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Comprehensive zonal subdivisions of Siberian Jurassic and their significance for Circum-Arctic correlations

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Abstract

We show the present state of the set of parallel zonal scales for the Siberian Jurassic, based on various fossil groups, and the principles of their construction. We discuss the significance of Siberian biostratigraphic scales for the Boreal zonal standard of the Jurassic units. The stratotype region for this standard must have a typical Boreal (Arctic rather than mixed) fauna. A possible candidate is Siberia (and the Arctic biochorema), which is located in the center of the Panboreal Superrealm, where the set of interrelated scales for various fossil groups is the most complete. The set of parallel zonal scales for the Siberian Jurassic is efficient for the subdivision and correlation of Jurassic units in various Arctic regions (Barents Sea shelf, northeastern Russia, Arctic Alaska, Arctic Canada).

Keywords: Jurassic; biostratigraphy; Boreal standard; Arctic paleobasins; Siberia

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Introduction

Jurassic sediments with a Boreal fauna, which are very widespread in Arctic regions, are one of the most promising hydrocarbon reservoirs (Gramberg et al., 1984; Kontorovich et al., 2010). The stratigraphic position and occurrence of highly carbonaceous Phanerozoic deposits in northern and Arctic regions, including those like the Jurassic Bazhenovka Formation, were always the focus of A.A. Trofimuk's attention (Gurari et al., 1963; Trofimuk, 1960, 1991, 1997; Trofimuk and Kontorovich, 1965) and remain important targets for the geologic study of the Arctic.

The Jurassic sediments extend as a continuous strip along the entire northern edge of Eurasia; they are known in northern Alaska and the adjacent waters, Arctic Canada, eastern and northern Greenland, and the shelf of the Norwegian and North Seas (Fig. 1). In northern Russia they form the world's largest field. Here, they extend from west to east almost continuously for over 5000 km (Saks et al., 1980). Within this enormous territory, the Jurassic rocks are almost exclusively terrigenous. Over the last 50 years, data reliable enough have been collected on the structure and relations of the Jurassic strata in the study area (Fig. 2). The Lower–Middle Jurassic and, partly, the Upper Jurassic strata in the Arctic basin show cyclicity, which is due to eustasy in the World Ocean (Zakharov et al., 1998). For example, the near-ubiquity of organic-enriched clays in the lower Toarcian permits dividing the Lower Jurassic strata in northwestern Europe and the Arctic basin into two parts. The Early Toarcian highly carbonaceous clays and mudstones are considered an interregional stratigraphic marker because of the typical homogeneous argillaceous composition and similar thickness in the huge territory of the Arctic basin and in Europe (Zakharov et al., 2006).

At interdepartmental stratigraphic meetings, regional stratigraphic charts of northern Russia were compiled. They show the composition, areas, and ages of Jurassic lithologic bodies, the degree of the section completeness, the character of lateral replacement in individual formations and members, and variation in their thicknesses (Koren' and Kotlyar, 2009; Resolution, 1991, 2004; Saks, 1981; Yakovleva, 1993). Lithostratigraphic units are correlated by general geologic and (in closed areas) geophysical methods, but mainly with the help of biostratigraphic data. The latter are especially efficient for studying marine strata, which are widespread in the framing and shelf of the Arctic seas. The Jurassic biostratigraphy of the Arctic regions was much contributed to by

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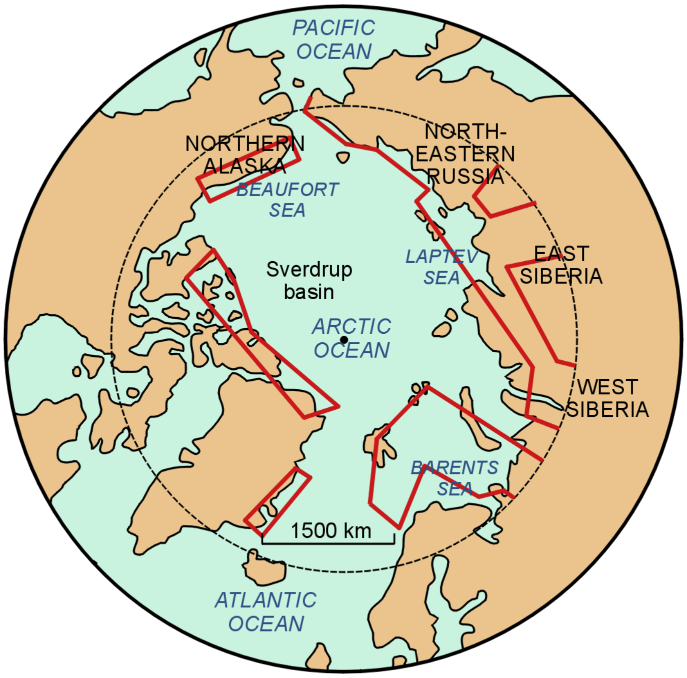


Fig. 1. Regions with Circum-Arctic Jurassic sediments.

NIIGA, VNIGRI, VSEGEI, SNIIGGiMS, and the Paleontology and Stratigraphy Department at the Institute of Geology and Geophysics (Siberian Branch of the USSR Academy of Sciences), founded by Trofimuk. The department was faced with the objective of compiling a reliable stratigraphic base for the geologic exploration of northern Siberia and the adjacent Arctic regions (Development, 2010). Modern biostratigraphic scales for the Siberian Jurassic match up to and surpass their foreign counterparts in the level of detail and incorporation of various fossil groups.

Biostratigraphic scales of the Boreal Jurassic are based on the idea that the biota develops by stages. The latter are manifested in relatively rapid irreversible changes in the faunal taxonomic composition, which are due to evolutionary transformations and migration. Evolution was governed by many concurrent environmental factors. The leading role belonged to global climate change and the changing paleobasin sizes, coastline shape, and paleolandscapes. The redistribution of sea/land boundaries entailed shifts in the sets of currents and affected the degree of the reunification/separation of the adjacent waters. Faunal interchange increased and decreased alternately. Sometimes some groups colonized the vast expanses of Boreal seas for a long time and evolved there; this resulted in the wide spread of the endemic groups of the Boreal fauna (Meledina et al., 2005; Zakharov et al., 2002).

In early studies (Saks et al., 1980), the Jurassic zonation was based on data on ammonite occurrence in the numerous sections of Central Siberia and northeastern Russia. The biostratigraphic zonation of the Jurassic and Neocomian suggested for northern Russia correlated well with that for North America, eastern Greenland, the East European Plain, and the Russian Far East.

The biostratigraphic studies were based on the assumption that biostratigraphic scales were applicable only within paleobiogeographic provinces, because zonal assemblages of ammonites and other fossils differed across biogeographic realms (Boreal–Atlantic, Arctic, Boreal–Pacific) and within the realms in individual provinces. Therefore, regional zonal scales have to comprise provincial zones with different index species. The stages when the taxonomic composition of ammonite and other faunal assemblages is geographically leveled (they are usually associated with transgression) correspond to zones with a wide geographic range. The latter form a system of biostratigraphic markers with isochronous boundaries on the scale (within the attainable accuracy of the biostratigraphic method).

In the Jurassic chart, such markers are present in the Psiloceras planorbis (Lower Hettangian), Amaltheus stokesi (Upper Pliensbachian), Dactylioceras athleticum, Zugodactylites monestieri (Lower Toarcian) Zones and the Oxycerites jugatus (lower Upper Bathonian), Cadoceras elatmae (Lower Callovian), Cardioceras cordatum (Lower Oxfordian), Aulacostephanus eudoxus (Upper Kimmeridgian), Pectinatites pectinatus (Lower Volgian), and Dorsoplanites maximus (Middle Volgian) Subzones (Saks et al., 1980, Tables 1–3).

The most reliable zones for correlations are those which can be correlated directly with the international standard. The zones best reflecting the local peculiarities and lying between the markers correlate with the international zonal standard only roughly. They can be correlated only by tracing zonal assemblages in the adjacent regions with the same taxa and gradual approximation to the standard.

Along with the ammonite scale, scales for other fossil groups were developed in some regions, and they also comprised lineage zones. It was emphasized that foraminifers, ostracods, radiolarians, spore–pollen assemblages, and dinocysts should play an increasing role in the subdivision and correlation of sections in closed areas. Modern parallel zonal scales for the Siberian Jurassic have been developed for almost all the major molluskan, microfaunal, and microphytofossil groups found in these strata (Shurygin et al., 2000).

