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The Distribution of Calcareous Nannofossils and Foraminifers in the Callovian, Oxfordian, and Volgian Deposits in the Southwest of Moscow

M. A. Ustinova
Geological Institute, Russian Academy of Sciences, Moscow, Russia
e-mail: ustinova_masha@mail.ru

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Abstract—The distribution of calcareous nannofossils and foraminifers occurring in the Callovian–Oxfordian deposits in the southwest of Moscow is studied. Nannoplankton-bearing beds and foraminiferal zones are distinguished. The *Retecapsa incompta* Beds correspond in range to the *Ophthalmidium sagittum–Epistomina volgensis* and *Ophthalmidium strumosum–Lenticulina brestica* foraminiferal zones as well as the lower part of *Epistomina uhligi–Lenticulina russiensis* Zone. The *Watznaueria manivitae, Crepidolithus perforata*, and *Watznaueria fossacincta* (lowermost part) beds span interval of the *Epistomina uhligi–Lenticulina russiensis* Zone. The *Watznaueria fossacincta* Beds are concurrent to the *Lenticulina ponderosa–Flabellamina lidiae* Zone of the foraminiferal scale.

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Key words: calcareous nannoplankton, foraminifers, Callovian, Oxfordian and Volgian stages.

INTRODUCTION

In the Moscow region, the stratigraphic subdivision of Jurassic deposits is well substantiated based on different groups of fossil organisms: ammonites, belemnites, ostracodes, and foraminifers (Sazonov and Sazonova, 1967; Kuznetsova, 1979; Azbel et al., 1991). This would certainly have been sufficient had it not been for the increased interest, recently, in the study and stratigraphic subdivision of Jurassic deposits based on the distribution of calcareous nannofossils. The detailed zonation of calcareous nannoplankton has not been elaborated for Jurassic deposits of the East European platform. Biostratigraphic zones used to be defined as intervals either between the first and last occurrence levels of certain index species, or between the levels characterizing the onset and end of acme for particular taxa that existed during considerably long time spans (Shumenko, 1987). In the European part of Russia, calcareous nannofossils remain practically unstudied except for two cases. One is the Gorodishche section of the Kimmeridgian–Volgian deposits in the Ul'yanovsk region, where the distribution of calcareous nannofossils is studied in great detail (Nikiforova, 1986; Lord et al., 1987; Cooper, 1987; Bown et al., 1988; Kessels et al., 2003) and the distinguished zones are correlated with analogous zones established in West European sections (Bown and Cooper, 1999). The other one is the Malinovyi Ravine reference section of the Callovian sediments (Nikiforova et al., 2001). It would be premature to say that nannoplankton zonations elaborated abroad can be used in the stratigraphy of Jurassic deposits in European Russia, where factual data are very limited so far. In 2004, I initiated a study of Jurassic calcareous nannoplankton in central areas of the Russian plate, using core samples from boreholes drilled within the Moscow area (Ustinova and Radugina, 2004). As a continuation of that study, this work aims to investigate calcareous nannofossils in core samples from boreholes 1 and 6, from which an incomplete geological succession of deposits has been recovered. Both boreholes were drilled in ul. Kosygina, Vorob'evy gori, Moscow (Fig. 1). Section descriptions and core samples were kindly put at my disposal by A.S. Alekseev. Foraminifers and their zones in Borehole 1 were determined by A. Azbel.

The drilling of Borehole 1 terminated in the Middle Carboniferous deposits of the Myachkovo Horizon at a depth of 98.5 m. The Jurassic succession begins here with the Lyublino Formation of the lower Callovian Substage and extends upward to the Fili Formation of the middle Volgian Substage. In other words, this borehole penetrated through sediments of the Callovian, Oxfordian, and Volgian stages, whereas the Kimmeridgian Stage is missing from the section. The drilling of Borehole 6 also terminated in deposits of the Myachkovo Horizon at a depth of 97 m. In this borehole, the basal Jurassic sediments correspond to the Moskvoretskaya Formation of the Bathonian, and the succes-

