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Belemnites and Biostratigraphy of the Jurassic–Cretaceous Boundary Deposits of Northern East Siberia: New Data on the Nordvik Peninsula

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Abstract—The study of new collections from the Urdyuk-Khaya Cape (Nordvik Peninsula) made it possible to specify the taxonomic composition of belemnites from the Volgian and basal Ryazanian in northern East Siberia. *Cylindroteuthis knoxvillensis* Anderson, 1945, *C.* cf. *newvillensis* Anderson, 1945, and *Arctoteuthis tehamaensis* (Stanton, 1895) known from northern California, as well as the new species *C. venusta* sp. nov. and *A. britanna* sp. nov. are first described from the Arctic region. Belemnite stratigraphy of Jurassic–Cretaceous boundary layers is fundamentally revised, allowing a new refined version of their scale to be proposed as a Boreal standard. Two independent successions of biostratigraphic units are defined in the section interval spanning the uppermost Middle Volgian Substage to the basal Ryazanian Stage: (1) *Liobelus russiensis* Zone, *Lagonibelus gustomesovi* and *Arctoteuthis porrectiformis* beds; (2) *Lagonibelus napaensis, Arctoteuthis tehamaensis*, and *Cylindroteuthis knoxvillensis* zones.

Keywords: belemnites, Cylindroteuthididae, biostratigraphy, Volgian and Ryazanian stages, East Siberia.

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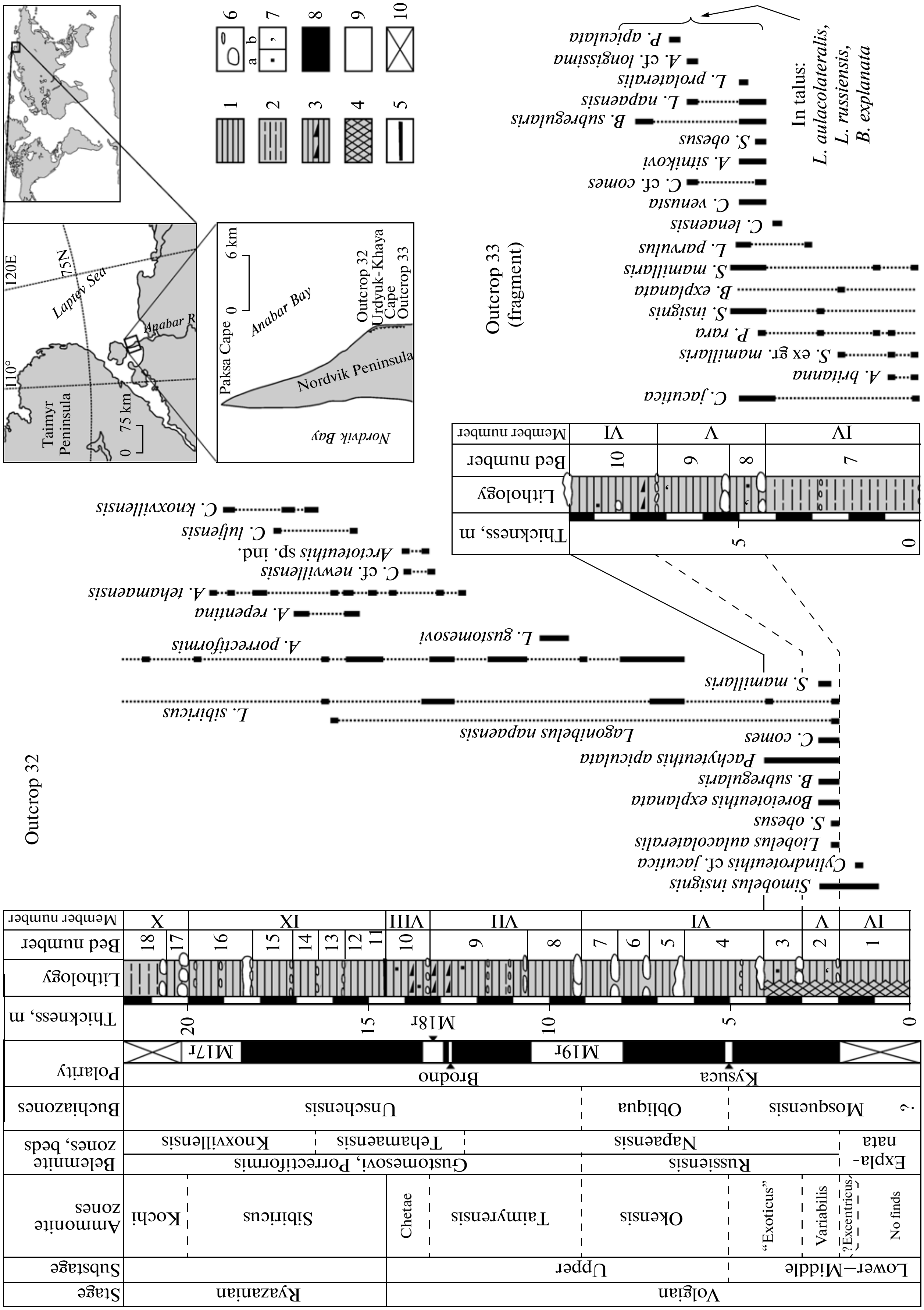
INTRODUCTION

The succession of zones and beds based on the distribution of belemnites is an element of the system of parallel (autonomous) scales of the Jurassic Boreal zonal standard (Zakharov et al., 1997). Recent versions of the Boreal zonal standard developed for the Jurassic–Cretaceous boundary interval are based on East Siberian zonal successions for all fossil groups except for dinocysts (Baraboshkin, 2004; Zakharov et al., 2005). This is because East Siberia hosts the best studied Upper Volgian and Ryazanian sections, unique with respect to their completeness and paleontological characteristics.[1] The Volgian–Ryazanian boundary strata with insignificant intrazonal hiatuses outcrop in the upper reaches of the Kheta River (*Granitsa*..., 1972; and others). Their complete section is described from cliffs on the Laptev Sea on the Nordvik Peninsula (Fig. 1), where they are investigated by paleontological–paleoecological, lithological–geochemical, magnetostratigraphic, and isotopic methods (Basov et al., 1970; *Granitsa*..., 1972; Kaplan et al., 1973; Zakharov and Yudovnyi, 1974; Zakharov et al., 1983; Dzyuba, 2004; Dzyuba et al., 2007; Houša et al., 2007; Zakharov and Rogov, 2008; Nikitenko et al., 2008; Mizera et al., 2010; Žák et al., 2011; and others).

In the Kheta River section, belemnites occur in the ammonite zones (a-zones): *Exoticus, Okensis*, uppermost *Taimyrensis*, beds attributed to the lower part of the *Kochi* Zone (Alekseev, 1984) and *Mesezhnikowi* (Saks and Nalnyaeva, 1964, 1966; *Opornyi*..., 1969; *Granitsa*..., 1972). The belemnite assemblages from the *Chetae* and *Sibiricus* a-zones remain unknown. No revision of belemnites has been performed in this section since the end of the 1960s. Despite the need for revision of the present identifications of belemnites, no additional material has been sampled so far. The belemnite assemblages from the Nordvik Peninsula have received more attention. They were studied by many researchers (Voronets, 1962; Saks and Nalnyaeva, 1964, 1966; Basov et al., 1970; *Granitsa*..., 1972; Zakharov et al., 1983; Shenfil, 1992, 1995; Dzyuba and Glushkov, 2000; Dzyuba, 2004; Dzyuba et al., 2007). All the available publications are informative with respect to taxa that occur in the stratigraphic interval spanning from the Oxfordian Stage to the Middle Volgian Substage, since precisely these sediments contain abundant belemnite rostra. Information on belemnites from the Upper Volgian Substage and most of the Ryazanian Stage is relatively scarce: the number of available species level belemnite identifications hardly exceeds a dozen among their limited

[1] Hereinafter, the Ryazanian is treated as a synonym for the "Boreal Berriasian."


Outcrop 32
Outcrop 33
(fragment)
Stage
Substage
Ammonite zones
Belemnite zones, beds
Buchiazones
Polarity
Thickness, m
Lithology
Bed number
Member number
Volgian
Ryazanian
Lower–Middle
Upper
No finds
?Excentricus
Variabilis
"Exoticus"
Okensis
Taimyrensis
Chetae
Sibiricus
Kochi
Explanata
Russiensis
Napaensis
Gustomesovi, Porrectiformis
Tehamaensis
Knoxvillensis
Mosquensis
Obliqua
Unschensis
Kysuca
Brodno
M19r
M18r
M17r
Simobelus insignis
Cylindroteuthis cf. jacutica
Liobelus aulacolateralis
S. obesus
Boreioteuthis explanata
B. subregularis
Pachyteuthis apiculata
C. comes
Lagonibelus napaensis
L. sibiricus
S. mamillaris
A. porrectiformis
L. gustomesovi
A. repentina
A. tehamaensis
C. cf. newvillensis
Arctoteuthis sp. ind.
C. tuljensis
C. knoxvillensis
C. jacutica
A. brittanna
S. ex gr. mamillaris
P. rara
S. insignis
B. explanata
S. mamillaris
L. parvulus
C. lenaensis
C. venusta
C. cf. comes
A. sitnikovi
S. obesus
B. subregularis
L. napaensis
L. prolateralis
A. cf. longissima
P. apiculata
In talus:
L. aulacolateralis,
L. russiensis,
B. explanata
Taimyr Peninsula
Laptev Sea
Anabar R.
75N
120E
110°
75 km
Paksa Cape
Anabar Bay
Nordvik Peninsula
Nordvik Bay
Outcrop 32
Urdyuk-Khaya Cape
Outcrop 33
6 km

finds. The corresponding sediments in the Nordvik Peninsula area were deposited in the relatively deep (150–200 m and deeper) remote part of a sea basin (Kaplan et al., 1973; Zakharov and Yudovnyi, 1974; and others), which probably explains the scarcity of cylindroteuthid finds in them.

