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Article

Biostratigraphy and sedimentary settings of the Bajocian-Bathonian beds of the Izhma River basin (European North of Russia)

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With 11 figures and 3 tables

Abstract: A comprehensive study of the Bajocian-Bathonian (Middle Jurassic) boundary beds in the basin of the Izhma River led to recognition of five lithological members. The lower sandstone member (0), recognised at the base of the visible section, contains only small bivalves. Based on the occurrence of the index species, Member I is referred to the Arcticus Zone (uppermost Upper Bajocian). Judging from its position in the section, Member II apparently corresponds to the Boreal Greenlandicus ammonite Zone (lowermost Lower Bathonian). Sandstone Member III, well characterised by macrofossils, corresponds to the Ishmae ammonite Zone (uppermost Lower Bathonian) and partly to the *Pachyteuthis tschernyschewi* belemnite Zone and the *Retroceramus bulunensis* bivalve Zone. Member IV, which contains only isolated belemnite rostra and microfauna is tentatively assigned to the Middle Bathonian. Based on microfossils, the upper four members belong to the *Trochammina* aff. *praesquamata* foraminiferal Zone. The sedimentary settings at the end of the Bajocian and Bathonian in the region studied are reconstructed. The macro- and microfaunal Upper Bajocian–Lower Bathonian assemblages from the basins of the Izhma River and the middle reaches of the Volga River (vicinity of Saratov) are compared.

Key words: Bajocian, Bathonian, Ammonoidea, Belemnoidea, Bivalvia, Foraminifera, Ostracoda, biostratigraphy, Pechorian North.

1. Introduction

For the first time, beds with *Arcticoceras* were established in European Russia, on the Izhma River (von Keyserling 1846), and were later traced in other Boreal regions, including East Greenland (Madsen 1904; Spath 1932), the Aleutian Islands, Canada, Alaska (Eichwald 1871; Imlay 1953; Frebold 1961), and northern and north-eastern Siberia (Pavlow 1914; Tuchkov 1954; Voronets 1962). At various times, these beds were assigned to the Lower Callovian (e.g., Sasonov 1957; Sachs 1976; Meledina 1987), or Upper or Middle Bathonian (Poulton 1987; Callomon 1993, 2003; Meledina 1994), until Mitta & Seltzer (2002, 2009) and Mitta et al. (2004, 2011) showed, based on the occurrences of the ammonite genera *Arcticoceras* and *Oraniceras* in the Boreal-Tethyan ecotone locality in the vicinity of Saratov, that these beds belong to the upper Lower Bathonian. Comprehensive studies in the Sokur Quarry and in the borehole in the same quarry near Saratov (Mitta et al. 2012b, 2014b), revealed the taxonomic composition of cephalopods, bivalves, and microfauna at the Bajocian and Bathonian boundary and allowed the reconstruction of the sedimentary settings. The biostratigraphic analysis of the faunal assemblages confirmed the correlation of the ammonite

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sub-Mediterranean (Fernández-López et al. 2009a, b) and Boreal scales of the previous decade. In addition, the ammonite zones were correlated with the Central Russian stratigraphic units based on belemnites, bivalves, and foraminifers.

The paper gives the results of the biostratigraphic and lithologic studies of the Bajocian-Bathonian transition beds of the Izhma River basin.

2. Historical background

As mentioned above, the first data on the Jurassic beds of the Izhma River were published by von Keyserling (1846). Later studies can be clearly divided into phases, based on periodical resumption of fieldwork.

The first stage is connected with general geological research in this region at the beginning of the last century (e.g., Pavlow 1909; Tchernyschew 1914). Descriptions of some ammonite (Sokolov 1912) and belemnite (Krimholz 1929) taxa were later published based on the material collected by these authors on the Izhma River.

The second stage included specialised palaeontological stratigraphic studies of the Middle Jurassic in the basin of the Izhma River in the 1950s-1970s by V.A. Gustomesov, V.S. Kravets, V.N. Sachs, S.V. Meledina, B.N. Shurygin, Y.S. Repin, S.P. Yakovleva and many others. As a result of the field research in the above region, descriptions of sections and/or ammonites and belemnites (Gustomesov 1960, 1964; Sachs & Nalnjaeva 1964, 1966, 1975; Sachs 1976; Meledina 1987, 1994; Meledina et al. 1998) were published, and data on stratigraphy and microfaunal and spore-pollen assemblages were provided (Kravets 1966; Chirva & Yakovleva 1982, 1983; Lev & Kravets 1982; Ilyina 1991; Kulikova 1993; Meledina & Zakharov 1996; Chirva et al. 1997). Results of this stage include summaries recently prepared by Yu.S. Repin and co-authors (Repin 2005, 2007; Repin et al. 2006, 2007).

The third, most recent stage, is related to field materials collected in the 21st century. The first studies of this stage (Mitta 2006, 2009) showed that not all intervals of the Bajocian-Bathonian were characterised by ammonites, or other macrofossils. In 2012 and 2013 several of the authors of this paper made a complex study of the sections in this region, VM (ammonites), LG (foraminifers and ostracods) and VK (sedimentology) (Mitta et al. 2013, 2014a). The materials collected during these two field trips were also studied by OD (belemnites), BSh (bivalves) and BN (foraminifers and ostracods).

3. Lithological characteristics of the sections

The fieldwork was conducted on the Dreshchanka River and near the Griva and Bychye Gorlo rapids of Izhma River (Figs. 1, 2). Middle Jurassic beds crop out on both banks of the multiple meanders of the Dreshchanka River (right tributary of the Izhma River). The Bajocian-Bathonian beds in this region are recognised as the Sysola Formation, represented by lithologically variable members. The lower member (Member 0, outcrops D-1, D-5), represented by grey pebbled-gravel sandstone, with visible thickness up to 0.2 m, is at the base of the section and is characterised by rare transitive bivalves. It is overlain by Member I (outcrops D-1, D-3, D-5), represented by the alternation of grey unconsolidated clayey-sandy and clayey-silty deposits, with a visible thickness of 2.6 m. Based on a single occurrence of *Arctocephalites arcticus* (Newton), this member belongs to the Boreal Arcticus Zone of the Upper Bajocian. The overlying member (II) is exposed in the same sections, is up to 2.7 m in thickness and is composed of dark-grey clay and clayey silts with an interbed of sand and sandstone. Based on its position in the section, this member is referred to the Lower Bathonian Greenlandicus Zone. It is overlain by member (III) of sandstone light-grey variously pebbled-gravel, calcareous, over 2 m thick with ammonites of the Lower Bathonian Ishmae Zone, including *Arcticoceras ishmae* (von Keyserling), *A. harlandi* Rawson, *Greencephalites* sp., bivalve shells, belemnite rostra, and large plant remains. Member III is visible in various states of completeness in outcrops along the Dreshchanka River (outcrops D-1 – D-9) and on the Izhma River near the Bychye Gorlo rapids (Outcrop I-2). Younger Jurassic deposits in the lower reaches of the Dreshchanka River are cut off, and the Lower Bathonian section is commonly overlain by Quaternary deposits.

The Lower Bathonian sandstone on the Izhma River downstream of the Griva rapids (Outcrop I-1) and in the middle reaches of the Dreshchanka River (Outcrop D-10), with an observational gap of 4-6 m, is overlain by member IV, represented by blue dark grey clay, up the section replaced by lighter-coloured clay, arenaceous-silty at the base, with rare arenaceous-gravel interbeds. At the top of the member there is a laterally inconsistent member of reddish-grey sand. The total visible thickness of Member IV under the layer of soil reaches 5.5 m. In the sections of the member dated presumably to the Middle Bathonian, of macrofossils there are only isolated belemnite rostra.

Fig. 1. Location of the Bajocian and Bathonian key sections in the Pechorian North (Izhma River basin) and Central Russia (Saratov area).

Below we give a detailed description of the generalised Bajocian-Bathonian section of the territory under investigation (Figs. 3, 4).

Upper Bajocian

The most complete Upper Bajocian is observed in outcrops D-1 and D-5 in the lower reaches of the Dreshchanka River. The visible portion of the lower member (0) is composed of grey weakly lithified sandstones variously grained with an admixture of rounded grains and pebble sizes, small inclusions of unidentifiable shell detritus and coalified plant remains. The sandstones are exposed directly in the riverbed forming small rapids at their places of exposure. The sandstones of Member 0 in the steep banks are overlain by sandy-silty-clayey member I, with a maximum thickness of 2.6 m. The appearance, composition and thickness of Member I are similar in all studied outcrops. The base of the member is composed of grey medium-grained compact argillaceous sands alternating with beds of dark grey clay and clayey silts. Upward in the section, the argillaceous sands are gradually replaced by dark-grey silty clays, with thin beds of silts and sands. The texture is horizontally-wavy and

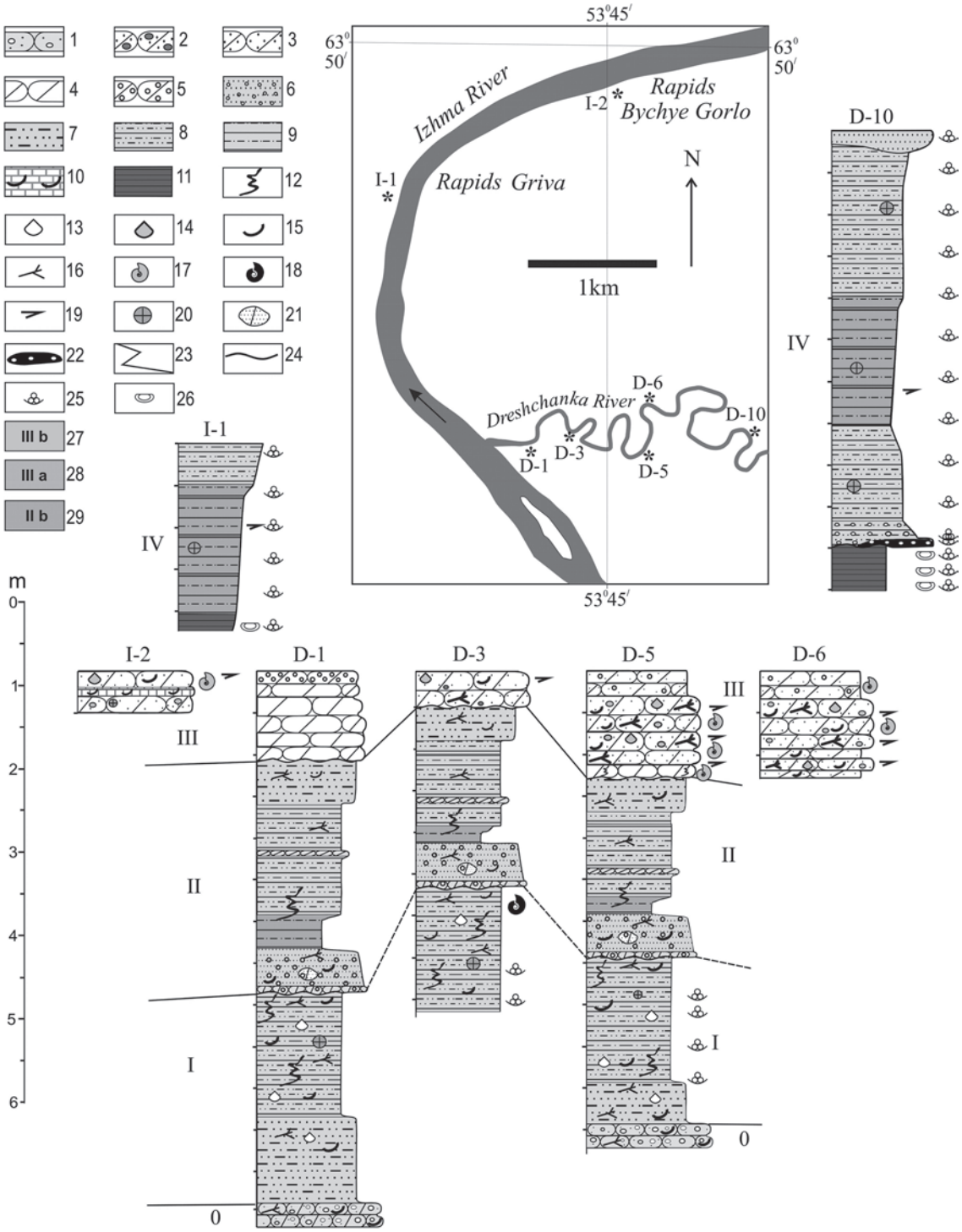

Fig. 2. Detailed map of the area under study and the most complete Bajocian-Bathonian sections. 1 – pebbled-gravel sandstone, 2 – pebbled-gravel calcareous sandstone, 3 – gravel calcareous sandstone, 4 – calcareous sandstone, 5 – calcareous sandstone with ferruginous ooliths, 6 – clayey sands with ferruginous ooliths, 7 – clayey sands, 8 – silty-sandy clay, 9 – silty clay, 10 –bioclastic limestone, 11 – plastic clay, 12 – bioturbation, 13 – complete valves of thin bivalve shells, 14 – complete thick bivalve shells or valves, 15 – fossil shell fragments, 16 – coalified plant organics, 17 – ammonites *in situ*, 18 – ammonites *ex situ*, 19 – belemnites, 20 – pyrite nodules, 21 – large sandy calcareous nodules, 22 – pyritized gravel sandstone, 23 – facies boundary, 24 – erosion bedding plane, 25 – foraminifers, 26 – ostracods, 27-29 – sublittoral bionomical zone: 27 – Inner part, Upper sublittoral zone (IIIb), 28 – Outer part, Upper sublittoral zone (IIIa), 29 – Inner part, Middle sublittoral zone (IIb).

