

The late Berriasian–Valanginian *Williriedellum salymicum* Beds (interval 2880–2890 m) (Braduchan et al. 1984; Kozlova 1994b) or Zone (Lipnizkaya 2006) include an assemblage with *Parvicingula gracilis* (Khabakov, 1937), *Parvicingula khabakovi* (Zhamoida, 1963), and *Williriedellum salymicum* (Kozlova, 1983). These upper Berriasian–Valanginian strata correspond to the *Hectoroceras kochi* and *Bojarkia mesezhnikovi* ammonite zones (Braduchan et al. 1984). Due to the presence of the primary marker taxon, *Parvicingula khabakovi*, these strata can be correlated with the *Parvicingula khabakovi* Zone (Vishnevskaya 2001). All assemblages of the Bazhenovo Formation also exhibit reduced diversity, a predominance of *Parvicingula* and a low abundance. Thus, these radiolarian zonations are similar to those proposed for the Arctic region of Russia (Vishnevskaya 2001; Vishnevskaya and Murchey 2002) and possible correlation is re-examined here. Based on the high diversity of *Parvicingula*, it is possible to equate the *Parvicingula* cf. *multipora* beds with the upper portion of the *Parvicingula jonesi* Zone, the *Parvicingula* cf. *seria* beds with the *Parvicingula haeckeli* Zone, the *Stichocapsa dolium* beds with the *Stichocapsa devorata arctica* Zone, and the *Williriedelum salymicum* beds with the *Parvicingula khabakovi* Zone (Tables 1, 2). A radiolarian event, with the onset of a new family and two new genera just above, and one new genus near the Jurassic–Cretaceous boundary, has also been recorded from the locality of Nordvik in Arctic Siberia (Bragin 2009).

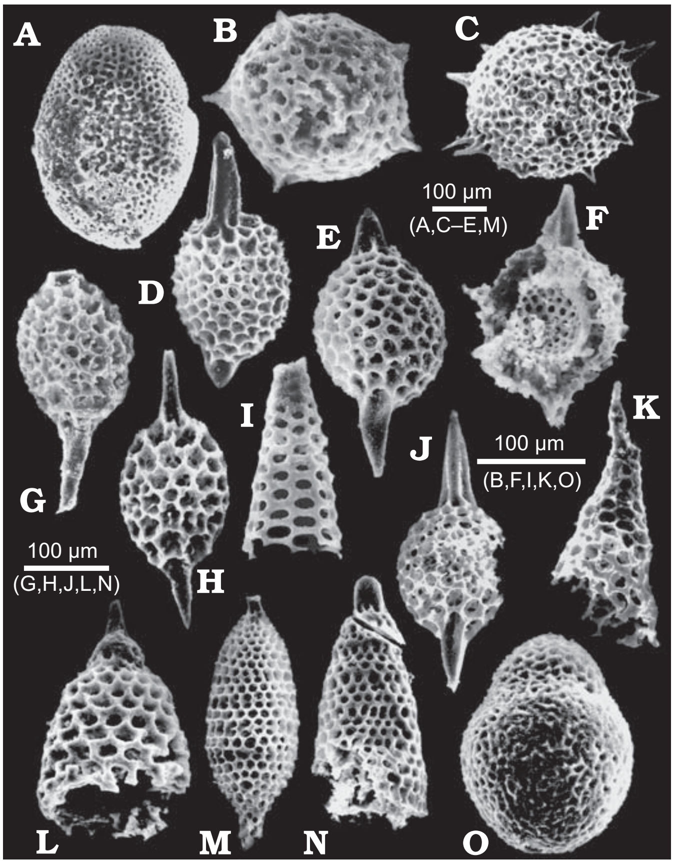

Fig. 8. Scanning electron micrographs of Late Cretaceous (Early Campanian) radiolarians from siliceous rocks of the Russian Pacific Rim (western Kamchatka, locality Palana, sample134/01). **A**. *Phaseliforma subcarinata* Pessagno, 1975, GIN N 134/01-R3. **B**, **C**. *Lithomespilus* aff. *coronatus* Squinabol, 1904. **B**. GIN N 134/01-R5a. **C**. GIN N 134/01-R5b. **D**, **E**, **J**. *Protoxiphotractus perplexus* Pessagno, 1973. **D**. GIN N 134/01-R-8a. **E**. GIN N 134/01-R8b. **J**. GIN N 134/01-R5c. **F**. *Protoxiphotractus*? sp., GIN N 134/01-R8. **G**. *Stylosphaera hastata* (Campbell and Clark, 1944); GIN N 134/01-R4. **H**. *Protoxiphotractus kirbui* Pessagno, 1973; GIN N 134/01-R6. **I**, **K**. *Cornutella californica* Campbell and Clark, 1944. **I**. GIN N 134/01-R11a. **K**. GIN N 134/01-R11b. **L**. *Coniforma antiochensis* Pessagno, 1969, GIN N 134/01-R-10. **M**. *Stichomitra livermorensis* (Campbell and Clark, 1944), GIN N 134/01-R15. **N**. *Amphipyndax stocki* (Campbell and Clark, 1944), GIN N 134/01-R17. **O**. *Theocapsomma* sp., GIN N 134/01-R12.