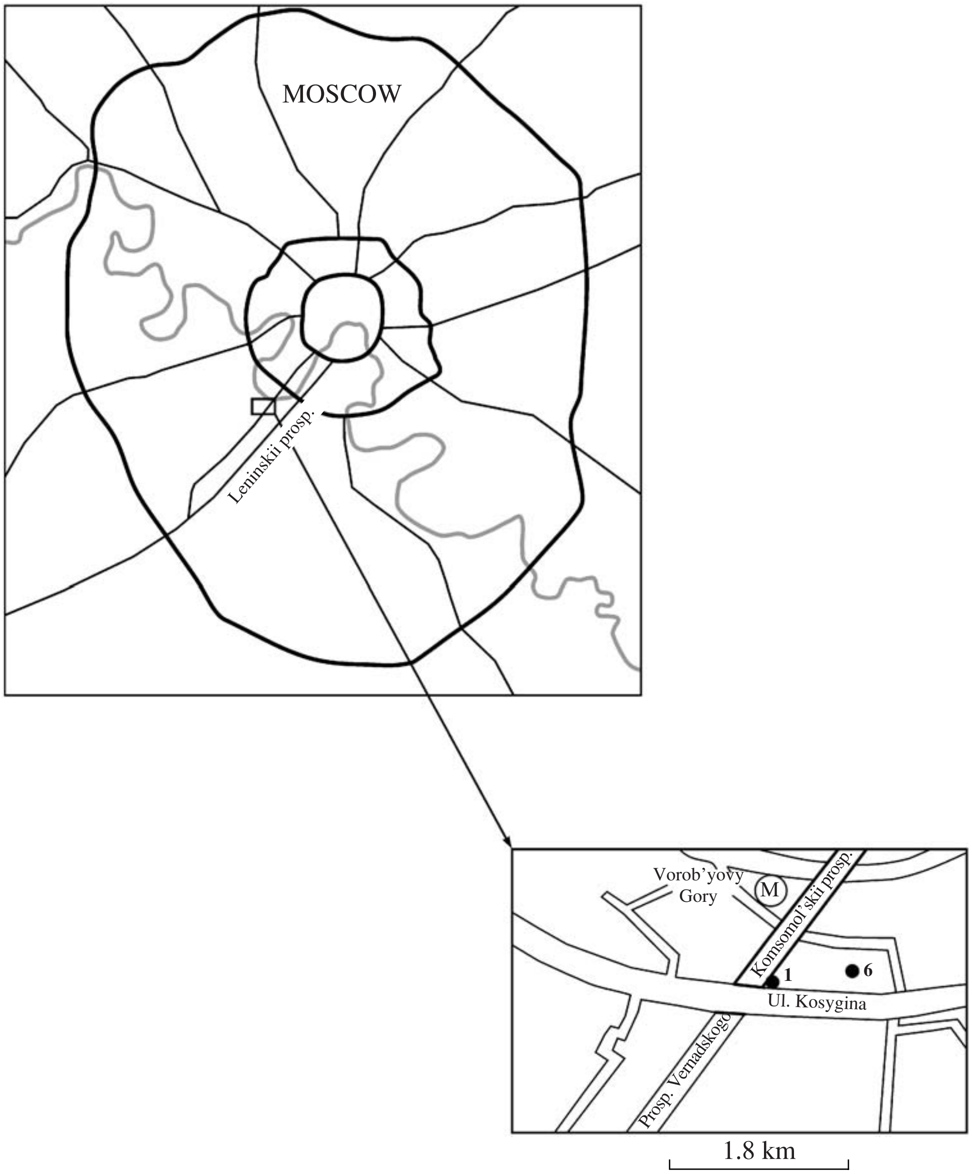


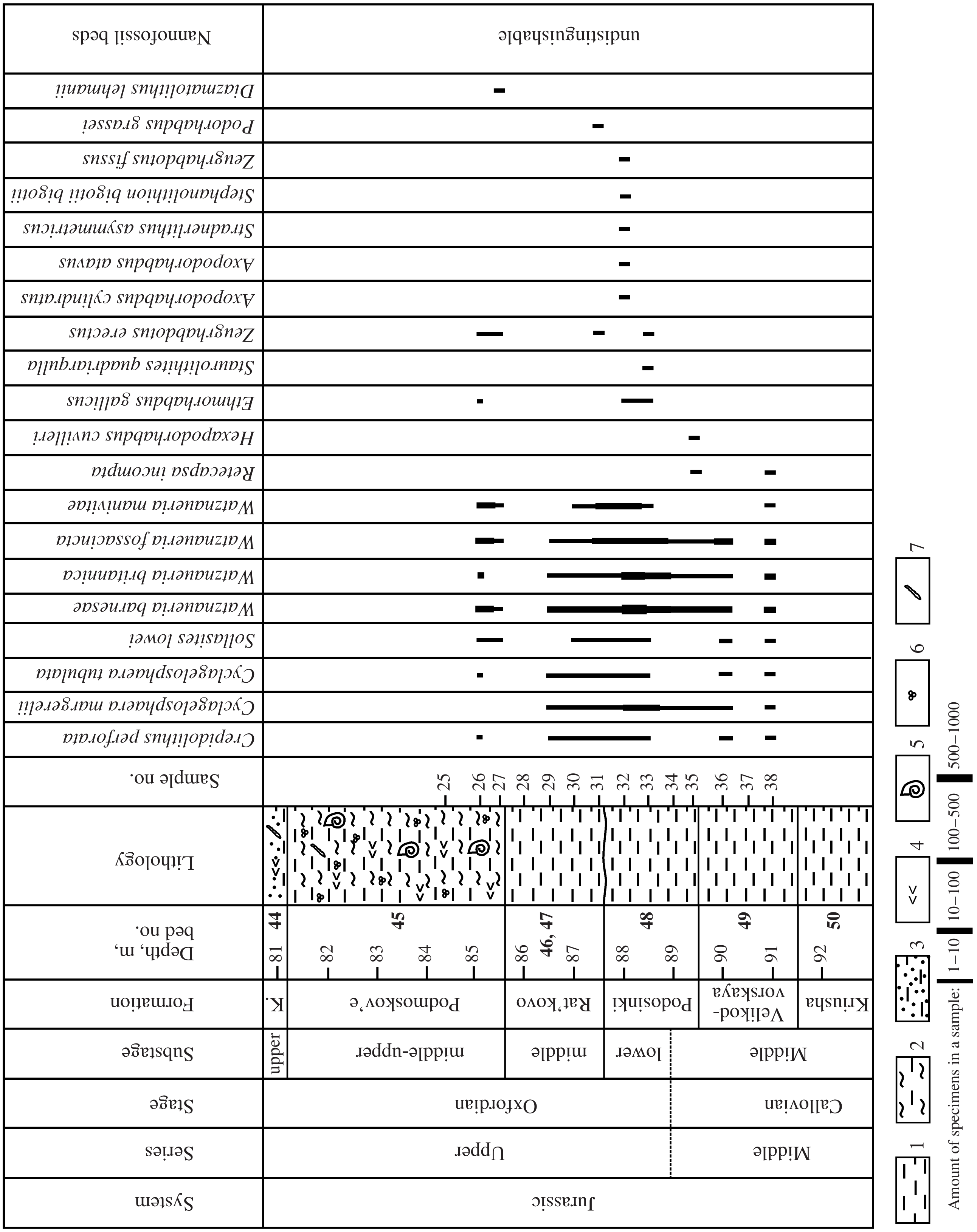
Fig. 1. Schematic map of drilling localities.

sion is crowned, as in Borehole 1, by the middle Volgian deposits. Subdivision into formations was performed by A.G. Olfer'ev in accordance with the Unified Stratigraphic Scheme for the Jurassic of the Russian platform, which was approved in 1988 by the ISC Bureau and in resolutions of the Jurassic and Cretaceous panels of the RISC (Olfer'ev, 2001; Shik and Olfer'ev, 2006). The subdivision was checked against the results of the γ-logging. In Borehole 1, sampling intervals corresponded to 0.3 m within the Oxfordian sediments and to 1 m within the upper Oxfordian–middle Volgian deposits. In Borehole 6, the sampling interval was uniform, corresponding to 0.3 m. In total, 62 samples have been collected from both boreholes for the investigation of nannofossils.

CHARACTERIZATION OF SECTION

Described below are the section intervals sampled for the investigation of nannofossils and foraminifers.

In Borehole 6, samples have been collected from the middle Callovian–Oxfordian deposits (Fig. 2). The middle Callovian Substage corresponds to deposits of the Kriusha and Velikodvorskaya formations. The Kriusha Formation (Bed 50, depth interval 94.3–91.7 m) is composed of poorly reworked, gravely inequigranular sands bearing ferruginate ooliths; and the formation is 2.9 m thick. Calcareous nannofossils have not been found in these sediments. The Velikodvorskaya Formation (Bed 49, depth interval 91.7–89.4 m) conformably resting on the Kriusha Formation is represented by brownish to light gray pelitic or aleuritic clays, bearing


System
Series
Stage
Substage
Formation
Depth, m, bed no.
Lithology
Sample no.
Crepidolithus perforata
Cyclagelosphaera margerelii
Cyclagelosphaera tubulata
Sollasites lowei
Watznaueria barnesae
Watznaueria britannica
Watznaueria fossacincta
Watznaueria manivitae
Retecapsa incompta
Hexapodorhabdus cuvillieri
Ethmorhabdus gallicus
Staurolithites quadriarculla
Zeugrhabdotus erectus
Axopodorhabdus cylindratus
Axopodorhabdus atavus
Stradnerlithus asymmetricus
Stephanolithion bigotii bigotii
Zeugrhabdotus fissus
Podorhabdus grassei
Diazmatolithus lehmanii
Nannofossil beds
undistinguishable
Jurassic
Middle
Upper
Callovian
Oxfordian
Middle
lower
middle
middle-upper
upper
Kriusha
Velikod-vorskaya
Podosinki
Rat'kovo
Podmoskov'e
K.
92
91
90
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88
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46, 47
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30
31
32
33
34
35
36
37
38
1
2
3
4
5
6
7
Amount of specimens in a sample:
1–10
10–100
100–500
500–1000

ferruginate ooliths at the base, abundant shell detritus, and laminae of oolitic marl. These sediments (2 m thick) are conformably overlain by deposits of the Podosinki Formation (Bed 48, depth interval 89.5–87.6 m) corresponding in age to the late Callovian–early Oxfordian. The light gray calcareous clays of the formation have a light lilac tint and contain branching plant remains, clayey phosphorite nodules, and interlayers of argillaceous and sometimes oolitic marl. The Podosinki Formation is 1.9 m thick. It is overlain with scouring by light gray, slightly micaceous clays of the middle Oxfordian Rat'kovo Formation (beds 47 and 46, depth interval 87.6–85.6 m) saturated with shell detritus. These clays are 2 m thick. The Podmoskov'e Formation conformably overlying the previous one and corresponding in age to the middle–late Oxfordian (Bed 45, depth interval 81.2–85.6 m) is the last one in the succession. The last formation 4.4 m thick is composed of gray to dark gray bituminous silty clays bearing abundant foraminifers in its lower part. As for calcareous nannofossils, they are represented by the following species occurring throughout the section: *Crepidolithus perforata* (Medd), *Cyclagelosphaera tubulata* (Grun and Zweili) Cooper, *Sollasites lowei* (Bukry), *Watznaueria barnesae* (Black) Perch-Nielsen, *W. britannica* (Stradner) Reinhardt, and *W. fossacincta* (Black) Bown et Cooper (Table I). The *Cyclagelosphaera deflandrei* (Manivit) and *Cycl. margerelii* Noël species are characteristic of the Podosinki and Velikodvorskaya formations. The assemblage of *Axopodorhabdus cylindratus* (Noël) Wise et Wind, *Ax. atavus* (Grun et al.), *Hexapodorhabdus cuvilleri* Noël, *Podorhabdus grassei* Noël, *Retecapsa incompta* Bown, *Staurolithites quadriarculla* (Noël), *Stradnerlithus asymmetricus* (Rood et al.), *Stephanolithion bigotii bigotii* Deflandre, and *Zeugrhabdotus fissus* Grun and Zweili are confined to the Podosinki Formation. The *Ethmorhabdus gallicus* Noël, *Zeugrhabdotus erectus* (Deflandre et Fert) Reinhardt, and *Watznaueria manivitae* Bukry taxa are confined to the Podosinki, Rat'kovo, and Podmoskov'e formations. The *Diazmatolithus lehmanii* Noël species is identified in the Podmoskov'e Formation only.

