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The Distribution of Early Callovian Foraminifers and Ostracods in the Bartolomeevka Section (Saratov Region): Comparative Analysis

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Abstract—The distribution of foraminifers in the Lower Callovian Khlebnovka Formation (Gowerianus and *Elatmae* ammonite Zones) of the Bartolomeevka section (Saratov region) was analyzed along with defining the Haplophragmoides infracalloviensis–Guttulina tatariensis zone that is correlated with ostracod zones and beds. The comparative analysis of the distribution of foraminifers and ostracods through the section with allowance for changes in their diversity and abundance in sediments of the Elatmae Zone revealed two transgressive–regressive cycles. The sediments of both cycles were deposited approximately at the same depths. The older and younger transgressions associated with the Arctic and Tethyan water masses, respectively. The foraminiferal assemblages demonstrate close relationshipships with bathymetry and water temperatures.

Keywords: Foraminifers, Ostracods, Khlebnovka Formation, Lower Callovian, Saratov region, transgressive–regressive cycles, paleoecology

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INTRODUCTION

Dain (1948) was the first to define the guide lower Callovian foraminiferal assemblage, which included the following species: *Ammobaculites* ex gr. *coprolithiformis* (Schwag.), *Discorbis tjeplovkaensis* Dain, *Globulina* (*Guttulina*) ex gr. *tatarienses* Mjatl., *Haplophragmoides infracalloviensis* Dain, and *H.* sp. aff. *nonioninoides* (Reuss).

G.N. Startseva, who contributed much to the study of Jurassic (including Callovian) foraminifers, identified and described new species of the genera *Reophax, Trochammina*, and *Nodosaria* (Startseva and Kozlova, 1972). Using the biometric method, this researcher investigated Upper Jurassic (including Callovian) representatives of the genus *Pseudolamarckina* and defined new species of this taxon (Startseva, 1972). Together with T.N. Khabarova, she studied the distribution of foraminifers in detail and defined zones in the Malinovyi Ravine Section (near Khlebnovka settlement, Saratov region), the lectostratotype of the Callovian Stage (Startseva and Khabarova, 1982). Subsequently, she proposed the foraminiferal zonal scale for the Upper Jurassic (including Callovian) interval of the Middle Volga region. This scale included the Ammodiscus colchicum local zone, Reophax scabrosus Beds, and Haplophragmoides infracalloviensis–Guttulina tatariensis Zone with two subzones: Marginulina mjatliukae–Guttulina tatarienses (correlative with the Macrocephalus ammonite beds) and Haplophragmoides infracalloviensis (corresponding to the Elatmae ammonite zone) (Startseva, 1986). It the last work, the author also considered the paleoecological aspects of Jurassic foraminifers from the Middle Volga region. They were grouped into three assemblages: calcareous (nodosariid), arenaceous, and calcareous dominated either by epistominids or ceratobuliminds, or ophtalmiid representatives.

On the basis of the distribution of these assemblages through the Late Jurassic (including Callovian) section and its comparison with the distribution of their present-day analogs, Startseva reconstructed their habitat conditions: inner shelf (0–50 m) for the Middle and Late Callovian, Oxfordian, and Late Kimmeridgian and outer shelf (up to 200 m) for the Early Callovian, Early Kimmerdgian, and Volgian ages. In her opinion, the presence of paleocoenoses dominated by arenaceous foraminifers is explained either by penetration of cold water masses into this region from the north during transgession expansion or by salinity lowering (Startseva, 1975). Subsequently, she continued paleoecological investigations together with S.O. Zorina using samples from the Tatarsko-Shatrishchenskaya-1 reference borehole (Startseva and Zorina, 2011). In this work, the authors consider general information on the relationships between the generic composition of foraminiferal assemblages and their habitat depths. For example, they demonstrated that representatives of the genera *Ammobaculites* and *Haplophragmoides* indicate depths of approximately 150–200 m.

When analyzing the extensive data on the distribution of foraminifers and ostracods in sections of the Saratov Volga region, Khabarova (1961) specified guide foraminiferal species for Jurassic sediments and listed characteristic ostracod species. For the lower Callovian interval (*Macrocephalites macrocephalus* and *Chamoussetia chamousseti* ammonite Zones), she noted the following guide species: *Haplophragmoides infracalloviensis* Dain, *H. ventosus* Hab., *Lituotuba nodus* Kosyr., *Discorbis tjeplovkaensis* Dain, *Guttulina tatariensis* Mjatl. among foraminifers, and *Procytheridea cinicinnusa* (Mand. in Lyub.), *Acantocythere* (*P.*) *milanovskyi* (Lyub.), and *Palaeocytheridea* (*P.*) *pavlovi* (Lyub.) among ostracods (generic names are given in accordance with recent classification).

In the Bartolomeevka section, which is located near Saratov, Tesakova and Sel'tser (2013) defined the Pyrocytheridea pergraphica–Camptocythere (Anabarocythere) starcevae ostracod beds in the Elatmae ammonite Zone and Acantocythere (Protacantocythere) milanovskyi Beds in the lower part of the *Subpatruus* Zone and described a new species and subspecies. Subsequently, these beds were ranked as subzones of the Palaeocytheridea (P.) pavlovi Zone (the Acantocythere (Protacantocythere) milanovskyi Beds were renamed and ranked as the Acantocythere (P.) milanovskyi–Procytheridea cinicinnusa Subzone; in addition, two new ostracod units were defined: Procytheridea cinicinnusa and Acantocythere (P.) milanovskyi Beds (Tesakova, 2014b).

In the Bartolomeevka section, foraminifers were never investigated. In this connection, it was of interest to define its assemblages and compare their distribution with that of ostracods, whose paleoecological properties in this section are unknown. The purpose of this work was to compare the distribution of foraminifers and ostracods in lithologically uniform lower Callovian sediments in the Bartolomeevka section, outline the factors that are responsible for changes in their compositions (are they synchronous and related to variations in the influx of nutrients or paleogeographic conditions), and correlate stratigraphic units on the basis of ostracods and foraminifers.

MATERIALS AND METHODS

The Bartolomeevka section, which comprises lower Callovian sediments that are attributed according to Sel'tser in (Tesakova and Sel'tser, 2013) to the *Elatmae*, *Gowerianus*, and *Calloviense* ammonite Zones, is located in the Saratov region 1 km south of the eponymous settlement and 300 m west of the junction of the ring highway and Vol'sk high road (Fig. 1). The Lower Callovian clays of this section (beds 1–3), which are approximately 11.3 m thick (Fig. 2), are attributed to the Khlebnovka Formation of the Kurdyumian regional stage (*Unifitsirovannaya*..., 2012).

