ISSN 0869-5938, Stratigraphy and Geological Correlation, 2021, Vol. 29, No. 6, pp. 680–709. © Pleiades Publishing, Ltd., 2021.
Russian Text © The Author(s), 2021, published in Stratigrafiya, Geologicheskaya Korrelyatsiya, 2021, Vol. 29, No. 6, pp. 54–83.

Biochronological Scale of the Upper Toarcian–Lower Aalenian of Eastern Siberia by Bivalve Mollusks of the Genus *Arctotis* Bodylevsky, 1960

O. A. Lutikov*

Geological Institute, Russian Academy of Sciences, Moscow, Russia
**e-mail: niipss@mail.ru*

Received March 9, 2021; revised April 2, 2021; accepted April 20, 2021

Abstract—On the basis of the study of shell morphogenesis, the classification of the Toarcian–Aalenian representatives of the genus *Arctotis* Bodylevsky, 1960 was refined. A sequence of species was established in the reference sections of Anabar Bay and Cape Tsvetkov (Eastern Taimyr), traced in a series of Toarcian and Aalenian sections in Eastern Siberia, and correlated with the Boreal ammonite scale. The biochronological scale was developed for the upper Toarcian–lower Aalenian on the basis of bivalve mollusks of the genus *Arctotis* (family Oxytomidae Ichikawa, 1958). This scale has its own chronological periodization and consists of four so-called oxyto-zones. The scale was used to carry out an interregional correlation of the upper Toarcian–lower Aalenian sections of Eastern Siberia (Anabar Bay, Cape Tsvetkov, Markha, Tyung, Kelimyar, Molodo, and Motorchuna rivers, boreholes drilled in the Vilyui syneclise) and northeastern Russia (Levy Kedon River basin). The chronostratigraphic volumes of oxyto-zones are determined by comparison with ammonite zones of the Boreal Standard: the Praearctotis milovae oxyto-zone corresponds to the Zugodactylites braunianus and Pseudolioceras compactile ammonite zones, the Praearctotis marchaensis oxyto-zone corresponds to the Pseudolioceras wuerttenbergeri Zone, the Praearctotis similis oxyto-zone corresponds to the Pseudolioceras falcodiscus Zone, and the Arctotis tabagensis oxyto-zone corresponds to the Pseudolioceras maclintocki Zone.

Keywords: Jurassic, Toarcian, Aalenian, bivalves, biochronological scale, Eastern Siberia
DOI: 10.1134/S086959382106006X

INTRODUCTION

The main method of parallelization of the regional stages of the Jurassic of the North of Russia with the stratotypes of the stages of the International Stratigraphic Chart (ISC) is the correlation of ammonite zones (*Zony*..., 1982). At the end of the 20th–beginning of the 21st century, specialists from Siberia and St. Petersburg developed two ammonite scales for the geological correlation of the Toarcian–Aalenian deposits of Northeast Asia (Knyazev, 1991; Knyazev et al., 2003; Polubotko and Repin, 1994; Repin, 2016, 2017; Shurygin et al., 2011; Zakharov et al., 1997). Compared with the Western European assemblage of Boreal ammonoids, the late Toarcian assemblage is depleted, although it has several genera and species in common with Western Europe (Meledina, 2000). Nevertheless, the issues of distinguishing the boundary between the Lower and Middle divisions of the Jurassic and the global correlation of the Toarcian–Aalenian sections with the ISC divisions and the sections in the north of Russia are still relevant. In recent publications, the lower boundary of the Aalenian in Eastern Siberia is proposed to be at the base of the Pseudolioceras maclintocki Zone (Knyazev et al., 2007a), and in northeastern Russia, it is proposed to be at the base of the beds with Pseudolioceras beyrichi orientale (Repin, 2016). There is no generally accepted correlation between the Toarcian and Aalenian for bivalve mollusk assemblages in northern Russia since it is believed that the upper Toarcian and lower Aalenian assemblages from these regions are endemic and differ from each other (Polubotko and Repin, 1992, 1994; Repin, 2020). Because of the rare occurrence of representatives of zonal ammonite species in the Toarcian–Aalenian deposits, it is not easy to directly use the general stratigraphic scale for dividing and correlating both outcrops and core sections (Shurygin et al., 2001). The boundary deposits of the lower and middle series of the Jurassic in Northern Siberia are usually dated as Toarcian–Aalenian (Shurygin et al., 2000).

The proposed biochronological scale for oxytomids was developed by studying the same sections of Northern Siberia (Anabar Bay, Cape Tsvetkov, Motorchuna and Markha rivers) and northeastern Russia (Levy Kedon River basin), as well as the Toarcian–lower Aalenian ammonite zonal scale (Knyazev et al., 2003; Zakharov et al., 1997; Shurygin et al., 2011). Therefore, the parallelization of the scale by bivalve mollusks has been performed relative to the Siberian ammonite scale (Fig. 1).

The main purpose of the scale is to show the periodization of sediments bearing zonal assemblages and the correlation to varying degrees of remote and different facies sections of the Lower–Middle Jurassic.

The first zonal scheme for the Jurassic of Northern Siberia was developed by V.I. Bodylevsky on the basis of studying materials from the Anabar–Khatanga region. As the index species, the scheme for the Toarcian and Aalenian includes, along with the ammonites, bivalves, assigned to two species: "*Pseudomonotis vai* sp. nov." for the upper Lias (=Toarcian) and "*Pseudomonotis lenaensis* (Lahusen)"[1] for the Aalenian (Bodylevsky, 1939).

At the Interdepartmental Stratigraphic Meeting on the Development of Unified Stratigraphic Schemes of Siberia in 1956, V.I. Bodylevsky suggested that representatives of this generic group can form a particular genetic series from the Toarcian to Valanginian in Northern Siberia (Bodylevsky, 1957). The studies performed by specialists from England and Argentina have established the (bipolar) distribution of the genus *Arctotis* in the Jurassic and Cretaceous (Crame, 1985; Crame et al., 1993; Damborenea, 1994; Damborenea et al., 2013).

The standard autonomous scales for bivalve mollusks included in the stratigraphic schemes of Siberia and northeastern Russia and which are the basis for geological studies (*Reshenie*..., 2004; *Resheniya*..., 2009) are based on taxa belonging to different families (Repin and Polubotko, 2004; Shurygin, 1987). On the basis of new data on the distribution of bivalves and ammonoids in sections, the standard scales for bivalves have continued to be improved (Repin and Polubotko, 2015; Shurygin et al., 2011). Thus, in the Regional Stratigraphic Chart of the Lower and Middle Jurassic of Central Siberia, adopted at the 3rd Interdepartmental Regional Stratigraphic Meeting on the Mesozoic and Cenozoic of Central Siberia in 1978, the beds with Propeamussium olenekense and Arctotis marchaensis correspond to the lower Aalenian (*Resheniya*..., 1981). According to modern concepts, the Arctotis marchaensis b-zone corresponds to the two upper a-zones of the Toarcian and part of the lower Aalenian of the Boreal ammonite standard; the Arctotis lenaensis b-zone corresponds to the upper part of the lower Aalenian, upper Aalenian, and lower Bajocian (Shurygin et al., 2011). In the Regional Stratigraphic Scheme of the Lower and Middle Jurassic of Western Siberia, adopted at the 6th Interdepartmental Stratigraphic Meeting for Consideration and Acceptance of Refined Stratigraphic Schemes of Mesozoic Deposits of Western Siberia in 2003, the beds with Arctotis marchaensis correspond to the upper part of the Nadoyakha Regional Stage and are correlated with the two upper a-zones of the Boreal ammonite standard of the Toarcian and the lower Aalenian. The beds with Arctotis lenaensis correspond to the Vym Regional Stage and the upper part of the Laida Regional Stage (*Reshenie*..., 2004). In the Regional Stratigraphic Chart of the Jurassic Deposits of northwestern Russia, adopted at the 3rd Interdepartmental Regional Stratigraphic Meeting on the Precambrian, Paleozoic, and Mesozoic of Northeastern Russia in 2002, the beds with Arctotis marchaensis correspond to the lower part of the Yaschan Regional Stage (Aalenian–lower Bajocian) (*Reshenia*..., 2009). According to the modern correlation (Repin, 2016), the siltstones with "Arctotis cf. marchaensis (Petr.)" in the Viliga River basin corresponds to the terminal zone of the Toarcian (Repin and Polubotko, 2015). In the Regional Stratigraphic Chart of the Jurassic Deposits of the Far East, adopted at the 4th Interdepartmental Regional Stratigraphic Meeting on the Precambrian and Phanerozoic of the South of the Far East and Eastern Transbaikalia in 1990, species "*Arctotis marchaensis* (Petr.)" and "*Arctotis* aff. *similis* Velikzh." were identified in sandstone–siltstone unit in the South Verkhoyansk structural and facies zone (Akachan and Allakh-Yun rivers), where they occur together with early Aalenian *Pseudolioceras maclintocki* (Haught). Species "*Arctotis lenaensis* (Lah.)" characterizes the Tymager Formation (Aalenian) and Usmankovo Formation (Bathonian) of the Upper Amur structural and facies zone (lower reaches of Shilka, Argun, and Amazar rivers) (*Resheniya*..., 1994).

Outside of Russia, in the stratigraphic chart of the Jurassic deposits of Argentina, representatives of the species *Arctotis frenguellii* (Damborenea) were cited in the description of beds with *Meleagrinella*, which correspond to part of the upper Toarcian and Aalenian (Damborenea, 1994; Riccardi et al., 2011).

[1] Later, this group of species was assigned to the genus *Arctotis* (Bodylevsky, 1960). Bodylevsky used the name *Arctotis lenaensis* (Lah.) for the Aalenian–Bajocian forms and *Arctotis sublaevis* (Bodyl.) for the Bajocian–Bathonian forms (Bodylevsky, 1957). Later, the name *Arctotis lenaensis* has become widely accepted in the stratigraphic correlations since this species was chosen as the index species for the lower Aalenian–lower Bajocian bivalves (Shurygin et al., 2000). The revision of the Jurassic and Cretaceous oxytomids has revealed that the lectotype of the species *Arctotis lenaensis* (Lah.), selected by V.I. Bodylevsky, comes from the Bathonian deposits (Zhigansk area), and the holotype of *Arctotis sublaevis* (Bodyl.) comes from the Aalenian–Bajocian deposits of the Nordvik region. Therefore, the name *Arctotis sublaevis* (Bodyl.) is used in this work, instead of "*Arctotis lenaensis*," to refer to the Siberian late Aalenian–Bajocian *Arctotis* species and for the Bathonian representatives, *Arctotis lenaensis* (Lah.). This issue was discussed in detail earlier (Lutikov and Shurygin, 2010). Below in the text, the names of taxa whose volume is interpreted by the author differently than that used in previous studies and the names of taxa that should be revised are given in quotation marks. The names of zones and layers with bivalves are given in their original form.

Zones of Jurassic System, 1982		Dean et al., 1961; Howarth, 1992		Elmi et al., 1997		Repin, 2016, 2017	Zakharov et al., 1997 Shurygin et al., 2011	This work
International Stratigraphic Chart		Zonal Standard of Northwestern Europe				Zonal Standard of Northeast Asia (NEA)		Oxytomid-based biochronological scale
Aalenian	Upper			Graphoceras concavum	Graphoceras formosum	Pseudolioceras (Tugurites) whiteavesi	Pseudolioceras (Tugurites) whiteavesi	Arctotis sublaevis
					Graphoceras concavum			
				Ludwigia murchisonae	Brasilia gigantea			
					Brasilia bradfordensis			
					Ludwigia murchisonae			
					Ludwigia haugi	Pseudolioceras maclintocki		
	Lower			Leioceras opalinum	Leioceras bifidatum		Pseudolioceras maclintocki	Arctotis tabagensis
					Leioceras opalinum	Pseudolioceras beyrichi orientale		
Toarcian	Upper	Dumorteria levesquei	Pleydellia aalensis	Pleydellia aalensis	Pleydellia lugdenensis	Pseudolioceras replicatum	Pseudolioceras falcodiscus	Praearctotis similis
					Pleydellia mactra			
			Dumortieria moorei	Dumorteria pseudoradiosa	Dumorteria pseudoradiosa			
			Dumortieria levesquei		Dumorteria levesque	Pseudolioceras paracompactile		
			Phlyseogrammoceras dispansum	Phlyseogrammoceras dispansum	Gruneria gruneri			
					Hammatoceras insigne	Pseudolioceras danilovi		
		Grammoceras thouarsense	Pseudogrammoceras strukmanni	Grammoceras thouarsense	Pseudogrammoceras fallaciosum		Pseudolioceras wuerttenbergeri	Praearctotis marchaensis
					Eseryceras fascigerum			
			Grammoceras striatulum		Grammoceras thouarsense	Pseudolioceras rozenkrantzi		
					Pseudogrammoceras bingmanni			
		Haugia variabilis		Haugia variabilis	Haugia vitiosa	Peronoceras spinatum	Pseudolioceras compactile	Praearctotis milovae
					Haugia illustris			
					Haugia variabilis			
	Lower	Hildoceras bifrons	Catacoeloceras crassum	Hidoceras bifrons	Hidoceras bifrons	Zugodactylites braunianus	Zugodactylites braunianus	
			Peronoceras fibulatum					

Fig. 1. Correlation scheme of the oxytomid-based biochronological scheme with the International Stratigraphic Chart and standard zonal scales developed for the upper Toarcian–Aalenian of the northwestern part of Western Europe and Northeast Asia.

The study of the collections of bivalve mollusks of the family Oxytomidae Ichikawa, 1958 from the Toarcian–Aalenian deposits of the north of Eastern Siberia and northeastern Russia, begun by O.A. Lutikov in the late 1980s, allowed us to establish the regularities of the evolution of some Jurassic–Cretaceous representatives of the family Oxytomidae Ichikawa, 1958 (Lutikov et al., 2010) and to perform a preliminary classification of taxa (Lutikov and Shurygin, 2010).

This work aims to develop a biochronological scale of the upper Toarcian–lower Aalenian for bivalve mollusks belonging to the genus *Arctotis* Bodylevsky, 1960 (family Oxytomidae Ichikawa, 1958) and to evaluate the scale for stratigraphic correlations.

The reason for the development of the scale was the wide distribution of *Arctotis* species in the upper Toarcian and Aalenian sections and the relatively high rates of morphogenesis in representatives of this group of bivalves. The main task was to develop a methodology for species classification. The major Toarcian and lower Aalenian sections of Eastern Siberia and northeastern Russia were correlated by tracing biostratons characterized by zonal species or zonal assemblages using the above the scale.

MATERIALS

From 1980 to 1987, the author was engaged in integrate litho- and biostratigraphic studies of Lower–Middle Jurassic reference sections of Eastern Siberia and northeastern Russia (Anabar Bay, East Taimyr, the Anabar, Kelimyar, Motorchuna, Markha, Vilyui, Tyung, Molodo, and Syungyude rivers, and tributaries of Levy Kedon River). The studies were performed by a team of specialists from SNIIGGIMS (Novosibirsk): V.P. Devyatov (lithology), V.G. Knyazev (ammonoids), O.A. Lutikov (bivalves), and V.V. Sap'yanik (foraminifers). Over the period of 1990–2008, the author studied core material from exploratory drilling wells in the Vilyui Syneclise, kindly provided by I.V. Budnikov and I.S. Pavlukhin (Fig. 2).

The main objects of study were collections of bivalve mollusks collected by the author and colleagues in outcrops of Toarcian–Aalenian deposits and from the borehole sections of exploratory drilling wells stored in the Department of Stratigraphy and Regional Geology of SNIIGGIMS (Novosibirsk). To clarify the systematics and stratigraphic position of some taxa, the following collections were studied: the collections of I.V. Polubotko and Yu.S. Repin from the sections of the Letnyaya River and tributaries of the Levy Kedon River, stored in the Department of Stratigraphy and Paleontology of VSEGEI (St. Petersburg); the collection of A.G. Rzhonsnitsky from the Markha River section; the collection of G.A. Ivanov from the Lena River section and the collection of T.M. Okuneva from the Gazimur River section, stored in the museum of the TsNIGR (St. Petersburg); the collection of T.I. Kirina from the Vilyui River section, stored in the VNIGRI Museum (St. Petersburg); the collection of V. I. Bodylevsky from the Yuryung-Tumus Peninsula section, stored in the museum of the St. Petersburg Mining University; the collection of B.N. Shurygin from the sections in the Yuryung-Tumus Peninsula and Anabar Bay, stored in the Laboratory of Paleontology and Stratigraphy of the Mesozoic and Cenozoic of the Institute of Petroleum Geology and Geophysics, Siberian Branch, Russian Academy of Sciences (Novosibirsk).

The author's collections contain more than 1000 specimens of oxytomids belonging to the genus *Arctotis* and representing more than 60 samples from 15 locations. The previously published list of studied specimens (Lutikov and Shyrugin, 2010) is supplemented in the section "Description of Zonal Species" of the present paper.

METHODS

Field studies. The stratigraphic subdivision of outcrops of Jurassic deposits in the north of Eastern Siberia and northeastern Russia was carried out on the basis of layer-by-layer correlation of sections of rhythmic terrigenous strata (Zakharov and Yudovny, 1967). Samples with bivalve mollusks were located at the lower boundary of the layers and the levels of finds of ammonoids. The species and generic belonging of all the accompanying characteristic bivalve assemblages were previously determined when describing the sections. Core samples were related to the lower boundaries of lithological bodies identified using geophysical methods.

Methods of systematics. In this study, the author followed the recommendations of Ruzhentsev (1960) when choosing taxonomy methods.

The ontogenetic approach, the principle of homology, and the principle of the main link were used. The ontogenesis was studied by comparing the contours of elements of hinge structures in shells of different sizes in samples from fossil assemblages (Zakharov, 1975) and the growth lines of elements of hinge structures on individual shells.