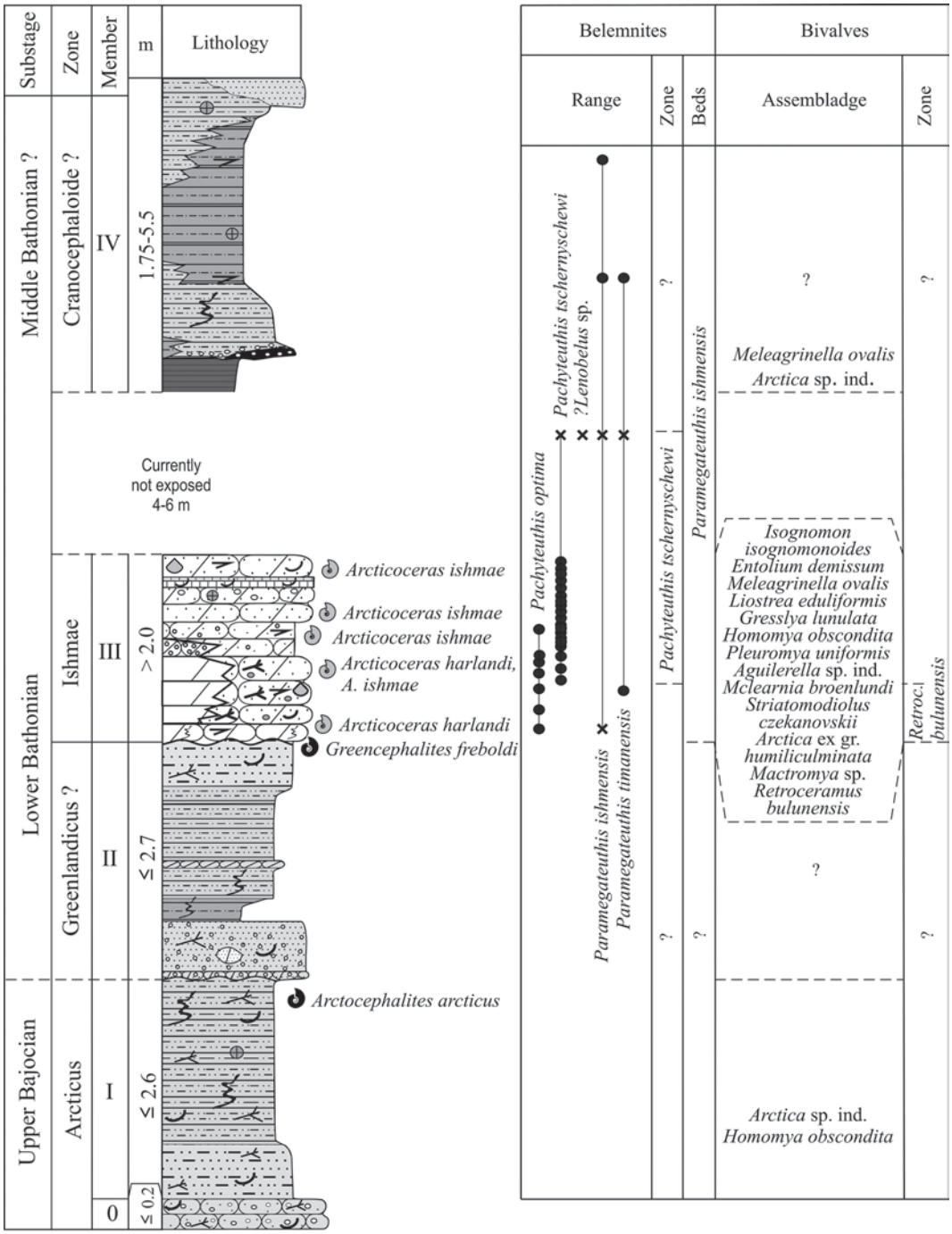

Fig. 3. The composite section of the Bajocian and Bathonian of Izhma River basin: distribution of cephalopods and bivalves (for legend see Fig. 2). Additional levels of belemnite records (see literature review in the text) are marked by crosses.

cross-bedded, often bioturbated. These beds contain infrequent shells of small bivalves, fragments of their valves, coalified plant detritus, and also small (up to 5 cm) pyrite nodules.

Lower Bathonian

The Lower Bathonian is represented by two members, distinguished lithologically. The lower, sandy-silty-clayey member II, up to 2.7 m thick, overlies the

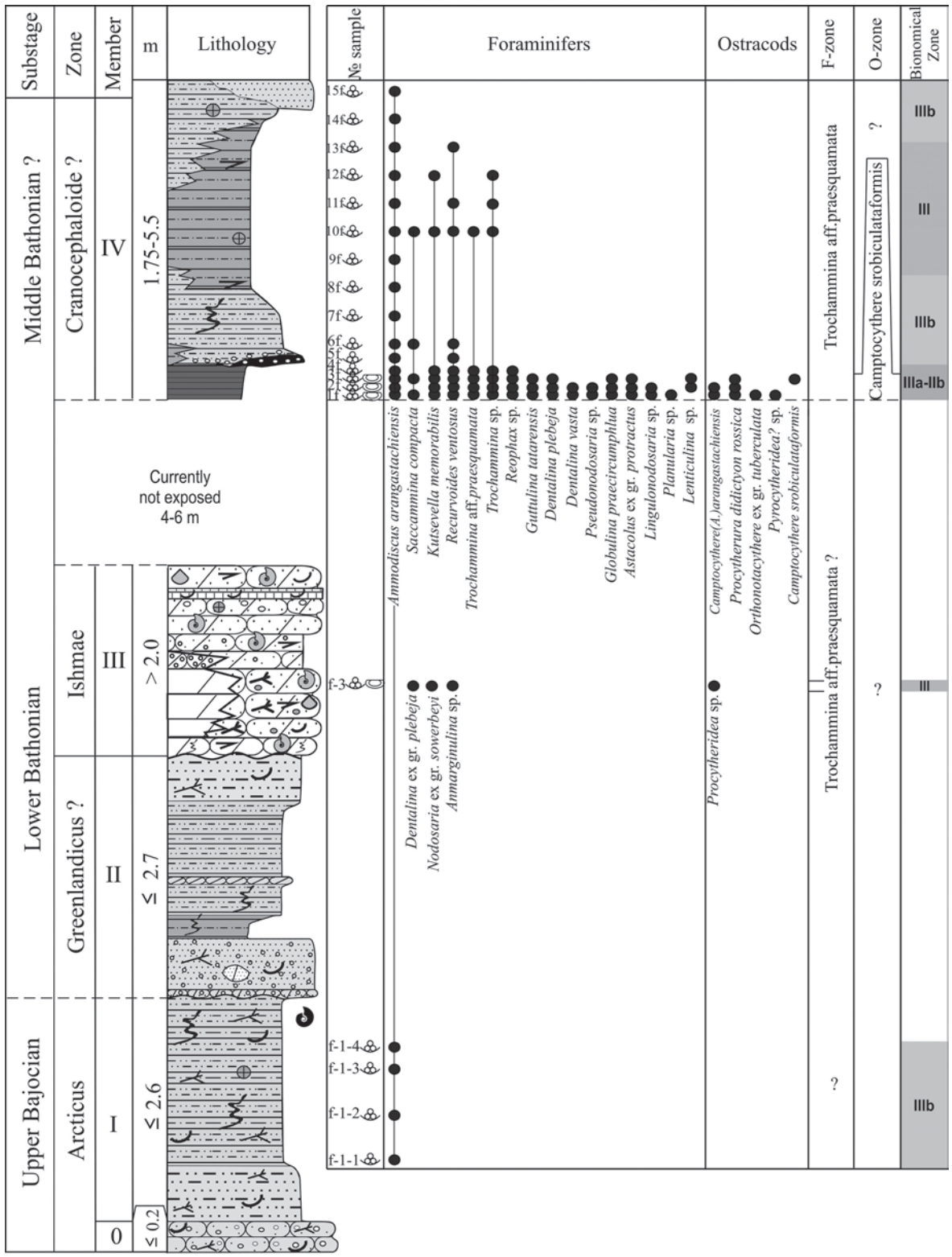

Fig. 4. The composite section of the Bajocian and Bathonian of Izhma River basin: distribution of foraminifers and ostracods (for legend see Fig. 2).

Bajocian beds conformably, with slight traces of erosion. The member is observed in outcrops D-1, 3, 5 in the steep left bank of the Dreshchanka River and is characterised by consistent composition and thickness. The member is represented by irregular alternation of sand and sandstone, silt and clay. The basal part of the member is composed of grey medium-grained calcareous sandstone. The base is composed of sandstone with ferruginous ooliths. The sandstone is overlain by clayey oolitic sand with rare fragments of bivalve shells, fragments of coalified plant debris, and large (up to 20 cm) pyrite nodules. The sands are overlain by dark-grey dense clay, up the section becoming lighter coloured, sandy clay with thin layers of silt, sand, and calcareous sandstone. The beds contain small coalified detritus. The texture is horizontal or horizontally wavy, less commonly small-scale cross-bedded, sometime bioturbated. The upper part of the member is composed of grey fine-grained clayey sands, with inclusions of bivalve shells fragments and fragments of coalified plant remains.

Member III, over 2 m thick, is represented by light-grey calcareous sandstone overlying the sand of member II with a distinct erosional bedding plane. The member forms ledges in steep riverbanks and rapids in the riverbeds of the Dreshchanka and Izhma rivers. The base of the member (in outcrops D-1, 3, 5) is horizontal, weakly eroded, and is very distinct. In the area studied, the member shows facies variations. In outcrops D-3 – D-9 on the Dreshchanka River, the member is composed of variously grained pebbled-gravel calcareous sandstone with numerous faunal remains and large (up to 0.5 m) fragments of coalified plant remains. The visible thickness of the sandstone outcrops is 0.5-1.3 m. To the west, near the mouth of the Dreshchanka River, the exposed D-1 member is composed of well-sorted medium-grained calcareous cross-bedded sandstone (0.9 m), in the upper part with a bed of 0.1 m of ferruginous ooliths. Faunal and plant remains are absent in this locality. In Outcrop I-2 on the Izhma River, 2.5 km to the northeast of the mouth of the Dreshchanka River, in a slightly more elevated site (0.5 m higher), the member is replaced by pebbled-gravel calcareous sandstone forming a large rapid Bychye Gorlo in the riverbed of the Izhma River. Here the sandstone contains a thin (up to 0.05 m) bed of bioclastic limestone. The sandstone contains infrequent faunal remains.

Middle? Bathonian

Beds that we tentatively assign to the Middle Bathonian are represented by sandy-clayey series of consistent facies, forming member IV with a visible thickness of up to 5.5 m. The riverbank sections on the Dreshchanka River (D-10) and Izhma River (I-1), after a gap in observation from 4 to 6 m above the sandstone of member III, contain light-blue-dark-grey plastic clay with rare inclusions of fine coaly detritus (the visible thickness is 0.3-0.5 m). In Outcrop I-1 on the left bank of the Izhma River, up the section, clays are gradually replaced by silty clay series with horizontally inconsistent beds and nests of light-brown silt and sand in its upper part. In an outcrop on the right bank of the Dreshchanka River (D-10), 3 km to the southwest, the clays are unconformably overlain by thin (0.3 m) layers of grey arenaceous clay with gravel inclusions. The basal horizons of the bed contain pyritic nodules, laterally becoming pyritized sandstone. Up the section, the gravel-pebbled material is absent, and the quantity of the arenaceous material in the clay gradually decreases. Most of member IV is composed of grey arenaceous-silty clay and dark-grey silty clay up to 1.5 m, with rare pyrite nodules. The top of the member (up to 0.3 m), observed under the soil is represented by reddish-brown strongly ferruginous sands and possibly also belongs to the Jurassic part of the section.

4. Biostratigraphy

The Bajocian-Bathonian sections in the Izhma River basin are very inconsistently characterised by ammonites. The only specimen of *Arctocephalites arcticus* (Newton), found earlier *ex situ* (Mitta 2006; 2009) in Outcrop D-3 remains the only substantiation of the assignment of member I to the Arcticus Zone. So far no ammonites (or other fossils, including microfauna) have been found in member II; this interval is referred to the Greenlandicus Zone only tentatively, based on the position in the section. No ammonites have been found in member IV either. The sandstone of member III is the most completely characterised by ammonites (and other macrofossils).