Western Kamchatka and Chukotka.—The former area extends beneath the Okhotsk Sea, the latter beneath the Bering Sea (Fig. 1). New data on age, composition and relationships of Mesozoic complexes of western Kamchatka and Chukotka were obtained during detailed studies carried out between 1998 and 2010 (Vishnevskaya et al. 1999, 2005; Vishnevskaya and Filatova 2008). These new data provide the basis for estimating the hydrocarbon potential of Mesozoic formations developed along the Okhotsk Sea shoreline. Some Jurassic to Cretaceous radiolarians from western Kam-

http://dx.doi.org/10.4202/app.2011.0040

chatka were described in detail by Vishnevskaya et al. (2005). The late Tithonian and Berriasian *Parvicingula khabakovi* assemblage (sample 603-5, 6) is characterised by a predominance of nassellarians (Fig. 3), especially *Parvicingula* (Vishnevskaya et al. 2005: pl. 41), which is typical of high palaeolatitudes, as shown in the Arctic samples. Unfortunately, all radiolarian finds derived from tectonostratigraphic sections (Fig. 2: localities 5, 5A, 5B). Jurassic and Cretaceous (sample 4-1) sites did not yield other fossils; only at one locality in Chukotka (Semiglawaya Mountain) *Buchia* is present (Fig. 2: locality 5B), together with radiolarians (Vishnevskaya and Filatova 2008). Thorough palaeontological studies of volcanogenic-siliceous sections conducted in western Kamchatka between 2002 and 2005 have demonstrated that both inoceramid remains and numerous identifiable calcareous foraminifera locally accompanied abundant Santonian–Campanian radiolarians.

A description of one Campanian radiolarian assemblage (Fig. 8) from the locality Palana (Fig. 2: locality 5; sample 134/01) is presented here for comparison with coeval faunas from the western Siberian Basin. In contrast to the Siberian assemblage, the *Prunobrachium crassum* assemblage (Kozlova and Gorbovetz 1966; Amon 2000), the *P. crassum* assemblage of Kamchatka (Fig. 8) is very diverse and includes *Protoxiphotractus perplexus* Pessagno, 1973; *Protoxiphotractus kirbyi* Pessagno, 1973; *Stylosphaera hastata* (Campbell and Clark, 1944); *Heliodiscus borealis* Vishnevskaya, 2002; *Spongasteriscus rozanovi* Vishnevskaya, 2002; *Prunopyle stansilavi* Vishnevskaya, 2002; *Cornutella californica* Campbell and Clark, 1944; *Coniforma antiochensis* Pessagno, 1969; *Stichomitra livermorensis* (Campbell and Clark, 1944); *Amphipyndax stocki* (Campbell and Clark, 1944); and other species (Vishnevskaya et al. 2005), but there is no *Prunobrachium* acme here. In some samples, radiolarians were found together with numerous cold-water benthic foraminifera. Only a single planktonic foraminiferal species co-occurs with the Early Campanian radiolarian assemblage from western Kamchatka, whereas the warmer-water, Late Santonian *Pseudoaulophacus floresensis* assemblage (Fig. 3) is accompanied by several planktonic foraminiferal species, namely *Archaeoglobigerina bosquensis* Pessagno, 1967; *Hedbergella delrioensis* (Carsey, 1926); *Hedbergella holmdelensis* Olsson,1964; *Heterohelix globulosa* (Ehrenberg, 1840); *Heterohelix reussi* (Cushman, 1938); and *Globigerinelloides ultramicra* (Subbotina, 1949). The underlying Santonian radiolarian *Pseudoaulophacus floresensis* assemblage of western Kamchatka includes many Californian species (Vishnevskaya et al. 2005).

Maximum erosional activity in the Pacific Ocean Basin, caused by tectonic activity, rearrangement of lithospheric plates, locally accompanied by a new volcanism phase (Basov and Vishnevskaya 1991) was recorded during the Late Cretaceous, with peaks at the Cenomanian–Turonian and Santonian–Campanian boundaries. The presence of numerous representatives of genera *Theocapsomma* and *Cryptamphorella* with submerged cephalis and *Excentrosphaerella* with an eccentric inner microsphere at these crisis intervals was recorded; this can probably be explained by good adaptation of these skeletal types to incisive changes in the water column (depth, oxygen content, etc.).