During 2003–2009, the Upper Jurassic–Lower Cretaceous sections of the Nordvik Peninsula were visited by scientists from the Geological Institute of the Russian Academy of Sciences (Moscow, Russia), Charles University (Prague, Czech Republic), and Trofimuk Institute of Petroleum Geology and Geophysics (Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russia). Most attention was paid to the Volgian–Ryazanian interval of these sections. Its particularly thorough examination for all macrofossils yielded a representative collection of belemnite rostra, which served as a basis for this work that continues previous taxonomic investigations of boreal belemnites from the Jurassic–Cretaceous boundary strata (Saks and Nalnyaeva, 1968; 1972, 1973; Nalnyaeva, 1984; Dzyuba, 2004, 2007, 2009; and others). In addition, the biostratigraphic analysis of new materials offers the opportunity to refine the belemnite zonation in a system of parallel biostratigraphic scales of the Boreal zonal standard.

MATERIAL

New collections of belemnite rostra from the family Cylindroteuthididae sampled from the Volgian and Ryazanian stages in the Nordvik Peninsula served as a material for this studies. Fossils were sampled in 2003 by V.A. Zakharov and M.A. Rogov (Geological Institute, Moscow) and M. Kostak (Karlov University, Prague, Czech Republic) and in 2007 and 2009 by field teams from the Institute of Petroleum Geology and Geophysics (Novosibirsk, Russia) headed by V.A. Marinov. In total, the collection includes approximately 50 intact specimens and approximately 110 incomplete rostra. For description of some species, additional material sampled by O.V. Shenfil (Institute of Petroleum Geology and Geophysics, Novosibirsk) from coeval sections of the Boyarka River and its tributaries (Kheta River basin) and Nordvik Peninsula in 1984–1989 was used. In addition, monographic belemnite collections Nos. 83, 84, 86, and 88 by V.N. Saks and T.I. Nalnyaeva stored in the Central Siberian Geological Museum (CSGM) at the Institute of Petroleum Geology and Geophysics (IPGM SB RAS), Siberian Branch, Russian Academy of Sciences (Novosibirsk) were also examined.

The Jurassic–Cretaceous strata on the Nordvik Peninsula are exposed in the Urdyuk-Khaya Cape area (outcrops 32 and 33), where they are largely composed of dark gray mudstone-like clays enriched in organic matter. The generally uniform structure is complicated by several horizons of phosphate–carbonate concretions. The examined interval of the section is approximately 24–27 m thick (Fig. 1). Most new belemnite finds originate from Outcrop 32.

NEW DATA ON THE TAXONOMIC COMPOSITION OF BELEMNITES

The lower half of the Volgian Stage yielded new species of the family Cylindoteuthididae: *Cylindroteuthis venusta* sp. nov. (Plate I, figs. 4, 5) endemic for northern Siberia and *Arctoteuthis britanna* sp. nov. (Plate I, figs. 2, 3; Fig. 1) characteristic of coeval strata of England. The same interval also contains *C. lenaensis* Sachs et Naln. (Plate I, fig. 7) and *Lagonibelus parvulus* (Gust.) (Plate III, fig. 1) first found in the Nordvik Peninsula. The last species, known from Lower–Middle Volgian boundary layers of the East European Platform, is recorded for the first time in northern Siberia. Finds of *A. repentina* (Sachs et Naln.) (Plate I, fig. 1) in the *Sibiricus* a-Zone of the Ryazanian Stage are of interest, since large rostra of this species were never found. The species *C. luljensis* Sachs occurring in basal layers of the Ryazanian Stage of the North and Supolar Urals was previously represented in northern Siberia by only one specimen (*Granitsa*..., 1972) found in the Kheta River section in layers now attributed to the *Kochi* a-Zone (Alekseev, 1984). This species is now identified in the *Sibiricus* a-Zone of the Nordvik Peninsula (Plate III, fig. 6). *C.* cf. *newvillensis* And. (Plate I, fig. 6) and *A. tehamaensis* (Stant.) (Plate III, figs. 2–5) found in the Volgian–Ryazanian boundary interval supplemented the list of Cylindroteuthididae taxa in common with the northern California assemblage. In addition, the stratigraphic distribution of *C. knoxvillensis* And. (Plate II, figs. 1–5), another species known from California, is specified. These new data are of importance for investigations aimed at correlation of Jurassic–Cretaceous boundary strata formed in different climatic zones (Dzyuba, 2010).

Other changes concerning the taxonomic composition of Nordvik cylindroteuthids should also be mentioned. For example, *Cylindroteuthis* (*Cylindroteuthis*)

←

Fig. 1. Location of the section of the Volgian and Ryazanian stages outcropping in the Nordvik Peninsula and distribution of belemnites.

Thicknesses of beds and sketches of concretions are given according to field materials by V.A. Marinov. Numbers of outcrops, members, and beds are after (Zakharov et al., 1983). Ammonite and Buchia zones are after (Zakharov et al., 1983; Zakharov and Rogov, 2008; Rogov and Zakharov, 2011); data on ammonites at the base of the section are given in original interpretation. Paleomagnetic scale is after (Houša et al., 2007).

(1) clay; (2) silty clay; (3) clay enriched with organic matter; (4) brecciation zone; (5) iridium anomaly in phosphatized chert (5 cm); (6) pyrite (a), glauconite (b); (7) carbonate concretions; (8–10) polarity: (8) normal, (9) reversed, (10) no data.