The biostratigraphic succession established in the Siberian Jurassic sections on the basis of bivalves, foraminifers, and ostracods is found in an enormous territory: in the framing of the Siberian Platform, West Siberia, and northeastern Russia (Nikitenko, 2009; Shurygin, 2005). This interval contains several levels related to the appearance of Circum-Boreal migratory benthic taxa in northern Siberia. Also, some critical boundaries marking the start of abrupt turnovers in macro- and microbenthic communities (Toarcian, Bajocian, and others) are well identified and occur interregionally. What is more, part of the biostratigraphic units distinguished for northern Siberia are well identified in the same volume in the Jurassic sections of almost all the Arctic regions. For example, the foraminiferal, ostracod, and bivalve zonation of the Siberian Jurassic is found in northeastern Russia, the Barents Sea shelf, and northern Alaska (Mickey et al., 1998; Nikitenko and Mickey, 2004; Shurygin, 2005). According to published data, these zones or their equivalents are found in Arctic Canada. A regular (well paleogeographically explicable)

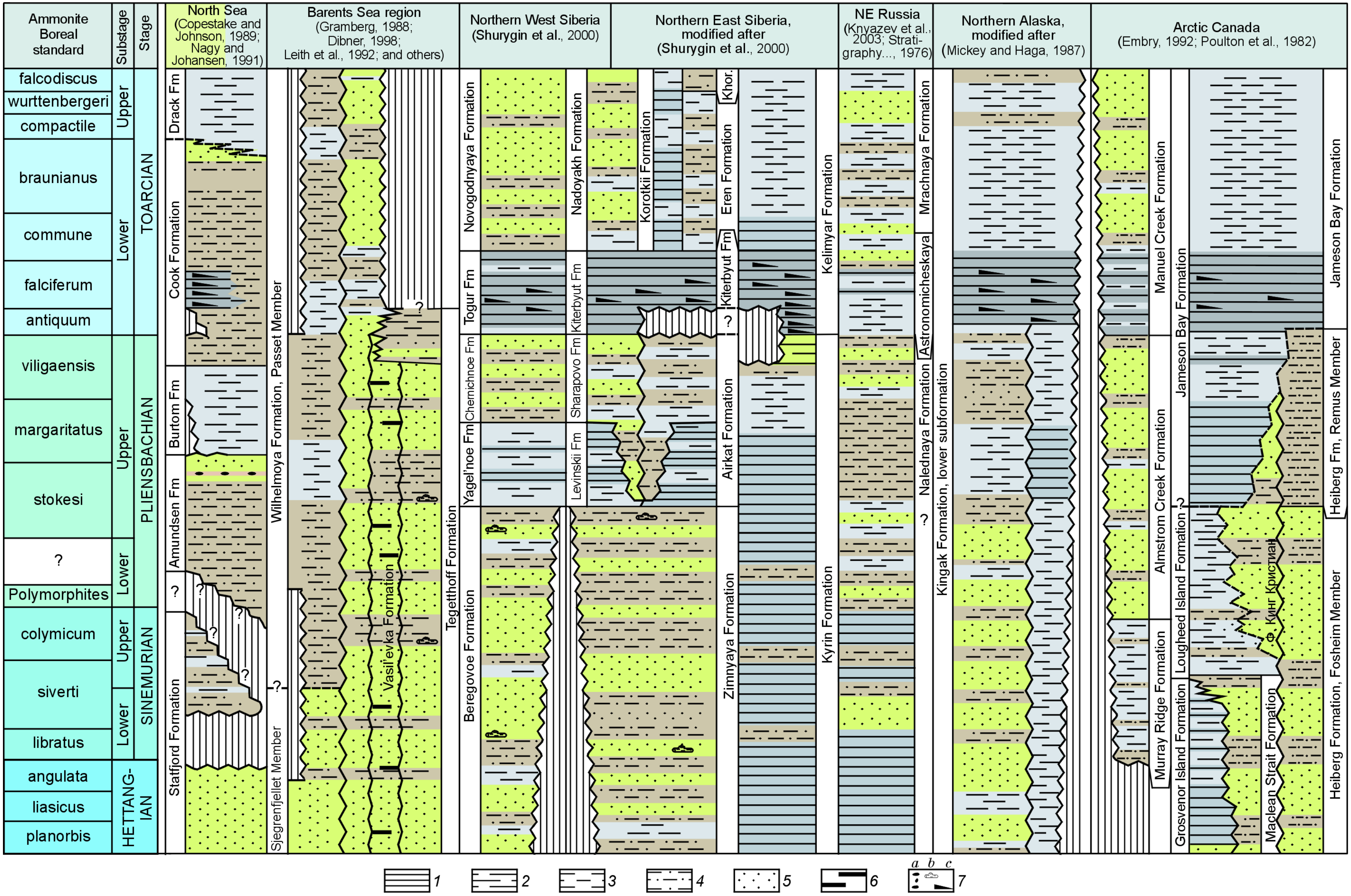


Fig. 2. Lower Jurassic lithostratigraphy of northern and Arctic regions. *1*, clays, mudstones; *2*, silty clays and mudstones; *3*, silts, siltstones; *4*, sandy silts and siltstones; *5*, sands, sandstones; *6*, coals, coal measures; *7*, pebbles (*a*), charred wood (*b*), organic-enriched clays (*c*).

change is observed in the lateral extent of the datums determined in the Siberian sections (Nikitenko, 2009; Shurygin, 2005).

A comprehensive analysis of the biostratigraphic succession based on micro- and macrobenthos and the lithostratigraphic structure of the sections permitted refining the stratigraphic position and volume of the lithostratigraphic units, seismic complexes, and their boundaries distinguished in the Barents Sea shelf (Fig. 2). It turned out that the Lower and Middle Jurassic sections of the Barents Sea shelf and Siberia had a very similar lithostratigraphic structure (Basov et al., 2009; Nikitenko, 2009) and the major seismic horizons in this shelf correlated well with those in northern West Siberia. The stratigraphic position of the seismic horizons is controlled by microfaunal biostratigraphic successions. Since the microbiota in the Barents Sea shelf and northern Siberia are of almost the same taxonomic composition and the sections have a similar lithostratigraphic structure, we presume that these basins had a similar character of sediment genesis and evolution in the Early and Middle Jurassic.

Parallel zonal scales for the Siberian Jurassic and the Boreal zonal standard

The biostratigraphic scales for the Siberian Jurassic have always been comprehensive. In accordance with the ideas of Trofimuk, who founded the Institute of Geology and Geophysics for comprehensive geologic studies in Siberia and the adjacent Arctic regions, experts on various fossil groups along with lithologists, geochemists, paleomagnetists, and other researchers examined key sections of Jurassic marine sediments in Boreal regions. Such sections, which contain a rich fauna of ammonites, belemnites, bivalves, foraminifers, and other groups, are located on the eastern slope of the Northern and Cispolar Urals; in the Kheta River basin; on the Nordvik and Yuryung-Tumus (Laptev Sea shore) Peninsulas; in the cliffs of the Anabar River basin, the Anabar estuary, and Anabar Bay; in the lower reaches of the Olenek and Lena Rivers; near the Vilyui River; on Bol'shoi Begichev Island. In northeastern Russia, the best sections are located in the Omolon pluton and along the coastline of the Sea of Okhotsk.

In the key sections, paleontologic samples were taken, the vertical and horizontal distribution limits of individual taxa were detected, and parallel zonal scales for individual fossil groups were developed. A correlated set of such scales is a comprehensive biostratigraphic scale, which permits a fairly detailed division of sedimentary strata with the help of the scale (scales) used in the given geologic setting.

The greatest progress has been made lately in the development of detailed scales for macro- and microfaunal parastratigraphic groups. In the last few decades, geologists have turned their attention to West Siberia and other closed territories where the Jurassic marine sediments at great depth are associated with sizable petroleum deposits. As a result, biostratigraphic studies began to extensively involve small foraminifers, ostracods, plant spores and pollen, and dinocysts (they are all more frequent in the core than ammonites, belemnites, or bivalves); a detailed zonation appeared for all these groups. The ammonite regional scale was correlated within attainable accuracy with the International Stratigraphic Chart. Afterward the other parallel scales, correlated with the ammonite regional scale, began to play an independent role, for example, in the sediment subdivision, correlation, and dating by core in closed areas.

The combination of the ammonite regional (priority) and the other (parallel) scales not only enlarged the possibilities of their areal application but also increased the level of detail and correlation for the comprehensive biostratigraphic scale (Fig. 3). In northern Russia the Jurassic System is divided into three series and 11 stages, which correspond to those in the International Stratigraphic Chart. The Lower Jurassic Series encompasses the Hettangian, Sinemurian, Pliensbachian, and Toarcian Stages; the Middle Jurassic, the Aalenian, Bajocian, Bathonian, and Callovian Stages; the Upper Jurassic, the Oxfordian, Kimmeridgian, and Volgian (corresponds mostly to the Tithonian) Stages.

The northern Siberian ammonite zonation of the Jurassic served as the basis for the Jurassic zonal standard offered by Novosibirsk paleontologists (zonal standard for the superior Jurassic marine biochorema, which is distinguished in the Northern Hemisphere) (Zakharov et al., 1997). A set of parallel scales for belemnites, bivalves, foraminifers, ostracods, spore–pollen assemblages, and dinocysts was presented in (Shurygin et al., 2000; Zakharov et al., 1997). The ammonite scale from the Boreal standard is the generalized ammonite regional scale reflecting the taxonomic composition of the Boreal Jurassic biota: in the Early Jurassic, at the provincial and realm level; since the Middle Jurassic, only at the realm level, with increasing internal differentiation. This is the priority scale, because it carries geochronologic information (Zhamoida, 2007). The parallel zonal scales for the other macrofaunal, microfaunal, and microphytofossil groups, which were calibrated against the priority scale, also belong to the Boreal standard. The comprehensive biostratigraphic scale for the Jurassic of Siberia, which was suggested as the Boreal standard, is unparalleled worldwide.