Sakhalin Basin.—Sakhalin Island is the northern continuation of the Japan island arc system and is subdivided tectonically into two parts: western and eastern Sakhalin. The eastern Sakhalin Basin extends beneath the Okhotsk Sea (Fig. 1); the onshore part of it is considered the major source rock for oil and gas in the area.

Up to the late 1990s, Jurassic–Cretaceous radiolarians from eastern Sakhalin were studied exclusively in thin sections. For the present paper the samples were analysed using new techniques for sample processing; SEM was used for illustration of Tithonian and Berriasian radiolarian assemblages extracted using the HF method of Pessagno (1977) (Fig. 9). Prior to the present study, only faunal lists were ever published for eastern Sakhalin; previous work (Vysotskii et al. 1998) did not include any scanning electron micrographs. The Tithonian assemblage was collected from tuffaceous chert of the Rocky Ridge tectonostratigraphic section in the eastern Sakhalin Basin (Fig. 2: locality 6; sample 114); it includes *Orbiculiforma lawreyensis* Pessagno, 1977; *Triactoma mexicana* Pessagno and Yang, 1989; *Podobursa tricola* Foreman, 1973; and *Triversus tsunoensis* (Aita, 1987). The late Tithonian age was determined by the first appearance of *Orbiculiforma lawreyensis* (De Wever et al. 2001). The Berriasian–Early Valanginian radiolarian assemblage (sample 102) originates from radiolarian cherts in the Samokhino tectonostratigraphic section (Fig. 2: locality 6) of the Aleksandrovsk area, eastern Sakhalin. It includes the following species: *Acaeniotyle diaphorogona* Foreman, 1973; *Pantanellium* aff. *masirahense* Dumitrica, 1997; *Archaeodictyomitra excellens* (Tan, 1927); *Archaeodictyomitra leptocostata* Wu and Li, 1982; *Archaeodictyomitra tumandae* Dumitrica, 1997; *Mirifusus mediodilatata* (Rüst, 1887); *Mirifusus appeninicum* Jud, 1994; *Mirifusus chenodes* (Renz, 1974); *Podobursa tythopora* (Foreman, 1973); *Pseudodictyomitra depressa* Baumgartner, 1984; *Sethocapsa kitoi* Jud, 1994; *Sethocapsa pseudouterculus* Aita, 1987; and *Tethysetta usotanensis* (Tumanda, 1989). The Berriasian–Early Valanginian age is based on the co-occurrence of *Sethocapsa kitoi* (UAZ 13-16) and *Mirifusus appeninicum* (UAZ 14-20) (De Wever et al. 2001). The Valanginian assemblage (sample 61) stems from siliceous tuffs of the Pilenga tectonostratigraphic section and includes *Cenodiscaella nummulitica* Aliev, 1965; *Ditrabs sansalvadorensis* (Pessagno, 1971); *Godia* cf. *coronata* (Tumanda, 1989); *Thanarla conica* (Aliev, 1965); *Thanarla* aff. *brouweri* (Tan, 1927); *Sethocapsa cetia* Foreman, 1973; *Sethocapsa* cf. *polyedra* Steiger, 1992; *Pseudodictyomitra* aff. *leptoconica* (Foreman, 1973); and *Xitus* cf. *robustum* Wu, 1993. The age is defined by the first appearance of *Thanarla conica* and the last occurrence of *Sethocapsa cetia* in the Valanginian (De Wever et al. 2001; Kurilov and Vishnevskaya 2011).

The typical Tethyan genera *Pantanellum*, *Tethysetta*, *Miri-*

fusus, and *Podobursa* are widely distributed here. Only rarely has *Parvicingula* been noted in this assemblage (Vishnevskaya et al. 2005). The co-existence of Tethyan and Pacific species illustrates their ecotone nature and will make them useful for both correlations on a regional scale and palaeogeographic interpretations.

