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ISOTOPIC AND FAUNAL RECORD OF HIGH PALEOTEMPERATURES IN THE KIMMERIDGIAN OF SUBPOLAR URALS

V.A. Zakharov, F. Baudin*, O.S. Dzyuba**, V. Daux*, K.V. Zverev***, and M. Renard*

Geological Institute of RAS, 7 Pyzhevsky per., Moscow, 109017, Russia
** Department of Sedimentary Geology, French Academy of Sciences,*
ESA 7073-FR 32, UPMC case 117, 4 place Jussieu 75252 Paris Cedex 05, France
*** Institute of Petroleum Geology, Siberian Branch of RAS,*
3 prosp. Akad. Koptyuga, Novosibirsk, 630090, Russia
**** SibSRIPI, 118 ul. 50 Let Oktyabrya, Tyumen', 625090, Russia*

The values δ^{18}O obtained from belemnite rostra of Subpolar Urals show extremely high paleotemperatures (20 °C on average) for Kimmeridgian times. This result is commensurate with the data previously obtained from the same locality (18.9 °C) and from adjacent regions: Timan-Pechora (18.5 °C), South Urals and Caspian region (18.6 °C). Somewhat higher values in Subpolar Urals are probably due to the warming of water in a shallow embayment. A warm subsurface current from the west, through the straits of Polar Urals, may also contribute to this local increase in temperature. Besides, the isotope ratio could be influenced by recurrent freshening of surface water owing to fluvial runoffs, which eventually raised the paleotemperature.

The evolution of paleotemperatures is in agreement with the succession of biotic events. The general drop in paleotemperatures observed from Early to Late Kimmeridgian corresponds to a decrease in the generic diversity of benthos. The maximum paleotemperatures in the Early Kimmeridgian coincide with the predominance of the thermophile family of bivalves Trigoniidae. A drastical drop in temperature in the Late Kimmeridgian was recorded above and below a bed with the least diversified benthos.

Throughout the Kimmeridgian, the composition of benthic communities was steadily dominated by suspension feeders. This implies that bottom water was persistently saturated with oxygen. Low-level deposit feeders appeared in benthic communities as late as the Early Kimmeridgian and were persistent in the Late Kimmeridgian and Early Volgian. They actually were of minor importance in benthic communities. Nevertheless, the occurrence of deposit feeders is indicative of an important event in the history of the Lyapinsky embayment in Subpolar Urals (advanced transgression and general deepening of the sea). A thin interbed of organic-rich shale at the base of the Eudoxus zone is a striking illustration of the maximum transgression. Taking into account that in Eudoxus time the sea covered the maximum areas in the vicinity of the North Sea and on the territory of Great Britain (Wignall, 1994), we can interpret this short episode in sedimentation of organic-rich shale as an indication of eustatic event in northern Eurasia as a whole.

Kimmeridgian, paleontology, paleoecology, lithology, paleogeography, oxygen isotope, paleotemperatures, Subpolar Urals

INTRODUCTION

Absolute paleotemperatures deduced from variations of stable oxygen isotope in biogenic carbonate have been steadily addressed since the early 1950s [1]. This parameter is extremely important to characterize one of the principal components of the Earth's climate — "warmth" and its variations in geologic time. Using indirect methods such as paleoecological (based on flora and fauna remains) and sedimentological (based on minerals, rock composition, evaporites, coals), we can obtain a relative "run of thermal curve" but cannot evaluate the warmth quantitatively. Measurement of ratios of stable isotopes of oxygen in biogenic carbonate actually provides quantitative parameters of warmth. This became evident after pioneering works by Bowen [2–4] on Jurassic and Early Cretaceous belemnite rostra. Despite early attempts [5–7] and subsequent success [8] in finding absolute paleotemperatures from Ca/Mg, the oxygen isotope curve remains the most reliable [9]. Successful elaboration of the Quaternary and Cenozoic paleotemperature curve obtained on the basis of data on oxygen isotopes from Atlantic and North Pacific foraminifer shells has inspired the researchers of the Mesozoic [10–12].

One of the earliest values (or even the maiden one) of absolute paleotemperature for the Jurassic and Cretaceous in the Arctic region was obtained in the 1950s from the Middle Jurassic and Lower Cretaceous (Valanginian) belemnite rostra sampled at the Anabar and Popigai Rivers, northern East Siberia. It was about 15 °C [13]. In the 1960s and 1970s, T.S. Berlin, V.N. Saks, R.V. Teis, and others analyzed oxygen isotopy in hundreds of belemnite rostra from the Jurassic and Cretaceous deposits in northern Eurasia [14, 15]. Annual paleotemperatures were calculated to be about 13–25 °C, tending to increase between Bathonian and Late Volgian times [14].

In the light of these data, the paleotemperatures reported in [16] for the Late Jurassic on the King Karl Land, Spitsbergen, equal to 9.4 °C are quite unexpected. The reconstructed position of the geographic North Pole in the Late Jurassic near the modern Bering Strait [17] implies that the Spitsbergen Archipelago was south of the northern margin of the Siberian Platform. Hence, in the north of East Siberia, the temperatures should be still lower than on King Karl Land. However, the data of paleoecology—increased generic diversity of bivalves—are indicative of persistent warming in the Late Jurassic in the north of East Siberia and rise in annual paleotemperatures from 16 to 18 °C [18].

PALEOGEOGRAPHIC SITUATION

The explored Kimmeridgian section denuded along the Lopsiya River (Figs. 1 and 2; Appendix) formed under the embayment conditions of an epicontinental West Siberian sea, covering the territory of more than 2 mln km^2 (Fig. 3). The bay was called Lyapinsky after one of the largest rivers in the Severnaya Sos'va basin. It is believed that Lyapinsky Bay was rather shallow and opened toward the NNE [19]. The narrow band of the Uralian Peninsula separated it from the Timan-Pechora Sea in the west, and the small Berezovsky Archipelago separated it from the West Siberian Sea in the east. A warm current coming from the west reached (recurrently) the bay from the north or through straits. In the Early Kimmeridgian it was oriented in the near-latitudinal direction, which is inferred from the "roses" of oriented directions of belemnite rostra measured in Bed 6, Exp. 42 (Fig. 4).

Lyapinsky Bay had stable communications with both West Siberian and Timan-Pechora Seas. Support for this comes from comparison of the systematic belemnite composition of these seas. Thus, of seven Kimmeridgian species of the genera *Pachyteuthis*, *Simobelus*, and *Lagonibelus* found in West Siberia [20–22], four species were encountered at the Lopsiya River. In the Timan-Pechora region, six species are known which belong to the above genera [23, 24]. Four of them are in common with the Uralian community composed of ten species. Nevertheless, the Lower Kimmeridgian belemnite assemblages of the Urals seem to be closer to the West Siberian as the latter contain the species *Pachyteuthis (Boreioteuthis) absoluta* (Fisch.) abundant at the Lopsiya River and making up here the base of the Lower Kimmeridgian belemnite assemblage. This species is absent from the Pechora basin. In European Russia it is known only from the upper Oxfordian of Moscow and Moscow Region. Throughout the Kimmeridgian, the ammonite assemblages of the Timan-Pechora Sea and Lyapinsky Bay were quite similar, which can be explained by similar hydrological parameters of these basins: temperature and salinity [25]. Most likely, Lyapinsky Bay communicated with the Timan-Pechora Sea through a temporary strait (or straits), whereas only a group of islands of the Severo-Sos'vinsky Archipelago separated Lyapinsky Bay from the West Siberian Sea (see Fig. 3).

The presence of strait(s) connecting Lyapinsky Bay with the Late Kimmeridgian Timan-Pechora Sea is also corroborated by a considerable similarity of assemblages of Late Kimmeridgian foraminifers from the basins of the Adz'va River, a right tributary of the Pechora River, and the Lopsiya River [26]. In turn, the Timan-Pechora Sea was connected with seas on the Russian Platform in the Kimmeridgian. This is inferred from common ammonite assemblages in these regions [25, 27]. The similarity of radiolarian assemblages suggests that the seas of the Russian Platform were directly connected with seas in South Europe and North Atlantic through northern margins of peri-Tethys [26]. To explain this phenomenon, we suppose that there was a warm current flowing from the Caspian region (peri-Tethys) northward to the Timan-Pechora Sea. Under the Coriolis forces, this current was pressed to the western shore of the Uralian Peninsula and, through temporary straits, reached Lyapinsky Bay (see