Plate I

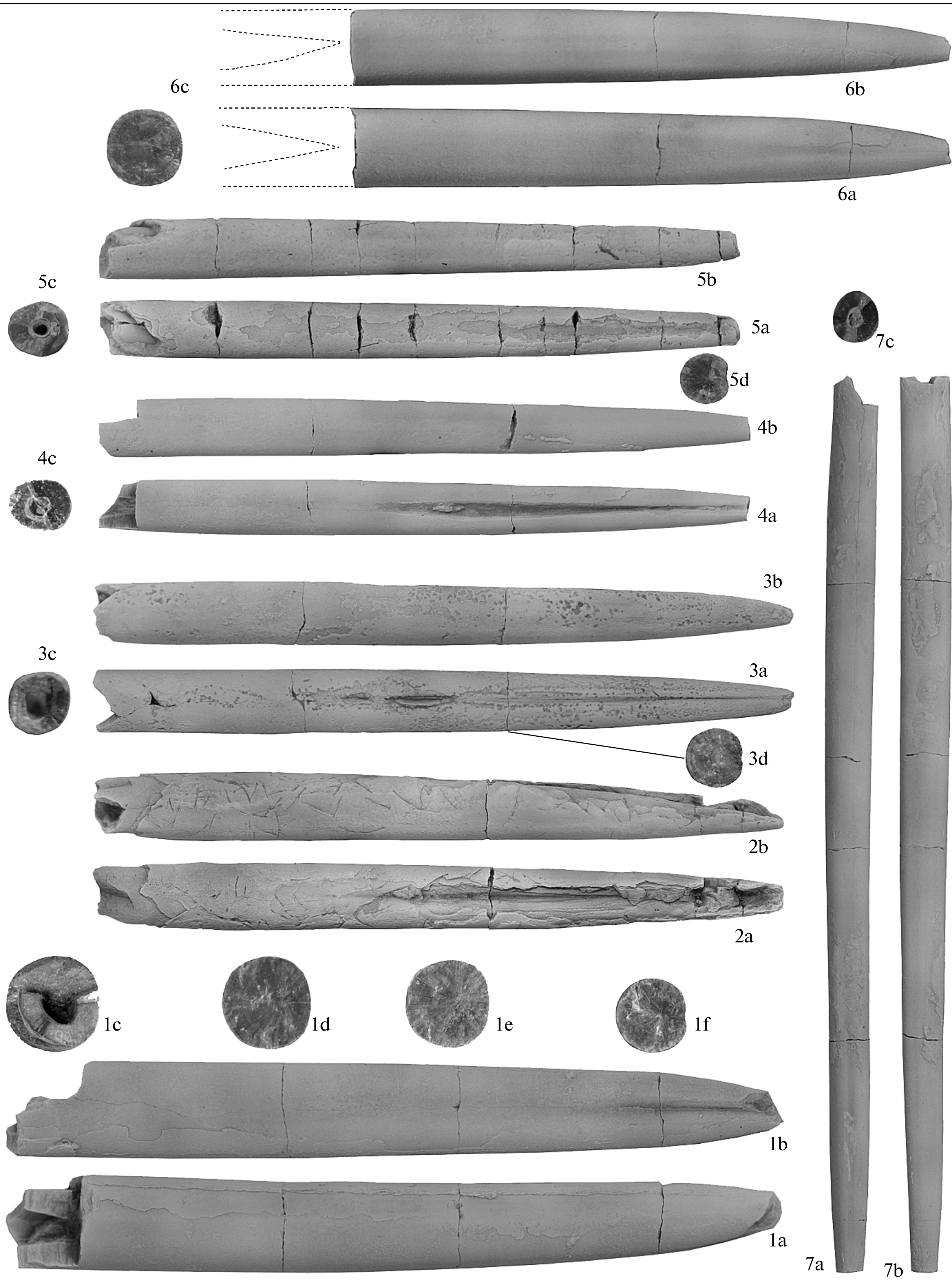

6b
6c
6a
5b
5c
5a
7c
5d
4b
4c
4a
3b
3c
3a
3d
2b
2a
1c
1d
1e
1f
1b
1a
7a
7b

Plate I. Belemnites from Jurassic–Cretaceous boundary sections of northern East Siberia. Here and in plates II and III, all the specimens (except for specially noted) are illustrated in natural size. Collections (nos. 680 and 2034) are stored in the Central Siberian Geological Museum (CSGM) at the Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences (Novosibirsk).
Specimens 1–4 originate from the Nordvik Peninsula and Specimen 5, from the Pravaya Boyarka River.
(1) *Arctoteuthis repentina* (Sachs et Naln.), Specimen 2034/16, Outcrop 32, Bed 12, 0.8 m above the base, Ryazanian Stage, *Sibiricus* a-Zone: (a) left lateral view, (b) ventral side view, (c) transverse section near the anterior end, (d–f) transverse sections at different levels of the postalveolar part; (2, 3) *A. britanna* sp. nov, Outcrop 33, Bed 7, Volgian Stage, ?Lower substage, lower part of the *Explanata* bl-Beds: (2) Specimen 2034/10, 3.4 m below the top of Bed 7: (a) ventral side view, (b) right lateral view; (3) holotype, Specimen 2034/9, 4.0 m below the top of Bed 7: (a) ventral side view, (b) right lateral view, (c) transverse section near the anterior end, (d) transverse section in the postaleveolar part; (4, 5) *Cylindroteuthis venusta* sp. nov, Middle Volgian Substage, *Variabilis* a-Zone: (4) holotype, Specimen 680/12, Outcrop 33, Bed 8: (a) ventral side view, (b) right lateral view, (c) transverse section near the anterior end, (5) Specimen 680/13, Outcrop 20, Bed 2: (a) ventral side view, (b) right lateral view, (c) transverse section near the anterior end, (d) transverse section in the apical region; (6) *C.* cf. *newvillensis* Anderson, Specimen 2034/2, Outcrop 32, Bed 10, 0.65 m below the top, Upper Volgian Substage, *Chetae* a-Zone: (a) ventral side view, (b) right side view, (c) transverse section near the anterior end; (7) *C. lenaensis* Sachs et Nalnjaeva, Specimen 2034/17, Outcrop 33, Bed 7, 0.4 m below the top of Bed 7, Middle Volgian Substage, upper part of the *Explanata* bl-Beds: (a) ventral side view, (b) right side view, (c) transverse section near the anterior end.

lepida Sachs et Naln. Formerly indicated from the uppermost Middle Volgian Substage and basal layers of the Ryazanian Stage (Dzyuba, 2004; Dzyuba et al., 2007), this species is now missing from the stratigraphic charts of belemnite distribution. This species is now considered as a synonym of the Cretaceous species *C. knoxvillensis* And., while rostra of Middle Volgian *C. lepida* served as a basis for defining *C. venusta* sp. nov. In my opinion, *Arctoteuthis sitnikovi* (Sachs et Naln.) cited among fossils from the Upper Volgian *Taimyrensis* a-Zone (Bed 9, Outcrop 32) in (Basov et al., 1970) could be identified based on rostra belonging to *A. tehamaensis* (Stant.). These species may easily be confused, when identification is based on single specimens (see section "Taxonomic description"). No rostra of *A. sitnikovi* were found in Jurassic–Cretaceous boundary sediments during their subsequent thorough examination; instead, several rostra of *A. tehamaensis* were found in these layers.

The following belemnite assemblage was recorded in talus of the Upper Volgian (Outcrop 33) (Dzyuba, 2004): *Cylindroteuthis* cf. *comes* Voron., *Arctoteuthis porrectiformis* (And.), *A. sitnikovi* (Sachs et Naln.), *Pachyteuthis apiculata* Sachs et Naln., *Boreioteuthis explanata* (Phill.), *Simobelus mamillaris* (Eichw.), *Liobelus russiensis* (d'Orb.), *L. aulacolateralis* (Gust.). All these belemnites were attributed to the Upper Volgian Substage section, near which they were found on the beach. Now, it is undoubted that most of the listed taxa originate from the uppermost part of the Middle Volgian Substage. The taxa *C.* cf. *comes*, *A. sitnikovi*, and *S. mamillaris* were previously registered in Outcrop 33 immediately in the *Variabilis* a-Zone (Basov et al., 1970; Dzyuba, 2004; and others). Now, the species *P. apiculata* is found in this a-zone (Fig. 1). In Outcrop 32, the latter also yielded *L. aulacolateralis*.

The analysis of the stratigraphic distribution of Volgian belemnites in the Cape Urdyuk-Khaya section made it necessary to specify refined correlation between outcrops 32 and 33. By lithological criteria, thicknesses and faunal characteristics both outcrops are readily correlative in the interval from the horizon of lenticular locally large (up to (0.25–0.3) × 1.5 m) concretions in the uppermost Middle Volgian Substage (base of Bed 4, Outcrop 32 and Bed 11, Outcrop 33) to a thin bed of hard calcareous–phosphate rock at the base of the Ryazanian Stage (Bed 11, Outcrop 32 and Bed 18, Outcrop 33). In the lower part of the Volgian Stage, correlation of these outcrops is rather ambiguous. Beds 1 and 2 of Outcrop 32 are traditionally correlated with beds 8 and 9 in Outcrop 33 (Basov et al., 1970; Zakharov et al., 1983; and others). At the same time, there is also another correlation variant, according to which Bed 2 of Outcrop 32 corresponds to the lower part of Bed 10 in Outcrop 33 (Zakharov and Rogov, 2008). In the upper part of Bed 10 in Outcrop 33 (upper (1.3 m), M.A. Rogov found ammonites *Laugeites* sp. juv., *L.* cf. *parvus* Donovan, *L.* aff. *parvus*, *Praechetaites exoticus* (Shulg.) and *L.* cf. *bicostatus* (Shulg.) characteristic of the "*Exoticus*" a-Zone, which corresponds to Bed 3 and basal part of Bed 4 of Outcrop 32[2]. Belemnites indicate, in turn, that the lower half of Bed 2 in Outcrop 32 most likely corresponds to Bed 8 of Outcrop 33. This interval is marked by the appearance of extremely diverse Cylindroteuthididae assemblages taxonomically identical in both outcrops (Fig. 1). In the overlying sequence, the latter is notably less diverse. No ammonites are found in beds 1 and 2 of Outcrop 32 and lower part of Bed 10 in Outcrop 33. Using bivalves, the entire interval under consideration corresponds to the *Mosquensis* Buchia-

[2] In connection with the discussion concerning the validity of *Exoticus* a-Zone defining in the Nordvik Peninsula section (Meledina et al., 2010; Rogov and Zakharov, 2011), the name of the latter in this work is given in quotes. The appearance level of *Praechetaites* representatives from the group of *P. exoticus* (Shulg.) and the quantitative prevalence of *Praechetaites* forms are considered as criteria for defining its lower boundary (Rogov and Zakharov, 2011). In Zakharov and Rogov (2008), this boundary is erroneously shown at the base of Bed 2 of Outcrop 32. The upper boundary of the "*Exoticus*" a-Zone marked by the first appearance level of *Craspedites okensis* (d'Orb.) is accepted as corresponding to the Kysuca paleomagnetic subchrone according to (Houša et al., 2007; Rogov and Zakharov, 2011).

Plate II

zone. The lower and middle parts of Member V in the Nordvik Peninsula are characterized by the foraminiferal assemblage of *Tortuosa* Beds defined in the upper part of the *Tortuosa–Vicinalis* foraminiferal zone (f-zone) (Nikitenko et al., 2008; Nikitenko, 2009). According to Nikitenko (personal communication), the examined samples originate from the lower part of Bed 2 (Outcrop 32), Bed 8, and lower part of Bed 3 (Outcrop 33). The uppermost part of the member (upper part of Bed 2 in Outcrop 32) yielded the foraminiferal assemblage of the *Veteranus–Emeljanzevi* f-Zone established also in overlying sediments (beds 3 and 4, Outcrop 32). Thus, all the data on Bed 2 of Outcrop 32 indicate that it includes sediments corresponding to beds 8 and 9 in Outcrop 33. This inference requires thorough analysis.

Beds 1–3 in Outcrop 32 are accessible for examination in a small area immediately adjacent to the brecciation zone along a normal NNW-trending fault with the amplitude of approximately 25 m (Basov et al., 1970, fig 1; Zakharov et al., 1983, fig. 3). Rocks in Outcrop 32 are exposed in the northern downdip block and dip mostly at low angles (from 9° to 22°) in a southwestern direction. Near the fault, dip angles amount to 45°. It is conceivable that beds 1–3 of Outcrop 32 are complicated by fractures, which may be missed. This means that some layers exposed in Outcrop 33, may be missing from them. In such areas, at least reduction of the true bed thicknesses should be expected, since normal faults are accompanied by extension movements. Consequently, Bed 2 in Outcrop 32 may include sediments corresponding to beds 8 and 9 of Outcrop 33 (*Variabilis* a-Zone). If this correlation is correct, Bed 1 in Outcrop 32 should correspond to the uppermost part of Bed 7 in Outcrop 33 (uppermost part of Member IV), which contains *Buchia mosquensis* (Buch.) (upper 2 m), *Taimyrosphinctes* ? sp. (0.3 m below the top) (Zakharov et al., 1983; Zakharov and Rogov, 2008), and foraminiferal assemblage of the *Tortuosa–Vicinalis* f-Zone (upper 4 m) (Nikitenko, 2009), in addition to the similar belemnite assemblage. The insignificant content of glauconite in the sediments under consideration, which is abundant in the overlying Member V, may also serve as indirect evidence for their synchronism.

BIOSTRATIGRAPHIC INFERENCES

A thorough investigation of Cylindroteuthididae belemnites may be effective for solving biostratigraphic problems. For example, recent studies of these fossils from the Nordvik Peninsula section made it possible to establish a boundary between the Kimmeridgan and Volgian stages in the latter (Dzyuba, 2004; Dzyuba et al., 2007). With the accumulation of data, it became clear that is should be placed in the interval of 4.0–4.5 m below the top of Member IV, since overlying sediments contain the Volgian assemblage of *Explanata* belemnite Beds (bl-Beds), while underlying strata correspond to the Kimmeridgian *Ingens* bl-Zone (*Septentrionalis* Subzone). This inference is confirmed by the data on microfossils (Nikitenko, 2009). No ammonites have yet been found in the Kimmeridgian–Volgian boundary layers of the Nordvik Peninsula. The Volgian Stage in this area previously included only the upper 2.0 m of Member IV (Basov et al., 1970; Zakharov et al., 1983; and others). New data allow a more refined belemnite scale to be proposed for the Jurassic–Cretaceous boundary interval.