Conclusions

- Two siliceous horizons with Boreal types of radiolarians are established. The Volgian (Tithonian–Berriasian) radiolarian fauna of the Russian Arctic Margin is endemic, being characterised by low diversity and high abundance of nassellarians among which *Parvicingula*, *Spinicingula* gen. nov., and Spongodisceacea prevail. Endemism of radiolarian faunas of the Russian Arctic Margin increases from the Kimmeridgian to the Middle/Late Volgian, while diversity decreases. The Campanian radiolarians of the Arctic have boreal affinities similar to coeval faunas from the Volga Basin.
- The complete absence of Tethyan species and genera such as *Tritrabs*, *Acanthocircus dicranacanthos* (Squinabol, 1914), *Archaeodictyomitra apiara* (Rüst, 1885), *Podocapsa amphitreptera* Foreman, 1973, *Andromeda*, *Mirifusus*, *Podobursa,* and others prevent correlations between Boreal and Tethyan Tithonian–Berriasian zonal schemes at this time; additional studies are needed. The abundant presence of *Parvicingula* within the oil shale sequences of the Russian Arctic Margin can be used to establish a preliminary Boreal zonation.
- Many representatives of typical Boreal genus *Parvicingula* and only one Tethyan genus *Pantanellum* have been demonstrated from the Russian Arctic Margin, while typical Tethyan genera such as *Pantanellum*, *Tethysetta*, *Mirifusus*, and *Podobursa* were found among coeval radiolarian faunas of the Russian Pacific Margin. In contrast to coeval Californian radiolarian assemblages, the comprehensive overview presented here shows that the family Pantanellidae was distributed along the Russian Arctic Margin (i.e., the European part of the North Boreal Province). Only polar spines of boreal Pantanelliidae are relatively short and massive. Also Pantanelliidae are widely distributed in the majority of localities along the Pacific margin, where we are dealing with a terrane that was displaced palaeolatitudinally from south to north along the Pacific margin. There are no associated megafossils.
- A marked change took place at the Jurassic–Cretaceous boundary in the Boreal Realm. The change of *Parvicingula*-rich assemblage into those rich in *Stichocapsa* and *Spinicingula* gen. nov. at this boundary has been noted in the North Arctic basins (Barents, Siberian, Laptev palaeoseas) of Russia. The Early/Middle Volgian (Kimmeridgian–Tithonian) fauna is dominated by *Parvicingula*, whereas in Late Volgian (Berriasian) faunas *Stichocapsa* and *Spinicingula* gen. nov. prevail. A decrease in chamber number was documented in Late Volgian representatives of the genera *Parvicingula* and *Stichocapsa*. *Stichocapsa devorata arctica* Vishnevskaya and Murchey, 2002 is a highly characteristic species in Berriasian assemblages of the North Arctic basins of Russia. The pantanelliid abundance in the Boreal province of the Russian Arctic bears some similarity to the Antarctic but differs from the Californian province as described by Pessagno (1977).
- The Early Campanian radiolarian associations of the Russian Pacific Margin are diverse. In contrast, only four or five genera (*Orbiculiforma*, *Prunobrachium*, *Lithostrobus*, *Amphipyndax*, and *Dictyomitra*) occur in coeval assemblages of the Siberian Arctic. The presence of similar radiolarian associations with Boreal affinities in the terranes of the Bering and Okhotsk regions may suggest the presence of synchronous bituminous facies on the shelf of the Russian north-east and in the Canadian sector.
- The main difference between Arctic and Pacific sequences lies in composition and tectonic setting of radiolarian-bearing rocks. They are presented by oil clay along the Arctic Margin and by jasper or tuffaceous chert in the Pacific. They are situated in normal sections with other fossils along the Arctic Margin and incorporated into tectonostratigraphic sections and practically without associated other fossils along the Russian Pacific Margin.
- 7. The description of two new genera and five new species are added; 60 characteristic radiolarian species typical of the Russian Arctic and Pacific Rims are illustrated.

Methods

The clay samples were boiled in H_2O_2 and treated with NaOH. The chert samples were treated with hydrofluoric (1–3 %) acid, the siliceous limestone samples with acetic (10%) and hydrofluoric (1–5%) acids. The resulting residues yielded well-preserved faunas that were studied for taxonomic and biostratigraphic purposes. Here, we summarise data supplied by Kozlova (1994b) and add our own, inclusive of SEM images of radiolarian assemblages (SEM ISI-160, GIN RAN, Moscow).

Systematic palaeontology

All species considered characteristic of the Russian Arctic and Pacific Rim are here illustrated (Figs. 4, 6–9). Some of them have never been provided with a complete description, because the original account was published in the Russian fond issue of VNIGRI, while others are planned to be published in a book on the Russian Arctic (BP Exploration Operating Company), or are impossible or difficult to locate to date, and should thus be considered nomina nuda. Unfortunately, some data cannot be accessed for reasons of confi-

http://dx.doi.org/10.4202/app.2011.0040

dentiality involving the Petroleum Company and its partners. All new radiolarian taxa illustrated in the present study are formally described below, inclusive of synonymies.

Class Radiolaria Müller, 1858

Subclass Euradiolaria Lameere, 1931

Suborder Polycystina Ehrenberg, 1838

Order Spumellaria Ehrenberg, 1875

Family Sponguridae Haeckel, 1862

Genus *Spongurus* Haeckel, 1862

Type species: *Spongurus cylindricus* Haeckel, 1860, Recent, Pacific ocean.

Spongurus arcticus Kozlova and Vishnevskaya sp. nov.

Fig. 7A–C.

Etymology: In reference to the Arctic Realm.

Holotype: GIN K22-2-57 (see Fig. 7A).

Type locality: Borehole 22, Ust-Manja, western Siberia, Russia.

Type horizon: Lower Campanian, Upper Cretaceous.