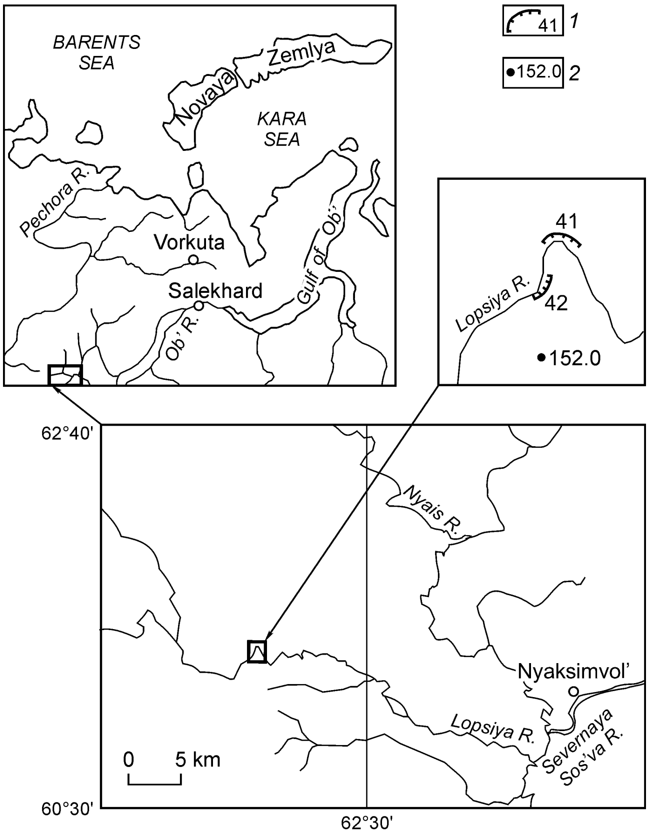


Fig. 1. Study area and schematic location of exposures of the Kimmeridgian Stage at the Lopsiya River (Subpolar Urals). ***1*** **— exposure,** ***2*** **— sea-level altitude, m.**

Fig. 3). To follow this path, the peri-Tethyan ammonites *Prorasenia* and *Aspidoceras* and bivalves Trigoniidae came to Lyapinsky Bay. The presence of a warm current along the Urals explains the fact that the line separating the Siberian and Indo-European paleofloristic realms in the Jurassic rises in front of the Urals and runs near-meridionally [28].

The climate was moderately warm, semihumid [29]. According to data of isotope-oxygen paleothermometry [14], annual water temperatures in Lyapinsky Bay was 18.9 °C in the Kimmeridgian. Nevertheless, these high annual temperatures in the bay are not in conflict with paleoecological data: In the Early Kimmeridgian thermophilic molluscs such as trigoniids existed in the bay, whereas in the Late Kimmeridgian, the bay was inhabited by various oysters and ammonites of the genus *Aulacostephanus*, with shells more than 0.5 m in diameter. Relatively high temperatures are inferred from migration of the above-mentioned peri-Tethyan ammonites *Prorasenia* (in the Kimmeridgian) and *Aspidoceras* (in the Late Kimmeridgian) to Lyapinsky Bay.

MATERIALS AND METHODS

Belemnite rostra were crushed into coarse fragments, which were clean up with 1% HCl (one per cent solution of hydrochloric acid). Specimens for oxygen isotope analysis were drilled from the cleaned surfaces, avoiding the median area of the rostra. The specimens were treated with anhydrous phosphoric acid in a vacuum at 25 °C. Accuracy was within 0.1‰ and was monitored through daily analyses of an internal standard. Routine corrections were applied to the raw data, and results are reported in standard δ notation as permissible (‰) deviation from PDB (Chicago) standard.

Twelve specimens of clays and two specimens of dark limestone were taken from Exposure 41 to measure the content of organic matter. The specimens were open air-dried and ground in a metal mortar to fine powder (2 μm). The content of organic carbon (% TOC — Total Organic Carbon) as well as its source and thermal maturation of organic matter were estimated using a Rock-Eval device to follow the method described by Espitalie et al. [30–32]. Results are reported in Table 1.

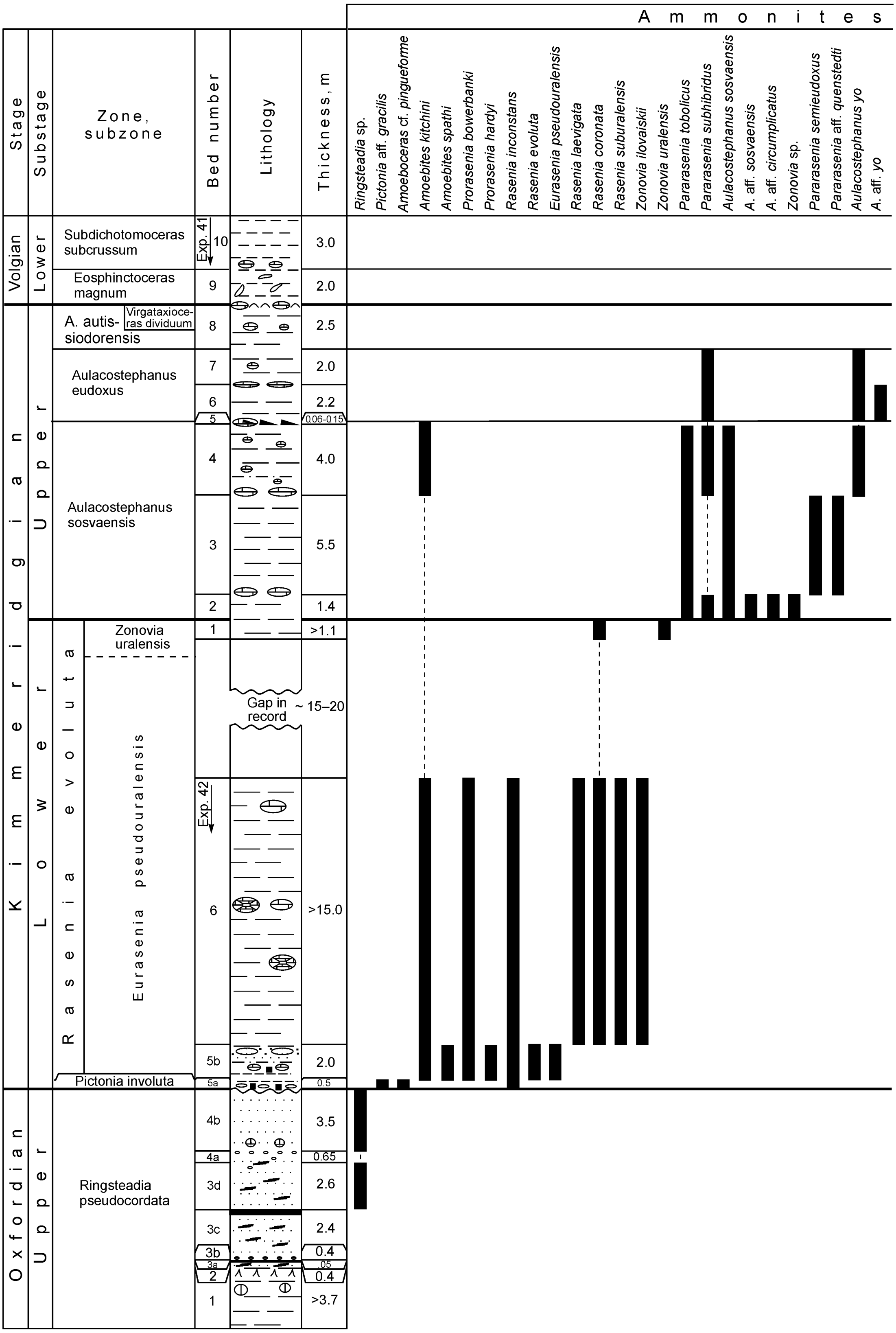
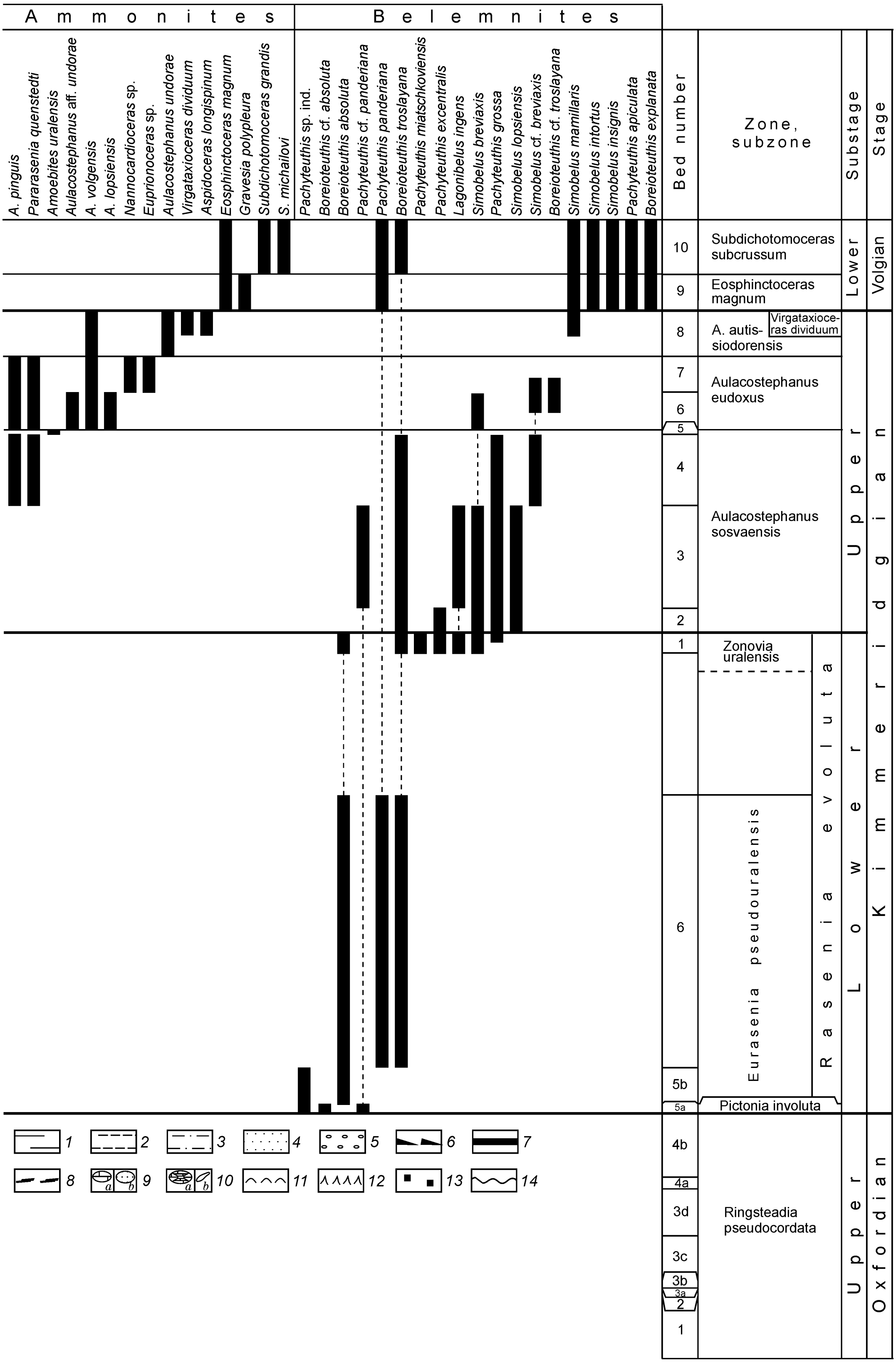