In the Siberian biostratigraphic belemnite scale, the interval spanning from the uppermost Middle Volgian Substage to the basal Ryazanian Stage previously included the *Liobelus russiensis* Beds and *Lagonibelus gustomesovi* Zone (Dzyuba, 2004). Owing to new finds on the Nordvik Peninsula, two parallel successions of biostratigraphic belemnite units are defined in this interval (Fig. 1): (1) *Liobelus russiensis* Zone, *Lagonibelus gustomesovi* and *Arctoteuthis porrectiformis* beds; (2) *Lagonibelus napaensis, Arctoteuthis tehamaensis*, and *Cylindroteuthis knoxvillensis* zones. As was exemplified by the Kimmeridgian–Volgian boundary strata (Dzyuba, 2004), parallel belemnite scales, first, provide more detailed subdivision of sections and, second, allow correlation of sections that were formed in different depositional environments or, even, different climatic belts. For example, index species of biostratigraphic units in the first succession are characteristic of high-latitude Arctic sections (Pechora River basin, North and Subpolar Urals, northern Siberia), except for *Liobelus russiensis* (D'Orb.), which occurs also in Central Russia and Northwest Europe. Zonal species of the second succession are known from sections of northern California, which were formed in climatic conditions of lower latitudes.

Plate II. Belemnites from Jurassic–Cretaceous boundary sections of northern East Siberia. Specimens 1–3, 5 originate from the Boyarka River and specimens 4, 6, 7 are from the Nordvik Peninsula.

(1–5) *Cylindroteuthis knoxvillensis* Anderson, Ryazanian Stage: (1) Specimen 2034/3, Outcrop 17, Bed 3, *Mesezhnikowi* a-Zone: (a) ventral side view, (b) right side view, (2) Specimen 2034/8, Outcrop 16, Bed 3, 3.0 m below the top, *Analogus* a-Zone, longitudinal section, (3) Specimen 2034/5, Outcrop 16, Bed 4 (base), *Analogus* a-Zone: (a) ventral side view, (b) right side view, (c) transverse section near the anterior end, (4) Specimen 2034/4, Outcrop 32, Bed 15 (base), *Sibiricus* a-Zone: (a) ventral side view, (b) right side view, (c) transverse section in the alveolar region, (5) Specimen 2034/6, Outcrop 16, Bed 1. 2.4 m below the top, *Kochi* a-Zone: (a) transverse section in the apical region, ×3.0, (b) transverse section near the tip of alveolus, ×3; (6) *Liobelus prolateralis* (Gustomesov), Specimen 2034/18, Outcrop 33, Bed 8, 0.7 m above the base, Middle Volgian Substage, *Variabilis* a-Zone, (a) left side view, (b) ventral side view; (7) *L. aulacolateralis* (Gustomesov), Specimen 2034/19, Outcrop 32, Bed 2 (base), Middle Volgian Substage, *Variabilis* a-Zone, (a) ventral side view, (b) right side view, (c) transverse section near the anterior end.

The high correlative potential of the new belemnite successions recommend them for inclusion into the Boreal zonal standard. The defined stratigraphic units are characterized below.

Liobelus russiensis bl-Zone

Index species: *Liobelus russiensis* (d'Orb.). In addition to the index species, the zonal belemnite assemblage includes *L. prolateralis* (Gust.) and *L. aulacolateralis* (Gust).

Characteristic assemblage: *Lagonibelus sibiricus* Sachs et Naln., *L. napaensis* (And.), *Acroteuthis mosquensis* (Pavl.), *Pachyteuthis* spp., and *Simobelus* spp.

Nomenclature. The unit is first defined instead of the former *Liobelus russiensis* bl-Beds (Dzyuba, 2004).

Stratotype: northern East Siberia, Nordvik Peninsula, outcrops 32 (beds 2–7) and 33 (beds 8–14), clays 7.2–10.0 m thick.

Additional sections: northern East Siberia, Boyarka River, Outcrop 23 (beds 10–16, Bed 1), Outcrop 20 (beds 1–2), Outcrop 19 (beds 1–5), sandy silt and silty clays approximately 21.6 m thick (*Opornyi...*, 1969); European Russia, Volga River, village of Gorodishchi vicinity, Outcrop 4 (beds 4–5) sands approximately 1.0 m thick (Dzyuba, 2007).

Boundaries. The lower boundary corresponds to the appearance level of the zonal assemblage, and the upper one, to the appearance of *Lagonibelus gustomesovi* Sachs et Naln.

Stratigraphic range: Middle–Upper Volgian substages, *Variabilis* to *Okensis* a-zones of Siberia, *Nikitini* to *Subditus* a-zones of European Russia.

Geographic distribution: European Russia, northern East Siberia, in the rank of beds in the Subpolar Urals and central areas of West Siberia (Dzyba, 2004). The zone may also be traced in northwestern Europe if more thorough examination of the sections of this region were performed, (Dzyuba, 2006).

Remarks. Previously, the stratigraphic interval of the *L. russiensis* bl-Zone in the Nordvik Peninsula was defined as corresponding to the *Liobelus russiensis* and *Lagonibelus napaensis* beds, since finds of the index species and other taxa from the zonal assemblage were exclusively confined to talus (Dzyuba, 2004, plate XXII, figs. 5. 6). The additional belemnite collection yielded *Liobelus prolateralis* (Plate II, fig. 6) and *L. aulacolateralis* (Plate II, fig. 7) found in situ in sediments of the *Variabilis* a-Zone (Fig. 1).

Lagonibelus gustomesovi–Arctoteuthis porrectiformis bl-Beds

Index species: *Lagonibelus gustomesovi* Sachs et Naln. and *Arctoteuthis porrectiformis* (And.).

Characteristic assemblage: *Lagonibelus* spp., *Arctoteuthis* spp., *Cylindroteuthis* spp.

Type sections: northern East Siberia, Nordvik Peninsula, Outcrop 32 (beds 8–18), clays, locally silty, 12.6 m thick. The upper part of this biostratigraphic unit in the Nordvik Peninsula is unrecognizable. The unit is established in the Boyarka River Basin, where its contact with the overlying *Simobelus curvulus* bl-Zone is observable (Shenfil, 1992).

Boundaries. The lower and upper boundaries correspond to the first appearance levels of *L. gustomesovi* and *Simobelus curvulus* (Sachs et Naln.), respectively.

Stratigraphic range: Upper Volgian Substage–basal Ryazanian Stage, from the base of the *Taimyrensis* a-Zone to the middle part of the *Analogus* a-Zone.

Geographic distribution: North and Subpoar Urals, northern East Siberia. In case of more thorough examination of sections in Pechora River basin, the beds may also be traced in this region.

Remarks. Previously, the *Lagonibelus gustomesovi* bl-Zone included in regional stratigraphic scales of West and East Siberia (Shurygin et al., 2000; *Reshenie...*, 2004) was defined instead of these beds (Shenfil, 1992; Beizel et al., 1997; Dzyuba, 2004, 2006). In northern East Siberia, its boundary was substantiated by a single find of the index species in Bed 8 of Outcrop 32 in the Nordvik Peninsula (Basov et al., 1970; Zakharov et al., 1983). No other specimens were ever found, since finds of *L. gustomesovi* in the Upper Volgian Substage are extremely rare in this region. Information on the distribution of this species in the Subpolar Urals is rather ambiguous (Dzyuba, 2004, p. 152). Consequently, *L. gustomesovi* does not meet the requirements of a zonal index species. Probably this is why Shenfil (1995) renamed the *Gustomesovi* bl-Zone as the *Gustomesovi–Knoxvillensis* bl-Zone. He considered the name *Cylindroteuthis knoxvillensis* And. as a senior subjective synonym of *Arctoteuthis porrectiformis* (And.) (O.V. Shenfil, personal communication). Rostra of the last species are typical of Jurassic–Cretaceous boundary strata, although its lower and upper distribution limits in Siberia are unclear. All these factors prevent this stratigraphic unit from being treated as a zone.

Lagonibelus napaensis bl-Zone

Index species: *Lagonibelus napaensis* (And.). The zonal assemblage includes *L. sibiricus* Sachs et Naln. and *Cylindroteuthis venusta* sp. nov., in addition to the index species.

Characteristic assemblage: *C. comes* Voron., *Arctoteuthis* sp., *Pachyteuthis apiculata* Sachs et Naln., *Boreioteuthis subregularis* (Sachs et Naln.), *Simobelus mamillaris* (Eichw.), *Liobelus russiensis* (d'Orb.), *L. prolateralis* (Gust.), and *L. aulacolateralis* (Gust.).

N o m e n c l a t u r e. The unit is defined for the first time.

S t r a t o t y p e: northern East Siberia, Nordvik Peninsula, outcrops 32 (beds 2–8, partly Bed 9) and 33 (beds 8–15, partly Bed 16), clays 10.2–13.0 m thick.

B o u n d a r i e s. The lower boundary is placed at the appearance level of the zonal assemblage and the upper one corresponds to the appearance of *Arctoteuthis tehamaensis* (Stant.).

S t r a t i g r a p h i c r a n g e: Middle–Upper Volgian substages, from the *Variabilis* a-Zone to the middle part of the *Taimyrensis* a-Zone.

G e o g r a p h i c d i s t r i b u t i o n: northern East Siberia.

Arctoteuthis tehamaensis bl-Zone

I n d e x s p e c i e s: *Arctoteuthis tehamaensis*

C h a r a c t e r i s t i c a s s e m b l a g e: *Cylindroteuthis* cf. *newvillensis* (And.), *Arctoteuthis porrectiformis* (And.), and *Lagonibelus sibiricus* (Sachs et Naln.).

