



Biostratigraphy and sedimentary settings of the Upper Bajocian-Lower Bathonian in the vicinity of Saratov (Central Russia)

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With 11 figures and 1 table

Abstract: This paper presents the results of a detailed study of the Bajocian-Bathonian sections in the “Sokur” Quarry near the city of Saratov and of a borehole drilled in the same quarry. The study of these Bajocian-Bathonian boundary beds, unique for the Boreal-Tethyan ecotone, offers a solution to the much-debated problem of the Middle Jurassic Boreal-Tethyan correlation. The Bajocian-Bathonian boundary beds of this section contain both Peri-Tethyan and Boreal ammonite species, allowing recognition of the Boreal ammonite zones and associated “Boreal” Bathonian zones based on belemnites, bivalves, and foraminifers. This integrated biostratigraphy allows correlation of the Late Bajocian-Early Bathonian boundary interval of the Boreal Jurassic scale with the Submediterranean standard scale.

Key words: Bajocian, Bathonian, Ammonoidea, Belemnoidea, Bivalvia, Foraminifera, sedimentology, Russian Platform, Boreal-Tethyan correlation.

1. Introduction

The Boreal-Tethyan correlation of the Bajocian-Bathonian beds is one of the most complex problems of Mesozoic biostratigraphy. The Boreal ammonite faunas of this geological age are known to be strikingly different in composition from contemporary Tethyan faunas. The standard scales of the Bajocian and Bathonian stages are based on the Western European (Submediterranean and North-western) ammonite successions (FERNÁNDEZ-LÓPEZ et al. 2009a, b). The Bajocian zonal scales of Eastern Greenland, Barents Sea, Pechora Basin, northern Siberia, north-eastern Russia, Arctic Canada, and northern Alaska are based on the ammonites of Boreal origin and therefore were only provisionally correlated with the standard scale (POULTON 1987; CALLOMON 2003; REPIN et al. 2007; MITTA 2009; SHURYGIN et al. 2011; NIKITENKO et al. 2013). The

standard zonal scale of the Upper Bajocian-Lower Bathonian is based on the succession of parkinsoniids, whereas arctocephalitins are used for subdividing the so-called “Boreal Bathonian”. The possibility of a direct Boreal-Tethyan correlation of the Bajocian-Bathonian boundary beds emerged only ten years ago. Then ammonites of the Peri-Tethyan family Parkinsoniidae (*Parkinsonia*, *Oraniceras*) and Boreal Cardioceratiidae (subfamily Arctocephalitinae: *Arcticoceras* and *Arctocephalites*) were discovered in the quarry of the Elshanskii clay deposit in the vicinity of Saratov. This quarry was named “Sokur” after the nearby Sokur Highway (Fig. 1). Because of the importance of this locality for stratigraphy, a borehole was drilled in the quarry to examine the older, Bajocian beds. The results of the combined study of the section of the quarry and the borehole are discussed below.

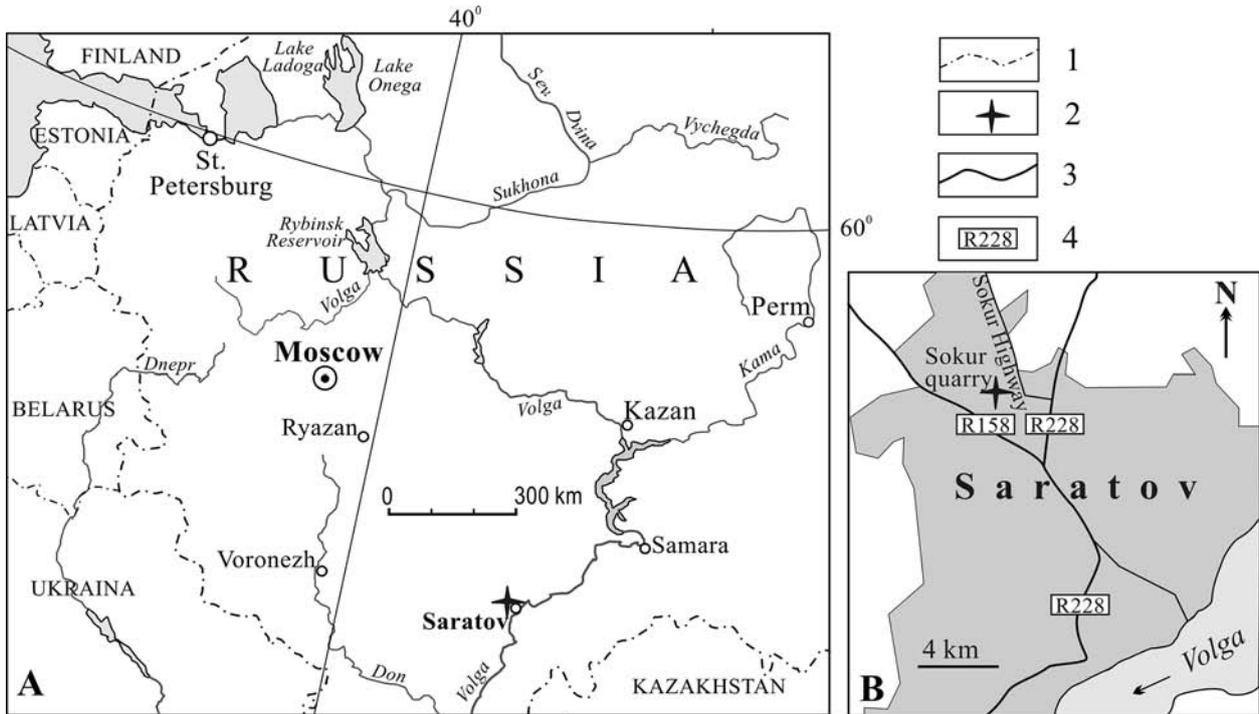


Fig. 1. Geographical location of the Sokur Quarry (A) in the vicinity of Saratov (B): 1 – state frontiers, 2 – Sokur Quarry location, 3 – main roads, 4 – regional road numbers.

2. Historical background

In their pioneering research in the Sokur Quarry MITTA & SELTZER (2002) showed that the clay beds of the Upper Bajocian *Pseudocosmoceras michalskii* Zone (partially equivalent of the Parkinsoni Standard Zone) is overlain by clay with sideritic nodules, *Oranicerias* and *Parkinsonia*, whereas the interval of the section slightly above yields shells of *Arcticoceras* and probably *Arctocephalites* (found loose). Beds with sideritic nodules in the lower “*Oranicerias* level” (*Oranicerias besnosovi* Zone) is considered as a potential correlative level for the Bathonian portion of the section, whereas the overlying so-called “belemnite level” (condensed bed with numerous belemnite rostra, pieces of carbonized wood, bivalve shells, and rare crinoidal ossicles) is considered to be a correlative level for the upper “*Arcticoceras*” portion of the section (*Arcticoceras ishmae* Zone). Subsequent studies included, apart from ammonites, other fossils from the Sokur sections such as belemnites, bivalves, gastropods, spore and pollen assemblages (MITTA et al. 2004). The Bajocian-Bathonian sections in the Pechora Basin (Izhma River), which

were studied at the same time, revealed *Arctocephalites arcticus* (NEWTON & TILL) and *A. frebaldi* SPATH (MITTA 2006, 2009). The correlation of the ammonite scales of the Upper Bajocian-Lower Bathonian in the Pechora Basin and the Volga River near Saratov with the chronobiostratigraphic scales of other regions have been discussed at a number of conferences (MITTA 2007; MITTA & SELTZER 2009).

A paper by the Novosibirsk palaeontologists S.V. MELEDINA, T.I. NALNJAIEVA, and B.N. SHURYGIN (MELEDINA et al. 2009) began a new stage in these studies. This paper critically discussed material and data published in previous articles and contested some previous biostratigraphic conclusions. The assumption of MELEDINA et al. (2009) was prompted by ammonites and stratigraphically important bivalves (retrocera-mids) found in the Sokur section mainly by amateur palaeontologists at levels that were not previously documented in details. The situation was complicated as the Bajocian-Bathonian boundary was placed lower in the section in the Siberian stratigraphic schemes, at the base of the *Arctocephalites arcticus* Zone (MELEDINA et al. 2005, SHURYGIN et al. 2011). MELEDINA et

al. (2009) agreed that the assignment of the *Pseudocoscoceras michalskii* Zone to the Upper Bajocian and the *Oraniceras besnosovi* Zone to the lower half of the Lower Bathonian was justified. However, the distribution of ammonites in the overlying portion of the section and the dating of the host beds were not well substantiated. MELEDINA and her co-authors suggested that all representatives of Boreal ammonites (*Arcticoceras* and *Arctocephalites*) in the Sokur section should have come from the “belemnite level” and/or from the overlying beds, and dated as Middle rather than Lower Bathonian. The identification of an ammonite imprint from the beds with *Arcticoceras ishmae* as *Parkinsonia* s.l. (MITTA & SELTZER 2002, pl. 5, fig. 2) was considered doubtful by MELEDINA et al. (2009). The “belemnite level” was discussed in their paper as a reworked horizon resulting from a stratigraphic gap corresponding to the *Arctocephalites arcticus*, *Arctocephalites greenlandicus*, and *Arcticoceras harlandi* zones. This conclusion was supported by a comparison of the stratigraphic distribution of ammonites, retroceramids, and some unidentified belemnites (described in MITTA et al. 2004) with that of an assemblage from the Bajocian-Bathonian beds of northern Siberia. In the Boreal Siberian scale, the Upper Bajocian correlates with the *Boreiocephalites borealis* and *Cranoccephalites gracilis* zones, whereas the Lower Bathonian correlates with the *Arctocephalites arcticus* and *Arctocephalites greenlandicus* zones, and the *Arcticoceras harlandi* and *Arcticoceras ishmae* zones are assigned to the Middle Bathonian (MELEDINA et al. 2009; SHURYGIN et al. 2011).

The critical paper of MELEDINA et al. (2009) prompted the next publication by MITTA et al. (2011), which also critically assessed MELEDINA's conclusion. MITTA et al. (2011) figured new material from the Sokur section (ammonites and belemnites), including a specimen of *Arcticoceras harlandi* RAWSON found 0.5 m below the “belemnite level”, in association with *Oraniceras* sp., and confirmed that the *Arcticoceras* Beds belonged to the Lower Bathonian.

It is noteworthy that the age of the beds with *Arcticoceras ishmae* and closely related species has been the subject of many discussions. KEYSERLING (1846) was the first to establish these beds in the basin of the Pechora River as the earliest Jurassic strata in that region. Later these beds were recognized in many other high latitude regions. For a long time these beds were tentatively assigned to the Lower Callovian (e.g., SASONOV 1957; MELEDINA 1987). Following CALLOMON's (1993) detailed research in East Greenland, beds

with *Arcticoceras* were assigned by various workers to the lower Upper Bathonian (POULTON 1987: Canada) or Middle Bathonian (MELEDINA 1994: northern Siberia and northern European Russia). Callomon considered that there were insufficient data for the Boreal-Tethyan correlation of this interval, and designated the entire succession of East Greenland Arctocephalitina- and Cadoceratina-based zones as “Boreal Bathonian”, an interval corresponding to the Upper Bajocian-Lower Callovian of the European standard scale.

In May 2012 a field team from Moscow and Novosibirsk, joined by geologists from Saratov (all co-authors of this paper) re-examined the section of the Bathonian beds in the Sokur Quarry (MITTA et al. 2012b: preliminary report). In October 2012 and July 2013, these authors conducted additional excavations in the quarry. The field work focused on the resolution of the debated stratigraphic issues discussed above. In addition, we used belemnite material collected in 2004 (by OD). This was supplemented by a study of the microfossils and sedimentology (LG, VK) of the core of the borehole purposefully drilled in 2003 (by AI and VS) with the aim to examine the basal part of the section.

3. Lithological and palaeontological characteristics of the Sokur section

Examination of the exposed section of the quarry showed that a part of the section refers to the Upper Bajocian (*Pseudocoscoceras michalskii* Zone) whereas the lowermost Bathonian (lower part of the *Oraniceras besnosovi* Zone) was not visible at that time. However, the middle part of the section was well exposed, and that included a transition from the clayey portion with Lower Bathonian fossils to the silty member of supposedly Middle Bathonian age, with a total thickness of 16.5 m. This allowed refinement of the lithology of members III and IV of the open part of the section (Fig. 2), accompanied by microfossil sampling and sedimentological study. Additional collecting of microfossils was also successful. It should be noted that the lower 1.5 m of the section could only be studied using a backhoe dipper, with the result that most of the macrofossils from this interval were not precisely positioned in the section.

We used the easily recognizable boundary between members III and IV and the so-called “belemnite level” (3-5 cm thick interlayer located 5.4 m below the top of Member III) as correlative marker levels. For technical reasons, the upper 1.5 m of the section were described but not sampled.