In total, 32 samples from 0.6 to 0.8 kg in weight were subjected to the microfaunal analysis. The samples were preliminarily boiled with soda were then washed through a sieve with a mesh of 0.1 mm. Foraminifers (mostly agglutinated with an insignificant admixture of secreted forms) are found in all the examined samples except for samples 7, and 29–32. Their preservation varies from poor (casts) to good; abundance ranges from 6 to 30 specimens in a sample. In some samples, the foraminiferal assemblage is represented exclusively by agglutinated forms (samples 4–6, 16, 23–25); samples 1–3, 11, 17, 19–21 contain rare pyritized casts of secreted forms, i.e., they were eliminated from the assemblage by unfavorable burial conditions. Sediments of the Calloviense Subzone (Calloviense Zone) are barren of microfaunal remains.

The habitat environments that were reconstructed for foraminiferal assemblages from the Elatmae Zone (Elatmae and Subpatruus Subzones) using variations in the proportions of agglutinated and secreted forms (A/S) are compared with similar reconstructions for ostracods (Fig. 3). The data on thermal and bathymetric preferences of ostracods and their confinement to different paleogeographic settings were used for this purpose. No such reconstructions were carried out for the Gowerianus Zone, where foraminiferal tests are scarce and poorly preserved, while ostracods are missing.

The ostracod collection (no. 372) is stored at the Chair of Paleontology of the Department of Geology in the Moscow State University. The foraminiferal collection (no. F-4/2013) is stored in the Geological Institute of the Russian Academy of Sciences.

The brief description of the Bartolomeevka section (from the base upsection) is given after (Tesakova and Sel'tser, 2013) (Fig. 2).

Khlebnovka Formation, Upper Subformation, Gowerianus Zone

Bed 1. Clays, ocherous gray with yellow tints, low-carbonate, containing rare nodules of ocherous poorly consolidated rock and regularly scattered different-sized small intergrowths of gypsum crystals. The basal part is represented by alternating ocherous gray and dark gray clays with a thin laterally unsustained intercalation of ocherous brown clays with gypsum and recrystallized belemnite rostra and fragments of mineralized wood. The sediments contain different macrofaunal remains: ammonites (*Sigaloceras* sp. 1, *Kepplerites* sp., and *Pseudocadoceras* sp.); belemnites (*Cylindroteuthis okensis* (Nikitin) and *Cyclindroteuthis* sp.); bivalves (*Gryphaea dilatata* Sowerby, *Astarte* sp., and *Lopha* sp.). Ostracods are missing. Sample 28 yielded foraminiferal forms *Haplophragmoides infracalloviensis* Dain

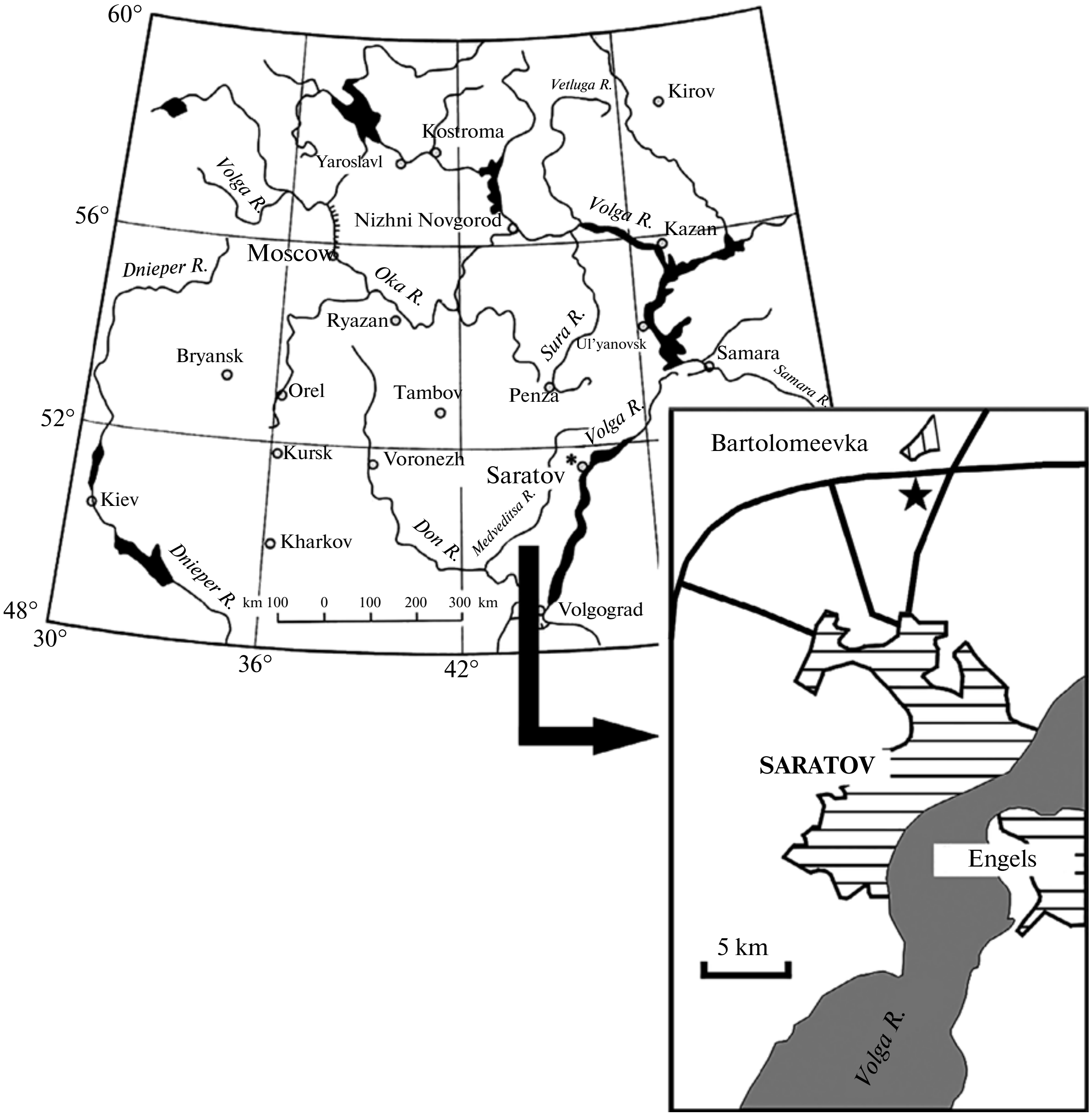


Fig. 1. The schematic location of the Bartolomeevka section, after (Tesakova and Sel'tser, 2013).

(cast), *Haplophragmoides* sp., and *Recurvoides ventosus* Chab. The thickness is 2 m.

