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A Boreal Toarcian Biochronological Zonation Based on Bivalve Mollusks of the Genus *Meleagrinella* Whitfield, 1885

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Abstract—Using the chronological sequence of species of the genus *Meleagrinella* Whitfield, 1885 (family Oxytomidae Ichikawa, 1958) established in the Toarcian deposits of Northeast Russia, eastern Siberia, and southern Germany, a biochronological zonation is proposed for the Lower Toarcian. Three oxyto-zones corresponding to zones of the Boreal Ammonite Scale are established: Meleagrinella golberti oxyto-zone = Tiltoniceras antiquum and Harpoceras falciferum zones; Meleagrinella substriata oxyto-zone = Dactylioceras commune Zone; Meleagrinella prima oxyto-zone = Zugodactylites braunianus and Pseudolioceras compactile zones. Using the proposed zonation, an interregional correlation of sections of the Lower Toarcian of Northern Russia (Astronomicheskaya, Saturn, Brodnaya, Start rivers), eastern Siberia (Anabar Bay, Markha, Tyung, Vilyui, Kelimyar, Motorchuna river, and boreholes in the Vilyui Syneclise) and southern Germany (the Ludwig Canal) is performed.

Keywords: Jurassic, Lower Toarcian, Suntar Formation, Eren Formation, Kiterbyut Formation, Start Formation, biochronological scale, eastern Siberia, northeastern Russia, Posidonienschiefer Formation, Germany

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INTRODUCTION

Early Toarcian deposits are widespread in the Northern Hemisphere and are clearly recognizable in Jurassic sections by their uniform clay composition and characteristic fossil assemblages (Knyazev et al., 2003). A detailed study of the change in the composition of rocks from the Pliensbachian to the Toarcian in the sections of Northwestern Europe showed that the change of shallow-water sediments to deep-water deposits can be traced over a large area and occurs within one or two ammonite zones (Hallam, 1975). The hypothesis of eustatic sea level rise and global transgression at the beginning of the Toarcian logically explains this phenomenon. The Early Toarcian transgression was significant, following the regression at the end of the Pliensbachian, and flooded areas in both the Northern and Southern Hemispheres (Hallam, 1983). At the boundary of the Pliensbachian and the Toarcian in the sections of northern Russia, in the sedimentation pattern, there is a rapid change in the depositional settings of the shallow sea close to the coast to the environment of a wide deepened shelf (Shurygin, 2005). Therefore, as a rule, the boundary of the formations is confined to this level (Devyatov and Kazakov, 1985; Repin and Polubotko, 1996, etc.). The transition occurs abruptly, bypassing intermediate settings (Zakharov, 1994; Repin and Polubotko, 2004; Zakharov et al., 2006). The parallelization of the regional horizons of Eastern Siberia and the North-East of Russia with the stages of the International Stratigraphic Scale (ISS) is mainly achieved by correlating ammonite zones. The global correlation of the upper part of the Pliensbachian sections with the ISC units is problematic due to the difference in the ammonite fauna in northeastern Asia (Repin, 1974; Dagis, 1976; Meledina and Shurygin, 2001) and in Western Europe (Page, 2003). The complete endemism of species of the terminal phase of the Pliensbachian necessitated the recognition of a local Amaltheus viligaensis Zone for Northeast Asia (Dagys, 1976). Despite the good recognition of Early Toarcian predominantly argillaceous deposits in sections, the correlation of the lower part of the Toarcian is complicated by the different range of biozones in the key ammonite species in Northeast Asia and Europe. In northwestern Europe, the base of the Toarcian is usually paced at the base of the tenuicostatum Zone (Buckman, 1910), which is recognized by the first mass appearance of *Dactylioceras* after the disappearance of *Pleuroceras* (Elmi et al., 1997; Page, 2003). In the global stratotype of the lower boundary of the Toarcian (GSSP) on the Peniche Peninsula (Portugal), the Pliensbachian–Toarcian boundary is drawn by the appearance of the ammonites *Dactylioceras (Eodactylites) simplex* (Fucini) in association with *Protogrammoceras (Paltarpites)* cf. *paltum* (Buckman) and *Tiltoniceras* aff. *capillatum* (Denckmann). This level correlates with the Protogrammoceras paltum biohorizon at the base of the Toarcian of northwestern Europe (Rocha et al., 2016). In northwestern Europe the first *Tiltoniceras* appear in the section above the base of the Toarcian. In Germany, the horizon with Tiltoniceras capillatum correlates with the upper half of the Dactylioceras tenuicostatum Zone (Hoffmann, 1968). In Spain, England, and France, the Tiltoniceras antiquum Biohorizon corresponds to the upper half of the Dactylioceras semicelatum subzone (Elmi et al., 1997; Page, 2003). In northeastern Russia, in the sections of the Astronomicheskaya and Brodnaya rivers, between the Late Pliensbachian *Amaltheus extremus* Repin, *Amaltheus viligaensis* (Tuchkov) and the Toarcian *Tiltoniceras antiquum* (Wright), there is an interval without ammonites, which, according to some sources, is about 2–3 m thick (Dagys, A.A. and Dagys, A.S., 1965; Dagys, 1968, 1974), according to others, about 1 m thick (Knyazev et al., 2003).

Most Russian experts draw the boundary between the Pliensbachian and the Toarcian by the disappearance of species of the genus *Amaltheus* and the appearance of species of the genus *Tiltoniceras* (Dagys, 1974; Meledina, 2000; Knyazev et al., 2003). In the zonation scheme proposed by Repin (2016), the lower boundary of the Toarcian is drawn above the appearance of the endemic species *Lioceratoides asiaticus* Repin. In eastern Siberia, due to the absence of finds of ammonites from the lower zone of the Toarcian, a regional hiatus was assumed at the boundary between the Pliensbachian and Toarcian (*Resheniya*..., 1981).

Russian specialists have been developing and improving zonal ammonite scales for more than 50 years for the geological correlation of the Early Toarcian deposits of Eastern Siberia and the North-East of Russia (Saks, 1962; Tuchkov, 1962; Dagys, 1968, 1974; Zakharov et al., 1997; Knyazev et al., 2003; Shurygin et al., 2011; Repin, 2016, etc.). Two zonal ammonite scales for the Toarcian were ratified by interdepartmental regional stratigraphic meetings for these territories (*Reshenie*..., 2004; *Resheniya*..., 2009). In the Lower Toarcian scales, ranges of the zones and their correlation with the ISS zonation are almost identical. There are only disagreements in interpretation of the status and nomenclature of some zones, as well as the degree of detail of subzones and beds with ammonites. In contrast, the Upper Toarcian scales are fundamentally different both in the ranges and in the nomenclature of zones. The correlation of modern ammonite scales of the Lower Toarcian and the lower zone of the Upper Toarcian of northeastern Asia with the zonation schemes of Western Europe are shown in Fig. 1.

In parallel to ammonite biostratigraphy, zonation schemes for other fossils, including those for bivalves, were developed for the Lower Jurassic. Current bivalve scales for the Toarcian of Eastern Siberia and Northeast Russia are based on successions of taxa belonging to different families and are used independently in both regions (Repin and Polubotko, 2004; Shurygin et al., 2011) (Fig. 1).

One of the most widespread groups of Toarcian bivalves is the family Oxytomidae Ichikawa, 1958. For some stratigraphic intervals, representatives of oxytomids dominate in oryctocenoses. This was used as the basis for the Boreal scale by bivalves that uses the succession of taxa belonging to the same family.

In the Regional Stratigraphic Scheme of the Jurassic deposits of the North-East of Russia, adopted at the 3rd Interdepartmental Regional Stratigraphic Conference on the Precambrian, Paleozoic and Mesozoic of the northeastern Russia (St. Petersburg, 2002), the Meleagrinella ex gr. substriata, Kedonella mytileformis Zone, which correlates with the Tiltoniceras antiquum and Harpoceras falciferum ammonite zones. In the part of the ammonite scale corresponding to the Dactylioceras commune, Zugodactylites braunianus, Peronoceras spinatum, and Pseudolioceras rosenkrantzi zones, the species *Meleagrinella faminaestriata* Polubotko is included in the characteristic assemblages (*Resheniya*..., 2009). In the Omolon stratigraphic area, *Meleagrinella* ex gr. *substriata* (Münster) characterizes the Start Formation and the Chirok Bed, the species *Meleagrinella faminaestriata* Polubotko is the marker species of the Chingandzha and Exa formations. In the Kobyume-Viliga stratigraphic area, *Meleagrinella* cf. *substriata* is reported from a sequence belonging to the Upper Triassic–Lower Jurassic Tikass Group. In the Arman-Viliga stratigraphic area, the species *Meleagrinella faminaestriata* characterizes the Columbiyskaya and Zazor formations (Nekrasov, 1976; *Resheniya*..., 1978, 2009; Repin and Polubotko, 1996) (Fig. 2).

Beds with Meleagrinella faminaestriata were recognized in the bivalve zonal scale of the Regional Stratigraphic Scheme of the Lower and Middle Jurassic of Western Siberia, adopted at the 6th Interdepartmental Regional Stratigraphic Meeting for Revision and Adoption of Stratigraphic Schemes of the Mesozoic in Western Siberia (Novosibirsk, 2003). The lower boundary of the beds is drawn within the Dactylioceras commune Zone. The beds correspond to the Dactylioceras commune (terminal part) ammonite zone, Zugodactylites braunianus and Pseudolioceras compactile ammonite zones (*Resheniya*..., 2004) and are traced to Eastern Siberia (Shurygin et al., 2000). In the Lena–Anabar structural-facies subregion, *Melea-*

Ammonite Subboreal standard scale (northern Great Britain)			Ammonite zonal scale in Germany		Ammonite zonal scale in northeastern Russia			Ammonite Boreal zonal standard scale		Bivalve zonal scales in northeastern Russia		Oxytomid Boreal biochronological scale
Howarth, 1992; Page, 2003			Riegrafet al., 1984; Knitter and Ohmert, 1983		Repin, 2016		Knyazev et al., 2003	Zakharv et al., 1997 Shurygin et. al., 2011		Repin and Polubotko, 2004	Shurygin et al., 2011	This study
Chronozone	Subchronolozone	Biohorizon	Zone	Subzone	Zone	Subzone, beds*	Zone	Zone	Subzone	Zone, beds*	*b*-zone, beds*	Oxyto-zone
Haugia variabilis	Haugia vitiosa	vitiosa	Haugia variabilis	Haugia vitiosa	Peronoceras spinatum		Pseudolioceras compactile	Pseudolioceras compactile		Pseudomytiloides marchaensis	Pseudomytiloides marchaensis	Meleagrinella prima
	Haugia illustris	phillipsi		Haugia illustris								
		illustris										
	Haugia variabilis	jugosa		Haugia variabilis						*Vaugonia* literata*		
		navis										
Hildoceras bifrons	Catacoeloceras crassum	crassum-semipolitum	Hildoceras bifrons	Catacoeloceras crassum	Zugodactilites braunianus		Pseudolioceras lythense	Zugodactilites braunianus	Porpoceras spinatum	Pseudomytiloides marati	*Meleagrinella faminaestriata*	
		crassum-bifrons										
	Peronoceras fibulatum	vortex		Peronoceras fibulatum					Zugodactilites monestieri			
		braunianus				*Osperlioceras* startense*						
		turriculatum										
	Dactylioceras commune	athleticum		Dactylioceras commune	Dactylioceras commune	*Hildaites* grandis*	Harpoceras subplanatum	Dactylioceras commune		Kedonella dagisi		Meleagrinella substriata
		commune										
		ovatum										
Harpoceras serpentinum	Harpoceras falciferum	falciferum	Harpoceras falciferum	Harpoceras falciferum	Harpoceras falciferum	Harpoceras falciferum	Harpoceras falciferum	Harpoceras falciferum	Harpoceras falciferum	Meleagrinella ex gr. substriata, Kedonella mytileformis	Dacryomya inflata, Tancredia bicarinata	Meleagrinella golberti
		pseudoserpentinium										
	Cleviceras exaratum	elegans		Harpoceras elegans		Cleviceras exaratum	Harpoceras exaratum		Harpoceras exaratum			
		exaratum		Harpoceras exaratum								
		elegantulum		Eleganticeras elegantulum	Eleganticeras elegantulum		Eleganticeras elegantulum		Eleganticeras elegantulum			
Dactylioceras tenuicostatum	Dactylioceras semicelatum	antiquum	Dactylioceras tenuicostatum	Dactylioceras semicelatum	Tiltoniceras antiquum	*Platyphylloceras* kedonicum*	Tiltoniceras antiquum	Tiltoniceras antiquum			*Corbulomima* sp.*	
		semicelatum										
	Dactylioceras tenuicostatum	tenuicostatum				*Arctomercaticeras* costatum*						
	Dactylioceras clevelandicum	clevelandicum		Dactylioceras clevelandicum		*Nodicoeloceras* compactum*						
		crosbeyi										
	Protogrammoceras paltum	paltum		Protogrammoceras paltum		*Lioceratoides* asiaticus*						