Later an attempt was made to modify the Boreal standard by introducing some ammonite zones distinguished in the East European craton, for example, in the Callovian and Kimmeridgian (Zakharov et al., 2005; Zhamoida and Petrov, 2008). We consider this a poor idea, because the very approach used in the Boreal standard of 1997 (to give as complete a picture as possible of a typical Boreal (Arctic) fauna) is violated. The stratotype region for this standard must have a typical Boreal (Arctic rather than mixed) fauna. Correspondingly, a possible candidate is Siberia (and the Arctic biochorema), which is located in the center of the Panboreal Superrealm, where the set of interrelated scales for various fossil groups is the most complete (Figs. 3, 4). Note that the regional scales for the boundary biochoremas of the Panboreal Superrealm (like the Jurassic zonal chart of the East European craton), which show mixed (ecotone) faunas, remain crucial in correlating the Boreal standard with the international one.

Note again that the scales for various fossil groups, which make up the Arctic Jurassic zonal standard together with the ammonite scale, were originally correlated with the Siberian ammonite scale, because they had been developed for the same sections.

Modern ammonite zonal scale for the Jurassic of Siberia

The state of the ammonite zonal scale now used for Jurassic in the Boreal and Subboreal regions of Russia is discussed in (Sei et al., 2006; Shurygin et al., 2000; Zakharov et al., 2010; Zhamoida and Petrov, 2008). Let us dwell upon the latest suggestions for modifying this scale.

The ammonite scale developed for the Lower Jurassic in the sections of the Omolon pluton and western Okhotsk region in the northeast (Repin and Polubotko, 1996) is the most complete and serves as a Lower Jurassic standard for almost all the regions of Russia, including northern Siberia. The Lower Jurassic contains zones matching those in the international standard.

On the basis of the generic sequence *Psiloceras–Alsatites–Schlotheimia*, the P. planorbis, A. liasicus, and Sch. angulata Standard Zones were distinguished within the Hettangian. The Lower Hettangian is known in Siberia by the presence of *Psiloceras* species in the Olenek River mouth (Dagys et al., 1980), near the Kelimyar River, and the Lena and Buur River basins (Knyazev et al., 1991). The Sinemurian encompasses three zones: Arietites libratus, Coroniceras siverti, and Angulaticeras kolymicum. The Lower/Upper substage boundary is placed in the upper Coroniceras siverti Zone.

The Pliensbachian is inhomogeneously constrained by ammonites. The Lower Pliensbachian in the northeast (Sei et al., 2006) is divided into *Polymorphites* beds, which were also distinguished previously (Stratigraphy, 1976), and the overlying *Fanninoceras* spp. beds, which have not been found in Siberian sections. The Upper Pliensbachian contains various *Amaltheus* (Amaltheidae) species, including local ones, and the endemic subgenus *Nordamaltheus* Repin. The substage encompasses three zones, which reflect the sequence of *Amaltheus* species: A. stokesi, A. margaritatus, and A. viligaensis. The two lower zones are also identified by *Amaltheus* finds in northern Siberia, near Nordvik Bay, and in the basins of the Anabar River, the Anabar estuary, and the Olenek River. The presence of all three Upper Pliensbachian zones in Siberia was established reliably with the help of ammonites only in the Lena River basin (Zhigansk district; the Syungyude and Molodo Rivers) (Knyazev et al., 1991).

Global transgression in the Northern Hemisphere in the late Early Jurassic caused the extensive development of the Toarcian Stage in northeastern Russia and northern Siberia. A Toarcian zonal standard was suggested for northeastern Asia in (Knyazev et al., 2003). The ammonite scale reflects the evolution of three subfamilies: Harpoceratinae, Dactylioceratinae, and Coeloceratinae. The first one is represented in the lower Toarcian by the genus *Tiltoniceras*, followed by *Eleganticeras*, *Harpoceras*, and *Pseudolioceras*. The third genus, which is the longest lived, forms a chain of species which serve as index ones in the Lower and Upper Toarcian, Aalenian, and lower Bajocian. The upper Lower Toarcian on the scales for northeast Russia and northern Siberia is conventionally identified by the species *Dactylioceras commune* and *Zugodactylites braunianus* (Dactylioceratidae), which are equivalent to the Hildoceras bifrons Zone in the international standard (Knyazev et al., 2003). Both genera are widespread in circumpolar basins, and the species which also occur in Western Europe permit direct comparison with the international zonal standard.

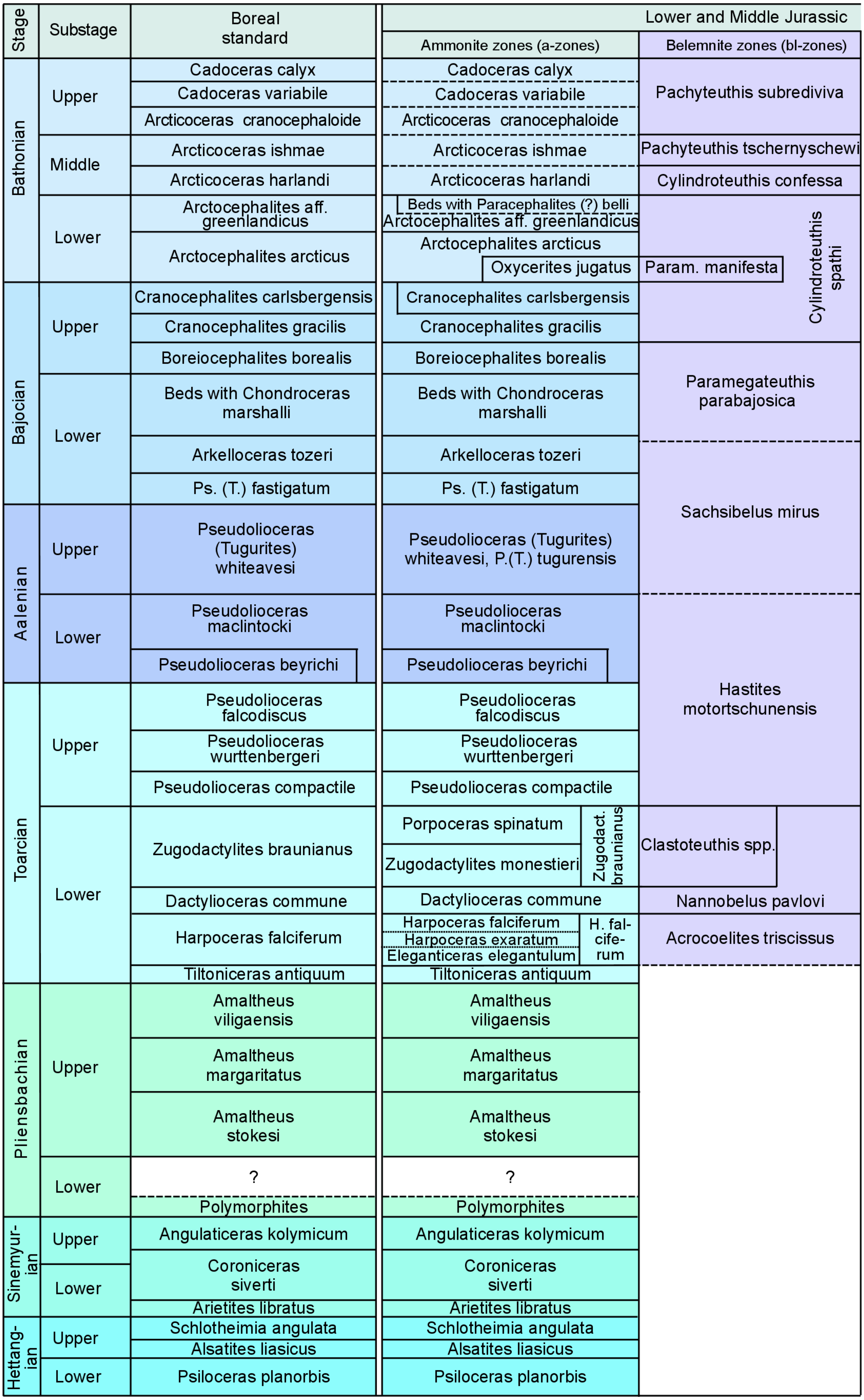
Since the Late Toarcian, only the genus *Pseudolioceras* existed in the Arctic seas, and this casts doubt upon the knowledge of the volume and subdivision of the Upper Toarcian. In the northeast, in the Kolyma River basin, the Upper Toarcian was divided into three zones (Polubotko and Repin, 1993) with an arbitrary position and volume. Almost simultaneously another tripartite subdivision appeared for the Upper Toarcian of northeastern Russia and northern Siberia, where, contrary to the above-mentioned subdivision, Western European species were the index ones (Knyazev, 1991; Knyazev et al., 1991, 2003). Considering that V.G. Knyazev's ammonite zonal scale for the Upper Toarcian correlates with the bivalve, foraminiferal, ostracod, and microphytofossil zones distinguished simultaneously in the same sections, this scale is still incorporated into the regional scale for northern Siberia and into the Boreal Jurassic zonal standard (Resolution, 2004; Shurygin et al., 2000; Zhamoida and Petrov, 2008).