Fig. 2. Stratigraphic section of the Kimmeridgian and occurrence of ammonites and belemnites in exposures along the Lopsiya River (Subpolar Urals). ***1*** **— clays;** ***2*** **— clayey siltstone, silty clay;** ***3*** **— sandy siltstone;** ***4*** **— sands;** ***5*** **— gravel- and pebblestone;** ***6*** **— bituminous clay;** ***7*** **— coal partings;** ***8*** **—**



coalified detritus; *9* — calcareous (*a*) and sandy (*b*) concretions; *10* — calcareous septarian (*a*) and fusiform (*b*) nodules; *11* — shelly interbed; *12* — rhizosphere; *13* — pyritized nodules around remains of shells and wood; *14* — wash-out boundaries.

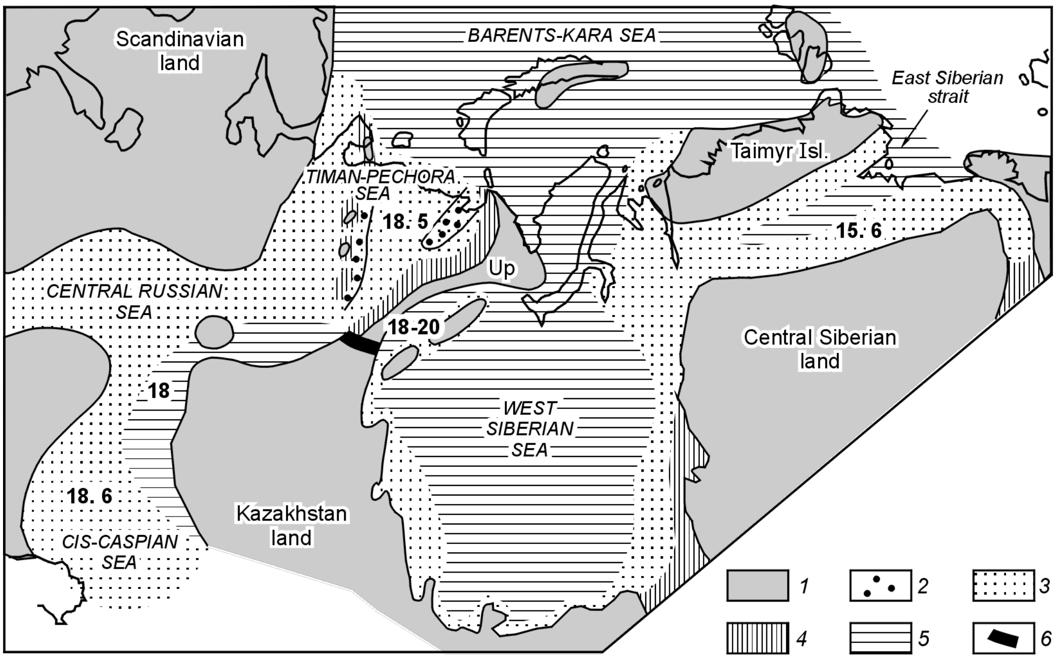


Fig. 3. Paleogeography of northern Eurasia in the Kimmeridgian. ***1*** **— land,** ***2*** **— littoral,** ***3*** **— upper sublittoral,** ***4*** **— sublittoral,** ***5*** **— lower sublittoral,** ***6*** **— temporary strait, UP — Uralian Peninsula; digits — centigrade temperature.**

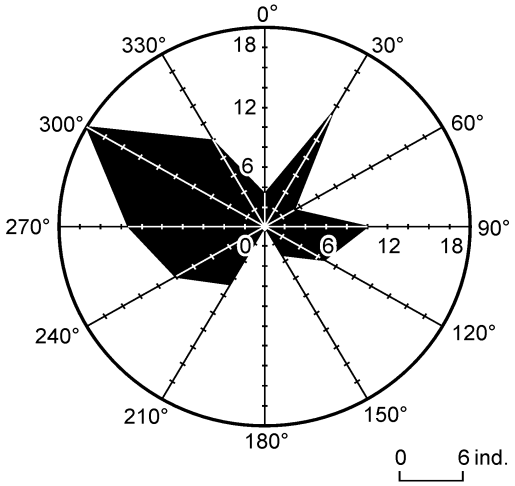


Fig. 4. Orientation of belemnite rostra in Bed 6, Exp. 42, at the Lopsiya River.

RESULTS

Values of $\delta^{18}O$ of belemnite rostra vary from –2.5 to –1.25‰ (see Table 1). On the assumption that during the biogenic precipitation of carbonate the equilibrium is kept and no subsequent diagenetic alteration occurs, the values of $\delta^{18}O$ of belemnite rostra and temperature are related as follows:

$$T\,(^\circ\mathrm{C}) = 16.5 - 4.3\cdot(\delta^{18}\mathrm{O}_{\mathrm{calcite}} - \delta^{18}\mathrm{O}_{\mathrm{water}}) + 0.14\cdot(\delta^{18}\mathrm{O}_{\mathrm{calcite}} - \delta^{18}\mathrm{O}_{\mathrm{water}})$$

Table 1

Evaluated δ^{18}O and δ^{13}C in Belemnite Rostra from the Kimmeridgian and Lower Volgian Substage at the Lopsiya River (Subpolar Urals)

Sp.	Exposure/bed (interval)	Ammonite zone (subzone)	Belemnite species	δ^{13}C	δ^{18}O	Paleo-tempe-rature, °C
				‰ PDB		
1	2	3	4	5	6	7
L/b-1	42/5a	Involuta	*Pachyteuthis* (*Boreioteuthis*) cf. *absoluta* (Fisch.)	2.30	–1.44	18.42
L/b-2	42/5b	Evoluta (pseudouralensis)	»	1.78	–2.50	23.27
L/b-3	42/6 (bottom)	»	*P.* (*B.*) *absoluta* (Fisch.)	2.43	–2.18	21.77
L/b-4	42/6 (0.0–1.0 m from bottom)	»	»	2.78	–1.37	18.11
L/b-5	42/6 (1.0–2.0 m from bottom)	»	»	1.05	–1.52	18.77
L/b-6	42/6 (2.0–3.0 m from bottom)	»	»	1.40	–1.91	20.53
L/b-7	42/6 (4.0–5.0 m from bottom)	»	*P.* (*B.*) *troslayana* (d'Orb.)	2.67	–1.55	18.91
L/b-8	42/6 (5.0–6.0 m from bottom)	»	*P.* (*B.*) *absoluta* (Fisch.)	2.30	–1.87	20.35
L/b-9	42/6 (6.0–8.0 m from bottom)	»	»	2.25	–1.39	18.20
L/b-10	42/6 (8.0–9.0 m from bottom)	»	»	2.07	–2.04	21.12
L/b-11	42/6 (9.0–10.0 m from bottom)	»	»	2.41	–2.04	21.12
L/b-12	41/1 (1.0 m below roof)	Evoluta (uralensis)	*P.* (*B.*) *troslayana* (d'Orb.)	1.81	–1.25	17.58
L/b-13	41/1–2 (contact)	Evoluta/sosvaensis	»	1.86	–2.01	20.99
L/b-14	41/2 (1.0 m after bottom)	Sosvaensis	»	2.22	–1.65	19.35
L/b-15	41/2–3 (contact)	»	»	1.72	–1.47	18.55
L/b-16	41/3 (1.0 m after bottom)	»	»	1.65	–1.32	17.89
L/b-17	41/3 (2.0 m after bottom)	»	»	1.92	–1.83	20.17
L/b-18	41/3 (3.30 m after bottom)	»	*Simobelus* (Simobelus) *breviaxis* (Pavl.)	1.63	–1.80	20.03
L/b-19	41/3 (5.0 m after bottom)	»	»	1.27	–1.87	20.35
L/b-20	41/4 (1.0 m after bottom)	»	*S.* (*S.*) cf. *breviaxis* (Pavl.)	1.08	–1.79	19.98
L/b-21	41/4 (2.0 m below roof)	»	»	0.03	–2.08	21.31
L/b-22	41/4 (1.0 m below roof)	»	»	1.58	–1.48	18.60
L/b-23	41/4 (roof)	»	»	0.82	–1.55	18.91

