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Palaeogeographic Reconstructions of the Natural Environment in Southeast Belarus during the Bathonian–Oxfordian Ages

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Abstract—Palaeogeographic reconstructions of the natural environments in Southeast Belarus during the Bathonian–Oxfordian were carried out using the method of conjugate analysis of facies, sedimentology, paleontology, and geochemistry. The results show the existence of lagoon environments at the end of the Bathonian with a gradually growing sea gulf in the Early Callovian and general marine regime developed by the end of Early Callovian that continued during the Middle–Late Callovian and Oxfordian. Transgression of the sea and intervention of marine faunas occurred in three directions: from Western Europe, Ukraine, and Central Russia. Mollusc and ostracod faunas had mixed characteristics with dominance of the Tethyan elements over the Arctic ones. In the Early Oxfordian the Eastern Paleobasin of Belarus had a stable connection with the Middle Russian Sea.

Keywords: Jurassic, Mollusca, Ostracoda, palaeogeography, Belarus
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INTRODUCTION

Jurassic deposits remained poorly known in Belarus until 1955. However, based on the similarity of the Jurassic faunas in Western and Eastern Europe Academician N.F. Bliodukho in 1922 assumed the presence of Jurassic deposits in the west of Belarus, as well as connection of the “Western and Russian Jurassic” on the territory of Belarus (*Istoriya*..., 1978). Deep drilling in the territory of Belarus that reached Jurassic sediments was started only in 1939 but was interrupted by WWII. Later, during 1945–1951 a large number of key and prospect wells were drilled and the first results of systematic state geological mapping at the 1 : 200000 scale were summarized. As a result the large scientific volume *Paleontology and Stratigraphy of the BSSR* was published in 1955: it contains description of the geological structure and paleontological characteristics of the Jurassic deposits. The first micropaleontologic studies in Belarus were conducted by Mityanina on Jurassic foraminifers (1955, 1957, 1963). During 1954–1977 borehole cores from Belarus were used for studies of various macrofossils in several scientific institutes of the Soviet Union, particularly numerous ammonites that were examined in VSEGEI (Leningrad) and LitSRGEI (Vilnius). The results of those studies were partly published (Rotkite, 1987, Sazonov, 1957, Sazonova and Sazonov, 1969) and partly were included in internal reports of Bodylevsky (1960), Krymgolts (1955, 1965), Luppov (1961), Rotkite (1975) and others.

The modern understanding of the Jurassic paleogeography of the northwestern part of the Dniepr–Donets Basin (East Belarus) was built via summaries on stratigraphic data from 1954 to 2010 (Moiseeva et al., 1983, Klimenko et al., 2005, Mamchik, 2005, Makhnach, 2010a). All the ammonite subdivisions of the Callovian and Oxfordian, described in the West European Standard were recognized (Mityanina, 1982; Karimova and Klimenko, 2010; Makhnach, 2013), along with studies on bivalves (Makhnach, 2010b), foraminifers (Karimova and Klimenko, 2003, 2010), and spore–pollen complexes (Klimenko, 1992; Karimova and Klimenko, 2010). As well, faunistic similarities with regions of the Tethys and the Middle Russian Sea were found (Nesterovich, 1976; Makhnach, 2010a). Additionally, it was discovered that paleogeographical events in the East of Belarus during the Callovian–Oxfordian Ages were more complex and diverse than previously assumed.

The present study is devoted to the paleogeography and paleoecology of the Callovian and Oxfordian deposits in the Gomel District of Belarus. It was carried out using the method of conjugate analysis. As basic methods of conjugate palaeogeographic analysis we chose: (a) geological approaches (observation of the rhythmicity of beds, lithologic analysis, etc.); (b) geochemical analysis combined with statistical data processing (using geochemical indicators and studies of chemical composition) (Makhnach, 2014); (c) paleontological methods (malacology and micropaleontology).

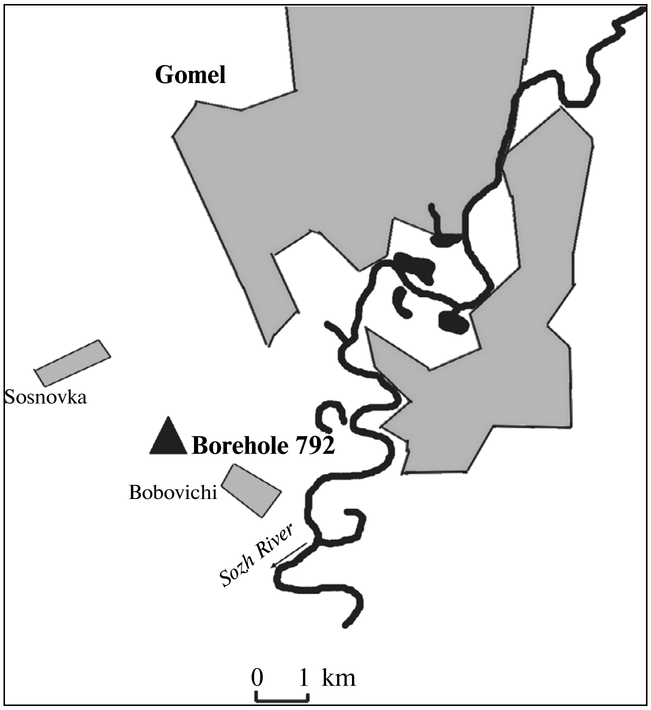

Fig. 1. The scheme of the location of borehole 792.

Determination of molluscs, as well as facial and geochemical analyses were carried out by V.V. Makhnach (BSU, Minsk), while ostracods were processed by E.M. Tesakova (MSU, Moscow).

SAMPLES AND APPLIED TECHNIQUES

Samples of Jurassic rocks and fossils were collected from the core of the borehole no. 792 that was drilled by the Belarusian Belgeologiya Geologic Exploration Expedition during a survey for diamond-bearing structures (Fig. 1). Jurassic sediments were reached at a depth of 264.0 m and continued down to 376.0 m. The Walawa Formation sandstone (Triassic) is underlying, while Lower Cretaceous (Valanginian) sands rest on the top of the Jurassic rocks.

The Jurassic section in the borehole was subdivided using ammonites, bivalves, foraminifers, and ostracods.

Middle and Upper Jurassic deposits were found in the borehole (Fig. 2). From the bottom upward Bathonian continental sediments occur, which are overlain by an erosion surface with Callovian and Oxfordian rocks on top; these are represented by successively alternating transgressive shallow-marine and regressive littoral facies. Signs of hiatus and erosion were spotted at the boundary of the beds 6 and 7 at the base of the Oxfordian deposits.

Eight samples, which were mainly clays and sands, were chosen for geochemical study (Makhnach, 2014). The parts of the section where they were collected are shown in Fig. 2.

For the paleontological studies, 43 molluscan specimens were collected (they are frequently occurred at groups in some levels), ostracods were derived from 13 samples (Fig. 2).