N o m e n c l a t u r e. The unit is defined for the first time.

S t r a t o t y p e: northern East Siberia, Nordvik Peninsula, Outcrop 32 (upper part of Bed 9, beds 10–13), clays approximately 4.0 m thick.

B o u n d a r i e s. The lower and upper boundaries are drawn at the appearance level of the index species and *Cylindroteuthis knoxvillensis* And., respectively.

S t r a t i g r a p h i c r a n g e: Upper Volgian Substage–basal Ryazanian Stage, from the uppermost part of the *Taimyrensis* a-Zone to the basal part of the *Sibiricus* a-Zone.

G e o g r a p h i c d i s t r i b u t i o n: northern East Siberia. In northern California, the index species is established in sections correlated with the upper part of the *Fischeriana* Subzone of the *Piochii* Buchiazone and aff. *Okensis* Buchiazone (Imlay and Jones, 1970).

Cylindroteuthis knoxvillensis bl-Zone

I n d e x s p e c i e s: *Cylindroteuthis knoxvillensis* And.

C h a r a c t e r i s t i c a s s e m b l a g e: *C. luljensis* Sachs, *Arctoteuthis tehamaensis* (Stant.), and *A. porrectiformis* (And.).

N o m e n c l a t u r e. The unit is defined for the first time.

T y p e s e c t i o n s: In the Nordvik Peninsula, the lower part of the zone represented by a clay to, locally, silty clay sequence approximately 5.4 m thick is recognizable in Outcrop 32. The upper part of this stratigraphic unit and its contact with the overlying *Simobelus curvulus* bl-Zone are established in the Boyarka River section: Outcrop 16 (beds 1–4), silty clays and clayey silt 25.7 m thick (Alekseev, 1984).

B o u n d a r i e s. The lower and upper boundaries correspond to the appearance levels of the index species and *Simobelus curvulus* (Sachs et Naln.), respectively.

S t r a t i g r a p h i c r a n g e: Ryazanian Stage, from the middle part of the *Sibiricus* a-Zone to the middle part of the *Analogus* a-Zone.

G e o g r a p h i c d i s t r i b u t i o n: northern East Siberia. In the North and Subpolar Urals, *C. knoxvillensis* is characteristic of the Ryazanian Stage beginning from the middle part of the *Sibiricus* a-Zone (Dzyuba, 2009). In northern California, this species is found in the CAS 28037 locality (Anderson, 1945) with outcropping sediments of the aff. *Okensis* Buchiazone (Imlay and Jones, 1970).

TAXONOMIC DESCRIPTION

The terminology and designation of morphological elements of rostra proposed in (Gustomesov, 1964; Saks and Nalnyaeva, 1964) are used in this work. Figure 2 illustrates the system of measurements. The following relative values were calculated: PA (%) = Pa (mm) × 100/DV (mm); (LL) (%) = LL (mm) × 100/DV; AR (%) = AR (mm) × 100/PA; ll (%) = ll (mm) × 100/dv (mm).

FAMILY CYLINDROTEUTHIDIDAE STOLLEY, 1919

SUBFAMILY CYLINDROTEUTHIDINAE STOLLEY, 1919

Genus *Cylindroteuthis* Bayle, 1878

***Cylindroteuthis venusta* sp. nov**

Plate I, fig. 4–5

?*Belemnites* (*Piesetrobelus*) *obeliscoides*: Pavlov, 1914, p. 15, plate I, figs. 5–6.

Cylindroteuthis (*Cylindroteuthis*) *lepida*: Saks and Nalnyaeva, 1964, p. 59 (pars), plate VI, figs. 2, 3, 6, sketch 11; Dzyuba, 2004, p. 46 (pars), plate III, figs. 3, 4.

S p e c i e s n a m e: from venusta (Latin) meaning fine, elegant.

H o l o t y p e: Specimen 680/12, CSGM in IGM SB RAS, Novosibirsk, Russia; northern East Siberia, Nordvik Peninsula, Outcrop 33, Bed 8; Volgian Stage, Middle Substage, *Variabilis* a-Zone; Dzyuba, 2004, plate III, fig. 3, reproduced in this work: Plate I, fig. 4.

D i a g n o s i s. Rostrum is large, strongly elongated to long (PA approximately 820–1060% under DV > 10 mm), with all sides practically straight and gradually converging to the apex imparting it a vague subconical shape. The ventral groove occupies one third to half of the rostrum length. The transverse section near the alveolus tip is rounded–subtrapezoid, laterally compressed (LL approximately 92–96%). Alveolus is shallow, straight, with the tip displaced toward the ventral side.

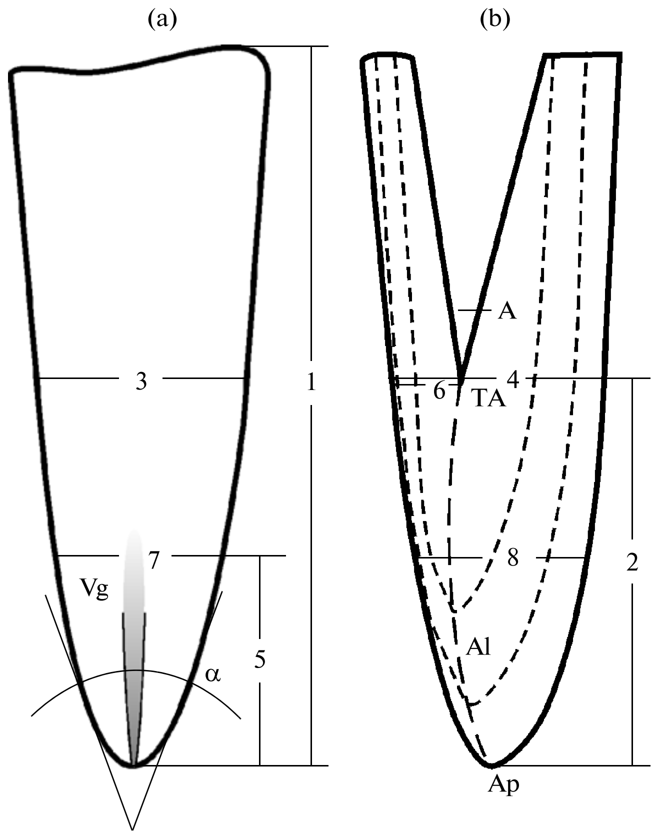


Fig. 2. Schematic sketch of morphological elements in belemnite rostra and system of their measurements.

(a) ventral side; (b) longitudinal section in the dorso-ventral plane. Elements of morphology: (A) alveolus, (Ap) apex, (TA) tip of alveolus, (Vg) ventral groove, (Al) apical line. Measured parameters: (1) total preserved length (R), (2) length of the postalveolar part of the rostrum (PA), (3) lateral diameter near the tip of the alveolus (LL), (4) dorso-ventral diameter near the tip of the alveolus (DV); (5) length of the apical region of the rostrum (AR), (6) ventral radius near the tip of the alveolus (Rv), (7) lateral diameter in the apical region of the rostrum (ll), (8) dorso-ventral diameter in the apical region of the rostrum (dv); (α) apical angle in the lateral plane.

D e s c r i p t i o n. Rostrum is large, long (PA 990–1060%), slightly subconical, with the elongated apical region. The apical angle is 13°. The apical tip is missing in all the specimens. The ventral side is flattened in the lower half of the rostrum, the dorsal side is convex. Lateral sides are with flattened surfaces inclined toward the dorsal edge. The ventral groove developed in the one third–half of the rostrum is narrow, relatively deep in the apical region and slightly widened away from the latter. Transverse section is rounded–subtrapezoid becoming near-triangular toward the anterior end, strongly compressed laterally in the alveolar region (LL 92–93%, ll 99–105%). Alveolus is shallow with the apex displaced toward the ventral side.

S i z e a n d p r o p o r t i o n s.

Specimen	R, mm	PA, mm	PA, %	DV, mm	LL, mm	LL, %	AR, mm	AR , %	α°	dv, mm	ll, mm	ll, %
680/12 (N)	113.5	106.0	1060	10.0	9.2	92	36.0	34	13	8.0	7.9	99
680/13 (B)	111.5	105.0	991	10.6	9.8	93	39.0	37	–	8.0	8.4	105

Note: (B) Boyarka River basin; (N) Nordvik Peninsula.

C o m p a r i s o n. By its general shape of the rostrum and development patterns of the ventral groove, the new species is very similar to *C. obeliscoides* (Pavl.) characteristic of the Upper Kimmeridgian–Lower Volgian. Dissimilar to the latter, it is characterized by the less elongated rostrum, rounded–subtrapezoid, not oval transverse section in the alveolar region. It is considerably shorter as compared with rostra of species *C. jacutuica* Sachs et Naln., *C. lenaensis* Sach et Naln., and *C. comes* Voron. From *C. newvillensis* And. occurring in younger layers of the Volgian Stage, the new species differs in the subconical shape, better developed ventral groove, and less rounded transverse section.

R e m a r k s. Rostra of *C.* (*C.*) *lepida* from the "uppermost lower Volgian Stage" (=uppermost Middle Volgian Substage) of the Anabar River basin described in (Saks and Nalnyaeva, 1964) belong to the species under consideration. From the holotype of *C.* (*C.*) *lepida* (Saks and Nalnyaeva, 1964, plate VI, fig. 1) originating from the Ryazanian Stage of the Maurynia River section and attributed in this work to the species *C. knoxvillensis* And. Middle Volgian specimens differ in the notable trapezoid patterns of the transverse section and best developed longer ventral groove. These distinctive features are also characteristic of specimens previously illustrated as *C.* (*C.*) *lepida* (Dzyba, 2004, plate III, fig. 3, 4). The monograph by (Saks and Nalnyaeva, 1964) includes also the sketch of the transverse section for one of the specimens (ibid, fig. 11) and photographs of transverse sections (ibid, plate VI, fig. 6), in addition to rostra illustrations.