The 60-m borehole was drilled at the bottom of the

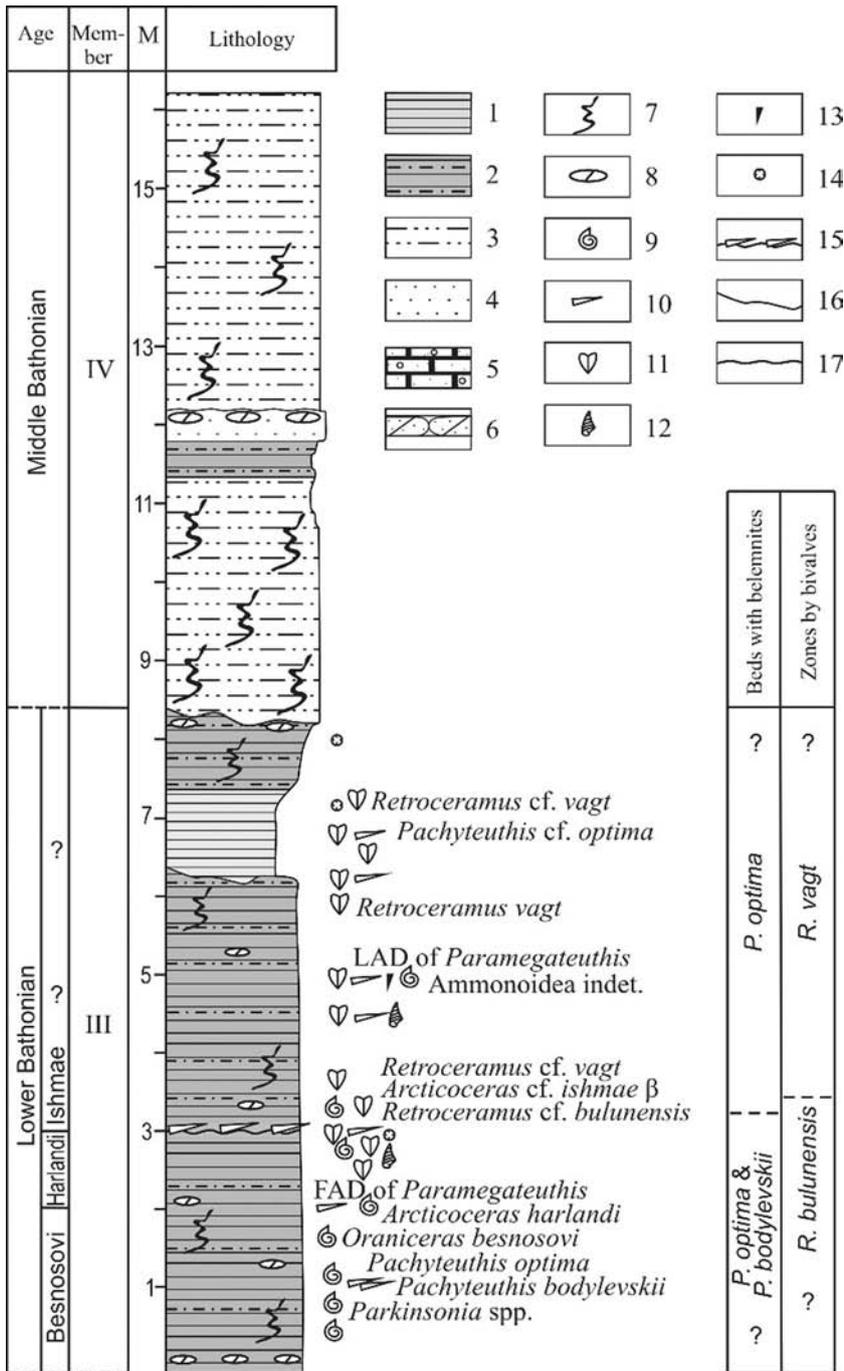


Fig. 2. The Bathonian section in the Sokur Quarry, on the observations of 2012 and 2013: 1 – clay, 2 – clay, intercalated with silt, 3 – silt, 4 – calcareous siltstone, 5 – bioclastic arenaceous limestone with relictual oolitic crusts, 6 – calcareous-quartz sandstone, 6 – ferruginous calcareous nodules, 7 – bioturbation structures, 8 – ferruginous nodules, 9–14 – fossils: 9 – ammonites, 10 – bivalves, 11 – gastropods, 12 – marine reptile teeth, 13 – “belemnite level”, 14 – crinoids, 15 – “belemnite level”, 16 – erosional pockets, 17 – supposed erosion bedding plane, FAD – first appearance datum, LAD – last appearance datum.

quarry (as it was in 2003). Ammonite identification from the core was presented by MITTA et al. (2011). Ammonite and bivalve record is specified in Fig. 3, whereas microfossil determinations (LG) are listed in Fig. 4. The sedimentological study of the core (VK) allowed the recognition of two members assignable to the Upper Bajocian (Michalskii Zone). The upper

two metres of the borehole were not sampled for core, but the overlapping interval between the exposed section (2012) and the uppermost core could be supplemented by observations made previously in the quarry, in particular in 2006, when the bottom of the quarry was deepened by overburden removal works (MITTA & SELTZER 2009). Fig. 4 shows a combined section of

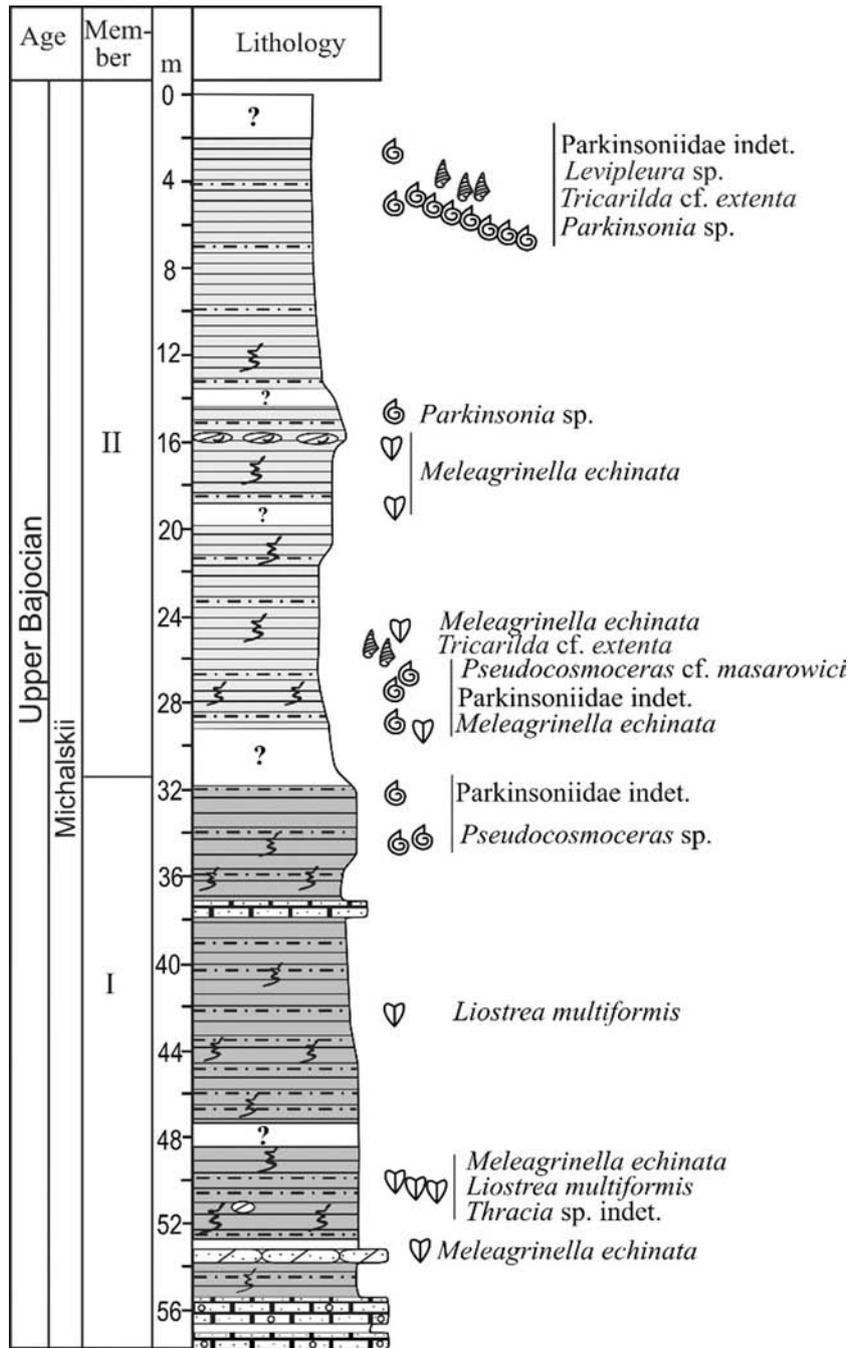


Fig. 3. The Upper Bajocian section in the Sokur borehole (for legend see Fig. 2). Figure shows the original markings of the depths.

the Bajocian-Bathonian beds in the vicinity of Saratov with the distribution of macro- and microfossils. The section is described below (from bottom to top).

Upper Bajocian (Fig. 3):

Clayey silts and silty non-calcareous clays with thin layers of calcareous sandstones and bioclastic arena-

ceous limestones at the base of the section represent the Bajocian interval. This unit contains macro- and microfossils (ammonites, bivalves, ostracods, foraminifers) and a small amount of scattered carbonaceous detritus. The thickness of the unit drilled in the borehole is ca. 57.5 m. Two Members are recognized.

The lower Member I up to the depth of 32.0 m is

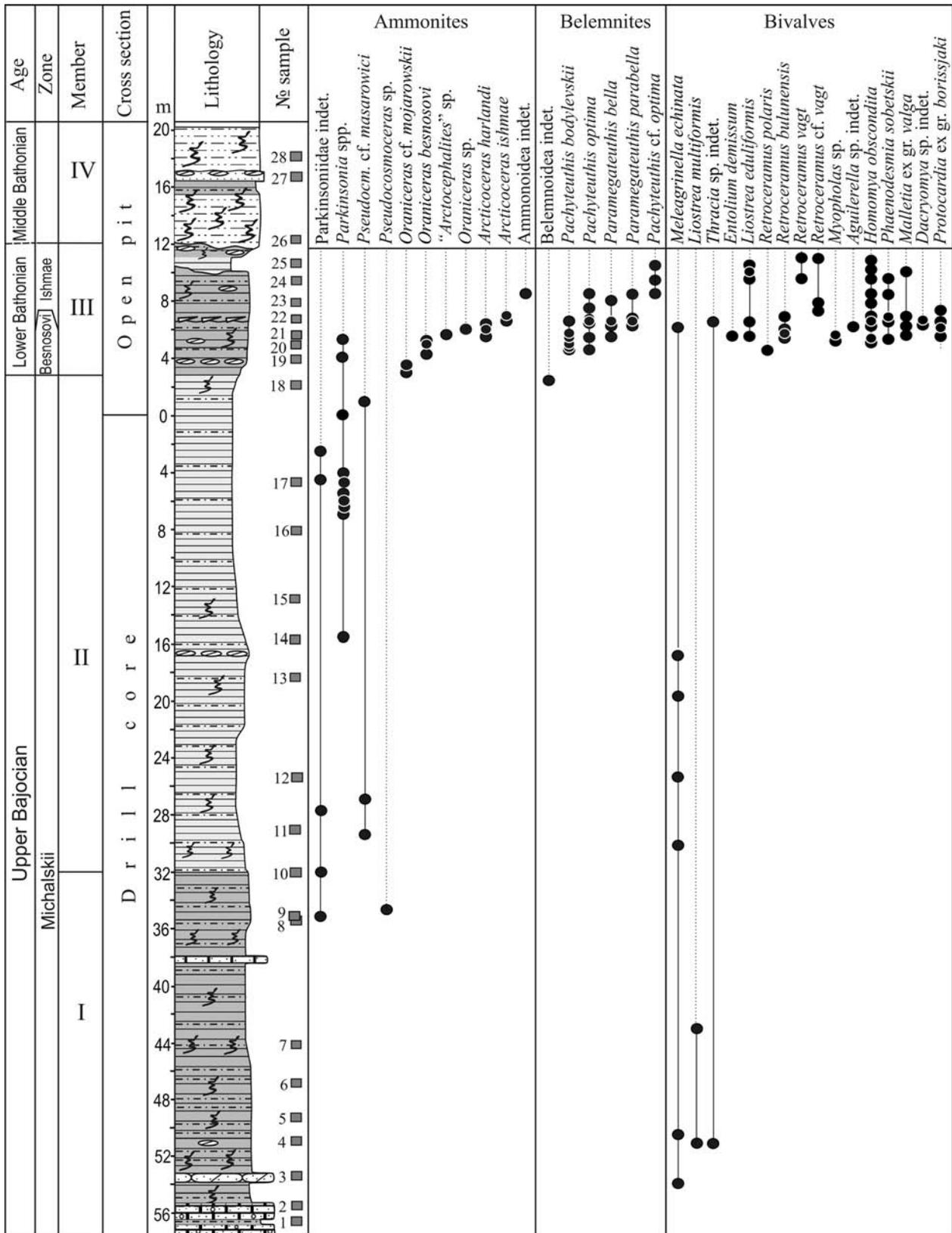
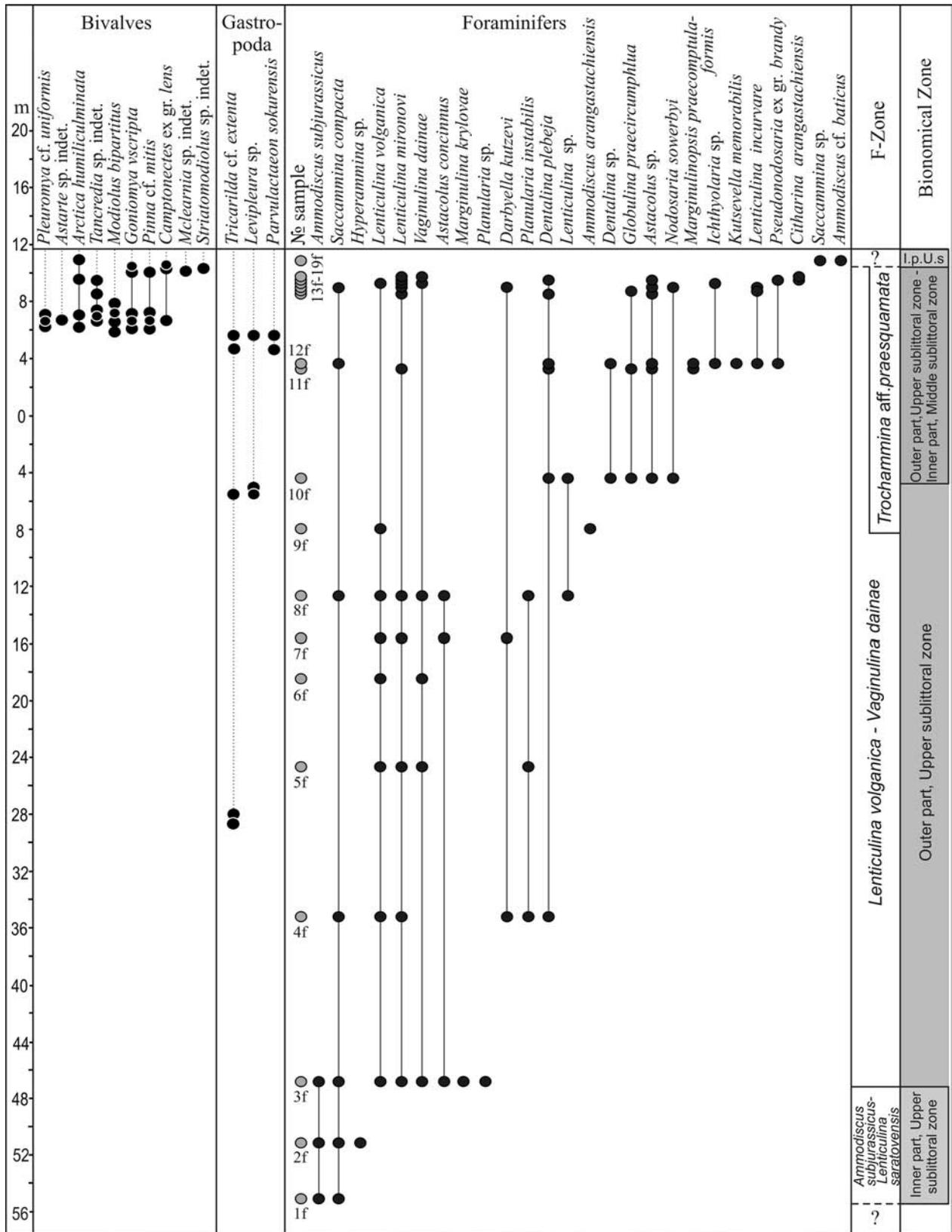