Khlebnovka Formation, Upper Subformation

Bed 2. Clays, dark gray to black (when wetted), with very thin siltstone laminae, abundant dispersed jarosite and intergrowths of gypsum crystals. The lower part of the unit contains incoherent brown marlstone nodules frequently with ammonite remains: *Chamoussetia* cf. *buckmani* Callomon et Wright, *Kepplerites* aff. *gowerianus* (J. Sowerby), *Kepplerites* sp., *Cadoceras tshernyshevi* D. Sokolov, *Cadoceras* sp. juv., *Pseudocadoceras* sp., and *Eckhardites pavlovi* (Smorodina). The thickness is 2.8 m.

Gowerianus **Zone**: samples 26, 27 taken from the 1-m-thick interval near the top of Bed 2 are barren of ostracods and contain agglutinated foraminifers *Haplophragmoides infracalloviensis*, *Recurvoides ventosus*, and *Lagenammia* sp., single casts of their secreted species *Astacolus* sp., *Ceratolamarckina* sp., *Lenticulina* sp., *Marginulina krylovae?* Mjatl., and casts of small gastropod species.

Elatmae **Zone**, ***Subpatruus*** **Subzone.** Samples 22–25 yielded diverse microfossils: ostracods *Procytheridea cinicinnusa* (Mand. in Lyub.), *Acantocythere* (*Pseudoacantocythere*) *milanovskyi* (Lyub.), *Procytherura didictyon rossica* Tesakova, *Patellacythere* sp., *Macrocypris aequabilis* Oertli, *Palaeocytheridea* (*P.*) *pavlovi* (Lyu.), *Fuhrbergiella* (*Praefuhrbergiella*) *archangelskyi* (Mand. in Lyub.); foraminifers *Ammobacu-*

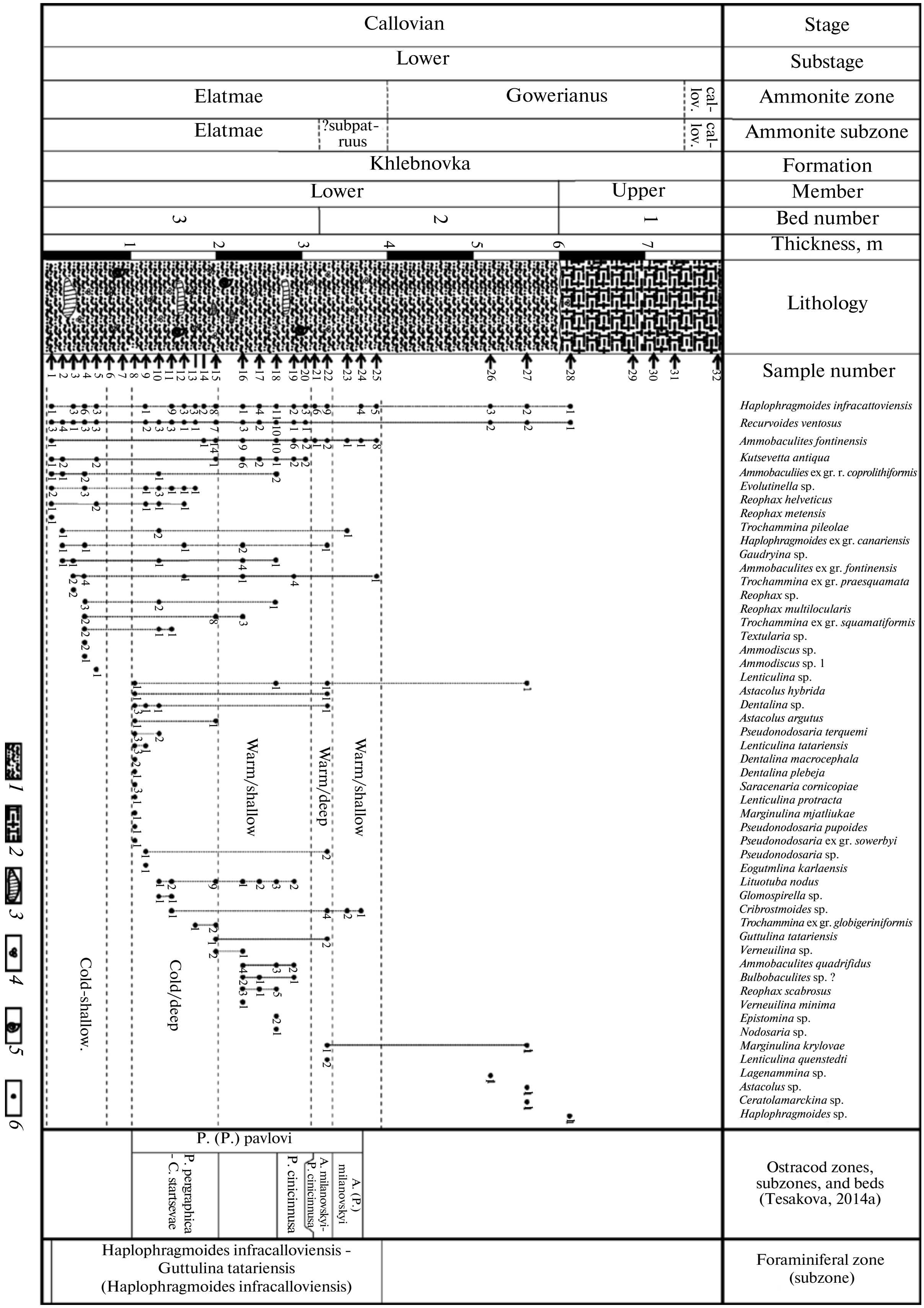


Fig. 2. Subdivision of the Bartolomeevka section on the basis of foraminiferal assemblages and correlation with ostracod-based stratigraphic units. (*1*) Silty clay; (*2*) low-carbonate clay; (*3*) clayey marlstone; (*4*) microfossils; (*5*) ammonite remains; (*6*) number of specimens in a sample.

lites fontinensis (Terq.), *A.* ex gr. *fontinensis* (Terq.), *Astacolus hybrida* (Terq.), *Cribrostomoides* sp., *Dentalina* sp., *Guttulina tatariensis* Mjatl.*, Haplophragmoides* ex gr. *canariensis* (Or.), *H. infracallovienses, Lenticulina quenstedti* (Gümb.), *Lenticulina* sp., *Marginulina krylovae* Mjatl., *Pseudonodosaria* sp., and *Trochammina pileolae* Starts (Plates 1 and 2).