Table 1 (continued)

1	2	3	4	5	6	7
L/b-24	41/6 (0.0–1.0 m from bottom)	Eudoxus	*S.* (*S.*) *breviaxis* (Pavl.)	1.29	–2.03	21.08
L/b-25	41/6 (1.0–2.0 m from bottom)	»	*S.* (*S.*) cf. *breviaxis* (Pavl.)	1.11	–1.85	20.26
L/b-26	41/7 (0.0–1.0 m from bottom)	»	»	1.95	–1.91	20.53
L/b-27	41/8 (roof)	Autissiodorensis (dividuum)	*S.* (*S.*) cf. *mamillaris* (Eichw.)	1.17	–2.12	21.49
L/b-28	41/8–9 (contact)	Autissiodorensis/ magnum	»	1.75	–2.29	22.28
L/b-29	41/9 (0.0–1.0 m from bottom)	Magnum	*S.* (*S.*) *intortus* (Sachs et Naln.)	1.80	–2.24	22.05
L/b-30	41/9 (1.0–2.0 m from bottom)	»	»	0.96	–1.71	19.62
L/b-31	41/10 (0.0–1.0 m from bottom)	Subcrussum	*Pachyteuthis* (*Boreioteuthis*) *explanata* (Phill.)	1.86	–1.34	17.98
L/b-32	41/10 (1.0–2.0 m from bottom)	»	»	1.19	–2.09	21.35
L/b-33	41/10 (2.0–3.0 m from bottom)	»	»	1.44	–1.28	17.71

where $\delta^{18}O_{calcite}$ and $\delta^{18}O_{water}$ are the isotope compositions of calcite rostra and sea water relative to PDB, respectively.

Given the Earth was free of ice in the Kimmeridgian, the value $\delta^{18}O_{water}$ is believed to be close to 1‰. The temperature estimated from belemnite rostra averages around 20 °C (with a permissible deviation of 1.5 °C; Fig. 5), varying from 17.5 to 23 °C.

The content of organic matter in the Upper Jurassic clays from the Lopsiya section varies from low to medium (from 0.5 to 1.1% TOC). Only dark clays of Bed 5 (Exp. 41) are well enriched in organics (Table 2). The total content of organic carbon varies from 14% at the base of this bed to 5.2% at its roof. Concretions of dark limestone of the same bed contain about 2.5% TOC.

Information on composition and maturity of organic matter may be obtained by pyrolysis [30–32]. Though the type of organic matter is usually determined by its element composition, such parameter as hydrogen index, HI, approximates the atomic hydrogen-to-carbon ratio, H/C, a critical factor in classification of organic matter. Given a wide range of HI values (from 12 to 471 mg HC/g TOC) (Table 2), the organic matter of the Lopsiya section seems to be distributed between types II and IV [30–32]. Laminated dark clays of Bed 5 (Exp. 41) show a higher HI (278 to 471 mg HC/g TOC) and probably contain organic matter of second type. This type forms mostly at the cost of phytoplankton and/or bacteria and is usually related to the regressive stage of development of sea basin [33]. Other argillites and shales have HI from low to medium (from 12 to 99 mg HC/g TOC), which is accompanied with low content of organic carbon and suggests a heavy alteration of organic matter (Type IV).

Temperatures of the maximum yield of pyrolytic products, T_{max}, vary from 406 to 424 °C, averaging 416 °C, which indicates that organic matter was not subjected to high temperatures during subduction and is not mature for oil formation yet.

PALEOBIOGEOGRAPHY AND PALEOECOLOGY

Macrofossils in the Kimmeridgian of Subpolar Urals are represented by molluscs alone. According to their mode of life, they are subdivided into two large groups: benthic (bivalves, gastropods, scaphopods) and nectobenthic (ammonites, belemnites).

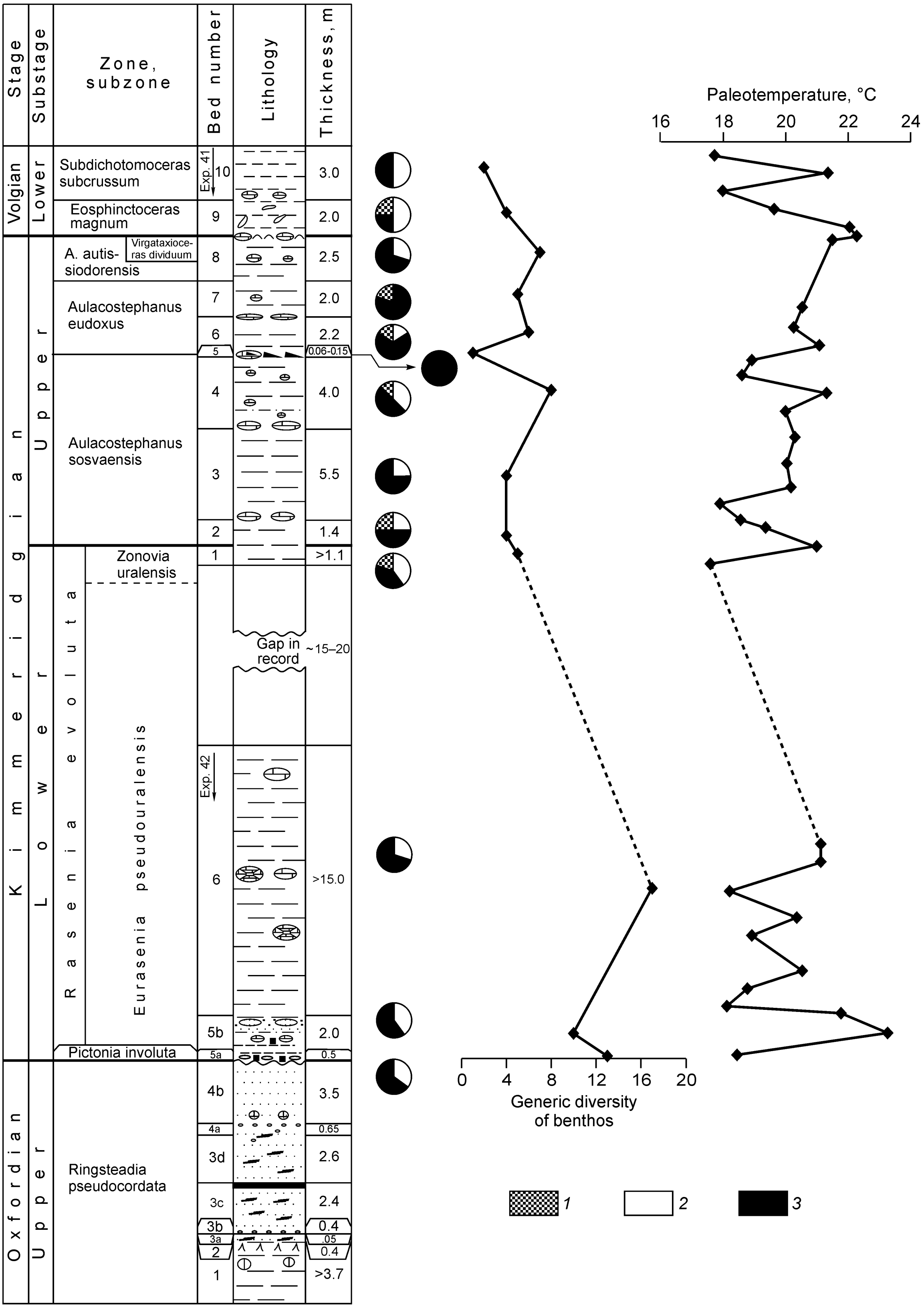


Fig. 5. Trophic structure of bottom communities, curve of generic diversity on benthos, and paleotemperature curve. ***1*** **— deposit feeders,** ***2*** **— mobile suspension feeders,** ***3*** **— immobile suspension feeders. The other symbols follow Fig. 2.**

Table 2

Geochemistry of Organic Matter of Kimmeridgian-Lower Volgian Rocks in Section along the Lopsiya River (Subpolar Urals)

Sp.	Exposure/bed	Rock	$CaCO_3$	TOC	T_{max}, °C	S1	S2	HI
			%			‰		mg HC/ g TOC
L/p-1	41/1	Clay	<3	1.17	424	0.04	0.90	77
L/p-2	41/2	»	<3	0.67	413	0.01	0.17	25
L/p-3	41/3	»	<3	0.53	421	0.02	0.13	25
L/p-4	41/3	»	<3	0.44	411	0.01	0.10	23
L/p-5	41/4	»	<3	0.64	415	0.02	0.14	22
L/p-6	41/5 (bottom)	Calcareous concretion	80	2.84	415	0.22	13.39	471
L/p-7	41/5 (top)	»	72	2.41	418	0.16	10.76	446
L/p-8	41/5 (bottom)	Bituminous clay	<3	13.83	408	1.75	38.40	278
L/p-9	41/5 (middle level)	»	<3	12.69	406	1.50	43.64	344
L/p-10	41/5 (top)	»	<3	5.16	420	0.18	5.09	99
L/p-11	41/6	Clay	<3	0.86	417	0.03	0.16	19
L/p-12	41/9	»	<3	0.51	426	0.01	0.06	12
L/p-13	41/10	»	<3	0.54	409	0.01	0.07	13

Note. S1 — amount of hydrocarbons generated by organic matter in the process of diagenesis, S2 — residual oil- and gas-generating potential which can be realized under the natural conditions.