Fig. 4. The composite section of the Bajocian and Bathonian near Saratov (Sokur Quarry): distribution of cephalopods, gastropods, bivalves and foraminifers (for legend see Fig. 2). The interval adjacent to Member III is reconstructed based on pre-



viously published data (MITTA & SELTZER 2002; MITTA et al. 2004), and based on samples collected in the preceding years.

composed of grey clayey siltstone interbedded with darker and compact silty clay. Bedding planes are horizontal-undulating. The texture is usually disrupted by small bioturbation structures. The basal portion of the member shows interbedding layers of calcareous sandstone and bioclastic arenaceous sandstone. Bioclasts are represented by fragments of bivalve shells. The siltstone beds often contain fragments of bivalve shells, whereas some clay beds contain small complete shells. The shell remains are distributed unevenly throughout the section, but most of them occur in the interval of 42.0–39.0 m. The upper part of the Member I contained infrequent ammonite remains (*Pseudocoscoceras?* sp. (depth 34.5 m); Parkinsoniidae gen. et sp. indet. (depth 34.6 m; 32.0 m)).

The interval 55.5–51.1 m contains a foraminiferal assemblage (Fig. 4), represented by *Ammodiscus subjurassicus* SARYTSHEVA & CHABAROVA, *Saccamina compacta* GERKE, and *Hyperammia* sp. From the level of 46.8 m, the foraminiferal assemblage changed, and the species diversity increased. The shells are here well preserved. *Lenticulina volganica* (DAIN), *L. mironovi* (DAIN), *Vaginulina dainae* (KOSYREVA) are common, whereas *Astacolus concinnus* (CHABAROVA), *Marginulina krylovae* MJATLIUK, *Darbyella kutzevi* DAIN, *Planularia instabilis* (TERQUEM) and *Dentalina plebeja* TERQUEM are less commonly found; *Ammodiscus subjurassicus* SARYTSHEVA & CHABAROVA, and *Saccamina compacta* GERKE are even more rare.

The lower half of the member contains the bivalves *Meleagrinnella echinata* (SMITH), *Liostrea multiformis* (KOCH) and *Thracia* sp. indet.

The total penetrated thickness of the member is 25.5 m.

The upper Member II is composed of grey and light-grey clays with thin layers of silt and occasional thin limestone beds with bivalve shells in the middle part of section. Bivalves are also found in clays, mainly between 29.3–13.1 m of the core. The texture of clay often distorted by small bioturbation structures, which become less common upward in the section. In the upper part of the core, beginning from the depth of ca. 8.0 m, traces of bioturbation are

absent or represented by occasional pyritized traces of boring bottom-dwelling organisms. In Member II, ammonites are uncommon. Their state of preservation only allows their identification in open nomenclature: Parkinsoniidae gen. et sp. indet. (depth 27.8 m; 4.5 m; 2.5 m), *Parkinsonia* sp. (depth 15.6 m; 6.9 m; 6.4 m; 6.2 m; 6.0 m; 5.2 m; 4.7 m; 4.0 m), *Pseudocoscoceras* cf. *masarowici* MURASHKIN (29.45 m; 27.0 m).

P. masarowici MURASHKIN (MITTA & SELTZER 2002, pl. 6, fig. 2) and small-sized *Parkinsonia* sp. (MITTA et al. 2004, pl. 1, fig. 5; MITTA et al. 2011, pl. 2, fig. 3) were figured from the upper part of Member II in the earlier exposed part of section, which is now inaccessible. Belemnnoidea indet. (juvenile rostrum with a partly preserved phragmocone) was found in situ in the upper beds of this member (MITTA et al. 2004).

Foraminifers identified from the lower part of Member II include: *Lenticulina volganica* (DAIN), *L. mironovi* (DAIN), *Vaginulina dainae* (KOSYREVA), with infrequent *Planularia instabilis* (TERQUEM), *Astacolus concinnus* (CHABAROVA), *Darbyella kutzevi* DAIN, *Saccamina compacta* GERKE, *Lenticulina* sp. The upper horizons of the member, at the depth of 8 m contains *Ammodiscus arangastachiensis* NIKITENKO characteristic of the basin of the Pechora River and northern Siberia, in association with *Lenticulina volganica* (DAIN). Upward in the section, at a depth of 4.4 m, the foraminiferal assemblage is dominated by *Globulina praecircumphlua* GERKE. *Dentalina plebeja* TERQUEM, *Nodosaria sowerbyi* SCHWAGER, *Lenticulina* sp., *Astacolus* sp., some other species are also present (Fig. 4). The lower half of the member contains the bivalves *Meleagrinnella echinata* (SMITH).

The thickness of the member is up to 35 m.

Lower Bathonian (Fig. 2):

This interval is represented by a Member (III) of variously silty grey and dark-grey micaceous, non-calcareous clays, with infrequent scattered ferruginous nodules forming lenticular layers in the lower part and at the top. The bedding of deposits is horizontal-undulating, emphasized by light-grey silt and small-sized carbonaceous detritus. The texture is in places dis-

Fig. 5. Early Bathonian ammonites from the Sokur Quarry, Saratov, Central Russia; scale bar 10 mm. **1–4** – *Parkinsonia* spp., lateral view; Besnosovi Zone; 1 – PIN RAS 5029/138, 2 – PIN RAS 5029/139, 3 – PIN RAS 5029/140, 4 – PIN RAS 5029/141. **5** – *Oraniceras besnosovi* MITTA & SELTZER, 2002, a: lateral view; b: ventral view; Besnosovi Zone; PIN RAS 5029/142. **6** – *Arcticoceras harlandi* RAWSON, 1982, a: lateral view; b: ventral view; Ishmae Zone; PIN RAS 5029/143.

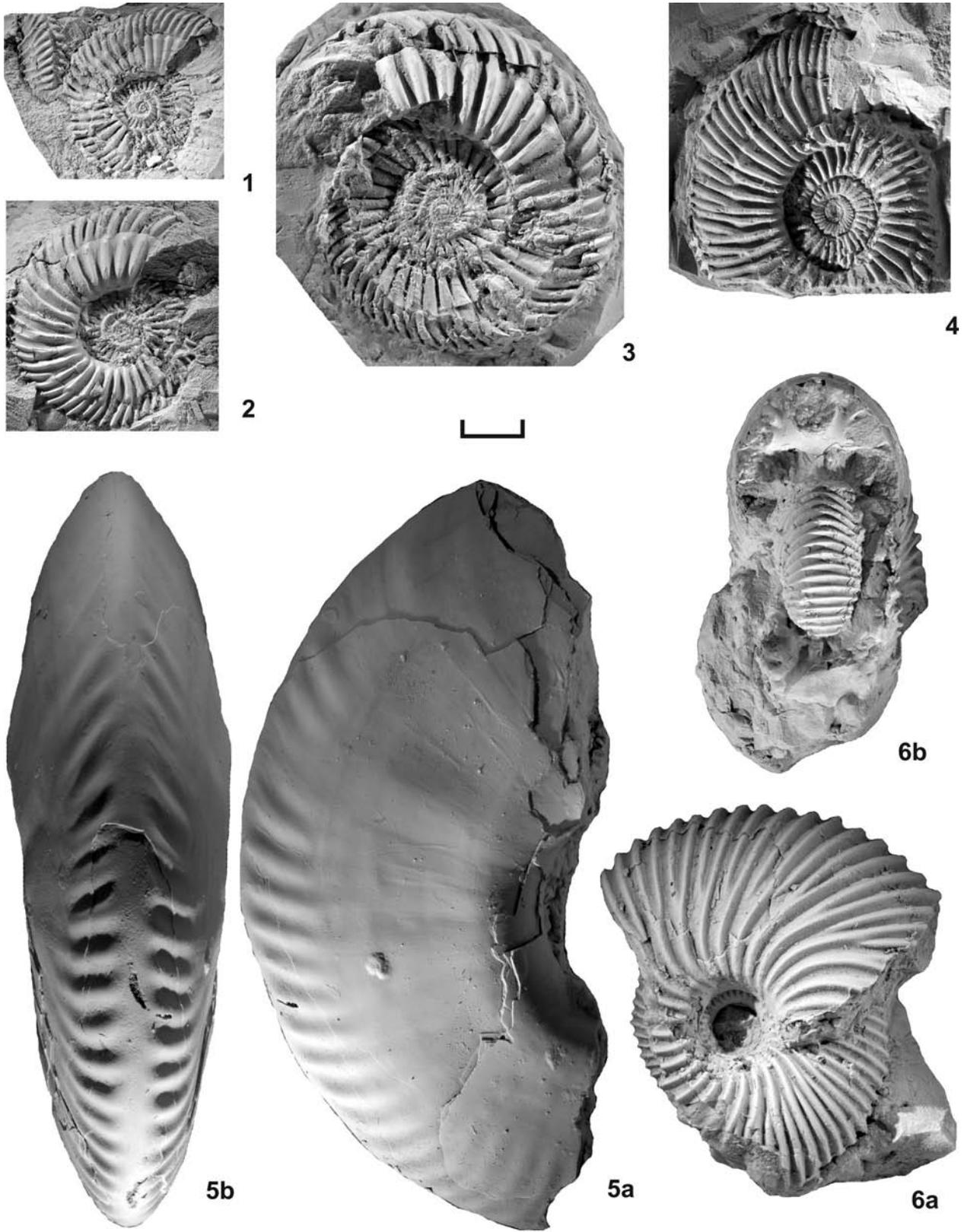


Fig. 5.

torted by bioturbation. The upper part of the Member III contains a layer of light-grey homogenized massive clays, up to 1.0 m thick. The basal boundary of the bed is erosional.

Detailed examination of the member showed that the interval of ca. 4 m above the “belemnite level” was previously overlooked. As a result, the thickness of the interval between the marker “belemnite level” and the base of the silty Member IV (base of Bed 6 in MITTA et al. 2004, 2011) was indicated as being approximately 1.4 m, whereas it is 5.4 m. The gap in observations resulted from the poor exposure of this part of the section in the previously excavated quarry walls. The member is well characterized by fossils, which are especially numerous and taxonomically diverse in its middle part (ammonites, belemnites, bivalves, gastropods, teeth and reptilian vertebra, crinoid columns and microfossils), near the bed with diverse belemnite rostra and accompanying remains of other molluscs (“belemnite level”). Beds and lenses with belemnite rostra and bivalve shells are also found upward in the section, but this level is the most consistent laterally. Upward in the section, the number of fossils gradually decreases, and only crinoid columns are found at the top of the member.

The lower 4.5 m of the Member III contain infrequent *Parkinsonia* spp. mainly represented by small, completely crushed shells (MITTA et al. 2011, pl. 2, fig. 2; here Figs. 5.1-5.4, 6.3-6.4). A thin (up to 0.8 m) interval of the basal part of the member contains *Oranicerias* cf. *mojarowskii* (MASAROWICH), whereas the first *Oranicerias besnosovi* MITTA & SELTZER appear (MITTA & SELTZER 2002, pl. 5, fig. 1; pl. 6, fig. 3; pl. 7, figs. 2-3; MITTA et al. 2004, pl. 1, fig. 1; here Figs 5.5a-b, 6.2) as well as the only specimen of *Sokurella galaczi* MITTA found *in situ* (coll. by S.A. BRATASHOVA). The same portion of the section was also marked by the first *in situ* occurrences of “*Arctocephalites*” and *Arcticoceras harlandi* RAWSON (Figs. 5.6a-b, 6.1a-b). The interval of distribution of the index species of the Besnosovi Zone is 1.5 m. *Arcticoceras harlandi* RAWSON (MITTA et al. 2011, pl. 1, fig. 5) and the last *Oranicerias* sp. are found upward in the section, 0.5 m below the “belemnite level”. Beds immediately below the “belemnite level” contain *Arcticoceras harlandi* RAWSON (MITTA & SELTZER 2002, pl. 1, fig. 1); apparently the same level yielded “*Arctocephalites*” sp. (MITTA & SELTZER 2002, pl. 4, fig. 2). The “belemnite level” yielded *Arcticoceras ishmae* (VON KEYSERLING) morph α (MITTA et al. 2011, pl. 2, fig. 1), whereas a

later morph of this species (β according to CALLOMON 1993) is found upward in the section (MITTA & SELTZER 2002, pl. 3, fig. 1).