To extract microfossils, 0.2–0.3 kg of clay was first soaked in cold water for a week; the samples were then boiled with sodium bicarbonate for 20 minutes. After this, the samples were placed in a 0.1 mm sieve and the clay particles were washed with water. Dried specimens were then sifted totally a 0.3 mm sieve. Ostracods were handpicked from each size fraction of 0.1–0.3 mm and greater than 0.3 mm using an MBS-9 binocular microscope. For each species in a sample is calculated completes shells and valves isolated (separate left and right), were taken into account, males and females shells, as well as the age of the molting stage. During statistical treatment of the data singular valves are taken as a unit, so that a complete shell was counted as two valves. All the ostracods were photographed in the electron microscopy laboratory of PIN RAS; they are shown in Plates 1–3. The collection is registered as No. 370 and is stored at the Geology Dept. of MSU (Chair of Paleontology).

The ostracods were found in 5 out of 13 processed samples and are represented by 27 morphs out of which 23 were identified to the species level; the rest were left in open nomenclature (Fig. 2). It should be noted that although Jurassic ostracods from Belarus were known and published in geological reports, their identifications and images are published here for the first time. In the following part the description of the borehole is given.

The 792 borehole of the Gomel prospecting object is located 6 km southwest of the town of Gomel at the northern outskirts of the village of Bobovichi (Fig. 1). From the bottom upward the following deposits were bored through.

Bathonian Stage *bed 1*. Quartz sand with layers of bluish-grey clays, quite dense with a rough break. Black carbonized floral remains and spores with triradial fissures were found. Reliable macrofossils or microfossils are absent. Depth interval, 376.0–364.4 m.

Callovian stage, lower substage.

Bed 2. Bluish-grey clays, non-calcareous, dense, like mudstone, horizontally bedded, generally with fine platy cleavage. At the top of the bed (to a depth of 344.2 m) some layers of dark-grey silty rich clays occur. In the middle part of the bed *Natica* sp., *Cylindroteuthis* sp., *Gryphaea* sp., *Meleagrinella* sp. and *Kepplerites* sp. were identified. Near the top of the bed some scarce badly preserved ostracods were found: *Glabellacythere* cf. *nuda* Wienholz and 7 Gen. sp (Plate 2). The depth interval of the bed is 364.4–339.0 m.

Bed 3. Dark-grey, in some layers, black, clay, humified, dense, horizontally bedded with fine platy cleavage and sprinkled micas on bedding surfaces. In the entire bed from the bottom upward the following were found: *Sigaloceras calloviensis* (d'Orb.), *Kepplerites* cf.

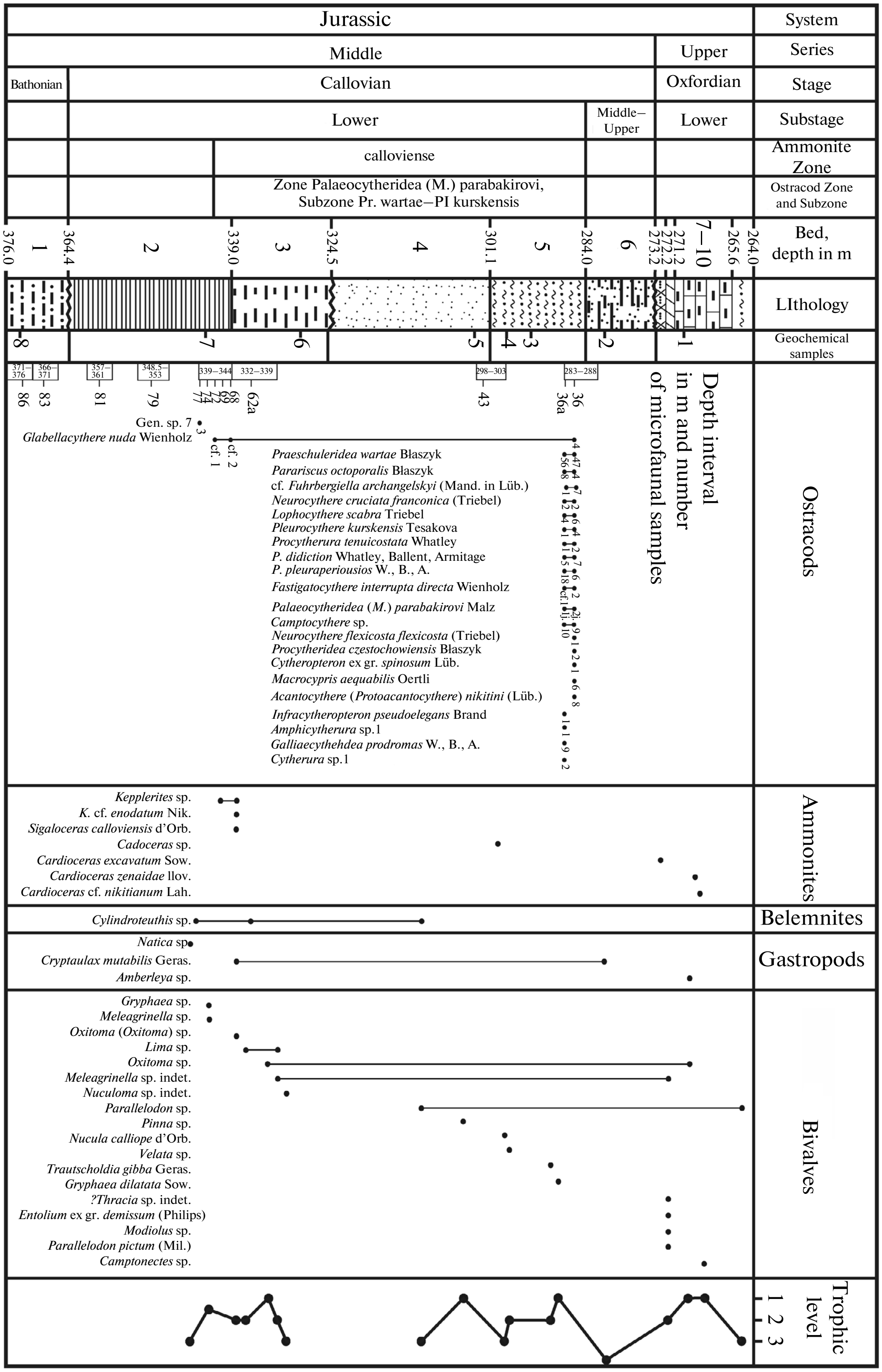

Fig. 2. The distribution of ostracods and molluscs in the section of borehole 792.