Elatmae Zone*, Elatmae* Subzone

Bed 3. Clay similar to that in the underlying unit that differs in higher viscosity and lower admixture of the silty component, containing regularly distributed large intergrowths and crystals of gypsum, marcasite nodules, cake-shaped concretions of clayey material, macro- and microfossils: ammonites *Cadoceras elatmae* (Nikitin), *Cadoceras* sp. juv.; ostracods *Pyrocytheridea pergraphica* Lyub., *Fuhrbergiella* (*Praefuhrbergiella*) *archangelskyi. Palaeocytheridea* (*P.*) *pavlovi*, *Camptocythere* (*Anabarocythere*) *starcevae* Tesakova, and *Macrocypris aequabilis*; foraminifers *Ammobaculites* ex gr. *coprolithiformis* (Schwag.), *A. fontinensis* (Terq.) *A.* ex gr. *fontinensis* (Terq.), *A. quadrifidus* (Mitjan.), *Ammodiscus* sp., *Ammodiscus* sp. 1, *Astacolus argutus* E. Byk., *A. hybrida* (Terq.). *Bulbobaculites* sp.?, *Dentalina macrocephala* (Kübl. Et Zwin.), *D. plebeja* Terq., *Dentalina* sp., *Eoguttulina karlaensis* Mjatl., *Epistomina* sp., *Evolutinella* sp., *Haplophragmoides infracallovienses* Dain, *H.* ex gr. *canariensis* (Orb.), *Gaudryina* sp., *Glomospirella* sp., *Kutseviella antiqua* Jak., *Lenticulina tatariensis* Mjatl., *L. protracta* (Born.), *Lituotuba nodus* Kosyr., *Marginulina mjatliukae* Mitjan., *Nodosaria* sp., *Pseudonodosaria pupoides* (Born.), *Ps. terquemi* (Mjatl.), *Ps.* ex g. *sowerbyi* (Schwag.), *Pseudonodosaria* sp., *Recurvoides ventosus*, *Reophax helveticus* Hauesler, *R. metensis* Fanke, *R. multilocularis* Hauesler, *Reophax scabrosus* Starts, *Reophax* sp., *Textularia* sp., *Saracenaria cornicopae* (Schwager), *Trochammina* ex gr. *globigeriniformis* (Parker et Jones), *T. pileolae* Starts, *T.* ex gr. *praesquamata* (Mjatl.), *T.* ex gr. *squamatiformis* Starts, *Verneuilina minima* Kosyr., and *Verneuilina* sp. (Plates 1 and 2). The apparent thickness is 4.5 m.

The finding of two poorly preserved radiolarian specimens in samples 2 and 21 provides grounds for assuming that they belonging to the early Callovian invertebrate fauna of the Saratov region (Fig. 2).

Comparison between distribution patterns of foraminifers and ostracods in the Bartolomeevka section. ***Foraminifers.*** The following foraminiferal species were obtained from the Bartolomeevka section: *Haplophragmoides infracallovienses*, *Kutseviella antiqua, Reophax ventosus, Eoguttulina karlaensis, Guttulina tatariensis, and Lenticulina tatariensis* (Fig. 2). All of them are characteristic of the lower Callovian H. infracallovienses Subzone of the H. infracallovienses–G. tatariensis Zone that developed in the European part of the former Soviet Union (Azbel' et al., 1991). The lectostratotype of this zone (Malinovyi Ravine Section) contains only forms with arenaceous tests. All of them are also present in the Bartolomeevka section (except for *Spirillina eichbergensis* (Kübler et Zwingli) (Saltykov and Sel'tser, 2006). At the same time, the foraminiferal assemblage from the Bartolomeevka section includes also secreted benthic forms. The early Callovian assemblage from the Elatmae Zone demonstrates compositional variations along the strike of the Khlebnovka Formation.

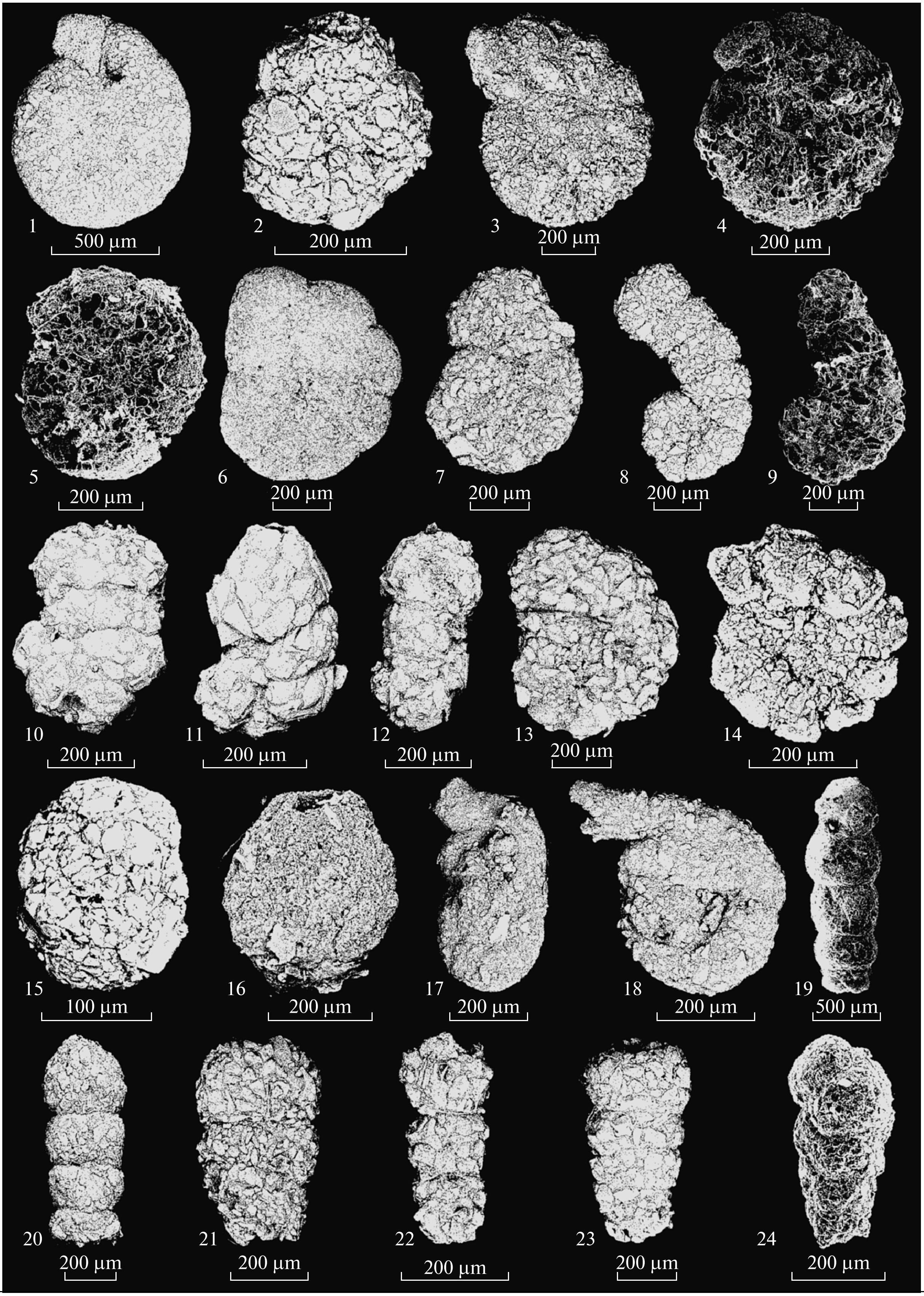
The curves of variations in diversity and abundance of foraminifers are very representative (Fig. 3). In the Elatmae Zone, diversity of foraminifers remains approximately constant exhibiting, nevertheless, two distinct intervals that are different in their abundance: F-I (samples 1–14) with low abundance and F-II (samples 15–25), which is characterized by a substantially high abundance. In each interval, the amplitude of the individual peaks of diversity and abundance decreases upsection. A notable increase in diversity and abundances is recorded in layers with concretions of clayey marlstone. The intermittent increase in diversity and abundance of foraminifers is interpreted as reflecting the high sea-level stand, since the growth of these parameters and share of secreted foraminifers is considered to indicate basin deepening (Startseva, 1975).