Belemnites are found throughout almost the entire Member III. Their rostra are only absent in the basal 1 m and the upper 1.5 m of the member. Previously all rostra identified to species level came from a thin (0.35 m) interval including the “belemnite level” (MITTA et al. 2004, 2011). Newly collected material allowed identifying the taxonomic composition through the whole Member III (Fig. 4). In the interval below the “belemnite level”, belemnites are mainly represented by the rostra of *Cylindroteuthidae*, e.g., *Pachyteuthis bodylevskii* SACHS & NALNJAIEVA (Fig. 7.1-7.3, 7.10) and *P. optima* SACHS & NALNJAIEVA (Figs. 7.9, 8.1, 8.2). The “belemnite level”, apart from *P. bodylevskii* and *P. optima*, contains two species of the Megateuthidae – *Paramegateuthis parabella* (BARSKOV) and *P. bella* (BARSKOV), previously described as species of the genus *Nannobelus* of the family Nannobelidae (MITTA et al. 2004). We discovered the oldest representatives of the genus *Paramegateuthis* in the Sokur Quarry, 1.0 m below the “belemnite level” (Fig. 7.6). The last representatives of the genus *Paramegateuthis* were found 1.9 m above the same marker level (Fig. 7.5). Above the “belemnite level”, belemnites are distributed unevenly, mainly as isolated rostra scattered in clayey beds. Only in the interval 3.5-4.0 m below the top of the member, there are accumulations of rostra of *Pachyteuthis*, usually with remains of other fossils. The upper part of the member contains exclusively rostra of *P. optima* (Fig. 8.3, 8.4), mainly poorly preserved.

The taxonomic composition of belemnite assemblages, previously established for Member III was the subject of a debate between I.S. BARSKOV (in MITTA et al. 2004, 2011) and T.I. NALNJAIEVA (in MELEDINA et al. 2009). Rostra of *Pachyteuthis subrediviva* (LEMOINE) identified by BARSKOV (in MITTA et al. 2004: 24, pl. 4, figs. 1-4) were assigned by NALNJAIEVA to *P. optima* SACHS & NALNJAIEVA and to ?*Cylindroteuthis* sp. (MELEDINA et al. 2009). In this paper, all these rostra are identified as *P. optima* (Table 1) because their ventral groove is very weakly developed, which is not characteristic of typical *P. subrediviva*. In addition, the age of belemnites from the Sokur Quarry is considerably older than the range of *P. subrediviva*, which appears in the Boreal Jurassic sections in the Upper Bathonian (MELEDINA et al. 1998; DZYUBA 2004; SHURYGIN et al. 2000, 2011). However, some *P. optima* rostra from the Sokur Quarry differ from typical representatives of *P.*

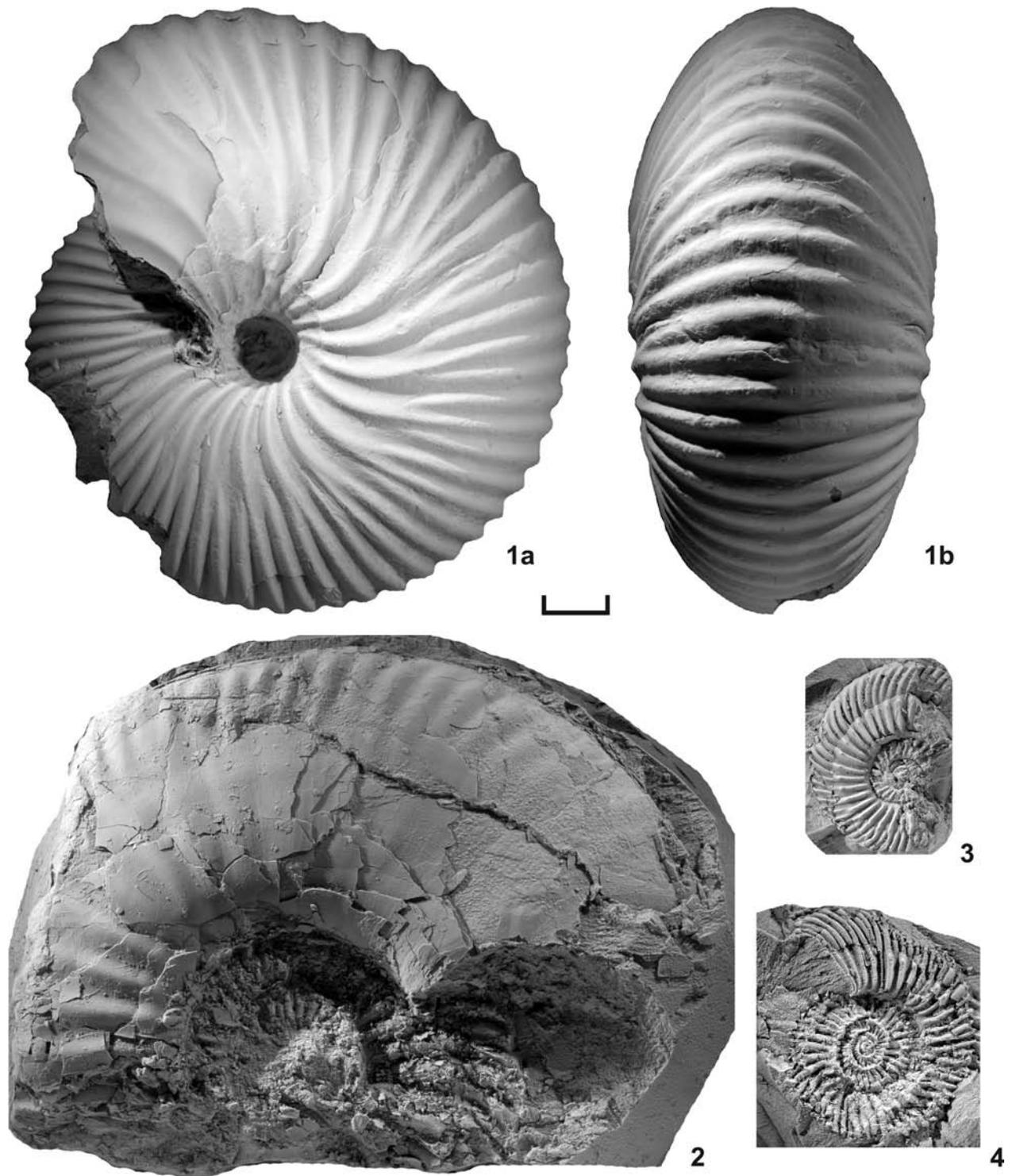


Fig. 6. Early Bathonian ammonites from the Sokur Quarry, Saratov, Central Russia; scale bar 10 mm. **1** – *Arcticoceras harlandi* RAWSON, 1982, a: lateral view; b: ventral view; Ishmae Zone; PIN RAS 5029/144. **2** – *Oraniceras besnosovi* MITTA & SELTZER, 2002, lateral view; Besnosovi Zone; PIN RAS 5029/145. **3, 4** – *Parkinsonia* spp., lateral view; Besnosovi Zone: 3 – PIN RAS 5029/146, 4 – PIN RAS 5029/147.

Table 1. Controversies about the taxonomic affiliation of belemnites from the Sokur section.

BARSKOV in MITTA et al. 2004	NALNJAeva in MELEDINA et al. 2009	DZYUBA (this paper)
<i>Paramegateuthis</i> cf. <i>pressa</i> NALNJAeva: pl. 3, figs. 1-2	<i>Paramegateuthis</i> cf. <i>pressa</i> NALNJAeva	<i>Paramegateuthis bella</i> (BARSKOV)
<i>Paramegateuthis</i> cf. <i>manifesta</i> NALNJAeva: pl. 3, figs. 3-4	<i>Paramegateuthis</i> cf. <i>manifesta</i> NALNJAeva	<i>Paramegateuthis parabella</i> (BARSKOV)
<i>Nannobelus bellus</i> BARSKOV: pl. 3, figs. 5-6	<i>Brachybelus</i> or <i>Mesoteuthis</i>	<i>Paramegateuthis bella</i> (BARSKOV)
<i>Nannobelus parabellus</i> BARSKOV: pl. 3, figs. 7-8	<i>Brachybelus</i> or <i>Mesoteuthis</i>	<i>Paramegateuthis parabella</i> (BARSKOV)
<i>Pachyteuthis subrediviva</i> (LEMOINE): pl. 4, figs. 1-2, pl. 4, fig. 3	<i>Pachyteuthis optima</i> SACHS & NALNJAeva ? <i>Cylindroteuthis</i> sp.	<i>Pachyteuthis optima</i> SACHS & NALNJAeva <i>Pachyteuthis optima</i> SACHS & NALNJAeva
BARSKOV in MITTA et al. 2011		
<i>Cylindroteuthis spathi</i> SACHS & NALNJAeva: pl. 1, figs. 1-3	–	Juveniles of <i>Pachyteuthis optima</i> SACHS & NALNJAeva or <i>P. bodylevskii</i> SACHS & NALNJAeva

optima (SACHS & NALNJAeva 1966: 20, pl. 1, fig. 2; pl. 2, figs. 1-4; text-fig. 2) in the more rounded transverse section and a more elongated shape, as previously indicated by MITTA et al. (2004), which was the reason of their preliminary assignment to *P. aff. subrediviva* and the proposed erection of a new species in the future (MITTA et al. 2012b). More attentive study of the entire material showed that the differences between the rostra from the Sokur Quarry and those of *P. optima* of the type collection from the Izhma River (Pechora Basin) are more likely intraspecific than interspecific. In the entire succession of Member III occurrences of

forms resembling the non-typical *P. optima* (MITTA et al. 2004, pl. 4, figs. 2-3) are accompanied by rostra (Fig. 8.1, 8.2; MITTA et al. 2004, pl. 4, fig. 1) very similar to the holotype of *P. optima*. On average, the greater elongation of the specimens of *P. optima* from the Sokur Quarry does not exceed the limits of variability of this species established by SACHS & NALNJAeva (1966), whereas the deviation of the shape of the transverse section from trapezoid to rounded subquadrate was already noted in the rostra from Kong Karls Land (DOYLE & KELLY 1988: 30, pl. 6, figs. 1-5, (?) 6-8) and Siberia (DZYUBA 2000: 348, pl. 1, fig. 8). Rostra

Fig. 7. Early Bathonian belemnites from the Sokur Quarry, Saratov, Central Russia; scale bar 10 mm. **1–3, 10** – *Pachyteuthis bodylevskii* SACHS & NALNJAeva, Besnosovi Zone; 1.9–2.0 m below the “belemnite level”: 1 – CSGM in IGM SB RAS 256/1: a – ventral view, b – right lateral view; 2 – CSGM in IGM SB RAS 256/2: a – transverse section near the anterior end, b – ventral view, c – left lateral view; 3 – CSGM in IGM SB RAS 256/3: a – ventral view, b – left lateral view, c – transverse section near the anterior end; d – transverse section slightly above the tip of the alveolus; 10 – CSGM in IGM SB RAS 256/10: a – ventral view, b – left lateral view, c – transverse section slightly above the tip of the alveolus; **4, 5, 8** – *Paramegateuthis parabella* (BARSKOV): 4 – Ishmae Subzone; “belemnite level”; CSGM in IGM SB RAS 256/4: longitudinal section; 5 – *Retroceramus vagt* B-Zone; 1.9 m above the “belemnite level”; CSGM in IGM SB RAS 256/5: a – ventral view, b – right lateral view, c – dorsal view; d – transverse section near the anterior end; 8 – Harlandi Subzone; 0.2 m below the “belemnite level”; CSGM in IGM SB RAS 256/8: a – ventral view, b – left lateral view, c – dorsal view; d – transverse section near the anterior end; **6, 7** – *Paramegateuthis bella* (BARSKOV): 6 – Harlandi Subzone; 1.0 m below the “belemnite level”; CSGM in IGM SB RAS 256/6: a – ventral view, b – right lateral view, c – dorsal view; d – transverse section near the anterior end; 7 – rounded rostrum from the *Retroceramus vagt* B-Zone; 1.5 m above the “belemnite level”; CSGM in IGM SB RAS 256/7: a – ventral view, b – left lateral view, c – dorsal view; d – transverse section near the anterior end; **9** – *Pachyteuthis optima* SACHS & NALNJAeva, Besnosovi Zone; 1.0–1.2 m below the “belemnite level”; CSGM in IGM SB RAS 256/9: a – ventral view, b – left lateral view; c – transverse section near the anterior end.