Diagnosis.—Elongated monoaxonic skeleton of small or average sizes, subrectangular in outline, with increased in width polar tips, without patagium and terminal spines.

Description.—Stick-shaped cylindrical spongy skeleton extending along one axis, covered by spongodiscid texture. Skeleton consisting of three main elements: spherical central part formed by several concentric or spiral cameral rings, surrounding central microsphere, and two polar processes terminating in pole-like beams. Polar processes and spherical central part as a rule have irregular spongodiscid tissue or are sometimes spongy-porous. Pylome located at one of the poles is quite rare.

Measurements (in μm).—Length of longitudinal axis: 190; length of transverse axis: 55; pore diameter: 3–8. The skeleton varies in size along the longitudinal (170–210) and transverse (45–70).

Remarks.—The new species differs from congeners in having a cylindrical, stick-shaped subrectangular skeleton and in the absence of firm polar spines.

Geographic and stratigraphic range.—Boreal realm; Arctic Margin, Kara, and Volga basins, Russia.

Order Nassellaria Ehrenberg, 1875

Family Lithostrobidae Petrushevskaya, 1975

Genus *Lithostrobus* (Bütschli, 1882, sensu Petrushevskaya and Kozlova, 1972)

Type species: *Lithostrobus monostichus* Haeckel, 1862, Recent, Pacific ocean.

Lithostrobus borealis Kozlova and Vishnevskaya sp. nov.

Fig. 7H–J.

Etymology: With reference to the Boreal Realm.

Holotype: GIN N K22-1-57 (see Fig. 7J).

Type locality: Borehole 22, Ust-Manja, western Siberia, Russia.

Type horizon: Lower Campanian, Upper Cretaceous.

Diagnosis.—Low conical domed multisegmented *Lithostrobus* with large perforate spheroidal cephalis bears high conical apical horn.

Description.—Test subconical, multisegmented with 3–4 post-abdominal segments becoming cylindrical distally. Cephalis subspherical, poreless, bearing a very strong short apical horn with two grooves. Thorax bears two lateral spines. Post-abdominal segments slightly increasing in width, but constant in height. All segments visibly separated. Test wall thick with transverse rows of polygonal pore frames; four rows per segment.

Measurements (in μm).—Total height 200–250, maximum width 140–150, height of cephalis and thorax together 60–80.

Remarks.—Differing from congeners in having of lateral spines, an apical horn with two grooves, but not circular in cross-section and four rows of pores per segment.

Geographic and stratigraphic range.—Lower Campanian; Western Siberian Basin, Russia.

Family Parvicingulidae Pessagno, 1977

Genus *Parvicingula* Pessagno, 1977

Type species: *Parvicingula santabarbarensis* Pessagno, 1977, Late Bathonian–Hauterivian, California Coast Ranges.

Parvicingula alata Kozlova and Vishnevskaya sp. nov.

Figs. 4T, 6F, G.

1994 *Parvicingula* sp. F; Kozlova 1994b: pl. 8:1–3, 6.

Etymology: In allusion to the wings.

Type material: Holotype N G-1-2K (see Fig. 6F), Paratype N667/68; both at the Museum of the Microfaunal Laboratory VNIGRI, St Petersburg.

Type locality: Gorodishce section, Uljanovsk, Volga Basin, Russia.

Type horizon: Upper Volgian.

Diagnosis.—Typical *Parvicingula* with dome shaped cephalothorax, bearing 3 short massive spines.

Description.—Test conical with nine (or more?) post-abdominal segments. Cephalis and thorax together dome shaped, irregularly perforated, with coarse to thorny surface. Apical horn massive, very short subconically, with apical pore; spines 2, L and D short, situated at centre of cephalo-thorax. Distinct complete circumferential ridge beginning at the base of the first post-abdominal segments. Thorax and following segments approximately equal in height, with three rows of uniform hexagonal pore frames; pores circular.

Measurements (in μm).—Total height 130–165, height of cephalis + thorax 35–42, height abdomen and following segments 23–27, test width (maximum) 65–75, cephalis width 40–57.

Remarks.—The new species differs from congeners in having external spines and a dome-shaped cephalo-thorax.