The study of new species within the group was carried out by comparative analysis of homologous parts of the ligament and byssus blocks of shells in samples from fossil assemblages separated in time and space. When studying the systematics of taxa, changes in the relative position of parts in the ligament and byssus blocks were taken as the main link in the evolution of oxytomids. Chronoclines in the evolution of oxytomids were empirically established. As a result of a posteriori weighting of characters, morphological characters characterizing supraspecific taxa were determined. Against the background of hypothetical evolutionary trends based on a visual assessment of changes in homologous parts in the ligament and byssus blocks

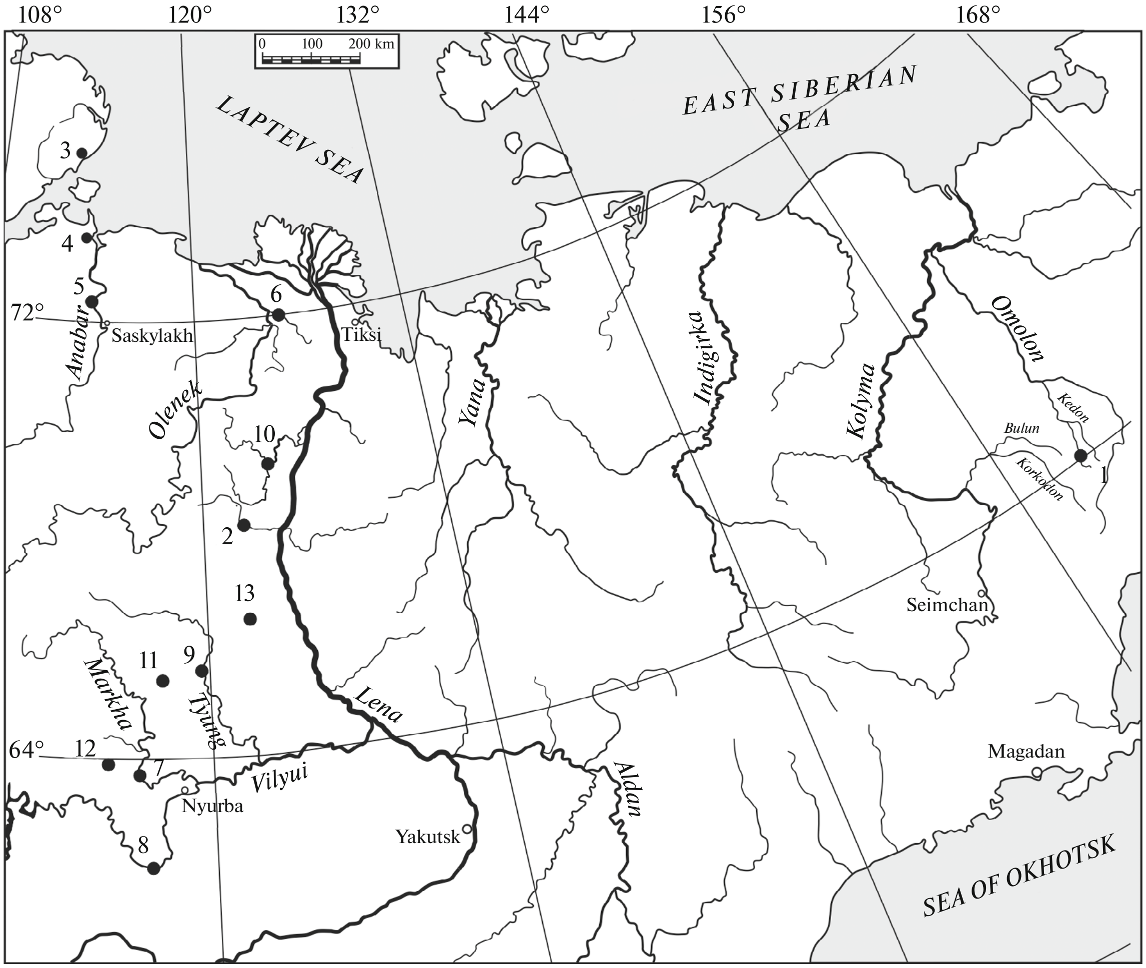


Fig. 2. Survey map of the studied upper Toarcian and lower Aalenian sections in Eastern Siberia and northeastern Russia. Areas of collections: (1) Levy Kedon River basin (Saturn, Start, Brodnaya, and Astronomicheskaya rivers), (2) Motorchuna River, (3) Cape Tsvetkov (Eastern Taimyr), (4) Anabar Bay, (5) Anabar River, (6) Kelimyar River, (7) Markha River, (8) Vilyui River, (9) Tyung River, (10) Syungyude and Molodo rivers. Drilling sites: (11) Tenkelyakh, (12) Pravoberezhny, (13) Serki-Lindensky.

over time, a primary classification of taxa was proposed (Lutikov and Shurygin, 2010). The conclusions on phylogeny were based on the comparison of types and subtypes of the ontogeny of ligament pits in Jurassic and Cretaceous forms belonging to different stratigraphic levels. The phylogenetic relationships between related groups of oxytomids were established using clade analysis (Lutikov et al., 2010).

Methods of classification. When choosing methods for classifying bivalve mollusks, the author followed the recommendations of Mayr (1969). The discreteness of species in the chronological sequence of species groups from the subgenera *Arctotis* (*Praearctotis*) and *Arctotis* (*Arctotis*) was determined by the method of a posteriori weighting of characters based on the experience of estimating the amount of phylogenetically significant information contained in the selected character. Classification and species diagnostics of taxa in this study were carried out using a quantitative assessment of the state of morphological characters in combination with data on morphogenesis.

Characters with high taxonomic potential:

(a) The shape of the anterior wing. An obtuse-angled anterior wing is present in Toarcian *Praearctotis*; a subrectangular anterior wing appears in Aalenian *Arctotis*.

(b) The width of the anterior wing. The narrow wing is typical for most of the Toarcian representatives of the subgenus *Praearctotis*. The moderately wide anterior wing is characteristic of latest Toarcian *Praearctotis*. The wide anterior wing is characteristic of the Aalenian–Bajocian taxa of the subgenus *Arctotis* s. str.

(c) The ratio of the convexity of valves. Biconvex valves are characteristic of taxa of the Toarcian subgenus *Praearctotis*; convex left valves and flat right valves are characteristic of early Aalenian *Arctotis* s. str. Convex-concave valves are typical of late Aalenian–Bajocian representatives of the subgenus *Arctotis* s. str.

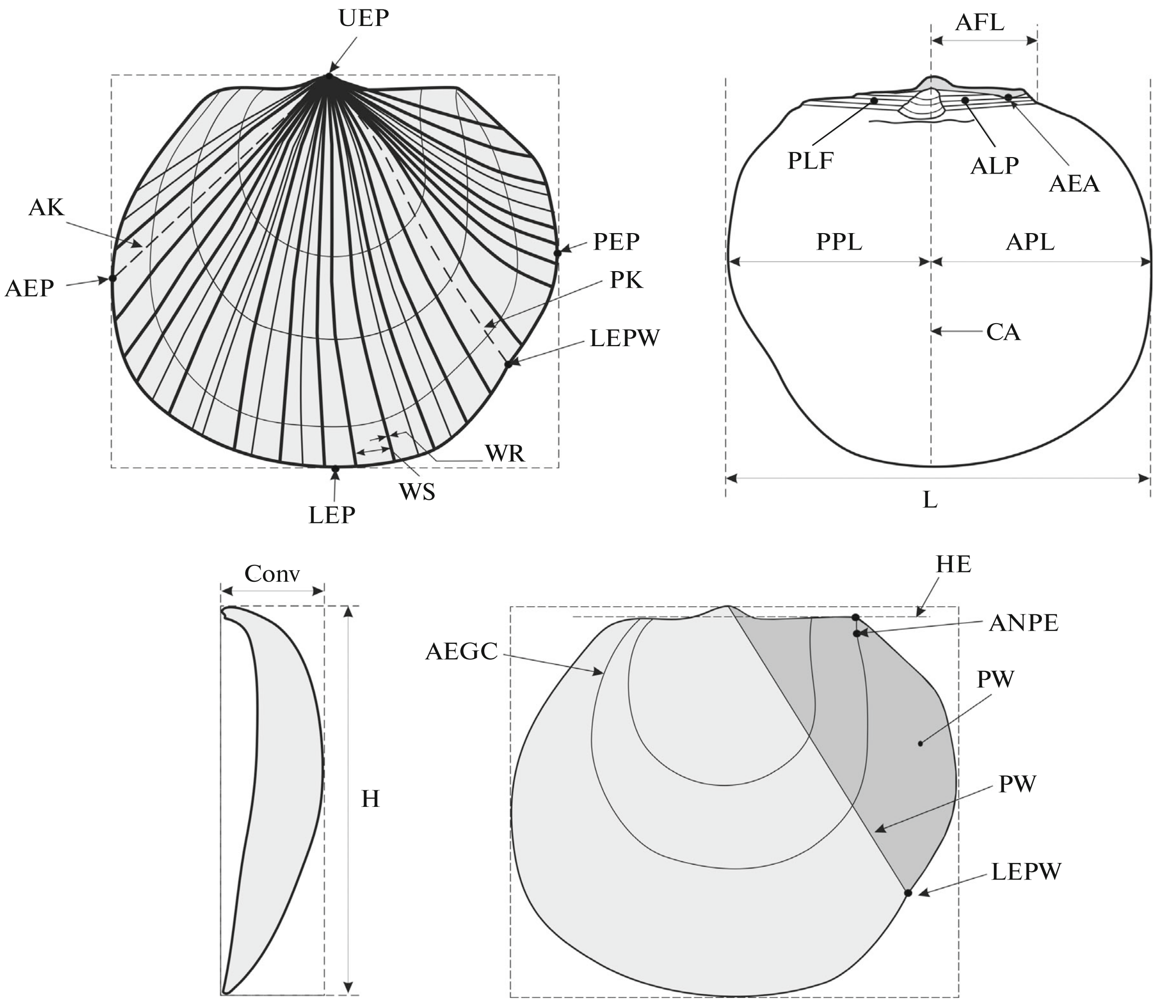


Fig. 3. Morphological elements of the left valve of *Arctotis* species. UEP—apical projection of upper edge, AEP—apical projection of the anterior edge, PEP—apical projection of the posterior edge, LEP—apical projection of the lower edge, AK—the anterior keel of the valve, PK—the posterior keel of the valve, CA—central axis of the valve, PLF—posterior back-ligament field, ALP—the anterior back-ligament field, AEA—the end of the anterior ear, PW—the posterior wing of the valve, HE—hinge edge, AEGC—the anterior edge of the growth center, LEPW—the lower end of the posterior wing of the valve, ANPE—the apical notch of the posterior edge of the growth center, WR—the width of ribs, WS—the width of intercostal spaces, LPP—the length of the posterior part, LAP—the length of the anterior part, L—length, Conv—convexity, H—height.

Characters with a low taxonomic potential include characters subject to age or individual variability: size, outline, symmetry, sloping, lengths of the anterior and posterior ligament fields, the density of ribbing. In addition, there are characters of the same category that are difficult to determine, such as the relative width of the intercostal spaces and the differentiation of ribs in width and height in orders of magnitude.

When determining the discreteness of species, the concept of the evolutionary species by J. Simpson was adopted. According to this concept, "An evolutionary species is a lineage (an ancestral-descendant sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies" (Simpson, 1961, p. 153).

Shell morphology and measurements. The concepts of such morphological characters as length, height, radial ribs, anterior edge, posterior edge, hinge edge, anterior eye, posterior eye, anterior part of the shell, posterior part of the shell, the convexity of a valve, ligament fossa, ligament field, ligament platform, and prominence are known in the literature on bivalves with a straight hinge (Koshelkina, 1963; Lutikov and Shurygin, 2010) (Fig. 3).

When describing the shape of the anterior wing of the left valve, new unified characters are used: angle of the anterior wing (AAW)—the angle between hinge edge (HE) and anterior edge of the last visible growth center; anterior keel (AK)—the line connecting UEP and AEP; apical projection of the outer edge of the anterior wing of the left valve (APAE)—the point of

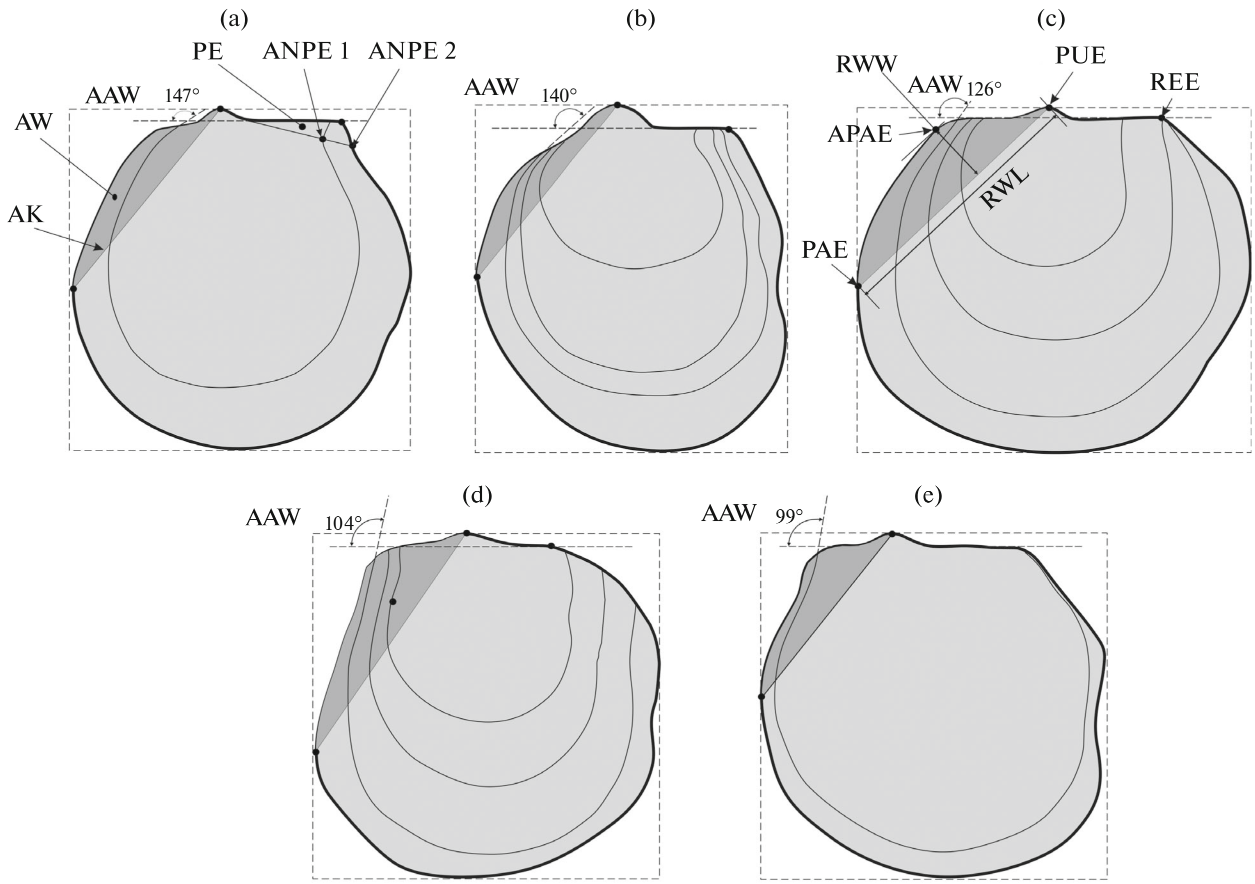


Fig. 4. Morphological elements of anterior and posterior wings of the left valve of *Arctotis* species. (a) *Arctotis* (*Praearctotis*) *milovae*, (b) *Arctotis* (*Praearctotis*) *marchaensis*, (c) *Arctotis* (*Praearctotis*) *similis*, (d) *Arctotis (Arctotis) tabagensis*, (e) *Arctotis* (*Arctotis*) *sublaevis*. Morphological elements: AW—anterior wing, AK—anterior keel, AAW—angle of the anterior wing, RWL—length of the bend of the outer wing of the right valve, RWW—width of the bend of the outer wing of the right valve, PUE—the apical projection of the upper edge, PE—posterior ear, PEE—the end of the posterior ear, ANPE 1—the apical notch of the posterior edge of the growth center, ANPE 2—the apical notch of the outer edge of the posterior wing, PAE—the apical projection of the anterior edge, APAE—the apical projection of the outer edge of the anterior wing of the left valve, PUE—the apical projection of the upper edge.

maximum remoteness of the outer edge from the keel; (RWL)—the distance between UEP and AEP; length of the bend of the outer wing of the right valve (RWW)—the distance between the keel and the APAE; anterior edge of the growth center (AEGC)—the arc of the growth center connecting to the edge of the valve. When describing the shape of the posterior wing of the left valve, the following characters were used: PK—the posterior keel, PW—the posterior wing, PE—the posterior ear (differentiated only in early Toarcian forms), LEPW—the lower end of the posterior wing, ANPE 1—the apical notch of the posterior edge of the growth center, ANPE 2—the apical notch of the outer edge of the posterior wing (Fig. 4).

To characterize the morphological elements of the shells, measurements were made on nine characters: (1) length (L), (2) height (H), (3) convexity (Conv), (4) length of the anterior part (AL), (5) length of the posterior part (PL), (6) length of the anterior ligament field (AFL), (7) ribbing (R)—the number of ribs on the shell section in the space between the anterior keel of a valve and the posterior keel, (8) width of intercostal spaces (WS)—the distance between parallel ribs, (9) width of the ribs (WR)—the distance between the edges of ribs (Fig. 3). When carrying out linear measurements of characters 1–6, only one parameter was measured (the height or length of a valve, depending on the degree of preservation of the material) using a caliper. The rest of the parameters were measured on images of shells using Photoshop software. Measurements of characters 7–9 were made using Photoshop and CorelDRAW. Measurements of characters of AAW, RWL, and RWW were made using CorelDRAW.

The quantitative assessment of the characters was developed on the basis of the methodology for studying the shape of shells with a straight hinge edge (Lutikov and Shurygin, 2010). The assessment of the characters was carried out by nine gradations (Fig. 5).

(1) Gradations by the size of a shell are determined by a height of valves (H).

Height (H), mm	Gradation by the size of the valve (4)	H/L ratio	Gradation by contours of the valve (2)	APL/L ratio	Gradations by the symmetry of the valve (3)
less 10.00	very small	less 0.95	very low	less 0.35	strongly nonequilateral
10.01–30.00	small	0.95–0.97	low	0.35–0.40	nonequilateral
30.01–50.00	average	0.98–1.02	isometric	0.41–0.45	moderately nonequilateral
50.01–70.00	large	1.03–1.05	high	0.45–0.50	equilateral
more 70.00	very large	more 1.05	very high		
Angle of the anterior wing (AAW)°	Gradations by the angle of the anterior wing of the left valve (4)	Conv/H ratio	Gradations by the convexity of the valve (5)	AFL/APL ratio	Gradations by the length of the front ligament field of the left valve (6)
less 85°	acute-angled	less 0.20	slightly convex	less 0.45	short
85°–105°	subrectangular	0.20–0.30	moderately convex	0.45–0.50	long
more 105°	obtuse	0.31–0.40	strongly convex	more 0.50	very long
		more 0.40	swollen		
R/L ratio	Gradation by density of ribbing on the valve (7)	WR/WS ratio	Gradations in the width of intercostal spaces (8)	RWW/RWL ratio	Gradations in the width of the anterior wing of the left valve (9)
less 1.00	rarely ribbed	less 1.50	very narrow	less 0.20	narrow
1.00–2.00	slightly ribbed	1.5–2.00	narrow		moderately wide
2.01–3.00	moderately ribbed	2.01–2.5	moderately wide	0.21–0.22	wide
3.01–4.00	strongly ribbed	2.51–3.00	wide		
more 4.00	densely ribbed	more 3.00	very wide	more 0.22	

Fig. 5. Morphological characters of oxytomids based on the quantitative assessment of signs.