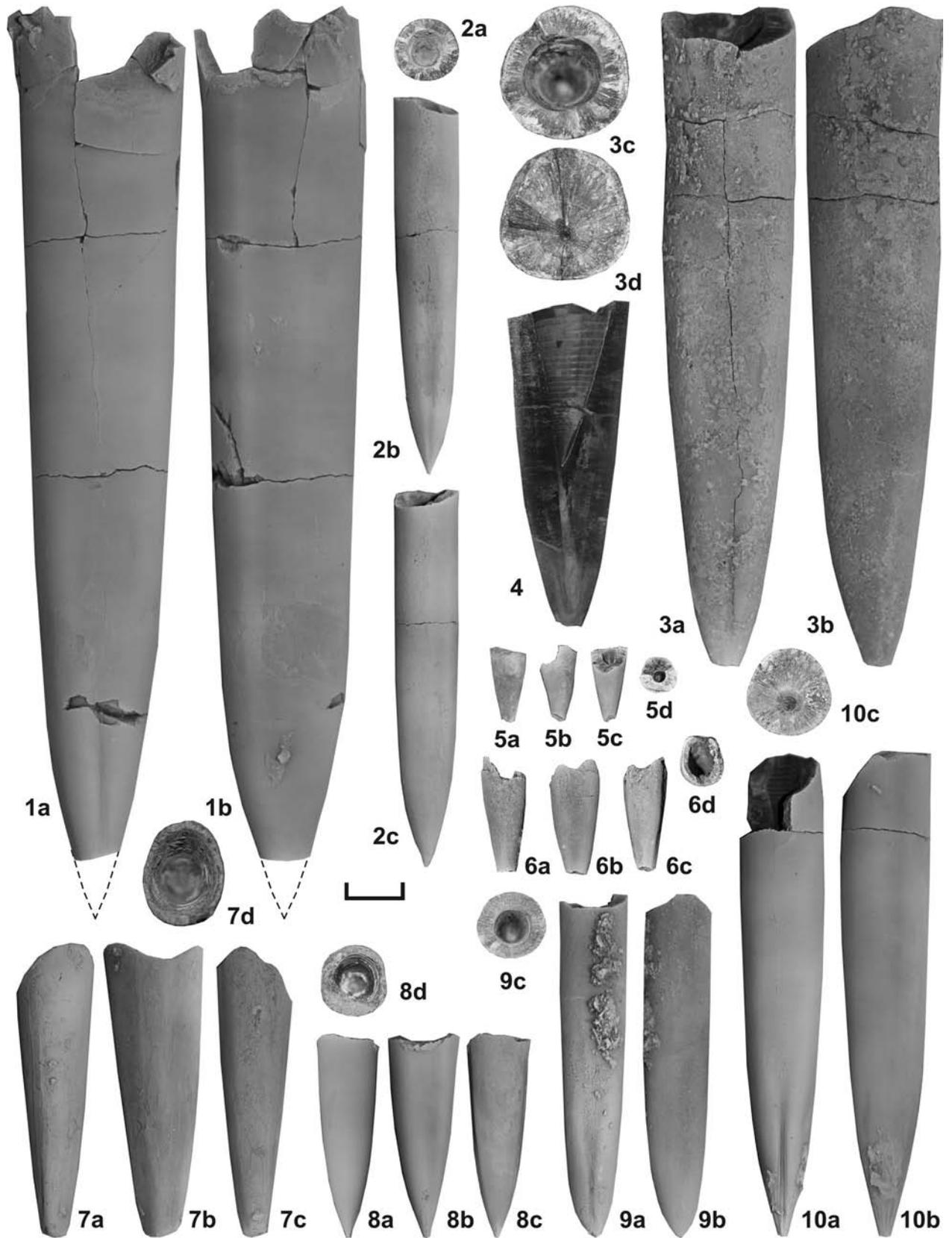


Fig. 7.

previously identified as *Cylindroteuthis spathi* SACHS & NALNJAIEVA (MITTA et al. 2011, pl. 1, figs. 1-3) most likely belong to juveniles of *Pachyteuthis optima* or *P. bодylevskii* SACHS & NALNJAIEVA. None of the figured belemnites from the Sokur Quarry had an elongation similar to that of *Cylindroteuthis*. Representatives of that genus were not found in the field seasons of 2012 and 2013.

Problems of generic assignment of rostra to *Nannobelus* were previously discussed in detail (BARSKOV in MITTA et al. 2004, 2011; NALNJAIEVA in MELEDINA et al. 2009). These are small, short and robust, conical rostra with an acute apex. Their profile is asymmetrical. Transverse sections of rostra are compressed, subcircular or elliptical. No traces of apical or alveolar grooves are present, though the apex may bear striae. Lateral lines consist of a broad dorsolateral depression, with a narrower and a less obvious depression below it. The apical line goniolineate (Fig. 7.4), the tip of alveolus is ventrally displaced, the phragmocone penetrates three fifth to two thirds of the rostrum. The Early Jurassic *Nannobelus* (non *Nannobelus* sensu SACHS & NALNJAIEVA 1970; see DOYLE 1991, 1994) rostra differ from these specimens by their symmetrical profile, weaker lateral lines, the ortholineate apical line and the smaller depth of penetration of the phragmocone. According to MELEDINA et al. (2009), '*Nannobelus*' specimens from Sokur section also resemble *Brachybelus* (= *Brevibelus*; see DOYLE 1992) and *Mesoteuthis*. However, *Brevibelus* can be distinguished by its less acute apex without striae, and cyrtolineate apical line. Based on the description given by WEIS & MARIOTTI (2007), *Mesoteuthis* is larger and more elongated, and shows two dorsolateral apical grooves and a diffuse apical line.

Only *Paramegateuthis* identified in open nomenclature have not been a subject of discussion. However, the rostra described as *P. cf. manifesta* NALNJAIEVA (MITTA et al. 2004: 22, pl. 3, figs. 3-4) are too short for this species. They are not similar to other known species of *Paramegateuthis*. They are similar to the associated rostra '*Nannobelus*' *parabellus* BARSKOV (MITTA et al. 2004: 19, pl. 3, figs. 7-8), except the latter lacks dorsolateral grooves. The similarity is also observed between '*Nannobelus*' *bellus* BARSKOV (MITTA et al. 2004: 19, pl. 3, figs. 5-6) and *Paramegateuthis* cf. *pressa* NALNJAIEVA (MITTA et al. 2004: 22, pl. 3, figs. 1-2). In addition, in *P. cf. pressa*, according to its description (ibid.), the dorsolateral grooves look like deep depressions extending along the entire rostrum's length, which is also characteristic of '*Nannobelus*' *bellus*. The greater lateral compression of specimens of *P. cf. pressa* figured by MITTA et al. (2004: 22, pl. 3, figs. 1-2, specimens CR-2784 and CR-2785) compared to other rostra identified under that name (MITTA et al. 2004: 22, specimens CR-2803, CR-2804 and CR-2805), and compared to the rostra of '*Nannobelus*' *bellus*, looks most likely to be a product of intraspecific variability. Therefore, all rostra of '*Nannobelus*' *bellus* and '*Paramegateuthis* cf. *pressa*' examined above are interpreted here as *Paramegateuthis bella* (BARSKOV). They cannot be assigned to *P. pressa*, which differs in possessing a shorter sheath-like form with a more conical profile. Apparently we here have two aberrant species of the genus *Paramegateuthis* – *P. parabella* (BARSKOV) and *P. bella* (BARSKOV) (Table 1), in which the dorsolateral grooves are not a stable characters even in early ontogeny, and completely disappear in adults (Fig. 7.5-7.8). It is known that dorso-

Fig. 8. Early Bathonian belemnites and bivalves from the Sokur Quarry, Saratov, Central Russia; scale bar 10 mm. **1, 2, 4** – *Pachyteuthis optima* SACHS & NALNJAIEVA: 1, 2 – Besnosovi Zone; 1.0-1.2 m below the “belemnite level”; 1 – CSGM in IGM SB RAS 256/11: a – ventral view, b – left lateral view; c – transverse section near the anterior end, d – transverse section in the apical region; 2 – CSGM in IGM SB RAS 256/12: a – ventral view, b – left lateral view; c – transverse section near the anterior end; 4 – *Retroceramus vagt* B-Zone; 1.9 m above the “belemnite level”; CSGM in IGM SB RAS 256/14: a – ventral view, b – left lateral view; c – transverse section above the tip of the alveolus; **3** – *Pachyteuthis* cf. *optima* SACHS & NALNJAIEVA, ventral view; *Retroceramus vagt* B-Zone; 1.5 m below the top of member III; CSGM in IGM SB RAS 256/13; **5** – *Homomya obscondita* KOSCHELKINA, a: left valve, external view, b: both valves, dorsal view; Ishmae Zone; the “belemnite level”; CSGM in IGM SB RAS 256/15. **6** – *Camptonectes* ex gr. *lens* (J. SOWERBY), a: left valve, b: right valve; *Retroceramus bulunensis* B-Zone; 1.7-1.8 m below the top of the member III; CSGM in IGM SB RAS 256/16. **7** – *Protocardia* ex gr. *borissjaki* PČELINCEV, left valve, external view; *Retroceramus vagt* B-Zone; 1.7-1.8 m below the top of the member III; CSGM in IGM SB RAS 256/17. **8** – *Modiolus bipartitus* (J. SOWERBY), left valve, external view; Ishmae Zone; the “belemnite level”; CSGM in IGM SB RAS 256/18. **9** – *Liostrea eduliformis* (SCHLOTHEIM), the agglomeration of valves; *Retroceramus bulunensis* B-Zone; 1.7-1.8 m below the top of the member III; CSGM in IGM SB RAS 256/19.

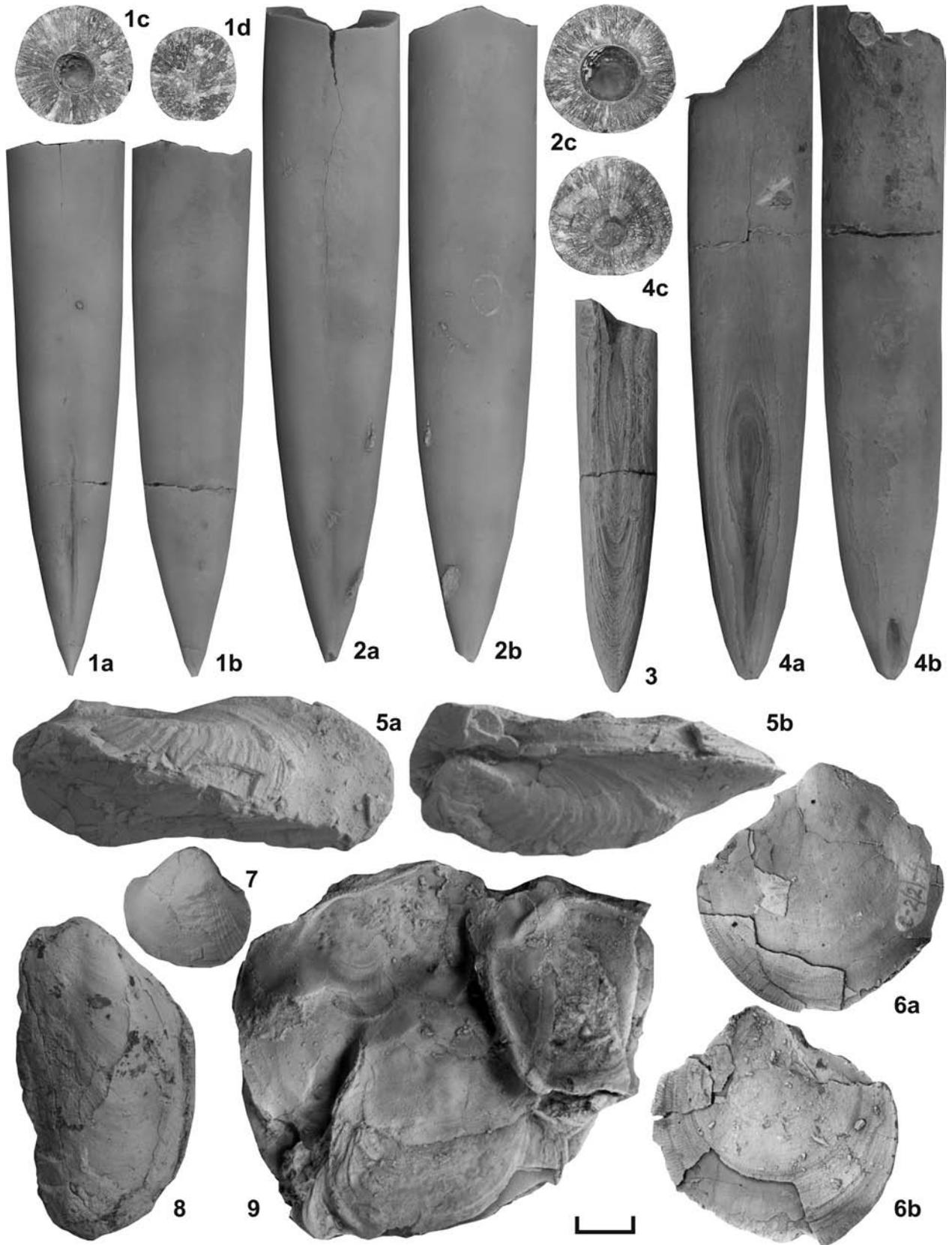


Fig. 8.

lateral grooves may not be present in all rostra of *Paramegateuthis*, although in most cases they are clearly observed (SACHS & NALNJAIEVA 1975).