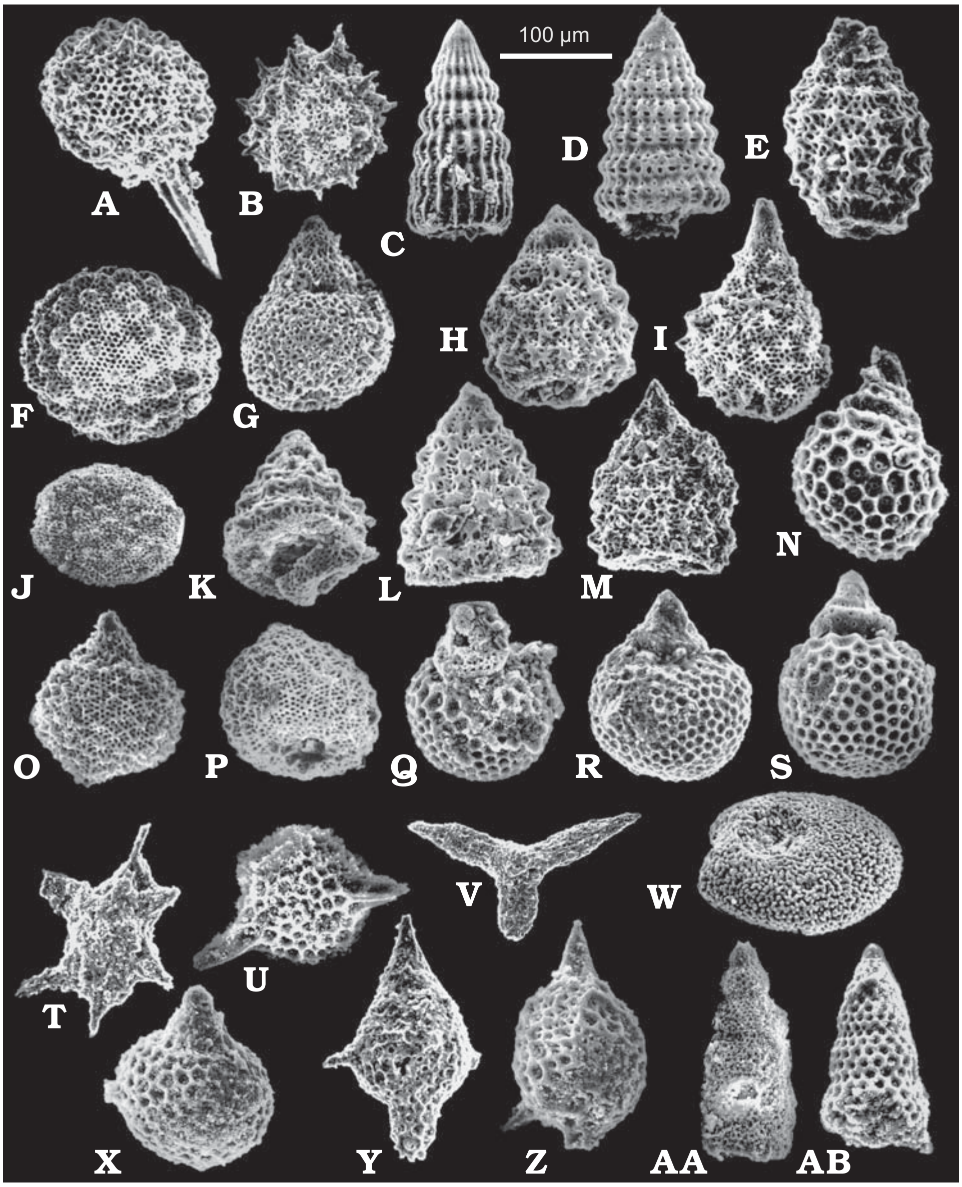

Fig. 9. Scanning electron micrographs of Berriasian (A–S) (sample 102-1, Tymov area, Veba River) and Tithonian radiolarian (T–AB) assemblages from the eastern Sakhalin Mountains (sample 114, locality Rocky Ridge). **A**. *Acaeniotyle* sp., GIN N 102-1-1. **B**. *Praeconocaryomma haeckeli* (Aliev, 1965), GIN N 102-1-3. **C**. *Archaeodictyomitra tumandae* Dumitrica, 1997, GIN N 102-1-20. **D**. *Archaeodictyomitra leptocostata* (Wu and Li, 1982), GIN N 102-1-22. **E**. *Tethysetta usotanensis* (Tumanda, 1989), GIN N 102-01-24. **F**. *Cenodiscaella numulitica* (Aliev, 1965), GIN N 102-1-5. **G**, **O**, **P**. *Syringocapsa lucifer* Baumgartner, 1984. **G**. GIN N 102-1-31. **O**. GIN N 102-1-33. **P**. GIN N 102-1-34. **H**. *Stichocapsa altiforamina* Tumanda, 1989, GIN N 102-1-35. **I**. *Mirifusus chenodes* (Renz, 1974), GIN N 102-1-36. **J**. *Godia* sp., GIN N 102-1-39. **K**, **L**. *Xitus* cf. *robustum* Wu, 1993. **K**. GIN N 102-1-41. **L**. GIN N 102-1-42. **M**. *Mirifusus appeninicus* Jud, 1994, GIN N 102-1-45. **N**, **S**. *Sethocapsa pseudouterculus* Aita, 1987. **N**. GIN N 102-1-46. **S**. GIN N 102-1-47. **Q**. *Sethocapsa zweili* Jud, 1994, GIN N 102-1-48. **R**. *Sethocapsa kitoi* Jud, 1994, GIN N 102-1-49. **T**. *Hexinastrum*? sp., GIN N 114-R1. **U**. *Triactoma mexicana* Pessagno and Yang, 1993, GIN N 114-R2. **V**. *Tritrabs* sp., GIN N 114-R5. **W**. *Orbiculiforma lowreyensis* Pessagno, 1977, GIN N 114-R6. **X**. *Zhamoidellum*? *ovum* Dumitrica, 1970, GIN N 114-R7a. **Y**, **Z**. *Podobursa tricola* Foreman, 1973, **Y**. GIN N 114-R8. **Z**. GIN N 114-R9. **AA**. *Stichomitra* cf. *tairai* Aita, 1987, GIN N 114-R10a. **AB**. *Triversus tsunoensis* (Aita, 1987), GIN N 114-R13.