After Keyserling (1846) and Sokolov (1912), who published descriptions of several specimens of *Arcticoceras ishmae* (von Keyserling), a monograph by Medelina (1987) was the most important publication on the Bathonian ammonites of the Pechora Basin. The monograph contains descriptions and illustrations of *A. ishmae* (von Keyserling), *A. kochi* Spath, *A. excentricum* Voronets, *A.* aff. *cranocephaloide* Callomon, and *A. harlandi* Rawson. In our opinion

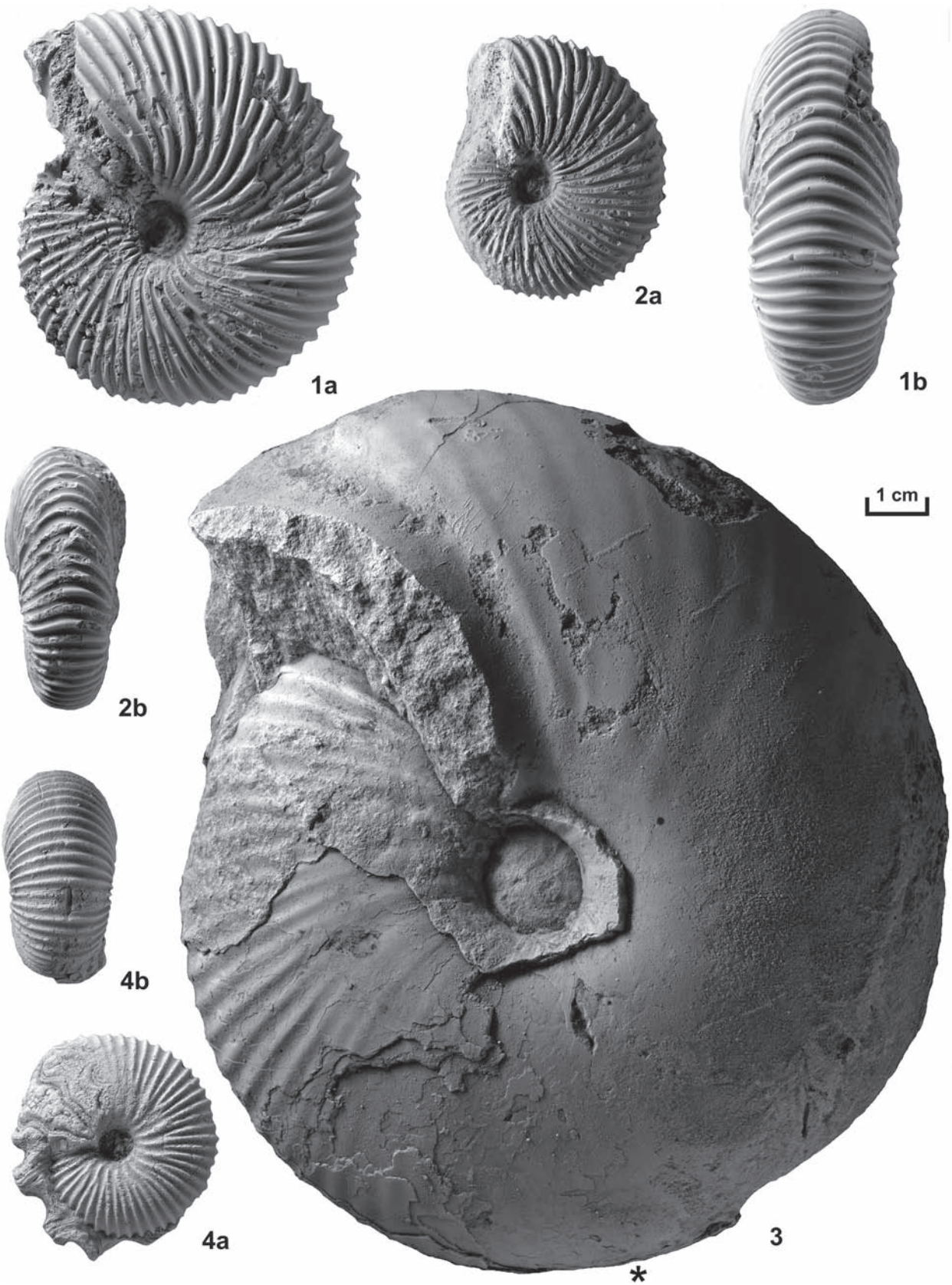

Fig. 5.

(Mitta & Seltzer 2002; Mitta 2009) all species of *Arcticoceras* figured in this and later works (Repin et al. 2006) belong to variations of two species, *A. ishmae* and *A. harlandi*, and come from the sandstone of member III (Ishmae Zone). The two species from the same interval in a section in the basin of the Izhma River were figured previously (Mitta & Seltzer 2002; Mitta 2009; Mitta et al. 2013, 2014a).

The interval of member III corresponds in the boreal scale to two biostratons, the Harlandi and Ishmae (zones, according to Poulton 1987; Meledina 1994). Callomon (1993) recognised the Ishmae Zone including the *harlandi*, *ishmae* alpha, beta and gamma horizons. Our observations on the Dreshchanka River show that *A. ishmae* is indeed usually found in the upper part of the member; but on the Izhma River (Bychye Gorlo rapid) both index species are found in the same level (Figs. 5.3, 6.3). Accordingly, in this region, we recognise the single Ishmae Zone corresponding to member III, without further subdivision. The previous workers (Meledina 1987, 1994; Repin et al. 2006) also did not subdivide the beds with *Arcticoceras* in the basin of the Izhma River. It is noteworthy that in the Sokur section in the vicinity of Saratov (e.g., Mitta & Seltzer 2002; Mitta et al. 2014b), the succession *A. harlandi* → *A. ishmae* is relatively well recognised, and the intervals of distribution of these species do not overlap.

An ammonite specimen identified as *Arctocephalites freboldi* (Spath) was earlier figured from the base of member III (Mitta 2009). Repin et al. (2007) designated this species as the type species of their new genus *Greencephalites*. According to Repin, apart from the type species, the genus included two species, previously described from the Yukon Territory (*Arctocephalites*? *belli* Poulton in Poulton 1987, pl. 17, figs. 1-3 [= *Greencephalites belli* (Poulton)]) and the vicinity of Saratov (*Arctocephalites* ex gr. *freboldi* in Mitta & Seltzer 2002, pl. 4, fig. 1 [= *Greencephalites* sp. nov.]).

The study of the collections from the "Boreal Bathonian" of East Greenland, mainly collected by J.H. Callomon and T. Birkelund and housed in the Museum of Natural History of Copenhagen confirmed the independent status of the genus *Greencephalites* (Mitta & Alsen 2013, 2014). In addition, an ammonite specimen was found in the Sokur section, in the vicinity of Saratov, agreeing in shell shape and ornamentation morphogenesis to the species *Greencephalites belli* (Poulton) (Fig. 7). A juvenile specimen of an ammonite species belonging to the same genus was found on the talus of member III on the Dreshchanka River (Outcrop D-5) in 2013 (Mitta et al. 2014a; here Fig. 5.4). The above shows that the recent studies did not provide any new data which could have changed our previous ammonite zonal scheme (Mitta 2009). Changes in the nomenclature of ammonites do not affect ammonite-based correlation.

The taxonomic studies of belemnites from the Bathonian of the Izhma River basin began over 85 years ago. The first studies were published by Krimholz (1929), who described the species *Cylindroteuthis tschernyschewi* [= *Pachyteuthis tschernyschewi* (Krimholz)] from the "Callovian" of the Izhma River (Razlivnoi Rapid, Vinla village). The distribution of this species in the Ishmae Zone in this region can now be considered as confirmed (Sachs 1976; Nalnjaeva 1989; Gustomesov 1990; Meledina et al. 1998). The description and/or illustrations of *P. tschernyschewi* are also present in works of Gustomesov (1964), Sachs & Nalnjaeva (1966), Nalnjaeva (1989), Meledina et al. (1998), Repin et al. (2006), Mitta et al. (2014a). Gustomesov (1964) indicated that the rostra of *P. tschernyschewi* come from the coarse-grained sandstone and the overlying black clay on the Izhma River (Razlivnoi Rapid). We identified 23 specimens of this species from several localities (I-2: 3 specimens, D-4: 2 specimens, D-5: 1 specimen, D-6: 10 specimens, D-7: 1 specimen, uncertain localities: 6 specimens) and only from the sandstone of member III (Figs. 3, 8.1). Apparently, part of the section between the Griva and Razlivnoi rapids (near section I-1) is no longer available for study: sandstone (visible thickness 0.5 m)

Fig. 5. Lower Bathonian Ishmae Zone ammonites from the Izhma River Basin (member III); scale bar 10 mm. **1 –** *Arcticoceras ishmae* (von Keyserling, 1846), phragmocone, a: lateral view; b: ventral view; Dreshchanka River, section D-9; PIN RAS 5029/148. **2 –** *Arcticoceras ishmae* (von Keyserling, 1846), phragmocone, a: lateral view; b: ventral view; Dreshchanka River, section D-9; PIN RAS 5029/149. **3 –** *Arcticoceras ishmae* (von Keyserling, 1846), adult shell with a complete body chamber and preserved aperture, lateral view; Izhma River, rapids Bychye Gorlo; PIN RAS 5029/150; the beginning of the body chamber is marked by an asterisks. **4 –** *Greencephalites* sp. juv., phragmocone, a: lateral view; b: ventral view; Dreshchanka River, section D-5, *ex situ*; PIN RAS 5029/151.

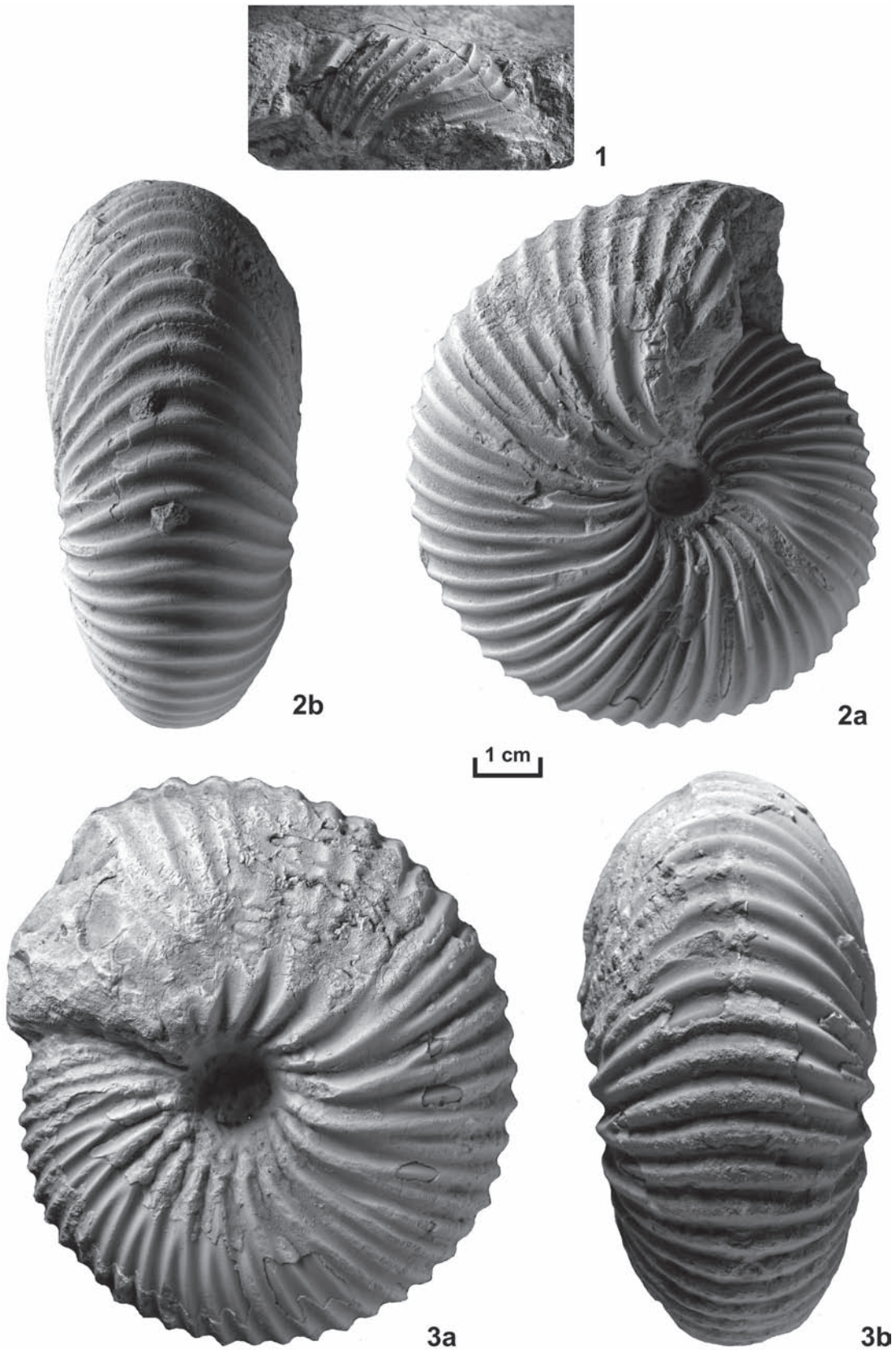

Fig. 6.