(2) Gradations by the symmetry of valves are determined by the ratio of the height of a shell to its length (H/L).

(3) Gradations by the symmetry of valves are determined by the ratio of the length of the anterior part to the length of a valve (APL/L).

(4) Gradations by the angle of the anterior wing (AAW) of valves are determined by the angle between the hinge edge of a valve and the tangent to the anterior edge of the last visible growth center.

(5) Gradations by the convexity of the left valve are determined by the ratio of the convexity of the left valve to its height (ConvL/H).

(6) Gradations by the length of the anterior ligament field of the left valve are determined by the ratio of the length of the anterior ligament field of the left valve to the length of its anterior part (ALP/APL).

(7) Gradations by the density of the ribbing of valves are determined by the ratio of the number of ribs along the lower edge of a shell in the area between apical projections of the anterior and posterior edges to the length of a shell (P/L).

(8) Gradations by the width of intercostal spaces are determined by the ratio (WS/WR) of the width of the intercostal space between adjacent ribs (WS) to that of the adjacent rib (WR). Since the width of the intercostal spaces is not uniform, the widest space between ribs along the lower or posterior edge of left valve was selected for measurements.

(9) Gradations by the width of the anterior wing of the left valve are determined by the ratio of the width of the anterior wing to the length of the anterior wing of the left valve (RWW/RWL).

Methodology for creating a biochronological scale. The biostratigraphic subdivision and correlation of the studied sections were carried out on the basis of the evolutionary method (Stepanov and Mesezhnikov, 1979). The presented upper Toarcian–lower Aalenian zonal scale is based on the phylogenetic sequence of species of the genus *Arctotis* (family Oxytomidae Ichikawa, 1958). The concept of biochronological scales (BChS) proposed by Chernykh (2016) and tested on lower Toarcian oxytomids (Lutikov and Arp, 2020) was applied as a methodological basis for the development of the scale.

The evolutionary changes in the state of characters established as a result of studying the morphogenesis of the ligament block in oxytomid shells from different stratigraphic units were taken as a phylogenetic chronocline when developing a biochronological scale. The various combinations of states of external characters of shells are the basis of the periodization of the scale. Accordingly, taxa were described on the basis of characters that appeared as a result of phylogenesis, and their boundaries were determined according to the states of these characters. The relative discreteness of the states of characters is explained by the incompleteness of the geological record (Darwin, 1872).

Distances with certain states of morphological characters correspond to the time of the existence of species. Owing to the individual variability of characters, the boundaries between taxa are dynamic (there are uncertainty intervals). The discreteness of taxa was determined by studying the morphogenesis with the method of estimating the amount of phyletic information in an empirically selected character (Mayr, 1969). As a result, a chronological sequence of states of taxonomically significant characters was established for the Toarcian and Aalenian and calibrated using an independent Boreal ammonite scale (Fig. 6).

On one hand, the genetic distances between taxa do not correspond to the chronological distances between the corresponding phylozones, since they are multiples of ammonite zones, the elementary subdivisions of the standard scale. On the other hand, "if the direction of evolution is correlated with periodicity, then it has its own time and can serve as a clock, although imperfect" (Krasilov, 1977, p. 29).

Therefore, in addition to the stratigraphic correlation, the oxytomid-based biochronological scale can be used for dating geological events. Since geological events determine the time, the simultaneity can be considered the coexistence of events for which the "earlier–later" relationships are indistinguishable and determined up to the chron. The simultaneity of the formation of geographically isolated paleopopulations is determined by their belonging to one of the classes of evolutionary events in the morphogenesis of the ligament block of a right valve. These events are in correspondence with the phases of formation of the direct subtype of the ligament pit, the angular subtype of the ligament pit, the spoon-shaped subtype of the ligament pit, and the "spoon" (completely concave ligament pit).

To determine the stratigraphic position of the beds with bivalve mollusks in the general sequence of zonal units, the Toarcian–Aalenian sections in Anabar Bay and Cape Tsvetkov, studied during field works in 1985 and 1987, were chosen as reference sections. The sequence of species identified in the reference sections was traced in the series of Toarcian–Aalenian sequences of Eastern Siberia (Motorchuna, Molodo, Syungyude, Markha, Tyung, and Vilyui rivers; boreholes in the Vilyui syneclise) and northeastern Russia (Levy Kedon River basin) to assess the correlation potential of the scale.

MORPHOGENESIS OF A SHELL OF GENUS *Arctotis* BODYLEVSKY, 1960 IN LATE TOARCIAN–EARLY AALENIAN

As a result of studying the regularities of the morphogenesis of the ligament block in Toarcian–Aalenian representatives of the family Oxytomidae Ichikawa,

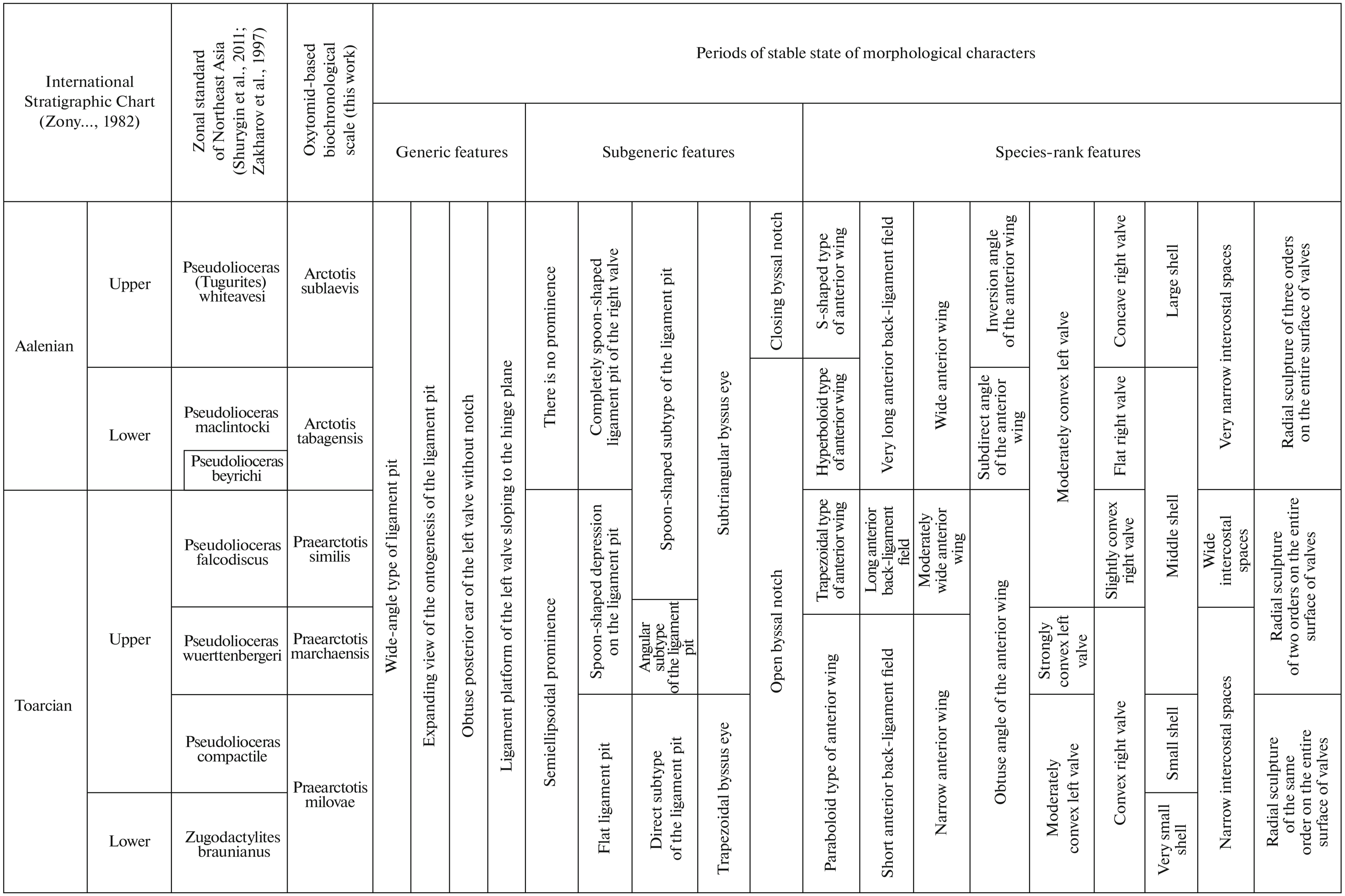


Fig. 6. Periodization of stable states of morphological characters relative to the divisions of the International Stratigraphic Chart and the Boreal ammonite scale.

1958, it was found that a direct subtype of the ligament pit appeared in the ligament block in the chronocline of the *Arctotis* lineage in the early Toarcian (Zugodactylites braunianus chron), and an angular subtype of the ligament pit appeared in the late Toarcian (Pseudolioceras wuerttenbergeri chron). A spoon-shaped subtype of the ligament pit appeared in the Pseudolioceras falcodiscus chron. The structural position of the elements of the ligament block of the right valve changed in early Aalenian (Pseudolioceras maclintocki chron): a completely concave ligament pit was formed, the length of the ligament platform decreased relative to that of the right valve, and the slope of the ligament pit of the left valve increased relative to the hinge plane of valves (Lutikov et al., 2010).

The change in the type of anterior wing of the left valve, which characterizes the appearance of the shell, was the basis for the periodization of the morphogenesis of shells in the late Toarcian–late Aalenian. The type of anterior wing was determined by a combination of three characters. Four types of anterior wing were identified in *Arctotis* species. The "paraboloid" type is characterized by a short ligament field (AFL/APL less than 0.45), a narrow anterior wing (RWW/RWL less than 0.15), and an obtuse anterior wing (AAW more than 105°). The "trapezoidal" type is characterized by a long ligament field (AFL/APL 0.45–0.50), a moderately wide anterior wing (RWW/RWL 0.15–0.20), and an obtuse anterior wing (AAW more than 105°). The "hyperboloid" type is characterized by a very long back-ligament field (AFL/APL more than 0.50), a wide anterior wing (RWW/RWL more than 0.20), and a subrectangular (AAW 85°–105°) or an acute-angled anterior wing (AAW less than 85°). The "S-shaped" type is characterized by a very long ligament field (AFL/APL more than 0.50), a wide anterior wing (RWW/RWL more than 0.20), and an inversion anterior wing: sub-rectangular (AAW 85°–105°) at the early stages of growth and obtuse (AAW more than 105°) at the late stages of growth.

As a result of comparing the types of anterior wing of the left valve in species from deposits belonging to different stratigraphic levels, it was found that morphogenesis in the chronocline of *Arctotis* (*Praearctotis*) *milovae*–*Arctotis* (*Praearctotis*) *marchaensis* (Petrova)–*Arctotis* (*Praearctotis*) *similis* Velikzhanina–*Arctotis* (*Arctotis*) *tabagaensis* (Petrova)–*Arctotis* (*Arctotis*) *sublaevis* (Bodylevsky) from the Zugodactylites braunianus chron to the Pseudolioceras whiteavesi chron evolved from species with a "paraboloid" type of anterior wing to those with a "trapezoidal" type and, next, to the forms with "hyperboloid" and "S-shaped" types of anterior wing. The morphogenesis of the anterior wing of the left valve passed from forms with an obtuse wing in the Toarcian to those with a sub-rectangular wing in the Aalenian.

The morphogenesis of the posterior ear of the left valve is traced from forms with a pointed end of the posterior ear at the juvenile stages in the early Toarcian to those with an obtuse posterior ear at the juvenile stages in late Toarcian. The discreteness of taxa of the species rank in the presented chronophylogenetic sequence of species of the subgenera *Prearctotis* and *Arctotis* was determined by the quantitative state of the characters established on the basis of studying the morphogenesis of the anterior wing and the posterior ear of the left valve.

The forms with the "paraboloid" type of anterior wing with a pointed posterior ear at the juvenile stages were attributed to the species *Arctotis* (Praearctotis) *milovae* (Okuneva), 2002, typical of the Zugodactylites braunianus Zone and Pseudolioceras compactile Zone in the upper Toarcian of Eastern Siberia, northeastern Russia, and Russian Far East (Plate I, fig. 1). The forms with the "paraboloid" type of anterior wing with a subrectangular posterior ear at the juvenile stages were attributed to the species *Arctotis* (Praearctotis) *marchaensis* (Petrova), 1947, typical of the Pseudoloceras wuerttenbergeri Zone in the upper Toarcian of Eastern Siberia (Plate I, fig. 2).

Forms with the "trapezoidal" type of anterior wing and obtuse posterior ear at juvenile stages are attributed to the species *Arctotis* (Praearctotis) *similis* Velikzhanina, 1966, typical of the Pseudoloceras falcodiscus Zone in the upper Toarcian of Eastern Siberia (Plate I, fig. 3). Forms with "hyperboloid" type of anterior wing and obtuse posterior ear at juvenile stages are attributed to the species *Arctotis* (Arctotis) *tabagensis* (Petrova), 1953, typical of the Pseudolioceras maclintocki Zone in the lower Aalenian of Eastern Siberia (Plate I, fig. 4). Forms with the "S-shaped" type of anterior wing and obtuse posterior ear at the juvenile stages are attributed to the species *Arctotis* (Arctotis) *sublaevis* (Bodylevsky), 1958, typical of the Pseudoloceras whiteavesi Zone (Plate I, fig. 5).

Taphonomic observations carried out during field studies indicate similar conditions for the existence of populations of each species: all of them lived in shallow water with active hydrodynamics. Consequently, morphological changes in populations can be explained only as a result of the stabilizing effect of selection, i.e., by evolutionary reasons.

RESULTS AND DISCUSSION

On the basis of the study of the morphogenesis of shells, the classification of Toarcian–Aalenian representatives of the genus *Arctotis* Bodylevsky, 1960 is clarified. The systematic affiliation of the supraspecific taxa identified as a result of a revision of the genus *Arctotis* Bodylevsky, 1960 (Lutikov and Shurygin, 2010) was determined with regard to the clade analysis of the systematics of the family Oxytomidae Ichikawa, 1958 (Lutikov et al., 2010).

The systematic affiliation of the taxa belonging to other families and included in the zonal complexes of oxyto-zones is determined on the basis of previous descriptions and monographic studies of bivalves (Krymgolts et al., 1953; *Polevoi*..., 1968; Polubotko, 1992; Zakharov and Shurygin, 1978). The analysis of the stratigraphic position of taxa established during the description of the sections was carried out using our field observations, as well as the data on lithostratigraphy and zonal stratigraphy given in (Knyazev et al., 1991, 2003; Shurygin et al., 2000; etc.).

The evolutionary sequence of species of the genus *Arctotis* Bodylevsky, 1960, which is traced in the series of Toarcian and Aalenian sequences of Eastern Siberia and correlated with the Boreal ammonite scale, was established in the reference sections of Anabar Bay and Cape Tsvetkov (Eastern Taimyr) (Figs. 7, 8). The biochronological scale by bivalve mollusks of the genus *Arctotis* was proposed for the upper Toarcian–lower Aalenian.

BIOCHRONOLOGICAL SUBDIVISIONS OF LATE TOARCIAN–EARLY AALENIAN BASED ON OXYTOMIDS

The biochronological scale was developed on the basis of studying the morphogenesis of bivalve shells and the succession of species belonging to the same phylogenetic lineage of the family Oxytomidae Ichikawa, 1958—the genus *Arctotis* Bodylevsky, 1960. The elementary divisions of the scale are "oxyto-zones." According to paleontological and stratigraphic criteria, oxyto-zones are phylozones or beds in which index species representing segments of the lineage of the genus *Arctotis* are distributed. The morphogenesis of the genus *Arctotis*, on one hand, has a direction that is recorded in a sequence of successive nonrepeating states of the ligament and byssus blocks. On the other hand, it is characterized by periodicity recorded in periods of a relatively stable state of various external morphological characters repeated at different stratigraphic levels. The different combinations of the state of external morphological characters that characterize species allow us to detect the periodization of the phylogenetic line.

The directed evolution of the genus *Arctotis* in combination with its periodicity is confined to a definite period, and the scale corresponding to the segments of the lineage of the genus can be considered as biochronological. The time of formation of oxyto-zones corresponds to the phases of the existence of index species. In specific sections, oxyto-zones are distinguished by the presence of index species or conditionally by assemblages of zonal species determined by their joint occurrence with the index species in stratotype sections. On the basis of the characteristics of the oxyto-zones, a clear correlation of the sections in the north of Eastern Siberia was carried out.

Praearctotis milovae oxyto-zone

N o m e n c l a t u r e. This oxyto-zone has been distinguished for the first time in the given chronostratigraphic volume. The Meleagrinella faminaestriata Subzone was previously distinguished by bivalves as a zonal subdivision in Eastern Siberia as corresponding to the upper part of Dactylioceras athleticum Zone and Zugodactylites monestieri Zone (Shurygin, 1987).

The species from the East Siberian sections that belonged to "*Meleagrinella faminaestriata*" were redetermined as *Arctotis* (*Praearctotis*) *milovae* (Okuneva) as a result of the revision (Lutikov and Shurygin, 2010). The Praearctotis milovae oxyto-zone corresponds to the Zugodactylites braunianus and Pseudolioceras compactile zones of the Boreal Standard.

I n d e x s p e c i e s: *Arctotis* (*Praearctotis*) *milovae* (Okuneva), 2002.

S t r a t o t y p e o f t h e o x y t o - z o n e: Eastern Siberia, Anabar Bay, outcrop 5, beds 75–79, Eren Formation, thickness 31.8 m.

Z o n a l a s s e m b l a g e of the oxyto-zone includes the following bivalve species: *Liostrea taimyrensis* Zakh. et Schur., *Dacryomya jacutica* (Petr.), *Modiolus numismalis* Opp., *Tancredia securiformis* Dunk., *Camptonectes* s.str., *Pseudomytiloides oviformis* (Khudyaev in Petrova, 1953), and *P. marchaensis* (Petr.).

P r i n c i p l e o f d i s t i n g u i s h i n g b o u n d a r i e s a n d s u b s t a n t i a t i o n o f a g e. The lower boundary of the Praearctotis milovae oxyto-zone is established according to the first occurrence of the index species. The upper boundary is established by the first occurrence of *Arctotis* (*Praearctotis*) *marchaensis* (Petr.).