Fig. 1. Correlation of ammonite and bivalve zonation schemes of the Lower Toarcian of Western Europe, the Mediterranean, and Northeast Asia.

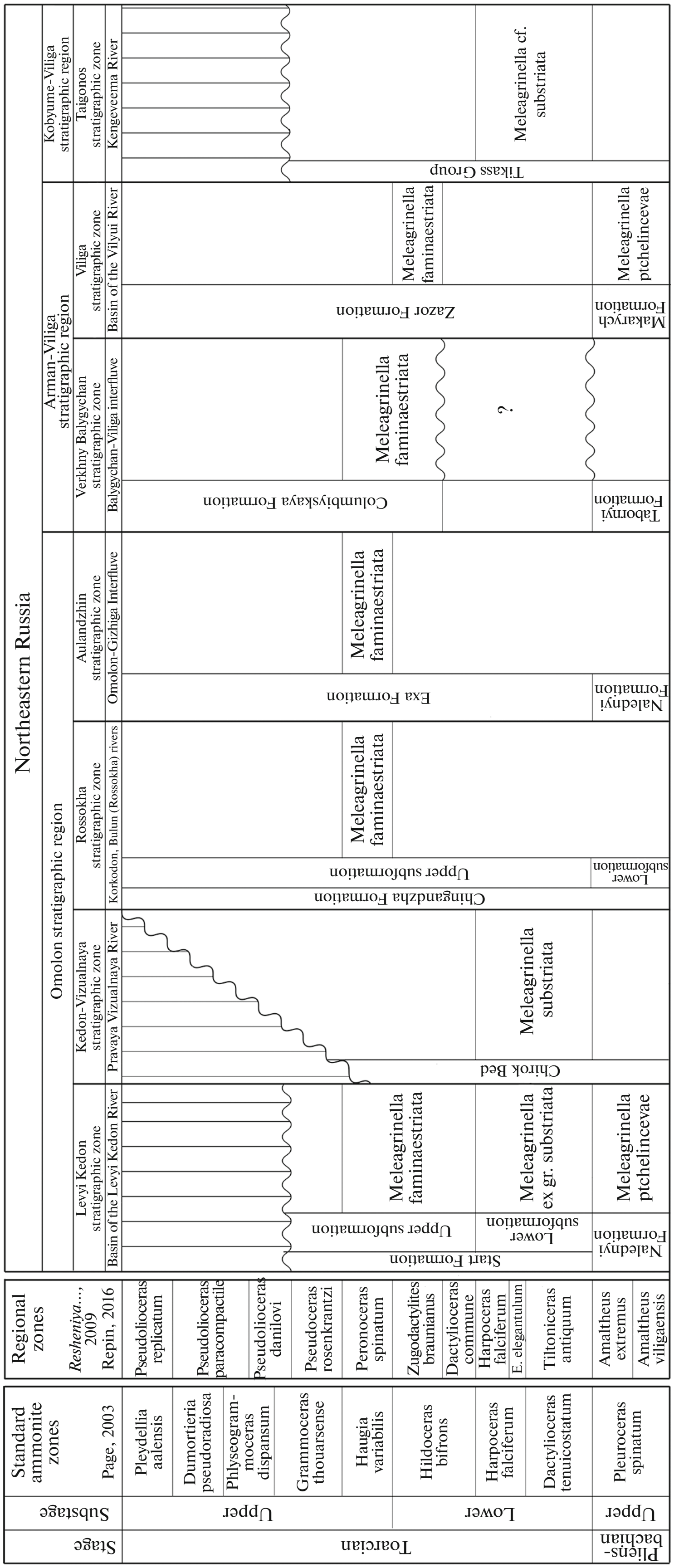

Fig. 2. Distribution and stratigraphic range of species belonging to the genus *Meleagrinella* in the Lower Toarcian in northeastern Russia (according to Nekrasov, 1976; Milova, 1980; *Resheniya*..., 2009).

grinella cf. *substriata* was reported from the Airkat Formation (*Stratigrafiya*..., 1976) and from the lower part of the Kelimyar Formation (Knyazev et al., 1984), while *Meleagrinella faminaestriata* was recorded from the Eren Formation (Nikitenko et al., 2013). In the Vilyuy structural-facies subregion, *Meleagrinella substriata* was reported from the lower part of the Suntar Formation, while *Meleagrinella faminaestriata* was recorded from the middle part of the Suntar Formation (Knyazev et al., 1991, 2003). In the Vilyuy structural-facies subregion, *Meleagrinella substriata* was found in the lower part of the Suntar Formation (Knyazev et al., 1991). In the Priverkhoyansk structural-facies subregion, *Meleagrinella substriata* was found in the lower parts of the Suntar Formation (Knyazev et al., 1991). In the Ob-Taz facies region, the species *Meleagrinella* cf. *substriata* characterizes the clay member of the lower subformation of the Kotukhta Formation (age equivalent of the Togur Formation) (Shurygin et al., 2000). In the Yamal-Gydan facies region, *Meleagrinella substriata* is known from the Kiterbyut Formation (Bodylevsky and Shulgina, 1958). Beds with *Meleagrinella faminaestriata* were recognized in the Nadoyakh Formation (Shurygin et al., 2000) (Fig. 3).

In Germany and England, *Meleagrinella substriata* was recorded from all three lower Toarcian ammonite zones (Hoffmann and Martin, 1960; Urlichs, 1971; Caswell et al., 2009).

As ammonites are rare in the Toarcian of Eastern Siberia, it is difficult to use ammonite scales for subdividing and correlating both natural outcrops and sections examined in boreholes. The study of extensive collections of bivalves collected by O.A. Lutikov and G. Arp in sections of the Toarcian of Russia and Germany, as well as revision of taxa belonging to the genus *Meleagrinella* Whitfield, 1885 was the basis for the development of a zonation scheme for bivalves, allowing detailed interregional correlation (Lutikov, Arp, in press). The first version of the Lower Toarcian bivalve scale using periodization of the stages of morphogenesis of the external shell morphology in *Meleagrinella substriata*, was presented at the VIII All-Russian meeting "Jurassic system of Russia: problems of stratigraphy and paleogeography" (Lutikov and Arp, 2020a, 2020b).

In 2022, the present authors obtained new information on the structure of the ligament plate in the syntype of *Meleagrinella substriata* from the type collection, as well as studied the ontogeny of the ligament plate and microsculpture of ostracum in the East Siberian "*Meleagrinella faminaestriata*" (=*Meleagrinella prima* sp. nov.) and *Arctotis marchaensis* (Petrova) (Lutikov and Arp, in press). The biochronological scale by oxytomids proposed in this paper is based on the results of a revision of the taxa of the genus *Meleagrinella* Whitfield, 1885.

PURPOSE, OBJECTIVES, SUBJECT AND OBJECTS OF RESEARCH

The aim of the study was to create a biozonal scale of the Lower Toarcian using the chronological succession of taxa of the genus *Meleagrinella* Whitfield, 1885. The main task was to assess the possibility of a scale for interregional stratigraphic correlations of natural outcrops and borehole sections of Toarcian deposits in northeast Asia and northwest Europe. The subject of the study are bivalve mollusks of the genus *Meleagrinella*. The objects of study are natural outcrops of Toarcian deposits in northeastern Russia, as well as natural outcrops and sections of Toarcian boreholes in eastern Siberia, and a Toarcian section discovered during the restoration of the Ludwigskanal near Dörlbach in southern Germany (Figs. 4, 5).

METHODS

The biochronological scale was proposed based on shell morphogenesis of the bivalve genus *Meleagrinella* Whitfield, 1885 of the family Oxytomidae Ichikawa, 1958. The concept of zonal biochronological scales was used as a methodological basis for the scale and was tested when developing a scale using bivalves of the genus *Arctotis* Bodylevsky, 1960 for the Toarcian-Aalenian deposits of Eastern Siberia (Lutikov, 2021). According to paleontological and stratigraphic criteria, subdivisions of the biochronological scale ("oxyto-zones") are phylozones. The procedure for recognizing oxyto-zones presumes the adoption of a stratigraphic hypothesis about the synchronism of deposits at different distances, marked by a taxon that is a portion of the phylogenetic lineage of the genus *Meleagrinella*.

The problem of global parallelism of changes in organisms (homotaxis) and synchrony for certain stratigraphic levels characterized by connections between basins was solved using the theory of centers of origin and migrations (Darwin, 1859). Since the dispersal of the zonal species took some time, the boundaries of the oxyto-zones are not absolutely synchronous, but on the scale of geological time an assumption is made that makes it possible to consider the oxyto-zones almost isochronous. It is believed that the use of benthos for chronostratigraphy is associated with significant difficulties due to the limited migratory abilities of these organisms (Stepanov and Mesezhnikov, 1979). For stratigraphic levels characterized by a decrease in connections between basins, as a result of parallel homological mutation of related groups in phyletic branches extending from a common ancestral trunk, similar forms appeared, forming a horizontal row (grade). Environmental factors influencing selection caused synchronous unidirectional changes in different species. In different populations, as well as in various related species, certain phenes simultaneously appeared in mass quantities or almost completely dis-