Plate 1

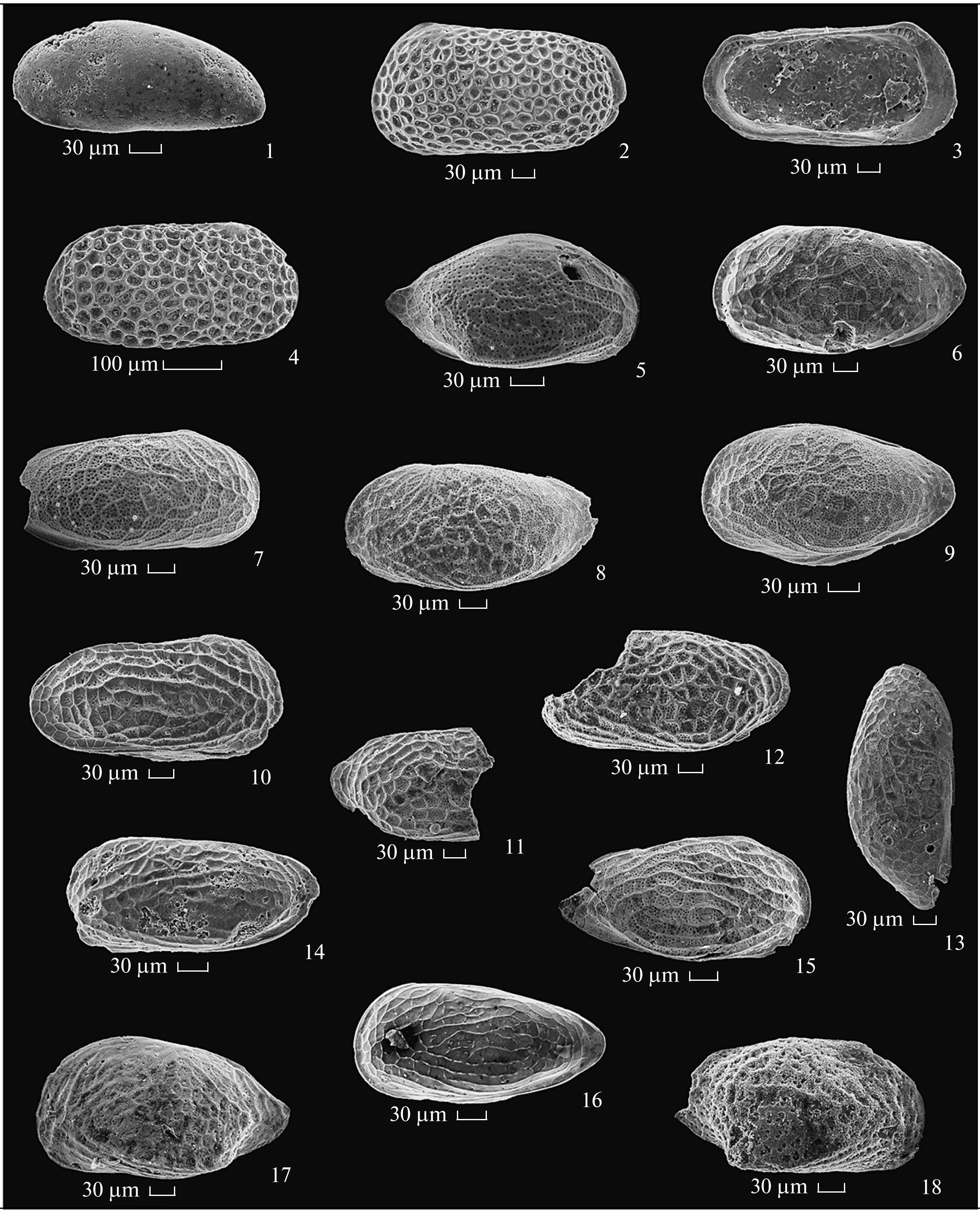

Plate 1. Ostracods from the studied section. The acronyms are: lv, left valve; rv, right valve; cs, complete shell; frg, fragment; Fml, female; Ml, male; DV, dorsal view; LV, view from left side; RV, view from right side; spc., specimen No. in collection. 1, *Macrocypris aeqabilis* Oertli, 1959: spc. No Belor–1–31, lv Fml; 2–4, *Parariscus octoporalis* Błaszyk, 1967: 2, spc. No Belor–1–12, lv Fml; 3, spc. No Belor–1–112, lv Fml from inside; 4, spc. No Belor–1–109, rv Fml; 5, *Cytherura* sp. l: spc. No Belor–1–63, rv Fml; 6–9, 13, *Procytherura didictyon* Whatl., Ball., Arm., 2001: 6, spc. No Belor–1–21, lv. Ml; 7, spc. No Belor–1–22, rv Ml; 8, spc. No Belor–1–117, lv Ml; 9, spc. No Belor–1–28, cs Fml LV; 13, spc. No Belor–1–119, lv DV; 10–12, *Procytherura pleuraperiousios* Whatl., Ball., Arm., 2001: 10, spc. No Belor–1–25, cs Fml RV; 11, spc. No Belor–1–59, rv frg; 12, spc. No Belor–1–71, lv frg; 14–16, *Procytherura tenuicostata* Whatley, 1970: 14, spc. No Belor–2–14, lv; 15, spc. No Belor–1–141, rv; 16, spc. No Belor–1–59, cs LV; 17, 18, *Cytheropteron* ex gr. *spinosum* Lüb., 1955: 17, spc. No Belor–1–118, lv; 18, spc. No Belor–1–20, rv.