Core samples collected from the Oxfordian–Volgian deposits of Borehole 1 show that the section interval with microfossils begins with the upper part of the Podosinki Formation (lower Oxfordian) that is identical in structure to concurrent deposits of Borehole 6, and is 1.2 m thick in total (Bed 25, depth interval 93.4–92.2 m). The foraminiferal assemblage of these deposits is represented by the following species: *Astacolus erucaeformis* (Wisn.), *A. primaeformis* (Mjatl.), *Falsopalmula deslongshampsi* (Terq.), *Ophthalmidium sagittum* (E. Byk.), *Nodosaria muensteriana* Gumb., *N. mutabilis* Terq., *N. procera* Wisn., *N. oxfordea* Mjatl., *Lenticulina attenuata* (Kubl. et Zwing.), *L. brueckmanni* (Mjatl.), *L. kostensis* Azbel, *L. parainflata* Grig., *L. russiensis* (Mjatl.), *Planularia beierana* (Gumb.), *Pseudolamarckina suvalkensis* Grig., *Epistomina intermedia* Mjatl., *E. multialveolata* Grig., *E. volgensis* Mjatl., *E. nemunensis* Grig., *E. parastelligera* (Hofk.), *E. gracilis* Dain, *Epistominita formastra* Azbel, and *Marginulina batrakieformis* Azbel (Fig. 3).

The scoured top of the Podosinki Formation is overlain by sediments of the Rat'kovo Formation (Bed 24, depth interval 92.2–91 m) that is of the same lithology as in Borehole 6, and is 1.2 m thick. The foraminiferal assemblage of the overlying formation is almost completely renewed as compared with the underlying one. The following taxa transit from the Podosinki into the Rat'kovo Formation: *Epistominita formastra* Azbel, *Nodosaria muensteriana* Gumb., *N. mutabilis* Terq., *Ophthalmidium sagittum* (E. Byk.), *Spirillina kuebleri* Mjatl., *Nodosaria procera* Wisn. whose stratigraphic range extends up to the Podmoskov'e Formation upper part, *Epistomina nemunensis* Grig. occurring up to the Ermolino Formation top, *E. volgensis* Mjatl. recorded up to the Kolomna Formation's lower part, *Lenticulina brestica* and *Falsopalmula deslongshampsi* (Terq.) encountered in the upper part of the Podmoskov'e Formation, *Pseudolamarckina suvalkensis* Grig. widespread up to the lower part of the Ermolino Formation, and *E. parastelligera* (Hofk.). Foraminiferal species characteristic of the Rat'kovo Formation only are *Bojarkaella turbiformis* (Schwag.), *Dentalina dolioligera* (Schwag.), *D. laevigata* Schwag., *Lenticulina hebetata* (Schwag.), *L. nostra* Grig., *Lingulonodosaria elsa* (Schwag.), *Nodosaria corallina* Gumb., *N. euglypha* Schwag, *N. tenuicostata* Starts., *Orthella paalzowi* E. Byk., *Pseudonodosaria pupoides* (Born.), and *Saracenaria raricostula* Azbel. The following taxa appear in this formation and transit into the overlying Podmoskov'e Formation: *Astacolus comptulus* (Schwag.), *Bojarkaella lagenoides* (Wisn.), *Epistomina multialveolata* Grig., *Marginulina affixa* Azbel, *Ophthalmidium strumosum* (Gumb.), and *Spirotroholina incerta* (Svetovost.-Habar.). The following foraminifers occur up to the lower part of the Kolomna Formation: *Citharina sokolovae* (Mjatl.), *Dentalina pseudoarcuata* Seibold, *Lenticulina compressaeformis* (Paalz.), *Lenticulina ectypa costate* Cordey, *Lingulonodosaria tuberosa* (Schwag.), *Planularia manibrium* (Schwag.), and *Rectoepistominoides fimbriatus* Azbel. The *Citharina chanica* (Mjatl.), *Epistomina uhligi* Mjatl., *Lenticulina sublenticularis* (Schwag.), and *Marginulinopsis pro-*

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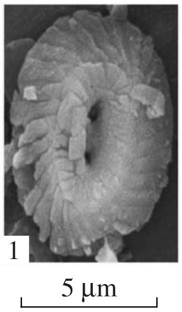
Fig. 2. Distribution of calcareous nannofossil species in the section of the Callovian–Oxfordian deposits recovered from Borehole 6: (1) clay; (2) aleuritic clay; (3) sandy clay; (4) mica admixture; (5) ammonites; (6) foraminifers; (7) fucoids; (K.) Kolomna Formation.