The constant presence of diverse cephalopods, in particular, such cosmopolitan genera of ammonites as *Ringsteadia*, *Pictonia*, *Amoeboceras*, *Rasenia*, *Aulacostephanus*, and *Aspidoceras* and cosmopolitan genera of belemnites such as *Pachyteuthis*, *Simobelus*, and *Lagonibelus* is indicative of normal saline water of the bay inhabited by these molluscs. The absolute salinities we earlier obtained to follow Ruker and Valentine [26, 34–36] by analyzing oyster shell matter, equal to 34–36‰, corroborate this inference. The fact that the same groups of cephalopods inhabited the seas in the north of Western Europe and even in Southern Europe, e.g., *Aspidoceras* [37], as well as the presence of representatives of the family Trigoniidae and numerous oysters among bivalves suggest that the water was sufficiently warm throughout the year. The mixed boreal-subtethyan composition of molluscs in an open embayment of the West Siberian Sea is determined by high extent of warm-up of its water and by the presence of open sea ways westward. Saks [38] and Zakharov [39] compared the thermal regime of North Siberian seas to the subtropical regime of the southern Sea of Japan and Biscay Bay. On the other hand, the cold-water-loving genus *Buchia*, quite abundant in the Arctic, was not found in the Upper Kimmeridgian at the Lopsiya River, and only one rare species *B. concentrica* (Sow.) was documented in the Lower Kimmeridgian. Thus, neither paleoclimatic, nor paleobiogeographic, nor paleoecological data contradict the values of isotope paleothermometry.

The bottom communities were represented largely by bivalves. Only in the Early Kimmeridgian did they coexist with two genera of gastropods, and in the Late Kimmeridgian, with one genus of scaphopods. Nearly all bivalves but the Late Kimmeridgian genus *Nuculoma* are referred to as suspension feeders. Representatives of this group were drastically predominant in bottom communities or made up most of them (see Fig. 5). Obviously, the bottom water was persistently oxygen-saturated. Only one episode — monospecific accumulation of a bivalve from the genus *Oxytoma* in bituminous clays (Bed 5, Exp. 41) — suggests a deficiency of oxygen under the sediment/water interface but not near the bottom, as larvae of *Oxytoma* falling in huge amounts onto the bottom needed oxygen. The basin's bottom was sufficiently soft because the dominating bivalves—astartids, trigoniids, and protocardia — buried themselves into the sediment.

Depth is the hardest-to-reconstruct characteristic of a paleoenvironment. Its reconstruction needs an interdisciplinary approach [40]. Taphonomic observations and paleoecological analysis, however, give sufficient information for preliminary conclusions. The field taphonomic observations have shown that the most abundant bivalves—astartids, protocardia, ostreids, neotaxodonts, and desmodonts—are buried either where they lived or nearby. Allochthonous burials are predominant only in the Lower Kimmeridgian. Thus, most of the bottom communities lived near the fair-weather wave base. The Early Kimmeridgian bottom communities lived, predominantly, above the storm wave base, and most of the Late Kimmeridgian communities inhabited sites of the sea bottom below the storm wave base. In accordance with our previous ideas, in the Late Jurassic, fair-weather wave base penetrated to a depth of 10 m, and storm wave base, to a depth of 20 m [40].

One of the characteristics of "maturity" of a community is its gradation, i.e., the species distribution pattern in accordance with the degree of predominance [41]. The degree of predominance of a particular genus (each genus in the explored communities is represented by a single species) was determined by the frequency of occurrence during taphonomic studies in a single thanatocoenosis [42]. The frequency of occurrence was determined by a number of individuals encountered in the thanatocoenosis for two hours of monitoring. According to occurrence frequency, all the genera are divided into five groups, each of which is estimated at a 100 point scale: abundant genera (more than 100) were estimated at 100; quite numerous genera (from more than 30 to many tens of individuals) were estimated at 30; very frequent and frequent genera that occur in a bed (from some tens of individuals to ten) were estimated at 15, scarce genera (3 to 9 individuals) were estimated at 5, and very rare genera (1–2 individuals) were estimated at 1. These parameters were used in constructing plots of domination: the better the gradation, the more mature the community is. The plot shows that the most mature communities existed in the Early Kimmeridgian (Beds 5a, 5b, and 6, Exp. 42; Fig. 6). The least mature communities existed in the Late Kimmeridgian (Beds 5, 6, 7, and 8). Communities from Beds 1–4 are to be considered intermediate. The Early Volgian communities (Beds 9 and 10) may be considered pioneering, since with a drastic domination of one genus (and species), the other characteristics of the structure, first of all, gradation and taxonomic diversity are not developed. Thus, each of these four groups of communities is at a certain stage of maturity, but none of them has reached the stage of mature community—the climax. For example, the Early Kimmeridgian communities (and the rest, by the way) lack a category of subdominants and the niche of detrital scavengers is not occupied at all (see Fig. 5). In terms of general biology, we can certainly state that during the Kimmeridgian there was no lasting and directed process of stabilization of all environmental factors. A certain factor was persistently dominating over others (*r*-selection was predominant). As a result, an optimal balance of factors has never been reached at which primarily biological capacities of a species to struggle for survival could manifest themselves (weak *K*-selection).

What are the reasons for rather frequent upset of the balance of factors in time? The simplest explanation comes from sea-level fluctuations, as they control all the main factors of the habitat of bottom communities: temperature, benthic hydrodynamics, and oxygen saturation of bottom water; sourceland of sediments and character of biotope; kind of food, its amount and preservation in the sediment and even, to a certain degree, salinity of surface water depending on how far from river mouths do habitats occur. In this context, the evolution of the first three communities exhibits a definite tendency for oriented stabilization, which is inferred from growing diversity and simultaneous change of a dominant: the genus *Protocardia* substitutes for the subgenus *Astarte (Nicaniella)* (manifestation of *K*-selection). This can be explained by some deepening of habitats and its stabilization at the level optimal for bottom fauna (near the basis of storm waves). However, the return of the dominant, the typical subgenus *Astarte* s. str., accompanied with a drastic decrease in taxonomic diversity brought the community back to the immature stage (see Fig. 6). This could be caused by a drastic deepening of bottom and variation in quantitative characteristics of the medium, in particular, by decreased temperature of bottom water. Succeeding communities again tend toward the complication of their structure: though weakly, diversity increases, gradation enhances, and a deposit feeder (*Nuculoma*) appears in the trophic structure. This is the time of stabilization of conditions at a new level. Next drastic restructuring of the environment occurs during the formation of an organic-rich interbed (Bed 5, Exp. 41). The monospecies community of suspension feeder *Oxytoma* is a bright testimony of anomalous pressure of a certain physical factor, most likely, the change of biotope type and simultaneously formation of dysoxic conditions beneath the sediment/water interface, which at once excluded the presence of vagrant suspension and deposit feeders of low level. A decrease in bottom temperature is also supposed. During accumulation of bituminous interbed the terrigene component played a subordinate role, and sourcelands were rather far. The three communities that followed the *Oxytoma* one have all characteristics of immature communities: taxonomic poverty, very poor gradation, no dominance of a certain genus, predominantly small size of shells (see Fig. 6). Fall of sea level and accompanying rise of bottom were not unidirectional and, possibly, often restructurings of sourcelands led to destabilization of biotopes. The nature of bottom communities inclines the explanation to this course of events. The beginning of the Volgian Age coincided with the restructuring of migration paths, because the subgenus *Astarte (Nicaniella)* again became dominant, but with a new species, which is evidently a pioneer. Its dominance during the study time interval was not accompanied by improvement of the pattern of benthic community. It is likely that during the time following a local biotic crisis (*Oxytoma* community)