Plate 2

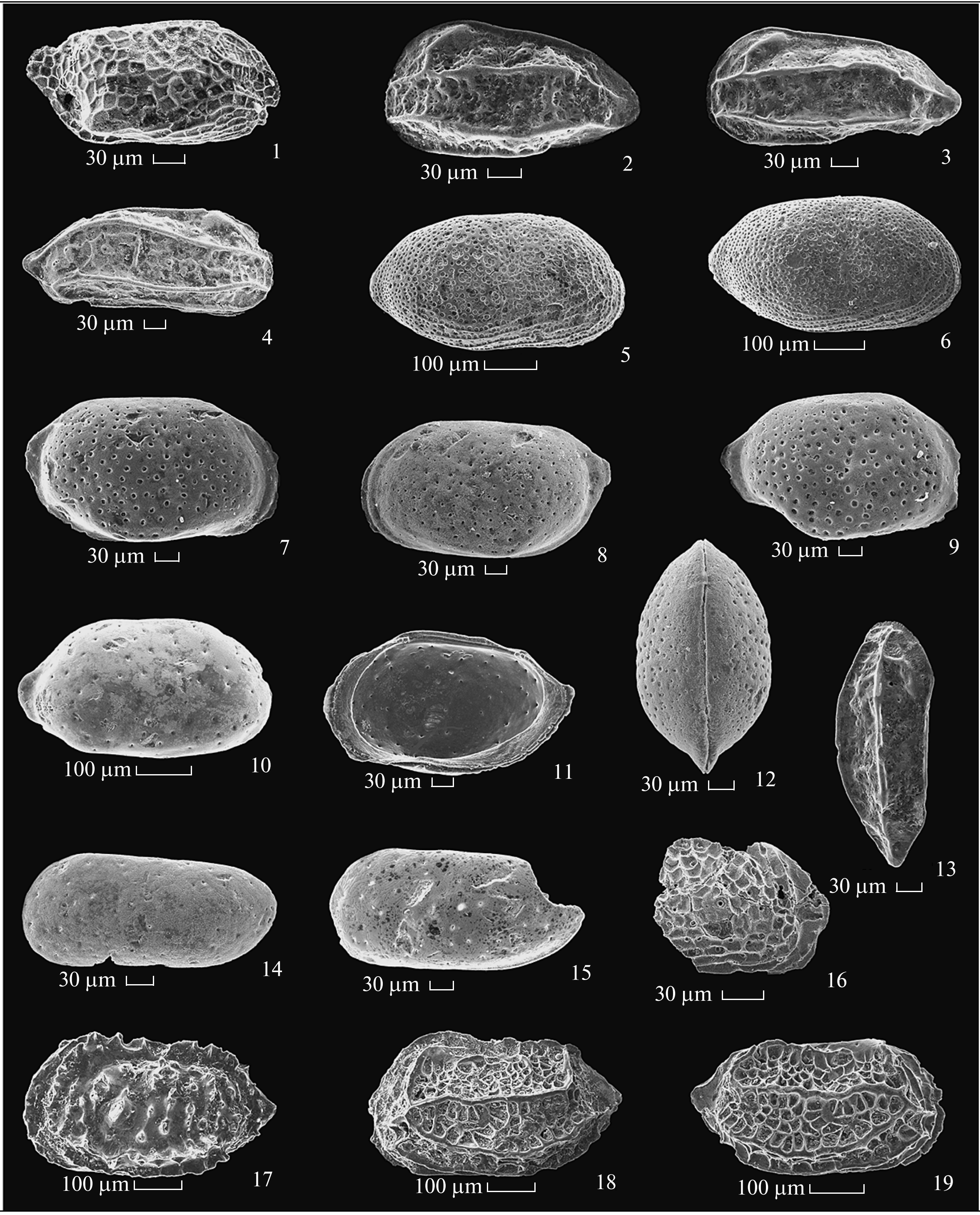

Plate 2. Ostracods from the studied section. 1, *Infracytheropteron pseudoelegans* Brand, 1990: spc. No Belor–1–73, rv; 2–4, 13, *Amphicytherura* sp. 1: 2, spc. No Belor–1–62, lv Fml; 3, spc. Belor–1–131, lv; 4, spc. No Belor–1–132, rv; 13, spc. No Belor–1–131, lv DV; 5, 6, *Procytheridea czestochowiensis* Błaszyk 1967: 5, spc. No Belor–1–8, rv Fml; 6, spc. No Belor–2–33, rv Fml; 7–9, 11,12, *Camptocythere* sp.: 7, spc. No Belor–1–52, rv Ml; 8, spc. No Belor–1–85, lv Ml; 9, spc. No Belor–1–l0, rv Fml; 11, spc. No Belor–1-53, rv Fml from inside; 12, spc. No Belor–1-32, cs Fml DV; 10, *Glabellacythere nuda* Wienholz, 1967: spc. No Belor–1–7, rv Fml; 14, 15, *Cyiheridea coarctata* Jones et Sherb., 1888: 14, spc. No Belor–1–67, lv; 15, spc. No Belor–2–18, lv frg; 16, *Fastigatocythere interrupta directa* Wienholz, 1967: spc. No Belor–1–1, rv frg; 17, *Lophocythere scabra* Triebel, 1951: spc. No Belor–2–8, lv Fml; 18, 19, *Neurocythere cruciata franconica* (Triebel, 1951): 18, spc. No Belor–1–45, lv Fml; 19, spc. No Belor–2–25, rv Fml.

Plate 3

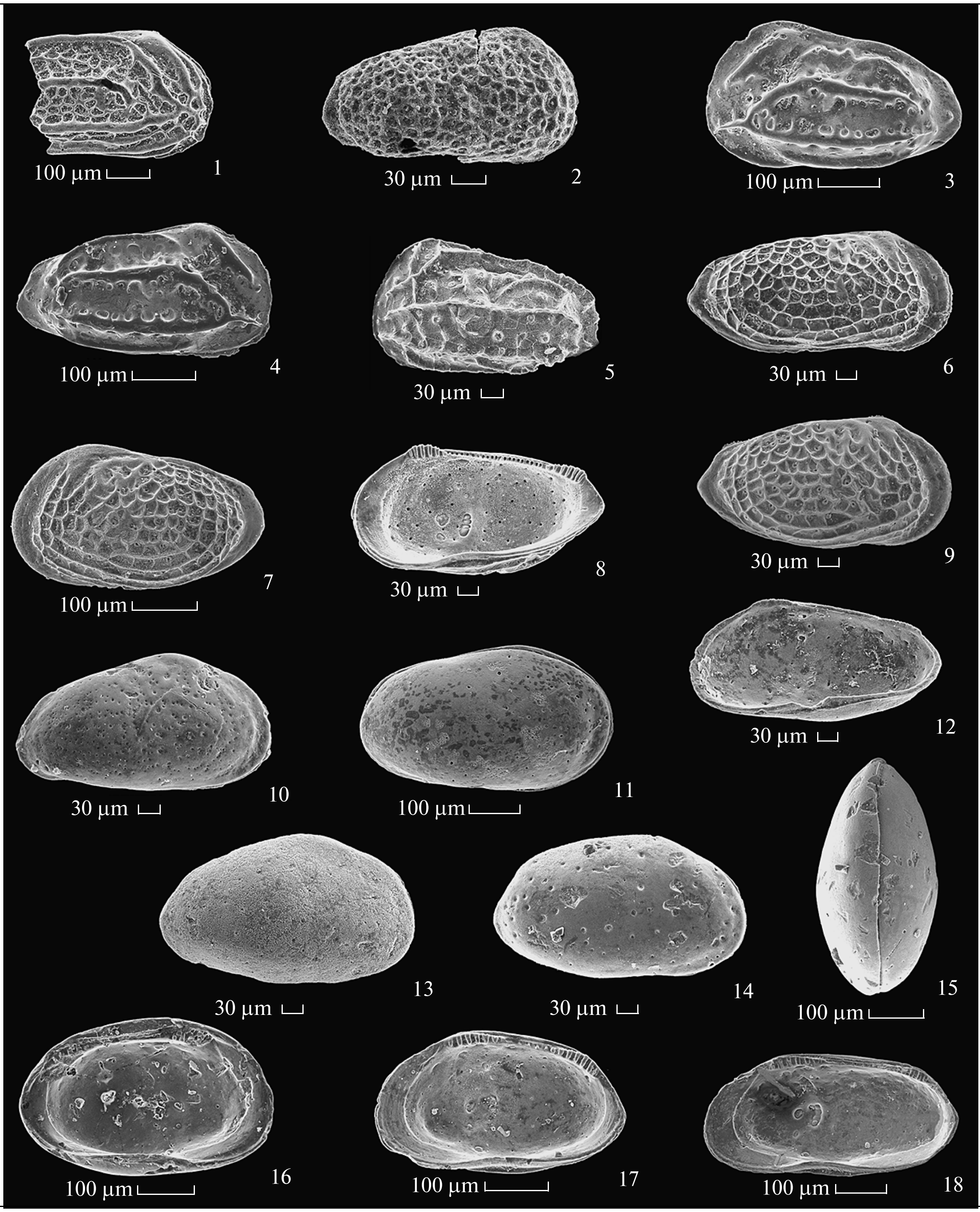

Plate 3. Ostracods from the studied section. 1, *Neurocythere flexicosta flexicosta* (Triebel, 1951): spc. No Belor–1–2, rv frg; 2, *Fuhrbergiella archangelskyi* (Mand. in Lüb., 1955): spc. No Belor–1–140, rv larvae; 3, 4, *Pleurocythere kurskensis* Tesakova in Tes. et al., 2009: 3, spc. No Belor–2–29, lv Fml; 4, spc. No Belor–2–30, rv Fml; 5, *Palaeocytheridea* (*M.*) *parabakirovi* Malz, 1962: spc. No Belor–1–6, lv larvae; 6–9, *Acantocythere* (*Protoacantocythere*) *nikitini* (Lüb., 1955): 6, spc. No Belor–1–16, rv Ml; 7, spc. No Belor–1–15, lv Fml; 8, spc. No Belor–1–18, rv Fml from inside; 9, spc. No Belor–1–17, rv Fml; 10–13, *Galliaecytheridea prodromos* Whatl., Ball., Arm., 2001: 10, spc. No Belor–1–103, rv Fml; 11, spc. No Belor–1–33, ws Fml RV; 12, spc. No Belor–1–104, rv Fml from inside; 13, spc. No Belor–1–102, rv Fml; 14–18, *Praeschuleridea wartae* Błaszyk, 1967: 14, spc. No Belor–1–39, rv Fml; 15, spc. No Belor–1–44, cs Fml DV; 16, spc. No Belor–2–31, lv Fml from inside; 17, spc. No Belor–1–40, rv Fml from inside; 18, spc. No Belor–2–32, rv Ml from inside.