Geographic and stratigraphic range.—Upper Volgian; Volga Basin, Russia.

Parvicingula papulata Kozlova and Vishnevskaya, sp. nov.

Fig. 6H.

1994 *Parvicingula papulata* Kozlova 1994b: pl. 5: 6, 8–11 (nomen nudum).

1998 *Parvicingula papulata* Kozlova; Vishnevskaya 1998: 63, pl. 8: m, n, pl. 12: i (nomen nudum).

Etymology: From Latin *papula*, meaning blister or a small nodule.

Type material: Holotype GIN P-1K (see Fig. 6H); paratype VNIGRI N667/65.

Type locality: Ukhta section, Pechora Basin, Russia. Range: Lower Kimmeridgian–Lower Volgian of Mezen (borehole 234).

Type horizon: Lower and Middle Volgian of Volga (Gorodishce) Basin.

http://dx.doi.org/10.4202/app.2011.0040

Diagnosis.—Typical *Parvicingula* with pyramidal shaped cephalothorax, bearing 1 well developed apical conical horn and 2 short papula shaped spines.

Description.—Test conical with five (or more?) post-abdominal segments. Cephalis and thorax together pyramidal-domed, cephalis without perforation, thorax irregularly perforated, with coarse to thorny surface. Apical horn massive, wide conical, with apical pore; spines 2, L and D short, pyramidal or papula shaped, situated at centre of cephalo-thorax. Distinct complete circumferential ridge beginning at the base of the first post-abdominal segments. Thorax and following segments approximately equal in height, with three rows of uniform hexagonal pore frames; pores circular in outer rows, circular to elliptical in middle row.

Measurements (in μm).—Total height 127–165, height of cephalis + thorax 43–46, height abdomen and following segments 23–27, test width (maximum) 74–95, cephalis width 50–63.

Remarks.—The new species differs from congeners in having papula- or nodule-shaped spines L and D.

Geographic and stratigraphic range.—Kimmeridgian–Middle Volgian of Mezen; Pechora and Volga basins, Russia.

Genus *Spinicingula* Kozlova and Vishnevskaya nov.

Type species: *Spinicingula certina* Kozlova and Vishnevskaya sp. nov.; see below.

Etymology: From Latin *spina,* thorn, prickle, needle and *cingula,* belt or girdle; test with thorns and belts (by analogy with *Parvicingula*).

Diagnosis.—The main shell construction is very similar to the one in *Parvicingula* Pessagno, 1977, but differs in having outer spines. Spines 2, L' and D' form massive longitudinal ridges or wings in the upper part of the shell; spine V' is short pyramid shaped or cone-shaped thorn, spines 2, 1', when present, similar.

Remarks.—From other parvicingulids, the new genus differs by having a system of outer spines.

Geographic and stratigraphic range.—Middle–Late Volgian, Boreal realm; Timan-Pechora Basin, Russia.

Spinicingula ceratina Kozlova and Vishnevskaya sp. nov.

Figs. 4H, 6B–E.

1994 *Parvicingula* sp. D; Kozlova 1994b: pl. 5: 1–4.

Etymology: From Latin *ceratinus*, horned.

Holotype: VNIGRI N 667/66 (see Fig. 6B).

Type locality: Borehole 5, Narjan-Mar, Timan-Pechora region, Russia.

Type horizon: Middle–Upper Volgian.

Diagnosis.—Parvicingulid-like skeleton without or with weakly developed circumferential ridges, bearing 1 apical and 4–6 additional spines.

Description.—Test subconical with 4 (or more?) post-abdominal segments, slightly undulating in outline. Cephalis together with thorax dome shaped, with short apical horn and outer spines. Segments slightly increasing in width and being constant in height. All segments separated internally by planiform ring-shaped portions. Test wall thick, subpolygonal to oval pore frames arranged in transverse rows in three rows per segment. Circumferential external ridges weakly developed or not developed. Pores relatively equal in size. Abdomen and following segments trapezoidal or X-shaped in cross section. Spine A conical, often very thick, spine V thinner, between A and V one large pore. Spines D and L extend outwards from near base of thorax (D) or near base of cephalis (L) as tooth-shaped wings, short, smooth, oval in cross section. Spines L short and rather small. Two short, cone-shaped smooth thorns in the middle portion of the cephalis, spines ”l”.