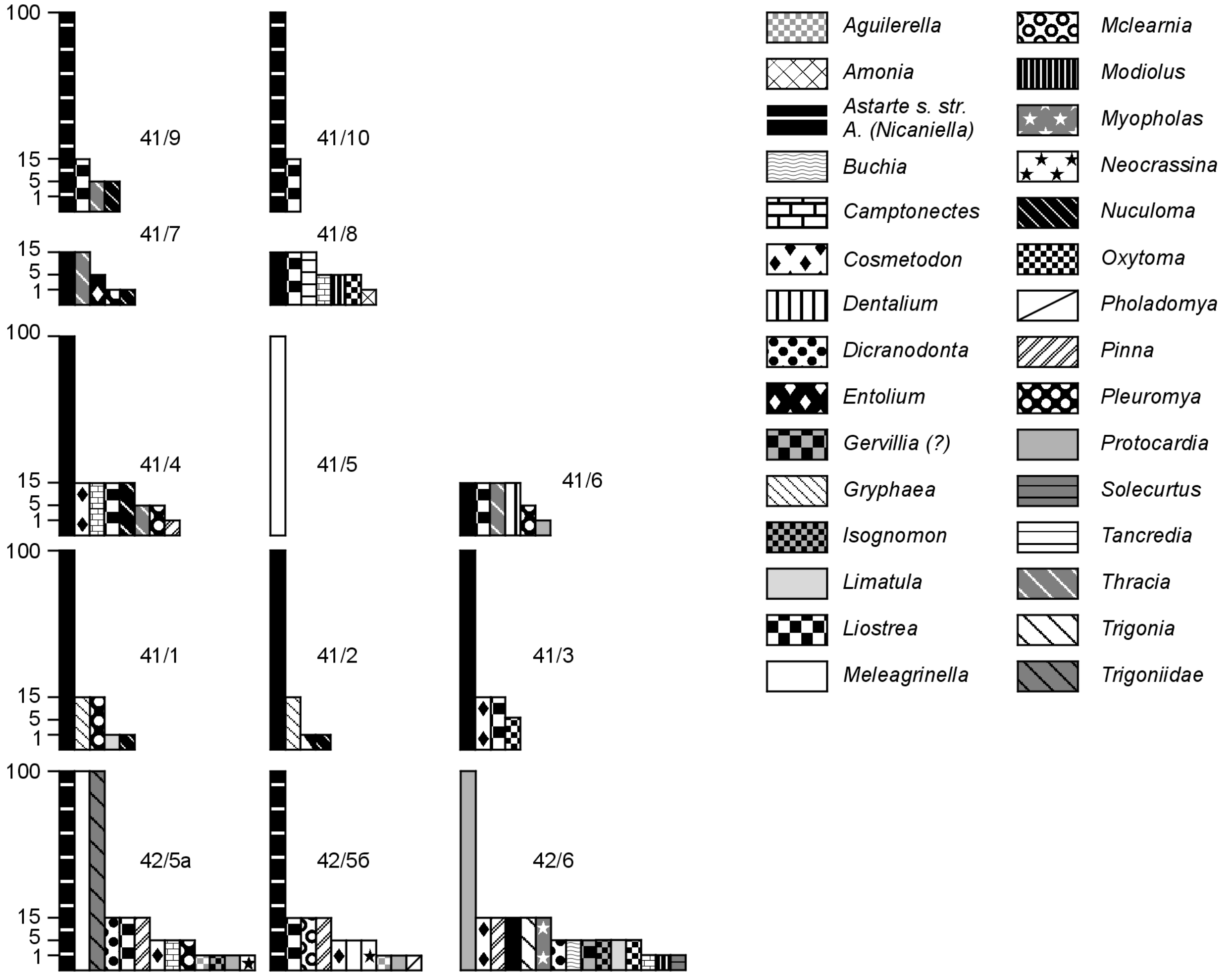


Fig. 6. Generic structure of bottom communities. Explanations in text.

more complicated though less pronounced bioevents took place, but they are not supported by benthic molluscs. These events should be "extracted" when analyzing the benthic microbiota.

DISCUSSION

In accordance with the available paleogeodynamic reconstructions [43–45], in the Late Jurassic the territory of Subpolar Urals was at a paleolatitude of 50–55°. The pole was nearby the Bering Strait [43, 44, 46]. The absolute paleotemperatures obtained by various authors in different years are in agreement with this hypothesis. Thus, in the end of the Jurassic (Middle Volgian time) annual paleotemperatures of surface sea water were 15 ℃ in the north of East Siberia (65–70°), 18 ℃, in Subpolar Urals (50–55°), and 22 ℃, in Eastern Greenland (40–45°) [3, 15, 26]. Though our data are more than 1 ℃ higher than the earlier calculated mean paleotemperatures for Subpolar Urals (Lopsiya River), they are within fluctuations of the values obtained by Teis et al. [15]. It is important that nearly the same high temperatures were obtained for adjacent basins: 18.5 ℃ for the Timan-Pechora basin, and 18.6 ℃, for the South Uralian and Caspian basins [15] situated somewhat west- and southward, respectively. For this reason we do not think that an annual paleotemperature of 17.9 ℃ for the Oxfordian–Kimmeridgian of the Folkland Plateau, situated at the southern paleolatitude of 55°, is too high as the authors themselves believe [47]. It is also quite natural that for the other site in the South Hemisphere, New Zealand, situated near the South Pole high annual temperatures were obtained, averaging 18 ℃ [9]. All these data are in agreement with the results obtained earlier for the Late Jurassic of the central Russian Platform, where a steady rise in paleotemperature during the Oxfordian was documented: from 7 ℃ in the Early Oxfordian to 18 ℃ in the Kimmeridgian [48]. These values agree with calculated models of paleotemperatures of the Earth's surface in the Kimmeridgian for the Russian Platform [49]. According to the authors' data, average paleotemperatures of winter months varied from 12 °C in the north to 20 °C in the south, and paleotemperatures of summer months averaged 16 °C and 24 °C, respectively. Taking into account our ideas that the rostrum material grow mostly in the summer, it is likely that the thermal regime of surface waters of Kimmeridgian boreal seas at paleolatitudes of 50–60° corresponded to that of the modern subtropics. It seems likely that to obtain actual annual paleotemperatures of surficial waters, at least 2–3 °C should be subtracted from the figures derived from belemnite matter. This inference is in agreement with the above paleobiogeographic and paleoecological data. Therefore, recent information on low annual paleotemperatures in Late Jurassic high-latitude seas is bewildering: 14.7 °C on the territory of Antarctic (James Ross Land, 57° S) and 9.4 °C on Spitsbergen (King Karl Land, 55° N) [16, 50]. The latter value seems to be especially underestimated as it is even lower than another value, 14.3 °C, reported for the Middle Jurassic of the island of King Karl Land. The last value agrees with data on northern East Siberia, 14.5 °C, but 9.4 °C contradicts all multiple measurements for the Upper Jurassic of East Siberia, persistently indicating paleotemperatures above 15 °C [15]. The Kimmeridgian-Tithonian paleotemeratures equal to 13.6–16 °C, obtained for Mallorca, one of the Balearian islands, also seem to be considerably underestimated [51]. In the late Jurassic period, this island was in the western Tethys, at 25–30°, in the habitat of colonial corals scleractinians, which by analogy with modern colonial corals, inhabited very warm seas. A high temperature of the water is also inferred from the structure of the section made up mostly of limestones. Synthesis of global data on the Jurassic period suggests two temperature maxima: in the Toarcian and Kimmeridgian-Tithonian [52].

Irrespective of absolute values, the curve of paleotemperatures is generally correlated with vestiges of some biotic events in the Kimmeridgian section of Subpolar Urals (see Fig. 5). Thus, the general decrease in absolute magnitudes coincides with a decrease in generic diversity of benthos from Early to Late Kimmeridgian. This might be, however, connected with a change of living conditions caused by a rise in water level: replacement of a severe biotope by a milder one, attenuation of bottom hydrodynamics, and simultaneously by some decrease in bottom water temperature. A short interval of time of accumulation of organic-rich shales (Bed 5 in Exp. 41) is accompanied by a drastic decrease in taxonomic diversity in this thin bed and is recorded by a drop in paleotemperature in beds above and below the marked level. This fact is as if in discrepancy with general ideas that anoxic events and related stages of deposition of organic-rich rocks in the Earth's history matched the periods of global warmings caused supposedly by eustatic sea-level rises [9, Fig. 10]. In fact, it would be more reasonable to explain the time of formation of organic-rich mud by rise of sea level, simultaneous deepening of biotope, and related decrease in temperature of bottom water. The restructuring of benthic communities that followed the highly carbonaceous event seems to confirm the inference that neither the character of biotope nor hydrodynamics, nor variations in water salinity were responsible for it. Taking into account the fact that in the Eudoxus phase the sea covered the maximum areas in the region of the North Sea and over the territory of Great Britain [53], this short episode of the formation of organic-rich shales might be considered a signal of a eustatic event in the north of Eurasia as a whole.

Undoubtedly, even small fluctuations of the Kimmeridgian paleotemperature curve are not accidental. But immature paleobiocoenoses of that time provide no definite information about the factors of animal habitats. Small changes in their structure cannot be unambiguously interpreted in agreement with a paleotemperature curve. Long-period thermal variations throughout the Mesozoic have long been established on the adjacent territory of northern Siberia [18]. On the general heat curve given in the mentioned publication, recurrent warming falls on the Kimmeridgian, which agrees with the data calculated from oxygen isotopes from belemnite rostra of Subpolar Urals.