enodatum (Nikitin), *K.* sp., *Cylindroteuthis* sp., *Lima* sp., *Nuculoma* sp. indet., *Meleagrinella* sp. indet., *Oxytoma* (*Oxytoma*) sp., *Cryptaulax mutabilis* Gerasimov, *Oxytoma* sp. and brachiopod (Rhynchonellidae). As well, onychites, fish remains, pyritized wood and calcareous foraminifers were observed (*Lenticulina*, *Epistomina*, and others). Ostracods are absent. The depth is 339.0–324.5 m.

Bed 4. Quartz sands, grey, in places to dark-grey or yellowish-grey, fine-grained silty. The upper part contains *Cylindroteuthis* sp., *Parallelodon* sp. and *Pinna* sp. Ostracods are missing. The depth interval is 324.5–301.1 m.

Bed 5. Quartz silt, grey, sometimes bluish with scarce micas, irregularly clayey and sandy. Alternation of more clayey and sandy varieties was observed. The clay content increases towards the top of the bed. From the bottom upward the following fossils were identified: *Cadoceras* sp., *Nucula calliope* d'Orb., *Velata* sp., *Trautscholdia gibba* Geras. and *Gryphaea dilatata* Sow. In the samples that were collected near the top of the bed numerous and various well-preserved ostracods were identified: *Macrocrypis aequabilis* Oertli, *Procytherura didictyon* Whatl., Ball., Arm., *P. tenuicostata* What., *Cytherura* sp.1, *Cytheropteron* ex gr. *spinosum* Lüb., *Infracytheropteron pseudoelegans* Brand, *Parariscus octoporalis* Błaszyk, *Camptocythere* sp., *Praeschuleridea wartae* Błas., *Fuhrbergiella archangelskyi* (Mand. in Lüb.), *Neurocythere cruciata franconica* (Trieb.), *N. flexicosta flexicosta* (Trieb.), *Lophocythere scabra* Trieb., *Fastigatocythere* cf. *interrupta directa* Wienh., *Acantocythere* (*Protoacantocythere*) *nikitini* (Lüb.), *Amphicytherura* sp.1, *Palaeocytheridea* (M.) *parabakirovi* Malz, *Pleurocythere kurskensis* Tes. in Tes. et al., *Glabellacythere nuda* Wienh., *Procytheridea czestochowiensis* Błas., *Galliaecytheridea prodromas* Wh., Bal., Arm., *Cytheridea coarctata* Jones et Sherb (shown in Plates 1–3). Along with molluscs and ostracods, pyritized wood, abundant foraminifers, crinoids, ophiuroideas, sea-cucumber sclerites, scaphopodas, belemnite statoliths, fish remnants, and occasional pyritized foraminifer moulds, as well as sponge spicules were found. The bed depth interval was 301.1–284.0 m.

Callovian stage, middle–upper substages. ***Bed 6.*** Slightly clayey sand. Macrofossils were identified through the entire bed: *Rhynchonella* sp. and *Cryptaulax mutabilis*. As well, large pieces of wood were found. The microfossils were not studied. The depth interval was 284.0–273.2 m.

Oxfordian stage, lower substage. ***Bed 7.*** Bluish-grey fine-grained silty quartz sandstone with an admixture of glauconite, occasional micas with a clayey–carbonate matrix with a rough break, non-bedded. Macrofossils, remnants of cephalopods *Cardioceras excavatun* (J. Sow) and brachiopods were found. The microfossils were not studied. The depth interval was 273.2–272.2 m.

Bed 8. Calcareous marl, greenish-grey in color with iron hydroxide patches, unevenly sandy and silty with fragments of greenish-grey fine-grained silty quartz sandstone with clayey–carbonate siliceous matrix, as well as ferriferous small pseudo-ooliths and conchas of *Thracia* sp. ind., *Entolium* ex gr. *demissum* (Phill.), *Modiolus* sp., *Meleagrinella* sp. ind., *Parallelodon pictum* (Milasch.). As well, ichnofossils were found along with sponge spicules and sea urchin spines. The microfossils were not studied. The depth interval was 272.2–271.2 m.

Bed 9. Light-grey fine-grained slightly clayey (to clayey in places) limestone with rough breaks. The following macrofossils were identified: *Oxytoma* sp., *Amberleya* sp., *Cardioceras zenaidae* Ilov., *Cardioceras* cf. *nikitianum* Lah., *Camptonectes* sp. The microfossils were not studied. The depth interval was 271.2.2–265.6 m.

Bed 10. Bluish-greenish-grey quartz silt, slightly calcareous, clayey, sandy. For macrofossils only *Parallelodon* sp. was found. The microfossils were not studied. The depth interval was 265.6–264.0 m.

FACIES ANALYSIS

The deposits that accumulated in the Jurassic time in the territory of East Belarus can be divided into two facies groups that embrace the entire spectrum of the local facies by using the following sedimentary features: (1) the velocity and type of sediment transport; (2) the type and intensity of the hydraulic regime in the basin; (3) sea level fluctuations; (4) climate; (5) chemical factors. In accordance with these parameters the following facies were recognized in the studied borehole.

The I group of facies: shallow-marine with clastic sedimentation. Sediments of bed 2 (339.0–364.4 m) belong to the *facies of alternating light-grey and dark-grey clays* that are typical for lagoons with interrupted connection to the sea and often varying environments (*Obstanovki*..., 1990). Such conditions are not favorable for normal marine faunas, and characterized by the low number of fossils recognized here.

The *facies of dark-grey, locally black humified* (Bed 3) belong to the same lithofacial type. Such deposits were formed under conditions of the littoral marine basin with a limited input of oxygen: in this the sedimentation environments were very close to that in a stagnant marshy basin. Under such conditions a large amount of vegetative detritus may be accumulated, since it has insufficient time to disintegrate; thus it was buried at the bottom in unoxidized form (ibid.).

Based on the modern data on the macrofauna complex it is possible to assume that an alternation of more dense, most probably clay–sand and soft substrates would be formed. Examples of dense substrate faunal complex include representatives of the genera *Lima*, *Meleagrinella*, *Entolium*, *Oxytoma*, and *Pinna*. Other genera, such as *Cryptaulax* and *Nuculoma*, are considered as soft substrate dwellers. In the section interval of 324.5–339.0 m in accordance with consecutive changes of the molluscs, viz., (from the bottom upward) *Lima* sp., *Nuculoma* sp. indet., *Meleagrinella* sp. indet., *Oxytoma* (*Oxytoma*) sp., and *Cryptaulax muta-*

bilis, alternation of dense and soft substrates may be suggested.