Sections from the Anabar River basin yielded fragments of rostra, which were determined as *Belemnites* (*Piesetrobelus*) *obeliscoides* (Pavlov, 1914). Subsequently, they were identified as *C.* (*C.*) *lepida* (Saks and Nal'nyaeva, 1964). It is conceivable that these rostra belong to *C. venusta*. On the contrary, judging from its size and image (Saks and Nalnyaeva, 1964, p. 60, plate VI, fig. 4), the rostrum of *C.* (*C.*) *lepida* from the *Sokolovi* a-Zone of the Lower Volgian Substage in the Kyuryuk River basin (lower reaches of the Lena River) may belong to *C. obeliscoides* (Pavl.), since it is notably longer than rostra of the new species (PA 1204% under DV 6.5 mm).

D i s t r i b u t i o n. Volgian Stage, Middle Substage, *Variabilis* a-Zone of northern East Siberia.

M a t e r i a l. Holotype and another well-preserved specimen from the Pravaya Boyarka River, Outcrop 20, Bed 2, *Variabilis* a-Zone.

Cylindroteuthis cf. *newvillensis* Anderson, 1945

Plate I, fig. 6

D e s c r i p t i o n. Rostrum is rather elongated (PA > 795%), large, subcylindrical. The apical region is relatively short, with apical angle of 21°, and apex displaced toward the dorsal side. The ventral side is flattened in the posterior half of the rostrum; lateral and dorsal sides of both rostra are slightly convex. The poorly developed ventral groove is located within limits of the apical region. The transverse section is almost rounded (LL 98%, ll 105%). The tip of alveolus is displaced toward the ventral side (Rv 44%).

S i z e a n d p r o p o r t i o n s.

Specimen	R, mm	DV, mm	LL, mm	LL, %	AR, mm	AR, %	α°	dv, mm	ll, mm	ll, %
2034/1 (N)	130	18.0	17.7	98	–	–	–	–	–	–
2034/2 (B)	105	*13.2	*13.5	*102	28.0	<27	21	10.1	10.6	105

*Near preserved anterior end of the rostrum.

C o m p a r i s o n. By the transverse section of its rostrum, degree of lateral compression, and development of the ventral groove, the belemnite species under consideration is similar to *C. knoxvillensis* And. occurring in basal layers of the Ryazanian Stage differing from the latter by relatively shorter postalveolar region and shorter apical region, which imparts a distinctly cylindrical shape to the rostrum.

R e m a r k s. The available rostra are very similar to *C. newvillensis* (Anderson, 1945, p. 988, plate IX, fig. 4) registered in northern California in the upper part of the Newville Group (CAS 28628 locality). Only incompleteness of found specimens and, thus, unknown degree of their elongation prevents from exact identification of them with the last species.

M a t e r i a l. Two incomplete rostra: one is lacking the alveolar region and another, the apical one. Both rostra originate from Outcrop 32 in the Nordvik Peninsula, Upper Volgian Substage. One of them is found in Bed 9 corresponding to the top of the *Taimyrensis* a-Zone and another, in Bed 10, *Chetae* a-Zone.

Cylindroteuthis knoxvillensis Anderson, 1945

Plate II, figs. 1–5

Cylindroteuthis knoxvillensis: Anderson, 1945, p. 987, plate IX, fig. 2; plate X, fig. 4.

Cylindroteuthis klamathonae: Anderson, 1945, p. 988, plate VIII, fig. 4.

Cylindroteuthis (*Cylindroteuthis*) *lepida*: Saks and Nalnyaeva, 1964, p. 59 (pars), plate VI, fig. 1.

H o l o t y p e. Specimen no. 8962, Museum of the Californian Academy of Sciences, San Francisco, USA; California, Glenn County, Watson Creek, Locality CAS 28037, Tithonian Stage, upper part of the Newville Group. Imlay and Jones (1970) correlated these sediments with the aff. *Okensis* Buchia-zone); Anderson, 1945, plate IX, fig. 2; plate X, fig. 4.

D e s c r i p t i o n. The rostrum is large, long (PA 940–1200% under DV > 10 mm), obscurely subconical to subcylindrical, although with the elongated apical region. The apex is tapered, occupies almost central position. The apical angle is acute (usually 14°–19°, up to 23°). The ventral side is flattened through the most part of the rostrum, with a shallow poorly recognizable groove in its lower half, narrow near the apex and widening toward the alveolar region. Lateral sides are slightly flattened; the dorsal side is convex. The transverse section is almost rounded laterally compressed near the tip of the alveolus (LL 94–99%) and dorso-ventrally depressed in the apical region (ll 99–110%).

The alveolus is straight, with its tip displaced toward the ventral side (Rv approximately 40%). The apical line near the tip of the alveolus is curved toward the ventral edge further following practically parallel to the latter. In the ontogenesis, the relative elongation of the postalveolar part of the rostrum changes insignificantly: 1080–1120% under DV 3.7–3.8 mm; 910–1100 under DV 6.5–8.0 mm; 940–1200 mm under DV 10–16 mm; 940–995% under DV 17.0–18.5 mm. The transverse section of juvenile rostra is rounded.

S i z e a n d p r o p o r t i o n s.

Specimen	R, mm	PA, mm	PA, %	DV, mm	LL, mm	LL, %	AR, mm	AR , %	α°	dv, mm	ll, mm	ll, %
2034/3 (B)	190	165.0	1024	16.1	–	–	47.0	29	23	13.9	14.4	104
2034/4 (N)	–	–	–	11.2	10.9	97	–	–	–	9.8	10.0	102
2034/5 (B)	121	109.8	1036	10.6	10.4	98	41.5	38	16	8.7	9.1	105
2034/6 (B)	105	–	–	10.4	9.8	94	–	–	–	8.4	8.4	100
2034/7 (B)	54.5	47.0	1044	4.5	4.5	100	16.5	35	14	4.0	4.3	108

V a r i a b i l i t y. Most rostra are subconical in shape; moreover, in some specimens uniform tapering toward the apex is so gradual that the apical region is vague. At the same time, there are varieties characterized by a subcylindrical shape through three quarters (and more) of the rostrum (AR approximately 30%). The apical angle in largest specimens amounts to 23°. The length of the postalveolar part is notably variable (see description). In some specimens from the *Kochi* a-Zone of the Boyarka River section, LL is 101%.

C o m p a r i s o n. From co-occurring belemnites *C. occidentalis* And. and *C. luljensis* Sachs the species under consideration differs in a less massive and longer rostrum with a less developed ventral groove.

R e m a r k s. Species *C. klamathonae* (Anderson, 1945) found in California together with *C. knoxvillensis* demonstrates no considerable differences with the latter. This opinion was shared by Saks and Nalnyaeva (1972) and probably by Stevens (1965, p. 161), who was the first to note that many species established by F.M. Anderson need revision and should be synonymized.

In my opinion, the holotype of *C. lepida* (Saks and Nalnyaeva, 1964) from the Ryazanian Stage of the Maurynia River section (North Urals) is characterized by all the typical features of *C. knoxvillensis*. Rostra confirming presence of this species in the North and Subpolar Urals are established in the *Sibiricus* and *Kochi* a-zones (Dzyuba, 2009). Another specimen of *C. lepida* from the same locality exhibits in the transverse section atypical widening toward the dorsal side (Saks and Nalnyaeva, 1964, plate VI, fig. 5). It is too short (PA 821% under DV 10.6 mm) to be attributed to the species under consideration; it is dorso-ventrally depressed near the tip of the alveolus (LL 104%), which indicates its belonging to the genus *Arctoteuthis*.

Shenfil (1992, 1995) determined *C. knoxvillensis* in East Siberian sections. This author considered the latter to be identical to both *C. lepida* Sachs and Naln. and *Arctoteuthis porrectiformis* (And.) (O.V. Shenfil, personal communication). In this connection, *C. knoxvillensis* was registered in the Volgian Stage, where, in my opinion, it is missing.

D i s t r i b u t i o n. The Ryazanian Stage in northern East Siberia, North and Subpolar Urals (most characteristic of the *Sibiricus* and *Kochi* a-zones); Berriasian Stage, aff. *Okensis* Buchiazone of northern California.

M a t e r i a l. Seven incomplete specimens from the Nordvik Peninsula, Outcrop 32, beds 14–16, *Sibiricus* a-Zone; 12 well-preserved specimens and 25 fragments from the Boyarka River basin, Outcrop 16: beds 1–2, *Kochi* a-Zone (12 specimens), beds 3–4, basal *Analogus* a-Zone (14 specimens) and Outcrop 17, beds 3–4, *Mesezhnikowi* a-Zone (11 specimens).

Genus *Arctoteuthis* Sachs et Nalnjaeva, 1964

***Arctoteuthis britanna* sp. nov.**

Plate I, figs. 2–3

Belemnites porrectus: Pavlow, 1982, p. 223, plate IV (I), figs. 3, 4.

N a m e o f t h e s p e c i e s originates from britanna (Latin) meaning Britain, where it was first recorded.

H o l o t y p e. Specimen no. 2034/9, CSGM at IGM SB RAS. Novosibirsk, Russia; northern East Siberia, Nordvik Peninsula, Outcrop 33, Bed 7, 4.0 m below the top; Volgian Stage, ?Lower Substage, lower part of the *Explanata* bl-Beds; Plate I, fig. 3.

D i a g n o s i s. Rostrum is large, long (PA approximately 940–1130% under DV > 10 mm), subcylindrical, with acute centrally located apex. The ventral groove is developed in form of a narrow furrow that occupies at least half of the rostrum length. The transverse section is round slightly depressed in the dorso-ventral direction. The alveolus is shallow, with the apex displaced toward the ventral side.

D e s c r i p t i o n. The rostrum is large, long (PA 940–991%), subcylindrical, with the moderately elongated apical region. The apical angle is approximately 18°. The ventral side is slightly flattened in the postalveolar part and exhibits a relatively deep groove developed through the half to three fifth of the rostrum length. Lateral and dorsal sides are slightly convex. The transverse section is round (LL 97–101%, ll 103–105%). The alveolus is shallow, with its tip displaced toward the ventral side.