The age of an oxyto-zone relative to the ammonite scale is determined by the sum of teilzones of index species in all known sections. *Arctotis* (*Praearctotis*) *milovae* (Okuneva) in the Anabar Bay section occurs together with *Zugodactylites braunianus* (Orb.) and *Pseudolioceras lythense* (Y. et B.); in the Markha River section it occurs together with *Zugodactylites braunianus* (Orb.). The author of the present paper has found species similar to *Arctotis* (*Praearctotis*) *milovae* (Okuneva) in the debris of beds with Pseudolioceras compactile (Simps.), Porpoceras vortex (Simps.), and Collina gemma Bonarelli in the Start River section (northeastern Russia). In the Gazimur River basin (Eastern Transbaikalia), *Arctotis* (*Praearctotis*) *milovae* (Okuneva) occurs in deposits above the level with Pseudolioceras rosenkrantzi A. Dagis (Okuneva, 2002). Since the local Peronoceras spinatum Zone in northeastern Russia is correlated with the Pseudolioceras compactile Zone of the Boreal Standard (Repin, 2016, 2017) and the position of the Pseudolioceras rosenkrantzi Zone relative to the Pseudolioceras compactile Zone is not generally accepted (Knyazev et al., 2003; Repin, 2016), it was reliably established that Praearctotis milovae oxyto-zone corresponds to the

Zugodactylites braunianus and Pseudolioceras compactile zones of the Boreal Standard (Shurygin et al., 2011) (Fig. 1).

C o r r e l a t i o n. The Praearctotis milovae oxyto-zone corresponds to the upper part of the Dacryomya inflata Zone, Tancredia bicarinata Zone, and Pseudomytiloides marchaensis Zone of the Boreal zonal standard by bivalve mollusks (Shurygin et al., 2011) and is correlated with the local Pseudolioceras rosenkrantzi Zone of the Far East on the basis of finds of the index species (Okuneva, 2002).

Praearctotis marchaensis oxyto-zone

N o m e n c l a t u r e. This zone was distinguished in the given chronostratigraphic volume for the first time. The Arctotis marchaensis Zone was established as a zonal subdivision of the lower part of the lower Aalenian of Eastern Siberia (Shurygin, 1987).

According to an analytical summary on the Jurassic stratigraphy of Siberia, the Arctotis marchaensis Zone covers part of the upper Toarcian and the lower part of the Aalenian; i.e., the upper boundary of the Toarcian (Lower–Middle Jurassic boundary) passes within this zone (Shurygin et al., 2000).

In this paper, the Praearctotis marchaensis oxyto-zone is correlated with the Pseudolioceras wuerttenbergeri Zone of the Boreal Standard. Owing to the revision of the species *Arctotis marchaensis* (Petrova), the range of the Arctotis marchaensis oxyto-zone has changed compared to the standard Arctotis marchaensis b-zone (Shurygin et al., 2000).

I n d e x   s p e c i e s: *Arctotis* (*Praearctotis*) *marchaensis* (Petrova, 1947).

S t r a t o t y p e   o f   t h e   o x y t o - z o n e: Eastern Siberia, Anabar Bay, outcrop 5, beds 80–88, Eren Formation, thickness 27.4 m.

Z o n a l   a s s e m b l a g e s of bivalves: *Oxytoma* ex gr. *jacksoni* Pomp., *Luciniola* sp.

P r i n c i p l e   o f   i d e n t i f i c a t i o n   o f   b o u n d a r i e s   a n d   s u b s t a n t i a t i o n   o f   a g e. The lower boundary of the Praearctotis marchaensis oxyto-zone was established according to the first occurrence of the index species; the upper boundary was established according to the appearance of *Arctotis* (*Praearctotis*) *similis* Velikzh.

The age of an oxyto-zone relative to the ammonite scale is determined by the sum of teilzones of the index species in all known sections. In the Anabar Bay section, the index species occupies a position in the middle part of the Eren Formation above the level with Zugodactylites braunianus (Orb.) and below the level with Pseudolioceras falcodiscus (Quenstedt) (Knyazev et al., 1991, 2003).

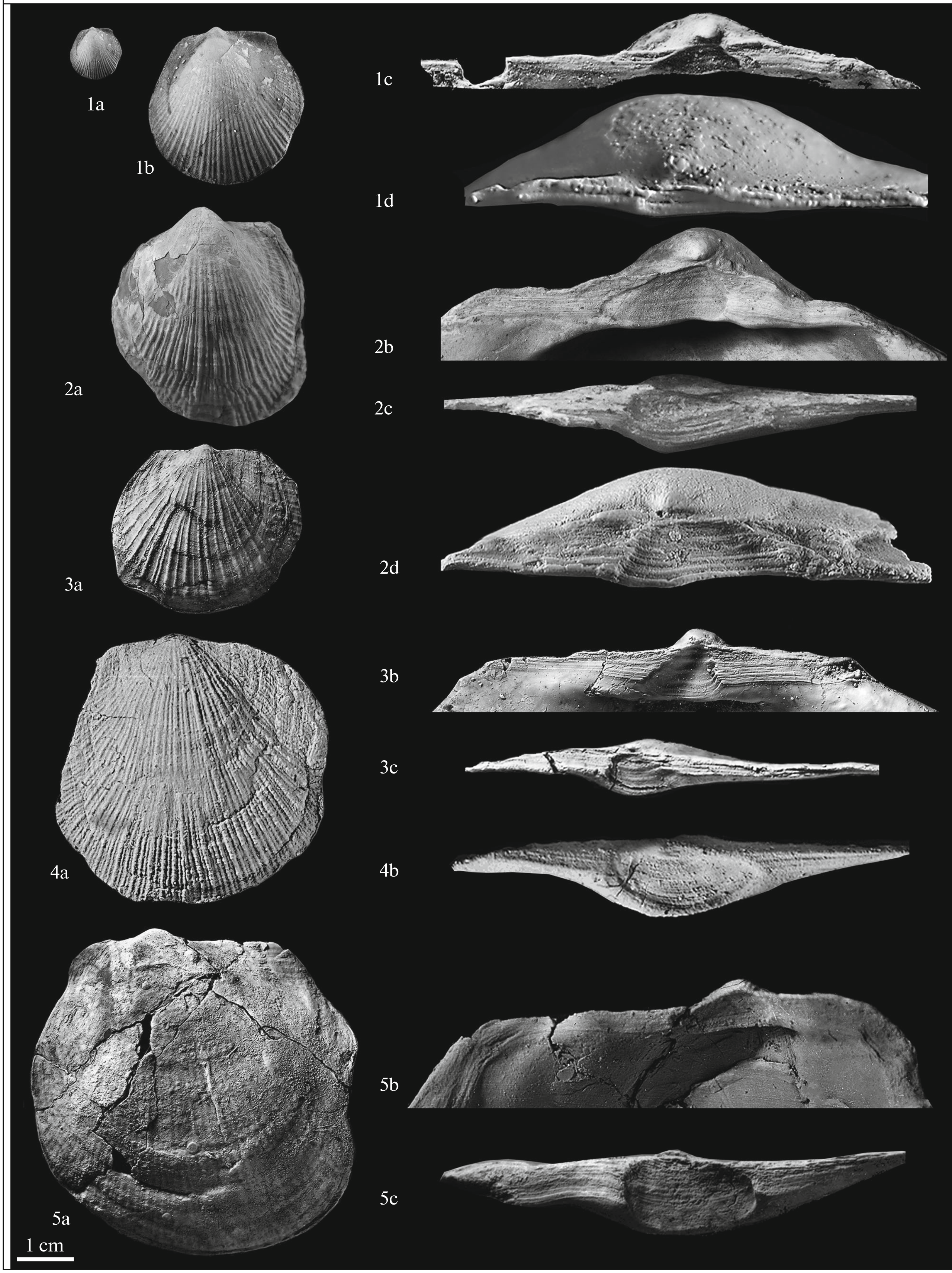
In the Markha River section, the species *Arctotis* (*Praearctotis*) *marchaensis* (Petr.) occupies a position below and above the level with Pseudolioceras wuerttenbergeri (Denckmann). It was reliably established that the Praearctotis marchaensis oxyto-zone corresponds only to the Pseudolioceras wuerttenbergeri Zone of the Boreal Standard (Shurygin et al., 2011) (Fig. 1).

C o r r e l a t i o n. The Praearctotis marchaensis oxyto-zone corresponds to the lower part of the Arctotis marchaensis b-zone of the zonal scale of the Boreal Standard for bivalves (Shurygin et al., 2011).

In northeastern Russia, *Arctotis* aff. *marchaensis* (Petg.), *Lenoceramus* sp., and *Camptonectes* sp. were found in deposits ascribed to the lower half of the Pseudolioceras danilovi Zone in the Letnyaya River section (Repin and Polubotko, 1993; Polubotko and Repin, 1994). The Praearctotis marchaensis oxyto-zone conditionally corresponds to the lower half of the local ammonite zone Pseudolioceras danilovi (Repin, 2017) (Fig. 1).

Plate I. Fig. 1. *Arctotis (Praearctotis) milovae* (Okuneva). (a) Spec. no. MKh-309/19, left valve, ×1; (b) the same, ×3, Markha, outcrop 6, bed 3, Sample no. MKh-229, lower Toarcian, Zugodactylites braunianus Zone; (c) spec. no. AG-103/2, ligament pit of the left valve, ×14, Anabar Bay, western coast, outcrop 5, bed 76, lower Toarcian, Zugodactylites braunianus Zone; (d) spec. no. TKh-1/1, direct subtype of ligament pit of the right valve, Tenkelyakh area, line 1060, borehole 350, depth 31 m, lower Toarcian. Fig. 2. *Arctotis* (*Praearctotis*) *marchaensis* (Petrova). (a) Spec. no. MKh-233/1, left valve, ×1; Markha R., outcrop 10, bed 8, upper Toarcian, Pseudolioceras wuerttenbergeri Zone; (b) spec. no. MKh/111-2; ligament pit of the left valve, ×3.5; Markha R., outcrop 4, loose from beds 2–3, upper Toarcian, Pseudolioceras wuerttenbergeri Zone ; (c) type spec. no. 574/5393-2, TsNIGR Museum (St. Petersburg), angular subtype of ligament pit of the right valve, ligament pit without spoon-shaped depression; Markha R., upper Toarcian, collection of G.T. Petrova (Pchelintseva); (d) spec. no. MX/111-1, angular subtype of ligament pit of the right valve, ligament pit with a narrow spoon-shaped depression, ×3.5; Markha R., outcrop 4, debris of beds 2–3, upper Toarcian, Pseudolioceras wuerttenbergeri Zone. Fig. 3. *Arctotis* (*Praearctotis*) *similis* Velikzhanina. (a) Spec. no. TR-19/1, left valve, ×1; Eastern Taimyr, Cape Tsvetkov, outcrop 5, bed 3, Sample no. TF-19, Lower Jurassic, upper Toarcian, Pseudolioceras falcodiscus Zone, (b) spec. no. MN-216/1, ligament pit of the left valve, ×4, Motorchuna R., outcrop 4, bed 2, Sample no. 216, upper Toarcian, Pseudolioceras falcodiscus Zone; (c) spec. no. TR-19/1, spoon-shaped subtype of ligament pit of the right valve, ligament pit with a wide spoon-shaped depression, ×4, Eastern Taimyr, Cape Tsvetkov, outcrop 5, bed 3, Sample no. TF-19, Lower Jurassic, upper Toarcian, Pseudolioceras falcodiscus Zone. Fig. 4. *Arctotis* (*Arctotis*) *tabagensis* (Petrova). (a) Spec. no. AG-116/1-l, left valve, ×1; (b) spec. no. AG-116/1-p, concave spoon-shaped ligament pit of a right valve, ×2.5, Anabar Bay, western coast, outcrop 5, bed 92; Middle Jurassic, condensed bed, lower–upper Aalenian (?). Fig. 5. *Arctotis* (*Arctotis*) *sublaevis* (Bodylevsky). (a) Spec. no. AN-18/1, left valve, ×1, Anabar R., outcrop 3, layer 8, Sample 18, Middle Jurassic, condensed bed, upper Aalenian–lower Bajocian (?); (b) strongly sloping ligament pit of the same specimen, ×2; (c) spec. no. AN-18/1-p, concave spoon-shaped, ligament pit of a right valve, ×2, Anabar R., outcrop 3, layer 8, Sample 18, Middle Jurassic, condensed bed, upper Aalenian–lower Bajocian (?).

Plate I



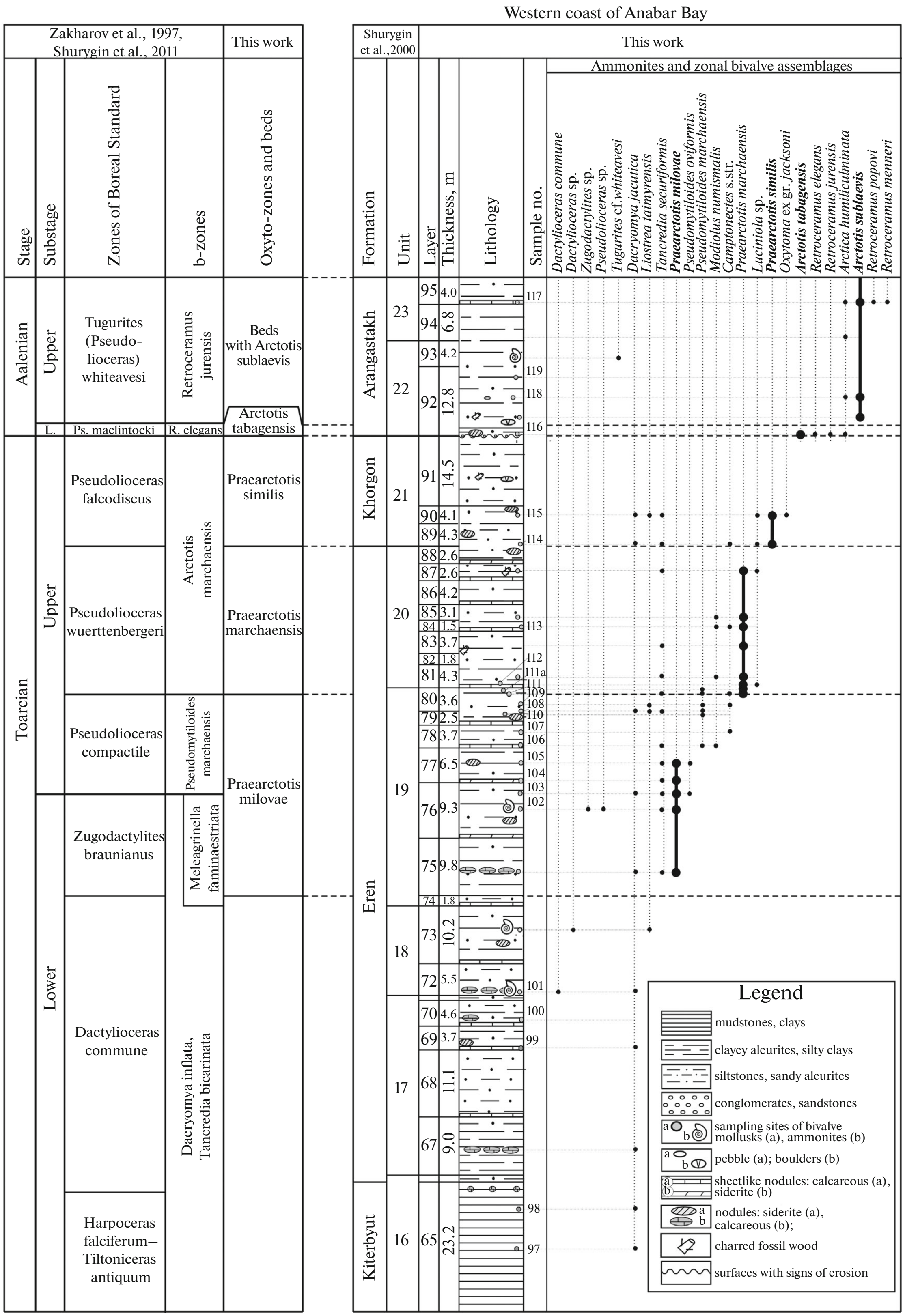


Fig. 7. Scheme of subdivision and correlation of Toarcian–Aalenian deposits of the western coast of Anabar Bay based on the distribution of index species of oxyto-zones and zonal assemblages.

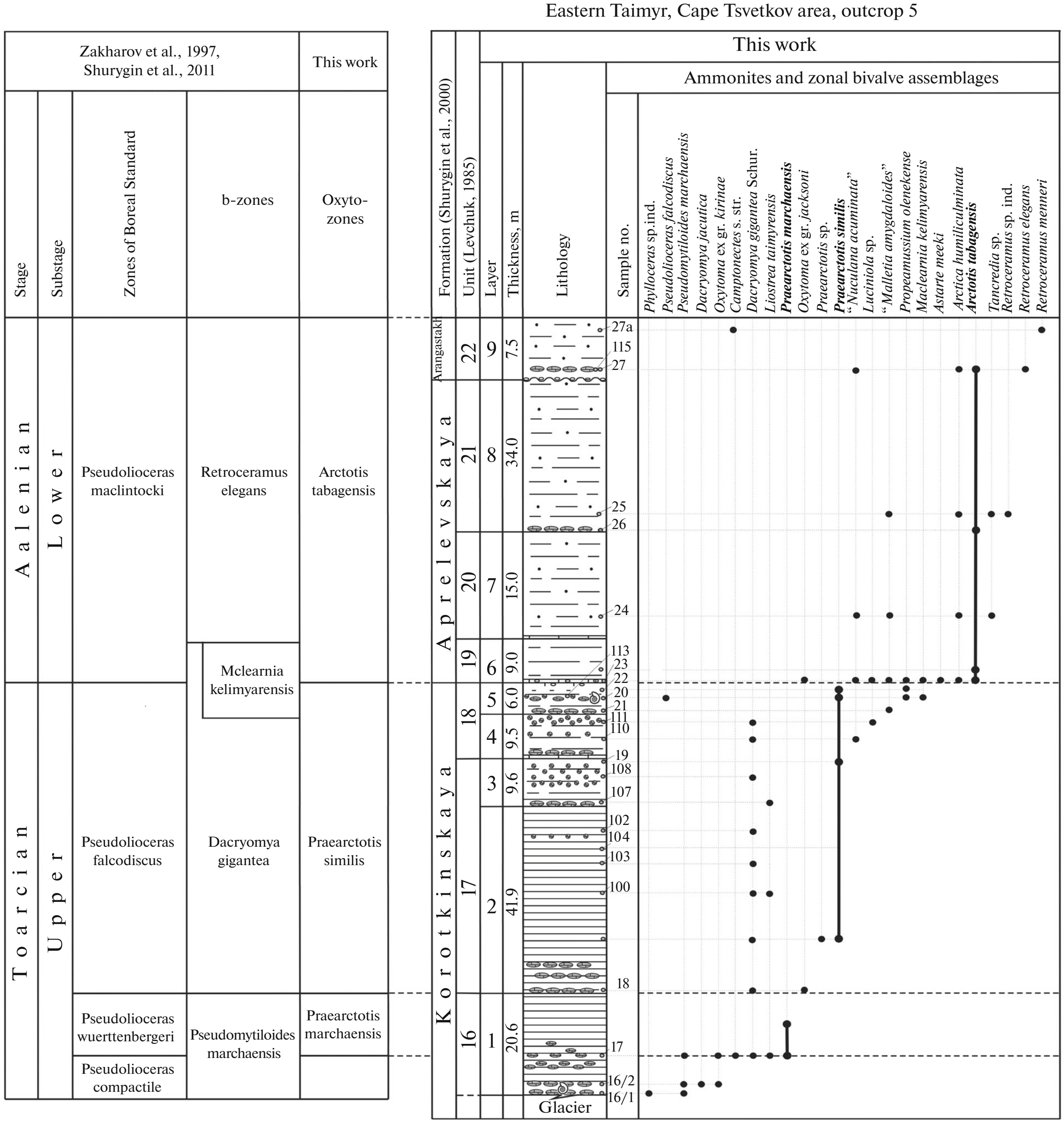


Fig. 8. Scheme of subdivision and correlation of upper Toarcian–lower Aalenian deposits of Cape Tsvetkov (Eastern Taimyr) based on the distribution of index species of oxyto-zones and zonal complexes.