CONCLUSIONS

The values $\delta^{18}O$ obtained from analysis of belemnite rostrum material have shown unusually high temperatures for the Kimmeridgian of Subpolar Urals averaging 20 °C. This result, however, differs little from the data obtained earlier from the same territory for the Upper Kimmeridgian (18.9 °C) as well as for the Kimmeridgian of the adjacent regions: Timan-Pechora (18.5 °C), Caspian and South Uralian (18.6 °C) [15]. Paleotemperatures in Subpolar Urals are somewhat higher because the shallow-water bay was well warmed up in the summer and belemnite rostrum material grew predominantly in the summer. In addition, the isotope ratios might have been affected by recurrent refreshenings of surface water by river run-off, as Subpolar Urals had a semihumid climate in the Kimmeridgian [29]. A strong effect is also supposed to be exerted by a warm surface current from the west through straits on the Polar Urals, a terrestrial barrier between the seas in the north of Eastern Europe and the West Siberian basin [26].

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APPENDIX

SECTION OF UPPER JURASSIC DEPOSITS ALONG THE LOPSIYA RIVER (EASTERN SLOPE OF THE SUBPOLAR URALS)

The Upper Jurassic deposits outcrop 50 km ustream from the mouth of the Lopsiya River, a left tributary of the Severnaya Sos'va River, and are represented by two exposures (see Fig. 1): Exp. 42 (Upper Oxfordian–Lower Kimmeridgian) and Exp. 41 (upper Lower Kimmeridgian–lower Lower Volgian Substage) situated one kilometer downstream from Exp. 42.

The Kimmeridgian section exposed there is one of the most biostratigraphically and sedimentologically complete sections on the territory where boreal-type deposits develop (Fig. 2). It benefits of the most detailed succession of ammonite zones [25]. The section is made up predominantly of clays with subordinate interbeds of clayey limestone which occur as horizontal series of concretions. Only the base of the section consists of fine-sandy rocks. Its brief description with complexes of mollusc genera is given below. The section is zoned according to Mesezhnikov [25], the numeration, thickness and short description of beds follow the results obtained during the 1997 field works, when a team of geologists of the Institute of Petroleum Geology, Novosibirsk, headed by Yu.I. Bogomolov, carried out its complex revised study. Ammonite occurrence in the section is given in accordance with data by Mesezhnikov* [25] and Yu.I. Bogomolov, belemnite occurrence, after O.S. Dzyuba [21], and occurrence of molluscs and gastropods, after V.A. Zakharov.

Exposure 42

Kimmeridgian Stage
Lower Substage
Pictonia involuta Zone

Thickness, m

Bed 5a. Lithology. Dark-gray clayey silt with lenses of coalified wood and a concretionary interbed of sandstone (up to 0.05 m) at the base. Its boundary with Bed 4b is sharp and is established by change of color and rock composition. Pyritized nodules (0.02×0.06 m) are found in remains of shells and wood.

Paleontological description. Ammonites: *Pictonia* aff. *gracilis* Tornquist*, *Amoeboceras (Amoeboceras)* cf. *pingueforme* Mesezhn.*, and *Rasenia (Rasenia) incostans* Spath*; belemnites (frequent at the bottom and rare in the rest of the bed): *Pachyteuthis (Pachyteuthis)* cf. *panderiana* (d'Orb.), *P. (Boreioteuthis)* cf. *absoluta* (Fisch.), and *Pachyteuthis* sp. ind.; bivalves: *Astarte (Nicaniella) extensa* (Phill.) (abundant), *Trigonia* sp. (abundant), *Dicranodonta* sp. (frequent), *Meleagrinella* aff. *subovalis* (Phill.) (abundant), *Neocrassina (Neocrassina)* aff. *orientalis* Zakh. (rare), *Liostrea* sp. (very frequent), *Pinna* sp. (frequent), *Isognomon* sp. (very rare), *Pleuromya* aff. *tellina* ag. (rare), *Cosmetodon* cf. *keyserlingi* (Orb.) (rare), *Camptonectes (Camptonectes)* cf. *lens* (Sow.) (rare), *Protocardia* sp. (very rare), and *Aguilerella* sp. (very rare) 0.01–0.5

Rasenia evoluta Zone
Eurasenia pseudouralensis Subzone

Bed 5b. Lithology. Brownish-gray lumpy sandy-clayey silts with rare fragments of mineralized wood and pyritized concretions similar to those from Bed 5a. At the level 1.5 m from the bottom occurs an interbed of large calcareous concretions. An interbed of gray plastic clay 0.3 m thick lies one meter apart from the top. At a distance of 0.4 m from the roof silt changes to large-lumpy fine- and medium-grained sandstone consolidated in places into a concretionary interbed.

Paleontological description. Ammonites: *Amoeboceras (Amoebites) kitchini* (Salf.)*, *A. (A.) spathi* Schulg.*, *Prorasenia bowerbanki* Spath, *P. hardyi* Spath, *Rasenia (Rasenia) inconstans* Spath*, *R. (R.) evoluta* Spath, and *R. (Eurasenia) pseudouralensis* Mesezhn.; belemnites: *Pachyteuthis (Boreioteuthis) absoluta* (Fisch.) (frequent) and *Pachyteuthis* sp. ind. (very rare); bivalves: *Astarte (Nicaniella) extensa* (Phill.) (abundant), *Pinna* sp. (frequent), *Neocrassina (Neocrassina) orientalis* Zakh. (rare), *Meleagrinella* aff. *subovalis* (Phill.) (rare), *Cosmetodon* cf. *keyserlingi* (Orb.) (rare), *Camptonectes (Mclearnia)* sp. (cf. *braeviauris*) (frequent), *Liostrea* sp. (frequent), *Protocardia* sp. (very rare), *Aguilerella* sp. (very rare), and *Pholadomya* sp. (very rare) . . . 2.0

Bed 6. Lithology. Dark-gray fine-lumpy plastic clays. Large calcareous septarian concretions are found throughout the bed. In places, pyrite grains occur.

Paleontological description. Ammonites: *Amoeboceras (Amoebites) kitchini* (Salf.)*, *Prorasenia bowerbanki* Spath, *Rasenia (Rasenia) inconstans* Spath*, *R. (R.) laevigata* Mesezhn.*, *R. (R.) coronata* Mesezhn.*, *R. (R.) suburalensis* Spath, and *Zonovia (Zonovia) ilovaiskii* (Sasonov); belemnites: *Pachyteuthis (Boreioteuthis)* *absoluta* (Fisch.) (abundant), *P. (B.) troslayana* (d'Orb.) (rare), and *P. (Pachyteuthis) panderiana* (d'Orb.) (very rare); bivalves: *Protocardia* sp. (abundant), *Cosmetodon* cf. *keyserlingi* (d'Orb.) (very frequent), *Trigonia* sp. (frequent), *Astarte (Astarte) lyapinensis toliyaensis* Zakh. (frequent), *Pinna* sp. (frequent), *Myopholas* sp. (rare), *Gervillia* sp. (rare), *Isognomon* sp. (rare), *Oxytoma (Oxytoma)* sp. (rare), *Dicranodonta* sp. (rare), *Limatula* cf. *consobrina* (d'Orb.) (rare), *Buchia concentrica* (Sow.) (rare), *Modiolus* sp. (very rare), *Camptonectes (Camptonectes)* sp. (very rare), and *Solecurtus* sp. (very rare); gastropods: *Turitella* sp. (frequent) and *Pleurotomaria* sp. (rare). . . . . >15

Observation hiatus 15–20

Exposure 41

Kimmeridgian Stage
Lower Substage
Rasenia evoluta Zone
Zonovia uralensis Subzone

Bed 1. Lithology. Dark-gray bluish plastic clays with thin horizontal lamination and small nodules of gray clay limestone.

Paleontological description. Ammonites: *Rasenia (Rasenia) coronata* Mesezhn.* and *Zonovia (Zonovia) uralensis* (d'Orb.); belemnites: *Pachyteuthis (Bereioteuthis) troslayana* (d'Orb.) (frequent), *P. (B.) absoluta* (Fisch.) (rare), *P. (Pachyteuthis) excentralis* (Young et Bird) (rare), *P. (P.) miatschkoviensis* (Ilov.) (very rare), *P. (P.) grossa* Dzjuba (very rare), *Lagonibelus (Lagonibelus) ingens* (Krimh.) (very rare), and *Simobelus (Simobelus) breviaxis* (Pavl.) (rare); bivalves: *Astarte (Astarte) lyapinensis lyapinensis* Zakh. (frequent), *A. (A.) lopsiyaensis lopsiyaensis* Zakh. (abundant), *Pleuromiya* sp. (frequent), *Gryphaea* sp. (frequent), *Limatula consorbina* (d'Orb.) (very rare), and *Nuculoma* sp. (very rare) 1.1

Upper Substage
Aulacostephanus sosvaensis Zone

Bed 2. Lithology. Clay as in Bed 1. At the bottom lies a concretionary interbed of gray clay limestone with ammonites, small bivalves, and belemnites.