S i z e a n d p r o p o r t i o n s.

Specimen	R, mm	PA, mm	PA, %	DV, mm	LL, mm	LL, %	AR, mm	AR, %	α°	dv, mm	ll, mm	ll, %
2034/9 (N)	122	107.0	991	10.8	10.9	101	34	32	18	9.0	9.3	103
2034/10 (N)	120	107.2	940	11.4	11.0	97	32	30	–	8.9	9.3	105

C o m p a r i s o n. In its rostrum shape, well-developed ventral groove, and transverse section outline, the new species is most similar to the Kimmeridgian species *A. urdjukhayensis* (Sachs et Naln.) and Volgian–Ryazanian *A. porrectiformis* (And.) differing from both of them by the degree of elongation in its postalveolar part: PA 940–1130% versus 1200–1400% in *A. urdjukhayensis* and 600–900% in *A. porrectiformis*. The length of the ventral groove is also different in these species: it is shorter than in the former and longer than in the latter.

R e m a r k s. A.P. Pavlov (Pavlow, 1892) identified rostra from the Lower Volgian Substage (Beds "F" of Speeton section in classification of Lamplugh (1889)) of England, which is undoubtedly identical with the new species. They are slightly longer as compared with the rostra from the examined collection (PA 1040–1130%), although this feature represents the only and hardly significant difference, which cannot prevent from identification of these taxa. From *Cylindroteuthis porrecta* (Phill.), the species under consideration exhibits more substantial differences. The holotype of *C. porrecta* (Phillips, 1865–1870, p. 121, plate XXII, fig. 81) is more elongated (PA approximately 1600%) and laterally much strongly compressed (LL around 80%). In this connection, it was previously suggested to designate rostra of Pavlov's *Belemnites porrectus* as *A.* aff. *porrectiformis* And. (Dzyuba, 2004, p. 46).

D i s t r i b u t i o n. Volgian Stage, Lower Substage of Northwest Europe (England) and northern East Siberia.

M a t e r i a l. Two well-preserved specimens from the type locality sampled 3.4 and 4.0 m below the top of Bed 7.

***Arctoteuthis tehamaensis* (Stanton, 1895)**

Plate III, figs. 2–5

Belemnites tehamaensis: Stanton, 1895, p. 84, plate XIX, figs. 1–3.

Cylindroteuthis tehamaensis: Anderson, 1945, p. 986.

H o l o t y p e. PAL no. 23098, Smithsonian National Museum of Natural History, Washington, USA; California, Tehama County, Elder Creek, South Fork, northwest of the Cooper's ranch house; Lower Cretaceous (Imlay and Jones in (Jones et al., 1969; Imlay and Jones, 1970) correlated this section with the Upper Jurassic, Tithonian Stage, upper part of the Fischeriana Subzone of the Piochii Buchiazone); Stanton, 1895, plate XIX, figs. 1–3.

D e s c r i p t i o n. The rostrum is large, long (PA 900–1000% under DV >10 mm), slightly subconical to subcylindrical. The apical region is strongly elongated, regularly conical. The apex is tapered, slightly displaced toward the dorsal side; the apical angle is 17°–21°. The ventral side is flattened; lateral and dorsal sides are convex. The narrow shallow ventral groove diverging from the tip of the apex is soon transformed into a wide flattened depression, distinct through almost entire postalveolar part of the rostrum. The transverse section is rounded, subtrapezoid, dorso-ventrally depressed (LL 102–108%, ll 103–113%).

The alveolus is characterized by a slightly eccentric tip (Rv 40–47%). The apical line is slightly curved being parallel to the ventral side. Juvenile rostra are slim, tapered, generally similar in shape to adult specimens and characterized by the close degree of relative elongation. The transverse section becomes soon dorso-ventrally depressed.

Plate III

S i z e a n d p r o p o r t i o n s.

Specimen	R, mm	PA, mm	PA, %	DV, mm	LL, mm	LL, %	AR, mm	AR , %	α°	dv, mm	ll, mm	ll, %
2034/11 (N)	175	134	937	14.3	15.3	107	55	41	20	11.5	12.5	109
2034/12 (B)	115	114	974	11.7	12.0	103	44	39	21	10.1	11.0	109
2034/13 (N)	100	100	1000	10.0	10.2	102	40	40	18	8.2	8.5	104
2034/14 (B)	98	86	925	9.3	9.8	105	35	41	17	7.9	8.4	106
2034/15 (N)	52	50	909	5.5	5.6	102	19	38	19	4.8	5.1	106

V a r i a b i l i t y. Some rostra are characterized by the deeper ventral groove due to secondary destruction of growth layers.

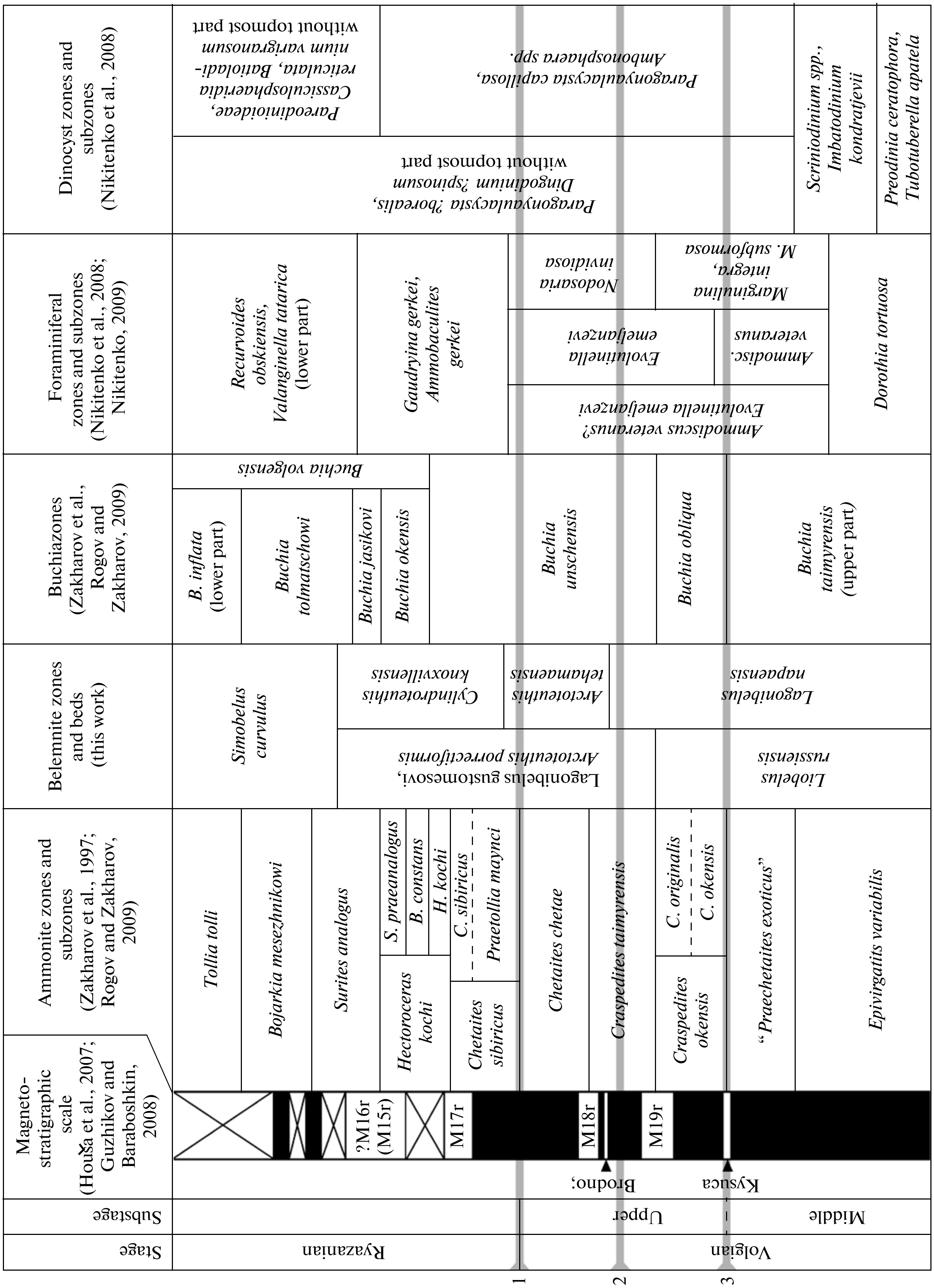
C o m p a r i s o n. By the general shape of the rostrum and transverse section, strongly elongated conical apical region, and poorly-developed ventral groove, the specimens under consideration correspond to *A. tehamaensis* illustrated in (Stanton, 1895). Unfortunately, it is impossible to determine relative elongation of the postalveolar part in the holotype, since it is represented by the rostrum lacking the alveolus. The preserved part is slightly shorter as compared with rostra in the examined collection: it constitutes >760% of the dorso-ventral diameter. Nevertheless, the observable specific combination of features makes this species readily recognizable.

The species in question is relatively longer as compared with the co-occurring *A. porrectiformis* (And.), characterized by the shorter and shallower ventral groove, and dorso-ventrally depressed transverse section near the tip of the alveolus. On the contrary, compared with *A. clavicula* (And.), it is substantially shorter. From *A. repentina* (Sachs et Naln.) occurring in the uppermost layers of the Volgian Stage and Lower Cretaceous, the species under consideration differs by its generally slender rostrum and lower degree of dorso-ventral depression. Similar rostrum is characteristic of the Volgian species *A. sitnikovi* (Sachs et Naln.), but *A. tehamaensis* is more elongated and is characterized by the shorter ventral groove. The characteristic feature of *A. tehamaensis*, which makes it different from all the above-mentioned taxa, is the elongated, almost perfectly conical posterior end of the rostrum. By this feature, it is similar to the Hauterivian species *A. pachsensis* (Sachs et Naln.), from which it differs in the longer rostrum, strongly flattened on the ventral side. In addition, adult specimens of *A. tehamaensis* were probably smaller compared with adults of *A. pachsensis*.