Praearctotis similis oxyto-zone

N o m e n c l a t u r e. This oxyto-zone is recognized for the first time.

I n d e x s p e c i e s: *Arctotis* (*Praearctotis*) *similis* Velikzhanina, 1966.

S t r a t o t y p e o f t h e o x y t o - z o n e: Eastern Siberia, Cape Tsvetkov, outcrop 5, beds 2–5, Korotkinskaya Formation, thickness 67 m.

Z o n a l a s s e m b l a g e of the oxyto-zone consists of species of bivalve mollusks: *Propeamussium olenekense* (Bodyl.), *Dacryomya gigantea* Zakh. et Schur., *Mclearnia kelimyarensis* Zakh. et Schur., "*Malletia amygdaloides* (Sow.)," and "*Nuculana acuminata* (Goldf.)", *Luciniola* sp.

P r i n c i p l e o f i d e n t i f i c a t i o n o f b o u n d a r i e s a n d s u b s t a n t i a t i o n o f a g e. The lower boundary of the Praearctotis similis oxyto-zone is established by the first occurrence of the index species; the upper boundary is established by the appearance of the index species of the overlying oxyto-zone—*Arctotis* (*Arctotis*) *tabagensis* (Petr.).

The age of an oxyto-zone relative to the ammonite scale is determined by the sum of teilzones of the index species in all known sections. In the Anabar Bay section, *Arctotis* (*Praearctotis*) *similis* is common in the Khorgon Formation. Ammonite *Pseudolioceras* sp. (cf. *maclintocki* Haugh.) (redetermined as *Pseudolioceras falcodiscus* (Quenstedt)) was found in the debris of layers of this formation (*Stratigrafiya*..., 1976) (Knyazev, 1991).

According to the author's data, the index species in the Cape Tsvetkov section (Eastern Taimyr) occupies a position below and above the beds with *Pseudolioceras* cf. *falcodiscus* (Quenstedt). Representatives of *Arctotis* (*Praearctotis*) *similis* Velikzh are distributed in the upper part of the Suntar Formation of the Motorchuna River section at the level with *Pseudolioceras falcodiscus* (Quenstedt) (Knyazev et al., 1991) and *Pseudolioceras motortschunense* Repin (Repin, 2017) and below the level with *Pseudolioceras maclintocki* (Haught.) (*Stratigrafiya*..., 1976). It was reliably established that the Praearctotis similis oxyto-zone corresponds to the Pseudolioceras falcodiscus Zone of the Boreal Standard (Shurygin et al., 2011) (Fig. 1).

C o r r e l a t i o n. The Praearctotis similis oxyto-zone corresponds to the upper part of the Arctotis marchaensis b-zone and the lower part of the Mclearnia kelymiarensis b-zone of the zonal scale of the Boreal Standard for bivalve mollusks (Shurygin et al., 2011). *Arctotis* cf. *marchaensis* (Petr.), *Propeamussium olenekense* (Bodyl.), *Camptonectes* sp., and *Malletia* ex gr. *amygdaloides* (Sow.) were described from deposits with *Pseudolioceras replicatum* in the Viliga River section (northeastern Russia) (Repin and Polubotko, 2015). The oxyto-zone corresponds conditionally to the upper part of the local ammonite Pseudolioceras danilovi Zone and the local ammonite Pseudolioceras paracompactile and Pseudolioceras replicatum zones in northeastern Russia (Repin, 2017) (Fig. 1).

Arctotis tabagensis oxyto-zone

N o m e n c l a t u r e. It is recognized for the first time.

I n d e x s p e c i e s: *Arctotis* (*Arctotis*) *tabagensis* (Petrova, 1953).

S t r a t o t y p e o f t h e o x y t o - z o n e: Eastern Siberia, Cape Tsvetkov, outcrop 5, layers 6–8; Aprelevskaya Formation, layer 9—Arangastakh Formation, thickness 67 m.

Z o n a l a s s e m b l a g e of the oxyto-zone consists of species of bivalve mollusks *Arctica humiliculminata* Schur., *Astarte meeki* Stant., Musculus sp., *Retroceramus elegans* Kosch., and *Tancredia* sp.

P r i n c i p l e o f i d e n t i f i c a t i o n o f b o u n d a r i e s a n d s u b s t a n t i a t i o n o f a g e. The lower boundary of the Arctotis tabagensis oxyto-zone was established according to the first occurrence of the index species; the upper boundary was established according to the appearance of *Arctotis* (*Arctotis*) *sublaevis* (Bodyl.)—the index species of above-lying beds. The age of oxyto-zone is determined relative to the ammonite scale is determined by the sum of telzones of the index species in all known sections.

On Cape Tsvetkov (Eastern Taimyr), *Arctotis* (*Arctotis*) *tabagensis* (Petr.) is common above the level with *Pseudolioceras* cf. *falcodiscus*. In the Anabar Bay section, this species occurs in a condensed layer at the base of the Arangastakh Formation together with *Retroceramus elegans* Kosch. and *Retroceramus jurensis* Kosch. below the level with *Pseudolioceras* (*Tugurites*) *whiteavesi* (White) and *P.* (*T.*) *fastigatum* (Meledina and Shurygin, 2000). In the Motorchuna River section, it occurs at the base of the Syungyude Formation at the level with *Pseudolioceras maclintocki* (Haught.) (*Stratigrafiya*..., 1976). The Arctotis tabagensis oxyto-zone is reliably correlated with the Pseudolioceras maclintocki Zone of the Boreal Standard (Shurygin et al., 2011) (Fig. 1).

C o r r e l a t i o n. The Arctotis tabagensis oxyto-zone corresponds to the upper part of the Maclearnia kelymiarensis b-zone and the lower part of the Retroceramus elegans b-zone of the zonal scale of the Boreal Standard by bivalve mollusks (Shurygin et al., 2011). "*Arctotis marchaensis* (Petr.)" and "*Arctotis* aff. *similis* Velikzh." were described in sandstone and siltstone unit (Akachan and Allakh-Yun rivers, northeastern Russia) with early Aalenian *Pseudolioceras maclintocki* (Haught), together with *Propeamussium olenekense* (Bodyl.) and "*Mytiloceramus priscus* Sey" (*Resheniya*..., 1994). The oxyto-zone corresponds conditionally to the local Pseudolioceras beyrichi orientale Zone and the lower part of the local Pseudolioceras maclintocki Zone of northeastern Russia (Repin, 2017) (Fig. 1).

DESCRIPTION OF ZONAL SPECIES

***Arctotis* (Praearctotis) *marchaensis* (Petrova, 1947)**

Plate II, figs. 1–13

Pseudomonotis (*Eumorphotis*) *marchaensis* Petrova: *Atlas*..., 1947, p. 123, Plate XII, figs. 13–15.

Pseudomonotis (*Eumorphotis*) vai Bodylevsky: *Atlas*..., 1947, p. 124, Plate XII, figs. 20–23.

Eumorphotis marchaensis: Krymgolts et al., 1953, p. 40, Plate IV, figs. 1–4.

Eumorphotis sparsicosta: Krymgolts et al., 1953, Plate V, figs. 7a, 7b, 7c, 8 (only).

Arctotis marchaensis: Koshelkina, 1963, p. 119, Plate II, figs. 4a–4c; Velikzhanina, 1966, p. 86, Plate I, fig. 15; Plate II, figs. 1–8; *Polevoi*..., 1968, Plate 40, fig. 5; Knyazev et al., 2003, p. 90, Plate 6, figs. 5, 7, 10.

Meleagrinella buschinskii Koschelkina: Koshelkina, 1963, p. 116, Plate II, figs. 3a, 3b.

Arctotis viluiensis Velikzhanina: Velikzhanina, 1966, pp. 89–90, Plate III, figs. 1–6 (only).

Holotype: TsNIGR Museum, St. Petersburg, spec. no. 574/5393, A.G. Rzhonsnitsky's collection (1915), images are given in *Atlas*..., 1947, p. 123, Plate XII, fig. 14; Krymgolts et al., 1953, p. 40, Plate IV, fig. 2; this paper, Plate II, fig. 1; Eastern Siberia, Markha River. Lower Jurassic, upper Toarcian.

Material. More than 100 complete shells and separate valves from the Suntar Formation of the Markha River section; type collection of species "*Pseudomonotis* (*Eumorphotis*) *marchaensis* " from the Markha River section, about 100 deformed shells and separate valves from the Eren Formation (Anabar Bay section); moulds of left valves from the upper Toarcian in the Saturn River section; about a dozen left and right valves of good preservation from core sections of boreholes drilled in the Tenkelyakh site; V.I. Bodylevsky's type collection of the species "*Pseudomonotis* (*Eumorphotis*) *vai*" from the Yuryung-Tumus Peninsula; B.N. Shurygin's collection, about 20 moulds from the Yuryung-Tumus Peninsula; T.I. Kirina's type collection of the species "*Arctotis viluiensis*" from the Vilyui River basin.

Diagnosis. Shell is often average-sized. The anterior wing is of "paraboloid" type, obtuse, narrow or very narrow. The anterior back-ligament field of the left valve is short. The left valve is strongly convex or swollen; the right valve is slightly convex. Radial ribs (up to 45) of two orders; intercostal spaces are narrow. The posterior wing of the left valve is ornamented with thin radial ribs (up to 15). The ligament platform of the left valve is located at a slight angle to the plane of closing of valves. An angular subtype of the ligament platform is characteristic of the right valve. The spoon-shaped depression occupies a smaller part of the ligament pit.

Measurements in mm and ratios: see Table 1.

Variability. Specimens from sections of the Markha River and Anabar Bay, from the boreholes drilled in the Tenkelyakh area, are predominantly average-sized; there are small (juvenile) specimens of less 30 mm in size. Height varies from 19.6 to 40.5 mm. The holotype of the species "*Praearctotis vai*" (Plate II, fig. 11) from the Yuryung-Tumus Peninsula section is larger (height, 59.2 mm), which is not typical of the taxon being described. The samples from the type locality of the species "*Praearctotis vai*" are dominated by average-sized shells up to 46.0 mm, similar in size to the Markha shells. It is possible that only individual specimens reached large sizes since their height exceeds the limits of the range of variability of this character.

The contours of the left valves vary from very low to very high. The H/L ratio varies from 0.90 to 1.12. Relative to the axis of symmetry, the left valve is variable from moderately nonequilateral to equilateral. The APL/L ratio varies from 0.43 to 0.48. We assume that the density of colonies of bivalves in the local occupied areas affected the contours and symmetry of the shells. The contours and symmetry of a shell are variable and are not considered species-specific characters.

The left valves of the studied specimens from the sections of the Markha River, Anabar Gulf, and the Tenkelyakh area wells are weakly ribbed. The R/L ratio in *Arctotis* (*Praearctotis*) *marchaensis* (Petrova, 1947) varies from 1.06 to 1.90 (in the holotype of the species *Praearctotis vai*, it is 1.03). By this character, these species are similar. The density of the ribbing is correlated with the composition of the sediments. Presumably, the state of this character depends on the remoteness of the habitat relative to the shore and depth. The early Toarcian forms—*Arctotis* (*Praearctotis*) *subsriata* (Muenster) and *Arctotis* (*Praearctotis*) *milovae* (Okuneva)—from the more clayey intervals of the section show a higher coefficient of ribbing compared to the described taxon.

The width of the intercostal spaces is correlated with the thickness of the ribs and the degree of ribbing. The WS/WR ratio in specimens from the sections of the Markha River and Anabar Bay and the sections of boreholes drilled in the Tenkelyakh area varies from 0.53 to 1.64. The taxon is characterized by narrow intercostal spaces and wide radial ribs. The WS/WR ratio in the holotype of the species "*Praearctotis vai*" is 1.03. By this character, these specimens are similar. The intercostal spaces in moulds of some specimens from the type locality of the species "*Praearctotis vai*" are moderately wide; the WS/WR ratio is 2.14, which is probably due to the lower density of radial ribs on the inner moulds. Presumably, the state of the character depends on the physical properties of the sea bottom. The described taxon, which inhabited clayey-silty bottom, has narrow intercostal spaces.

The left valve is strongly convex or swollen. The Conv/H ratio varies from 0.31 to 0.47. The convexity of the left valves in taxa belonging to the phyletic line of the genus *Arctotis* changes periodically. Along with the described taxon, strongly convex or swollen left valves are typical of shells of the Bathonian *Arctotis* (*Arctotis*) *lenaensis* (Lahusen) and Volgian *Arctotis* (*Canadarctotis*) *intermedia* (Bodylevsky). Presumably, strongly convex or swollen shells are characteristic of forms that lived under conditions of intense wave action. The weak density of the ribbing and the strongly convex left valve are specific to taxa of the species rank that inhabited coastal shallow water environments.

The anterior back-ligament field of a left valve is short.

The AFL/APL ratio varies in a range of 0.35–0.41. The anterior wing of the left valve is narrow. The RWW/RWL ratio is from 0.09 to 0.20. The anterior wing is obtuse. The angle of the anterior wing of the left valve (AAW) varies from 121° to 144°. The "paraboloid" type of anterior wing is characterized by the following characters: a short back-ligament field, a narrow anterior wing, and an obtuse angle of the anterior wing of a left valve. The "paraboloid" type is specific to the group of late Toarcian species and the described taxon.

C o m p a r i s o n. According to the outline, symmetry, and the angle of the anterior wing of the left valve, the described species is similar to the holotype of *Arctotis* (*Praearctotis*) *similis* Velikzhanina, 1966 (Velikzhanina, 1966, pp. 90–92, Plate II, fig. 9). It is distinguished by a narrower anterior wing, a short anterior ligament field of the left valve, an angular subtype of the ligament pit, and narrower intercostal spaces.

R e m a r k s. According to the type of anterior wing and angular subtype of the ligament platform, the holotype *Prearctotis marchaensis* from the upper Toarcian of the Lena–Vilyui area (Markha R.) (*Atlas*..., 1947, p. 123, Plate XII, fig. 14; this work, Plate II, fig. 1) and holotype "*Pseudomonotis* (*Eumorphotis*) *vai*" from the upper Toarcian of the Nordvik area (Yuryung-Tumus Peninsula) (*Atlas*..., 1947, p. 124, Plate XII, fig. 20; this work, Plate II, fig. 11) are attributed to the same group. The species described by V.I. Bodylevsky was previously considered as an independent species referred to the subgenus *Arctotis* (*Praearctotis*) (Lutikov and Shurygin, 2010).

Since the size and width of the intercostal spaces on a left valve are variable in the samples and are not species-specific, "*Arctotis* (*Praearctotis*) *vai*" is considered in the present paper as a junior synonym of *Arctotis* (*Praearctotis*) *marchaensis*.

According to the type of anterior wing and the convexity of the left valve, the holotype *Arctotis* (*Praearctotis*) *marchaensis* from the upper Toarcian Lena–Vilyui area (Markha R.), and holotype "*Arctotis viluiensis*" from the upper Toarcian of the Lena–Vilyui area (Vilyui R.) (Velikzhanina, 1966, pp. 89–90, Plate III, fig. 1; this work, Plate III, fig. 1) belong to the same group. The species was previously considered by L.S. Velikzhanina as an independent species (Lutikov and Shurygin, 2010).

Since the values of the convexity and length of the anterior back-ligament field of the left valve in the holotypes of the species distinguished by G.T. Petrova and L.S. Velikzhanina are almost identical, the species "*Arctotis viluiensis*" is considered as a junior synonym of *Arctotis* (*Praearctotis*) *marchaensis*.

Meleagrinella buschinskii was described from the Lena–Vilyui area (Markha R.) (Koshelkina, 1963, p. 38, Plate II, fig. 3). The type collection of G. I. Bushinsky, including the holotype, comes from the ferruginous sandstones of the Suntar Formation, including *Arctotis* (*Praearctotis*) *marchaensis*. According to the type of anterior wing, the contours of valves, the convexity, and the ornamentation, the species described by Z.V. Koshelkina is similar to *Arctotis* (Praearctotis) *marchaensis*, and we deal with its junior synonym.

G e o l o g i c a l a g e a n d g e o g r a p h i c d i s t r i b u t i o n. Upper Toarcian, Praearctotis marchaensis oxyto-zone. Western and Eastern Siberia, northeastern Russia.

***Arctotis* (*Praearctotis*) *similis* Velikzhanina, 1966**

Plate III, figs. 1–8

Arctotis similis Velikzhanina: Velikzhanina, 1966, p. 89, Plate II, figs. 9–10 (only).

Arctotis viluiensis Velikzhanina: Velikzhanina, 1966, p. 89, Plate III, fig. 7 (only).

Pseudomonotis aff. *elegans*: Pchelintsev, 1933, p. 47, Plate III, fig. 45.

Meleagrinella cf. *echinata* (Smith): Wierzbowski, 1981, p. 219, Plate 8, figs. 6–8.

Arctotis (*Praearctotis*) *viluiensis*: Lutikov and Shurygin, 2010, Plate I, fig. 8; Plate II, fig. 4; Plate III, figs. 23–26.

Praearctotis viluiensis: Lutikov et al., 2010, Plate I, fig. 12.

H o l o t y p e: spec. no. 14/653, left valve. VNIGRI Museum, St. Petersburg, T.I. Kirina's collection (1961). Images are given in Velikzhanina, 1966, Plate II, fig. 9; this paper, Plate III, fig. 2; Eastern Siberia, Vilyui R. Lower Jurassic, upper Toarcian.