In the Middle Jurassic, there was a considerable change in the taxonomic composition of ammonites in the Arctic seas because of their isolation from the Western European ones (Meledina et al., 2005). Here, European genera and species were nearly absent. At the same time, the connection with the northern Paleopacific became closer.

The Aalenian in the Boreal Jurassic, except its bottom, is constrained by the ammonite subgenus *Pseudolioceras* (*Tugurites*). The Aalenian zonation was originally developed for the Russian Far East and northeastern Russia, but it also proved to be applicable to northern Siberia (Stratigraphy, 1976). The Lower Aalenian is taken to be equal to one zone (Pseudolioceras (T.) maclintocki), whose lower part contains *P.* (P.) *beyrichi* beds. These beds are sometimes interpreted as an independent zone (Zakharov et al., 2010; Zhamoida and Petrov, 2008). Considering that *P.* (P.) *beyrichi* is also recorded in the Upper Toarcian, it is suggested to constrain the Lower Aalenian by the species *P.* (T.) *maclintocki* (Knyazev et al., 2003). As regards the *P.* (P.) *beyrichi* beds, it is reasonable to interpret them as nominal beds at the Upper Toarcian–Lower Aalenian boundary.

The Upper Aalenian is more widespread in northern Russia and the Russian Far East than the Lower Aalenian. It encompasses one zone: in East Asia, P. (Tugurites) tugurense; in northern Siberia, P. (T.) whiteavesi. These species cooccur in the northeast, but only the latter is found in the north (Shurygin et al., 2000). We are not warranted in believing that the *T. tugurense* beds are confined to the upper T. whiteavesi Zone, as suggested later (Zakharov et al., 2010; Zhamoida and Petrov, 2008).

The lower Bajocian contains the P. (T.) fastigatum Zone, whose bottom marks the lower boundary of the Boreal



Stage	Substage	Boreal standard	Lower and Middle Jurassic	
			Ammonite zones (a-zones)	Belemnite zones (bl-zones)
Bathonian	Upper	Cadoceras calyx	Cadoceras calyx	Pachyteuthis subrediviva
		Cadoceras variabile	Cadoceras variabile	
		Arcticoceras cranocephaloide	Arcticoceras cranocephaloide	
	Middle	Arcticoceras ishmae	Arcticoceras ishmae	Pachyteuthis tschernyschewi
		Arcticoceras harlandi	Arcticoceras harlandi	Cylindroteuthis confessa
	Lower	Arctocephalites aff. greenlandicus	Beds with Paracephalites (?) belli Arctocephalites aff. greenlandicus	Cylindroteuthis spathi
		Arctocephalites arcticus	Arctocephalites arcticus Oxycerites jugatus	Param. manifesta
Bajocian	Upper	Cranocephalites carlsbergensis	Cranocephalites carlsbergensis	
		Cranocephalites gracilis	Cranocephalites gracilis	
		Boreiocephalites borealis	Boreiocephalites borealis	Paramegateuthis parabajosica
	Lower	Beds with Chondroceras marshalli	Beds with Chondroceras marshalli	
		Arkelloceras tozeri	Arkelloceras tozeri	Sachsibelus mirus
		Ps. (T.) fastigatum	Ps. (T.) fastigatum	
Aalenian	Upper	Pseudolioceras (Tugurites) whiteavesi	Pseudolioceras (Tugurites) whiteavesi, P.(T.) tugurensis	
	Lower	Pseudolioceras maclintocki	Pseudolioceras maclintocki	Hastites motortschunensis
		Pseudolioceras beyrichi	Pseudolioceras beyrichi	
Toarcian	Upper	Pseudolioceras falcodiscus	Pseudolioceras falcodiscus	
		Pseudolioceras wurttenbergeri	Pseudolioceras wurttenbergeri	
		Pseudolioceras compactile	Pseudolioceras compactile	
	Lower	Zugodactylites braunianus	Porpoceras spinatum Zugodactylites monestieri Zugodact. braunianus	Clastoteuthis spp.
		Dactylioceras commune	Dactylioceras commune	Nannobelus pavlovi
		Harpoceras falciferum	Harpoceras falciferum Harpoceras exaratum Eleganticeras elegantulum H. falciferum	Acrocoelites triscissus
		Tiltoniceras antiquum	Tiltoniceras antiquum	
Pliensbachian	Upper	Amaltheus viligaensis	Amaltheus viligaensis	
		Amaltheus margaritatus	Amaltheus margaritatus	
		Amaltheus stokesi	Amaltheus stokesi	
	Lower	?	?	
		Polymorphites	Polymorphites	
Sinemurian	Upper	Angulaticeras kolymicum	Angulaticeras kolymicum	
	Lower	Coroniceras siverti	Coroniceras siverti	
		Arietites libratus	Arietites libratus	
Hettangian	Upper	Schlotheimia angulata	Schlotheimia angulata	
		Alsatites liasicus	Alsatites liasicus	
	Lower	Psiloceras planorbis	Psiloceras planorbis	

Fig. 3. Jurassic zonal scales for Siberia and the Boreal standard.

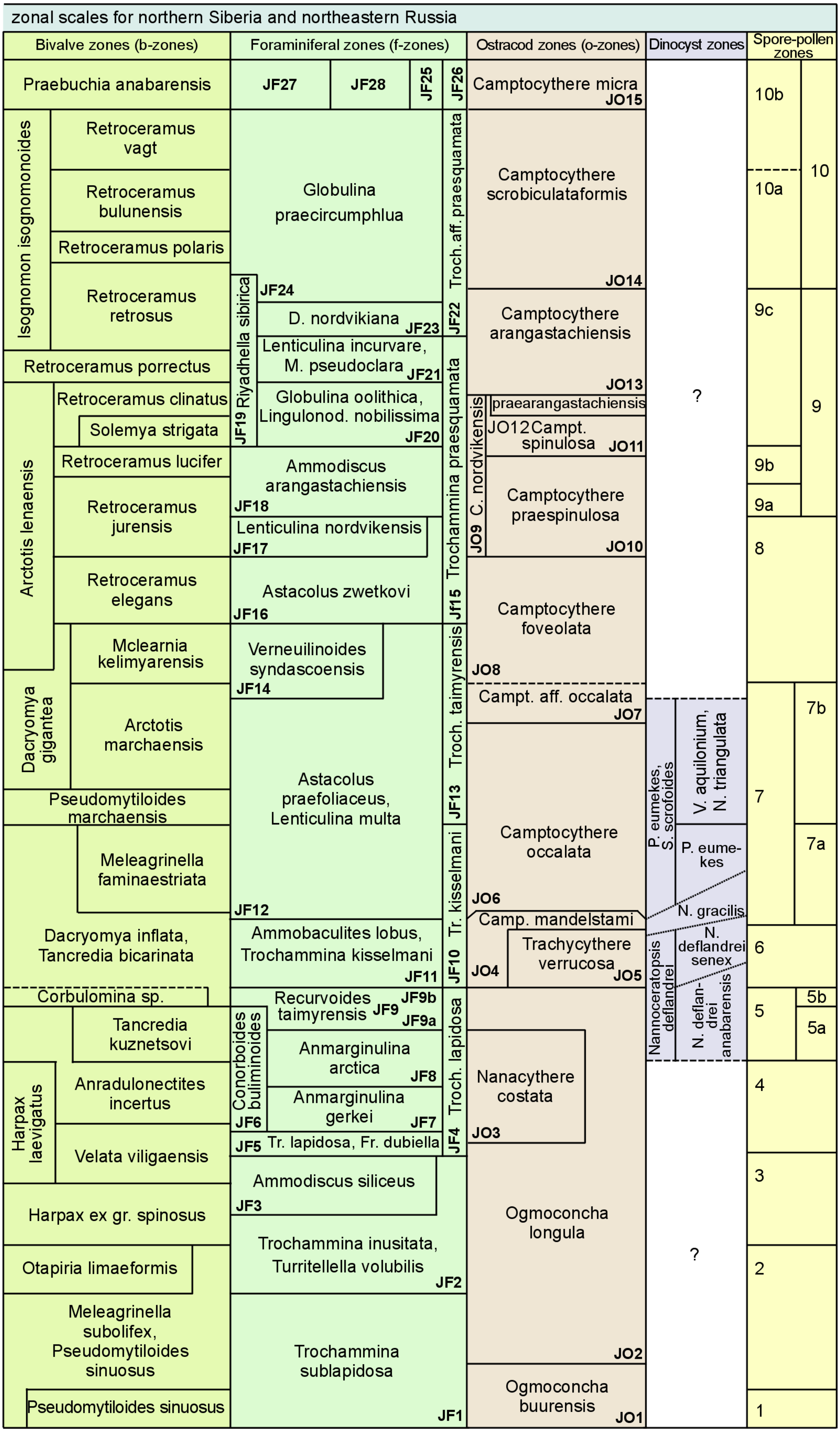
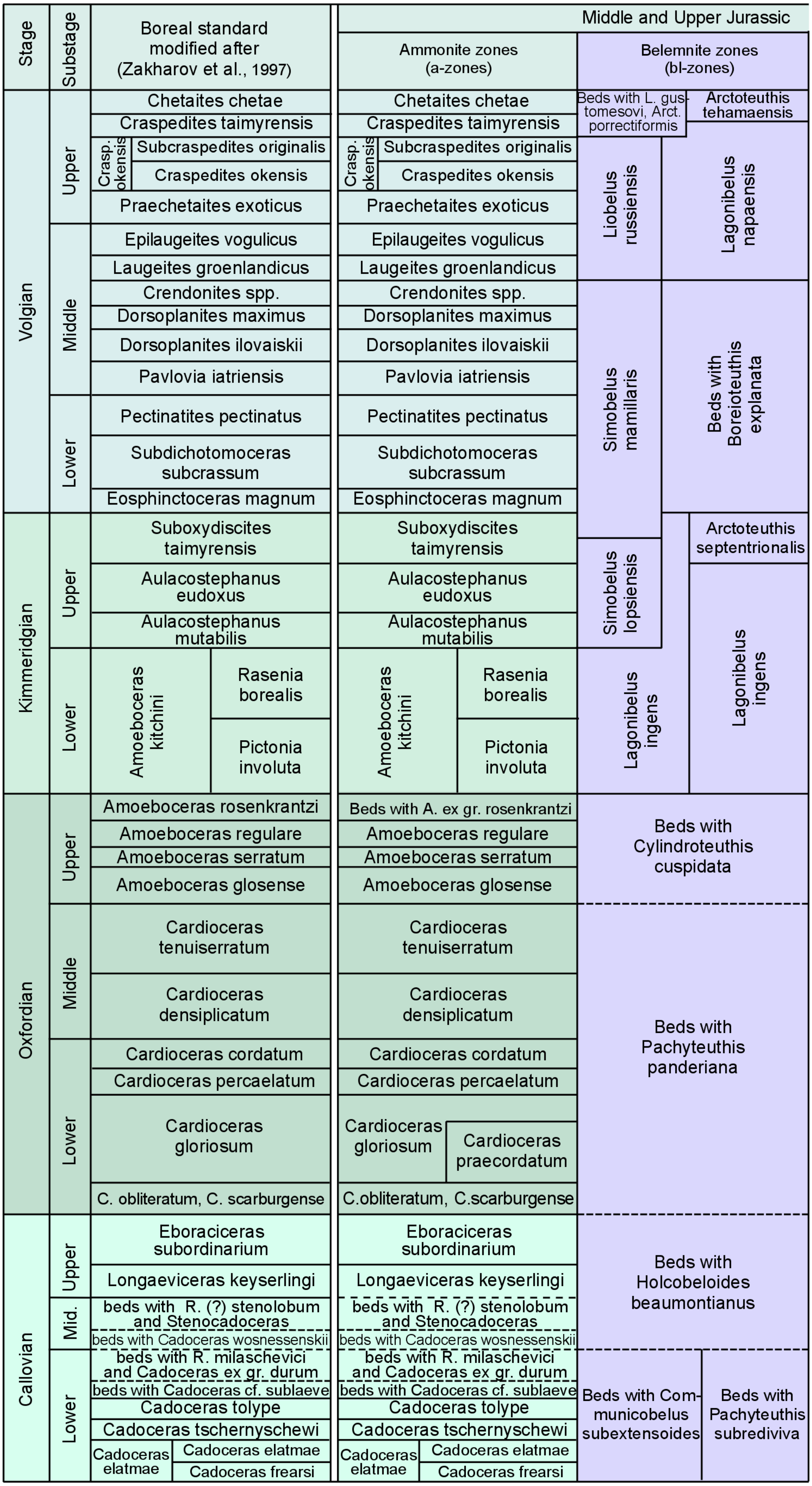