The bivalve assemblages from this member (according to the 2012 and 2013 results) contain representatives of 22 genera (Figs. 4, 8-9). Taphonomic studies in the Sokur section showed that most bivalves were buried in situ or near sites they had inhabited. The preservation of specimens is good. The shells are not rounded, not preferentially oriented, and unsorted either by weight or by shape. In summary, bivalve shells are classified as autochthonous. At the same time, the section contains infrequent small lenses with complete shells and fragments of bivalves and belemnite rostra of various degree of roundness, which indicate allochthony of these fossils. Various levels in the member (Fig. 4) showed representatives of *Phaenodesmia sobetskii* ROMANOV, *Malletia* ex gr. *valga* SHURYGIN, *Protocardia* ex gr. *borissjaki* PČELINCEV, *Arctica humiliculminata* SHURYGIN, *Goniomya vscripta* (J. SOWERBY), *Liostrea eduliformis* (SCHLOTHEIM), *Pinna* cf. *mitis* PHILLIPS, *Tancredia* sp. indet., and *Homomya obscondita* KOSCHELKINA. The lower portion of the member apart from the above species contains *Modiolus bipartitus* (J. SOWERBY), *Pleuromya* cf. *uniformis* (J. SOWERBY), *Dacryomya* sp. indet., *Astarte* sp. indet., *Entolium demissum* (PHILLIPS), *Meleagrinnella echinata* (SMITH), *Myopholas* sp., *Aguilerella* sp. indet., *Thracia* sp. indet., whereas the upper part contains *Striatomodiolus* sp. indet., *Camptonectes* ex gr. *lens* (J. SOWERBY), and *Mclearnia* sp. indet. In addition, the member contains species of *Retroceramus*, the succession of appearance of which in the section corresponds to that in Siberian sections (SHURYGIN et al. 2011). In the lower portion of the member *R. bulunensis* KOSCHELKINA was found below the marker “belemnite level” and immediately above it. It is replaced approximately 0.40-0.50 m above the marker level by *R. vagt* KOSCHELKINA and *R. cf. vagt*. Judging from the elongated shell, relatively short wing and characteristic ontogeny, a loosely col-

lected shell previously figured by MITTA et al. (2004, pl. 7, fig. 4, pl. 8, fig. 1) as *R. retrorsus* (KEYSERLING) should also be assigned to *R. vagt*. The shell of *R. polaris* was found at the 2.0 m below the “belemnite level” (unfortunately, this shell has been crushed).

The foraminiferal assemblage of Member III includes *Saccamina compacta* GERKE (Fig. 10.1), *Lenticulina volganica* (DAIN) (Fig. 10.8), *L. mironovi* (DAIN) (Fig. 10.10-10.11), *L. incurvare* GERKE & SCHAROVSKAJA (Fig. 10.13), *Vaginulina dainae* (KOSYREVA) (Fig. 10.19), *Darbyella kutzevi* DAIN, *Dentalina plebeja* TERQUEM, *Globulina praecircumphlua* GERKE (Fig. 10.22), *Nodosaria sowerbyi* SCHWAGER, *Marginulinopsis praecomptulaformis* GERKE & SCHAROVSKAJA (Fig. 10.14-10.15), *Kutsevelia memorabilis* SCHAROVSKAJA (Fig. 10.4), *Pseudonodosaria* ex gr. *brandi* TAPPAN (Fig. 10.6), *Citharina arangastachiensis* NIKITENKO (Fig. 10.17), *Astacolus* sp. (Fig. 10.16), and *Ichthyolaria* sp. (Fig. 10.5) and some other taxa (Fig. 4). The upper part of Member III (1 m below the top) contains a very different foraminiferal assemblage. All calcareous taxa disappear, and only small agglutinated *Ammodiscus* cf. *baticus* DAIN and *Saccamina* sp. are present (Fig. 4).

Middle? Bathonian:

This unit overlies the clay of Member III with no visible gap. The yellowish grey silt and micaceous finely arenaceous (Member IV) represent the Middle? Bathonian. Deposits strongly bioturbated at the base. The bedding surfaces show by clear trace fossils (crawling traces). The interval 3.5-3.9 m above the base of the member contains a bed of strongly lithified calcareous dark brownish (on the weathered surface), ferruginous siltstone, 0.3-0.4 m thick. The lower and upper boundaries of the bed are clear and even. No macro- or microfossils are discovered in Member IV. The visible thickness of the Member IV is up to 8 m.

Members I-III commonly contain gastropod shells, identified by J. GRÜNDEL from the exposed section

Fig. 9. Early Bathonian bivalves from the Sokur Quarry, Saratov, Central Russia; scale bar 10 mm. **1** – *Retroceramus vagt* KOSCHELKINA, a: both valves, posterior view, b: right valve (deformed), external view, c: both valves, dorsal view; *Retroceramus vagt* B-Zone; 2.0-2.2 m below the top of the member III; CSGM in IGM SB RAS 256/20. **2, 4** – *Retroceramus bulunensis* KOSCHELKINA; Ishmae Zone; *Retroceramus bulunensis* B-Zone; 0.5 m below the “belemnite level”: **2** – left valve, external view, CSGM in IGM SB RAS 256/21, **4** – right valve, juv., external view, CSGM in IGM SB RAS 256/22. **3** – *Retroceramus* cf. *vagt* KOSCHELKINA, right valve (fragment), external view; Ishmae Zone; *Retroceramus vagt* B-Zone; 0.5 m above the “belemnite level”, CSGM in IGM SB RAS 256/23.

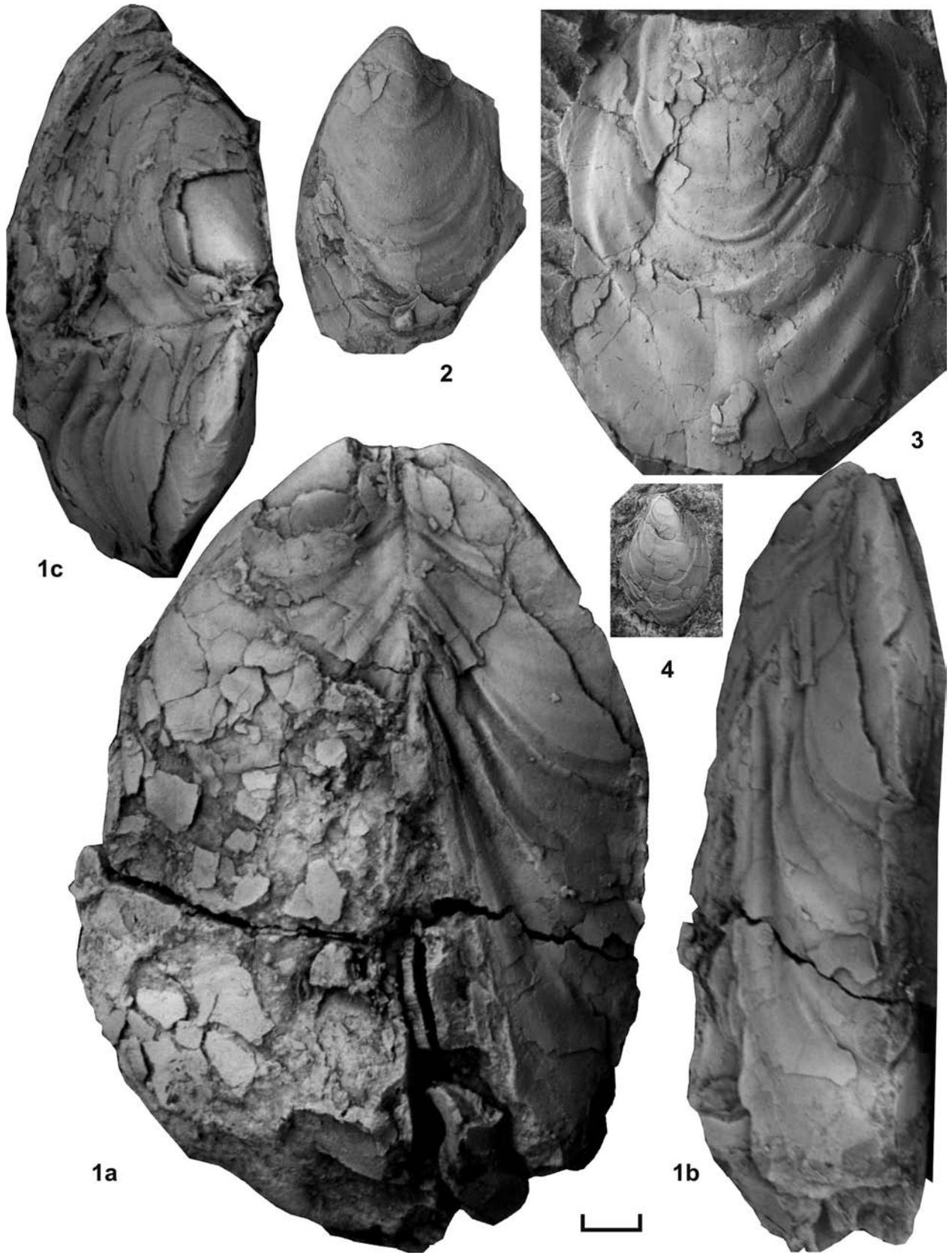


Fig. 9.

(MITTA et al. 2004) and from the borehole (collected by LG), all shown in Figs. 3 and 4. Crinoid columns are found in accumulations within “belemnite level” and in the very top of Member III. The upper portion of the upper part of Member III also contained a tooth of a marine reptile (MITTA et al. 2012b, pl. 3, fig. 1), identified by M.S. ARKHANGELSKY as Ichthyosauria indet. (pers. comm.).

4. Biostratigraphy

Material collected in 2012 added to the previously collected fossils. This includes macrofossils, primarily cephalopods and bivalves (retroceramids important for biostratigraphy) and microfossils (foraminifers). The latter were especially important to characterize the lower portion of the section (in the borehole), that contained few ammonites that could be identified to species.

The first ammonites, identified from the upper part of member I (depth 32 m) as *Pseudocosmoceras* sp. and Parkinsoniidae gen. et sp. indet., are also found throughout Member II (which also contains numerous small-sized *Parkinsonia* spp. and occasional *Pseudocosmoceras* cf. *masarowici* MURASHKIN). This allows

the assignment of Members I and II to the Upper Bajocian Michalskii Zone. The lower boundary of this zone is drawn provisionally, based on the first appearance of *Pseudocosmoceras*, although, considering the taxonomic composition of bivalves (*Meleagrinnella*, *Liostraea*, *Thracia*, etc.), the entire underlying part of the section might be assigned to the same zone. However, bivalves found in members I and II are biostratigraphically not diagnostic, because they are represented by species found across the entire Upper Bajocian-Lower Bathonian, and even in most of the Middle Jurassic.

The basal portion of Member III (ca. 0.8 m thick) contains *Parkinsonia* spp. and, less commonly, *Oranicerias* cf. *mojarowskii* (MASAROWICH). The overlying beds also contain frequent *Parkinsonia* spp., but also *Oranicerias besnosovi* MITTA & SELTZER, infrequent “*Arctocephalites*” ex gr. *frebaldi* (SPATH) and, apparently, *Sokurella galaczi* MITTA (MITTA 2004). The last confirmed *Oranicerias besnosovi* were found 1.2 m below the “belemnite level”, 0.2 m below the first confirmed appearance of *Arcticoceras harlandi* RAWSON. Previously, the lowermost occurrence of this species was fixed in the section 0.5 m below the “belemnite level” (MITTA et al. 2011, pl. 1, fig. 5), in association with *Oranicerias* sp.

Fig. 10. Late Bajocian – Early Bathonian foraminifers from the Sokur Quarry, Saratov, Central Russia. **1** – *Saccamina compacta* GERKE, LG-01, lateral view, X 116; Ishmae Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 15f. **2** – *Ammodiscus subjurassicus* SARYTCHEVA & CHABAROVA, LG-02, lateral view, X 116; Michalskii Zone; *Ammodiscus subjurassicus* – *Lenticulina saratovensis* F-Zone, sample 1f. **3** – *Ammodiscus arangastachiensis* NIKITENKO, LG-03, lateral view, X 24; Michalskii Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 9f. **4** – *Kutsevella memorabilis* (SCHAROVSKAJA), LG-04, lateral view, X 77; Besnosovi Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 12f. **5** – *Ichthyolaria* sp., LG-05, X 66; Ishmae Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 16f. **6** – *Pseudonodosaria* ex gr. *brandy* (TAPPAN), LG-06, X 91; Ishmae Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 17f. **7, 8** – *Lenticulina volganica* (DAIN), 7- LG-07, lateral view, X 48; Michalskii Zone; *Lenticulina volganica* – *Vaginulina dainae* F-Zone, sample 5f; 8 – LG-08, lateral view, X 57; Ishmae Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 16f. **9, 10, 11, 12** – *Lenticulina mironovi* (DAIN), 9 – LG-09, lateral view, X 97; Michalskii Zone; *Lenticulina volganica* – *Vaginulina dainae* F-Zone, sample 3f; 10 – LG-10, lateral view, X 127; Ishmae Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 13f; 11 – LG-11, ventral view, X 100; Ishmae Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 15f; 12 – LG-12, lateral view, X 72; Michalskii Zone; *Lenticulina volganica*–*Vaginulina dainae* F-Zone, sample 5f. **13** – *Lenticulina incurvare* GERKE & SCHAROVSKAJA, LG-13, lateral view, X 111; Besnosovi Zone; *Trochammina* aff. *praesquamata* F - Zone, sample 12f. **14, 15** – *Marginulinopsis praecomptulaformis* (GERKE & SCHAROVSKAJA), 14 – LG-14, lateral view, X 105; Besnosovi Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 12f; 15 – LG-15, lateral view, X 106; Besnosovi Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 11f. **16** – *Astacolus* sp., LG-16, lateral view, X 76; Besnosovi Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 12f. **17** – *Citharina arangastachiensis* NIKITENKO, LG-17, lateral view, X 40; Ishmae Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 17f. **18, 19** – *Vaginulina dainae* (KOSYREVA), 18 – LG-18, lateral view, X 69; Michalskii Zone; *Lenticulina volganica*–*Vaginulina dainae* F-Zone, sample 3f; 19 – LG-19, lateral view, X 67; Ishmae Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 16f. **20, 21, 22** – *Globulina praecircumphlua* GERKE, 1968, 20 – LG-20, X 120; 21 – LG-21, X 86; Michalskii Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 10f; 22 – LG-22, X 120; Besnosovi Zone; *Trochammina* aff. *praesquamata* F-Zone, sample 11f.