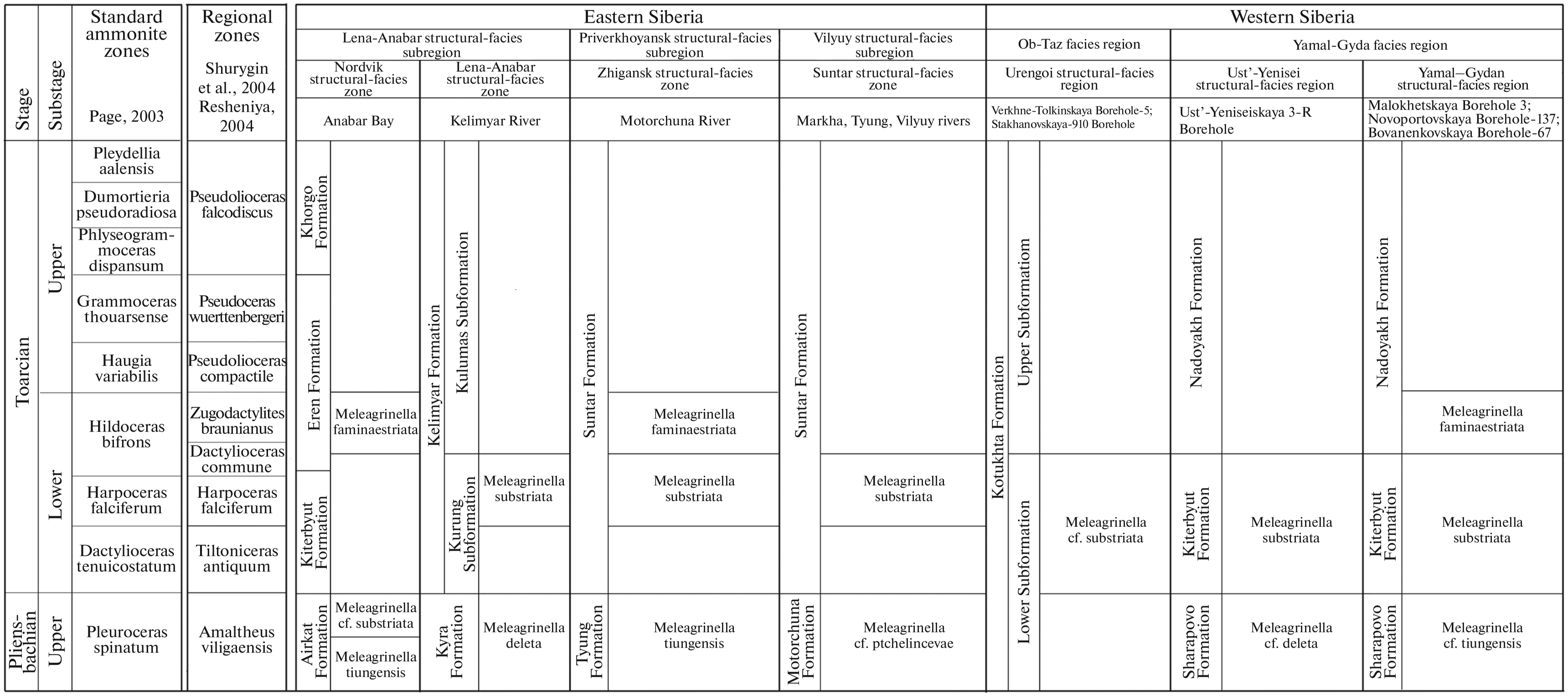

Fig. 3. Distribution and stratigraphic range of species of the genus *Meleagrinella* in the Lower Toarcian of Western and Eastern Siberia (according to *Stratigrafiya*..., 1976; *Resheniya*..., 1981; Knyazev et al., 1984, 1991; Shurygin et al., 2000; *Reshenie*..., 2004).

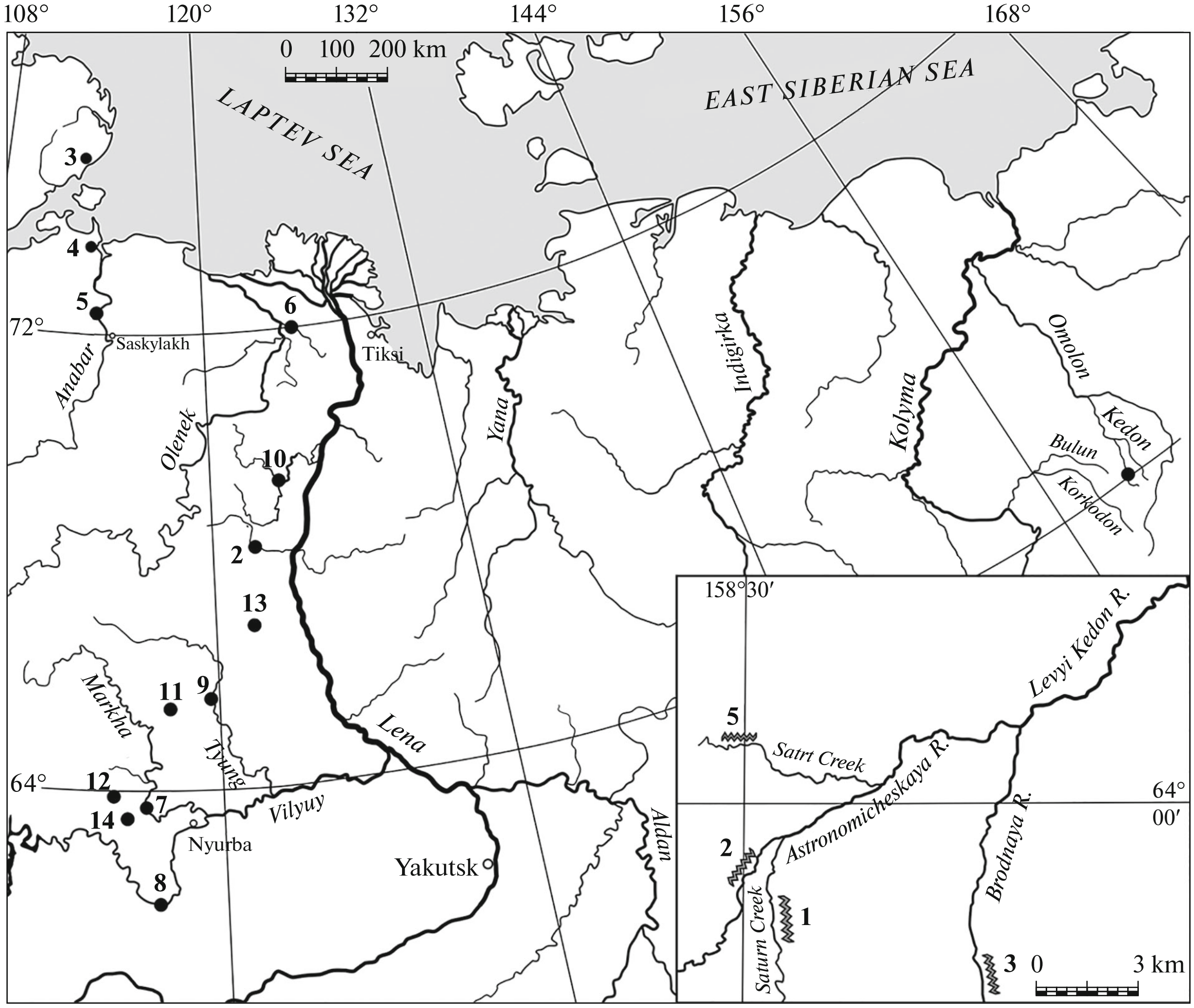

Fig. 4. Map of studied Lower Toarcian sections in Northeastern Russia and Eastern Siberia. Northeastern Russia. Natural outcrops: (1) basin of the Levyi Kedon River (inset shows field numbering of outcrops: 1—Saturn River, 2—Astronomicheskaya River, 3—Brodnaya River, 5—Start River); Eastern Siberia; natural outcrop: 2—Motorchuna River; 3—Cape Tsvetkov (Eastern Taimyr); 4—Anabar Bay; 5—Anabar River; 6—Kelimyar River; 7—Markha; 8—Vilyuy River; 9—Tyung River; 10—Sungyude, Molodo rivers. Drilling sites: 11—Tenkelyakh site (Tyukyan—Markha interfluve), 12—Pravoberezhnyi site (Markha—Vilyuy interfluve), 13—Serki-Linden site (Tyung—Lena interfluve), 14—Ottur site (Markha—Vilyuy interfluve).

appeared. In this case, the zonal classification was built using the concept of chronocline parallelism (Krassilov, 1977). The morphogenesis of the genus *Meleagrinella*, on the one hand, had a direction, which is imprinted in the sequence of successive states of the ligament plate and byssal ear, on the other hand, it had a periodicity, expressed as a relatively stable state of various external morphological traits in certain intervals of sections. Various combinations of internal and external morphological features of shells form the basis of the periodization of the geochronological scale. The directed evolution of internal characters of the genus *Meleagrinella*, along with the periodic differentiation of external characters, has its own time, and the scale corresponding to segments of the phylogenetic line of the genus can be considered as biochronological. The time of formation of oxyto-zones corresponds to the phases of existence of index species.

In the course of a long-term study of Lower-Middle Jurassic bivalves of the family Oxytomidae Ichikawa, 1958 (Lutikov and Shurygin, 2010; Lutikov et al., 2010, 2022; Lutikov and Arp, 2020a, 2020b; Lutikov, 2021), a hypothesis was formed about the continuity of the evolutionary succession of the genera *Meleagrinella* and *Arctotis*, widespread in the Toarcian-Aalenian deposits of the Northern Hemisphere.

Evolutionary changes in internal features, established as a result of studying the morphogenesis of the ligament plate in *Meleagrinella* and *Arctotis* shells originating from different stratigraphic sequences, were taken as a phylogenetic chronocline when constructing a biochronological zonation scheme. In the estab-

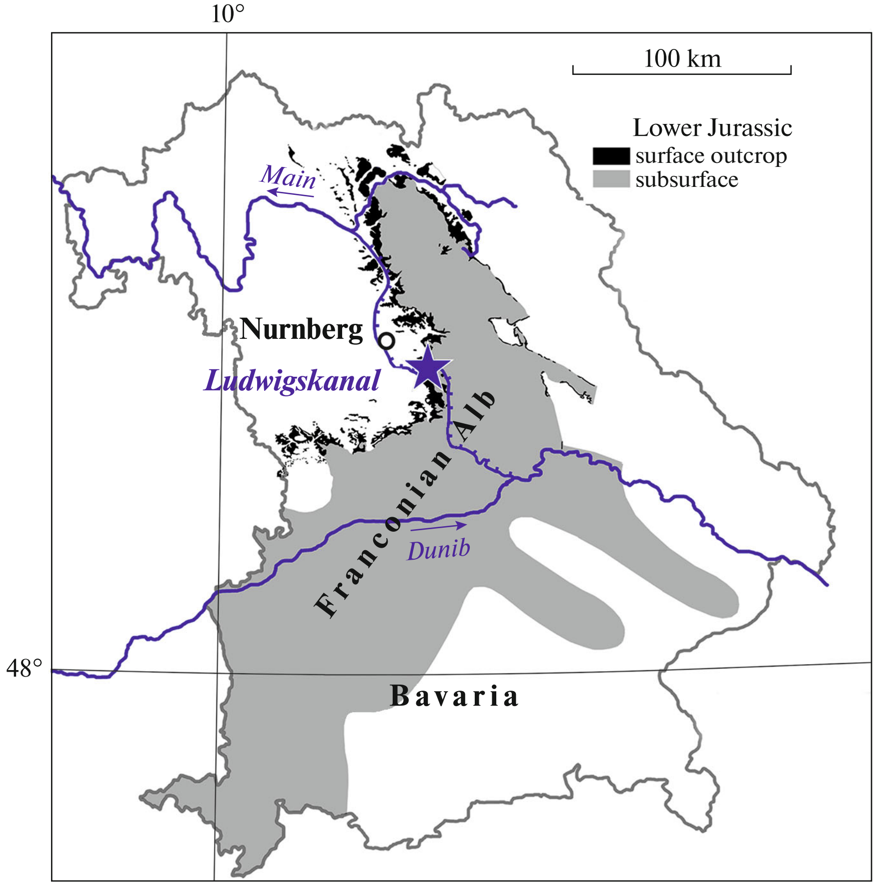

Fig. 5. Location map of the studied Lower Toarcian section in Southern Germany. The asterisk indicates the Ludwigskanal section near the village of Dörlbach.

lished chronophylogenetic sequence of the *Praemeleagrinella*, *Clathrolima*, *Meleagrinella* s.str., *Praearctotis*, and *Arctotis* s.str. groups, the species boundaries were determined by weighted characters. The relative discreteness of traits is explained by the incompleteness of the geological record (Darwin, 1872).