Plate I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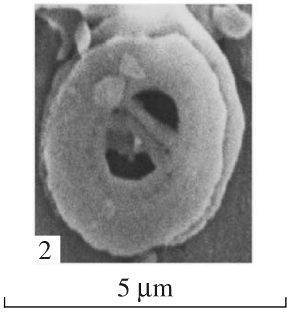
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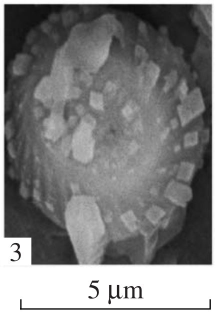
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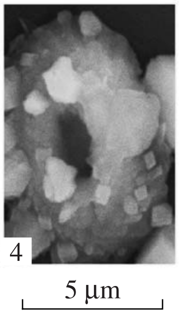
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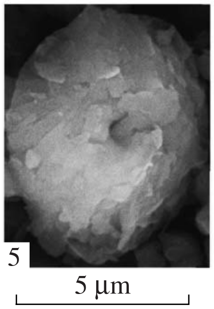
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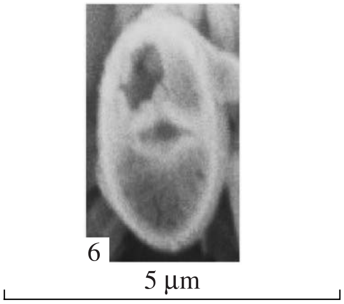
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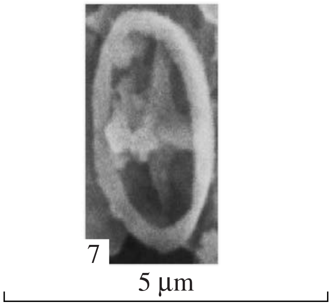
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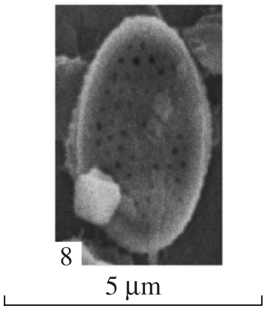
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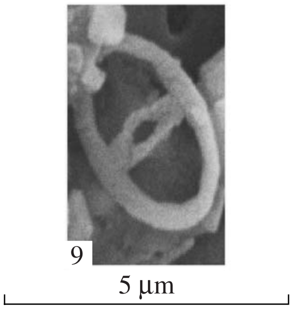
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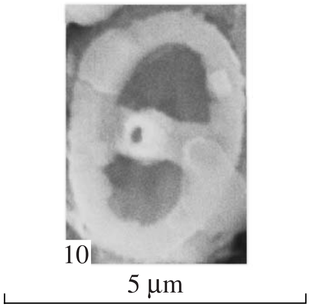
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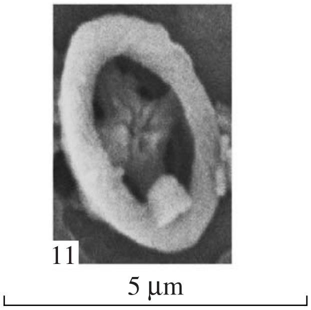
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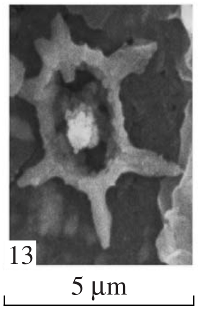
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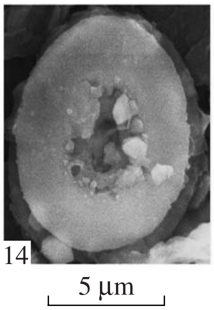
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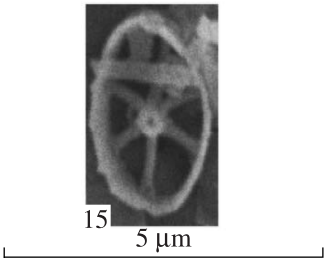
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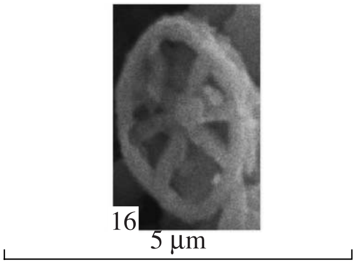
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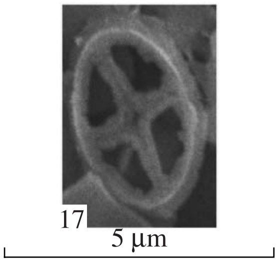
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cera (Kapt.) species are dispersed in the section up to upper part of the Ermolino Formation.

The Rat'kovo Formation is conformably overlain by the Podmoskov'e Formation (Bed 23, depth interval 91–84 m) that is 7 m thick. The foraminiferal assemblage, which is typical only of the latter formation, includes the following taxa: *Astacolus informis* (Schwag.), *Bullopora? neotorica* Azbel, *Dentalina cylindrica* Schwag., *Dentalina oppeli* Schwag., *Dentalina sinemuriensis* Terq., *Epistomina* ex. gr. *decorata* Kapt., *Lenticulina pirjatiensis* Pjatk., *Lenticulina suprajurassica* (Schwag.), *Ramulina splendida* Paalz., and *Tolypammina bulbifera* (Paalz.). The following taxa transit from this level into the Kolomna Formation: *Citharina ornitocephala* (Wisn.), *Dentalina bicornus* Schwag., *Dentalina bullata* Schwag., *Dentalina cytharella* (Terq.), *Dentalina jurassica* Gumb., *Globulina oolithica* Terq., *Marginulinopsis crepidulaeformis* (Gumb.), *Ramulina spandeli* Paalz., *Ramulina splendida* Paalz., *Rectoepistominoides fimbriatus* Azbel, and *Troholina transversarii* Paalz. The *Lenticulina* aff. *tumidiscula* Pjatk. species transit higher into the Ermolino Formation.

The Kolomna Formation of the late Oxfordian age overlies the Podmoskov'e Formation without hiatus. Being 5 m thick (Bed 22, depth interval 84–79 m), it is composed of aleuritic clays locally grading into clayey aleurites. These light gray, intensely bioturbated clays with abundant fucoids are of a dark gray color with a brownish tint in the upper part. The following species represent foraminifers occurring only in the Kolomna Formation: *Dentalina laevis* Schwag., *Dentalina oolithica* Terq., *Dentalina sublenticularis* Schwag., *Globulina oolithica* Terq., *Lenticulina comae* E. Byk. et Azbel, *Lenticulina russiensis* (Mjatl.), *Lenticulina turgida* (Schwag.), and *Lenticulina tympana* Grig. The *Marginulina declivis* (Schwag.) and *Saracenaria feriata* Grig. species transit into the overlying formation.

The Kolomna Formation is conformably overlain by the Ermolino Formation of the late Oxfordian age also. The latter is composed of glauconite clays that are dark gray to black in color, contain abundant pyrite nodules and shell detritus, and are 8 m thick (Bed 21, depth interval 79–71 m). The foraminiferal assemblage characteristic of this formation only consists of *Dentalina* cf. *turgida* (Schwag.), *Epistomina praetatariensis* Umansk., *Epistomina raslovensis* Azbel, *Epistomina unzhensis* Azbel, and *Planularia multicostata* K. Kuzn.

The Ermolino Formation is overlain with scouring by greenish black quartz-glauconite sands and clayey aleurites containing phosphorite nodules and pebbles of the Kostroma Formation rocks. These sediments that are 0.2 m thick in total (with a depth interval of 71–70.8 m) are overlain again with scouring by deposits of the Egor'evskaya Formation of the Middle Volgian. This formation is composed of quartz-glauconite fine-grained sands and clayey aleurites with pebble, phosphorite nodules, belemnites, phosphatized pelecypod, and ammonite casts. The sediments are irregularly calcareous. The thickness of the formation is 0.9 m (Bed 20, depth interval 70.8–69.9 m). The bed has not been sampled for foraminiferal analysis.

The 5.7-m thick Fili Formation (Bed 19, depth interval 69.9–64.2 m) of the late Volgian age conformably rests on the Egor'evskaya Formation. It is composed of dark gray fine-grained glauconite-mica sands and aleurites containing abundant organic remains. The foraminiferal assemblage of the formation includes the following: *Astacolus aquilonicus* (Mjatl.), *A. loinoensis* Dain, *Citharina brevis* (Furss. et Pol.), *C. raricostata* (Furss. et Pol.), *Lagena hispida* Reuss, *Lenticulina infravolgaensis* (Furss. et Pol.), *L. ponderosa* Mjatl., *L.* ex. gr. *sulkata* (Wal. et Jakob), *Marginulina pseudolinearis* K. Kuzn., *M. robusta* Reuss, *M. striatocostata* Reuss, *M.* ex gr. *nupera* K. Kuzn., *Marginulinita pyramidalis* (Koch), *Marginulinopsis embaensis* (Furss. et Pol.), *Nodosaria scythicus* (Furss. et Pol.), *Saracenaria mirabilissima* (Furss. et Pol.), *S. pravoslavlevi* (Furss. et Pol.), and *Tristix temirica* Dain.

The Lopatino Formation of the upper Volgian Substage crowns the section. As it is barren of nannofossils, its description is omitted in this work.