The *A/S value* is frequently used for reconstructing the depths of a basin: in shallow-water basins, the share of arenaceous forms increases toward the shore-

Plate 1. Agglutinated foraminifers from the Haplophragmoides infracalloviensis–Guttulina tatariensis Zone (lower Callovian). Specimens 1 and 3 are from Sample 5, 2 and 20 from Sample 4, 7, 10–12, 17, 18, and 22 from Sample 16.

(1) *Haplophragmoides infracalloviensis* Dain: side view, GIN, no. F-4/2013, specimen 7; (2) *Haplophragmoides* ex. gr. *canariensis* (Orb.): side view, GIN, no. F-4/2013, specimen 6; (3–5) *Recurvoides ventosus* Hab. side view: (3) GIN, no. F-4/2013, specimen 8, (4) GIN, no. F-4/2013, specimen 30, (5) GIN, no. F-4/2013, specimen 35; (6, 7) *Ammobaculites fontinensis* (Terq.), side view: (6) GIN, no. F-4/2013, specimen 56, (7) GIN, no. F-4/2013, specimen 37; (8, 9) *Ammobaculites* ex. gr. *fontinensis* (Terq.), side view: (8) GIN, no. F-4/2013, specimen 24, (9) GIN, no. F-4/2013, specimen 6, Sample 12, (9) GIN, no. F-4/2013, specimen 32; (10–12) *Ammobaculites* ex gr. *coprolithiformis* (Schwag.), side view: (10) GIN, no. F-4/2013, specimen 39, (11) GIN, no. F-4/2013, specimen 47, (12) GIN, no. F-4/2013, specimen 42; (13) *Kutsevella antiqua* Jak.: side view, GIN, no. F-4/2013, specimen 29, Sample 15; (14) *Evolutinella* sp.: side view, GIN, no. F-4/2013, specimen 23, Sample 9; (15) *Trochammina pileolae* Starts: dorsal view, GIN, no. F-4/2013, specimen 3, Sample 2; (16) *Saccammina* sp.: side view, GIN, no. F-4/2013, specimen 60, Sample 23; (17, 18) *Lituotuba nodus* Kosyr.: (17) side view, GIN, no. F-4/2013, specimen 41, (18) GIN, no. F-4/2013, specimen 40; (19) *Reophax helveticus* (Haeus): side view, GIN, no. F-4/2013, specimen 22, Sample 9; (20) *Reophax multilocularis* Haeus: .: side view, GIN, no. F-4/2013, specimen 5; (21) *Reophax scabrosus* Starts: side view, GIN, no. F-4/2013, specimen 34; (22) *Reophax* sp.: side view, GIN, no. F-4/2013, specimen 43; (23) *Gaudryina* sp.: side view, GIN, no. F-4/2013, specimen 1, Sample 2; (24) *Verneuilina*sp.: side view, GIN, no. F-4/2013, specimen 26, Sample 15.

Plate 1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line. The analysis of the defined foraminiferal assemblages reveals that the A/S value increases regularly at the levels that are marked by their higher diversity and abundance, i.e., corresponding to the basin deepening phases (Fig. 3). As for intervals F-I and F-II as a whole, it follows from changes in the A/S values that the depth of the basin during deposition of sediments from interval F-1 was likely greater as compared with the later period: in Sample 5, secreted foraminifers constitute 100% of the assemblage. As the A/S value within each interval decreases upsection we assume that the depth of the basin gradually increased in corresponding periods.

Thus, on the basis of changes in the abundance of foraminiferal tests (Fig. 3), it may be concluded that the lower part of this section accumulated at shallower depths as compared with the upper one and each interval was marked by gradual shoaling of the basin (F-I < F-II↓). The changes in diversity of the assemblage show that both its intervals were formed at approximately similar depths and each of them also demonstrates some shoaling upsection (F-I = F-II↓). According to variations in the A/S values, the accumulation depth of sediments from the lower part of the section was greater as compared with that characteristic of sediments from its upper portion; each of its parts reflects gradual deepening of the basin (F-I > F-II↑). Such opposite trends in changes of diversity, abundance, and A/S values require explanation. It is unclear what factor was responsible for the sharp increase in abundance of foraminifers in Interval F-II and what the nature is of foraminiferal intervals F-I and F-II. The analysis of the second microbenthic group (ostracods) provides answers to these questions.

Ostracods. The assemblages of this microfossils also allow two intervals (O-I and O-II) to be defined in the section, corresponding to F-I and F-II (Fig. 3). Like their foraminiferal counterparts, the *curves of diversity and abundance of ostacods* exhibit peaks at the same levels. The *curves of ostracod diversity* that were obtained for the O-I and O-II intervals are generally similar with each other and the amplitude of changes for each of them distinctly increases upsection (in direct proportion to the increase in the share of secreted foraminiferal tests and inversely to the diversity and abundance curves). This implies that a cyclic process was repeated twice in the section (in the upper and lower parts of the Elatmae Zone) and related to the intermittent deepening of the basin during these sedimentation intervals, i.e., two transgressive–regressive (TR) cycles. Inasmuch as the maximum diversity of ostracods in intervals O-I and O-II is similar, these cycles were likely characterized by similar intensities (O-I = O-II↑), i.e., the ostracod subzones and beds correspond to the deepest sediments in each cycle and the Palaeocytheridea (P.) pavlovi Zone, to the deep part of the first cycle and the entire second cycle.