Fig. 3 (continued).



Stage	Substage	Boreal standard modified after (Zakharov et al., 1997)		Middle and Upper Jurassic			
				Ammonite zones (a-zones)		Belemnite zones (bl-zones)	
Volgian	Upper	Chetaites chetae		Chetaites chetae		Beds with L. gustomesovi, Arct. porrectiformis	Arctoteuthis tehamaensis
		Craspedites taimyrensis		Craspedites taimyrensis			Lagonibelus napaensis
		Crasp. okensis	Subcraspedites originalis	Crasp. okensis	Subcraspedites originalis	Liobelus russiensis	
			Craspedites okensis		Craspedites okensis		
		Praechetaites exoticus		Praechetaites exoticus			
	Middle	Epilaugeites vogulicus		Epilaugeites vogulicus			
		Laugeites groenlandicus		Laugeites groenlandicus			
		Crendonites spp.		Crendonites spp.		Simobelus mamillaris	Beds with Boreioteuthis explanata
		Dorsoplanites maximus		Dorsoplanites maximus			
		Dorsoplanites ilovaiskii		Dorsoplanites ilovaiskii			
		Pavlovia iatriensis		Pavlovia iatriensis			
	Lower	Pectinatites pectinatus		Pectinatites pectinatus			
		Subdichotomoceras subcrassum		Subdichotomoceras subcrassum			
		Eosphinctoceras magnum		Eosphinctoceras magnum			
Kimmeridgian	Upper	Suboxydiscites taimyrensis		Suboxydiscites taimyrensis		Simobelus lopsiensis	Arctoteuthis septentrionalis
		Aulacostephanus eudoxus		Aulacostephanus eudoxus			Lagonibelus ingens
		Aulacostephanus mutabilis		Aulacostephanus mutabilis			
	Lower	Amoeboceras kitchini	Rasenia borealis	Amoeboceras kitchini	Rasenia borealis	Lagonibelus ingens	
			Pictonia involuta		Pictonia involuta		
Oxfordian	Upper	Amoeboceras rosenkrantzi		Beds with A. ex gr. rosenkrantzi		Beds with Cylindroteuthis cuspidata	
		Amoeboceras regulare		Amoeboceras regulare			
		Amoeboceras serratum		Amoeboceras serratum			
		Amoeboceras glosense		Amoeboceras glosense			
	Middle	Cardioceras tenuiserratum		Cardioceras tenuiserratum		Beds with Pachyteuthis panderiana	
		Cardioceras densiplicatum		Cardioceras densiplicatum			
	Lower	Cardioceras cordatum		Cardioceras cordatum			
		Cardioceras percaelatum		Cardioceras percaelatum			
		Cardioceras gloriosum		Cardioceras gloriosum	Cardioceras praecordatum		
		C. obliteratum, C. scarburgense		C.obliteratum, C.scarburgense			
Callovian	Upper	Eboraciceras subordinarium		Eboraciceras subordinarium		Beds with Holcobeloides beaumontianus	
		Longaeviceras keyserlingi		Longaeviceras keyserlingi			
	Mid.	beds with R. (?) stenolobum and Stenocadoceras		beds with R. (?) stenolobum and Stenocadoceras			
		beds with Cadoceras wosnessenskii		beds with Cadoceras wosnessenskii			
	Lower	beds with R. milaschevici and Cadoceras ex gr. durum		beds with R. milaschevici and Cadoceras ex gr. durum		Beds with Communicobelus subextensoides	Beds with Pachyteuthis subrediviva
		beds with Cadoceras cf. sublaeve		beds with Cadoceras cf. sublaeve			
		Cadoceras tolype		Cadoceras tolype			
		Cadoceras tschernyschewi		Cadoceras tschernyschewi			
		Cadoceras elatmae	Cadoceras elatmae	Cadoceras elatmae	Cadoceras elatmae		
			Cadoceras frearsi		Cadoceras frearsi		

Fig. 3 (*continued*).