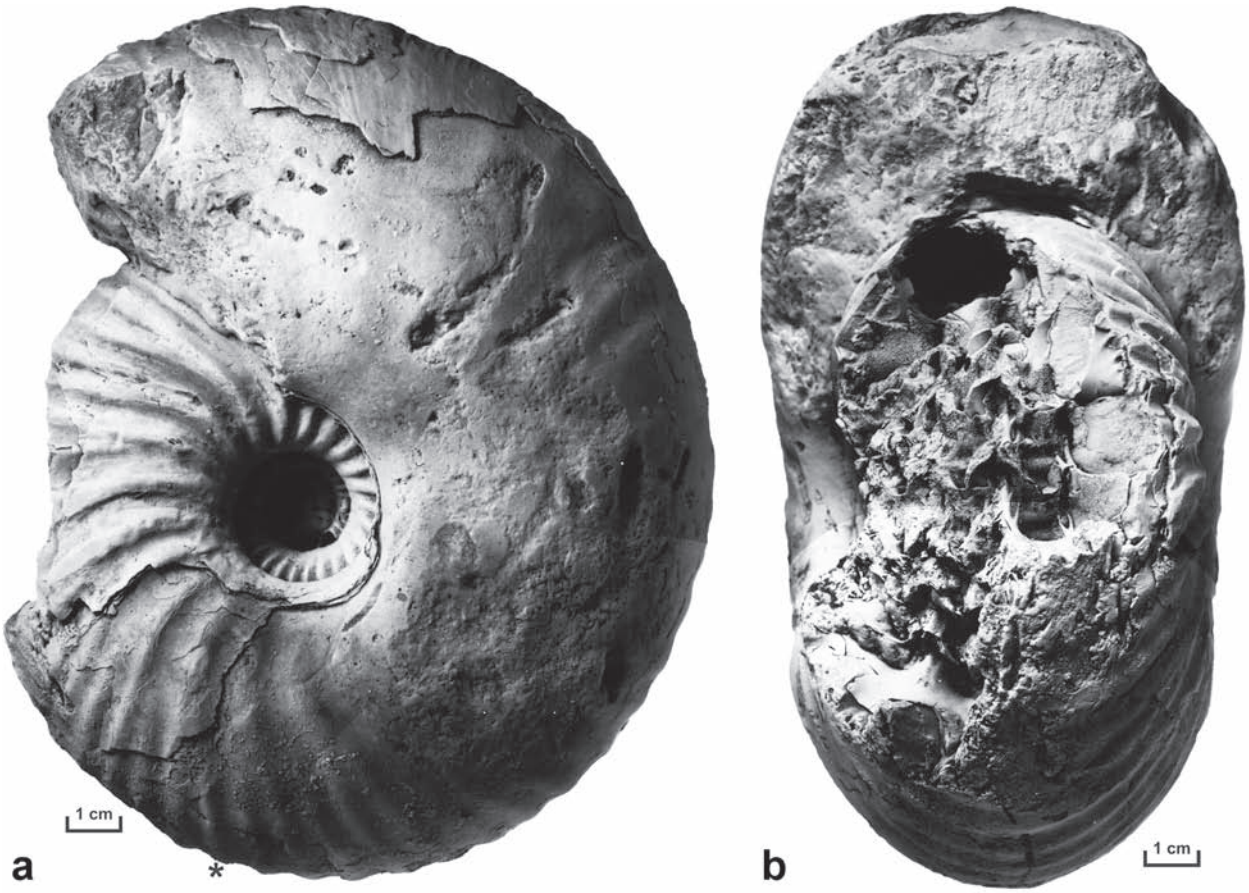

Fig. 7. *Greencephalites belli* (Poulton, 1987), adult specimen with body chamber, a: lateral view; b: ventral view; Sokur Quarry, Saratov, Central Russia; Lower Bathonian (*ex situ*); PIN RAS 5029/155.

with *Arcticoceras* and overlying dark-grey clay (visible thickness 1.0 m) with large belemnite rostra were indicated from here by Meledina and Shurygin (field observation of 1972).

P. tschernyschewi is the most abundant belemnite in the sections, occurring throughout almost entire member III and in the previously recognised basal horizons in member IV. Therefore following Nalnjaeva (in Meledina et al. 1998) we assigned the upper part of the *Arcticoceras*-bearing beds (i.e., the upper part of member III) to the *P. tschernyschewi* belemnite Zone, which in Siberia corresponds to the Ishmae ammonite Zone, which in this region does not include the interval with *Arcticoceras harlandi* (Meledina et al. 1991; Shurygin et al. 2000, 2011; Nikitenko et al. 2013). The lower part of member IV (now covered by talus) is also tentatively assigned to this belemnite zone (Fig. 3).

The black clay near the Razlivnoi Rapid on the Izhma River, according to Gustomesov (1960), also contains *Paramegateuthis ishmensis* (Gustomesov) and *P.*

Fig. 6. Lower Bathonian Ishmae Zone ammonites from the Izhma River Basin (member III); scale bar 10 mm. **1** – *Costacadoceras bluethgeni* Rawson, 1982 [= microconch of *Arcticoceras*], final part of the body chamber with preserved aperture; Izhma River, rapids Bychye Gorlo; PIN RAS 5029/152. **2** – *Arcticoceras ishmae* (von Keyserling, 1846), phragmocone, a: lateral view; b: ventral view; Dreshchanka River, section D-9; PIN RAS 5029/153. **3** – *Arcticoceras harlandi* Rawson, 1982, phragmocone, a: lateral view; b: ventral view; Izhma River, rapids Bychye Gorlo; PIN RAS 5029/154.

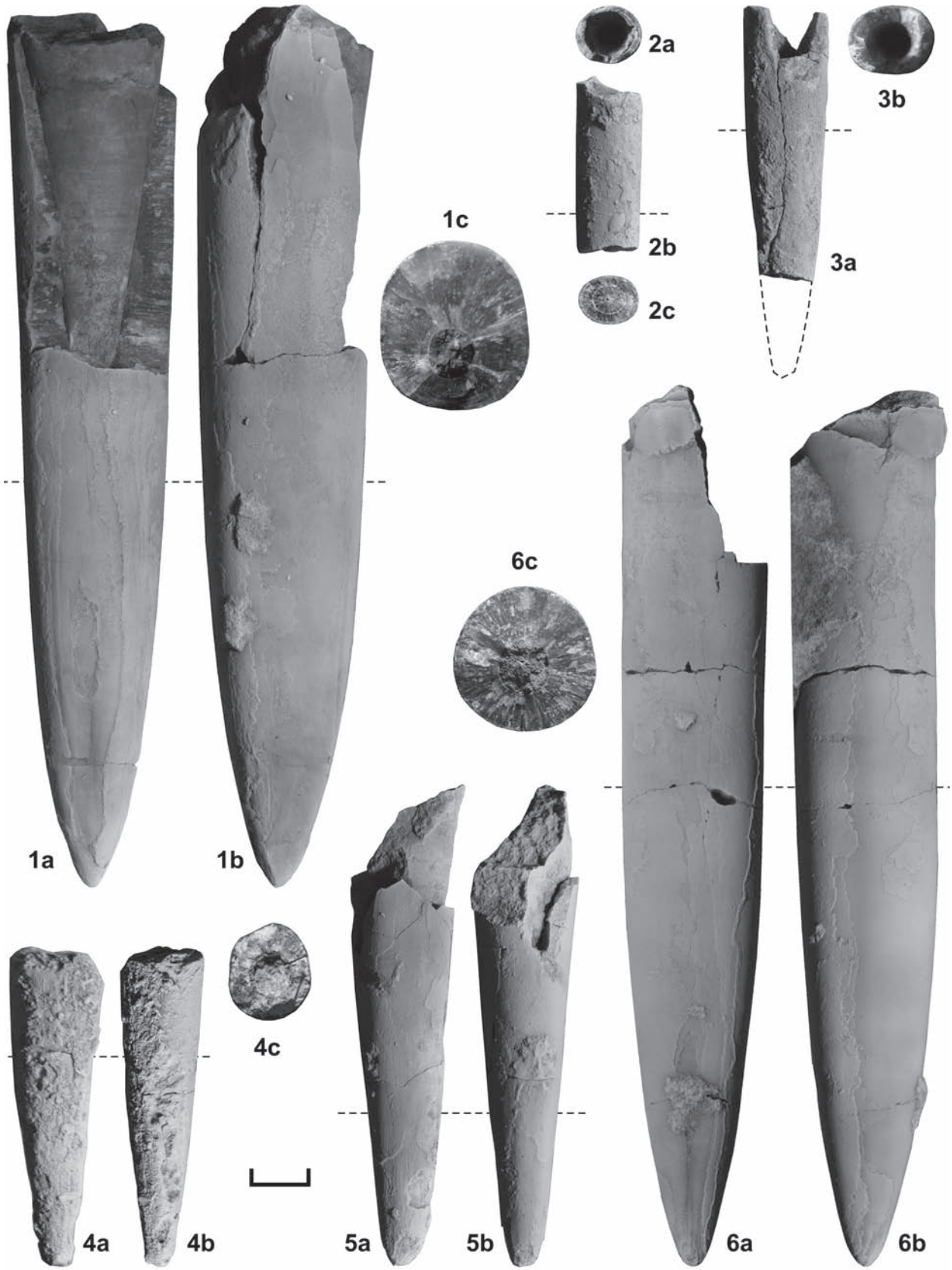

Fig. 8.

timanensis (Gustomesov). In total five specimens of *P. ishmensis* (Gustomesov 1960; Sachs & Nalnjaeva 1975; Meledina et al. 1998) and two specimens of *P. timanensis* (Gustomesov 1960; Repin et al. 2006) have been recorded previously from the basin of the Izhma River. The study of museum collections shows that only two rostra of *P. ishmensis* (Sachs & Nalnjaeva 1975, pl. 11, fig. 3; Meledina et al. 1998, plate-fig. 4) come from member III (the basal horizons, according to Meledina et al. 1998), all other members of this genus apparently come from the overlying clay. We identified *P. ishmensis* (Fig. 8.2, 8.3) from member IV (I-1: 1 specimen; D-10: 1 specimen), whereas *P. timanensis* (Fig. 8.4, 8.5) was found in both members III (D-5: 1 specimen) and IV (I-1: 1 specimen). Evidently, these species are very rare in the basin of the Izhma River. In the literature on Spitzbergen, Siberia, and the Far East (e.g., Sachs & Nalnjaeva 1975; Sachs 1976; Meledina et al. 1987, 1991; Challinor et al. 1992; Nalnjaeva et al. 2011), *P. ishmensis* and *P. timanensis* are recorded at various levels within the interval of the Upper Bajocian-Bathonian in its current interpretation. Apparently, not only the geological age of the localities, but also the taxonomic affinity of some of these belemnites require revision. For instance, a specimen of *P. ishmensis* (Nalnjaeva 1974, pl. 8, fig. 4; = Sachs & Nalnjaeva 1975, pl. 11, fig. 1), found together with the early *Arctocephalites* on the western coast of the Anabar Bay (Sachs 1976), has closely spaced, long and distinct dorsolateral grooves, not at all typical of *P. ishmensis*, but commonly found in a closely related species *P. manifesta* Nalnjaeva. Recent studies in northern Siberia, on the Yuryung-Tumus Peninsula (Dzyuba, unpublished data) showed clearly that both *P. ishmensis* and *P. timanensis* are restricted to the lower half of Bathonian. Here they simultaneously appear above the Arcticus Zone within the undivided *Retroceramus polaris – R. bulunensis* bivalve Zone. The species *P. ishmensis* was also found in the overlying *Retroceramus vagt* Zone. Unfortunately, on the Yuryung-Tumus Peninsula, the rock series with these belemnites supposedly embracing the interval from the aff. Greenlandicus to the Ishmae Zone and possibly above, contains few ammonites (Nikitenko et al. 2013). The *R. vagt* bivalve Zone in the Siberian zonal scale corresponds to the Ishmae – Cranocephaloide ammonite zones (Shurygin 2005; Shurygin et al. 2011; Nikitenko et al. 2013), i.e., the upper part of the Lower Bathonian and Middle Bathonian. In the basin of the Izhma River, like in northern Siberia, LAD (last appearance datum) of *Paramegateuthis timanensis* is lower than that of *P. ishmensis*, and therefore the assignment of member IV (beginning from the visible base) to the Middle Bathonian does not contradict the existing data on belemnites.

According to Sachs & Nalnjaeva (1964, 1966), the earliest belemnite assemblages from the basin of the Izhma River contain *Communicobelus subextensus* (Nikitin), *Holcobeloides hemisulcatus* Sachs & Nalnjaeva, *Pachyteuthis optima* Sachs & Nalnjaeva and *P. bodylevskii* Sachs & Nalnjaeva, which later, together with two other species, *Holcobeloides beaumontianus* (d'Orbigny) and *Pachyteuthis subrediviva* (Lemoine), are commonly included in taxonomic list of belemnites from the Ishmae ammonite Zone (e.g., Sachs 1976; Nalnjaeva 1983, 1986, 1989; Meledina 1987; Repin 2005; Repin et al. 2006: 6-9, non table 2, pp. 48-49). Based on the revision of old collection from the basin of the Izhma River (coll. of Kravets 1959 and Meledina 1972) Nalnjaeva (in Meledina et al. 1998) concluded that of these taxa only *Pachyteuthis optima* is actually found in the Ishmae Zone. All other listed species are typical of the Upper Bathonian–Callovian, as is also reflected in a recently published work (Repin et al. 2006, table 2, pp. 48-49). We also found *P. optima* (Fig. 8.6) in Member III (D-4: 2 specimens; D-5: 2 specimens; D-6: 3 specimens). It is noteworthy that *P. bodylevskii*, co-occurring with *P. optima* in the Lower

Fig. 8. Lower-Middle Bathonian belemnites from the Izhma River Basin; scale bar 10 mm; dash line shows level position of the tip of the alveolus. 1 – *Pachyteuthis tschernyschewi* belemnite Zone; 2–4 – uppermost *Paramegateuthis ishmensis* belemnite Beds; 5, 6 – lowermost *P. ishmensis* belemnite Beds. **1** – *Pachyteuthis tschernyschewi* (Krimholz); Dreshchanka River, section D-4; CSGM 256/24: a – ventral view, b – right lateral view, c – cross section in the alveolar region; **2, 3** – *Paramegateuthis ishmensis* (Gustomesov): 2 – Dreshchanka River, section D-10; CSGM 256/25: a – cross section at the anterior end, b – lateral view, c – cross section at the broken end; 3 – Izhma River, rapids Griva, section I-1; CSGM 256/26: a – lateral view, b – cross section at the anterior end; **4, 5** – *Paramegateuthis timanensis* (Gustomesov): 4 – Izhma River, rapids Griva, section I-1; CSGM 256/27: a – lateral view, b – dorsal or ventral view, c – cross section at the anterior end; 5 – Dreshchanka River, section D-5; CSGM 256/28: a – right lateral view, b – dorsal view; **6** – *Pachyteuthis optima* Sachs & Nalnjaeva; Dreshchanka River, section D-5; CSGM 256/29: a – ventral view, b – right lateral view, c – cross section in the alveolar region.