Comparison of paleoecological and paleogeographic reconstructions based on foraminifers, ostracods, and ammonites. The first TR cycle (C-I) (lower 2 m of Bed 3, samples 1–14) reflects the onset of transgression. Judging from the composition of ostracod assemblages, the latter advanced to the East European Platform from the north and southeast, as in reconstructions of Gulyaev (2005) for the *P. poultoni*/*M. jacuoti* hemera (the beginning of the Elatmae phase) and apparently corresponds the end of the first (Tethyan ammonites)–second (boreal ammonites) immigration levels that were recorded at the base of the *Elatmae* Zone (Rogov et al., 2009). The presence of the Tethyan taxon *Palaeocytheridea* (*P.*) *pavlovi* indicates water exchange of the Central Russian sea with the Tethys Ocean via the Caspian region during the *Elatmae* phase, since this species is known in the Saratov and Ul'yanovsk Volga regions and was never found in West Europe and the Dnieper–Donets depression (DDD); subsequently, since the end of the early Callovian Age, *Paleocytheridea* representatives became common for all of Europe. The influence of northern waters was substantially stronger as compared with Tethyan water masses, which is evident from the prevalence of Arctic ostracod species of the genera *Camptocythere* Tribel and *Paleocytheridea* Lyub. in this part of the section. Thus, the corresponding water mass may be evaluated as cold.

The foraminiferal assemblages from sediments of this cycle are also characterized by a coldwater appearance. It appears that the water was cold even over shoals (the lower part of the section, samples 1–7),

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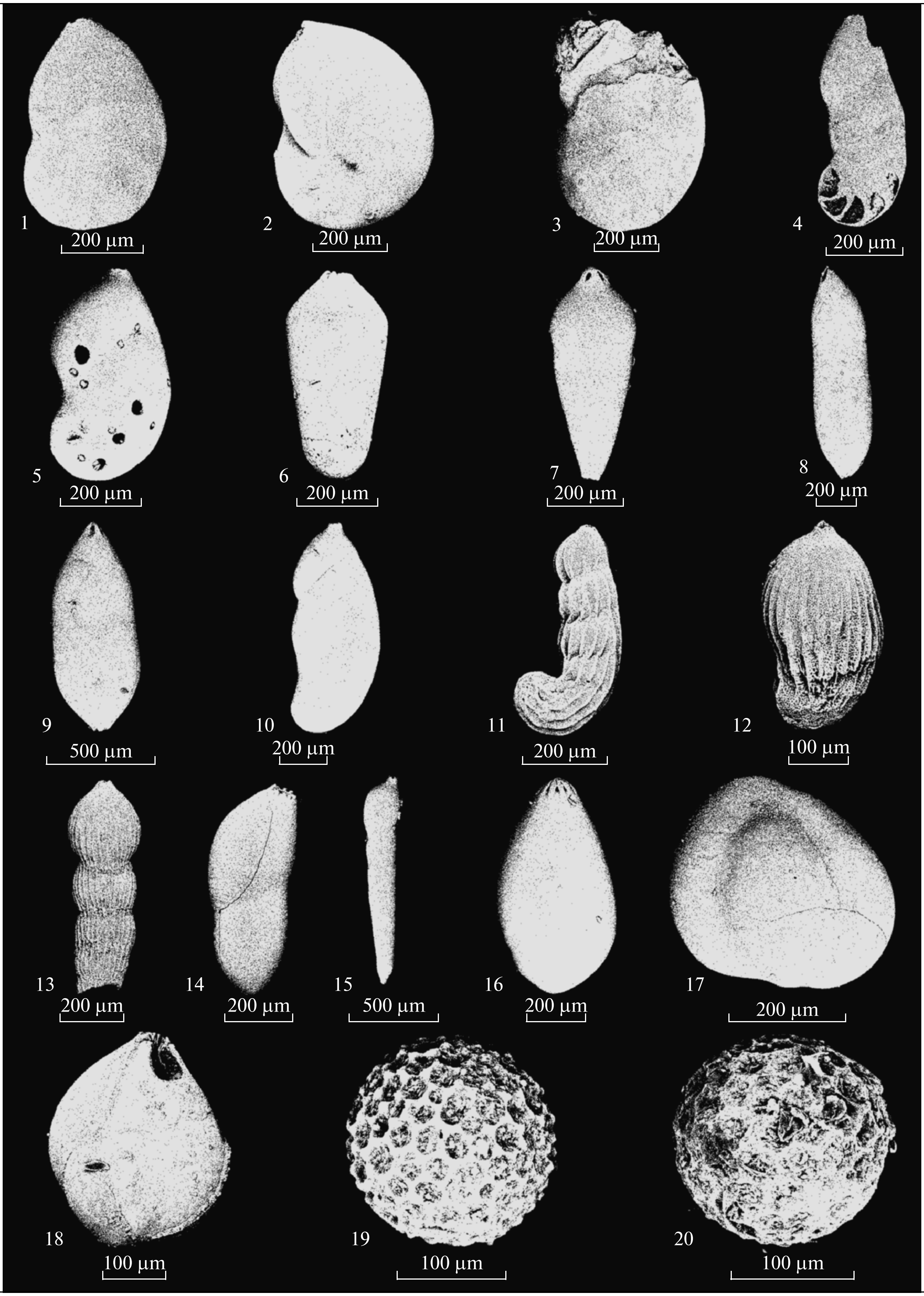
Plate 2. Secreted foraminifers from the Haplophragmpoides infracalloviensis–Guttulina tatariensis Zone (lower Callovian). Specimens 1, 2, 5–7, 10, 14, and 15 originate from Sample 8.

(1, 2) *Lenticulina tatariensis* (Majatl.), side view: (1) GIN, no. F-4/2013, specimen 9, (2) GIN, no. F-4/2013, specimen 13; (3) *Lenticulina* sp.: side view, GIN, no. F-4/2013, specimen 59, Sample 23; (4) *Astacolus hybrida* (Terq.): side view, GIN, no. F-4/2013, specimen 58; (5) *Saracenaria cornicopiae* (Schwag.): side view, GIN, no. F-4/2013, specimen 10; (6) *Pseudonodosaria pupoides* (Terq.): side view, GIN, no. F-4/2013, specimen 12; (7) *Pseudonodosaria terquemi* Mjatl.: side view, GIN, no. F-4/2013, specimen 74; (8, 9) *Pseudonodosaria* sp., side view: (8) GIN, no. F-4/2013, specimen 20, Sample 9, (9) GIN, no. F-4/2013, specimen 53, Sample 22; (10) *Planularia protracta* Born.: side view, GIN, no. F-4/2013, specimen 17; (11) *Marginulina mjatliukae* Schokh.: side view, GIN, no. F-4/2013, specimen 15; (12) *Marginulina krylovae* Mjatl.: side view, GIN, no. F-4/2013, specimen 54, Sample 22; (13) *Nodosaria* sp.: side view, GIN, no. F-4/2013, specimen 38, Sample 18; (14) *Dentalina macrocephala* (Kübl. et Zwin.): side view, GIN, no. F-4/2013, specimen 16; (15) *Dentalina* sp.: side view, GIN, no. F-4/2013, specimen 19; (16) *Eoguttulina karlaensis* Mjatl.: side view, GIN, no. F-4/2013, specimen 21 (17, 18) *Guttulina tatariensis* Mjatl.: (17) side view, GIN, no. F-4/2013, specimen 51, Sample 22, (18) apertural view, GIN, no. F-4/2013, specimen 52, Sample 22; (19, 20) radiolarians: (19) GIN, no. F-4/2013, specimen 2, Sample 2, (20) GIN, no. F-4/2013, specimen 48, Sample 21.