M a t e r i a l. About a dozen left and right valves of good preservation from the upper unit of the Korotkinskaya Formation (unit 18) (Cape Tsvetkov, Eastern Taimyr); five left and two right valves, several cores and imprints of left and right valves from shell depos-

Plate II. Figs. 1–13. *Arctotis* (*Praearctotis*) *marchaensis* (Petrova, 1947). (1) Holotype, spec. no. 574/5393-1, (a) left valve, outer view; (b) left valve, anterolateral view, ×1; (c) paratype, spec. no. 574/5393-2, right valve, inside view; Markha R., upper Toarcian (A.G. Rzhonsnitsky's collection, TsNIGR Museum (St. Petersburg); (2) spec. no. MKh-111/2, left valve, outer view, ×1; Markha R., outcrop 4, loose from bed 2–3, Sample 111, upper Toarcian; (3) spec. no. MKh-111/3, (a) left valve, (b) anterior view; Markha R., outcrop 4, loose, upper Toarcian; (4) spec. no. MKh-220/6 l, (a) left valve, (b) anterior view; Markha R., outcrop 5, loose, Sample 220, upper Toarcian; (5) spec. no. MKh-233/2, (a) left valve, ×1; (b) the same, anterolateral view, ×1; (c) hinge edge view, ×2.5; Markha R., outcrop 10, layer 8, upper Toarcian; (6) spec. no. MKh-233/1, left valve, outer view, ×1; Markha R., outcrop 10, bed 8, upper Toarcian; (7) spec. no. TKh-1/5, (a) left valve of juvenile specimen, outer view; (b) the same, ×2; Tenkelyakh area, line 1080, borehole 350, depth 35 m, upper Toarcian; (8) spec. no. TKh-1/2, (a) right valve of juvenile specimen, outer view; (b) the same, ×2; Tenkelyakh site, line 1080, borehole 350, depth 35 m, upper Toarcian; (9) spec. no. AG-37/1, deformed left valve, outer view, ×1, Anabar Bay, outcrop 4, bed 18, upper Toarcian; (10) spec. no. AG-37/2, right valve, outer view, ×1, Anabar Bay, outcrop 4, layer 18, upper Toarcian; (11) spec. no. 7/306, holotype "*Arctotis vai*" Bodylevsky, (a) left valve, outer view, ×1; (b) outer view, ×1; Yuryung-Tumus Peninsula, upper Toarcian, Paleontological-Stratigraphic Museum of Mining University (St. Petersburg, V.I. Bodylevsky's collection); (12) spec. no. 8/306, right valve, inner view, ×1, Yuryung-Tumus Peninsula, upper Toarcian, Paleontological-Stratigraphic Museum of Mining University (St. Petersburg, V.I. Bodylevsky's collection); (13) spec. no. N-73/ 2913/1 l, (a) mould of the left valve, ×1; (b) core of a shell, outer view, ×1; (c) mould of the right valve, ×1; Yuryung-Tumus Peninsula, upper Toarcian, B.N. Shurygin's collection (Institute of Petroleum Geology and Geophysics, Novosibirsk).

Plate II

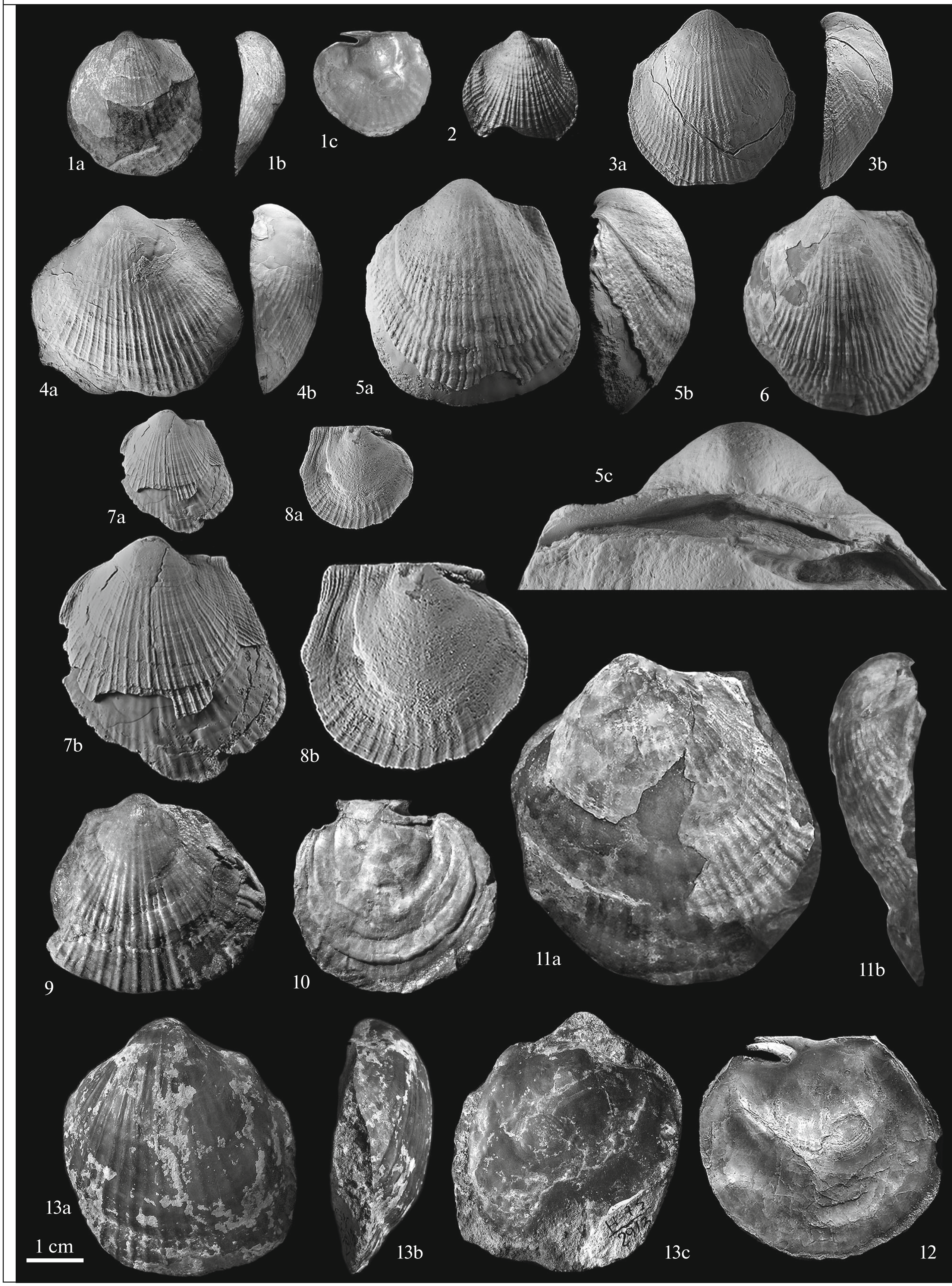

1a
1b
1c
2
3a
3b
4a
4b
5a
5b
6
5c
7a
8a
7b
8b
9
10
11a
11b
13a
1 cm
13b
13c
12

Table 1. Measurements (mm) and ratios

Collection no., valve	Locality	L	H	H/L	Conv	Conv/H	APL	APL/L	AFL	APL/AFL	AAW	R	R/L	WR/WS	RWW/RWL
574/5393 l, holotype	Markha R., upper Toarcian, TsNIGR Museum, St. Petersburg, A.G. Rzhosnistrky's collection	24.07	26.0	1.08	9.36	0.36	10.63	0.44	3.68	0.35	132°	32	1.33	1.10	0.17
574/5393 r, type specimen	The same	21.2	19.0	0.90	–	–	11.9	0.56	6.9	0.58	–	–	–	–	–
MKh-111/2 l	Markha R., outcrop 4, loose from beds 2–3, Sample 111, upper Toarcian	20.70	19.6?	0.95?	6.0	0.31	10.20	0.49	3.60	0.34	126°	26	1.26	1.06	0.15
MKx-111/3 l	The same	30.41	31.6	1.09	13.17	0.42	14.52	0.48	–	–	121°	45	1.55	1.23	0.16
MKx-220/6 l	Markha R., outcrop 5, loose, Sample 220, upper Toarcian	38.02	34.1	0.90	13.22	0.39	16.38	0.43	6.52	0.40	127°	41	1.10	1.64	0.09
MKx-233/1 l	Markha R., outcrop 10, bed 8, Sample 233, upper Toarcian	35.00	39.1	1.12	–	–	16.3	0.47	–	–	130°	43	1.23	0.92	0.15
MKx-233/2 l	The same	38.25	40.5	1.06	18.97	0.47	17.57	0.46	7.28	0.41	119°	44	1.17	0.53	0.15
TKh-1/5 l	Tenkelyakh area, line 1080, borehole 350, depth 35 m	21.8	22.6	1.04	6.5	0.29	9.5	0.44	3.81	0.40	144°	37	1.70	1.49	0.17
TKh-1/2 r	The same	20.55	18.9	0.92	2.8	0.15	9.02	0.50	5.04	0.56	–	33	1.62	1.50	–
AG-37/1 l	Anabar Bay, outcrop 4, bed 18, upper Toarcian	39.08	35.7	0.95	–	–	16.72	0.43	–	–	135°	34	0.90	1.28	0.20
AG-37/2 r	The same	36.27	34.7	0.96	–	–	16.30	0.45	–	–	–	28	0.77	–	–
7/306 l, holotype "*Pseudomonotis* (*Eumorphotis*) *vai*"	Yuryung-Tumus Peninsula, upper Toarcian, Museum of Mining Institute, St. Petersburg, V.I. Bodylevsky's collection	55.48	59.2	1.06	17.36	0.29	21.21	0.38	–	–	119°	30	0.87	1.03	0.13
8/306 r, type specimen	The same	43.52	40.18	0.92	–	–	21.46	0.49	12.57	0.59	–	–	–	–	–
N-73/ 2913/1 l	Yuryung-Tumus Peninsula, upper Toarcian, Institute of Petroleum Geology and Geophysics Museum, Novosibirsk, B.N. Shurygin's collection	42.06	46.3	1.10	14.27	0.31	18.84	0.45	7.66	0.41	144°	22	–	2.14	0.15
N-73/ 2913/1 r	The same	37.80	36.20	0.96	4.11	0.11	17.48	0.46	–	–	–	–	–	–	–
no. 20/653, holotype "*Arctotis viluiensis*"	Vilyui R., outcrop 54-56, Sample 1394, upper Toarcian, VNIGRI Museum, T.I. Kirina's collection	39.33	36.2	0.92	13.89	0.38	18.33	0.47	6.78	0.37	135°	35	0.89	1.13	0.17

its of the Khorgon Formation (Anabar Bay); about ten well-preserved left and right valves from the upper part of the Suntar Formation (Motorchuna River basin); T.I. Kirina's type collection of the species "*Arctotis similis*" from the Suntar Formation in the Vilyui River section.

D i a g n o s i s. Shell is often average-sized. The anterior wing is of the "trapezoidal" type, obtuse, moderately wide. The left valve is moderately convex; the right valve is flat. Radial ribs (25–40) of two orders; intercostal spaces are often very wide. The posterior wing of the left wing is ornamented with thin radial ribs (16). The ligament platform of the left valve is located at a large angle to the hinge plane of valves. The ligament tip is of the spoon-shaped subtype. The spoon-shaped depression occupies the largest part of the ligament pit. The ligament platform of the right valve is long.

M e a s u r e m e n t s i n m m a n d r a t i o s: see Table 2.

V a r i a b i l i t y. Left valves of specimens from the sections of the Motorchuna River, Cape Tsvetkov (Eastern Taimyr), and Anabar Bay are small- or average-sized. The height of the left valve varies from 28.4 to 31.5 mm.

The outline of left valves are variable, from very low to equal. The H/L ratio varies from 0.88 to 0.96. The H/L ratio in specimens from the Vilyui River section (T.I. Kirina's collection) is 0.99. Relative to the axis of symmetry, the left valve varies from moderately nonequilateral to equilateral. The APL/L ratio varies from 0.42 to 0.49.

The left valves of specimens from the sections of the Motorchuna and Vilyui rivers and Cape Tsvetkov (the middle part of the Korotkinskaya Formation) are rarely ornamented with ribs. The coefficient of ribbing (RL) varies from 0.72 to 0.99. The ribbing density in specimens from the Anabar Bay section (Khorgon Formation) (Plate III, figs. 7, 8) is higher (up to 1.28). Intercostal spaces in specimens from the Motorchuna River, Cape Tsvetkov, and Vilyui River sections are moderately wide to very wide. The WS/WR ratio varies from 2.02 to 4.79.

The intercostal spaces in specimens from the Anabar Bay section (Khorgon Formation) and one specimen from the Cape Tsvetkov section (the upper part of the Korotkinskaya Formation) (Plate III, fig. 4) are narrow; the WS/WR ratio varies from 1.14 to 1.24. In terms of the density of the ribbing and the width of the intercostal spaces, the specimens from the Anabar Bay section and the specimen from the upper member of the Korotkinskaya Formation of the Cape Tsvetkov section are similar to *Arctotis* (*Arctotis*) *tabagensis*, being different in the type of anterior wing. Further research allows one to isolate these forms within the same phylogenetic lineage as a taxon occupying an intermediate position between *Arctotis* (*Praearctotis*) *similis* and *Arctotis* (*Arctotis*) *tabagensis*.

The left wing is moderately convex. The convexity coefficient (Vp/V) was measured only in one case (0.25).

The anterior ligament field of the left wing is long.

The AFL/APL ratio varies in the range of 0.44–0.54. The anterior wing of the left valve varies from narrow to moderately wide. The RWW/RWL ratio varies from 0.16 to 0.22. The anterior wing is obtuse. The angle of the anterior wing of a left valve (AAW) varies from 112° to 146°.

The "trapezoidal" type of anterior wing is characterized by a long back-ligament field, a narrow or moderately wide anterior wing, and an obtuse angle of the anterior wing of the left valve. The "trapezoidal" type is specific only to the described taxon.

C o m p a r i s o n. According to the spoon-shaped subtype of the ligament pit of the right valve, and the convexity of the left valve, the described species is similar to *Arctotis* (*Arctotis*) *tabagensis* (Petrova, 1966) (Krymgolts et al., 1953, pp. 89–90, Plate IV, figs. 6–7), being different in a longer ligament platform of the right valve, an obtuse anterior wing, and wide intercostal spaces. It is different from *Arctotis frenguellii* (Damborenea et al., 2013, p. 124, fig. 6.1 p) from the Toarcian–Aalenian deposits of Argentina in a narrow anterior wing (RWW/RWL ratio in the Argentine species is 0.26), and significantly fewer number of ribs.

R e m a r k s. When describing the species *similis*, L.S. Velikzhanina chose a specimen represented by the left valve (Velikzhanina, 1966, Plate II, fig. 9), from the Toarcian–Aalenian boundary deposits (Suntar Formation) in the Vilyui River basin as the holotype. The left valves of our specimens from the upper Toarcian of the Zhigansk, Lena–Anabar, and Eastern Taimyr regions belong to the species *similis* on the basis of the external similarity to the holotype in the contours of the anterior wing.

According to the presence of a weakly expressed prominence on the left valves of specimens from the Korotkinskaya Formation in the Cape Tsvetkov section (Plate I, fig. 8) and the Suntar Formation in the Motorchuna River section, the *similis* group should be assigned to the subgenus *Praearctotis*. According to the type of anterior wing, the representatives of this group occupy an intermediate position between the late Toarcian group *marchaensis* with a narrow wing and the Aalenian group *tabagensis* with a wide wing.

Arctotis similis Velikzh. (Velikzhanina, 1966, p. 89, Plate II, figs. 9–11) and *A. viluiensis* Velikzh. (Velikzhanina, 1966, p. 89, Plate III, figs. 1–7) were described from the unit of sands and ferruginous sandstones with a thin conglomerate horizon at the base located in the upper part of the Suntar Formation of the Vilyui River section. The holotype of the species *Arctotis similis* is tied to outcrop 54 in the Vilyui River section. The holotype of the species "*Arctotis viluiensis*" was described in outcrops 54–56 in the Vilyui River section (Velikzhanina, 1966; Kirina, 1966). Previously, both species were considered synonyms (Lutikov and

Shurygin, 2010). When studying the original collection of T.I. Kirina, stored in the VNIGRI Museum, it was found that the holotype of *Arctotis similis* has a moderately convex left valve and a very long anterior ligament field (Plate III, fig. 2). The holotype of "*Arctotis viluiensis*" has a strongly convex left valve and short anterior ligament field (Plate III, fig. 1).

According to the description by L.S. Velikzhanina, the main difference in the sculpture between these two species is that the ribs of the first order in "*A. viluiensis*" are very strong, distinct, almost three times thinner than the wide intercostal spaces enclosing the ribs of the second order.

According to this character, some of our specimens from the Eastern Taimyr and Motorchuna River sections (Plate III, figs. 3, 5) are close to the specimen of "*Arctotis viluiensis*" from the Markha River (Velikzhanina, 1966, Plate III, fig. 7).

Another sign of the difference between the species is wavelike growth wrinkles characteristic of *Arctotis similis*. According to this character, all our specimens from the Korotkinskaya Formation (Eastern Taimyr), the Khorgon Formation (Anabar Bay), and the Suntar Formation (Motorchuna River) (Plate III, figs. 3–8) are close to *Arctotis similis* in the description by Velikzhanina (1966, Plate II, figs. 9–11).

The sculpture of some forms from the upper half of member 18 (Eastern Taimyr section) is represented by many radial ribs (Plate III, fig. 4). There are specimens with densely arranged ribs from the Khorgon Formation in the Anabar Bay section (Plate III, figs. 7, 8). These specimens have narrow intercostal spaces and were previously assigned to *tabagensis* (Lutikov and Shurygin, 2010, Plate IV, figs. 1–2). Since the degree of ribbing may depend on facies conditions, this sign is not considered species-specific. All morphological varieties with an obtuse and moderately wide anterior wing of the left valve and a long or very long anterior ligament field are assigned to *Arctotis* (*Praearctotis*) *similis* Velikzh.

Species "*Arctotis viliuensis*" (Velikzhanina, 1966) is included in the synonymy of *Arctotis* (*Praearctotis*) *marchaensis* (*Atlas*..., 1947).

G e o l o g i c a l a g e a n d g e o g r a p h i c d i s t r i b u t i o n. Lower Jurassic, upper Toarcian, Pseudolioceras falcodiscus Zone, Praearctotis similis oxytozone. Upper Toarcian of Eastern Siberia, Spitsbergen, the Russian Far East, and the Caucasus.

***Arctotis* (*Arctotis*) *tabagensis* (Petrova, 1953)**

Plate III, figs. 9–14

Eumorphotis tabagensis Petrova: Krymgolts et al., 1953, pp. 89–90, Plate IV, figs. 6–7.

Arctotis (*Arctotis*) *tabagensis*: Lutikov and Shurygin, 2010, Plate IV, figs. 3–7.

H o l o t y p e: TsNIGR Museum, St. Petersburg, spec. no 602/5393, mould of a left valve, G.A. Ivanov's collection (1925). Figured in Krymgolts et al., 1953, Plate IV, fig. 6; this work, Plate III, fig. 9; Eastern Siberia, Lena R., Tabaga Cliff (Verknii Kangalassky Kamien). Middle Jurassic, lower Aalenian.

M a t e r i a l. About a dozen complete shells and several moulds of left valves from the Kystatym Formation (the sections of Syungyude and Molodo river basins), a right valve and an imprint of a left valve from siltstones of the Syungyude Formation (Motorchuna River section); about a dozen shells from the lower part of the Arangastakh Formation (Anabar Bay), about 15 moulds from the Aprelevskaya Formation (Eastern Taimyr), G.T. Petrova's type collection from the Lena River, stored at the TsNIGR Museum.