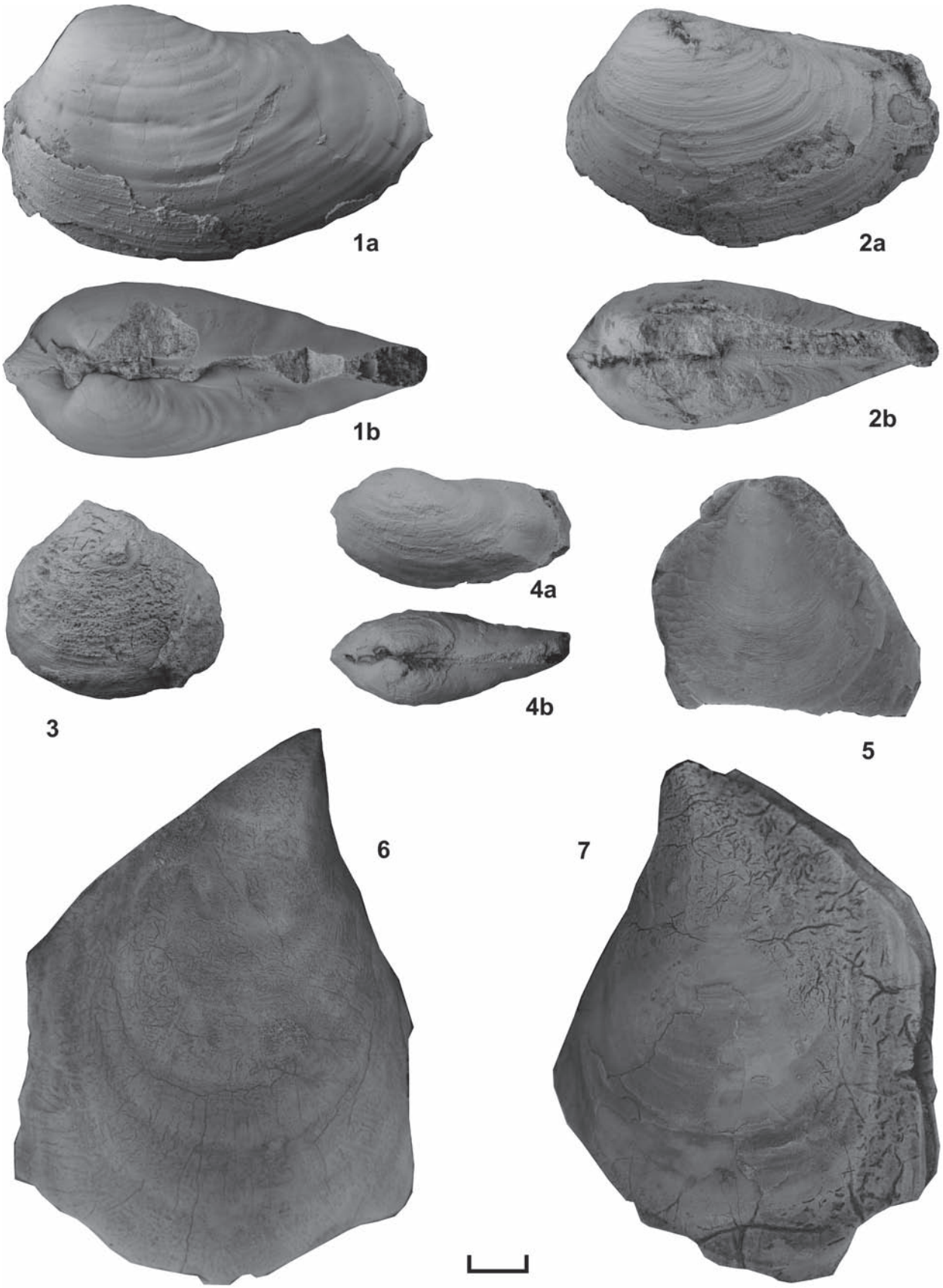

Fig. 9.

Bathonian (up to the Harlandi–Ishmae Subzone transition) of Central Russia (Mitta et al. 2014b) is absent in the Ishmae Zone of studied region. The identification of the only figured specimen of *P. bodylevskii* from the Middle Callovian of the Izhma River (Sachs & Nalnjaeva 1966, text-fig. 5) is doubtful. The study of this specimen showed that the rostrum is rounded by abrasion. *P. bodylevskii* is not characteristic of the Callovian Stage (Mitta et al. 2014b).

A fragment of a subhastate, slightly depressed rostrum, which Nalnjaeva identified as *Belemnopsis* sp. ind. (Meledina et al. 1998, plate-fig. 5; = Repin et al. 2006, pl. 52, fig. 2) is a unique occurrence in the *Pachyteuthis tschernyschewi* Zone. However, in comparison with true representatives of the Tethyan genus *Belemnopsis* (or *Pachybelemnopsis* in many publications) the ventral groove of belemnite from the Izhma River basin starts at the apex, initially deeply incised, later expanding and flattening. Judging from the characters the rostrum can belong to the genus *Lenobelus* (Pseudodicoelitidae), the last representatives of which (*L.* cf. *viligaensis* Sachs) is known from Kong Karls Land (Svalbard) both below the occurrences of *Arcticoceras* (Passet Member), and probably together with *Arcticoceras* (within the basal beds of the Dunérfjellet Member) (Doyle & Kelly 1988). Uncertain generic affinity of this belemnite also results from the absence of the anterior part of the rostrum and consequently it is not possible to confirm that the dorsal groove typical of the Pseudodicoelitidae was present in this specimen. Another specimen of *Belemnopsis* sp. ind. (Meledina et al. 1998, plate-fig. 6; = Repin et al. 2006, pl. 52, fig. 3), representing the apical region of a small, compressed rostrum, most likely belongs to the genus *Pachyteuthis*. Judging from the information on the label, both rostra were found by Meledina and Shurygin in 1972 on the Izhma River in an outcrop between the Griva and Razlivnoi rapids, together with *Pachyteuthis tschernyschewi* (Krimholz).

In general, belemnites in members III and IV are represented by Boreal genera from the following families: Cylindroteuthididae (*Pachyteuthis*), Megateuthididae (*Paramegateuthis*) and supposedly Pseudodicoelitidae (*Lenobelus*). Our observations confirm the recognition of units with belemnites in the basin of the Pechora River, the *Paramegateuthis ishmensis* Beds and *Pachyteuthis tschernyschewi* Zone (Meledina et al. 1998). In contrast to the scheme accepted here, the *Paramegateuthis ishmensis* Beds were restricted to the lower part of *Arcticoceras*-bearing beds.

Comparison of the Lower Bathonian belemnite assemblages from all studied outcrops to those from the Sokur section in the vicinity of Saratov (Mitta et al. 2014b) suggests that the middle part of the Lower Bathonian (interval corresponding to the Central Russian belemnite Beds with *Pachyteuthis optima* and *P. bodylevskii*) was eroded in the basin of the Izhma River. Both index species are very abundant in the interval of the upper part of the Besnosovi Zone – Harlandi Subzone of the Ishmae Zone in the Sokur Quarry, whereas in the basin of the Izhma River, occurrences of *P. optima* are rare (Fig. 3). *P. bodylevskii* is absent in the sections studied. It is difficult to imagine that this typically Arctic species spread south, to the region of Saratov, not via the Pechora Basin. Unfortunately, in the key sections on the Dreshchanka River, in which we could observe the contact of member III with the underlying beds, and in which it is possible to recognise the lower part of the Ishmae Zone, belemnite occurrences are either very rare (D-3: field observation only; D-5), or absent (D-1). In the basin of the Izhma River other Early Bathonian species established in the Sokur Quarry – *Paramegateuthis bella* (Barskov) and *P. papabella* (Barskov) are also absent, but this could be because of their endemism. Thus, except *Pachyteuthis optima*, the assemblages of the localities under comparison have no belemnite species in common. In both sections, *P. optima* disappears within the Lower Bathonian.

The assemblages of Bajocian-Bathonian bivalves in basin of the Izhma River are still poorly studied. After description and illustration of some species of bivalves from the Jurassic beds of the basin of the

Fig. 9. Lower Bathonian bivalves from the Izhma River Basin (Ishmae Zone, member III); scale bar 10 mm. **1, 2** – *Pleuromya uniformis* (Sowerby); Dreshchanka River, section D-6: 1 – CSGM 256/30, both valves: a – left valve, b – dorsal view; 2 – CSGM 256/31, both valves: a – left valve, b – dorsal view; **3** – *Arctica* ex gr. *humiliculminata* Shurygin; Dreshchanka River, section D-6; CSGM 256/32, left valve; **4** – *Homomya obscondita* (Koschelkina); Dreshchanka River, section D-5; CSGM 256/33, both valves: a – left valve, b – dorsal view; **5** – *Entolium demissum* (Phillips); Dreshchanka River, section D-5; CSGM 256/34, left valve; **6, 7** – *Isognomon isognomonoides* (Stahl): 6 – Dreshchanka River, section D-5, CSGM 256/35, right valve; 7 – Dreshchanka River, section D-7, CSGM 256/36, left valve.

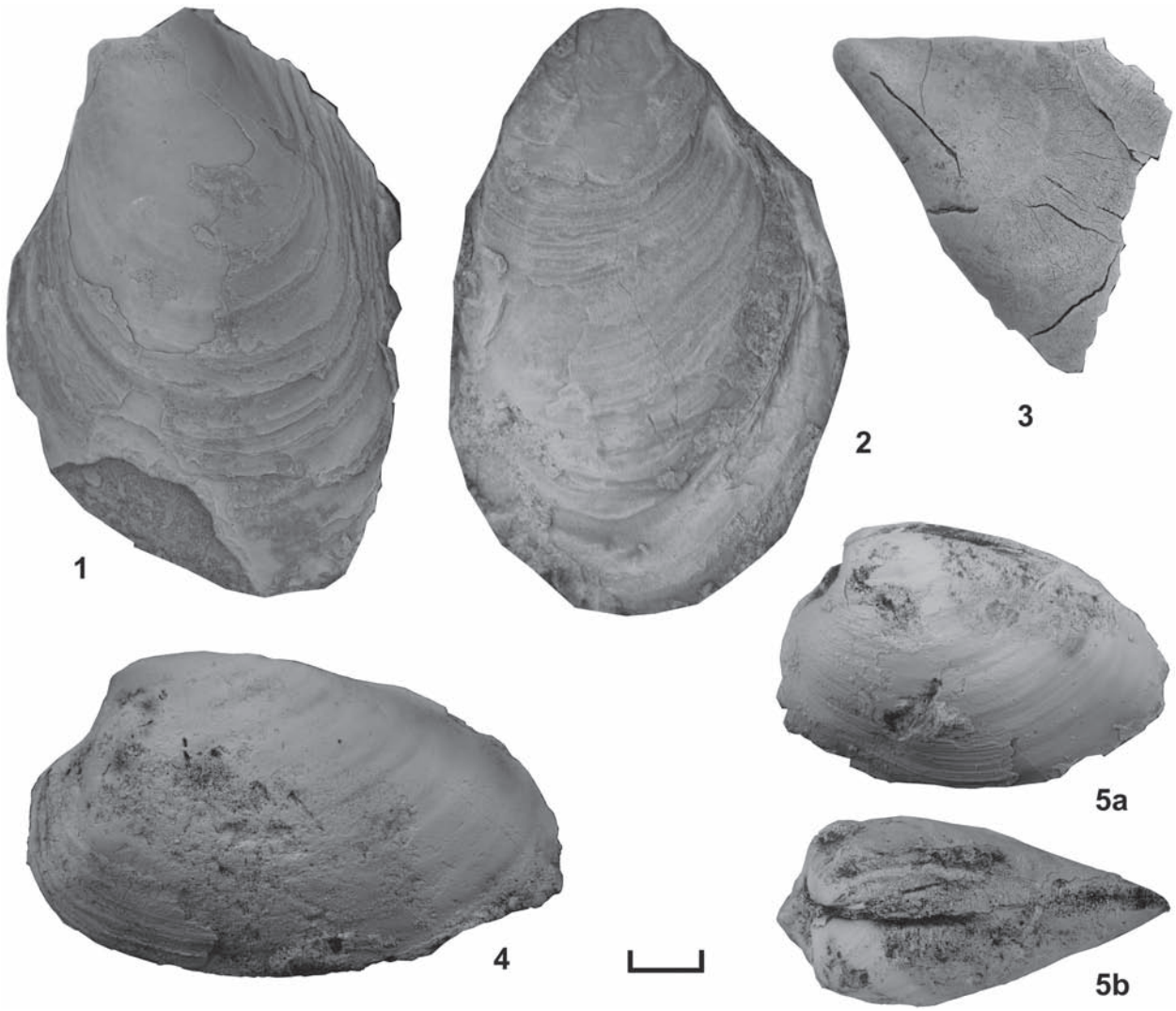

Fig. 10. Lower Bathonian bivalves from the Izhma River Basin (Ishmae Zone, member III); scale bar 10 mm. **1, 2** – *Retroceramus bulunensis* Koschelkina; Dreshchanka River, section D-6: 1 – CSGM 256/37, left valve; 2 – CSGM 256/38, deformed right valve; **3** – *Aguilerella* sp. ind.; Dreshchanka River, section D-5; CSGM 256/39, left valve; **4, 5** – *Gresslya lunulata* Agassiz; Dreshchanka River, section D-6: 4 – CSGM 256/40, left valve; 5 – CSGM 256/41, both valves: a – left valve, b – dorsal view.