A facies of fine-grained quartz sand with remains of benthic animals, where *Pinna* sp., *Cylindroteuthis* sp. and *Parallelodon* sp. were identified was recognized in bed 4 (301.1–324.5 m). The sand grains are covered with a ferriferous cover. The sand to all appearances accumulated from dredging after storms and then was re-deposited by waves. The lithologic features of the sand imply shelf littoral environments (*Obstanovki*..., 1990). The macrofossils are consistent with shallow-water conditions. The geochemical analyses (Makhnach, 2014) point to a decrease of salinity, possibly due to drainage from dry land. As well, a high concentration of hydrogen sulphide was revealed in the near-bottom layer.

Beds 5 and 6 (273.2–301.1 m) are ascribed to the *facies of interbedding of unevenly clayey and sandy silt with poorly clayey sand*, which is typical of a littoral zone (*Obstanovki*..., 1990) that apparently formed under the conditions of a periodically changing sea level.

The II group of facies: shallow-marine with carbonate sedimentation. All the rock varieties of this group occur in the depth interval of 264–273.2 m.

The facies of quartz silty fine-grained sandstone, which corresponds to bed 7, was formed in the environment of the upper sublittoral zone on the background of general shallowing (ibid.). This sediment contains *Cardioceras excavatum* and brachiopods.

The facies of calcareous marl with fragments of sandstone and fine-grained limestone. This facies, which corresponds to beds 8 and 9, was deposited in a warm climate within the limits of the sublittoral zone (ibid.) with a salinity, considering the mollusc complex, that approaches a normal marine one.

The facies of poorly calcareous quartz, clayey and sandy silt (bed 10) reflects the sedimentation conditions of the littoral zone with periodical changes of the sea level (*Obstanovki*..., 1990).

CYCLES AND RHYTHMS IN THE STRUCTURE OF THE SECTION

The conducted analysis of the facies changes through the section permitted us to recover repeating rock complexes or even complexes of facies. Tracing of the rhythms in the section allows not only the recognition of facies and groups of facies but indirect determination of ancient tectonic movements.

The cycles in the studied section indicate a tendency towards the submergence of the northwest part of the Voronezh anticlise from the Bathonian to Late Callovian and then uplift in the Early Oxfordian (Fig. 2). The cycles imply a reciprocating character of the tectonic motion and reflect several transgressive–regressive cycles (TRCs). A complete TRC should be characterized by two sedimentary cycles of direct and reverse trends, or pro- and recyclite (Maslov, 2005). The procyclite part corresponds to the transgressive part while the recyclite part is regressive; graphically, this may be depicted as two triangles connected vertex to vertex (an “hourglass”). Altogether in the studied section 4 TRCs were recognized. The three lower TRCs have transgressive parts only, with not always preserved complete facies sequence.

The first sedimentary cycle (procyclite) has a Bathonian Age (bed 1). The cycle lacks a complete lithologic sequence, as only its middle part is preserved. A hiatus was found at the boundary of the Bathonian and Lower Callovian (between beds 1 and 2). The next cycle corresponds to the early Callovian; this is also incomplete, being represented by only its middle and upper parts. The third cycle encompasses the following subdivisions of the Callovian up to the boundary with the Oxfordian. This sedimentation cycle preserves a complete sequence of facies. Two sedimentation cycles were recognized in the Lower Oxfordian deposits (pro- and recyclites), with conjugate vertices that correspond to a complete TRC. In the lower part of the Lower Oxfordian an incomplete procyclite was revealed: this one has lower psammitic and upper marl parts. The overlying recyclite has only lower and middle parts.

This model of cycles may indicate a possible protrusion of salt domes during the Jurassic in Belarus (Makhnach et al., 2001).

PALEONTOLOGICAL ANALYSIS

Molluscs. In the sampled borehole core various molluscs were recovered: cephalopods, gastropods, and bivalves. They are distributed unevenly in the studied section. At a certain level their concentration increases. Their preservation degree varies in different facies, but usually it is bad.

Ammonites from the genera *Kepplerites* Neumayr and *Sigaloceras* Hyatt at the boundary layers between beds 2 and 3, as well as *Cadoceras* Fischer in the middle of bed 5 permits to consider beds 2–5 as belonging to the Lower Callovian Calloviense Zone (Fig. 2). The occurrence above this (beds 7 and 9) of the genus Cardioceras Neumayr et Uhlig determines these deposits as Lower Oxfordian. The bivalves and gastropods are represented by long-living forms and do not contradict this conclusion.

Benthic molluscs from trophic zones are tightly related to the content of organic matter, hydrodynamics, and bottom relief, as well as type of sediments, which depends on depth. The studied bivalves belong to three trophic groups: nonmotile suspension-feeders (*Camptonectes* Agassiz, *Oxytoma* Meek, *Gryphaea* Lam., *Pinna* L., *Modiolus* Lam.), mobile suspension-feeders (*Entolium* Meek, *Lima* Bruguiere, *Meleagrinella* Whitfield, *Trautscholdia* Cox et Arkell), collecting (*Parallelodon* Meek et Worthen), and burrowing deposit-feeders (*Cryptaulax* Tate). For every trophic level we introduce a corresponding coefficient: 1, the shallowest-water (littoral) zone of nonmotile suspension-feeders (coarse- and medium-grained sands with the maximum organic matter content in the near-bottom dredge and maximal hydrodynamics); 2, shallow-water of mobile suspension-feeders (medium- and fine-grained sands with an elevated organic matter content in the near-bottom dredge and heightened hydrodynamics); 3, a deeper zone of collecting deposit-feeders (fine-grained sands and pelite with the maximum organic matter content at the near-bottom levels and minimal hydrodynamics); 4, a relatively deep-water zone of burrowing deposit-feeders (dominantly pelite, with the maximum organic matter content at the near-bottom levels, weakened or minimal hydrodynamics). A coefficient increment of 0.5 indicates intermediate conditions between the trophic zones.

Along the section the trophic levels and the depth changes that correspond to them (from the section bottom upward) occur in the following way (Fig. 2): in the upper part of bed 2 a transition from a zone of deposit-feeders to zone of suspension-feeders one was recognized; further upward the stabilization of the environmental conditions is observed, expressed in an increase in the hydrodynamic action and risen organic matter content at the near-bottom level: this is the contact zone between suspension-feeders and deposit-feeders. The common trend toward a transition to a suspension-feeders zone suggests shallowing of the sea basin. In bed 3 while passing towards the top, a descending trend that reflects basin deepening is supported by a shift from suspension-feeders to deposit-feeders. For bed 4, despite the fact that the facies correspond to a shallow-water environment, brief sea-level fluctuations cannot be ruled out, considering the transition from deposit-feeders to suspension-feeders. It is possible that natural conditions and levels of the ecological tolerance of the species allowed their coexistence.