By its nature, the zonation is event-driven. In the Pliensbachian-Toarcian sequence of evolutionary changes in the homological structures of the ligament plate in *Meleagrinella*, three newly formed structures were identified at three stratigraphic levels using a gradation system. In the Late Pliensbachian, the "oblique-expanding" nature of the ontogeny of the ligament fossa arose; an acute-angled ligament socket formed in the *Dactylioceras* commune phase; a subsymmetrical ligament socket appeared in the *Zugodactylites braunianus* phase (Lutikov and Arp, in press). The sequence of oxyto-zones in the reference section of the Lower Toarcian, exposed in natural outcrops along the Astronomicheskaya and Saturn rivers (Levyi Kedon stratigraphic zone), was consistent with the established boundaries of ammonite zones of the Boreal ammonite scale (Knyazev et al., 2003). The boundaries of the oxyto-zones in this section conventionally coincided with the most stratigraphically closely spaced boundaries of the ammonite zones. The chronometric age of the oxyto-zones was determined by the ammonite zones. The calibration of the biochronological scale with the International Stratigraphic Scale (ISS) was carried out by tracing the oxyto-zones in the Ludwigskanal section in southern Germany and correlating the boundaries of the oxyto-zones with the boundaries of the ammonite zones that form the basis of the ISS established in this section.

The zonation scheme proposed for biostratigraphic correlations results from conclusions on the phylogeny of the genus *Meleagrinella* Whitfield, 1885 (Lutikov and Arp, in press). When subdividing sections, the entire assemblage of associated zonal taxa of bivalves was taken into account in order to determine the range of biostratigrapic units. To assess the correlation potential of the scale, the sequence of oxyto-zones was recognized in sections representing different facies of the Lower Toarcian (Anabar Bay, Kelimyar, Motorchuna, Markha, Tyung, and Vilyuy rivers), located in four structural-facies zones of Eastern Siberia: Nordvik, Lena-Anabar, Zhigan, Suntar, and in the Toarcian sections of the Franconian Alb in Southern Germany (Ludwigskanal, Dörlbach).

BIOCHRONOLOGICAL SUBDIVISIONS OF THE TOARCIAN USING BIVALVES OF THE GENUS *MELEAGRINELLA* WHITFIELD, 1885

The basis of the proposed Boreal biochronological scale is the chronological succession of bivalves of the genus *Meleagrinella*. To study the sequence of biostratigraphic units with bivalve mollusks, a section along the Astronomicheskaya River and the overlying section along the Saturn River (basin of the Levyi Kedon River), was considered as a reference section, since these deposits are most abundantly characterized by ammonites in northeast Asia.

Both sections are located at a distance of about 1 km from each other (Figs. 6, 7). A sequence of three species of the genus *Meleagrinella* was established in the Toarcian, on the basis of which a biozonal scale was constructed. The characteristics given for the zonal assemblages of the scale subdivisions are derived from our own field and laboratory research, also taking into account information from literature (Koshelkina, 1980; Milova, 1988; Knyazev et al., 1991, 2003; Shurygin et al., 2000; Repin and Polubotko, 2004; Devyatov et al., 2010; etc.). The taxonomic affiliation of most of the associated bivalves belonging to other families was determined using previous monographic descriptions (Krymgolts et al., 1953; *Polevoi*..., 1968; Zakharov and Shurygin, 1978; Milova, 1988).

The systematic affiliation of bivalves of to the families Bakevellidae King, 1950 and Retroceramidae Koschelkina, 1971 was determined using the revision by Polubotko (1992) and Nevesskaya et al. (2013). The stratigraphic range of the Beds with *Praebuchia? faminaestriata* (Polubotko) in sections on the Astronomicheskaya and Saturn rivers has been emended. It corresponds to the Pseudolioceras compactile, P. wuerttenbergeri, and P. falcodiscus zones of the Boreal ammonite scale. The *Meleagrinella* scale is correlated with the Boreal ammonite zones (Shurygin et al., 2011). Using ammonite levels established in the section of the Ludwigskanal (Dörlbach, Germany) (Arp et al., 2021), the scale was calibrated with Subboreal ammonite zones (Page, 2003).

Meleagrinella golberti Oxyto-zone

N o m e n c l a t u r e. The zone is recognized to replace the "*Praemeleagrinella* sp. 1" and *Praearctotis* sp. 1 proposed earlier (Lutikov and Arp, 2020b). The Meleagrinella ex gr. substriata and Kedonella mytileformis bivalves zone corresponding to the Tiltoniceras antiquum and Harpoceras falciferum ammonite zones was first identified by Polubotko and Repin (2004) for northeastern Russia (Repin and Polubotko, 2004). *Meleagrinella* from the lower two zones of the Toarcian from the sections of Eastern Siberia, northeastern Russia, and Germany were previously classified as *Meleagrinella substriata* (Knyazev et al., 2003), *Meleagrinella* ex gr. *substriata* (Repin and Polubotko, 2004), *Meleagrinella (Praemeleagrinella)* sp. 1 and *Praearctotis* sp. 1 (Lutikov and Arp, 2020a). As a result of the revision, they were assigned to the new species *Meleagrinella (Praemeleagrinella?) golberti* Lutikov et Arp (Lutikov and Arp, 2023). The Meleagrinella golberti oxyto-zone corresponds to the Tiltoniceras antiquum and Harpoceras falciferum zones of the Boreal standard (Shurygin et al., 2011).

I n d e x s p e c i e s: *Meleagrinella (Praemeleagrinella ?) golberti* Lutikov et Arp.

S t r a t o t y p e o f t h e o x y t o - z o n e: Northeastern Russia, Levyi Kedon stratigraphic zone, Start Formation, basin of the Levyi Kedon River (Astronomicheskaya River) (Fig. 4, outcrop 2, Beds 5–14). Thickness 34.6 m.

T h e z o n a l a s s e m b l a g e of the oxyto-zoneincludes the bivalves: *Kedonella brodnensis* Polub., *K. mytileformis* (Polub.), *K.* ex gr. dubius (Sowerby), *Nicaniella* sp., *Dacryomya jacutica* (Petr.), *Tancredia stubendorffi* Schmidt., *Liostrea (Deltostrea)* ex gr. *taimyrensis* Zakh. et Schur., *Corbulomima* sp., *Meleagrinella (P. ?)* aff. *golberti*, *Entolium kedonensis* Milova.

B o u n d a r i e s a n d a g e. The lower boundary of the oxyto-zone is established by the appearance of the index species. The upper boundary is drawn by the appearance of *Meleagrinella (Clathrolima) substriata*. The chronological range of the oxyto-zone is determined by the sum of the occurrences of the index species in all known sections. In the section on the Astronomicheskaya River, the first occurrence of the species *Meleagrinella golberti* was recorded 2.2 m above the level with the last Pliensbachian ammonites *Amaltheus (Amaltheus) viligaensis*. At the base of Toarcian, the index species was found together with *Tiltoniceras antiquum*, *Dactylioceras crosbeyi* (Simpson), and *Nodicoeloceras catinus* Fischer. The last records of the index species were found together with *Harpoceras falciferum*. On the Brodnaya River, shell accumulations with *Meleagrinella (P.?)* aff. *golberti* were found in association with *Harpoceras falciferum*.

On the Kelimyar river, the first appearance of *Meleagrinella (P. ?) golberti* was recorded in outcrops 14 and 16 in the interval of 0.7–0.8 m from the base of the Kelimyar Formation. In Outcrop 16, at a level of 1.0 m from the base of the Kelimyar Formation, the ammonite *Tiltoniceras* sp. ind. was found. In the interval of 1.0–1.1 m, the oxyto-zone index species was found together with *"Harpoceras" (=Cleviceras) exaratum* (Young et Bird), *Harpoceras falciferum* (Knyazev et al., 1984) (Fig. 8).

In southern Germany, in the Dörlbach locality (Bavaria), the index species was found in the Laibstein II Member. Associated ammonites included *Cleviceras exaratum, C. elegans* (Sowerby), *Harpoceras serpentinum* (Schlotheim) were found with it (Fig. 9, layer 8). In Northern Germany, in the locality of Adenstedt (Lower Saxony), the index species was found in

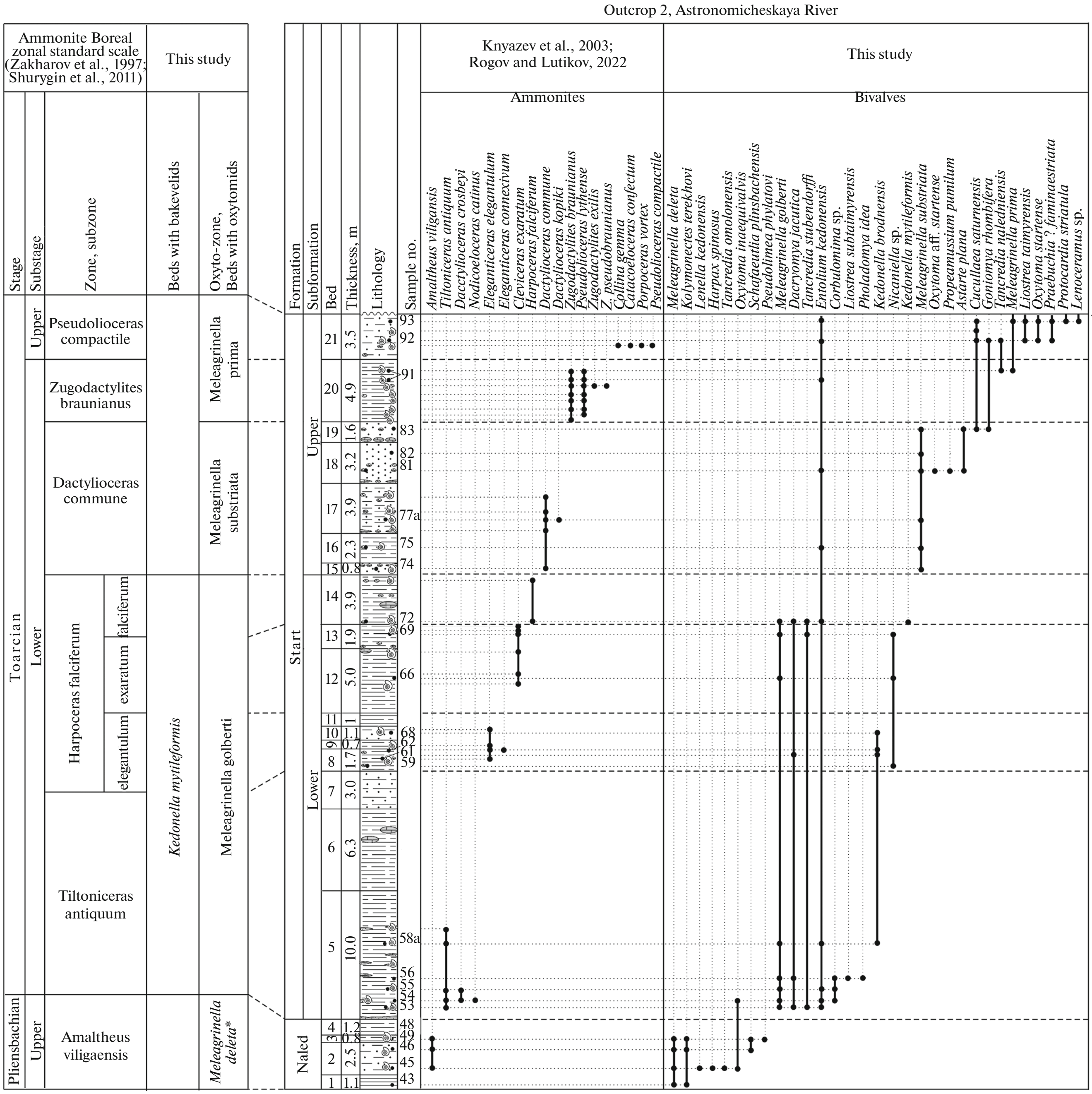

Fig. 6. Section of the Toarcian deposits of the Astronomicheskaya River with stratigraphic ranges of ammonites and bivalves. Legend in Fig. 10.

the section of a temporary construction pit together with the ammonites *Hildaites murleyi* (Moxon) (Lutikov and Arp, 2023).