Pechora River published by Keyserling (1846), the assemblages of bivalves from the Middle Jurassic of the Izhma River were only rarely mentioned in describing the Jurassic stratigraphy of this region (Sachs 1976; Meledina 1987, Meledina & Zakharov 1996; Repin et al. 2006).

The distribution of bivalves in the studied Bajocian-Bathonian sections in the basin of the Izhma River is very inconsistent. Some beds within Member I in Outcrop D-5 contain fragments of bivalve shells *Arctica* sp. ind. and rare small *Homomya obscondita* (Koschelkina), which are commonly found in the Bajocian-Bathonian beds of the Boreal sections. Bivalve shell fragments found in Member II (see the description of the section above) are not identified. The bivalve assemblage of Member III is the richest and most abundant. Outcrop D-5 contained *Isognomon isognomonoides* (Stahl), *Entolium demissum* (Phillips), *Meleagrinella ovalis* (Phillips), *Liostrea eduliformis* (Schlotheim), *Gresslya lunulata* Agassiz, *Homomya obscondita* (Koschelkina), *Pleuromya uniformis* (Sowerby), *Aguilerella* sp. ind. Bivalve as-

semblage from Member III, exposed in Outcrop D-6, contained *Mclearnia broenlundi* (Ravn), *Entolium demissum*, *Meleagrinella ovalis*, *Liostrea eduliformis*, *Striatomodiolus czekanovskii* (Lahusen), *Gresslya lunulata*, *Pleuromya uniformis*, *Arctica* ex gr. *humiliculminata* Shurygin, *Mactromya* sp. Shells of *Retroceramus bulunensis* Koschelkina were collected loosely in the same outcrop. Species discovered in the assemblage of Member III are widespread in the upper Bajocian and Bathonian of Boreal sections (Zakharov & Shurygin 1978; Shurygin 2005; Shurygin et al. 2011). Only occurrences of *Retroceramus* have stratigraphic significance. *Retroceramus bulunensis*, found loosely in Outcrop D-6, is the index species of a zone, which in the Siberian sections contained ammonites *Arctocephalites* aff. *greenlandicus* and *Arcticoceras harlandi* (Meledina et al. 1991; Shurygin et al. 2011).

In Central Russia, in the Sokur section in the vicinity of Saratov, where the succession of ammonites *Arcticoceras harlandi* ➞ *A. ishmae* is relatively well developed, the majority of the representatives of *Retroceramus bulunensis* are also confined to the interval with the ammonites *A. harlandi* (Mitta et al. 2014b). Hence, it is possible that shells of *Retroceramus bulunensis* found near Outcrop D-6 on the Izhma River come from the lower (below occurrences of *A. ishmae*) portion of Member III, which is characterised by *A. harlandi* in Outcrop D-5 (Fig. 3) and belong to the upper part of the *Retroceramus bulunensis* Zone. The index species *Retroceramus vagt* Koschelkina characteristic of the *A. ishmae*-bearing beds in northern Siberia and Sokur section, has not yet been discovered in the upper part of Member III on the Izhma River, and the position of the upper boundary of the *Retroceramus bulunensis* Zone has not yet been reliably determined in the sections studied here.

Some layers in Member IV contain small valves of *Meleagrinella ovalis* (Phillips) and *Arctica* sp. ind.

The upper Middle Jurassic microfaunal remains (foraminifers and ostracods) from the Pechora Basin were intensely studied at the end of the 1970s-1980s (Sachs 1976; Chirva & Yakovleva 1982; Lev & Kravets 1982). These studies resulted in the recognition of foraminiferal assemblages with *Ammodiscus pseudoinfimus* Gerke & Sossipatrova [= *A. arangastachiensis* Nikitenko] and *Lenticulina volganica* (Dain) (or the assemblage with *Lenticulina* spp.) and overlying assemblage with *Riydhella sibirica* (Mjatliuk), characteristic of the upper part of the Sysol Formation and lower part of the Churkino Formation of the Pechora Basin. No ammonites were found in these beds, and the stratigraphic position of the foraminiferal assemblage was debatable. Usually they were considered as Bathonian (Chirva & Yakovleva 1982; Grigelis 1982) based on the comparison with foraminiferal assemblages from the upper Middle Jurassic of Siberia containing ammonite genera *Boreiocephalites*, *Cranocephalites* and *Arctocephalites*, which are currently dated as Bajocian and Lower Bathonian (Shurygin et al. 2011; Nikitenko et al. 2013). It was noted that the two assemblages contained mostly identical species, so the assemblage with *Riydhella sibirica* can be separated only if the index species, which has an interrupted distribution, is found (Chirva & Yakovleva 1982). The beds with *R. sibirica* also show the appearance in the upper part of *Guttulina tatarensis* Mjatliuk, *Dentalina plebeja* Terquem and other species mostly occurring in the overlying deposits. The impoverished and taxonomically variable foraminiferal assemblage from beds overlying beds with the *Riydhella sibirica* assemblage was considered as the Lower-Middle Callovian (e.g., Chirva &, Yakovleva 1982, 1983; Grigelis 1982; Gramberg 1988; Basov et al. 1989; Yakovleva 1993; Repin et al. 2007).

Later, the analysis of the facies affinity of the taxa and refinement of the diagnoses and correlation of the Pechora foraminiferal assemblages with the Siberian assemblages allowed their stratigraphic range to be updated (Basov et al. 2008a, b; Basov et al. 2009; Nikitenko 2009; Mitta et al. 2012a). For instance, the interval with *Riydhella sibirica* is at present considered as the *Chondroceras* cf. *marshalli* – *Arctocephalites arcticus* (lower part) ammonite zones of the Siberian ammonite scale (Nikitenko et al. 2013).

Data on foraminifers from the Middle Jurassic beds exposed in the outcrops of the Izhma and Dreshchanka rivers are still very scarce. An impoverished assemblage with *Tolypammina* sp., *Lituotuba* sp., *Ammodiscus pseudoinfimus* Gerke & Sossipatrova [=*Ammodiscus arangastachiensis* Nikitenko] was recorded from the silt and clayey sand member on the Dreshchanka River in the stratigraphic descriptions of sections (Sachs 1976).

The distribution of the microfaunal assemblages in the Bajocian-Bathonian beds studied in the basin of the Izhma River is very inconsistent. Member I contains a virtually monospecific association with *Ammodiscus arangastachiensis*. No foraminifera were recorded in the mainly sandy member II. Rock matrix from the body chamber of the ammonite *Arcticoceras* from Member III (Outcrop D-7) contained poorly preserved microfauna. The assemblage is represented

by the calcareous foraminifers *Dentalina* ex gr. *plebeja* Terquem, *Nodosaria* ex gr. *sowerbyi* Schwager, *Anmarginulina* sp., and the ostracode *Procythoridea* sp. Despite the poor preservation of the shells, the microfaunal assemblage is relatively diverse and can be correlated with that from the Sokur Quarry in the vicinity of Saratov and provisionally assigned to the foraminiferal *Trochammina* aff. *praesquamata* Zone (Mitta et al. 2014b).

The basal horizons of Member IV (Outcrop D-10) yielded an abundant and taxonomically diverse assemblage with *Ammodiscus arangastachiensis* Nikitenko, *Saccammina compacta* Gerke, *Kutsevella memorabilis* (Scharovskaja), *Recurvoides ventosus* Chabarova, *Trochammina* aff. *praesquamata* Mjatliuk (Fig. 11.3), *Trochammina* sp., *Reophax* sp., *Guttulina tatarensis* Mjatliuk), *Dentalina plebeja* Terquem, *Dentalina vasta* Mjatliuk (Fig. 11.6), *Pseudonodosaria* sp., *Globulina praecircumphlua* Gerke (Fig. 11.7), *Astacolus* ex gr. *protractus* (Borneman), *Lingulonodosaria* sp., *Lenticulina* sp. (Fig. 11.8), *Planularia* sp. (Fig. 4). Slightly up the section, the taxonomic diversity abruptly decreases. Calcareous taxa disappear. The assemblage contains *Ammodiscus arangastachiensis* Nikitenko, *Saccammina compacta* Gerke and *Trochammina* aff. *praesquamata* Mjatliuk. Up the section, the more strongly clayey rocks again contain *Trochammina* sp., *Recurvoides ventosus* Chabarova, and *Kutsevella memorabilis* (Scharovskaja). The silt of the top of Member IV contained only *Ammodiscus arangastachiensis* Nikitenko.

Section I-1 on the Izhma River, in the clay of the visible base of Member IV, also contains a taxonomically diverse foraminiferal assemblage, equivalent to the assemblage described from the clay of section D-10. It should be noted that the foraminiferal assemblage from Outcrop I-1, while having an almost identical taxonomic composition, is impoverished in quantitty compared to Outcrop D-10. The overlying silty clay of section I-1 also contains a monospecific assemblage with *Ammodiscus arangastachiensis.*

The foraminiferal assemblage of Member IV characterises the foraminiferal *Trochammina* aff. *praesquamata* JF22 Zone (Nikitenko 2009; Mitta et al. 2012a). Taking into consideration the absence in the assemblages of representatives of *Riyadhella sibirica* and some other characteristic species, this part of the section most likely corresponds to the upper part of the JF22 Zone. In the Arctic regions of Eastern Siberia (Anabar River, Yuryung-Tumus Peninsula), the upper part of the JF22 Zone characterised by a similar foraminiferal assemblage, contains the ammonites *Arctocephalites* spp. and *Arcticoceras* spp. (Nikitenko 2009). Accordingly, the clayey-silty member IV of the sections in the Dreshchanka and Izhma rivers possibly corresponds to the Ishmae – Cranocephaloide Zones.

Apart from the foraminifers, the Middle Jurassic deposits contain ostracods. The first scheme of subdivision of the upper Middle Jurassic of the Pechora Basin based on ostracod assemblages was proposed by Lev & Kravets (1982). These beds contained the assemblage with *Camptocythere dextra* Gerke & Lev [= *C.* (*Anabarocythere*) *arangastachiensis* Nikitenko] and *C. scrobiculata* Gerke & Lev [= *C.* (*C.*) *scrobiculataformis* Nikitenko], occurring together with foraminifers of the assemblage with *Riyadhella sibirica*. The overlying portion of the section contained the ostracod assemblage with *Pyrocytheridea pura* Gerke &

Fig. 11. Uppermost Bajocian to Middle Bathonian foraminifers and ostracods from the Izhma River Basin (*Trochammina* aff. *praesquamata* F-Zone). **1**. *Ammodiscus arangastachiensis* Nikitenko, LG-01/14, X 33; bottom of member IV, Izhma River, rapids Griva; **2**. *Kutsevella memorabilis* (Scharovskaja), LG-02/14, X 82; bottom of member IV, Izhma River, rapids Griva; **3**. *Trochammina* aff. *praesquamata* Mjatliuk, LG-03/14, dorsal view, X 120 ; Dreshchanka River, section No 10, sample 2f; **4**. *Trochammina* aff. *praesquamata* Mjatliuk, LG-04/14, dorsal view, X 139 ; bottom of member IV, Izhma River, rapids Griva; **5**. *Geinitzinita crassata* (Gerke), LG-05/14, X 107; bottom of member IV, Izhma River, rapids Griva; **6**. *Dentalina vasta* Mjatliuk, LG-06/14, X 70; Dreshchanka River, section No 10, sample 1f; **7.** *Globulina praecircumphlua* Gerke, LG-06/14, X 105; section No 10, sample 2f; **8**. *Lenticulina* sp. LG-07/14, X 117; Dreshchanka River, section No 10, sample 2f; **9.** *Guttulina tatarensis* Mjatliuk, LG-09/14, X 135; bottom of member IV, Izhma River, rapids Griva; **10, 11.** *Camptocythere (Anabarocythere) arangastachiensis* Nikitenko, 10.-LG-10/14, complete shell, lateral view (RV), X 84; *Camptocythere scrobiculataformis* O- Zone, Dreshchanka River, section No 10, sample 1f; 11.- LG-11/14, complete shell, lateral view (LV), X 87; *Camptocythere arangastachiensis – Camptocythere scrobiculataformis* O- Zones, bottom of member IV, Izhma River, rapids Griva; **12.** *Camptocythere (Camptocythere) scrobiculataformis* Nikitenko, LG-12/14, complete shell, lateral view (RV), X 71; *Camptocythere scrobiculatoformis* O- Zone, Dreshchanka River, section No 10, sample 3f; **13.** *Procytherura didictyon rossica* Tesakova, LG-13/14, complete shell, lateral view (LV), X 114; *Camptocythere scrobiculataformis* O- Zone, Dreshchanka River, section No 10, sample 2f.