Bed 5 is characterized by a descending trend, which is reflected in the transition from deposit-feeders to suspension-feeders; in the middle of the bed, stabilization of conditions is observed. The top of bed 5 and base of bed 6 biologically marks the transition from the shallow-water toward the deep-water environment along with a change of the trophic level from suspension-feeders to deposit-feeders. Bed 8 contains characteristic faunas of errant and sedentary sestonophages. In bed 9 the environment conditions were stable; during this interval the basin was inhabited by sedentary and nonmotile suspension-feeders. During accumulation of bed 10 deepening of the basin occurred with a transition to the deposit-feeders zone. It is notable that the geochemical trends according to the facies index in certain intervals of the section are similar, while they are different in other intervals, which is due to the low frequency of sampling (Fig. 3). Bed 8, according to its geochemistry is not representative due to the formation at this level of a geochemical barrier, which considerably distorts the paleoecologic information.

The molluscs in the section are represented by typical Boreal taxa (*Cylindroteuthis*, *Cadoceras*, *Cardioceras*, *Parallelodon*, and others). However it should be noted that these faunas represented by immigrant taxa. The quite high frequency of the occurrence of these faunas in the section allows one to assume the existence of migration routes. Bed 7 contains both typical boreal species as well as tethyan ones that are found in Western Europe and southwards in the Dniepr–Donets Depression (DDD) (*Kepplerites* and *Meleagrinella*). Some findings of the *Gryphaea* genus (its salt tolerance limits are 18–20‰) point to freshening from dry lands. Bed 6 is also characterized by boreal species; however, the number of Tethyan faunas from West Europe and the DDD is quite high. Bed 5 contains mixed faunas from the Middle Russian Sea, West Europe and the DDD: similar animal communities are traced further up the section. Beds 9 and 10 are dominated with boreal fauna.

The findings of the genus *Entolium*, which is common in both northern and southern basins, is quite interesting: its appearance was noted in Belarusian territory at the level of the Lower Callovian and at the boundary between the Upper Callovian and Lower Oxfordian. It is possible that this genus migrated from the Middle Russian Sea.

The presence of the genera *Lima*, *Oxytoma*, and *Ostrea* in the molluscan assemblages indicates normal marine conditions with a salinity of c. 34.5–36‰ and good aeration. Analysis of the geochemical data shows that by the Oxfordian the salinity increased, presumably by 5‰ (Makhnach, 2014).

This new study allowed the identification of faunas that earlier not known in Belarus, namely, *Velata* Quenstedt, *Nucula* Lam., *Nuculana* Link, and *Thracia* Leach in Blainville (Makhnach, 2010).

The complex of molluscs during the Callovian–Oxfordian was formed in both zonal and ecotone conditions, which is obvious from the trophic trend and systematic composition, due to the Western Europe–Belarus, DDD–Belarus, and Middle Russian Sea–Belarus migration passages, as described above. The frequent changes in the trophic trend point to frequent changes of the environment, which is typical of an ecotone. Both the barrier and filtering functions of an ecotone space determine changes of the migration flows of faunas.

Ostracods are distributed in the section highly unevenly (Fig. 2). In the lower part of the section, bed 1 (Bathonian, samples 86 and 83) and the lower half of bed 2 (Lower Callovian, samples 81 and 79) ostracods were not detected. The washings contained abundant quartz with different grains and various degrees of roundness, pyritized wood, and scarce foraminifers. It is likely that a very shallow littoral zone of the basin occurred here, where ostracod valves were not preserved (were dissolved) after burial in the anisomerous psammite sediments. The upper part of bed 2 corresponds to areas of the bottom that were more remote from the shoreline, since in samples 77, 72, and 68 quartz grains occur only in the fine fraction. Pyrite is quite abundant here. As well, muscovite, onychytes, fragments of gastropod conchs, bivalves, ammonites,

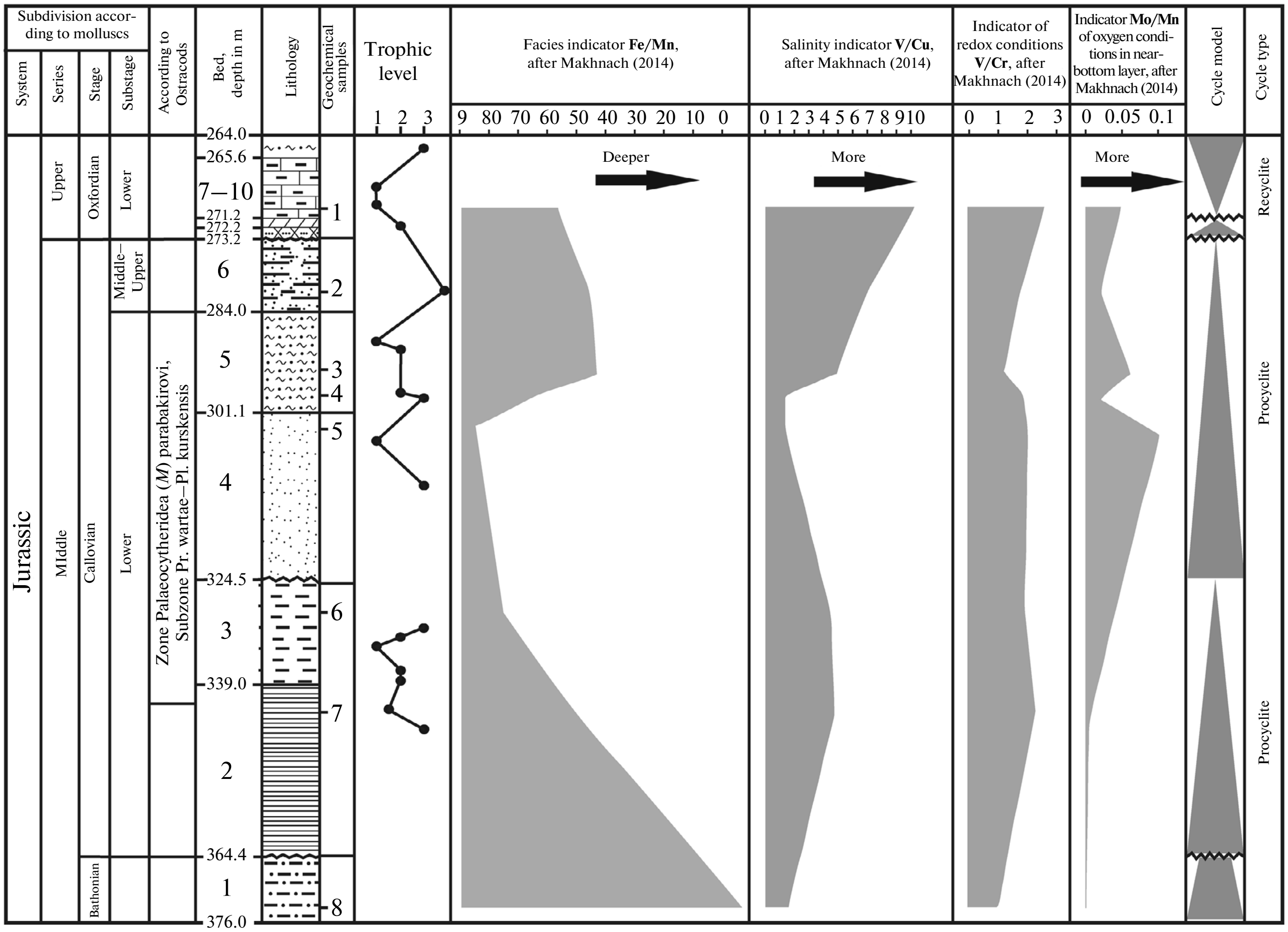

Fig. 3. Geochemical indicators of physical–geographic conditions and model of sedimentary cycles in borehole 792.

sparse agglutinated and calcareous foraminifers (*Lenticulina*, *Epistomina* and other) along with solitary fragments of ostracod valves (*Glabellacythere* cf. *nuda*, Gen. sp. 7) were found. The close proximity of this interval to the shoreline was determined quite clearly.