In England, near Port Mulgrave (Yorkshire), *"Meleagrinella substriata"* (=*Meleagrinella golberti*) occurs together with *Protogrammoceras paltum* (Buckman), *Eleganticeras elegantulum*, *Lytoceras crenatum* (Buckman), *Cleviceras exaratum, C. elegans*, *Hildaites murleyi* (Caswell et al., 2009; Morris et al., 2019).

In Western Canada on the Scalp Creek River (Southern Alberta), the species "*Meleagrinella* sp." (=*Meleagrinella golberti*) was found together with *Cleviceras exaratum* (Martindale and Aberhan, 2017).

Thus, the Meleagrinella (Praemeleagrinella ?) golberti biozone corresponds to the Tiltoniceras antiquum and Harpoceras falciferum zones of the Boreal ammonite zonation scheme (Shurygin et al., 2011) and, accordingly, to the Dactylioceras teniucostatum and Harpoceras serpentinum zones of the Subboreal zona-

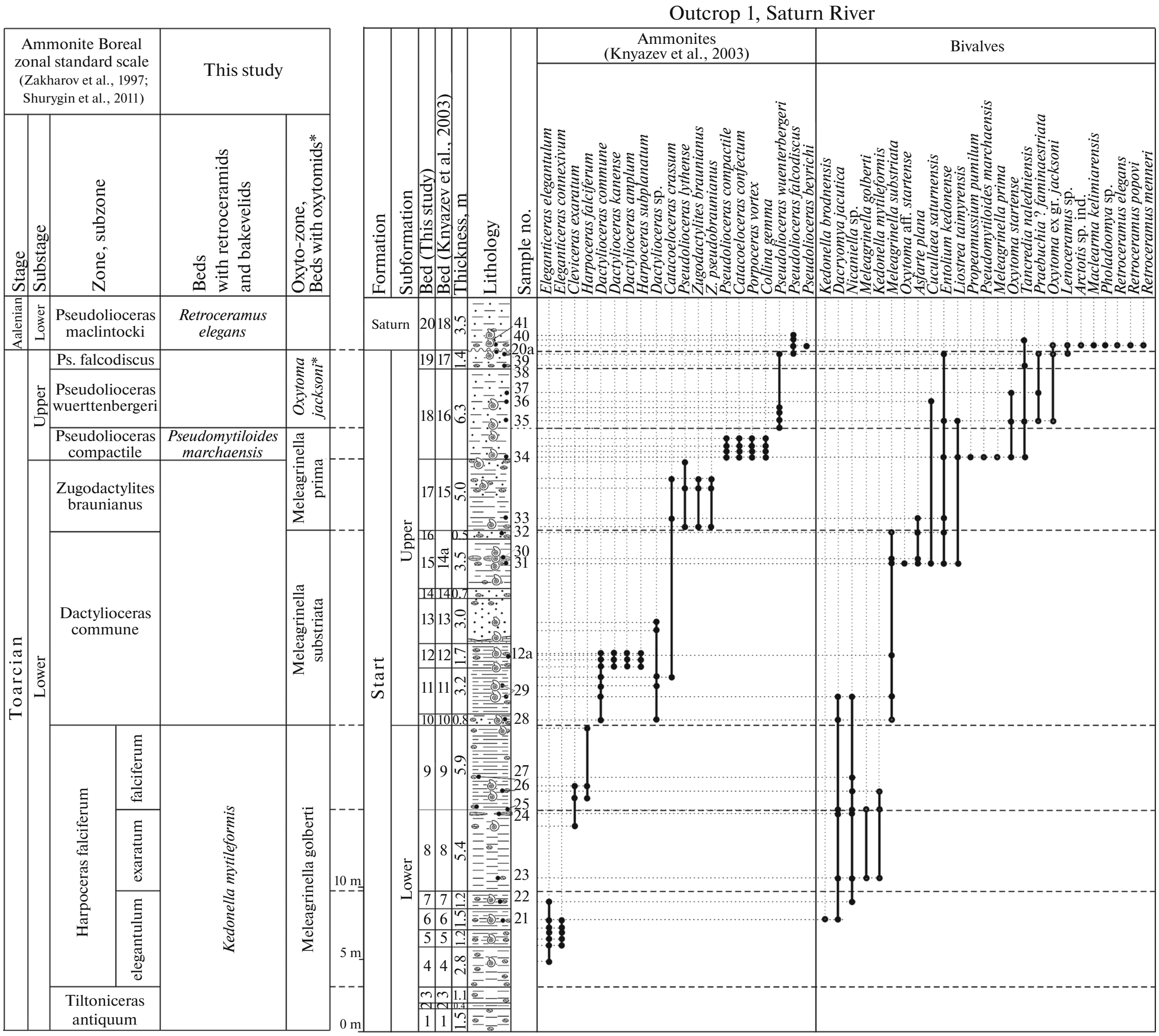

Fig. 7. Section of the Toarcian deposits of the Saturn River with stratigraphic ranges of ammonites and bivalves. Legend in Fig. 10.

tion scheme (Page, 2003). The range of the Meleagrinella golberti oxyto-zone corresponds to the biozone of the index species. The lower boundary of the oxyto-zone coincides with the base of the Tiltoniceras antiquum zone. The upper boundary coincides with the base of the Dactylioceras commune zone of the Boreal ammonite scale (Zakharov et al., 1997; Shurygin et al., 2011).

C o r r e l a t i o n. The Meleagrinella golberti oxyto-zone corresponds to the lower part of the Dacryomya inflata and Tancredia bicarinata b-zone, including Beds with *Corbulomima* sp. of the bivalve zonation scheme (Shurygin et al., 2011). The oxyto-zone corresponds to the Meleagrinella ex gr. substriata, Kedonella mytiliformis zone of the zonal bivalve scale adopted for northeastern Russia (*Resheniya*..., 2009). In southern Germany, in the Franconian Alb (Dörlbach, Germany), the lower part of the Posidonienschiefer Formation (up to 0.35 m thick) belongs to this oxyto-zone (Fig. 9, Beds 7–10). Laibstein Bed I (Fig. 9, Bed 7) contains bivalves *Kedonella* ex gr. *dubius*, *Nicaniella* sp. and the ammonites *Tiltoniceras antiquum, Cleviceras exaratum, Hildaites murleyi*, and *Lytoceras ceratophagum* (Quenstedt) (Arp et al., 2021). *Eleganticeras elegantulum* have been found in this area by private collectors, but the exact position of these ammonites within the Laibstein I nodule bed is not known. Laibstein Bed II (Fig. 9, Bed 8) contains the bivalves *Meleagrinella golberti, Kedonella* ex gr. *dubius, Camptonectes* s.str., *Goniomya rhombifera* (Goldf.),

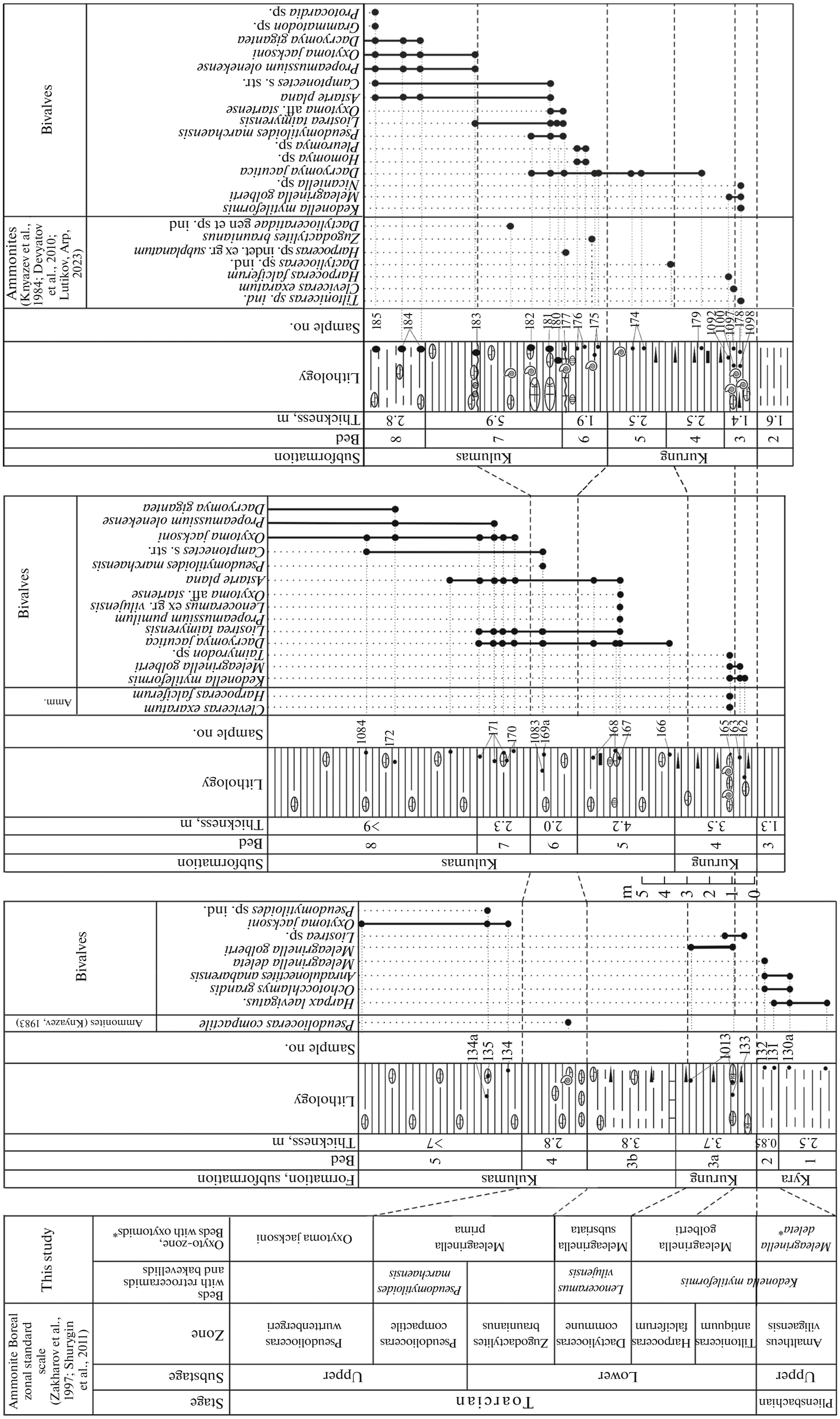

Fig. 8. Correlation scheme of the sections on the Kelimyar River with stratigraphic ranges of ammonites and bivalves. Legend in Fig. 10.