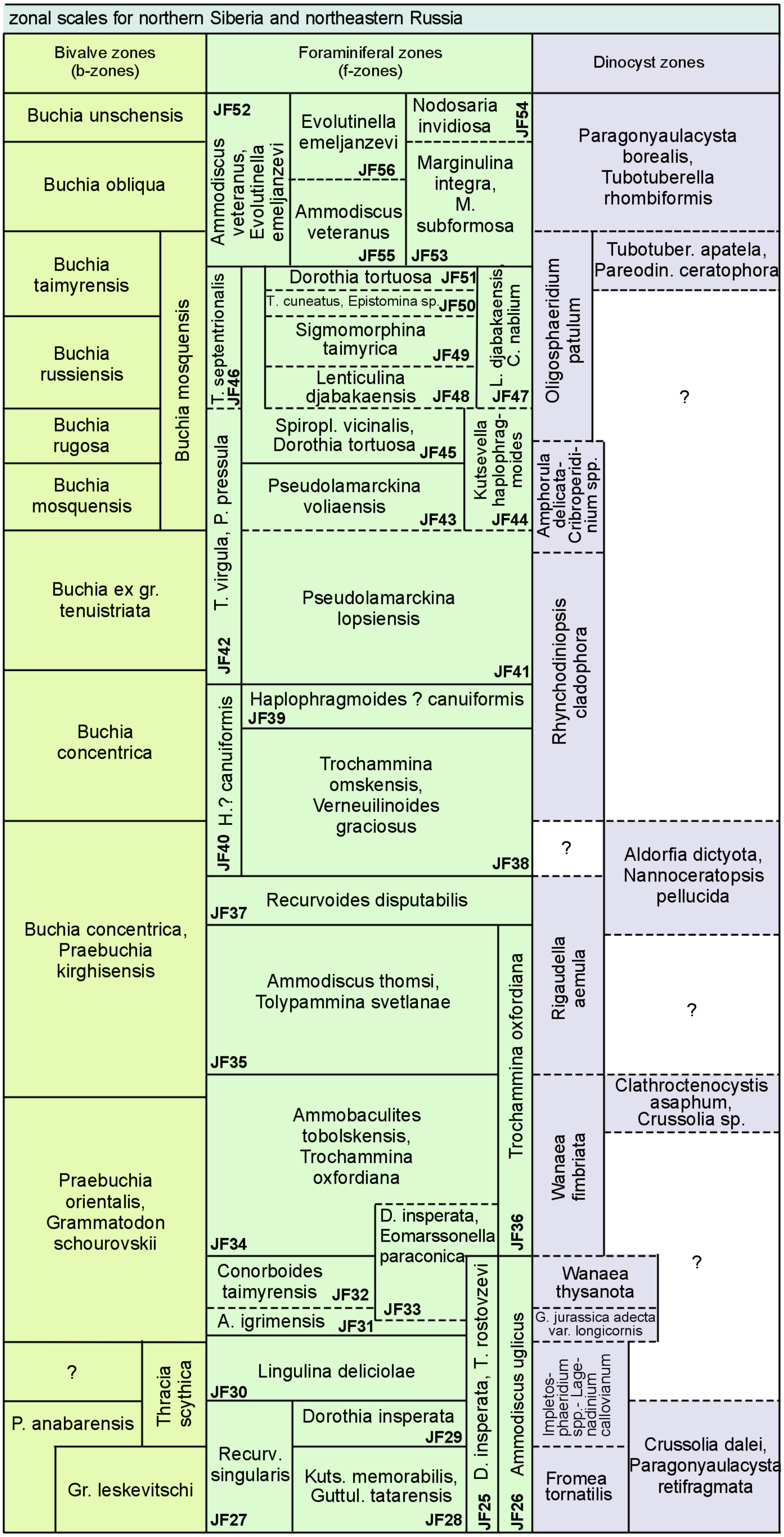


Fig. 3 (*continued*).

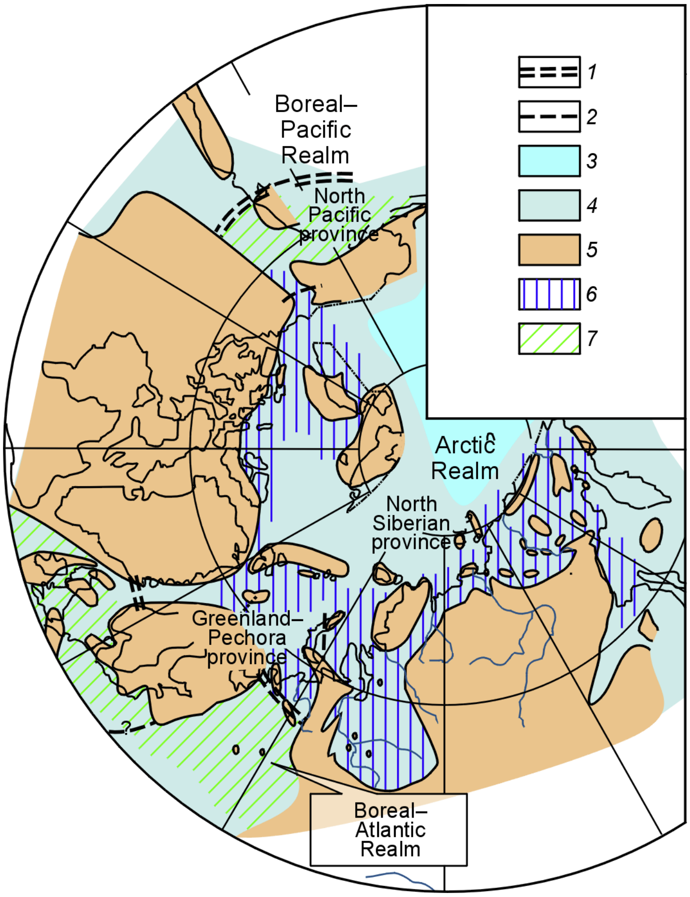


Fig. 4. Jurassic regions with a predominantly Arctic fauna (coverage zone of the Siberian scales). The biogeographic setting in the Arctic basin is shown for the Callovian. *1*, realm boundaries; *2*, provincial boundaries; *3*, South Anyui Ocean; *4*, epicontinental seas; *5*, land; *6*, predominantly Arctic fauna; *7*, mixed Lower Boreal and Arctic fauna.

Bajocian. The overlying part of the Lower Bajocian is constrained by rare ammonites, which make up the Arkelloceras tozeri and Chondroceras marschalli Local Zones in the northeast (Sei et al., 2006). They are also both shown in the regional charts of northern Siberia and the Russian Far East, though the latter was denoted as *Ch. marschalli* beds (Shurygin et al., 2000; Zhamoida and Petrov, 2008). The A. tozeri Zone occurs the most widely and is coeval with the Otoites sauzei Standard Zone, as demonstrated in Canadian sections (Hall, 1984). The presence of this zone in Siberia is confirmed in the Anabar area by finds of ammonites very similar to the genus *Arkelloceras*; they were originally described as *Erycitoides* and then renamed *Arkelloceras* (?) (Shurygin et al., 2000).

The upper Lower Bajocian, which corresponds to the northeastern Ch. marschalli Zone and the Stephanoceras humphriesianum Standard Zone, is constrained in the Anabar area by *Normannites* sp. and *Stephanoceras* sp. (Meledina, 1994).

The Lower/Upper Bajocian boundary is marked by the appearance of the highly specialized subfamily Arctocephalitinae of the family Cardioceratidae. Arctocephalitinae form the generic sequence *Boreiocephalites–Cranocephalites–Arctocephalites–Arcticoceras*, which is replaced by the genus *Cadoceras* (Cadoceratinae) in the Upper Bathonian. The most complete and ammonite-richest sections are located in northern Siberia, where a zonal succession for the Upper Bajocian and Bathonian was established. The regional zones cannot be correlated directly with the standard ones for lack of common species. The zone-by-zone correlation of the Siberian and standard scales is quite arbitrary: the morphologic similarity of the genera *Chondroceras* and *Boreiocephalites* is interpreted as a sign of their stratigraphic proximity and suggests that *Boreiocephalites* occur at a higher level than the Lower Bajocian *Chondroceras* (approximately at the level of the Upper Bajocian Strenoceras niortense Zone). In the lower Arctocephalites arcticus Zone, the presence of the genus *Oxycerites*, which is represented by ammonites close to the Lower Bathonian species *O. aspidoides* from Western Europe, suggests that the zone should be assigned to the Lower Bathonian (approximately in the lower Zigzagiceras zigzag Zone).

The Siberian zones located between B. borealis and A. arcticus as well as the subsequent Boreal Bathonian zones are correlated with the standard-scale zones only roughly, and the correlation is the subject of ongoing debate. The latest regional charts (Resolution, 2004; Shurygin et al., 2000) use the correlation chart by S.V. Meledina (1994).

The Arctocephalites Zones belong to the Lower Bathonian, and the underlying Cranocephalites gracilis Zone of Siberia, which is equivalent to two zones from eastern Greenland (C. indistinctus, C. pompeckji), belongs to the upper Upper Bajocian (Garantiana garantiana) and Parkinsonia parkinsoni Zones in the standard). The overlying zones with *Arcticoceras* (*A. harlandi*, *A. ishmae*) are assigned to the Middle Bathonian. Experts on the Jurassic of European Russia suggest dating all these zones as more ancient (Mitta et al., 2004). In the Saratov Volga region, the genus *Arcticoceras* was found over the Oraniceras besnosovi Local Zone, which correlates with the Bathonian bottom in the standard. This is why the A. ishmae and A. harlandi Zones should be transferred to the Lower Bathonian. The complete or partial Early Bathonian age of the A. ishmae Zone is also confirmed paleomagnetically (Zakharov et al., 2010). We recommended that one not hasten to modify the accepted correlation chart (Meledina et al., 2009).

The Boreal Upper Bathonian zonation for northern East Siberia has been refined recently. A zonal succession equivalent to that from eastern Greenland has been recorded: Arcticoceras cranocephaloide, Cadoceras variabile, and C. calyx (Knyazev et al., 2009). The Bathonian/Callovian boundary has been placed between the zones C. calyx and C. elatmae. Also, the Lower Callovian zonation for northern Siberia has been changed considerably. A unified scale for northern Siberia has been offered, which comprises the C. elatmae Zone with the C. frearsi and C. elatmae (instead of the former C. anabarense) Subzones, the C. tschernyschewi and C. tolype Zones, *C.* cf. *sublaeve* beds and those with *Rondiceras milaschevici* and *Cadoceras* ex gr. *durum* Buckm. (part of the former Middle Callovian).

The presence of the species *C. elatmae* (Nik.), *C. frearsi* (Orb.), *C. tolype* Buckm., and *C. emelianzevi* Vor. both in Siberia and in Eastern and Western Europe permits direct correlation of some Siberian zones with the ones in eastern Greenland and the standard ones. Therefore, the part of the interval which used to be assigned to the Middle Callovian belongs to the upper Lower Callovian, which is complete in Siberia (Knyazev et al., 2010). The Callovian ammonite succession of northern Siberia, like the Bathonian one, is a standard for the Russian Boreal regions. New data on the zonal structure of the Upper Bathonian and Lower Callovian in northern Siberia, supported by ammonite studies, should be reflected in the modern Boreal standard.