As for the distribution of nannofossils in the section, we note that most of them are represented by cosmopolitan taxa of wide geographic and stratigraphic ranges. The following species occur practically throughout the

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Plate I. Most common species of calcareous nannofossils occurring in sediments recovered from Borehole 1:

(1, 2) *Watznaueria Britannica* (Stradner, 1963): (1) distal side, (2) proximal side (Sample 21, upper Oxfordian); (3) *Watznaueria barnesae* (Black, 1959), distal side (Sample 21, upper Oxfordian); (4) *Watznaueria fossacincta* (Black, 1971a), distal side (Sample 21, upper Oxfordian); (5) *Watznaueria manivitae* Bukry, 1973d, distal side (Sample 21, upper Oxfordian); (6, 7) *Staurolithites quadriarculla* (Noël, 1965): (6) proximal side, (7) distal side (Sample 21, upper Oxfordian); (8) *Crepidolithus perforate* (Medd, 1979), proximal side (Sample 21, upper Oxfordian); (9,10) *Zeugrhabdotus erectus* (Deflandre, 1954): (9) distal side (Sample 21, upper Oxfordian), (10) proximal side (Sample 21, upper Oxfordian); (11) *Retecapsa chizobrachiata* (Gartner, 1968), distal side (Sample 21, upper Oxfordian); (12) *Polypodorhabdus escaigii* Noël, 1965, distal side (Sample 21, upper Oxfordian); (13) *Stephanolithion bigotii bigotii* Deflandre, 1939, distal side (Sample 28, upper Oxfordian); (14) *Podorhabdus grassei* Noël, 1965, proximal side (Sample 28, upper Oxfordian): (15, 16) *Stradnerlithus geometricus* (Gorka, 1957): (15) distal side (Sample 21, upper Oxfordian), (16) proximal side (Sample 21, upper Oxfordian); (17) *Staurolithites stradneri* (Rood et al., 1971), proximal side (Sample 21, upper Oxfordian).

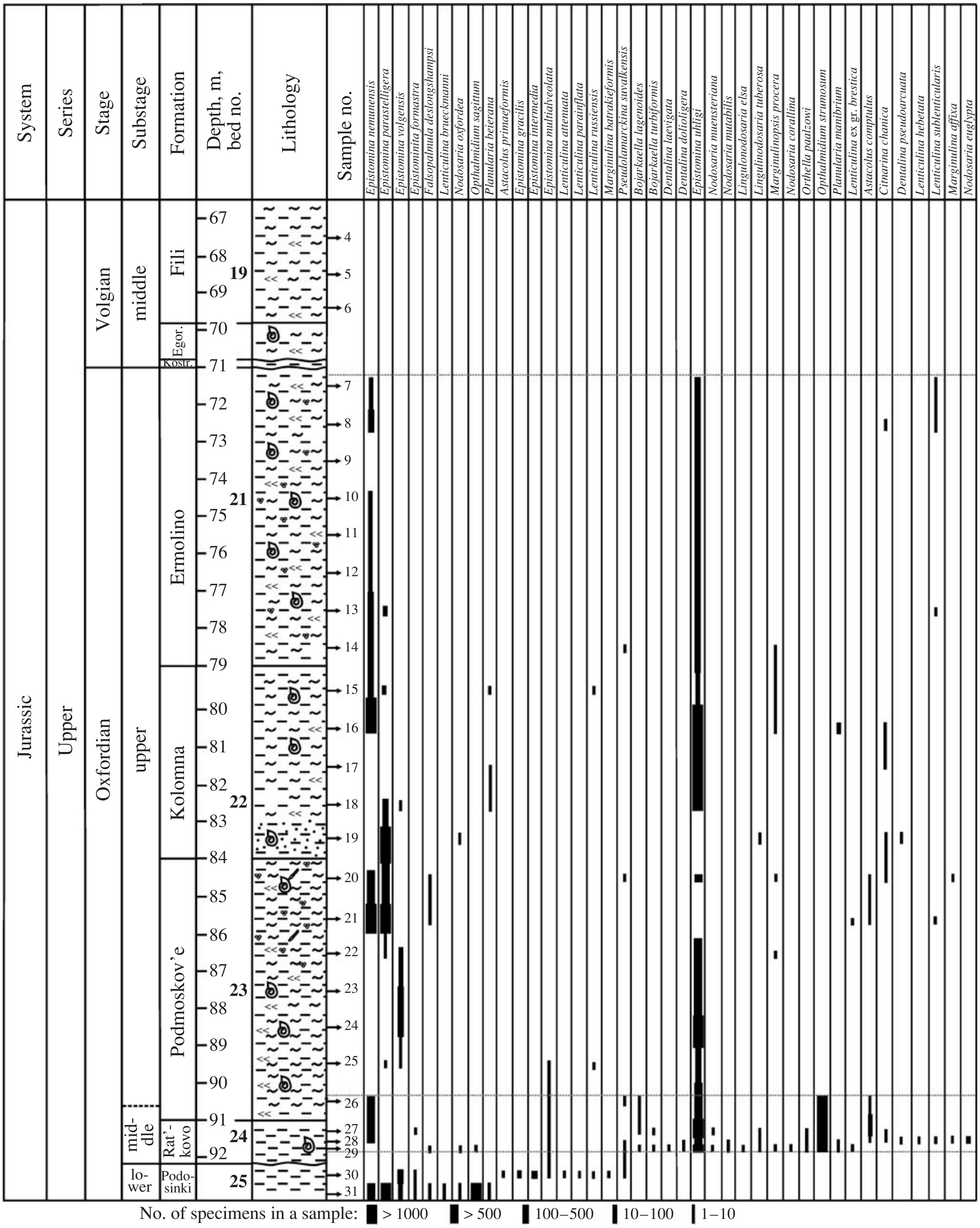

Fig. 3. Distribution of foraminiferal species in section of the Oxfordian–Volgian deposits recovered from Borehole 1, symbols for lithology as in Fig. 2: (I) *Ophthalmidium sagittum–Epistomina volgensis* Zone; (II) *Ophthalmidium strumosum–Lenticulina brestica* Zone.