R e m a r k s. Rostra belonging to *A. tehamaensis* from the Upper Volgian Substage in northern East Siberia were, probably, identified as *A. sitnikovi* (Sachs et Naln.). In all the sections of this substage (Nordvik Peninsula, Kheta River), they are established only in the upper part of the *Taimyrensis* a-Zone (Saks and Nalnyaeva, 1964; *Opornyi*…, 1969; Zakharov et al., 1983), where *A. tehamaensis* was recently found. Taking into consideration significant similarity between compared species, this allows the assumption that former identifications were erroneous. All the typical representatives of *A. sitnikovi* are found in the Lower and Middle Substages of the Volgian Stage in East Siberia (Saks and Nalnyaeva, 1964, p. 122, plate XXVIII, figs. 1–3, sketch 37). Unfortunately, none of the Upper Volgian specimens was illustrated. The above-mentioned assumption should be considered true also for the finds of *A. sitnikovi* in the Upper Volgian Substage–Ryazanian Stage of the Pechora River basin (Nalnyaeva, 1984), which were also never illustrated. According to recent data (Repin et al., 2006), in the section of this region they appear in the uppermost part of the Upper Volgian Substage.

D i s t r i b u t i o n. The Volgian–Ryazanian boundary layers: from the uppermost *Taimyrensis* a-Zone to basal *Analogus* a-Zone in northern East Siberia and, probably, Pechora River basin; upper part of

Plate III. Belemnites from Jurassic–Cetaceous boundary sections of northern East Siberia.
Specimens 1, 2, 4–6 originate from the Nordvik Peninsula and Specimen 3, from the Boyarka River.
(1) *Lagonibelus parvulus* (Gustomesov), Specimen 2034/20, Outcrop 33, Bed 8, 0.6 m above the base, Middle Volgian Substage, *Variabilis* a-Zone, (a) ventral side view, (b) right side view, (c) transverse section near the anterior end, (d) transverse section at the beginning of the postalveolar part; (2–5) *Arctoteuthis tehamaensis* (Stanton), Ryazanian Stage: (2) Specimen 2034/13, Outcrop 32, Bed 15, 0.1 m below the top, *Sibiricus* a-Zone: (a) ventral side view, (b) right side view, (c) transverse section near the anterior end, (3) Specimen 2034/12, Outcrop 16, Bed 4 (base), *Analogus* a-Zone: (a) ventral side view, (b) right side view, (c) transverse section near the anterior end, (4) Specimen 2034/11, Outcrop 32, Bed 16, 0.6 m above the base, *Sibiricus* a-Zone: (a) ventral side view, (b) right side view, (c) transverse section near the tip of alveoulus, (d, e) transverse section at different levels of the postalveolar part, (5) Specimen 2034/15, Outcrop 32, Bed 15, 0.1 m below the top, *Sibiricus* a-Zone: (a) ventral side view, (b) right side view, (c) transverse section near the anterior end; (6) *Cylindroteuthis luljensis* Sachs, Specimen 2034/21, Outcrop 32, Bed 12, 0.85 m above the base, Ryazanian Stage, *Sibiricus* a-Zone: (a) ventral side view, (b) right side view, (c) transverse section near the anterior end.



Stage
Ryazanian
Volgian
Substage
Upper
Middle
Magneto-stratigraphic scale (Houša et al., 2007; Guzhikov and Baraboshkin, 2008)
?M16r (M15r)
M17r
M18r
M19r
Brodno;
Kysuca
Ammonite zones and subzones (Zakharov et al., 1997; Rogov and Zakharov, 2009)
Tollia tolli
Bojarkia mesezhnikowi
Surites analogus
Hectoroceras kochi
S. praeanalogus
B. constans
H. kochi
Chetaites sibiricus
C. sibiricus
Praetollia maynci
Chetaites chetae
Craspedites taimyrensis
Craspedites okensis
C. originalis
C. okensis
“Praechetaites exoticus”
Epivirgatites variabilis
Belemnite zones and beds (this work)
Simobelus curvulus
Cylindroteuthis knoxvillensis
Arctoteuthis tehamaensis
Lagonibelus napaensis
Lagonibelus gustomesovi, Arctoteuthis porrectiformis
Liobelus russiensis
Buchiazones (Zakharov et al., Rogov and Zakharov, 2009)
B. inflata (lower part)
Buchia tolmatschowi
Buchia jasikovi
Buchia okensis
Buchia volgensis
Buchia unschensis
Buchia obliqua
Buchia taimyrensis (upper part)
Foraminiferal zones and subzones (Nikitenko et al., 2008; Nikitenko, 2009)
Recurvoides obskiensis, Valanginella tatarica (lower part)
Gaudryina gerkei, Ammobaculites gerkei
Nodosaria invidiosa
Marginulina integra, M. subformosa
Evolutinella emeljanzevi
Ammodisc. veteranus
Ammodiscus veteranus? Evolutinella emeljanzevi
Dorothia tortuosa
Dinocyst zones and subzones (Nikitenko et al., 2008)
Pareodinioideae, Cassiculosphaeridia reticulata, Batioladinium varigranosum without topmost part
Paragonyaulacysta capillosa, Ambonosphaera spp.
Paragonyaulacysta ?borealis, Dingodinium ?spinosum without topmost part
Scriniodinium spp., Imbatodinium kondratjevii
Preodinia ceratophora, Tubotuberella apatela
1
2
3

Fig. 3. Belemnite zones and beds in the system of parallel scales available for the Jurassic–Cretaceous boundary interval of northern East Siberia.

The *Surites analogus* Zone is accepted without its subdivision into subzones after (Igol'nikov, 2006). The dashed line designates boundaries, the position of which relative to the paleomagnetic scale is unknown.

(1–3) existing versions for the position of the Jurassic–Cretaceous boundary: (1) traditional for boreal regions, (2) according to paleomagnetic data (Houša et al., 2007), (3) accepted in 1996 by the resolution of the Interdepartmental Stratigraphic Committee of the Russian Federation (Zhamoida and Prozorovskaya, 1997; Rostovtsev and Prozorowsky, 1997). For other symbols, see Fig. 1.

the *Fischeriana* Subzone of the *Piochii* Buchiazone and aff. *Okensis* Buchiazone of northern California. In the Subpolar Urals (Yatria River), the species is registered among belemnite assemblages of the *Kochi* a-Zone of the Ryazanian Stage (Dzyuba, 2009).

Material. Four well-preserved specimens and 10 incomplete specimens from the Nordvik Peninsula, Outcrop 32: Bed 9, interval 0.0–1.0 m below the top, uppermost *Taimyrensis* a-Zone (two specimens); Bed 10, *Chetae* a-Zone (two specimens); beds 12–16, *Sibiricus* a-Zone (10 specimens); eight variably preserved specimens from the Boyarka River section, Outcrop 16: Bed 2, *Kochi* a-Zone (two specimens); beds 3–4, basal *Analogus* a-Zone (six specimens).

CONCLUSIONS

The belemnite biostratigraphic scale discussed in this work is based on taxa which provide correlation of East Siberian sections with their counterparts from the Urals and Pechora basin. Some levels are traceable to Northwest Europe (*Russiensis* bl-Zone) and northern California (*Tehamaensis* and *Knoxvillensis* bl-zones). As compared with the previous version of the belemnite scale that was included into a system of parallel (autonomous) scales of the Boreal zonal standard (Zakharov et al., 1997, 2005), the proposed scale is characterized by the higher correlative potential and provides more detailed subdivision of sections. Its refinement in the Jurassic–Cretaceous boundary sections of northern East Siberia allows additional co-intervals to be defined in the system of parallel zonal scales of this region (Fig. 3), which increases the correlative potential of this system at the infrazonal level. The co-intervals correspond to zone overlapping interval between parallel scales based on different fossil groups (Nikitenko and Shurygin, 1994; Shurygin et al., 2000). Of greatest interest is the co-interval of the *Taimyrensis* and *Tehamaensis* bl-zones, which includes a narrow zone of reversed polarity representing an important paleomagnetic reference level interpreted as an analog of the Brodno Subzone (M19n.1r) (Houša et al., 2007). The subzone in question is defined near the Jurassic–Cretaceous boundary in several Tethyan sections of Slovakia, Italy, and Spain (Houša et al., 1999, 2004; Pruner et al., 2010; and others).

It is remarkable that approximately half of the boundaries of the newly defined belemnite-based stratigraphic units exhibit no correlation with any boundaries in scales based on other fossil groups. This is characteristic of lower boundaries of the *Tehamaensis, Knoxvillensis*, and *Curvulus* bl-zones. This indicates that the belemnite scale comprises units with evolutionary boundaries that are independent of paleoecological or depositional factors. The exceptions are lower boundaries of the *Russiensis* and *Napaensis* bl-zones located at the same level with each other and bases of most biostratigraphic units based on other fossil groups (ammonites, foraminifers, dinocysts). Long ago at the initial stage of investigations in the Nordvik Peninsula, it was assumed that high abundance of rostra in most of Kimmeridgian and, partly, Volgian sediments, the Middle Volgian *Variabilis* a-Zone included, is explained by reworking with removal of fine-grained fractions and potential hiatuses in sections (Basov et al., 1970). A similar phenomenon was also described for the lower part of the Volgian Stage in the Boyarka River basin (*Opornyi*..., 1969). If such deposition environments really existed in the Nordvik Peninsula area, it may explain the strict coincidence of boundaries between biostratigraphic units at the base of the *Variabilis* a-Zone.

Further investigation in the region under consideration should be aimed at thorough revision of Jurassic–Cretaceous boundary sections in the Kheta River basin.

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