The Middle Callovian has a limited distribution in northern Siberia. The most complete section is located on Bol'shoi Begichev Island. The Middle Callovian was also recorded on the eastern Taimyr Peninsula, near the Chernokhrebetnaya River, in the Olenek River basin, on Franz Josef Land, and on Novaya Zemlya.

The Middle Callovian in the Siberian sections was constrained by the species *Rondiceras tscheffkini* (Orb.), *R. taimyrense* (Meled.), *Stenocadoceras* spp., and individual *Pseudocadoceras* species. The species *Cadoceras nikolajevi* Bodyl., *C. wosnessenskii* (Grew.), and *C. declinatum* Voron. were also interpreted as Middle Callovian. However, most of the dates applied to isolated ammonite finds which were not associated with a particular section; therefore, the dating was arbitrary.

In recent years the Middle Callovian has been studied extensively by experts in European Russia (Kiselev, 2001; and others). Detailed scales have been developed for the Middle Callovian, with zones, subzones, and faunal horizons correlating well with the zones and intrazonal units of the international standard, because the East European sections contain various *Kosmoceras* and *Erymnoceras* species (the latter serve for distinguishing Middle Callovian zones and subzones in the standard). Some species from Siberia, Alaska (Imlay, 1953), and Arctic Canada (Frebold, 1964), which used to be interpreted as Lower or Upper Callovian, are now interpreted as Middle Callovian. Also, these species were assigned to different genera (*Cadoceras*, *Longaeviceras*, or *Rondiceras*).

According to modern data on the stratigraphic ranges of some Cardioceratidae species, part of the sediments which used to be assigned to the Middle Callovian should belong to the Lower Callovian (Knyazev et al., 2010). This conclusion was supported by new ammonite finds and revisions of the previous data. An ammonite was reidentified as *Cadoceras* ex gr. *durum* Buckm.; it had been assigned to *Erymnoceras*, but it was, in fact, the coarse-ribbed inside of the phragmocone of a large smooth *Cadoceras* shell. The sections in European Russia demonstrated that the species *Rondiceras milaschevici* and *R. tscheffkini* were typical not only of the Middle Callovian but also, partly, of the Lower Callovian. Therefore, it is wrong to use this species as a Middle Callovian index in the Boreal standard (Zakharov et al., 2005; Zhamoida and Petrov, 2008). Now it is suggested to place the Lower/Middle Callovian boundary along the top of the *Cadoceras* ex gr. *durum* Buckm. beds, which were recorded in place of the former *Rondiceras milaschevici* and *Erymnoceras* beds. These beds are overlain by Middle Callovian *Rondiceras* beds (Knyazev et al., 2010).

During the last field season (2010), Knyazev found a continuous section of sediments with characteristic *Cadoceras* specimens overlying the Lower Callovian in the lower reaches of the section Ystannakh-Khocho. Since a sequence of species of this genus had been established in the Middle Callovian of European Russia, the Siberian ammonites were assigned to the Middle Callovian *Cadoceras wosnessenskii* (Grew.). The type locality of this species is southern Alaska, where it coexists with the Middle Callovian *Stenocadoceras* (Imlay, 1953). It was also found in European Russia by D.N. Kiselev in the Kosmoceras jason Zone. The presence of this species in the Callovian section near the settlement of Ystannakh-Khocho (Olenek Bay) proves the existence of *Cadoceras wosnessenskii* (Grew.) beds, which are equivalents of the lower Middle Callovian.

The existence of the overlying part of the Middle Callovian in Siberia is supported by ample evidence: first and foremost, ammonites from the eastern Taimyr Peninsula and Bol'shoi Begichev Island. Apparently, the upper Middle Callovian should be looked for at the bottom of the Upper Callovian Longaeviceras keyserlingi Zone, and this requires additional field studies. For the time being, it is reasonable to preserve the conventional names *Rondiceras* (?) *stenolobum* and *Stenocadoceras* for the corresponding beds (but not zone), as it was done in the latest Boreal standard (Zakharov et al., 2005; Zhamoida and Petrov, 2008). Thus, the Middle Callovian on the Siberian scale can be divided into two parts: *Cadoceras wosnessenskii* (Grew.) beds and those with *Rondiceras* (?) *stenolobum* and *Stenocadoceras*, the lowermost of which correspond to the lower Middle Callovian in the standard.

The Upper Callovian of Siberia encompass two zones: Longaeviceras keyserlingi and Eboraciceras subordinarium (Shurygin et al., 2000; Zakharov et al., 1997). For the Pechora River basin, there is a different subdivision of the Upper Callovian, which is based on the reidentification of Siberian ammonites; it is suggested to incorporate it into the Boreal ("Arctic") standard instead of the existing ones (Repin, 2007). However, the modifications of the ammonite classification suggested in (Repin, 2007) are dubious and require checking. For the time being, it is reasonable to preserve the existing zones on the Siberian scale and possibly incorporate them into the Boreal standard instead of the Peltoceras athleta and Quenstedtoceras lamberti Zones, which are constrained in eastern Greenland by European species and coincide with the standard ones.

The Upper Jurassic begins with the Oxfordian Stage. The lower boundary of the Oxfordian is marked by the appearance of the subfamily Cardioceratinae (genus *Cardioceras*). The Oxfordian sediments are widespread in Siberia and northeastern Russia, but the section is often shortened because of numerous outwashes. The zonation of the Lower Oxfordian units of Siberia was developed by Knyazev (Kniazev, 1975). The standard sections are located in the Anabar River basin and on the eastern Taimyr Peninsula. The Siberian zones were also transferred to the Boreal standard. The Lower Oxfordian scale for Siberia has not changed of late: the Cardioceras obliteratum Zone; the C. gloriosum Zone with the C. praecordatum Lower Subzone; the C. percaelatum and C. cordatum Zones. The British bipartite subdivision of the Lower Oxfordian (Zakharov et al., 2005) seems unsuitable and unnecessary for Siberia.

The Middle and Upper Oxfordian zonation was developed in Scotland (Isle of Skye) and eastern Greenland (Sykes and Callomon, 1979; Sykes and Surlyk, 1976). It can be used almost without changes for the sections of Spitsbergen, Franz Josef Land, the eastern Taimyr Peninsula, the Anabar River basin, West Siberia, and other localities where the Oxfordian is fragmentary. Regional charts do not always use the same zonal indices, but zone-by-zone correlations, including those with the Boreal standard reflecting the Scottish zonal succession, as a rule, present no difficulties.

The Oxfordian type section of Siberia is located near the Chernokhrebetnaya River (eastern Taimyr Peninsula), where all three substages and the constituent zones were stripped. The researchers A.N. Aleinikov and S.V. Meledina (1993) developed a detailed zonation of the Middle and Upper Oxfordian on the eastern Taimyr Peninsula. The Cardioceras densiplicatum and C. tenuiserratum Zones were revealed in the Middle Oxfordian, and the Upper Oxfordian encompasses the Amoeboceras glosense Zone with two subzones (A. ilovaiskii, A. glosense); the A. serratum and A. regulare Zones and *A.* ex gr. *rosenkrantzi* beds. All these zones are present in the Oxfordian of the Siberian scale (the Oxfordian is topped by the A. ex gr. rosenkrantzi Zone, which is equivalent to that in eastern Greenland). Exactly this structure of the Middle and Upper Oxfordian is shown on the biostratigraphic scale for the Siberian Jurassic and in the Boreal standard (Shurygin et al., 2000; Zakharov et al., 1997).

The correlation boundaries of Boreal and Subboreal (standard) zones have been changed recently. This has been done on the basis of new data on the Middle–Upper Oxfordian of the East European craton, where an international expert group studied Oxfordian outcrops in the Kostroma Region (near the settlement of Mikhalenino). Here, the Middle and Upper Oxfordian contain numerous ammonites, which comprise exclusively Boreal Cardioceratidae and Subboreal Aulacostephaninae; locally also Mediterranean Perisphinctidae, Oppeliidae, and Aspidoceratinae (Glowniak et al., 2010). The authors have developed a detailed scale, with the Boreal zones divided into subzones and faunal horizons, and refined the correlation chart. In the latest Jurassic Boreal standard (Zhamoida and Petrov, 2008), all the Middle and Upper Oxfordian Boreal zones are preserved, which we consider absolutely correct.

The Kimmeridgian zonal scale was developed for the Cispolar Urals (Mesezhnikov, 1984). Exactly this scale is a standard incorporated into all the Siberian boiostratigraphic charts and into the Boreal standard (Resolution, 2004; Shurygin et al., 2000; Zakharov et al., 1997).

The Lower Kimmeridgian encompasses the Amoeboceras kitchini Zone with two subzones: Pictonia involuta and Rasenia borealis. The Oxfordian/Kimmeridgian boundary was marked by the appearance of *Amoeboceras* from the *A. kitchini* group, which replace the Oxfordian species of this genus. For the western Panboreal Realm (eastern Greenland, Spitsbergen, southwestern Barents Sea shelf), an independent *Amoeboceras* zonation was developed for the Kimmeridgian (Wierzbowski, 1989; Wierzbowski and Smelror, 1993).