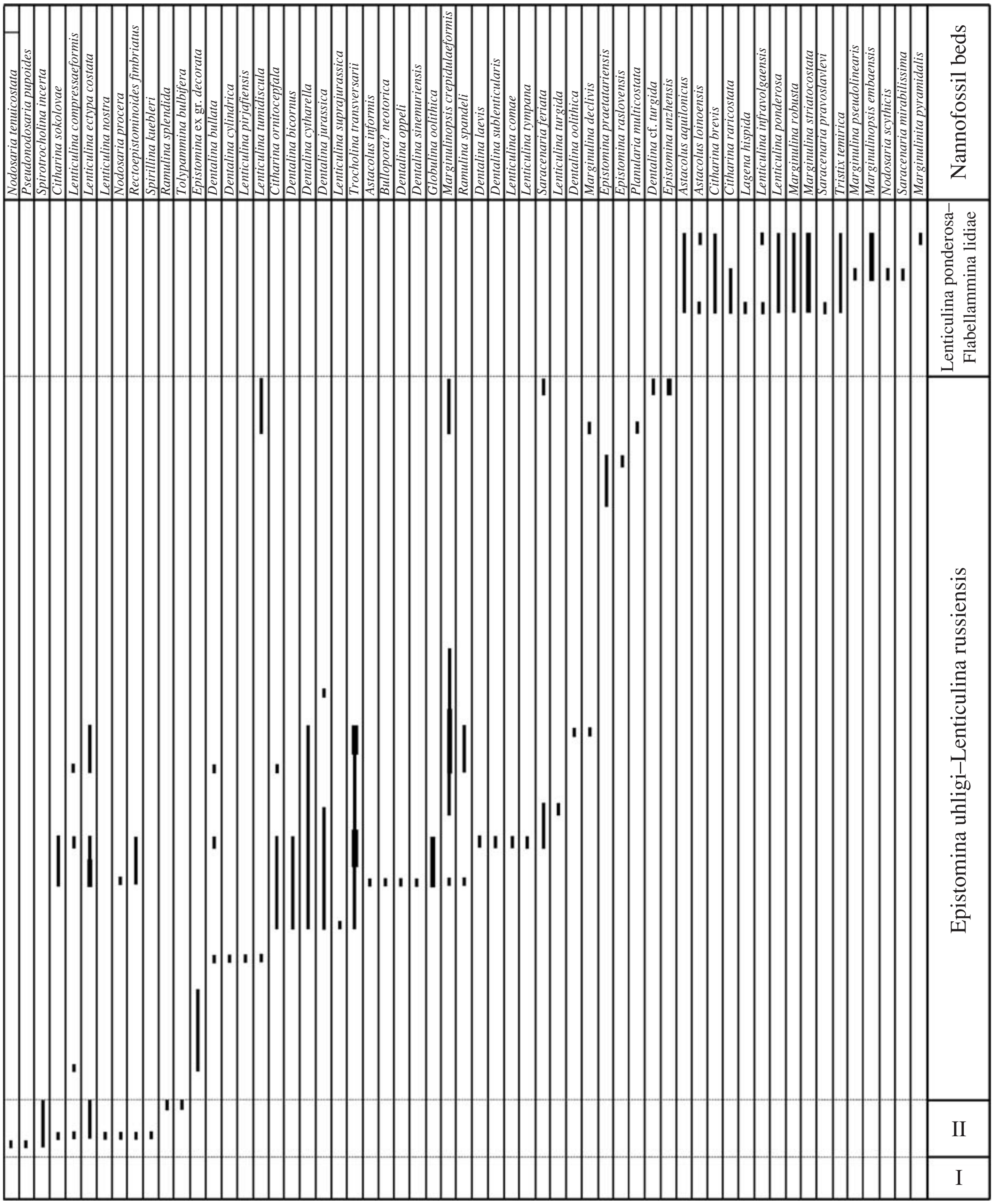

Fig. 3. (Contd.)

section: *Axopodorhabdus cylindratus* (Noël) Wise et Wind, *Cyclagelosphaera margerelii* Noël, *Discorhabdus corollatus* Noël, *Ethmorhabdus gallicus* Noël, *Retecapsa shizobrachiata* (Gartner) Grun et Allemann, *Sollasites lowei* (Bukry), *Staurolithites quadriarculla* (Noël) Wilcoxon, *St. stradneri* (Rood et al.) Bown comb. nov, *Watznaueria barnesae* (Black) Perch-Nielsen, *W. britannica* (Stradner) Reinhardt, *W. fossacincta* (Black) Bown et Cooper, and *Zeugrhabdotus erectus* (Deflandre et Fert) Reinhardt. Narrower stratigraphic ranges (from the Podosinki to the Ermolino Formation top) are characteristic of *Crepidolithus perforata* (Medd) and *Watznaueria manivitae* Bukry. The *Cyclagelosphaera tubulata* (Grun and Zweili) Cooper and *Stephanolithion bigotii bigotii* Deflandre species are dispersed beginning from the Podosinki Formation to the top of the Egor'evskaya Formation. The occurrence interval of the *Discorhabdus longicornis?* (Deflandre) extends from the Rat'kovo Formation to the lower part of the Fili Formation. The distribution range of *Axopodorhabdus atavus* (Grun et al.) Bown, *Lotharingius crucicentralis* (Medd), and *Retecapsa incompta* Bown is constrained by the Podosinki Formation and the basal interval of the Kolomna Formation. The upper occurrence level of *Triscutum expansus* (Medd) and *Hexapodorhabdus cuvilleri* Noël corresponds to the Kolomna Formation's upper part. The upper part of the Rat'kovo Formation and the lower part of the Kolomna Formation yield *Discorhabdus striatus* Moshkovithz and Ehrlich along with *Podorhabdus grassei* Noël. The following species appear in the Podmoskov'e Formation and transit up to the Fili Formation: *Biscutum dubium* (Noël) and *Diazmatolithus lehmanii* Noël. *Triscutum beaminsterensis* Dockerill is identified in the Podmoskov'e Formation only. *Cretarhabdus conicus*? Bramlett and Martini, *Staurolithites* cf. *lumina* Bown sp. nov., and *Stephanolithion brevispinus* (Wind and Wise) occur exclusively in the Fili Formation.

FORAMINIFERS

Foraminifers occurring throughout the section of Borehole 1 are well preserved. Foraminiferal zonation is established based on either the species combinations (assemblage zones), or the mass abundance of diagnostic species (acme zones) (Azbel et al., 1991). Zonal assemblages of foraminifers include species identified in the zone stratotype, which are of narrow stratigraphic and wide geographic ranges (Azbel et al., 1986). The foraminiferal assemblage from the upper part of the Podosinki Formation is characteristic of the lower–middle Oxfordian *Ophthalmidium sagittum–Epistomina volgensis* Zone (Azbel et al., 1991), whose characteristic species are *Ophthalmidium sagittum* (E. Byk.), *Lenticulina attenuata* (Kubl. et Zwing.), *L. brueckmanni* (Mjatl.), *Epistomina volgensis* Mjatl., *E. intermedia* Mjatl., and *E. gracilis Dain.* We note that epistominids significantly prevail here over the other foraminiferal taxa.

The transition to the overlying *Ophthalmidium strumosum–Lenticulina brestica* Zone, whose lower and upper boundaries are defined in the Rat'kovo and Podmoskov'e (lower part) formations, respectively, is marked, beginning from a depth of 91.8 m, by the nearly complete disappearance of species typical of the previous zone. The lower boundary of the reference zone is defined at the first occurrence level of *Ophthalmidium strumosum* (Gumb.), *Lenticulina ectypa costate* Cordey, and *Astacolus comptulus* (Schwag.) (Azbel et al., 1986). The other characteristic species of that zone are *Orthella paalzowi* E. Byk., *Epistomina uhligi* Mjatl., and *E. nemunensis* Grig. (Azbel et al., 1991).

The *Epistomina uhligi–Lenticulina russiensis* Zone spans almost entirely the Podmoskov'e Formation and the overlying Kolomna and Ermolino formations. Despite the wide stratigraphic range of foraminifers characterizing this zone, including the index species, its typical species *Epistomina nemunensis* Grig. and *Epistomina uhligi* Mjatl. significantly prevail in abundance (over 1000 specimens) over the other species identified in the sample studied and in the underlying zone. The lower boundary of the zone under consideration is defined at the disappearance level of the *Ophthalmidium* forms. As compared with the underlying zone, the foraminiferal assemblage from the zone in question is of a less diverse taxonomic composition and lacks taxa typical of this zone only (Azbel et al., 1986). It is also remarkable that the foraminiferal assemblage from samples 19 and 20 includes foraminifers occurring in the underlying zone, but is lacking the *Ophthalmidium* species. This suggests that compositional changes in microfaunas were gradual rather than sudden.

According to the composition of its foraminiferal assemblage, the Fili Formation formerly attributed to the middle Volgian Substage spans the *Lenticulina ponderosa–Flabellamina lidiae* Zone of the late Volgian (Azbel et al., 1991). Boundaries of this zone are constrained by the distribution ranges of the following characteristic index species: *Lenticulina ponderosa* Mjatl, *Lenticulina infravolgaensis* (Furss. et Pol.), *Marginulina robusta* Reuss, and *Marginulinopsis embaensis* (Furss. et Pol.).

It is interesting that exclusively benthic forms represent all foraminifers. This is the nodosariid-epistominid type of fauna, characteristic of the Boreal–Atlantic paleozoogeographic province (Azbel et al., 1991; Grigyalis, 1985). Faunas of this type originated in the Callovian and existed until the end of the Kimmeridgian. During the Volgian, they gradually gave place to nodosariid faunas (Kuznetsova, 1979).