D i a g n o s i s. Shell average- to very large-sized. The anterior wing is of "hyperboloid" type, subrectangular, wide. The anterior back-ligament field of a left valve is very long. The left valve is moderately convex; the right valve, flat. Radial ribs of three orders amount to 50 to 60; intercostal spaces are very narrow.

The posterior wing of the left valve is ornamented with radial ribs (up to 20). The ligament platform of the left wing is steeply inclined relative to the hinge plane of valves. The ligament platform of the right

→

Plate III. Fig. 1. *Arctotis* (*Praearctotis*) *marchaensis* (Petrova, 1947), spec. no. 20/653 (holotype "*Arctotis viluiensis*" Velikzhanina), VNIGRI Museum, T.I. Kirina's collection, mould of the left valve, ×1; Vilyui R., outcrops 54–56, Sample 1394, upper Toarcian. Figs. 2–7. *Arctotis* (*Praearctotis*) *similis* Velikzhanina, 1966. (2) Holotype, spec. no. 14/653, VNIGRI Museum, T.I. Kirina's collection, left valve, ×1; Vilyui R., outcrop 54, Sample 1953, upper Toarcian; (3) spec. no. TR-19/1, left valve outer view, ×1; Eastern Taimyr, Cape Tsvetkov, outcrop 5, bed 3, Sample TF-19, Lower Jurassic, upper Toarcian; (4) spec. no. f-113/1, left valve, outer view, ×1; Eastern Taimyr, Cape Tsvetkov, outcrop 5, bed 5, Sample f-113, Lower Jurassic, upper Toarcian; (5) spec. no. MN-216/1, (a) left valve, outer view, ×1; (b) left valve, lateral view, ×1; Motorchuna R., outcrop 4, bed 2, Lower Jurassic, upper Toarcian; (6) spec. no. MN-216/2, right valve outer view, ×1; the same, the same age; (7) spec. no. AG-114/1, core of a left valve, outer view, ×1; Anabar Bay, western coast, outcrop 5, bed 89; Middle Jurassic, upper Toarcian; (8) spec. no. AG-114/2, imprint of a right valve, ×1, the same, the same age. Figs. 9–14. *Arctotis* (*Arctotis*) *tabagensis* (Petrova, 1953). (9) Holotype, spec. no. 602/5393, core of the left valve, ×1; Lena R., Cape Tabaginsky (Bolshoi Kangalass Kamien), Middle Jurassic, Aalenian; Museum TsNIGR (St. Petersburg), G.A. Ivanov's collection; (10) spec. no. TF-26/1, mould of the left valve, ×1; Eastern Taimyr, Cape Tsvetkov, outcrop 5, bed 8, Sample TF-26, Middle Jurassic, lower Aalenian; (11) spec. no. 82 f/1, (a) core of the left valve, ×1; (b) imprint of the same valve, ×1; Eastern Taimyr, Cape Tsvetkov, outcrop 7/1, bed 3, top, Sample 82f, Middle Jurassic, lower Aalenian; (12) spec. no. AG-116/1, left valve, outer view, ×1, Anabar Bay, western coast, outcrop 5, layer 92, Middle Jurassic, lower Aalenian; (13) spec. no. AG-116/2, right valve, outer view, ×1, the same, the same age; (14) spec. no. TF-26/2, core of the left valve, ×1; the same, the same age; (14) spec. no. TKh-36/1, mould of the left valve, ×1, Tenkelyakh site, line 160, borehole 36, depth, 26 m.

Plate III

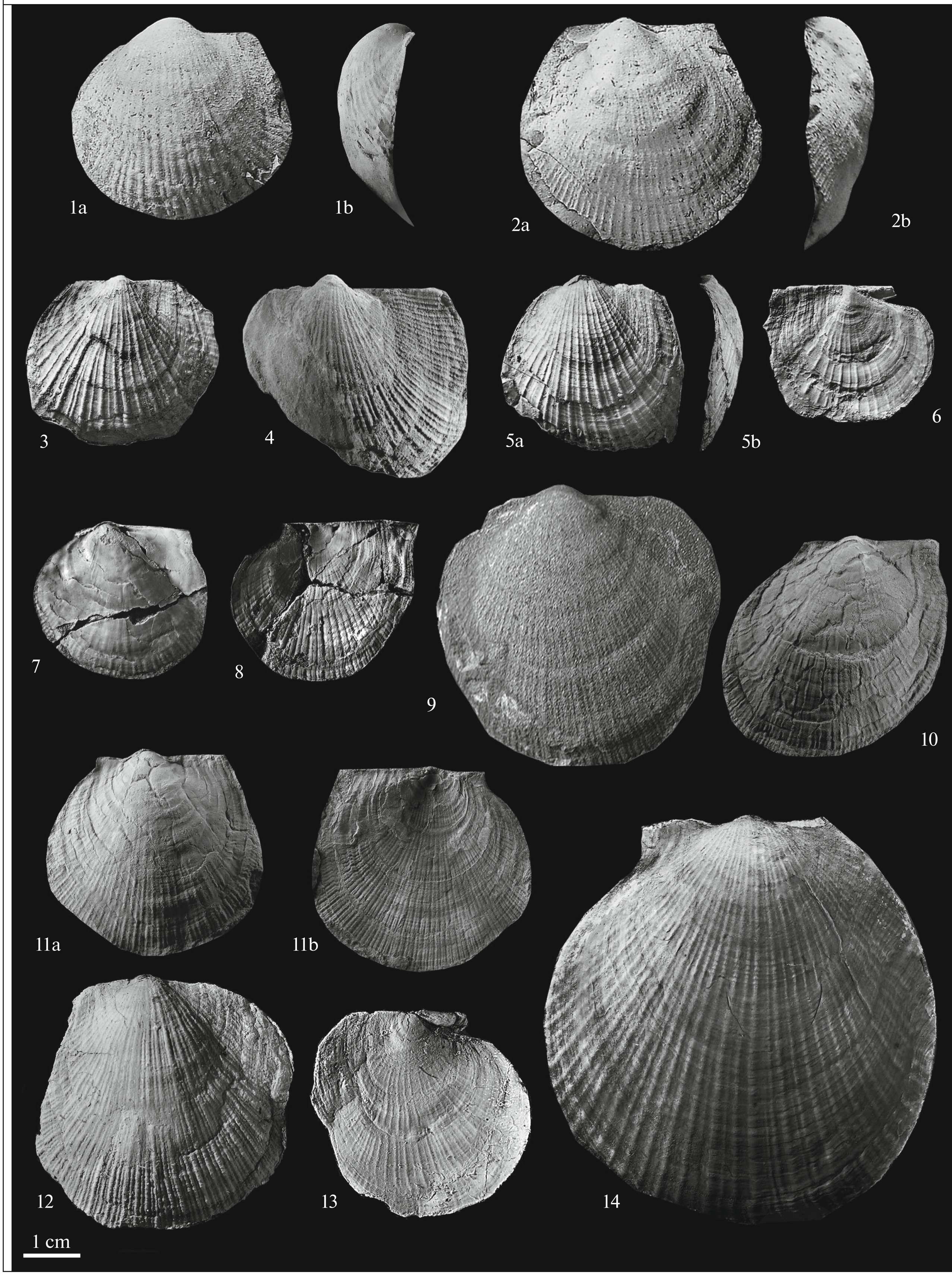


Table 2. Measurements (mm) and ratios

Collection no., valve	Locality	L	H	H/L	Conv	Conv/H	APL	APL/L	AFL	APL/AFL	AAW	R	R/L	WR/WS	RWW/RWL
MN-216/1 l	Motorchuna R., outcrop 4, bed 2, upper Toarcian	32.81	31.5	0.96	8.0	0.25	14.52	0.44	6.35	0.44	146°	26	0.79	2.02	0.16
MN-216/2 r	The same	30.69	24.6	0.80	2.0	0.08	15.5	0.50	8.3	0.54	115°	25	0.81	3.28	0.20
TR-19/1 l	Eastern Taimyr, outcrop 5, bed 3, Lower Jurassic, upper Toarcian	34.71	30.6	0.88	–	–	17.02	0.49	9.10	0.53	136°	25	0.72	4.79	0.22
f-113/1 l	Eastern Taimyr, outcrop 5, layer 5, outcrop no. f-113, Lower Jurassic, upper Toarcian	40.00	–	–	–	–	–	–	–	–	115°	–	–	1.14	–
AG-114/1 l	Anabar Bay, western coast, outcrop 5, bed 89, upper Toarcian	31.28	28.4	0.91	–	–	13.25	0.42	6.27	0.47	112°	40	1.28	1.24	0.16
AG-114/2 r	The same	33.95	29.0	0.93	–	–	13.0	0.42	5.88	0.45	–	40	1.28	–	–
no. 14/653, holotype	Vilyui R., outcrop 54, Sample 1953, upper Toarcian, VNIGRI Museum, T.I. Kirina's collection	42.96	41.6	0.97	12.54	0.30	18.84	0.44	10.20	0.54	131°	40	0.93	2.03	0.20

valve is of the spoon-shaped subtype. The spoon-shaped depression completely occupies the ligament pit. The ligament platform of the right valve is short.

M e a s u r e m e n t s i n m m a n d r a t i o s: see Table 3.

V a r i a b i l i t y. Left valves of studied specimens from the Lena River, Anabar Bay, and Cape Tsvetkov are predominantly small- or average-sized (30.0–50.0 mm). Several specimens from the boreholes drilled in the Tenkelyakh area (Plate III, fig. 14) are larger, about 70.0 mm. It is possible that only individual specimens reached large sizes when their height exceeded the limits of the range of variability of this character. Species from the boreholes drilled in the Tenkelyakh area are similar in size to the Aalenian–Bajocian taxon *Arctotis* (*Arctotis*) *sublaevis*, being different in the type of an anterior wing. Perhaps, further research will allow one to isolate these forms within the same phylogenetic line, as a taxon occupying an intermediate position between *Arctotis* (*Praearctotis*) *similis* and *Arctotis* (*Arctotis*) *sublaevis*.

The contours of left valves vary from very low to high. The H/L ratio varies from 0.95 to 1.04.

The left valve is variable from moderately nonequilateral to equilateral relative to the axis of symmetry. The APL/L coefficient varies from 0.43 to 0.46.

Left valves are slightly ribbed. The coefficient of ribbing (R/L) varies from 1.28 to 1.85. This taxon is characterized by the appearance of intercalated ribs of the third order in the spaces between the ribs of the second order over the entire surface of a shell. The intercostal spaces in specimens from the sections of the Lena River basin, Cape Tsvetkov, and the Tenkelyakh site are very narrow. The WS/WR ratio varies from 1.05 to 1.25.

The left valve is moderately convex. The convexity coefficient (Conv/H) was measured only in one specimen (0.26).

The anterior ligament field of the left wing is very long. The AFL/APL coefficient is in the range of 0.51–0.64. The anterior wing of the left valve is wide. The RWW/RWL coefficient varies from 0.20 to 0.26. The anterior wing is subrectangular. The angle of the anterior wing of the left valve (AAW) varies in a range of 89°–104°.

A very long back-ligament field, a wide anterior wing, and a subrectangular anterior wing of the left valve are characters of the "hyperboloid" type of anterior wing. The "hyperboloid" type is characteristic only of the described taxon.

C o m p a r i s o n. The described species differs from *Arctotis* (*Arctotis*) *sublaevis* from the upper Aalenian and lower Bajocian of the Nordvik, Zhigansk, Lena–Anabar, and Eastern Taimyr areas in a subrectangular anterior wing of the left valve at all stages of growth (the anterior wing of the species *sublaevis* is obtuse at the late stages of growth), flat right valve (the right valve of the species *sublaevis* is concave), and open byssal groove at all stages of growth (in the species *sublaevis*, the byssal groove is overgrown in large shells at late stages of growth). It differs from *Arctotis frenguellii* (Damborenea et al., 2013, p. 124, fig. 6.1 p) from the Toarcian–Aalenian deposits of Argentina in the hyperboloid type of anterior wing of the left valve (the anterior wing of the species from Argentina is of trapezoidal type).

R e m a r k s. The holotype of the species *tabagensis* is represented by the mould of a left valve and comes from the Yakutian Formation of the Aalenian age (Plate III, fig. 9). Our specimens from the Aalenian deposits of Anabar Bay (Plate III, figs. 10, 12) and Eastern Taimyr (Plate III, figs. 13, 15) are similar to the holotype in the subrectangular shape of the anterior wing.

G e o l o g i c a l a g e a n d g e o g r a p h i c d i s t r i b u t i o n. Aalenian Stage, lower substage, Pseudolioceras maclintocki Zone, Praearctotis tabagensis oxyto-zone, Western Siberia, Eastern Siberia: Anabar Bay, Eastern Taimyr, basins of the Lena, Molodo, Motorchuna, Vilyui, Markha, and Tyung rivers.

CONCLUSIONS

On the basis of the monographic study of collections of bivalve mollusks from Toarcian–Aalenian sequences of Eastern Siberia, the taxa of bivalve mollusks of the genus *Arctotis* Bodylevsky, 1960 were revised. The classification of species taxa was developed on the basis of a new approach to the classification of oxytomids proposed by the author for the first time. The taxa were classified on the basis of studying the morphogenesis of the ligament and byssus blocks of both valves of a shell and evaluating the taxonomic significance of the signs of external morphology. It was found that, against the background of the gradual development of a morphotype with a developed spoon in the phylogenetic series of *Arctotis* (Praearctotis)–*Arctotis* (Arctotis), the state of other unique signs (the length of the anterior ligament field, the angle and width of the anterior wing, the ratio of the convexity of valves, and orders of ribbing) also changed.

In the interval from the early Toarcian to early Aalenian, the type of anterior wing of the left valve gradually changed from the "paraboloid" to the "trapezoidal" type and then to the "hyperboloid" type. The morphogenesis of a ligament block of a shell and an anterior wing of a left valve in representatives of the genus *Arctotis* demonstrates relatively high rates of evolution, approximately corresponding to that of the ammonite chrons.

The morphogenetic sequence of species of the genus *Arctotis* Bodylevsky, 1960 identified in the upper Toarcian–lower Aalenian reference sections of Anabar Bay and Cape Tsvetkov (Eastern Taimyr) has been traced in other sections of Eastern Siberia (Moto-

Table 3. Measurements (mm) and ratios

Collection no., valve	Locality	L	H	H/L	Conv	Conv/H	APL	APL/L	AFL	APL/AFL	AAW	R	R/L	WR/WS	RWW/RWL
602/5393 l holotype	Lena R., Upper Kangalass Kamien, lower Aalenian	49.50	48.85	0.98	–	–	22.42	0.45	–	–	97°	60	1.28	–	–
AG-116/1 l	Anabar Bay, western coast, outcrop 5, layer 92, the base, Sample 116, lower–upper (?) Aalenian	46.14	47.8	1.04	–	–	19.68	0.43	12.62	0.64	104°	68	1.47	1.14	0.26
AG-116/2 r	The same	40.49	38.2	0.94	–	–	21.91	0.54	10.20	0.47	–	38	0.94	1.20	–
TKh/160/36-26/1 l	Tenkelyakh area, line 160, borehole 36, depth 26.0 m, lower Aalenian	–	73.2	–	–	–	36.37	–	19.43	0.53	90°	46	–	1.25	0.23
f/82-26/1 l core	Eastern Taimyr, outcrop 7/1, layer 3, Sample 82, lower Aalenian	38.62	36.8	0.95	–	–	17.82	0.46	9.02	0.51	89°	63	1.63	1.05	0.20
f/82-26/2 l imprint	The same	38.87	–	–	–	–	–	–	–	–	89°	72	1.85	1.22	0.24

rchuna, Molodo, Markha, Tyung, and Vilyui rivers, in boreholes drilled within the Vilyui syneclise).

On the basis of this sequence, an oxytomid-based biochronological scale for the upper Toarcian–lower Aalenian is proposed. Index species representing the segments of the phylogenetic line of the genus *Arctotis* Bodylevsky, 1960 characterize the subdivisions of the scale—oxyto-zones. Four oxyto-zones have been identified for the Toarcian–lower Aalenian sections, which can be used for biostratigraphic correlation and chronological indexing of geological events along with ammonites: Praearctotis milovae oxyto-zone (=Zugodactylites braunianus Zone and Pseudolioceras compactile Zone), Praearctotis marchaensis oxyto-zone (=Pseudolioceras wuerttenbergeri Zone), Praearctotis similis oxyto-zone (=Pseudolioceras falcodiscus Zone), Arctotis tabagensis oxyto-zone (=Pseudolioceras maclintocki Zone). Using this scale, we have performed the regional correlation of the Toarcian–Aalenian sections of Eastern Siberia, northeastern Russia, and the Russian Far East.

In addition, the scale was correlated with the adopted ammonite scales (*Reshenie*..., 2004; *Resheniya*..., 2009). This scale is considered parallel to the existing bivalve-based stratigraphic scales (Repin and Polubotko, 2004; Shurygin et al., 2011).

ACKNOWLEDGMENTS

I want to express gratitude to my colleagues, having participated in joint fieldworks, V.P. Devyatov (Siberian Research Institute of Geology, Geophysics, and Mineral Raw Materials, Novosibirsk), V.G. Knyazev (Diamond and Precious Metal Geology Institute, Siberian Branch of Russian Academy of Sciences, Yakutsk), and I.V. Sapyanik (Siberian Research Institute of Geology, Geophysics, and Mineral Raw Materials, Novosibirsk), who kindly provided the additional material on the lithological and paleontological characteristics of the sections.

I am grateful to Yu.S. Repin (All-Russian Petroleum Research Exploration Institute, St. Petersburg) and M.A. Rogov (Geological Institute, Russian Academy of Sciences, Moscow) for essential consultations during the preparation of this work and B.N. Shurygin (Institute of Petroleum Geology and Geophysics, Siberian Branch, Russian Academy of Sciences, Novosibirsk), A.S. Biakov (North-East Interdisciplinary Scientific Research Institute, Far Eastern Branch, Russian Academy of Sciences, Magadan), and V.S. Vishnevskaya and Yu.B. Gladenkov (Geological Institute, Russian Academy of Sciences, Moscow) for some valuable comments and recommendations that helped to improve the manuscript.

I want to express my sincere gratitude to all the specialists listed for their help in preparing the manuscript.

I want to express my special gratitude to my scientific supervisor V.A. Zakharov (Geological Institute, Russian Academy of Sciences, Moscow) for the essential advice during the research and the preparation of this article.

FUNDING

This work was performed within the framework of state assignment of the Geological Institute, Russian Academy of Sciences, supported by the Russian Foundation for Basic Research and National Center for Scientific Research of France within the framework of research project no. 21-55-15015.