Measurements (in μm).—Total height 120–125, maximum width 93–100, height of cephalis and thorax together 35–42.

Remarks.—Differing from species of *Parvicingula* in having weakly developed circumferential ridges (or altogether absent) and in possessing spines next to or surrounding the massive apical horn.

Geographic and stratigraphic range.—Middle and Upper Volgian of Pechora Basin of Russia and Upper Volgian of Volga Basin of Russia.

Family Xitidae Pessagno, 1977

Genus *Quasicrolanium* Kozlova and Vishnevskaya nov.

Type species: *Stichopilidium plaocephala* Kozlova, 1976, Kolguev Island, Borehole 140, depth 472–481 m, Upper Jurassic, Volgian Stage, upper substage.

Etymology: From Greek *quasi*, “as if” , in allusion to its close similarity to *Crolanium*.

Diagnosis.—Test multisegmented, trihedral-pyramidal in form, with three ribs extending from top of thorax (rib “D”), or of abdomen (ribs “L”) to distal portion. Cephalis hemispherical, with short conical spines “A”, “V” and 2, 1’; remaining segments with concave wall as in Parvicingulidae; last segment free of ribs may be circular in cross section and turn into a long tube. Abdomen and post-abdominal segments separated externally by concentric circumferential ridges, not circular, but crooked triangle-shaped. Test network regularly hexagonal with four to six transverse rows of small round pores at each segment.

Species included.—*Quasicrolanium planocephala* (Kozlova, 1976).

Remarks.—The new genus is closely related to *Crolanium* Pessagno, 1977 and *Pseudocrolanium* Jud, 1994, having outer ribs in common. The distinguishing feature is the presence of longitudinal ribs on the entire test segments, with exception of the last one; segments and ribs, bearing net on the test wall, resemble to landing-net.

It is doubtful if this new genus can be attributed to the same family as *Crolanium* and *Pseudocrolanium*. *Quasicrolanium* gen. nov. differs from members of the Stichocapsidae by having concave, not convex, segments and transverse circumferential ridges at chamber boundaries. From parvicingulid genera it can be distinguished by possessing three longitudinal ribs and fewer pores at each segment: 4–6 rows (predominantly 6).

Geographic and stratigraphic range.—Late Volgian in height latitudes of Northern Hemisphere; Timan-Pechore Basin and eastern Ural Slope, Russia.

Quasicrolanium planocephala (Kozlova, 1976)

Fig. 6A.

1976 *Stichopilidium planocephala*; Kozlova 1976: 82, fig. 3.
1983 *Stichopilidium planocephala* Kozlova, 1976; Kozlova 1983: 81–82, fig. 3.
1994 *Pseudocrolanium planocephala* (Kozlova, 1976); Kozlova 1994b: pl. 8: 1–3.
1999 *Quasicrolanium planocephala* (Kozlova, 1976); Repin et al. 1999: 36.

Remarks.—Originally, Kozlova (1994) planned to describe a new genus, *Pseudocrolanium* (Kozlova 1994a) and referred to the present species as *Pseudocrolanium planocephala* (Kozlova, 1994) Kozlova, 1994. However, the genus *Pseudocrolanium* Jud, 1994 (Jud 1994: 96) differs in having nodular ridges, three radially protruding spines only in the distal part of the test and longitudinal costae along central part of test.

Acknowledgements

We are grateful to Kirilla I. Kuznezova (Geological Institute, Moscow, Russia) and Sergey V. Lyurov (Syktykvkar University, Syktykvkar, Russia) for identification of associated foraminifera, to Edward O. Amon (Paleontological Institute, Moscow, Russia) and Nikita Yu. Bragin (Geological Institute, Moscow, Russia) for careful pre-review of an earlier version of the typescript, to Annika Sanfilippo (La Jolla, USA), Christofer Hollis (Wellington, New Zealand), Emile Pessagno (Texas University, Texas, USA), Marta Bąk (Institute of Geological Sciences, Jagiellonian University, Kraków, Poland), and Nevenka Djeric (Belgrad University, Serbia) for critical comments and editing. We also thank John W.M. Jagt (Maastricht, the Netherlands) for detailed linguistic correction and editorial assistance as well as Elena Jagt-Yazykova (Opole, Poland) for technical handling and editorial advice. This work was supported by the Programme of the Presidium of the Russian Academy of Sciences "Origin and Evolution of the Biosphere", Russian Foundation for Basic Research (project no. 09-05-64342).

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