CALCAREOUS NANNOFOSSILS

As the available materials are insufficient for establishing the nannoplankton zonation, it seems reasonable to distinguish the nannofossil beds in the Oxfordian–Volgian deposits penetrated by drilling in the Vorob'evy gori. The beds are distinguished based on the last occurrence levels of the index species in the studied section, although in Western Europe they all are of very wide stratigraphic ranges.

It is likely that calcareous nannofossils are dispersed throughout the section except for the interval of the Krusha Formation (Borehole 6). They are poorly preserved in general, being hardly appropriate for distinguishing (with confidence) zones and beds based on the

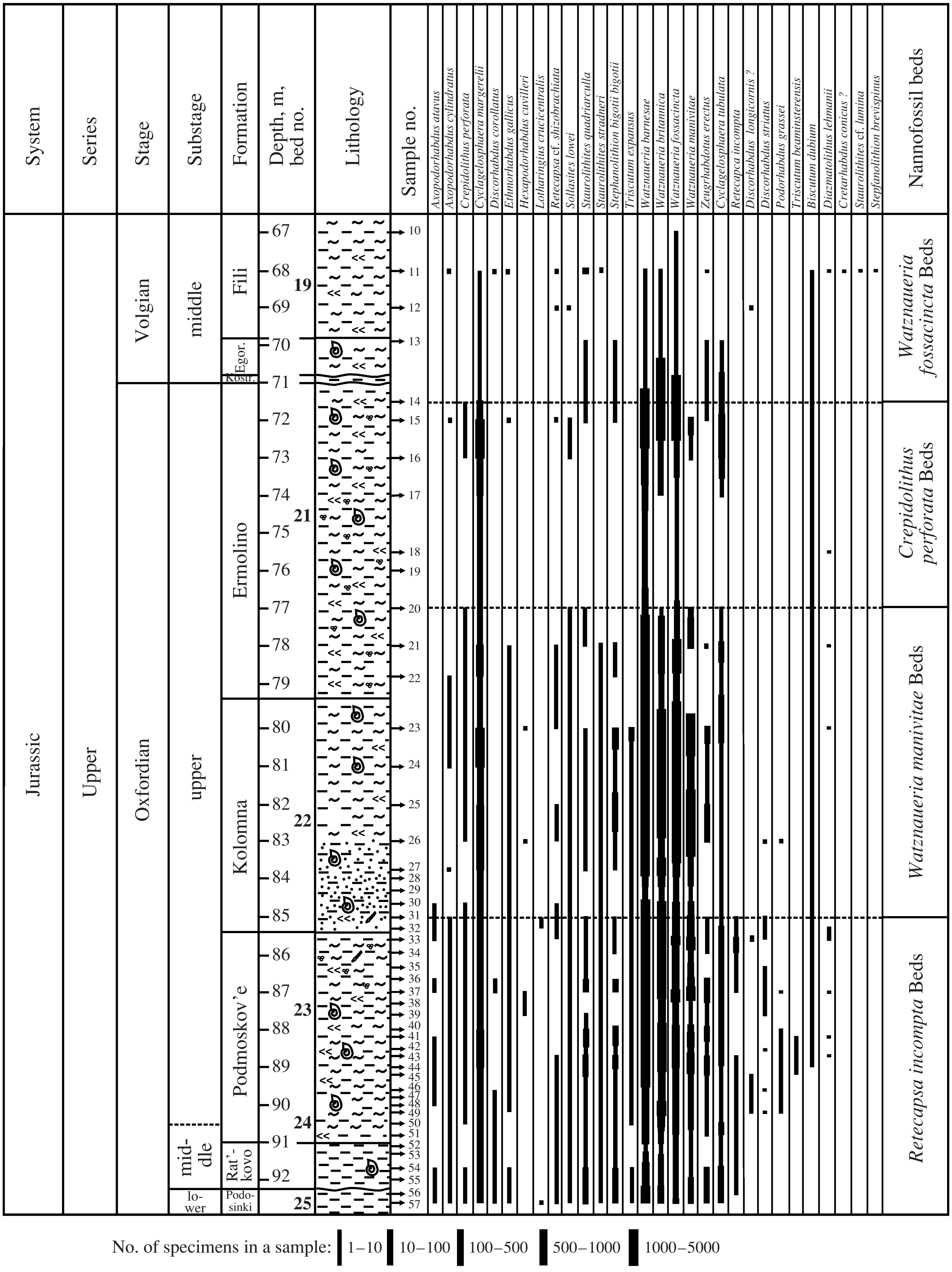

Fig. 4. Distribution of calcareous nannofossil species in the Oxfordian–middle Volgian section Vorob'evy gori. 1, symbols for lithology as in Fig. 2.

taxonomic composition of the assemblages. Nevertheless, it should be noted that eight species of nannofossils are identified in the Velikodvorskaya Formation, 19 species in the Podosinki Formation, 12 species in the Rat'kovo Formation, and 10 species in the Podmoskov'e Formation. In the Malinovyi Ravine reference section (the Saratov region), Nikiforova (Nikiforova et al., 2001) determined in concurrent deposits a more thermophilic assemblage of calcareous nannofossils with the index species *Ansulosphaera helvetica* Grun et Zweili. Assemblages of calcareous nannofossils from the Vorob'evy gori and Malinovyi Ravine sections are similar in general. However, the assemblage of the Velikodvorskaya Formation is certainly less diverse than the concurrent assemblage from the Saratov region, which consists of 19 taxa.

As for fossil representatives of nannoplankton from Borehole 1, they are found in all the samples in satisfactory- to well-preserved conditions, and are appropriate for biostratigraphic analysis. According to the results obtained, the Podosinki, Rat'kovo, Podmoskov'e, and lowermost part of the Kolomna formations can be attributed to the *Retecapsa incompta* Beds (in Western Europe, the general stratigraphic range of the beds corresponds to the upper Toarcian–middle Oxfordian range; Fig. 4). This index species is missing in the overlying deposits. This interval of the beds also yielded a limited amount of the *Lotharingius crucicentralis* species used to distinguish the synonymous subzone in the Oxfordian deposits of Western Europe (except for their topmost and lower parts), although it was mentioned there that the occurrence rate of this taxon is successively decreasing from the bottom upwards (Bown and Cooper, 1999). It is likely that the *Lotharingius crucicentralis* also is of a wider stratigraphic range in the section of Borehole 1, although it has not been found at higher levels of the section. The general distribution range of this species corresponds to the lower Toarcian–upper Oxfordian. The other characteristic taxa of the beds are the *Discorhabdus striatus* and *Triscutum beamisterensis*, whose distribution ranges in Western Europe correspond respectively to the lower Toarcian–upper Oxfordian and lower Bathonian–middle Oxfordian (Bown and Cooper, 1999).

The Kolomna and lower part of the Ermolino formations are distinguished as the *Watznaueria manivitae* Beds, because an abundance of this index species is much higher in both subdivisions than in the underlying formations. In Western Europe, the stratigraphic range of this taxon corresponds to the upper Bajocian–upper Kimmeridgian (Bown and Cooper, 1999). The *Watznaueria barnesae, W. britannica*, and *W. fossacincta* species are also more abundant in the beds (Fig. 4). The *Crepidolithus perforata, Sollasites lowei, Staurolithites quadriarculla, W. britannica*, and *Cyclagelosphaera tubulata*, species, which disappear toward the top of the beds, appear again after a break in their occurrence in the upper part of the Ermolino Formation that is attributed to the *Crepidolithus perforata* Beds. In Western Europe, the index species of the beds is widespread in the lower Callovian–lower Kimmeridgian stratigraphic interval and does not occur in the overlying deposits (Bown and Cooper, 1999). The *Hexapodorhabdus cuvilleri* Subzone of the upper Oxfordian–upper Kimmeridgian is another biostratigraphic unit of Western European sections (Bown and Cooper, 1999).