Plate 2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since the sediments contain only agglutinated foraminiferal tests, while secreted foraminifers, gastropod, and ammonite shells are dissolved, being present only in the form of pyritized casts. The prevalence of agglutinated foraminiferal species in cold waters was also noted in (Startseva, 1975). It should be noted that finds of West European foraminifers (*Astacolus hybrida, Lenticulina quenstedtii, L. protracta, Ammobaculites fontinensis, Dentalina macrocephala, D. plebeja, Pseudonodosaria pupoides, Reophax helveticus, R. metensis, R. multilocularis, and Saracenaria cornicopiae*) through the entire section of C-I indicates water exchange between the Central Russian and West European paleobasins at that time. Thus, judging from the distribution of foraminifers, this interval of the section should correspond to the reconstruction by Gulyaev for the *P. elatmae anabarense* and *P. elatmae elatmae* hemera (end of the Elatmae phase), when the Central Russian sea was complicated by the newly formed Dniester western branch in addition to the existed Pechora and Caspian branches and its circulation system included a single boreal current that was separated into the eastern and western branches and reflects a second immigration level (with boreal ammonites) (Rogov et al., 2009).

The second TR cycle (C-II) (the overlying 2 m of the section. upper part of Bed 3—lower part of Bed 2, samples 15–25) is characterized by the change in the general trend of the transgression. The total disappearance of Arctic ostracod taxa and the presence of thermophilic forms from West Europe and the Dnieper–Donets basin (*Procytheridea*, *Acantocythere, Palaeocytheridea*) along with *P.* (*P.*) *pavlovi* indicate the cessation of the water influx from the north, opening of the western migration corridor, and penetration of Tethyan waters via the Dniester branch and North Caspian depression from the west and southeast. This scenario corresponds to the reconstruction in (Guilyaev, 2005) for the *C. crobyloides* hemera of the terminal Subpatruus phase and the single immigration level (Tethyan ammonites) recorded in the *Subpatruus* Zone (Rogov et al., 2009).

This explains the fact that the formation of the lower (C-I) and upper (C-II) parts of the section that were presumably deposited in similar bathymetric environments is reflected by an increase in the abundance of both microfossil groups precisely in its upper part.

In our opinion, the sediments that constitute the section were deposited at depths of 50 m, since ostracods are mostly represented by species with large and medium shells up to 0.5–0.9 mm across (Tesakova and Sel'tser, 2013), which is characteristic of the macrophyte biotope. The diversity of such large ostracods increases to a depth of approximately 50 m (Tesakova, 2014a, 2014); therefore, their diversity and abundance peaks in the shallow early Callovian sea corresponded to transgressive episodes. The other feature that indicates deepwater settings for diverse and abundant ostracod assemblages (samples 8 and 22) is the presence of the species *P. didictyon rossica* and *F.* (*P.*) *archangelskyi*, which dwelt in conditionally deepwater environments. The high sea level stand is emphasized by the presence of genera from the Tethys ocean (*Palaeocytheridea*) and West Siberian paleobasin (*Camptocythere* and *Pyrocytheridea*) (Tesakova, 2014a, 2014b).

Judging from the distribution of ostracods (Fig. 3), the lower half of each cycle reflects shallower settings as compared with the upper one; shallow-water environments were also characteristic of the period that corresponds to the formation of the upper part of the O-II cycle. Thus, five different settings are reconstructed for the section (from the base upward): cold/shallow, cold/deep, warm/shallow, warm/deep, and warm/shallow. The foraminiferal distribution (Fig. 2) shows that most species (approximately 80%) colonized the basin during the first, cold, transgression; their assemblage is represented by cold-resistant eurythermal forms. Two immigration waves are noted: during the shallow- and deep-water phases of the first cycle. The gradual warming was accompanied by the disappearance of cold-resistant forms from the assemblage against the background, first, of growth in the abundance of eutythermal species and then its decrease: the notable peaks in the lower part of the abundance curve (F-II) become gradually smoothed upsection. Only five eurythermal and eurybathic forms survived by the end of the *Subpatruus* hemera. It is remarkable that foraminifers that immigrated at the beginning of the second, warm, TR cycle are represented by eight species and only two species appeared during the maximum phase of the warm transgression. It is conceivable that such a phenomenon is explained by basin shoaling, decreased influx (cessation?) of sea waters, and development of a well-heated lagoon with unstable (low?) salinity.

The paleoecology of the foraminifers. A comparative analysis of the foraminiferal distribution in different intervals of the section that correspond to different bathymetric and thermal environments (Figs. 2 and 3) allows their ecological groups to be defined. The proposed discrimination of foraminifers according to their depth and temperature preferences is preliminarily and requires additional testing by statistically reliable data on different sections:

(1) ***shallow-water coldwater species*** present only in the lower part of Interval F-I: *Reophax metensis, Ammodiscus* sp. 1. *Textularia* sp.; (2) ***shallow-water thermophilic***: *Reophax scabrosus, Verneuilina minima, V.* sp., *Ammobaculites* ex gr. *quadrifidus, Bulbobaculites* sp.?, *Nodosaria* sp., and *Epistomina* sp.; (3) ***shallow-water eurythermal***: *Kutsevella antiqua, Ammobacuites* ex gr. *coprolithiformis, Gaudryina* sp., *Reophax multilocularis, and Reophax* sp.; (4) ***deepwater cold-resistant***: *Dentalina macrocephala, D. plebeja, Lenticulina tatariensis, Eoguttulina karlaensis, Marginulina mjatliukae, Pseudonodosaria pupoides, Ps. terquemi, Ps.* ex gr., *sowerbyi*, *Saracenaria cornicopiae, Glompospirella* sp. possibly *Asracolus argutus*, and *Trocham-*