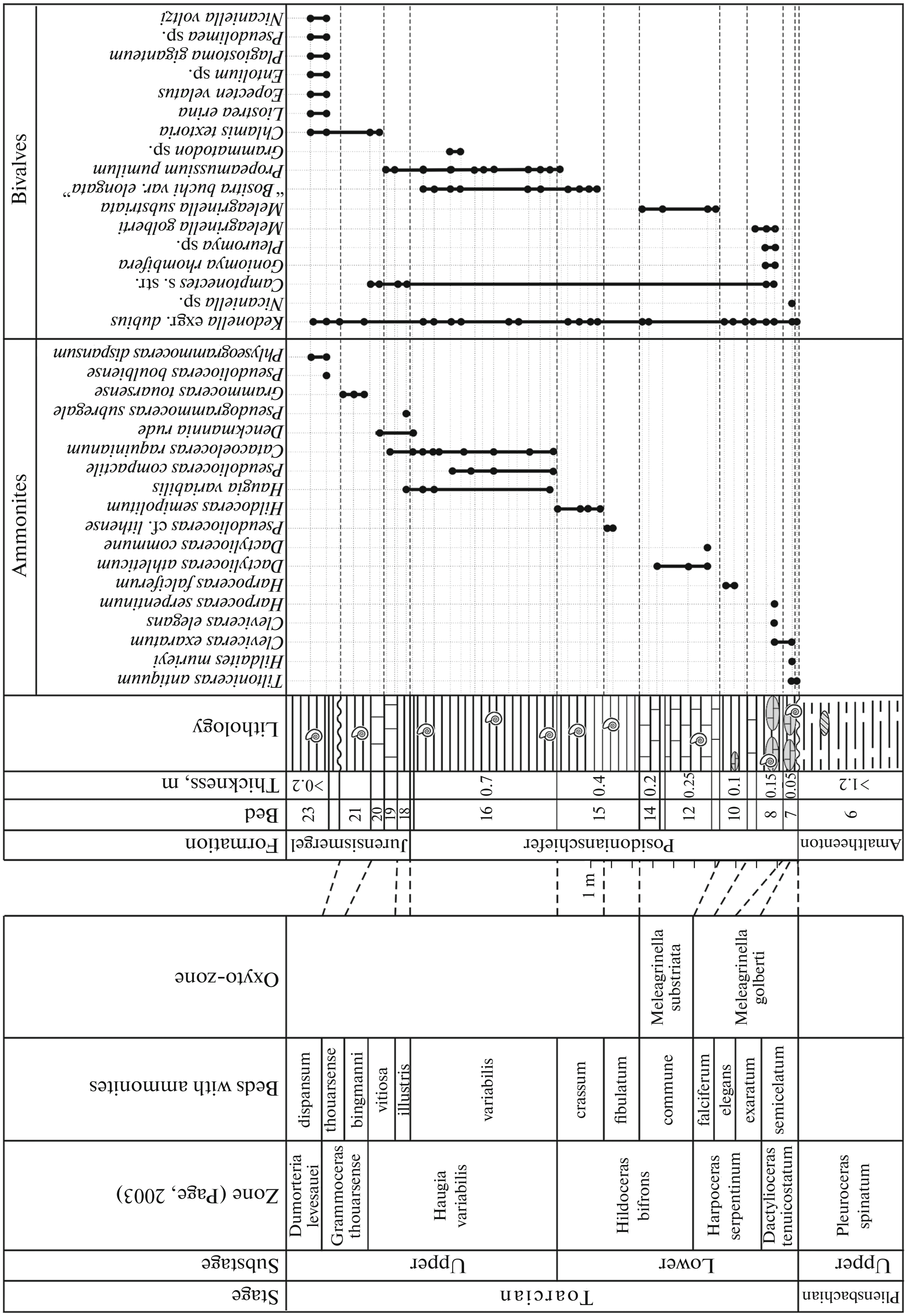

Fig. 9. Section of the Toarcian deposits of the Ludwigskanal (Dörlbach, southern Germany) with stratigraphic ranges of ammonites and bivalves. Legend in Fig. 10.

Pleuromya sp., and the ammonites *Cleviceras elegans, C.* cf. *exaratum*, *Phylloceras heterophyllum* (Sowerby), *Harpoceras serpentinum, "Peronoceras" desplacei* (d'Orbigny), *Nodicoeloceras crassoides* (Simpson), *Dactylioceras semiannulatum* Howarth, and *D. anguinum* (Reinecke). The "Fish Scale Bed" (Fig. 9, Bed 9) contains the bivalves *Meleagrinella (P.?) golberti, Kedonella* ex gr. *dubius* and the ammonites *Cleviceras elegans* (Arp et al., 2021). This part of the section (Fig. 9, Beds 7–10) correlates with the Dactylioceras tenuicostatum and Harpoceras falciferum Zones of the German ammonite zonation scheme (Riegraf et al., 1984) and with the Dactylioceras tenuicostatum and Harpoceras serpentinum Zones of the Subboreal standard ammonite zonation scheme (Page, 2003).

In the Levyi Kedon structural-facies [?] zone, this oxyto-zone is recognized in the section on the Astronomicheskaya River (Fig. 6, Beds 5–14); Saturn River (after Knyazev et al., 2003, Beds 1–9) (Fig. 7, Beds 1–9), on the Brodnaya River (according to Knyazev et al., 2003, Beds 16–18) based on finds of a zonal assemblage with *Meleagrinella (P.?) golberti, Kedonella brodnensis, K. mytiliformis,* and *Nicaniella* sp.

In the Lena-Anabar structural-facies zone (Kelimyar River), this oxyto-zone includes the lower part of the Kurung Subformation (0–3.0 m), which is part of the Kelimyar Formation (Fig. 8, outcrop 5, Bed 3a; Outcrop 14, Bed 4, Outcrop 16, Beds 3–4). The oxyto-zone is recognized by the finds of the zonal assemblage with *Meleagrinella (P.?) golberti, Kedonella mytiliformis, Dacryomya jacutica* (Petr.), and *Nicaniella* sp. In Outcrop 16, at a level of 1.0 m from the base of the Kelimyar Formation, the ammonites *Tiltoniceras* sp. ind. occurred (Lutikov, Arp, 2023). Ammonites *"Harpoceras" (=Cleviceras) exaratum* and *Harpoceras falciferum* were found at a level of 1.1 m (Knyazev et al., 1984, 2003). This oxyto-zone in the section of the Kelimyar River is about 3.0 m thick.

In the Suntar structural-facies zone, the oxyto-zone includes Member I and the lower part of Member II of the Suntar Formation (according to Knyazev et al., 2003, Tyung River, Outcrop 13, Beds 1–6; Outcrop 14, Beds 1–4; Outcrop 15a, Beds 1–2). The oxyto-zone is recognized by the findings of the zonal assemblage: *Meleagrinella (P. ?) golberti, Kedonella mytileformis, Dacryomya jacutica, Tancredia stubendorffi*, and *Liostrea (Deltostrea) taimyrensis*. The ammonites *Eleganticeras elegantulum, "Harpoceras" (=Cleviceras) exaratum*, and *H. falciferum* are found in this part of the section (Knyazev et al., 2003). The visible thickness of the oxyto-zone on the Tyung River is about 13 m. On the Vilyuy and Markha rivers, the oxyto-zone is distinguished by the presence of the zonal assemblage: *Meleagrinella (P.?) golberti, Kedonella mytileformis, Dacryomya jacutica, Tancredia stubendorffi, Liostrea (Deltostrea)* ex gr. *taimyrensis* (after Knyazev et al., 2003, Vilyuy River, Outcrop 19, Beds 15–18; Markha River, Outcrop 6, Beds 6–7). Based on the finds of the index species *Meleagrinella (P.?) golberti*, the oxyto-zone was established in the Ottursky Field (the Markha–Vilyuy interfluve).

In the Zhigansk structural-facies zone (Motorchuna River), the lower 4.2 m of the Suntar Formation belong to this oxyto-zone. The oxyto-zone is recognized by the finds of the zonal assemblage: *Meleagrinella (P.?) golberti, M. (P.?)* aff. *golberti*, *Kedonella brodnensis, K. mytiliformis*.

In the Nordvik structural-facies zone (Anabar Bay), the oxyto-zone includes most of the Kiterbyut Formation according to the finds of the zonal assemblage: *Meleagrinella (P.?) golberti, Kedonella mytileformis* (Fig. 10, Outcrop 5, Bed 64, lower 19 m).

Meleagrinella substriata Oxyto-zone

N o m e n c l a t u r e. This zone is recognized for the first time in this chronostratigraphic range. The oxyto-zone corresponds to the Dactylioceras commune (=Harpoceras subplanatum) Zone of the Boreal ammonite zonation scheme (Zakharov et al., 1997; Knyazev et al., 2003; Shurygin et al., 2011) and the Hildoceras bifrons Zone (=Dactylioceras commune Subzone) of the Subboreal ammonite zonation scheme (Page, 2003).

I n d e x s p e c i e s: *Meleagrinella (Clathrolima) substriata* (Münster), 1831.

S t r a t o t y p e o f t h e o x y t o - z o n e: Northeastern Russia, Levyi Kedon stratigraphic zone, Start Formation, basin of the Levyi Kedon River (Astronomicheskaya River), thickness 11.8 m (Fig. 6, Outcrop 2, Bed 15–19).

T h e z o n a l a s s e m b l a g e of the oxyto-zone includes the following bivalve species: *Propeamussium pumilum* (Lam.), *Astarte plana* Milova, *Cucullaea saturnensis* Milova, *Oxytoma* aff. *startense* Polub., *Mytiloceramus (Lenoceramus) vilujensis* Polub., *Tancredia bicarinata* Schurygin, *Modiolus tiungensis* Petr.

B o u n d a r i e s a n d a g e. The lower boundary is establshed by the appearance of the index species. The upper boundary is drawn at the base of the Meleagrinella prima oxyto-zone. The chronological range of the oxyto-zone is determined by the sum of the occurrences of the index species in all known sections.

In the stratotype on the Astronomicheskaya River, the index species *Meleagrinella (C.) substriata* appears together with *Dactylioceras commune* (Sowerby). The last finds of the index species are recorded in Beds without ammonites below the level of occurrence of *Pseudolioceras lythense* (Young et Bird), *Zugodactylites braunianus* (d'Orbigny) (Fig. 6).

On the Vilyuy and Tyung rivers, the index species *Meleagrinella (C.) substriata* was found together with *Dactylioceras commune*.