Sediments of the Egor'evskaya and Fili formations have been deposited after a break in sedimentation. Both formations can be attributed, though with reservations, to the *Watznaueria fossacincta* Beds, as this taxon is most abundant in their sediments. The same species is widespread in Western Europe, where its abundance rate considerably increases starting from the end of the Oxfordian Age (Bown and Cooper, 1999). Above a depth level of 66.5 m, calcareous nannofossils do not occur. It should be mentioned in addition that the assemblage of calcareous nannofossils from Borehole 1 is compositionally similar to that from the middle Volgian Substage of the Gorodishche section in the Ul'yanovsk region (Bown and Cooper, 1999, Kessels et al., 2003). Characteristic features of both assemblages are their low species' diversity and prevalence of forms representing the *Watznaueria* genus.

RESULTS

Two groups of fossil organisms, whose tolerance to environmental factors is not identical, are studied in this work. The evolution and distribution of benthic foraminifers depends on the substratum character, salinity, temperature, gaseous regime of the waters at the bottom, etc. (Kuznetsova, 1979), whereas the development and distribution of calcareous nannoplankton depends on the surface water's saturation with nutrients, salinity, and temperature. As is known, the Moscow region hosted a shallow-water sea basin in the terminal Middle–Late Jurassic time, and it is interesting to reconstruct habitat environments in that basin based on relations between the assemblages of foraminifers and calcareous nannoplankton. As one can see in the diagram illustrating changes in the abundance of calcareous nannoplankton and foraminifers depending on the depth of drilling (Fig. 5), the abundance peaks of species representing two groups of organisms were asynchronous during the accumulation time of the Rat'kovo, Podmoskov'e, and Kolomna (lower sandy part) formations (depth interval 92–83 m). As the increase in the diversity of the coccolithophorids species was accompanied at that time by a decrease in the diversity of the benthic foraminifers species, one can suggest that periods of favorable thermal regime in surface waters and their saturation with nutrients were concurrent to events responsible for the emergence of a gaseous regime at the bottom of the water, which is unfavorable for benthos. Later, during the accumulation time of the remaining part of the Kolomna Formation and the Ermolino Formation, the evolution trends of coccolithophorids and foraminifers were more or less uniform. In terms of the section's stratigraphic subdivision, based on both groups of fossil organisms, the *Retecapsa incompta* Beds can be correlated with the *Ophthalmidium sagittum–Epistomina volgensis, Ophthalmidium strumosum–Lenticulina brestica*, and *Epistomina uhligi–Lenticulina russiensis* (lower part) foraminiferal zones (Table 1)—considering the *Watznaueria manivitae–Crepidolithus perforate* Beds as concurrent to the remaining part of the *Epistomina uhligi–Lenticulina russiensis* Zone and the *Watznaueria fossacincta* beds to the *Lenticulina ponderosa–Flabellamina lidiae* Zone.

The obtained data on the composition of calcareous nannofossils from Borehole 1 show that their cosmopolitan species representing the *Watznaueria (W. barnesae, W. fossacincta, W. britannica)* genus, which are tolerant to changes in paleoecologic environments and (importantly) are resistant to dissolution during diagenesis, are the most abundant in the section. The high occurrence rate of *W. barnesae, W. fossacincta*, and *W. britannica* throughout the section suggest a high temperature and mesotrophic conditions on the surface of the waters (Ruffell et al., 2002; Kessels et al., 2003). As has been estimated (Riboulleau et al., 1998), the seawater's temperature increased from 5.6–10.9°C in the late Callovian–initial middle Oxfordian time to 20°C in the terminal Oxfordian–initial Kimmeridgian epoch. This inference is consistent with data on foraminifers (Kuznetsova, 1979) and the main tendency of climatic changes: global cold-water environments existed until the middle Oxfordian, whereas the subsequent gradual warming was accompanied by general rise in the sea-level that was favorable for an intense development of marine organisms with calcareous skeletons (Giraud et al., 2006; Rais et al., 2007). In the middle Volgian epoch, the temperature of surface waters was lower, corresponding to 15–17°C (Riboulleau et al., 1998). The abundance of species with thin light skeletons, e.g., of *St. bigotii bigotii, Z. erectus, E. gallicus*, or *D. corollatus*, was much lower (1 to 10 specimens per sample). The factors probably responsible for this situation were their low resistance to dissolution and habitat environments that were unfavorable for their existence at that time. In general, calcareous nannoplankton of the considered time span was identical in terms of preferable life environment to today's nannoplankton, which prefers

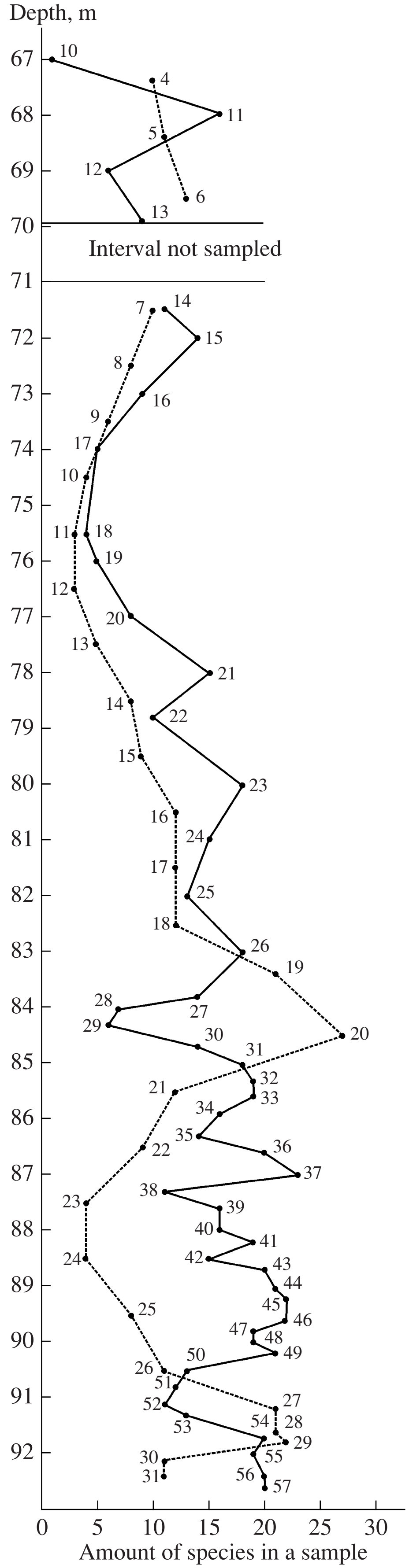

Fig. 5. Variation curves illustrating changes in the abundance of calcareous nannofossil (solid line) and foraminiferal (dashed line) species depending on depth in Borehole 1; numerals in the figure denote sample numbers.

Zonal subdivision of the Oxfordian and middle Volgian deposits recovered from Borehole 1 based on foraminifers and calcareous nannofossils

System	Series	Stage	Substage	Formation	Foraminiferal zones (Sei et al., 2006)	Nannofossil beds
Jurassic	Upper	Volgian	middle	Fili	*Lenticulina ponderosa – Flabellamina lidiae*	*Watznaueria fossacincta* Beds
				Egor.		
				Kostr.		
		Oxfordian	upper	Ermolino	*Epistomina uhligi – Lenticulina russiensis*	*Crepidolithus perforata* Beds
				Kolomna		*Watznaueris manivitae* Beds
				Podmoskov'e		*Retecapsa incompta* Beds
			middle	Rat'kovo	*Ophthalmidium strumosum – Lenticulina brestica*	
			lower	Podosinki	*Ophthalmidium sagittum – Epistomina volgensis*	

to dwell in the photic zone of open seas and oceans, being most diverse in low tropical latitudes. The high-latitude seas are populated by particular species only (Bown and Cooper, 1999).

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