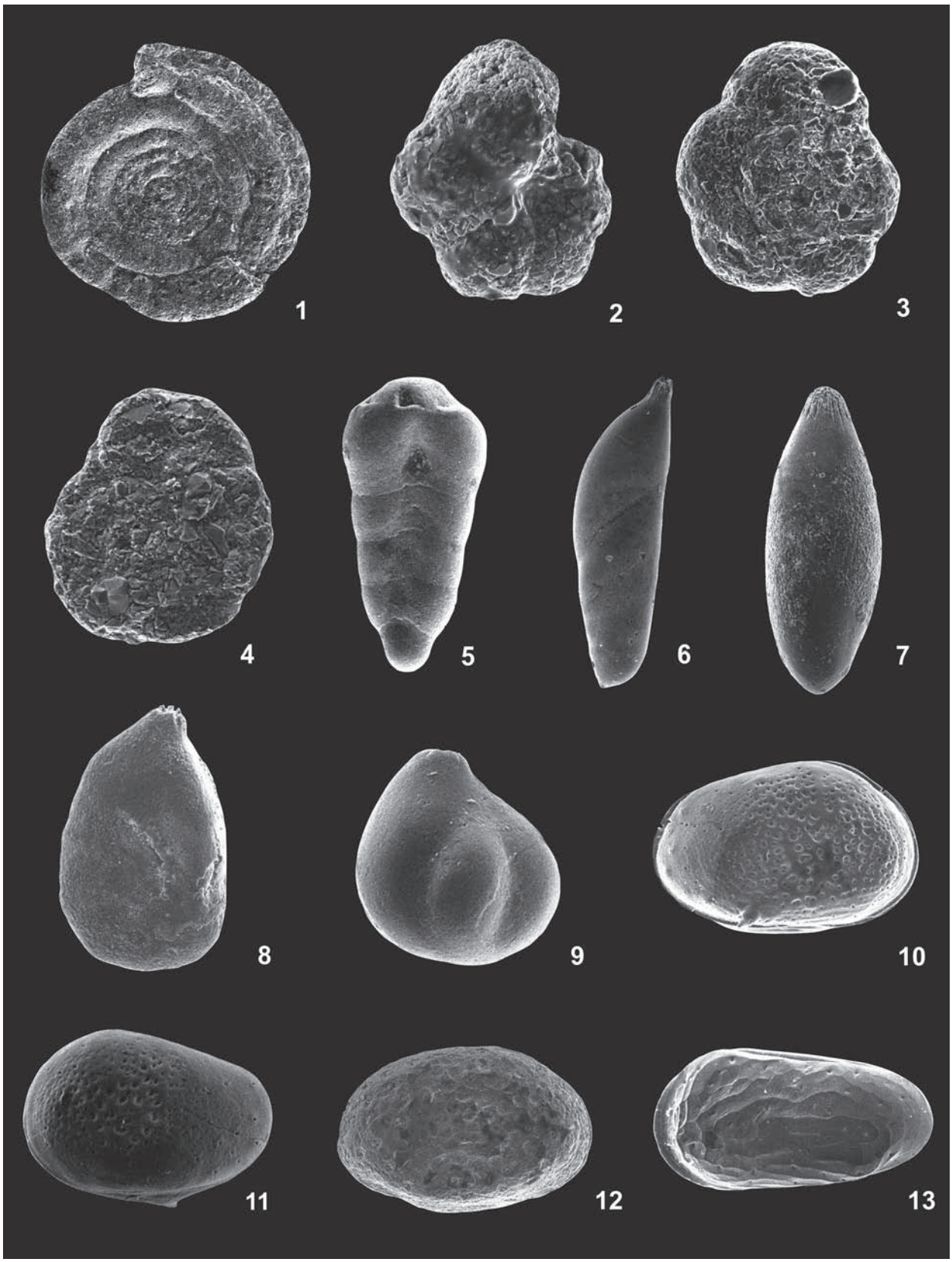

Fig. 11.

Lev, which still contains index species of the underlying ostracod assemblage. The lower portion of the beds with the *P. pura* assemblage is also characterised by the foraminiferal assemblage with *Riyadhella sibirica*. The succession of the ostracod assemblages is reliably calibrated by foraminiferal zones, as ostracods and foraminifers come from the same samples (Chirva & Yakovleva 1982, 1983; Lev & Kravets 1982).

Recent studies allow revision of the nomenclature of some genera and species and the updating of the stratigraphic position of the ostracod zones (Nikitenko 1994, 2009; Mitta et al. 2012a).

The ostracod assemblage found on the Dreshchanka River, in clay of the base of Member IV (Outcrop D-10) contains *Camptocythere* (*Anabarocythere*) *arangastachiensis* Nikitenko (Fig. 11.10), *Procytherura didiction rossica* Tesakova (Fig. 11.13), *Camptocythere* (*Camptocythere*) *scrobiculataformis* Nikitenko (Fig. 11.12), *Orthonotacythere* ex gr. *tuberculata* Sharapova, *Pyrocytheridea*? sp. The Outcrop I-1 on the Izhma River included only *Camptocythere* (*Anabarocythere*) *arangastachiensis* Nikitenko (Fig. 11.11). In the Arctic regions of Eastern Siberia this assemblage is typical of the *Camptocythere scrobiculataformis* JO14 Zone, which has a stratigraphic range corresponding to the Arcticus – Cranocephaloide ammonite Zone (Nikitenko 2009). Taking into account occurrences of the ostracods *Orthonotacythere* ex gr. *tuberculata* Sharapova and *Pyrocytheridea*? sp., which in North Siberian sections are not found below the aff. Greenlandicus ammonite Zone, it can also be suggested that the stratigraphic level of the base of member IV on the Dreshchanka River corresponds to the Ishmae – Cranocephaloide Zones.

5. Sedimentary settings

In the Late Bajocian and Early and Middle Bathonian, the territory studied was covered by a southern region of the shallow-shelf Boreal palaeobasin, with mainly clastic sedimentation. The sandy and arenaceous-silty-clayey Members 0 and I, apparently, represent a single transgressive cyclite reflecting gradual change in coastal marine high-energy sedimentary settings (Member 0) to relatively deeper, low-energy settings (Member I). Hence at the end of the Late Bajocian (Arcticus Zone), the palaeobasin (palaeostrait according to Repin 2005) gradually deepened in the area of the modern Izhma River. The sedimentation at the end of the Arcticus Zone was accompanied by frequent sedimentary pauses, during which in the conditions of good aeration of bottom water layers, sediments were partly bioturbated. The saturation of the deposits by small plant detritus of continental origin (C_{org} up to 1.12) resulted in abundant pyritization, mainly small nodules scattered in the bedded arenaceous-silty-clayey deposits. The secondary sulphide mineralization was a product of bacterial sulphate reduction in the reduced settings during the diagenesis of sediment containing an admixture of “fresh” organic matter (Strakhov 1960). The foraminiferal association from Member I is represented by a single genus *Ammodiscus*. In accordance with the palaeoecological affiliations of foraminiferal genera in the bionomic zones of the sea developed on the basis of the Jurassic microfauna of northern Siberia (Nikitenko 2009), such associations are characteristic of the shallow zone of the upper sublittoral with unstable salinity and hydrodynamics (IIIb – Inner part, Upper sublittoral zone) (Fig. 4).

The Lower Bathonian interval observed in outcrops shows a distinctly regressive structure. The Lower Bathonian overlies the Upper Bajocian clay over a sedimentary discontinuity suggesting a gap in sedimentation at the Bajocian-Bathonian transition.

Member II is composed of uniform sandy and silty-clayey deposits, accumulated in the semi-isolated gulf in the environment of constant wave activity, suggested by the presence in the sediment of a considerable amount of ferruginous oolithsand small textures of wave genesis. The deposits are saturated by small plant detritus of continental origin (C_{org} 0.47-0.7). Beds with maximum amount of organics contain large pyrite nodules.

The overlying member III has a more complex structure and diverse lithological composition and overlies sands of Member II with clear erosion. In the northern and eastern sections, Member III (supposedly in the upper part) is mainly composed of tempestites. The beds are represented by calcareous sandstone variously grained gravel-pebbled, frequently containing numerous, variously sized, complete and less commonly disintegrated fossils, with large fragments of coalified plant remains randomly scattered on the bedding planes and isolated thin layers of detritus coquina limestones. The deposits were accumulated in the coastal shoal in the environment affected by episodic storm of varying intensity and length. In the southwest direction (Outcrop D-1), the tempestites are replaced by well-sorted sandstone with thick oblique wavy bedding containing isolated layers of oolitic sandstone ac-

cumulated on the shallow shelf at some distance from the coastline. The assemblage of microfauna from Member III is represented by foraminiferal genera *Dentalina, Nodosaria, Anmarginulina,* and ostracods of the genus *Procytheridea*. The taxonomic composition of the microbenthic association is characteristic of the shallow marine environment with normal salinity (III – Upper sublittoral zone) (Fig. 4).

The macrofaunal oryctocoenosis of Member III is characterised by usually well-preserved isolated valves and complete shells (the shells not rounded; the edges and auricles are not broken off, with two valves commonly preserved). There is no prevalent orientation and sorting by size of bivalve shells. Usually shells are scattered over the bed and do not form large accumulations. The member also contains well-preserved relatively large and small unsorted belemnite rostra, large ammonite shells, and oyster shells in life positions. There are also desmodontids, also in life positions. All the listed characters suggest the absence of large post-mortem transportation. The predominance of thick-walled reophilic bivalves (*Gresslya, Pleuromya, Isognomon, Ostrea,* and *Mclearnia*) and the taphonomy of oryctocoenoses suggest a shallow, well-heated marine basin with episodes of high-energy conditions.

Thus, in the Early Bathonian, the sedimentation in the region studied occurred in the upper zones of a wave dominated shallow shelf. The sedimentary settings changed from coastal marine (in the Greenlandicus? Zone) to coastal-continental reflecting a regressive stage in the evolution of the palaeobasin just before the Ishmae Zone.

Because the boundary between Members III and IV was not observed in the sections (due to a gap in observation from 4 to 6 m), it is possible that Member III is the base of the cyclite characterizing the maximum southward transgression to the Russian Platform. Dark-grey bluish finely disperse clay of the visible base of Member IV, in outcrops D-10 and I-1 are likely to represent the upper part of this transgressive cyclite, which is gradually and without a gap overlain by clayey-silty deposits. The pelitic structure and massive texture indicate a relatively deep shelf origin of the clay deposits. The absence of bioturbation and sulphide mineralization in the clay while the organics content is relatively high (C_{org} up to 0.7), apparently suggests intensive deepening of the basin during sedimentation. The taxonomic diversity and abundance of foraminiferal shells in microfaunal associations in the lower part of Member IV sharply increases. That beds contain members of the genera *Ammodiscus, Saccammina, Kutsevella, Recurvoides, Trochammina, Reophax, Guttulina, Dentalina, Pseudonodosaria, Globulina, Lingulonodosaria, Lenticulina,* and *Planularia*. The associations are dominated by agglutinated foraminifera represented by tens of specimens. The beds also contain ostracod genera *Camptocythere, Procytherura, Orthonotacythere,* and *Pyrocytheridea*. This microbenthic association is characteristic of shallow basin away from coastline with relatively low energy, and stable salinity (IIIa – Outer part, Upper sublittoral zone). Some samples contain considerable number of polymorphinids (genus *Guttulina*), characteristic of boreal basins for associations of foraminifers of the upper middle sublittoral (IIb – Inner part, Middle sublittoral zone) (Fig. 4).

The overlying Member IV is connected with the underlying clay by a gradual transition characterised by a weak facies variability and presence of local gaps. The absence of a sharp boundary with the underlying clay indicates a gradual decrease in basin deepening rate and shallowing of the studied zone of the palaeobasin. The deposits were accumulated at a distance from the shoreline in a relatively shallow shelf zone in the environment of weak bottom currents and within the storm wave base. The sedimentation was accompanied by episodic pauses in sedimentation, during which clayey-silty sediments were partly bioturbated. Member IV also contains considerable amounts of small plant detritus of continental origin (C_{org} up to 0.68). In some areas (Outcrop D-10) during episodes of decreased siliciclastic sediment, accumulation of OM resulted in the deposition of think local horizons of secondary pyritization.

Microfauna, found in this part of the section, also suggests a change in the sedimentary environment. Ostracods disappear, and the taxonomic diversity of foraminifers decreases. The associations represented by the genera *Ammodiscus, Saccammina, Kutsevella, Recurvoides,* and *Trochammina,* typical of the shallow zone of the upper sublittoral (III – Upper sublittoral zone). The deposits also contain monotaxonic foraminiferal associations represented by the single genus *Ammodiscus,* characterizing shallow shelf settings with unstable salinity and hydrodynamics (IIIb – Inner part, Upper sublittoral zone) (Fig. 4).