Reviewers A.S. Biakov, V.S. Vishnevskaya, and B.N. Shurygin

REFERENCES

Atlas rukovodyashchikh form iskopaemykh faun SSSR. T. 8. Nizhnii i srednii otdely yurskoi sistemy (Atlas of Index Forms of Fossil Faunas of the USSR. Vol. 8: Lower and Middle Jurassic), Moscow–Leningrad: Gosgeolizdat, 1947 [in Russian].

Bodylevsky, V.I., On the stratigraphy of Mesozoic deposits of the Anabar–Khatanga area, *Probl. Arktiki*, 1939, nos. 10–11, pp. 65–67.

Bodylevsky, V.I., Controversial issues of stratigraphy of Jurassic and Cretaceous deposits of the Soviet Arctic, in *Tr. Mezhved. soveshch. po razrabotke unifitsirovannykh stratigraficheskikh skhem Sibiri 1956 g.* (Proc. Interdepart. Conf. on Development of Unified Stratigr. Schemes of Siberia, 1956), Leningrad: Gos. Nauchno-Tekhn. Izd. Neft. Gorno-Toplivn. Liter., 1957, pp. 92–98.

Bodylevsky, V.I., A new Late Jurassic representative of Aviculopectinidae in Taimyr, in *Novye vidy drevnikh rastenii i bespozvonochnykh SSSR. Ch. 2* (New Species of Ancient Plants and Invertebrates of the USSR. Pt. 2), Moscow: Gosgeoltekhizdat, 1960, pp. 44–45.

Chernykh, V.V., *Osnovy zonal'noi biokhronologii* (Foundations of Zonal Biochronology), Ekaterinburg: Inst. Geol. Geokhim. Ural. Otd. Ross. Akad. Nauk, 2016 [in Russian].

Crame, J.A., New Late Jurassic oxytomid bivalves from the Antarctic Peninsula region, *British Antarctic Surv. Bull.*, 1985, no. 69, pp. 35–55.

Crame, J.A., Pirrie, D., Crampton, J.P., and Duante, A.M., Stratigraphy and regional significance of the Upper Jurassic–Lower Cretaceous Byers Group, Livingston Island, Antarctica, *J. Geol. Soc. London*, 1993, vol. 50, pp. 1075–1087.

Damborenea, S.E., Circum-Pacific correlation of Argentine Early and Middle Jurassic bivalve zones, in *Proc. 3rd. Int. Symp. Jurassic Stratigr., Poitiers, 1991*, Cariou, E. and Hanztpercgue, P., Eds., *Geobios*, 1994, vol. 27, pp. 141–147.

Damborenea, S.E., Echevarría, J., and Ros-Franch, S., *Southern Hemisphere Palaeobiogeography of Triassic-Jurassic Marine Bivalves*, Dordrecht: Springer, 2013.

Darwin, Ch., *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*, London, 1872.

Dean, W., Donovan, D., and Howarth, M., Liassic ammonite zones and subzones of the North-West Province, *Bull. Brit. Mus. (Nat. Hist.) Geol.*, 1961, vol. 4, no. 10, pp. 438–498.

Elmi, S., Rulleau, I., Gabilly, I., and Mouterde, R., Toarcien, in Biostratigraphie du Jurassiquc Oucstcuropecn et Meditcrraneen: Zonations Paralleles et Distribution des Invertebres et Microfossiles, *Bull. Cent. Rech. Elf Explor. Prod.*, 1997, vol. 17, pp. 25–36.

Howarth, M., *The Ammonite Family Hildoceratidae in the Lower Jurassic of Britain*, London: Monogr. Palaeontograph. Soc., 1992.

Kirina, T.I., Stratigraphy of Lower Jurassic deposits of western part of the Vilyui syneclise, in *Tr. VNIGRI. Vyp. 249* (Trans. All-Russ. Petrol. Res. Explor. Inst. Vol. 249), Leningrad: Nedra, 1966, pp. 18–71.

Knyazev, V.G., Toarcian Harpoceratinae from the north of the Asian USSR, in *Detal'naya stratigrafiya i paleontologiya yury i mela Sibiri* (Detailed Stratigraphy and Paleontology of Jurassic and Cretaceous of Siberia), Novosibirsk: Nauka, 1991, pp. 37–46.

Knyazev, V.G., Devyatov, V.P., and Shurygin, B.N., *Stratigrafiya i paleogeografiya rannei yury vostoka Sibirskoi platformy* (Lower Jurassic Stratigraphy and Paleogeography of the East Siberian Platform), Yakutsk: Yakutsk. Nauchn. Tsentr Sib. Otd. Ross. Akad. Nauk, 1991 [in Russian].

Knyazev, V.G., Kutygin, R.V., Devyatov, V.P., Nikitenko, B.L., and Shurygin, B.N., *Zonal'nyi standart toarskogo yarusa Severo-Vostoka aziatskoi chasti Rossii* (The Zonal Standard of the Toarcian Stage of the Northeastern Asia), Yakutsk: Izd. Sib. Otd. Ross. Akad. Nauk, 2003 [in Russian]

Knyazev, V.G., Devyatov V.P., and Mel'nik, O.A., The reference section of the Aalenian and the Lower Bajocian stages of Eastern Siberia (Molodo River basin), *Otech. Geol.*, 2007a, no. 5, pp. 39–42.

Knyazev, V.G., Kutygin, R.T., and Mel'nik, A.O., A Toarcian–Early Bajocian biochronological scale for northeastern Asia, based on Harpoceratinae (Ammonoidea), in *Voprosy stratigrafii, paleontologii i paleogeografii (posvyashch. 100-letiyu so dnya rozhd. G.Ya. Krymgol'tsa)* (Problems of Stratigraphy, Paleontology, and Paleogeography (Devoted to the 100th Anniversary of G.Ya. Krymgol'ts), St. Petersburg: Sankt-Peterburg. Gos, Univ., 2007b, pp. 77–91.

Koshelkina, Z.V., Stratigraphy and bivalves of the Jurassic deposits of the Vilyui Syneclise and Cis-Verkhoyansk Foredeep, in *Tr. SVKNII* (Trans. Shilo North-East Interdisciplinary Sci. Res. Inst. FEB RAS), 1963, vol. 5.

Krassilov, V.A., *Evolyutsiya i biostratigrafiya* (Evolution and Biostratigraphy), Moscow: Nauka, 1977 [in Russian].

Krymgol'ts, G.Ya., Petrova, G.T., and Pchelintsev, V.F., Stratigraphy and fauna of the Mesozoic marine deposits of North Siberia, in *Tr. NIIGA. T. XLV* (Tr. Nauchno-Issled. Inst. Geol. Arkt., Vol. XLV), Moscow–Leningrad: Izd. Glavsevmorputi, 1953.

Lutikov, O.A. and Arp, G., A Lower Toarcian biochronological scale based on bivalve mollusks of the family Oxytomidae Ichikawa, 1958, in *Mater. VIII Vseross. soveshch. s mezhd. uchastiem "Yurskaya sistema Rossii: problemy stratigrafii i paleogeografii". Onlain-konf., 7-10 sentyabrya 2020 g.* (Proc. VIII All-Russ. Conf. with Int. Participation "Jurassic System of Russia: Problems of Stratigraphy and Paleogeography," September 7–10, 2020), Zakharov, V.A., Ed., Syktyvkar: Inst. Geol. Komi Naucn. Tsentra Ural. Otd. Ross. Akad. Nauk, 2020, pp. 132–141.

Lutikov, O.A. and Shurygin, B.N., New data on systematics of Jurassic and Cretaceous bivalve mollusks of the family Oxytomidae Ichikawa, 1958, *News Paleontol. Stratigr.*, 2010, vol. 14, pp. 111–140.

Lutikov, O.A., Temkin, I.E., and Shurygin, B.N., Phylogeny and evolution of ontogeny of the family Oxytomidae Ichikawa, 1958 (Mollusca: Bivalvia), *Stratigr. Geol. Correl.*, 2010, vol. 18, no. 4, pp. 376–391.

Mayr, E., *Principles of Systematic Zoology*, New York: McGraw-Hill, 1969.

Meledina, S.V., The Toarcian zonal scale in Northern Siberia, *Russ. Geol. Geophys.*, 2000, vol. 41, no. 7, pp. 952–960.

Meledina, S.V. and Shurygin, B.N., The Aalenian Stage (Middle Jurassic) of East Siberia: Zonation, index bivalves and ammonoids, *Russ. Geol. Geophys.*, 2000, vol. 41, nos. 2–3, pp. 73–85.

Okuneva, T.M., Jurassic system. Lower and Middle Divisions. Marine Deposits and mollusks, in *Atlas fauny i flory paleozoya i mezozoya Zabaikal'ya* (Atlas of the Fauna and Flora of the Paleozoic–Mesozoic of Transbaikalia), Novosibirsk: Nauka, Sib. Izd. Firma Ross. Akad. Nauk, 2002, pp. 354–387.

Pchelintsev, V.F., Upper Lias fauna of Caucasus, *Tr. Vsesoyuz. geologo-razved. obshch.*, 1933, vol. 253.

Polevoi atlas yurskoi fauny i flory Severo-Vostoka SSSR (Field Atlas of the Jurassic Fauna and Flora of the Northeastern USSR), Efimova, A.F., Kinasov, V.P., Paraketsov, K.V., Eds., Magadan: Magad. Knizhn. Izd., 1968 [in Russian].

Polubotko, I.V., Inoceram bivalves of the Lower and Middle Jurassic of the North-East of USSR and Northern Siberia, in *Atlas rukovodyashchikh grupp fauny mezozoya Yuga i Vostoka SSSR* (Atlas of the Leading Groups of the Mesozoic Fauna of the South and East of the USSR), St. Petersburg: Nedra, 1992.

Polubotko, I.V. and Repin, Yu.S., The problem of Upper Toarcian in northeastern Asia, in *Geologicheskaya istoriya Arktiki v mezozoe i kainozoe* (Geological History of the Arctic in Mesozoic and Cenozoic), St. Petersburg: VNIIOkeanologiya, 1992, pp. 41–48.

Polubotko, I.V. and Repin, Yu.S., Zonal subdivision and correlation of Toarcian and Aalenian deposits of Northern Siberia and northeastern Russia, in *Zonal'nye podrazdeleniya i mezhregional'naya korrelyatsiya paleozoiskikh i mezozoiskikh otlozhenii Rossii i sopredel'nykh territorii. Kn. 2. Mezozoi* (Zonal Subdivisions and Interregional Correlation of Paleozoic and Mesozoic Deposits of Russia and Adjacent Areas. Book 2: Mesozoic), St. Petersburg: Vseross. Nauchno-Issled. Geol. Inst., 1994, pp. 51–78.

Repin, Yu.S., Lower Jurassic ammonite geologic time scale of Northeast Asia, *Neftegaz. Geol. Teor. Prakt.*, 2016, vol. 11, no. 4, pp. 1–45.

Repin, Yu.S., Biostratigraphic boundaries of divisions of the Jurassic, *Neftegaz. Geol. Teor. Prakt.*, 2020, vol. 15, no. 1, pp. 1–33.

Repin, Yu.S., Genus *Pseudolioceras* Buckman (Ammonoidea) of Arctic Jurassic area, *Neftegaz. Geol. Teor. Prakt.*, 2017, vol. 11, no. 4, pp. 1–46.

Repin, Yu.S. and Polubotko, I.V., Zonal division of the Upper Toarcian in the north-east of Russia, *Stratigr. Geol. Correl.*, 1993, vol. 1, no. 1, pp. 109–117.

Repin, Yu.S. and Polubotko, I.V., Toarcian biochronology of Arctic paleozoohoria, in *Stratigrafiya neftegazonosnykh basseinov Rossii* (Stratigraphy of Petroleum Basins of Russia), St. Petersburg: Nedra, 2004, pp. 93–124.

Repin, Yu.S. and Polubotko, I.V., Jurassic stratigraphic section of Northern Priokhot'e: Stratigraphy, lithology, *Neftegaz. Geol. Teor. Prakt.*, 2015, vol. 10, no. 4, pp. 1–42.

Reshenie 6-go Mezhvedomstvennogo stratigraficheskogo soveshchaniya po rassmotreniyu i prinyatiyu utochnennykh stratigraficheskikh skhem mezozoiskikh otlozhenii Zapadnoi Sibiri (Resolution of the 6th Interdepartmental Stratigraphic Conference on Considering and Adopting the Stratigraphic Refined Schemes of Mesozoic Deposits of Western Siberia), Gurari, F.G., Ed., Novosibirsk: Sib. Nauchno-Issled. Inst. Geol., Geofiz., Miner. Syr'ya, 2004 [in Russian].

Resheniya 3-go Mezhvedomstvennogo regional'nogo stratigraficheskogo soveshchaniya po dokembriyu, paleozoyu i mezozoyu Severo-Vostoka Rossii, Sankt-Peterburg, 2002 (Resolution of the 3rd Interdepartmental Regional Stratigraphic Conferences on Precambrian, Paleozoic, and Mesozoic of Northeastern Russia. St. Petersburg, 2002), St. Petersburg: Vseross. Nauchno-Issled. Geol. Inst., 2009 [in Russian].

Resheniya 4-go Mezhvedomstvennogo regional'nogo stratigraficheskogo soveshchaniya po dokembriyu i fanerozoyu yuga Dal'nego Vostoka i Vostochnogo Zabaikal'ya (Resolution of the 4th Interdepartmental Stratigraphical Meeting on the Precambrian and Phanerozoic of the Southern Far East and Eastern Transbaikalia, Khabarovsk, 1990), Turbin, M.T., Ed., Khabarovsk: Khabarovsk. Gos. Gorno-Geol. Predpr, 1994.

Resheniya i trudy 3-go Mezhvedomstvennogo regional'nogo stratigraficheskogo soveshchaniya po mezozoyu i kainozoyu Srednei Sibiri (Resolution and Processions of the III Interdepartmental Regional Stratigraphic Conference on Mesozoic and Cenozoic of Central Siberia), Novosibirsk: Sib. Nauchno-Issled. Inst. Geol. Geofiz. Miner. Syr'ya, 1981 [in Russian].

Riccardi, A.C., Damborenea, S.E., Mancenido, M.O., and Leanza, H.A., Megainvertebrados del Jurásico y su importancia geobiológica, in *Proc. XVIII Congreso Geologico Argentino. Geologia y Recursos Minerales de la Provincia del Neuquen*, Leanza, H.A. et al., Eds., 2011, pp. 441–464.

Ruzhentsev, V.E., Principles of systematics, system, and phylogeny of Paleozoic ammonoids, in *Tr. Paleontol. Inst. Akad. Nauk SSSR* (Trans. Paleontol. Inst. Russ. Acad. Sci.), 1960, vol. 83.

Shurygin, B.N., Stratigraphic volume and position of Lower and Middle Jurassic in Northern Siberia based on bivalve mollusks, *Russ. Geol. Geophys.*, 1987, no. 11, pp. 3–11.

Shurygin, B.N., Nikitenko, B.L., Devyatov, V.P., Il'ina, V.I., Meledina, S.V., Gaideburova, E.A., Dzyuba, O.S., Kazakov, A.M., and Mogucheva, N.K., *Stratigrafiya neftegazonosnykh basseinov Sibiri. Yurskaya sistema* (The Stratigraphy of Oil and Gas Basins of Siberia. Jurassic System), Novosibirsk: Izd. Sib. Otd. Ross. Akad. Nauk, 2000 [in Russian].

Shurygin, B.N., Devyatov, V.P., Zakharov, V.A., Knyazev, V.G., Il'ina, V.I., Meledina, S.V., Nikitenko, B.L., and Grinenko, V.S., Jurassic stratigraphy of Eastern Siberia (the state of knowledge, the main problems and ways of their solution), *Vestn. Goskomgeol.: Mater. Geol. Polezn. Iskop. Resp. Sakha (Yakutiya)*, 2001, no. 1, pp. 112–139.

Shurygin, B.N., Nikitenko, B.L., Meledina, S.V., Dzyuba, O.S., and Knyazev, V.G., Comprehensive zonal subdivisions of Siberian Jurassic and their significance for Circum-Arctic correlations, *Russ. Geol. Geophys.*, 2011, vol. 52, no. 8, pp. 825–844.

Simpson, G.G., *Principles of Animal Taxonomy*, New York: Columbia Univ. Press, 1961.

Stepanov, D.L. and Mesezhnikov, M.S., *Obshchaya stratigrafiya (Printsipy i metody stratigraficheskikh issledovanii)* (General Stratigraphy (Principles and Methods of Stratigraphic Studies)), Leningrad: Nedra, 1979 [in Russian].

Stratigrafiya yurskoi sistemy severa SSSR (Stratigraphy of Jurassic System of the Northern USSR), Moscow: Nauka, 1976 [in Russian].

Velikzhanina, L.S., Representatives of genera *Meleagrinella* and *Arctotis* from the Lower Jurassic of Western Siberia, in *Geologiya i neftegazonosnost' Zapadnoi Yakutii* (Geology and the Petroleum Potential of Western Siberia), Leningrad: Nedra, 1966, pp. 80–120.

Wierzbowski, A., Kulicki, C., and Pugaczewska, H., Fauna and stratigraphy of the uppermost Triassic and the Toarcian and Aalenian deposits in the Sassenfjorden, Spitsbergen, *Acta Palaeontol. Polon.*, 1981, vol. 26, pp. 195–241.

Zakharov, V.A., The concept of population in the paleontology of marine invertebrates, *Biol. Morya*, 1975, no. 3, pp. 3–12.

Zakharov, V.A. and Shurygin, B.N., *Biogeografiya, fatsii i stratigrafiya srednei yury Sovetskoi Arktiki (po dvustvorchatym mollyuskam)* (Biogeography, Facies, and Stratigraphy of the Middle Jurassic of the Soviet Arctic), Novosibirsk: Nauka, 1978 [in Russian].

Zakharov, V.A. and Yudovny, E.G., Principles of layer-by-layer correlation of the rhythmic terrigenous sections (on example of the Neocomian of the Boyarka River reference section, Khatanga depression), in *Problemy paleontologicheskogo obosnovaniya detal'noi stratigrafii mezozoya Sibiri i Dal'nego Vostoka. K Mezhdunarodnomu kollokviumu po yurskoi sisteme (Lyuksemburg, iyul', 1967 g.)* (Problems of Paleontological Substantiation of Detailed Stratigraphy of Siberia and Far East. To International Colloquim in Luxembourg, July 1967), Leningrad: Nauka, 1967, pp. 28–40.

Zakharov, V.A., Bogomolov, Yu.I., Il'ina, V.I., Konstantinov, A.G., Kurushin, N.I., Lebedeva, N.K., Meledina, S.V., Nikitenko, B.L., Sobolev, E.S., and Shurygin, B.N., Boreal zonal standard and biostratigraphy of the Siberian Mesozoic, *Russ. Geol. Geophys.*, 1997, vol. 38, no. 5, pp. 965–993.

Zony yurskoi sistemy v SSSR (Zones of the Jurassic System in the USSR), Krymgol'ts, G.Ya., Ed., Leningrad: Nauka, 1982 [in Russian].

Translated by D. Voroshchuk