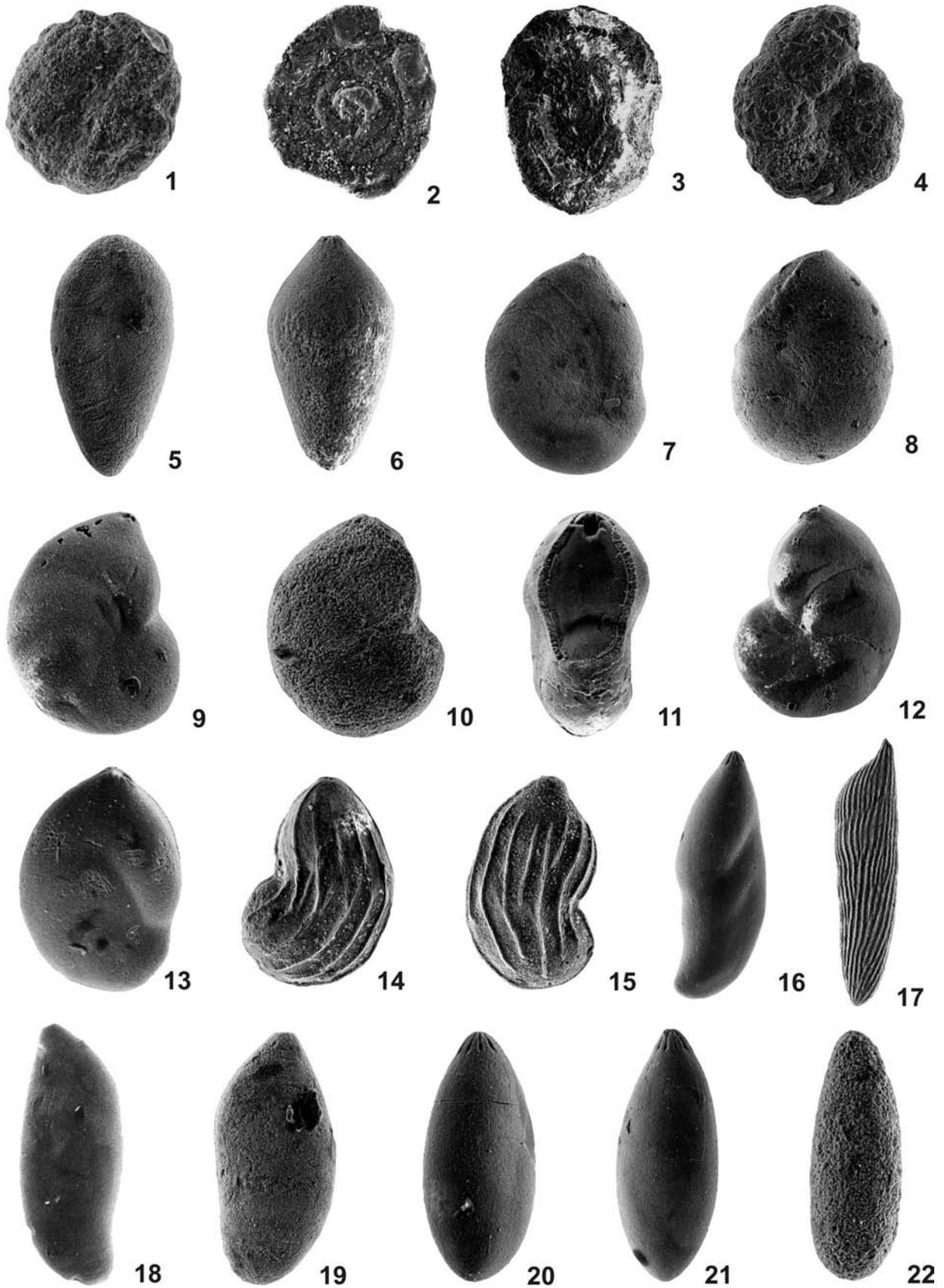


Fig. 10.

Figured fossils from the “belemnite level” previously included *Arcticoceras ishmae* (v. KEYSERLING) (morph α , after CALLOMON 1993) (MITTA et al. 2011, pl. 2, fig. 2), and a specimen of morph β of the same species found somewhat above (MITTA & SELTZER 2002, pl. 3, fig. 1). A microconch specimen of *A. ishmae* β was also found 0.4 m above the “belemnite level” (MITTA et al. 2012b, pl. 2, fig. 2).

This succession of ammonites from Member III suggests the presence of at least three distinct ammonite-bearing strata: with *Oraniceras* and “*Arctocephalites*”, with *Arcticoceras harlandi* and *Oraniceras* sp., below the “belemnite level”, and with *Arcticoceras ishmae* above it. The interval of distribution of *Oraniceras* in Peri-Tethyan regions corresponds to the Convergens and Macrescens subzones of the Standard Zigzag Zone, which should approximately correspond to the Besnosovi Zone. The association of the last *Oraniceras* with the first *Arcticoceras* certainly indicates an Early Bathonian age of the Harlandi Subzone of the Ishmae Zone, which corresponds to the upper part of the Zigzag Zone of the Standard scale. The range and rank of the “*Arcticoceras*” beds are interpreted differently by different authors. POULTON (1987) recognized the separate Harlandi and Ishmae Zones, whereas CALLOMON (1993) recognized the Ishmae Zone with the faunal horizons *harlandi*, *ishmae* α , *ishmae* β , and *crassiplicatum*. In this paper we follow MELEDINA (1987) and accept the Ishmae Zone, with the Harlandi and Ishmae subzones. The *crassiplicatum* Horizon is probably Middle Bathonian (MITTA & ALSÉN 2013).

The “belemnite level” probably characterizes an erosional level. However, judging from the ammonite succession, this gap corresponds to one faunal horizon (*ishmae* α), rather than two-three ammonite zones, as had been suggested by MELEDINA et al. (2009).

Beds above the “belemnite level” contain poorly preserved ammonites. The mould previously identified as *Parkinsonia* s.l. (MITTA & SELTZER 2002, pl. 5, fig. 2) should apparently belong to Arctocephalitinae (MELEDINA et al. 2009; MITTA et al. 2011). A small crushed ammonite specimen found 1.9 m above the “belemnite level” and identified in the field as Parkinsoniidae indet. (MITTA et al. 2012, fig. 1), probably also belongs to the Arctocephalitinae. Crushed shells of these taxa are difficult to distinguish when ventral ornamentation cannot be examined. Judging from its position in the section the Ishmae Subzone is also Lower Bathonian and corresponds to the upper part of the Zigzag Zone and the Tenuiplicatus Zone of the Standard scale. Taking in account the absence of distinct traces of erosion,

the upper boundary of the Ishmae Subzone is drawn provisionally, at the top of Member III.

Two intervals based on Boreal belemnites were recognized in the Sokur Quarry: beds with *Pachyteuthis optima* and *P. bodylevskii*, corresponding to the overlapping parts of the range zones of these species; and beds with *P. optima*, in which *P. bodylevskii* SACHS & NALNJAIEVA is absent (Fig. 2). It should be noted that, unlike ammonites and retroceramids, zonal Arctic belemnite species have not been found in the Sokur section. The species *P. bodylevskii* is recorded in the section for the first time. The earliest representatives of this species are known in Siberia, in the Pechora Basin and in the Kong Karls Land. In the Anabar Region of Siberia, the species was thought to occur in the *Arcticoceras kochi* Zone (e.g., SACHS 1976; ZAKHAROV & SHURYGIN 1978), which presently is interpreted as the Harlandi–Ishmae zones of the Boreal scale (SHURYGIN et al. 2000, 2011). Claims of this species having been found in association with the Bajocian ammonites of the genus *Cranocephalites* in the Yuryung-Tumus Peninsula (SACHS & NALNJAIEVA 1975; ZAKHAROV & SHURYGIN 1978) were not confirmed by subsequent, more detailed studies (MELEDINA et al. 1987). *P. bodylevskii* was recorded in association with *Arcticoceras ishmae* (v. KEYSERLING) at the Izhma River in the basin of the Pechora River (SACHS 1976). In Kong Karls Land this species was found in the upper part of the Passet Member that lacks ammonites (DOYLE & KELLY 1988: 29, pl. 5, figs. 15–17). These beds are overlain by the Retziusfjellet Member, the basal part of which yielded *Arcticoceras harlandi* RAWSON. The holotype of the species *P. bodylevskii* (SACHS & NALNJAIEVA 1966, pl. 3, fig. 2) comes from material collected by DIBNER (DIBNER & SHULGINA 1960) on the Hooker Island of the Franz Josef Land archipelago; it was indicated as coming from the Callovian, because in the 1960 *Arcticoceras*-containing beds were correlated as Callovian. The Upper Callovian rostrum from Bolshoi Begichev Island, known only from two photographs of transverse sections (SACHS & NALNJAIEVA 1966, pl. 3, fig. 3a, b), differs from the Bathonian *P. bodylevskii* in the less strongly flattened flanks and most likely belongs to a different, perhaps undescribed species of *Pachyteuthis*. Hence, most confirmed occurrences of *P. bodylevskii* in the Arctic sections come from the Harlandi and Ishmae subzones, though it may potentially be found in the underlying beds, judging by the data from Kong Karls Land; i.e. in the Arctic sections this species occurs in the same stratigraphic interval as in the Sokur section (Figs. 2, 4). The species *Pachy-*

teuthis optima SACHS & NALNJAIEVA, according to the data assembled by DZYUBA (2004), has a very wide geochronological range (Late Bajocian-Callovian) and is probably in need of revision. In the Sokur Quarry, the first appearance of *Paramegateuthis* is observed in the Lower Bathonian, at the base of Harlandi Subzone (Fig. 2). Nevertheless, in the vicinity of Saratov this genus is also known from the Bajocian, if we take into account the recorded by A.N. IVANOVA (1959: 365, pl. 16, fig. 1) '*Mesoteuthis*' *bajosicus* (= *Paramegateuthis* (?) *bajosicus* (IVANOVA), fide SACHS & NALNJAIEVA 1975: 59) from a borehole drilled on the right bank of the Volga River, near the Saratov. Belemnites of the genus *Paramegateuthis* are common in the Bajocian and Bathonian, and supposedly also Aalenian, of Arctic regions (e.g., DOYLE & KELLY 1988: Kong Karls Land; MELEDINA et al. 1998, 2005: Arctic Russia), but have also been recorded from the Upper Bajocian of Russian Far East (CHALLINOR et al. 1992) and the uppermost Aalenian-Lower Bajocian of Bulgaria (STOYANOVA-VERGILOVA 1983, 1990).

The bivalve assemblage found in the core borehole (members I and II) has no particular meaning (Fig. 4). Only the species *Meleagrinnella echinata* (SMITH) can be considered a characteristic species for the Bajocian and Bathonian of the Russian Platform. The lower part of the section, previously exposed in the quarry (upper part of Member II and Member III), but not observed in the course of the field work of 2012, according to earlier publications (MITTA et al. 2004, 2011) included representatives of *Meleagrinnella*, *Thracia*, *Oxytoma*, *Modiolus*, *Protocardia*, and a juvenile specimen of *Retroceramus* sp., the assemblage of which does not give a unequivocal definition of the age. In the lower part of Member III (Besnosovi Zone) we found a similar assemblage of bivalves. The bivalve assemblage from the overlying succession (with ammonites *Arcticoceras harlandi*, *A. ishmae* and the upper part of Member III without ammonites) is represented by both typically Boreal-Arctic, and Tethyan taxa. For instance, *Pinna* and *Goniomya*, characteristic of the bivalve assemblages of Tethyan and Lower Boreal regions, were found both in the lower and upper parts of Member III. Representatives of these genera in Siberian sections appear only in the Callovian and are characteristic of the Upper Jurassic assemblages of these regions. Species of *Retroceramus* found in this interval are biostratigraphically informative. Taking into account the range of typical species of *Retroceramus* in the section studied, it is possible to determine the position of two zones defined on bivalves in the Si-

berian sections: *Retroceramus bulunensis* and *R. vagt* (Figs. 2, 4). Their correlation with the cardioceratid-based zones in our section is very similar to that in the Siberian sections. The upper part of the zone based on the bivalve *Retroceramus bulunensis* corresponds to the lower part of the Ishmae Zone (with *Arcticoceras harlandi*), whereas the lower part of the bivalve *Retroceramus vagt* Zone corresponds to the upper part of the Ishmae Zone. The upper part of Member III, which lacks ammonites, also contains the index species of the *Retroceramus vagt* Zone, whereas the overlying Member IV does not contain bivalves. Because in the Siberian sections, which are well characterized by ammonites and *Retroceramus*, the range of the *Retroceramus vagt* Zone corresponds to the combined range of two ammonite zones, Ishmae and Cranocephaloide (SHURYGIN et al. 2011), it could be suggested that some upper part of Member III might belong to the ammonite Cranocephaloide Zone. MITTA et al. (2004, pl. 6, fig. 1) figured a loosely collected shell of *Retroceramus*, identified as *R. aff. polaris* KOSCHELKINA, whose identification as *R. polaris* is here confirmed. Hence it could be suggested that the beds with *Retroceramus bulunensis* in our section could also be underlain by layers equivalent to the Siberian bivalve *R. polaris* Zone, which in the type Siberian sections of the zone correlates with the lower part of the Greenlandicus Zone and the upper part of the Arcticus Zone.