Paleontological description. Ammonites: *Aulacostephanus (Pararasenia) tobolicus* (Khud.), *A. (P.) subhibridus* Mesezhn., *A. (Aulacostephanus) sosvaensis* (Sason.), *A. (A.)* aff. *sosvaensis* (Sason.), *A. (A.)* aff. *circumplicatus* (Qu.)*, and *Zonovia* sp.*; belemnites: *Pachyteuthis (Borioteuthis) troslayana* (d'Orb.) (very rare), *P. (Pachyteuthis) excentralis* (Young et Bird) (rare), *P. (P.) grossa* Dzjuba (very rare), *Simobelus (Simobelus) breviaxis* (Pavl.) (frequent), and *S. (S.) lopsiensis* Dzjuba (very rare); bivalves: *Astarte (Astarte) lyapinensis lyapinensis* Zakh. (abundant), *A. (A.) lopsiyaensis lopsiyaensis* Zakh. (abundant), *Gryphaea* sp. (frequent), *Grammatodon* cf. *rhomboidalis* (Contejean) (very rare), and *Nuculoma* sp. (very rare) 1.4

Bed 3. Lithology. Clay is the same. At the bottom and 3.30 m apart from the bottom lie flattened concretions of gray limestone with large ammonites.

Paleontological description. Ammonites: *Aulacostephanus (Aulacostephanus) sosvaensis* (Sason.), *A. (Pararasenia) tobolicus* (Khud.), *A. (P.) semieudoxus* Schneid.*, and *A. (P.)* aff. *quenstedti* Durand.; belemnites: *Pachyteuthis (Boreioteuthis) troslayana* (d'Orb.) (rare), *P. (Pachyteuthis)* cf. *panderiana* (d'Orb.) (very rare), *P. (P.) grossa* Dzjuba (very frequent), *Lagonibelus (Lagonibelus) ingens* (Krimh.) (very rare), *Simobelus (Simobelus) breviaxis* (Pavl.) (rare), and *S. (S.) lopsiensis* Dzjuba (rare); bivalves: *Astarte (Astarte) lopsiyaensis lopsiyaensis* Zakh. (abundant), *Cosmetodon keyserlingi* (d'Orb.) (very frequent), *Liostrea* sp. (frequent), and *Oxytoma* cf. *expansa* Phill. (rare) 5.5

Bed 4. Lithology. The same clay. At the bottom of the bed are elongate ellipsoid concretions of gray clay limestone. Smaller concretions are scattered over the bed. At the level 0.7 m from the bottom is a thin interbed of sandy silt with coal and small calcareous nodules.

Paleontological description. Ammonites: *Amoeboceras (Amoebites) kitchini* (Salf.), *Aulacostephanus (Aulacostephanus) sosvaensis* (Sason.), *A. (A.) yo* (d'Orb.), *A. (A.) pinguis* Ziegler, *A. (Pararasenia) quenstedti* Durand., *A. (P.) tobolicus* (Khud.), and *A. (P.) subhibridus* Mesezhn.; belemnites: *Pachyteuthis (Boreioteuthis) troslayana* (d'Orb.) (very rare), *P. (Pachyteuthis) grossa* Dzjuba (very rare), and *Simobelus (Simobelus)* cf. *breviaxis* (Pavl.) (very rare); bivalves: *Astarte (Astarte) lopsiyaensis lopsiyaensis* Zakh. (abundant), *Grammatodon* cf. *rhomboidalis* (Contejean) (very frequent), *Liostrea* sp. (frequent), *Camptonectes (Camptonectes)* cf. *lens* Sow. (frequent), *Nuculoma* sp. (frequent), *Thracia* sp. (frequent), *Pleuromiya* sp. (frequent), *Pinna* sp. (very rare) 4.0

Bed 5. Lithology. Dark organic-rich clay, brown on the weathered surface, in places changing to organic-rich limestone.

Paleontological description. Ammonites: *Amoeboceras (Amoebites) kitchini* (Salf.) and *A. (A.) uralensis* Mesezhn.*; bivalves: *Melegrinella* sp. (abundant) 0.06–0.15

Aulacostephanus eudoxus zone

Bed 6. Lithology. Gray bluish plastic clays.

Paleontological description. Ammonites: *Aulacostephanus (Aulacostephanus)* aff. *undorae* (Pavl.), *A. (A.) yo* (d'Orb.), *A. (A.)* aff. *yo* (d'Orb.), *A. (A.) pinguis* Ziegler, *A. (A.) volgensis* (Vischn.), *A. (A.) lopsiensis* Mesezhn., *A. (Pararasenia) quenstedti* Durand., and *A. (P.) subhibridus* Mesezhn.; belemnites: *Pachyteuthis (Boreioteuthis)* cf. *troslayana* (d'Orb.) (very rare), *Simobelus (Simobelus) breviaxis* (Pavl.) (very rare), and *S. (S.)* cf. *breviaxis* (Pavl.) (very rare); bivalves: *Liostrea* sp. (very frequent), *Astarte (Astarte) lopsiyaensis lopsiyaensis* Zakh. (frequent), *Thracia* sp. (frequent), *Dentalium* sp. (frequent), *Pleuromiya* sp. (rare), and *Protocardia* sp. (very rare) 2.2

Bed 7. Lithology. The same clay. At the bottom are flattened round concretions of gray clay limestone (to 1 m in diameter) with fauna.

Paleontological description. Ammonites: *Amoeboceras (Nannocardioceras)* sp.*, *A. (Euprionoceras)* sp.*, *Aulacostephanus (Aulacostephanus) yo* (d'Orb.), *A. (A.) pimguis* Ziegler, *A. (A.) volgensis* (Vischn.), *A. (Pararasenia) subhibridus* Mesezhn., and *A. (P.) quenstedti* Durand; belemnites: *Pachyteuthis (Boreioteuthis)* cf. *troslayana* (d'Orb.) (very rare), and *Simobelus (Simobelus)* cf. *breviaxis* (very rare); bivalves: *Thracia* sp. (very frequent), *Astarte (Astarte) lopsiyaensis lopsiyaensis* Zakh. (frequent), *Entolium demissum* Phill. (rare), *Nuculoma* sp. (very rare), and *Pleuromiya* sp. (very rare) 2.0

Aulacostephanus autissiodorensis Zone
Virgataxioceras dividuum Subzone (upper 1.5 m)

Bed 8. Lithology. The same clay. The bed contains flattened round concretions of gray limestone to 0.6 m across.

Paleontological description. Ammonites: *Aulacostephanus (Aulacostephanus) volgensis* (Vischn.), *A. (A.) undorae* (Pavl.), *Virgataxioceras dividuum* Mesezhn.*, and *Aspidoceras longispinum* (Sow.); belemnites: *Simobelus (Simobelus) mamillaris* (Eichw.) (very rare); bivalves: *Astarte (Astarte) lopsiyaensis lopsiyaensis* Zakh. (frequent), *Liostrea* sp. (very frequent), *Tancredia* sp. (frequent), *Camptonectes (Camptonectes)* cf. *lens* (rare), *Oxytoma* sp. (rare), *Modiolus* sp. (rare), and *Anomia (Placunopsis)* sp. (very rare) 2.5

Volgian Stage
Lower Substage
Eosphinctoceras magnum Zone

Bed 9. Lithology. Gray silty clay. The basal part embraces concretionary interbed of gray massive limestone, occasionally thinning out and is traceable as a loose shelly interbed. Small (up to 0.15 m) round and fusiform limestone concretions are scattered over the bed.

Paleontological description. Ammonites: *Eosphinctoceras magnum* Mesezhn. and *Gravesia polypleura* Hahn*; belemnites: *Simobelus (Simobelus) mamillaris* (Eichw.) (frequent), *S. (S.) insignis* (Sachs et Naln.) (frequent), *S. (S.) intortus* (Sachs et Naln.) (rare), *Pachyteuthis (Pachyteutis) panderiana* (d'Orb.) (rare), *P. (P.) apiculata* Sachs et Naln. (very rare), and *P. (Boreioteuthis) explanata* (Phill.) (frequent); bivalves: *Astarte (Nicaniella) supraextensa* Zakh. (abundant), *Liostrea* sp. (frequent), *Thracia* sp. (rare), and *Nuculoma* sp. (rare) 2.0

Subdichotomoceras subcrassum Zone

Bed 10. Lithology. Clay as in Bed 9. Septarian concretions of gray massive limestone (up to 0.25 m) occur at the base.

Paleontological description. Ammonites: *Subdichotomoceras (Subdichotomoceras) grandis* Mesezhn., *S. (S.) michailovi* Mesezhn., and *Eosphinctoceras magnum* Mesezhn.; belemnites: *Simobelus (Simobelus) mamillaris* (Eichw.) (very rare), *S. (S.) insignis* (Sachs et Naln.) (rare), *S. (S.) intortus* (Sachs et Naln.) (very rare), *Pachyteuthis (Pachyteuthis) panderiana* (d'Obr.) (rare), *P. (P.) apiculata* Sachs et Naln. (very rare), *P. (Boreioteuthis) troslayana* (d'Orb.) (very rare), and *P. (B.) explanata* (Phill.) (frequent); bivalves: *Astarte (Nicaniella) supraextensa* Zakh. (abundant) and *Liostrea* sp. (frequent). 3.0

The detritus of Exp. 41 contains *Lagonibelus (Lagonibelus) sarygulensis* (Krimh.) and *Pachyteuthis (Pachyteuthis) miatschkoviensis* (Ilov.) near outcrops of the Upper Kimmeridgian Substage (Exp. 41, Bed 2?) [21].

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