The samples that contain fine-grained quartz, abundant pyrite, and relatively rich faunal associations, alternate in the section with samples (74 and 69) that are compositionally similar to those from the lower part of the bed, which is dominated by anisomerous poorly rounded quartz, pyritized wood, and lacks any fauna. No ostracods were detected in bed 3 (Lower Callovian, sample 62-a). Here, a large quantity of mica (muscovite) was observed, together with quartz and pyrite. As well, pyritized wood, fish remains, belemnites, ammonite fragments, bivalves, and gastropods, along with scarce foraminifera (Polymorphynidae) occurred. Sample 43 (Lower Callovian, Bed 4) also lacks any microfossils. However, the Lower Callovian clays of bed 5 (samples 36 and 36-a) hold large quantities of various microfossils, including ostracods. In the washings, fine quartz sand with minor additions of glauconite and pyrite and organic remains were found in practically equal proportions: pyritized wood, shell detritus (bivalves, gastropods, and ammonites), belemnite guards and statoliths, scaphopodas, very abundant foraminifers, crinoids, ophiuroids, holothuria sclerites, sponge spicules, fish remains, and ostracods. These are presented by 23 morph, of which 18 were identified to the species level, while 6 were left in open nomenclature. The microfaunas were not studied further up the section.

From the point of view of biostratigraphy the ostracod complex of bed 5 has a mixed composition with substantial dominance of taxa that are typical for the Lower Callovian of the Russian Plate (RP) (Gowerianus and Calloviense Ammonite Zones, the Ostracod Zone Plaeocytheridea (M.) parabakirovi, Pr. wartae–Pl. kurskensis (Tesakova, 2014a) Subzone): *Camptocythere* sp., *Glabellacythere nuda*, *Neurocythere cruciata franconica*, *N. flexicosta*, *Palaeocytheridea* (*M.*) *parabakirovi*, *Praeschuleridea wartae*, *Pleurocythere kurskensis*, *Macrocypris aequabilis*, *Procytherura tenuicostata*, *P. didiction*, *P. pleuraperiousios*, *Parariscus octoporalis*, *Lophocythere scabra*, *Fuhrbergiella archangel-*

skyi, and *Fastigatocythere interrupita directa*. The first four species are the most typical for this subzone.

As well, the Callovian species *Gallaecytheridea prodromas*, which was identified in the section of borehole 792, is quite similar to *G. franzy* Tes., which is also common in precisely this subzone. The species *Acantocythere* (*P.*) *nikitini* is found in the Lower Callovian of the RP and common in the underlying Subpatruus Subzone of the Elatmae Zone. Ostracods *Cytheridea coarctata*, *Procytheridea czestochowiensis*, *Infracytheropteron pseudoelegans* and *Amphicytherura* sp. 1 are even older and are known in the Middle and Upper Bathonian deposits of England, Poland, Germany, and Normandy. Hence, according to the complex of ostracods from borehole 792 (the Gomel prospecting object) the sediments of the 283–344 m depth interval should be ascribed to the Lower Callovian, ostracod zone Palaeocytheridea (M.) parabakirovi, subzone Pr. wartae–Pl. kurskensis.

The ostracod complex was formed under conditions of mixing Tethyan and Arctic waters, with considerable dominance of warm waters. An Arctic contribution is proven by the presence of the genus *Camptocythere*, while the genera *Parariscus*, *Pleurocythere*, *Acantocythere*, *Praeschuleridea*, *Palaeocytheridea*, and *Galliaecytheridea* are considered to be typically Tethyan (Tesakova, 2014a, b). Since among the studied ostracods the majority of taxa have valves of medium and large sizes (0.5–0.9 mm) it is possible to confidently assume that they lived at a shallow depth, which did not exceed 40–50 m. Considering the relatively narrow diversity of the complex the upper limit was presumably below 15–20 m (Tesakova, 2014b). The ostracods from the 283–288 m interval demonstrate that normal marine salinity occurred here. A morphofunctional analysis of their valve sculpture suggests that the ostracods inhabited muddy–sandy ground under conditions of moderate hydrodynamic influence and normal saturation of the near-bottom waters with oxygen.

CONCLUSIONS

The paleoecological and paleogeographical reconstructions of the natural environments of the southwest of Belarus in the Bathonian–Oxfordian Ages that were carried out using different techniques demonstrate not only good agreement with each other but also with the conclusions of earlier studies (Sazonova and Sazonov, 1969), while considerably supplementing and examining them. We note that the conjugate analysis of the geochemistry, facies, and sedimentology of the studied section, in conjunction with the paleontological data that was obtained independently on macrofauna and microfauna, greatly increases the reliability of such reconstructions. However, when using different methods for paleoenvironmental reconstructions one should aspire to a complex scheme of sampling for various types of analysis from each level of a section. Jurassic ostracods from the Belarus were determined and figured for the first time.

As a result of this study it was revealed that by the end of the Bathonian the lagoon conditions began to change gradually to marine ones in the southwest of Belarus; the salinity increased and the near-bottom waters were well aerated. At the end of the Bathonian–Early Callovian considerable erosion occurred as the result of a marine transgression that came from the north of Ukraine, which explains the above-described complex of facies. In the Early Callovian longitudinal currents dominated, affecting the paleogeographic conditions in the area of the Cis-Dniepr monocline and Pripyat depression; these conditions resembled those of a growing sea gulf. At the end of the early Callovian in the southwest of Belarus a normal marine regime was settled with depths from 15–20, but not exceeding 40–50 m, with calm hydrodynamic conditions and normal saturation of the near-bottom waters with oxygen. The water mass simultaneously experienced influences of the Arctic and Tethys oceans, nevertheless it was warm: the microfaunal complex contains both Arctic and Tethyan components with the clear dominance of the latter.

The complexes of the studied molluscs include migrants from the Middle Russian Sea, more often represented by deposit-feeders (more deep-water faunas) and immigrant taxa from of Western Europe and the DDD: as a rule the latter were suspension-feeders that inhabited shallower waters. The composition of the trophic groups of molluscs along the section indicates periodic changes of the sea level during the Early Callovian–Early Oxfordian, which is supported by facies analysis and geochemical data.

The growth or decrease of the number of taxa of migrating molluscs suggests strengthening or weakening of the links to various paleobasins of the East European Platform. Three chief migration routs are recognized for the Early Callovian: the Western Europe–Belarus, Middle Russian Sea–Belarus, and DDD–Belarus routes, which depended on marine currents and also eustatic variations of the sea levels. A steady connection between the Middle Russian Sea and the East Belarus paleobasin during the Early Oxfordian was found.

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