Foraminifers recognized in the section refer to two foraminiferal zones of the Upper Bajocian-Lower Bathonian of the central and southern regions of the Russian Platform: *Ammodiscus subjurassicus* – *Lenticulina saratovensis* and *Lenticulina volganica* – *Vaginulina dainae* zones. However, the upper part of the Volganica – Dainae F-Zone (upper part of Member II, at a depth of 8.0 m of the borehole) shows the appearance of *Ammodiscus arangastachiensis* NIKITENKO, which is a species with zonal meaning in the northern regions of the Russian Platform (MITTA et al. 2012a), and also northern Siberia (NIKITENKO 2009; SHURYGIN et al. 2000, 2011). A foraminiferal assemblage recognized in the topmost Member II (at a depth of 4.4 m) is dominated by *Globulina praecircumphlua* GERKE, which is an index species of the *G. praecircumphlua* F-Zone of northern Siberia (e.g., NIKITENKO 2009). The taxonomic composition of the foraminiferal assemblage from the upper part of the borehole (beginning at a depth of 8.0 m and above), and in the open part of the section corresponds to that of the *Trochammina* aff. *praesquamata* F-Zone of the Russian Platform (MITTA et al. 2012a). The assemblage of the *Trochammina* aff.

praesquamata F-Zone is interesting in that it contains species characteristic both of the central and southern regions of the Russian Platform and typical Arctic species. The presence of the latter suggests the connection of the Central Russian Sea with Boreal basins as early as in the Late Bajocian.

5. Sedimentary setting

The section of the Bajocian-Bathonian deposits represents part of a sedimentary macrocycle indicating transgressive and regressive episodes in the evolution of the Central Russian sedimentary basin at the end of the Late Bajocian, Early and Middle? Bathonian. The succession shows a smaller-level cyclicity reflecting periodical fluctuations of sea level.

The basal horizons of Member I are composed of irregularly cyclical terrigenous-clayey and terrigenous-carbonate (packstone and grainstone) beds of diverse facies, that accumulated on a relatively shallow shelf within a high-energy environment with an influx of quartz arenaceous and bioclastic material. Upward in the section, from the depth of 53.0–48.0 m the succession shows deeper sea settings. The silt and clay within the cyclites are sometimes bioturbated, which suggests a slower sedimentation rate and reduced influx of clastics. The beds contain a small amount of scattered carbonaceous plant detritus, whereas C_{org} does not usually exceed 0.22%. Judging from examination of microfossil samples from a depth of 51.1 m of the borehole, the foraminiferal association is characterized by representatives of the genera *Ammodiscus*, *Saccammina*, and *Hyperammina*. Using the palaeoecological typification of the foraminiferal genera according to bionomical zones of the sea developed for the Jurassic microfossils of northern Siberia (NIKITENKO 2009), it is possible to conclude that this association characterized a high-energy coastal-shallow zone with variable salinity (Inner part, upper sublittoral zone, Fig. 4). As the basin developed and deepened, the structure and composition of the foraminiferal assemblages changed: previously dominating members of *Ammodiscus* and *Saccammina* became less abundant. In contrast, species of *Lenticulina*, *Astacolus*, and *Vaginulina*, which are typical of the assemblages of the more distal shallow zone (outer part, upper sublittoral zone; Fig. 4), appeared.

The boundary between members I and II is not observed in the borehole core. Apparently, Member II gradually follows Member I, which suggests increased transgression and gradual deepening of this part of

the basin. The most part of Member II is composed of silty-clayey deposits of similar facies that accumulated on the distal but shallow shelf. The upper part of the Member II is dominated by weakly silty clay with distinctly subdominant millimetre-thick beds of silt. The sedimentation occurred in quiet settings with periodical weak currents and possibly in geomorphological depressions of the sea floor. The upper part of the Member III shows almost complete disappearance of bioturbation textures and an increase of C_{org} to 0.55%. One can suppose, that these deposits apparently indicate the maximum transgression that led to the fusion of the “Boreal” and “Tethyan” waters in the Central Russian Basin. The Late Bajocian foraminiferal assemblages (second half of the Michalskii Phase = time of the accumulation of Member II) are dominated by *Lenticulina* and *Vaginulina*, with *Astacolus* and *Planularia* being subdominant. Overall, this taxonomic composition of the microbenthic association suggests low-energy shallow-water distal settings and stable salinity (outer part, upper sublittoral zone). At the end of the Late Bajocian, the association showed a change of dominants, i.e., polymorphinids (genus *Globulina*) became abundant. In addition, taxa characteristic of the “Boreal” kind appear in the assemblages. This suggests a deepening basin (probably inner part, middle sublittoral zone) (Fig. 4), and an influx of “Boreal” waters in the basin under consideration.

Gradually, but rapidly the clay of Member II are replaced upward in the section by silty clay of Member III. The boundary between two members is marked by accumulation of early diagenetic calcareous nodules, sometimes forming beds inconsistent laterally and vertically, which could be formed because of change in the sedimentary settings (arrested sedimentation) at the Bajocian-Bathonian boundary. The middle and upper parts of the Member III also show various synsedimentary gaps caused by local sedimentation arrests. The most distinct level in the section is the so-called “belemnite level”, which is an erosional bedding plane with accumulations of variously sized belemnite rostra (some of them rounded), fragments and complete ammonite shells, isolated valves and complete bivalves. Member III differs from the underlying Upper Bajocian clay in diverse obliquely and undulating-layered textures suggesting active influence of bottom currents on sedimentation. Sedimentary textures are often, but irregularly bioturbated. The upper part of Member III (1 m below the top) contains a thin layer of weakly silty homogenous massive clay that accumulated as a result of abundant influx of finely dispersed siliciclastics and

Submediterranean Realm			Subboreal Realm		Boreal Realm		
West Europe			Central Russia		East Greenland		North Siberia
Middle Bathonian	Progracilis		ammonites not found		Cranocephaloide	<i>crassiplicatum</i>	Cranocephaloide
Lower Bathonian	Tenuiplicatus		Ishmae	<i>ishmae</i> β	Ishmae	<i>ishmae</i> β	Ishmae
				<i>ishmae</i> α		<i>ishmae</i> α	
	Yeovilensis			<i>harlandi</i>		<i>harlandi</i>	Harlandi
	Zigzag	Macrescens	Besnosovi	<i>besnosovi</i>	Greenlandicus	<i>frebaldi</i>	Greenlandicus
Convergens		<i>mojarowskii</i>		<i>greenlandicus</i>			
				<i>micrumbilicatus</i>			
Upper Bajocian	Parkinsoni	Bomfordi	Michalskii	<i>masarowici</i>	Arcticus	<i>delicatus</i>	Arcticus
		Truellei	<i>michalskii</i>	<i>arcticus</i>		Jugatus	

Fig. 11. Chronostratigraphic subdivision of the Upper Bajocian-Lower Bathonian of the Russian Platform and correlation with the West European primary Standard (FERNÁNDEZ-LÓPEZ et al. 2009a, b) and the East Greenland/North Siberian secondary (Boreal) Standard (SHURYGIN et al. 2011).

its accumulation in low-energy depressions. Later, the accumulated clay was homogenized by bioturbation. This member consistently contains fine carbonaceous plant detritus, whereas C_{org} reaches 0.77%. Judging from the structure, granulometry and texture, Member III was formed on a moderately deep distal shelf with clastic sedimentation and episodes of high energy. The texture and structure of the beds and diverse fossils of Member III suggest expansion of the basin.

The Early Bathonian macro- and microfossil assemblages in this region are unusual. They included taxa characteristic of the Boreal-Arctic, low Boreal and Tethyan palaeobasins, which indicates stabilization of connections of the Central Russian and Arctic marine basins. For most bivalve genera of these assemblages the optimal setting is a shallow sea (outer upper sublittoral, sometimes upper part of the middle sublittoral) with well-aerated bottom water layers, judging from palaeoecological classifications of benthos and analyses of benthic catens of Siberian palaeoseas (e.g., ZAKHAROV & SHURYGIN 1978; SHURYGIN 2005). The distribution of cephalopods (ammonites and belemnites), crinoids and scaphopods present in this section, apart from bivalves, does not contradict this interpretation (suggesting sedimentation in a permanent but relatively shallow marine basin with normal salinity). Oysters,

Myopholas, *Pinna* and *Goniomya* found at various levels indicate that the climate was warm, and the basin was shallow. Bivalve taxa preferring soft substrates are numerous in associations (*Malletia*, *Phaenodesmia*, *Modiolus*, *Striatomodiolus*, *Astarte*, and others), whereas the development of soft substrates was connected with the remoteness from sources of clastics. The reduction in the taxonomic diversity of bivalve associations at the end of the period corresponding to the accumulation of Member III could be connected to substantial change in substrate, bottom hydrodynamics, and gas regime of the bottom water layers. The intrusion of Boreal taxa to low latitude biotopes (which were alien for Boreal taxa) destabilized previously formed associations of bivalves, but did not cause the Boreal assemblages to prosper.

Associations of the Early Bathonian microbenthic organisms (time of formation of Member III) are relatively diverse and are represented by *Lenticulina*, *Astaculus*, *Marginulinopsis*, *Pseudonodasaria*, *Globulina*, *Dentalina*, *Citharina*, and others. The taxonomic composition of the assemblages is typical of a moderately deep-sea zone (Iib – inner part, middle sublittoral zone) (Fig. 4).

The uppermost part of Member III, taking into account the gradual transition to silt of Member IV, sug-

gests the beginning of a regressive phase. In this part of Member III cephalopod fossils were not found, and the bivalve assemblage is impoverished. The taxonomic composition of foraminifers was sharply reduced, and all calcareous taxa disappeared. The communities are represented by the eurybiontic *Ammodiscus* and *Saccamina*, typical of the shallow shelf (IIIb – inner part, upper sublittoral zone, Fig. 4).

Member IV is represented by non-calcareous silt of uniform facies, almost entirely disrupted by bioturbation in the lower part of the section, which resulted in the sedimentary textures not being preserved. The bedding surfaces show numerous large (up to 20 cm long and up to 1 cm wide) trace fossils (crawling and boring traces) filled in by a darker clayey-silty matrix to be referred to benthic organisms that lived on and in the substrate. In the middle part of the Member IV there is a consistent bed of concretionary calcareous strongly ferruginous siltstone (0.3–0.4 m thick), probably representing a cyanobacterially driven hardground formed at the bottom of a shallow basin when sedimentation ceased. The sediments above the concretionary bed are very much like those beneath it, although the amount of bioturbation gradually decreases towards the top of the member. No macro- or microfossils (apart from the trace fossils) were found in these beds. The carbonaceous plant detritus is virtually absent (C_{org} is less than 0.1%). Member IV was deposited in the environment of a very shallow sea in the studied zone of the Central Russian sedimentary basin and corresponds to the maximum low-stand at the Lower/Middle Bathonian boundary, at the time of increasing climate aridization.

6. Conclusions

The integrated study of the Bajocian–Bathonian beds in the vicinity of Saratov allowed the refinement of the ammonite biostratigraphy. The refined ammonite succession and its taxonomic composition confirm the placement of the Ishmae Zone (beds with *Arcticoceras ishmae* and *A. harlandi*, or Subzone, according to some authors) to the Lower Bathonian. Accordingly, the zonal stratigraphic schemes of the Boreal regions need to be emended (Fig. 11).

The taxonomic composition of belemnites has been updated, resolving discrepancies in the ammonite and belemnite dating. The list of highly endemic index species in the current Arctic belemnite-based scales does not allow recognition of Siberian or Pechora belemnite-based units in the Sokur succession. Never-

theless, it is possible to establish here common Arctic (Pechora Basin, Siberia and Arctic Islands) species of *Pachyteuthis* (Cylindroteuthidae). Two aberrant species of the genus *Paramegateuthis* (Megateuthidae) are also recognized here in the Lower Bathonian. Two local units “beds with belemnites” are distinguished in the section.

The bivalve distribution in the studied succession has been updated. The bivalve assemblage from the beds with the ammonites *Arcticoceras harlandi* and *A. ishmae* and the upper part of Member III lacking ammonites includes both typically Boreal–Arctic, and Low Boreal taxa. Equivalents of the two Boreal bivalve zones (*Retroceramus bulunensis* and *Retroceramus vagt*) have been established based on the distribution of *Retroceramus*. Their correlation with the cardioceratid-based zones in the section studied is very similar to that in the Siberian sections. Beds with *R. bulunensis* in this succession may be underlain by the equivalents of the Siberian bivalve *Retroceramus polaris* Zone, which in the type sections in Siberia corresponds to the lower part of the ammonite Greenlandicus Zone and the upper part of the Arcticus Zone.

The foraminiferal zones *Ammodiscus subjurasicus* – *Lenticulina saratovensis* and *Lenticulina volganica* – *Vaginulina dainae*, traditionally recognized in the Bajocian–Bathonian of the Russian Platform have been recognized in the Sokur section. The appearance of the index species and associated assemblages characteristic for the foraminiferal zones of the Pechora Basin and northern Siberia are for the first time recognized in the upper part of the *Lenticulina volganica* – *Vaginulina dainae* Zone. Importantly, the earlier onset of the Boreal transgression was shown. Sedimentological and microfossil studies indicate that at the end of the Late Bajocian (second half of the Michalskii Zone), an increased transgression resulted in the fusion of the “Boreal” and “Tethyan” waters in the Central Russian Basin. This occurred at the end of the Bajocian, when Boreal taxa gradually invaded the Central Russian marine basin, which was originally inhabited solely by fauna of “Tethyan” origin. The late appearance of the first molluscs of Boreal origin (arctocephalitins, cylindroteuthids, and retroceramids), which only occurred in this area in the early Bathonian, can be explained by their slower spreading (compared to microorganisms) and by the paucity of their preservation and occurrences. At the end of the Early Bathonian, both sedimentological and palaeontological data indicate the beginning of a regressive cycle, which reached its maximum in the Middle Bathonian.

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