6. Discussion and conclusions

There are other contemporaneous stratigraphic successions in the Pechora Region. Exposures of sand-

Table 1. Foraminifera biostratigraphy of the Upper Bajocian – Lower Callovian in the Central Russia and Pechora River Basin (present paper). Subboreal and Boreal ammonite zonations follow Mitta (2005, 2009).

Substage		Volga River basin			Pechora River basin		
		Ammonite zonation	Foraminifera zonation		Ammonite zonation	Foraminifera zonation	
Lower Callovian		Cadoceras elatmae	Haplophragmoides infracalloviensis - Guttulina tatarensis		Cadoceras elatmae	H.infracalloviensis - G. tatarensis	Kutsevella instabile - Astacolus batrakiensis
Bathonian	Upper	Cadoceras apertum			?		Kutsevella memorabilis - Guttulina tatarensis
		Paracadoceras keuppi			Paracadoceras keuppi		
	M.	ammonites not found	Ammodiscus baticus	?	ammonites not found	Trochammina aff.praesquamata	Ammodiscus arangastachiensis - Recurvoides anabarensis
	Lower	Arcticoceras ishmae	Lenticulina volganica-Vaginulina dainae	Trochammina aff.praesquamata	Arcticoceras ishmae		
		Oraniceras besnosovi			ammonites not found		
Upper Bajocian		Pseudocosmoceras michalskii	Ammodiscus subjurassicus-Lenticulina saratovensis	?	Arctocephalites arcticus		Riyadhella sibirica

stone belonging to the Ishmae Zone are also recorded in the Izhma River basin, on the Verkhnii Odes River near the village of Odesdino (Bodylevsky 1963), 55 km southeast of the mouth of the Dreshchanka River. However, these sections have not been studied sufficiently to allow positive correlation.

Arcticoceras ishmae, *A. harlandi*, etc., *Retroceramus retrorsus*, and *R. bulunensis* are recorded by Repin (2005) from the Bolshezemelskaya tundra, in nodules and lenses of calcareous sandstone in silty-argillaceous sands, total thickness around 5 m. This section (Nikiforova Shchelia) is located on the Adzva River, 12 km above its mouth, 400 km northeast of the mouth of the Dreshchanka River. This interval is underlain by thin beds of clay, sand, and coal, of total thickness ca. 1.2 m, with no faunal remains. About 100-120 m upstream, after an observational gap, Repin indicated beds of the Upper Callovian sandstone with abundant ammonites.

Bathonian beds were also established in 150 km northwest on the Pizhma River (Churkino section) where the Bathonian-Callovian boundary beds are represented by clay with layers of sideritic nodules, with a total thickness around 20 m, which were originally assigned to the Lower Callovian Elatmae Zone (Meledina 1987). Subsequent studies based on additional collections, allowed the recognition of beds with the Early Bathonian *Oraniceras* cf. *gyrumbilicum* and *Gonolkites* ex gr. *convergens*; Late Bathonian *Cadoceras variabile*; Early Callovian *C.* ex gr. *elatmae* and *C. falsum*; *C. pishmae* and *C. simulans* (Meledina 1994; Meledina & Zakharov 1996). However, *Oraniceras* cf. *gyrumbilicum* (Quenstedt) from this locality most likely belongs to the cardioceratid genus *Eckhardites* (Mitta 2000), whereas ammonites identified by Meledina as *Cadoceras* (*Streptocadoceras*) *variabile* Spath, to *Paracadoceras keuppi* Mitta (Mitta 2005). A small ammonite identified by Meledina as *Gonolkites* ex gr. *convergens* Buckman, most likely belongs to *Paracadoceras nageli* Mitta. Taking into account these revised identifications, the lower part of the Churkino section belongs to the Upper Bathonian Keuppi Zone, and the upper (larger) part belongs to the Lower Callovian Elatmae Zone. These conclusions are supported by the distribution of foraminifers in the section on the Pizhma River. A bed-by-bed list of these foraminifers was given in Meledina (1987). The correlation of the Lower Bajocian-Lower Callovian in the basins of the Pechora River and middle reaches of the Volga River on the basis of foraminiferal assemblages taking into account new data on Bathonian foraminifers from the basin of the Izhma River agrees with the ammonite-based correlations (Table 1).

The analysis of the ammonite distribution in the sections of the basin of the Izhma River does not allow the recognition of two stratigraphic units in the interval, which here is referred to as the Ishmae Zone, as it was done in the Siberian scale, containing the Harlandi and Ishmae zones (Tables 2, 3). Callomon (1993, 2003), the world expert of the "Boreal Bathonian" and author of this subdivision, did not designate the interval of *Arcticoceras harlandi* Rawson as a separate subzone, treating it as a lower faunal horizon of the Ishmae Zone

Table 2. Belemnite biostratigraphy of the Lower-Middle Bathonian in the Central Russia (Mitta et al. 2014b), Izhma River Basin (present paper) and northern Siberia (Shurygin et al. 2000, 2011; Nikitenko et al. 2013). Subboreal and Boreal ammonite zonations follow Mitta et al. (2014b).

Substage	Subboreal Realm		Boreal Realm			
	Central Russia (Sokur)		Izhma River Basin		Northern Siberia	
	Ammonites	Belemnites	Belemnites		Belemnites	Ammonites
Middle Bathonian	No finds		*Paramegateuthis ishmensis* Beds	?	*Pach. subrediviva* Beds (lower part)	Cranocephaloide
Lower Bathonian	Ishmae	*Pachyteuthis optima* Beds		*Pachyteuthis tschernyschewi* Zone	*Pachyteuthis tschernyschewi* Zone	Ishmae
		Pachyteuthis optima & P. bodylevskii Beds		?	*Cylindroteuthis confessa* Beds	Harlandi
	Besnosovi	No finds		No finds	*Cylindroteuthis spathi* Zone (upper part)	Greenlandicus

Table 3. Bivalve biostratigraphy of the Lower-Middle Bathonian in the Central Russia (Mitta et al. 2014b), Izhma River Basin (present paper) and northern Siberia (Shurygin et al. 2000, 2011; Nikitenko et al. 2013). Subboreal and Boreal ammonite zonations follow Mitta et al. (2014b).

Substage	Subboreal Realm		Boreal Realm		
	Central Russia (Sokur)		Izhma River Basin	Northern Siberia	
	Ammonites	Bivalves	Bivalves	Bivalves	Ammonites
Middle Bathonian	No finds		?	*Retroceramus vagt* Zone	Cranocephaloide
Lower Bathonian	Ishmae	*Retroceramus vagt* Zone			Ishmae
		Retroceramus bulunensis Zone	*Retroceramus bulunensis* Zone	*Retroceramus bulunensis* Zone	Harlandi
	Besnosovi	?	No finds		Greenlandicus
		R. polaris Zone		*R. polaris* Zone (upper part)	
		No finds			

(with the overlying horizons *A. ishmae* α, *A. ishmae* β and *A. crassiplicatum* Callomon in MS). *A. harlandi*, as in the original description, "… differs from other *Arcticoceras* in having a less narrow venter, over which the ribs curve forward only slightly" (Rawson 1982: 98). These differences, on the whole insufficient for species separation, are observed on our material mainly on phragmocones and reflect the morphological transition from the last *Arctocephalites* (*A. greenlandicus* Spath) to *Arcticoceras*. The range of *A. harlandi* cannot be further subdivided and cannot be used for a standard subzone. We accept the Ishmae Zone as including the *A. harlandi*, *A. ishmae* α, and *A. ishmae* β horizons, i.e., corresponding to the range of "Beds with *Ammonites Ishmae*" (Member III in this paper), originally recognised on the Izhma River. In this interpretation, the interval of the Middle Bathonian in the Boreal scale includes the *crassiplicatum*, *cranocephaloide* and *tychonis* horizons, i.e., the uppermost levels of the Ishmae Zone *sensu* Callomon 1993, and the Cranocephaloide Zone.

Taking into account the latest data, Meledina (2014) in her discussion of the Bajocian-Bathonian correlation in Siberia, agrees with the bipartite subdivision of the Lower Bathonian (with the Besnosovi and Ishmae Zones for the Russian platform, and with Greenlandicus and Ishmae zones for East Greenland and Siberia). However, in the scheme for the Russian platform (Meledina 2014, table 1) she incorrectly cited the Unified scheme (Mitta et al. 2012a), which includes *Garantiana* Beds, approximately corresponding to the lower part of the Upper Bajocian, i.e., the Niortense and Garantiana zones, rather than *Pseudogarantiana* Beds, corresponding to the Humphriesianum and

Niortense zones of the standard scale. The correlation proposed by Meledina of the Arcticus Zone with the entire interval of the Upper Bajocian of the standard scale including three ammonite zones is doubtful. In the Boreal scale, this zone is subdivided only into two units, faunal *arcticus* and *delicatus* horizons of East Greenland (Callomon 1993), and the Jugatus and Arcticus subzones in Siberia (Meledina 1994). In our opinion, the Arcticus Zone correlates with the uppermost Bajocian, approximately corresponding to the Michalskii Zone of the Russian Platform and largest part of the Parkinsoni Zone of the Western European standard (without its lowermost Acris Subzone: Mitta 2009). The Late Bajocian Peritethyan basins show greater taxonomic diversity of ammonites compared to the Boreal basins. However, even taking into account a possibly accelerated evolution of Tethyan ammonites, it is difficult to accept during the time of existence of two successive Boreal species of one cardioceratids genus (*Arctocephalites arcticus* (Newton) ➞ *A. delicatus* Callomon MS; East Greenland: Callomon 1993), or even one species (for Siberia *A. arcticus* is indicated for two subzones: Meledina 1994), in the Peritethyan basin several successive genera changed, in several lineages at the same time.

The distribution of belemnites and biostratigraphically important bivalves of the Bathonian Stage and adjacent stages in the Pechora Basin is insufficiently studied. In the Izhma River sections, it is possible to recognise only few biostratigraphic units traced from Siberia via the Pechora Basin to Central Russia (Sokur section). Compared to the results of the preceding papers in the basin of the Izhma River, it is established that belemnites *Paramegateuthis ishmensis* (Gustomesov) and *P. timanensis* (Gustomesov) have a wider vertical range, and as a result members III and IV are completely assigned to the *P. ishmensis* Beds (Fig. 3). It is noteworthy that the bivalve *Retroceramus bulunensis* Koschelkina, characteristic in Siberia of beds yielded *Arcticoceras harlandi*, supposedly comes from the lower part of sandy Member III, whereas the belemnite *Pachyteuthis tschernyschewi* (Krimholz) (in Siberia found only together with *Arcticoceras ishmae*) is reliably found in the higher horizons of this member. These occurrences in the basin of the Izhma River allow the recognition of the Siberian zones *Retroceramus bulunensis* (incompletely) and *Pachyteuthis tschernyschewi* (Tables 2, 3). The *Retroceramus bulunensis* Zone is present in the sections of the northern Pechora Basin (judging from the records of the index species from the Adzva River (Repin 2005)) and can be traced far to the south of Central Russia up to the vicinity of Saratov (Mitta et al. 2014b). *Retroceramus vagt*, the index species of the overlying bivalve zone, well represented in Siberia and in the Sokur section is found neither in Member III, nor in the overlying beds. The upper part of the Ishmae Zone and overlying series in the Izhma River Basin require more detailed investigations for reliable interpretation of this phenomenon.

Judging from belemnites, the base of the Middle Bathonian can lie in the interval, which at present is not visible in the Izhma River Basin. The LAD of the index species of the *Pachyteuthis tschernyschewi* belemnite Zone, the top of which in the Siberian sections corresponds to the Lower-Middle Bathonian boundary (Table 2), was recorded by Gustomesov (1964) in the clay below the visible base of member IV (Fig. 3).

The analysis of sedimentology and taphonomy of Bajocian-Bathonian beds studied in the basin of the Izhma River suggest that they were deposited in the shallow shelf of the Boreal palaeobasin, the fauna of which, judging from the Sokur section (near Saratov) reached the southern regions of the Central Russian palaeobasin (meridional palaeostrait?). The comparison of the Bathonian assemblages of macro- and microfauna in the basin of the Izhma River with the Siberian and Sokur successions indicates that they are taxonomically most similar to the Arctic palaeofaunas. The Early-Middle Bathonian belemnite assemblages from the Izhma River basin are typically Arctic, whereas in the Sokur section, Arctic species represent only half of the belemnite assemblages. The Early Bathonian bivalve assemblages from the Izhma River Basin are represented by species characteristic of this interval in the Siberian sections and do not contain Low-Boreal bivalves, which constitute an essential part of the Early Bathonian assemblages of the Sokur section. The assemblages of the Early Bathonian microfauna in the basin of the Izhma River against the background of predominance of Arctic taxa also contain representatives of the Low-Boreal species, but much less than in the Sokur section. It can be suggested that the connection of the Arctic Basin with the Low-Boreal basins of the Russian Platform at the end of the Bajocian and in the Early Bathonian occurred via the meridional strait through the Pechora Basin.

Judging from the sedimentological features of the sections studied, there were two transgressive-regressive cycles. At the end of the Late Bajocian (Arcticus Zone) the Izhma region of the palaeobasin gradually deepened and later became shallower just before the

Ishmae Zone. Deposition of Member III occurred in the upper zones of the shallow shelf with episodes of variously strong and long storms. Taking into account the lithology of the overlying series, Member III can be considered as a basal member of a transgressive-regressive cyclecharacterizing the maximum transgression in the southern direction on the Russian Platform.

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