In the Ludwigskanal section (Dörlbach, Germany), the index species occurs in abundance within

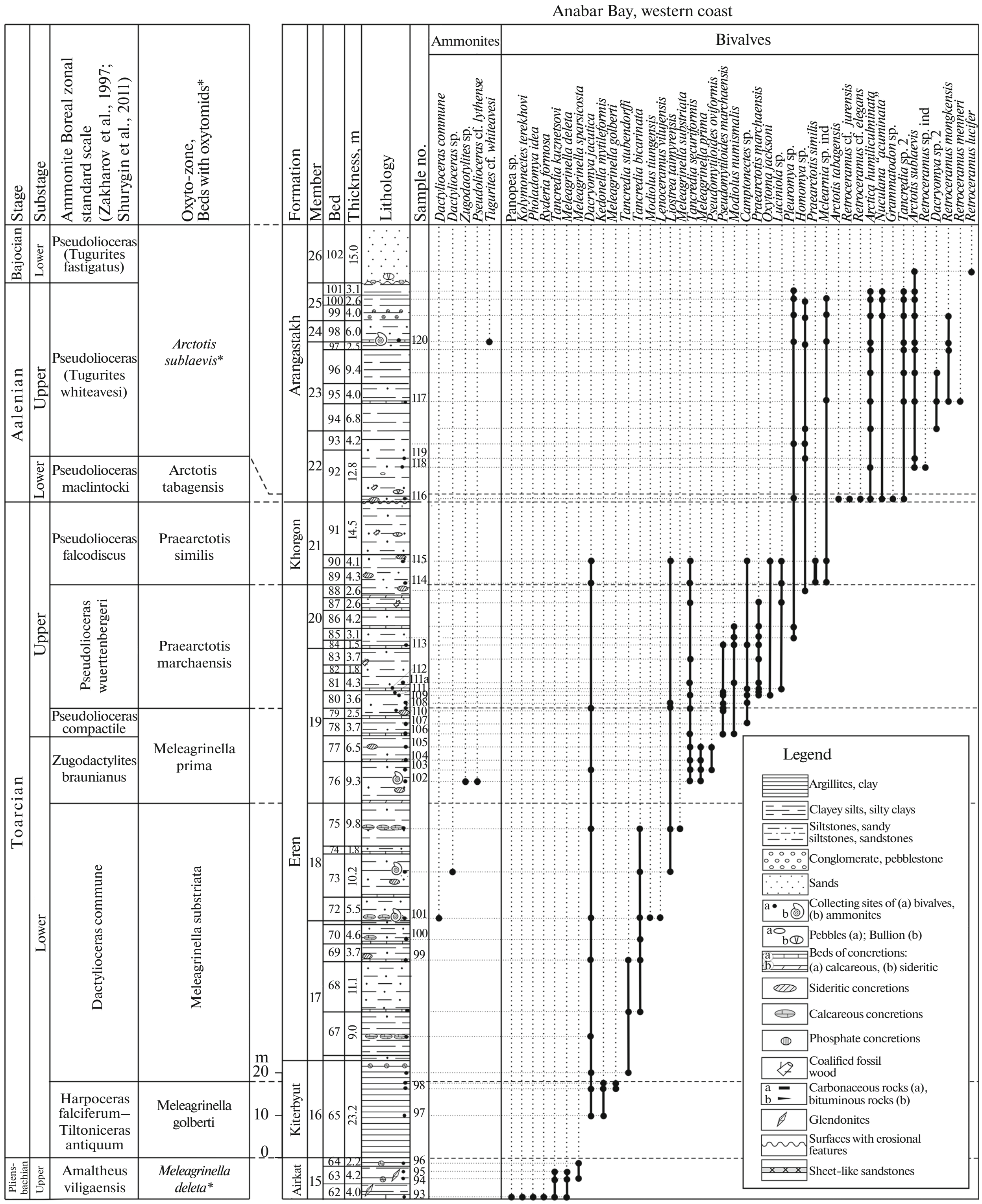

Fig. 10. Section of the Toarcian deposits of the western coast of the Anabar Bay with stratigraphic ranges of ammonites and bivalves.

and just below the "*Dactylioceras-Monotis*-Bed" of the Posidonienschiefer Formation (Fig. 9, Beds 11–14).

The index species *Meleagrinella (C.) substriata* is found with the ammonites *Dactylioceras commune, D. athleticum* (Simpson).

The chronological extent of the oxyto-zone corresponds to the Dactylioceras commune (=Harpoceras subplanatum) Zone of the Boreal ammonite zonation scheme (Zakharov et al., 1997; Knyazev et al., 2003; Shurygin et al., 2011) and the Dactylioceras commune Subzone (Hildoceras bifrons Zone) of the Subboreal ammonite zonation scheme (Page, 2003).

Correlation. The Meleagrinella substriata oxyto-zone corresponds to the upper part of the Dacryomya inflata and Tancredia bicarinata b-zone of the bivalve zonation scheme (Shurygin et al., 2011). In the zonal scale for bivalves adopted for northeastern Russia, the Meleagrinella substriata oxyto-zone corresponds to the Kedonella dagysi Zone (*Resheniya*..., 2009).

In southern Germany, in the Franconian Alb, the oxyto-zone includes the Dactylioceras-Monotis-Bed (0.4 m thick) (Fig. 9, Beds 11–14) of the Posidonienschiefer Formation. It contains the bivalves *Meleagrinella (Clathrolima) substriata, Kedonella* ex gr. *dubius* and ammonites *Dactylioceras athleticum*. This part of the section corresponds to the Hildoceras bifrons Zone (Dactylioceras commune Subzone) of the German ammonite zonation scheme (Riegraf et al., 1984) and correlates with the D. commune Subzone of the Subboreal ammonite zonation scheme (Page, 2003).

In the Levyi Kedon stratigraphic zone, the oxyto-zone is distinguished on the Astronomicheskaya River (Fig. 6, Outcrop 2, Beds 15–19) and on the Astronomicheskaya River and on the Saturn River (Fig. 7, Outcrop 1, Beds 10–16) based on finds of a zonal assemblage with *Meleagrinella (C.) substriata, Propeamussium pumilum, Astarte plana, Cucullaea saturnensis,* and *Oxytoma* aff. *startense*.

In the Lena-Anabar structural-facies zone (Kelimyar River), no index species of the zone was found.

The clays of the Kelimyar Formation contain bivalves typical of the Meleagrinella substriata oxyto-zone: *Mytiloceramus (Lenoceramus) vilujensis* and *Propeamussium pumilum* (Fig. 8, Outcrop 14, Bed 5). At 6.0 m from the base of the Kelimyar Formation, *Dactylioceras* sp. ind. (Fig. 8, Outcrop 16, Bed 5) (Devyatov et al., 2010) was found, and 7 m from the base of the Kelimyar Formation, A.V. Golbert in 1983 discovered *Zugodactylites braunianus* (Fig. 8, Outcrop 16, Bed 6) (Knyazev et al., 2003). Beds with *Mytiloceramus* (*Lenoceramus*) *vilujensis* and Beds with *Zugodactylites braunianus* on the Kelimyars River occupy a position in the section between the Meleagrinella golberti oxyto-zone and the Pseudomytiloides marchaensis b-zone. This part of the section corresponds to the Dactylioceras commune (Harpoceras subplanatum) and Zugodactylites braunianus (=Pseudolioceras lythense) zones of the Boreal ammonite zonation scheme (Zakharov et al., 1997; Knyazev et al., 2003; Shurygin et al., 2011).

In the Suntar structural-facies zone (Tyung River), the upper part of the second member of the Suntar Formation belongs to this oxyto-zone. The oxyto-zone is recognized in the section on the Tyung River on the basis of finds of a zonal assemblage with *Meleagrinella (C.) substriata*, *Mytiloceramus (L.) vilujensis, Tancredia bicarinata* (after Knyazev et al., 2003, Tyung River, Outcrop 13, Bed 7; Outcrop 14, Beds 5–6; Outcrop 15a, Beds 3–4; Outcrop 15, Bed 2). The following ammonites have been reported from this level: *Dactylioceras commune, D. amplum* Dagys*, D. kanense* McLearn*, D. suntarense* Krimholz*, D. crassifactum* (Simpson)*, Catacoeloceras crassum* (Young et Bird) (Knyazev et al., 2003).

On the Vilyuy River, the oxyto-zone is distinguished by findings of a zonal assemblage with *Meleagrinella (C.) substriata, Mytiloceramus (L.) vilujensis*, and *Tancredia bicarinata* (according to Knyazev et al., 2003, Vilyui River, Outcrop 19, Bed 11).

The index species has not been found on the Markha river. Beds with *Lenoceramus vilujensis* are recognized in the upper part of the second member and in the lower part of the third member, which correspond to the Dactylioceras commune (=Harpoceras subplanatum) Zone of the Boreal ammonite zonation scheme (Zakharov et al., 1997; Knyazev et al., 2003; Shurygin et al., 2011) and correlate with the Meleagrinella substriata oxyto-zone (Fig. 10, Outcrop 6, Beds 4–6; Outcrop 10, Beds 4–7; Outcrop 10, Bed 9). The oxyto-zone is recognized in the section of Borehole 350, profile 1060, of the Tenkelyakh drilling site, by the presence of the index species (Fig. 11, Member III–lower part of Member IV). In the Nordvik structural-facies zone (Anabar Bay), the oxyto-zone is distinguished by the finding of an index species and a zonal assemblage of bivalves (Fig. 10, Outcrop 5, Bed 65 (upper) – Bed 75). The oxyto-zone probably includes the terminal part of the Kiterbyut Formation (about 4.2 m), which contains *Dacryomya jacutica* and *Tancredia bicarinata* and correlates with the D. commune (= Harpoceras subplanatum) Zone of the Boreal ammonite zonation scheme based on the finds of *Dactylioceras* sp. ind. (Stratigraphy..., 1976; Knyazev et al., 2003). The oxyto-zone includes the lower part of the Eren Formation, which contains *Meleagrinella (C.) substriata, Lenoceramus vilujensis, Modiolus tiungensis* Petr., *Liostrea (Deltostrea) taimyrensis*, and the ammonites *Dactylioceras commune, D. suntarense* Krimholz, *Catacoeloceras crassum* (Knyazev et al., 2003). In the Zhigansk structural-facies zone (Motorchuna River), the zone has not been established; this part of the Toarcian section is probably obscured by a gap.