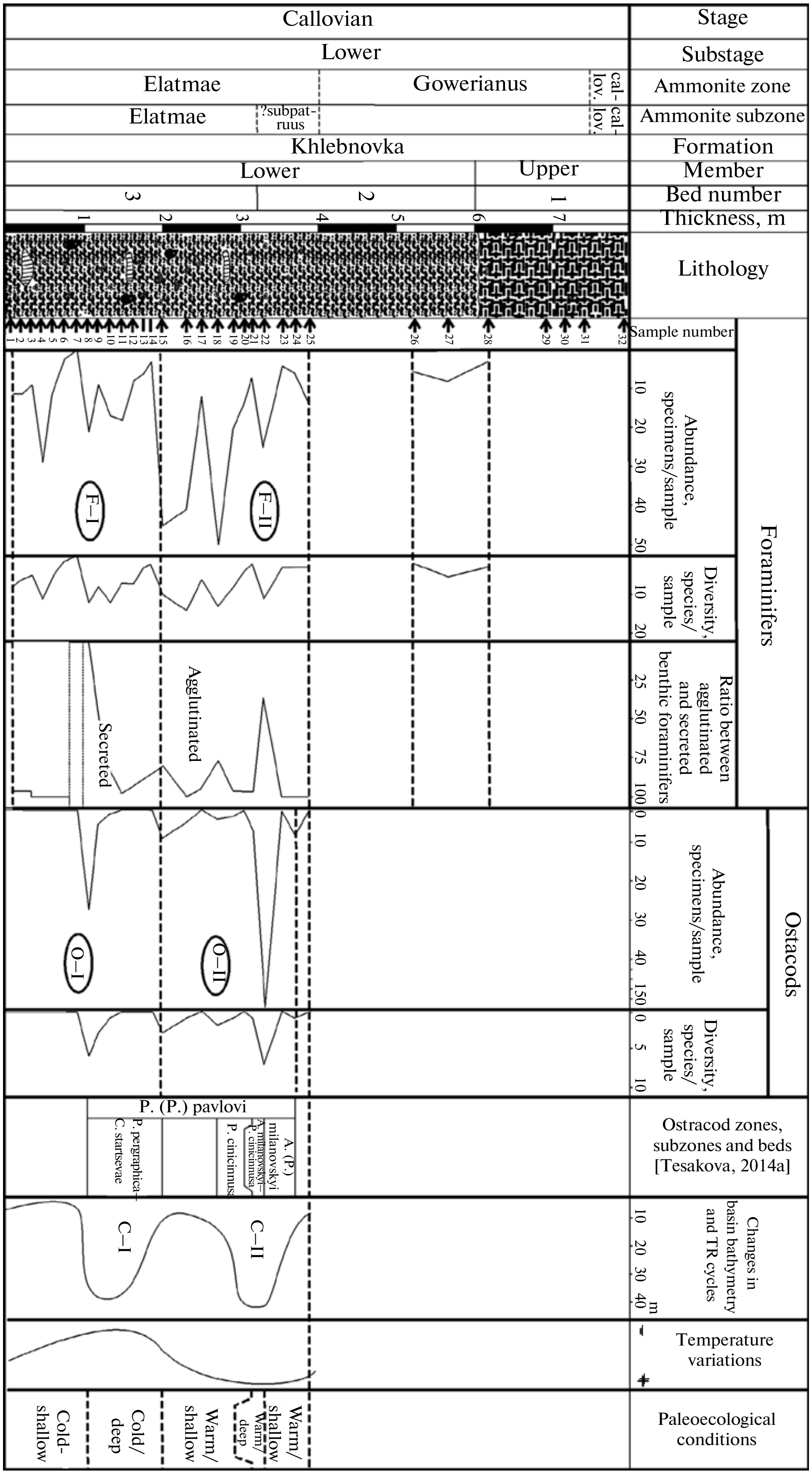

Fig. 3. Variations in the diversity and abundance of foraminifers and ostracods and their interpretation.

mina ex gr. *globigeriniformis*, since they disappear at the boundary with the shallow warm zone; (5) ***deepwater thermophilic***: *Lenticulina quenstedtii, Marginulina krylovae*; (6) ***deepwater eurythermal***: *Astacolus hybrida, Pseudonodosaria* sp., *Dentalina* sp., and *Lenticulina* sp.; (7) ***eurybathic cold-resistant***: *Evolutinella* sp., *Reophax heleveticus*, and *Trochammina* ex gr. *globigeriniformis*; (8) ***eurybathic termophilic***: *Ammobaculites fontinensis* and *Guttulina tatariensis*; (9) ***eurybathic eurythermal***: *Haplophragmoides infracalloviensis, H.* ex gr. *canariensis, Lituotuba nodus, Recurvodes ventosus, Ammobaculites* ex gr. *fontinensis, Trochammina pileolae, T.* ex gr. *praesquamata*, and *Cribrostomoides* sp.

CONCLUSIONS

On the basis of the presented data, it may postulated that the Elatmae ammonite zone comprises two TR cycles (C-I and C-II), which correspond to the lower and upper parts of the section that was substantiated by foraminiferal and ostracod assemblages (Fig. 3) and differ from each other by the corresponding paleogeographic situations. The latter was determined by the difference in the general trend of transgression and, correspondingly, water temperature. Our materials are quite consistent with the data in (Gulyaev, 2005; Rogov et al., 2009) and specify the reconstruction by V.A. Zakharov, who defined in the lower Callovian section of the East European Platform a single TR cycle within the Elatmae and Calloviense phases, with the transgression maximum confined to the first of them (Sahagian et al., 1996). Reconstructions based on foraminiferal and ostracod assemblages appeared to be more detailed as compared with interpretations by Kiselev (2004), who suggested a single powerful current for the early Callovian, which penetrated to the East European Platform via the Pechora strait that diverges into two western (Dniester) and eastern (North Caspian) branches, and opposite warm currents from the Tethys.

If the changes in the paleocological properties of microfossil assemblages and paleogeographic settings reconstructed on their basis are taken into consideration, the boundary between the *Elatmae* and *Subpatruus* subzones in the Bartolomeevka section should be placed approximately in the middle of Bed 3, i.e., below its present-day level.

Judging from the ostracod distribution, the maximum depths of the basin never exceeded 50 m, amounting most likely to a few tens of meters (Tesakova, 2014a, 2014b). Such a conclusion conflicts with the opinion of G.N. Startseva, who believed that the depths of the outer shelf in the Volga region during the early Callovian were approximately 100–200 m (Startseva, 1975; Startseva and Zorina, 2011). At the same time, it is supported by the facies analysis, which suggests relatively shallow settings for the Ul'yanovsk–Saratov trough (up to 20–30 m) at that time and is quite consistent with the paleobathymetric curve of V. Zakharov (Sahagian et al., 1996).

The analysis of the distribution of foraminiferal assemblages in different bathymetric and thermal settings made it possible to preliminarily define nine of their ecological groups.

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