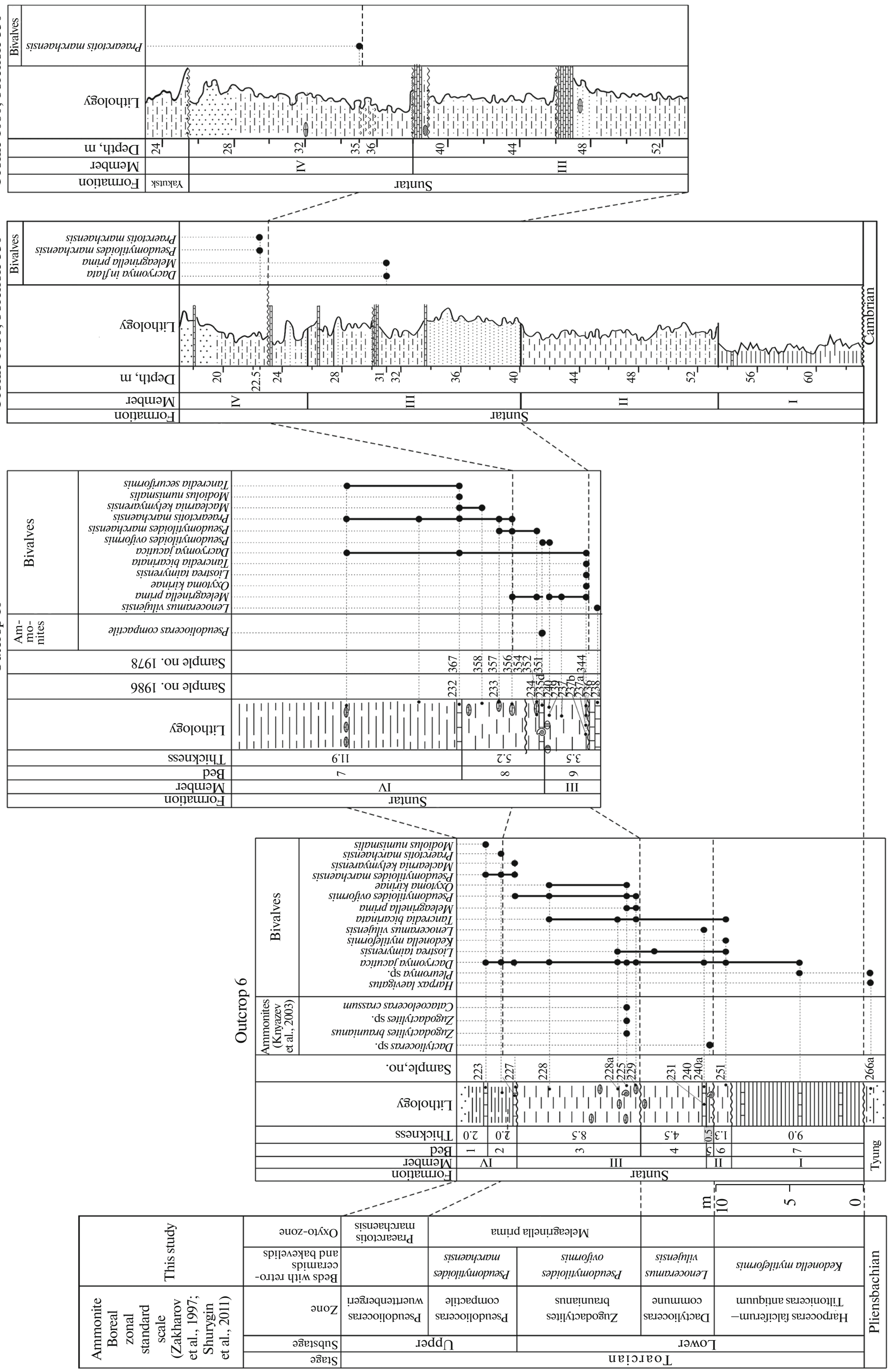

Fig. 11. Correlation scheme of the sections on the Markha River and Tenkelyakh site. Legend in Fig. 10.

Meleagrinella prima Oxyto-zone

N o m e n c l a t u r e. The oxyto-zone is proposed to replace the Praearctotis milovae Zone (Lutikov, 2021) following the re-identification of the index species (Lutikov and Arp, 2023). The Meleagrinella prima oxyto-zone corresponds in range to the Zugodactylites braunianus (=Pseudolioceras lythense) and Pseudolioceras compactile zones of the Boreal standard.

I n d e x s p e c i e s: *Meleagrinella (Meleagrinella) prima* Lutikov, 2022.

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 76–79, Eren Formation, thickness 22 m (Fig. 10).

P a r a s t r a t o t y p e o f t h e o x y t o - z o n e: northeastern Russia, Levyi Kedon stratigraphic zone, Start Formation, basin of the Levyi Kedon River (Astronomicheskaya River), thickness 8.4 m (Fig. 6, Outcrop 2, Beds 20–21).

Z o n a l a s s e m b l a g e of the oxyto-zone is composed of the bivalves: *Pseudomytiloides oviformis* (Khudyaev in Petrova, 1953), *P. marati* Polub., *P. marchaensis* (Petr.), *Meleagrinella* (*Clathrolima*) sp., *Modiolus numismalis* Opp., *Tancredia securiformis* Dunk., *Praebuchia ? faminaestriata* (Polub.), *Oxytoma startense* Polub., *O. kirinae* Velikz., Camptonectes s.str.

B o u n d a r i e s a n d a g e. The lower boundary of the Meleagrinella prima oxyto-zone is established by the first appearance of the index species. The upper boundary is drawn at the base of the Arctotis marchaensis oxyto-zone.

The age of the oxyto-zone according to the ammonite scale is determined by the sum of the occurrences of the index species in all known sections.

In the section of the Anabar Bay, *Meleagrinella (M.) prima* occurs together with *Zugodactylites braunianus* and *Pseudolioceras lythense*; in the section of the Markha River it is found together with *Z. braunianus*. In Northeast Russia, at the Astronomicheskaya River, the index species was found together with *Z. braunianus, P. lythense, P. compactile* (Simps.), *Porpoceras vortex* (Simps.), and *Collina gemma* Bonarelli (Fig. 6). The Meleagrinella prima oxyto-zone reliably corresponds to the Zugodactylites braunianus (=Pseudolioceras lythense) and Pseudolioceras compactile (=Harpoceras subplanatum) zones of the Boreal standard (Fig. 1).

C o r r e l a t i o n. The Meleagrinella prima oxyto-zone corresponds to the upper part of the Meleagrinella faminaestriata b-zone and the Pseudomytioides marchaensis Zone of the Boreal bivalve standard zonal scheme (Shurygin et al., 2011). In the bivalve zonal scheme adopted for northeastern Russia, the Meleagrinella prima oxyto-zone corresponds to the Mytiloceramus marati Zone and the lower part of the M. marchaensis Zone, including the Beds with Vaugonia literata (*Resheniya*..., 2009).

In the stratotype in the Anabar Bay (Nordvik structural-facies zone), the Meleagrinella prima oxyto-zone is distinguished in the middle part of the Eren Formation based on finds of the zonal species and a zonal assemblage with *Modiolus numismalis, Tancredia securiformis, Pseudomytiloides oviformis*, and *P. marchaensis* (Fig. 10, Outcrop 5, Beds 76–79, Outcrop 4, Beds 18–22).

In the Levyi Kedon structural-facies zone, the oxyto-zone is recognized by the presence of *Meleagrinella (M.) prima* and the zonal complex with *Pseudomytiloides marchaensis, Oxytoma startense, Praebuchia ? faminaestriat*a in the section on the Astronomicheskaya River (Fig. 6, Outcrop 2, Beds 20–21), and on the Saturn River (after Knyazev et al., 2003, Outcrop 1, Beds 15–16).

In the Lena-Anabar structural-facies zone (Kelimyar River), no index species of the zone was found. The clays of the Kelimyar Formation contain bivalves characteristic of the oxyto-zone: *Pseudomytiloides marchaensis* (Fig. 8, Outcrop 16, Bed 7).

In the Suntar structural-facies zone, the oxyto-zone was established in the section of the Markha River and in the boreholes of the Tenkelyakh site according to the finds of *Meleagrinella (M.) prima* and the zonal assemblage with *Pseudomytiloides oviformis, Pseudomytiloides markhaensis* (Fig. 11). The zone includes the upper part of the third member of the Suntar Formation. The ammonites *Zugodactylites braunianus, Catacoeloceras crassum*, and *Pseudolioceras compactile* are reported from this part (Knyazev et al., 2003).

In the Zhigansk structural-facies zone (Motorchuna River), the zone has not been established; this part of the Toarcian section is probably obscured by a gap.

In southern Germany, in the Franconian Alb (Dörlbach, Germany), the zonal assemblage of Meleagrinella prima oxyto-zone bivalves has not been established. In the section of the Ludwigskanal, the "Bifrons Shale" Member 0.4 m thick (Fig. 9, Member 15) contains the bivalves *Kedonella* ex gr. *dubius*, "*Bositra buchi* var. *elongata*" (Goldfuss) and ammonites *Hildoceras semipolitum* Buckman (2, 17, 18, and 22 cm below the top); *Pseudolioceras* cf. *lythense* (20 cm below the top), *Phylloceras heterophyllum* (28 cm below the top) (Arp et al., 2021). In this section, according to the joint occurrence of the ammonites *Pseudolioceras* cf. *lythense* and *Hildoceras semipolitum*, the lower Toarcian Catacеloceras crassum Subzone of the of the Subboreal ammonite zonation scheme (Page, 2003) correlates with the Zugodactylites braunianus (=Pseudolioceras lythense) Zone of the Boreal ammonite zonation scheme (Knyazev et al., 2003).

The member "Variabilis Shale" (Fig. 9, Member 16), 0.7 m thick, contains bivalve mollusks "*Bositra buchi* var. *elongata*", *Kedonella* ex gr. *dubius*, *Propeamussium pumilum, Grammatodon* sp. and ammonites *Haugia variabilis* (d'Orbigny) (13 cm below the top), *Pseudo-*

lioceras compactile (13, 19, 21, 24, 25, 37 and 65 cm below the top), *Cataceloceras raquinianum* (d'Orbigny) (3, 7, 13, 15, 19, 22, 37, 38 and 53 cm below the top), *Denckmannia* cf. *rude* (Simpson), *Haugia jugosa* (Sowerby), *Mucrodactylites mucronatus* (d'Orbigny), *Lytoceras* cf. *cornucopia* (Young et Bird), *L. sublineatum* (Oppel) (Arp et al., 2021). Thus, in this section, according to the joint occurrence of the ammonites *Pseudolioceras compactile* and *Haugia variabilis*, the Upper Toarcian Haugia variabilis Zone of the Subboreal ammonite zonation scheme (Page, 2003) correlates with the Pseudolioceras compactile Zone of the Boreal ammonite zonation scheme (Knyazev et al., 2003).

CONCLUSIONS

As a result of a monographic study of the genus *Meleagrinella* in the Lower Toarcian and lower Upper Toarcian, a phylogenetic sequence of three separate taxa was identified. These taxa were used to substantiate elementary biostratigraphic units—oxyto-zones recognized in the Northern Hemisphere in the areas of distribution of Boreal deposits within the Panboreal paleogeographic superrealm. The sequence of key species of the genus *Meleagrinella* was established in the Toarcian reference sections on the left bank of the Astronomicheskaya River and the right bank of the Astronomicheskaya River and Saturn River (upper reaches of the Levyi Kedon River, Omolon River basin), and then traced in a series of sections in the northeastern Russia, in Eastern Siberia and southern Germany.

Stratigraphic control of the positions of each oxyto-zone in the sections was carried out using the Boreal standard of the previously developed ammonite zonation scheme. As a result, each oxyto-zone was associated with specific genera and species of ammonites: the Meleagrinella golberti oxyto-zone corresponds to the Tiltoniceras antiquum and Harpoceras falciferum zones; the M. substriata oxyto-zone corresponds to the Dactylioceras commune Zone; the M. prima oxyto-zone corresponds to the Zugodactylites braunianus and Pseudolioceras compactile zones (Zakharov et al., 1997; Shurygin et al., 2011).

Long-term studies of specific sections have confirmed the high efficiency and reliability of detailed correlation of intra- and inter-regional Toarcian sections. The established oxyto-zones have been successfully used for inter-regional correlation of specific Toarcian sections of the North-East of Russia along the Astronomicheskaya, Saturn, Brodnaya and Start rivers,; Eastern Siberia along the banks of the Anabar Bay, along the Markha, Tyung, Vilyui, Kelimyar, Motorchuna rivers in the Vilyui syneclise (boreholes) and Germany (near Dörlbach, Berg, Adenstedt).

The proposed oxytomiid bivalve zonation scheme was parallelized with the already put into practice ammonite scales and scales for different groups of macro- and microfossils (*Resheniya*..., 2004; 2009). The scale is included in the system of existing parallel regional scales for other bivalves (Repin and Polubotko, 2004; Shurygin et al., 2011).

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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