The Upper Kimmeridgian, which is zoned in Siberia on the basis of *Aulacostephanus* species (Perisphinctidae), encompasses the parallel Amoeboceras (Euprionoceras) kochi and A. (Hoplocardioceras) elegans Zones, each of them divided into two faunal horizons. In the latest Boreal standard (Zhamoida and Petrov, 2008), the Kimmeridgian encompasses Amoeboceras and Aulacostephanus Parallel Zones.

The Boreal Upper Kimmeridgian is topped by the Suboxydiscites (former Oxydiscites) taimyrensis Zone, as established previously for the eastern Taimyr Peninsula and the Khatanga basin and recently for the Pechora River basin, the Nordvik Peninsula, and the western Spitsbergen and the Barents Sea shelf (Rogov and Wierzbowski, 2009; Zakharov et al., 2010). This zone is equivalent to the Aulacostephanus autissiodorensis Zone in the international standard.

The Volgian Stage is still studied permanently and comprehensively in various Russian regions. The greatest changes to its zonation were made owing to the reinvestigation of the Volgian in the Russian Plate and at some Siberian localities. On the Siberian scale, the Volgian encompasses the zones recorded in the Northern and Cispolar Urals (Mesezhnikov, 1984). In the Lower Volgian, the most prominent Pectinatites pectinatus Top Zone is considered the Siberian equivalent of the Eastern European zone in the stage stratotype. The researcher M.S. Mesezhnikov (1984) pointed out the presence of the Lower Volgian genera *Subdichotomoceras* and *Eosphinctoceras* in the Khatanga River basin, which were older than *Pectinatites*, suggesting that the Lower Volgian was more complete and widespread in Siberia and not confined to its upper part with *Pectinatites*. Later the genus *Pectinatites* was recorded in the Cispolar Urals in the two lower zones of the Lower Volgian, and V.A. Zakharov et al. (2005) incorporated equivalent zones constrained by *Pectinatites* species into the Lower Volgian of the renewed Jurassic zonal standard instead of the two conventional lower Siberian zones. A complete succession of these zones was recorded in Great Britain and France; a less complete one, in eastern Greenland (Zhamoida and Petrov, 2008). However, in our view, it is preferable that the E. magnum, S. subcrassum, and P. pectinatus Zones be preserved in the Lower Volgian of the Urals scale and, consequently, on the unified Siberian scale and in the Boreal standard in the volume attributed to them now. Thus, the two lower zones in the Lower Volgian of northern Siberia are now E. magnum and S. subcrassum. The former correlates with the lower part of the Ilovaiskya klimovi Standard Zone; the latter, with its upper part as well as the I. sokolovi Zone and the lower I. pseudoscythicus Zone (Zakharov et al., 2010).

The Middle Volgian is divided into six zones based on ammonites of the subfamily Dorsoplanitinae: Pavlovia iatriensis, Dorsoplanites ilovaiskii, D. maximus, Taimyrosphinctes excentricus, Laugeites groenlandicus, and Epilaugeites vogulicus. However, the T. excentricus Zone was distinguished only for western Siberia (central and eastern Taimyr Peninsula, Anabar River basin), whereas *Dorsoplanites sachsi* is cited (Krymholts et al., 1988) as the zonal index for eastern Siberia (lower reaches of the Lena River, Lena–Olenek interfluve). In later papers the Siberian scale contained the T. excentricum Unified Zone (Shurygin et al., 2000; Zakharov et al., 1997, 2010). In the Cispolar Urals, it was replaced by the Crendonites spp. Zone, which was later incorporated into the Boreal standard (Zakharov et al., 2005, 2010; Zhamoida and Petrov, 2008).

The correlation chart of the Siberian zones and the Middle Volgian zones in the Volga River stratotype have been modified recently. For example, the L. groenlandicus and E. vogulicus Zones, which used to be considered equivalent to the E. nikitini Zone, are interpreted in the latest charts as corresponding to this zone, except its upper part. The volume of the Middle Volgian on the Siberian scale increased, because the Praechetaites exoticus Zone was transferred from the Upper to the Middle Volgian (Zhamoida and Petrov, 2008; Zakharov et al., 2010). To the P. exothicus Zone, the authors assigned not only the section interval constrained exclusively by *Praechetaites* species but also the underlying interval, where *Praechetaites* coexist with the typical Middle Volgian *Laugeites*. The P. exoticus Zone was originally found in the Kheta River basin as beds containing exclusively *Praechetaites* (Saks, 1969). These authors extended the obvious conclusion about the Middle Volgian age of the lower beds, where *Praechetaites* and *Laugeites* coexisted, to the overlying interval which contained only *Praechetaites*. Note that this interval was found in the Volgian not only in the Kheta River basin but also on western Spitsbergen Island (Rogov, 2010). Therefore, if the entire interval between the Laugeites groenlandicus and Craspedites okensis Zones, which is differently ammonite-constrained in its lower and upper parts, is incorporated into the Middle Volgian, this does not seem convincing. It would be more correct to interpret the lower Middle Volgian as a separate zone (or subzone) and to preserve the P. exoticus Zone, in accordance with the original understanding, as *Praechetaites* spp. beds (Meledina et al., 2010).

The Upper Volgian units of Siberia encompass the Craspedites okensis, C. taimyrensis, and Chetaites chetae Zones, the first one comprising the C. okensis and C. originalis Subzones. The level of the mass appearance of *Craspedites* is underlain by the P. exoticus Zone (Subzone), which is interpreted either as topping the Middle Volgian or as opening the Upper Volgian.

The Jurassic/Cretaceous boundary in areas with the Volgian Stage remains a subject of animated discussion. The latest, convincing enough, evidence that this boundary lies within the C. taimyrensis Zone has been obtained from the Siberian type section of the Jurassic/Cretaceous boundary sediments on the Nordvik Peninsula (Houša et al., 2007).

Parallel zonal scales based on parastratigraphic groups

By the early 1980s, after many-year studies, paleontologists from the Institute of Geology and Geophysics, NIIGA, ZapSibNIGNI, SNIIGGiMS, VNIGRI, and other organizations developed Jurassic biostratigraphic scales for West and East Siberia based on parastratigraphic groups (Regional..., 1981; Saks, 1981; Stratigraphy, 1976). Now the belemnite, bivalve, and microfaunal scales have become considerably more detailed.

Belemnites are one of the most widespread fossil groups, and they are well preserved in Jurassic strata. They can abound where ammonites, buchias, and other biostratigraphically important macrofossils are absent or rare. Therefore, belemnite zonal scales for the Siberian Jurassic have been developed intensely over the last few decades (Dzyuba, 2000, 2004, 2011; Meledina et al., 1991; Nal'nyaeva, 1986; Shenfil', 1995). The succession of belemnite zones and beds is the part of the parallel (independent) scales of the Boreal zonal standard (Shurygin et al., 2000; Zakharov et al., 1997).

In terms of biostratigraphic units, the belemnite zones are mainly interval zones, assemblage zones, or, less often, the taxon range zones and encompass from 1–2 ammonite zones to a substage or slightly more. Making a phylozone scale is now possible, but less necessary, because belemnites in individual lineages do not evolve rapidly enough to ensure a detailed subdivision of the sediments, whereas using transformations in different lineages makes it possible.

In the Lower Jurassic of Siberia (below the Toarcian), belemnite rostra are almost unknown, except individual rostrum-like finds taken for belemnites (Knyazev et al., 1991; Sachs and Nalnjaeva, 1975; and others). Note that belemnites are quite frequent in Western Europe in Lower Jurassic intervals below the Toarcian. Thus, they may well have occasionally penetrated the Siberian seas before the Toarcian, but their mass colonization and autochthonous evolution in Arctic paleobasins undoubtedly began in the Toarcian.

In the Toarcian, Middle Jurassic, and Upper Jurassic of Siberia, belemnites are among the permanent constituents of fossil assemblages in marine strata. Their distribution over the section and area is quite nonuniform. Abundant in the Toarcian, they become less abundant in the Aalenian fossil assemblages, are fairly rare in the Bajocian and frequent again in the Bathonian, Callovian, and Upper Jurassic.

Belemnites from the Toarcian and Middle Jurassic outcrops in the northern and eastern framing of the Siberian Platform are well studied (Sachs and Nalnjaeva, 1975; Saks and Nal'nyaeva, 1972; and others), and this permitted developing a belemnite zonation of this interval (Meledina et al., 1991; Nal'nyaeva, 1986; and others). Zonal successions for the Toarcian, Aalenian, and, partly, Bajocian and Bathonian are based on Megateuthididae, Passaloteuthididae, and Hastitidae, which are widespread in these sediments. Siberian belemnite zones can be traced in northeastern Russia. These scales have not changed considerably since the publication of the Boreal zonal standard (Zakharov et al., 1997) (Fig. 3).

The belemnite zonation of the Upper Bajocian, Bathonian, Callovian, Oxfordian, Kimmeridgian, and Volgian in Siberia is based on species of the family Cylindroteuthididae. The study of this family begun by V.N. Saks and T.I. Nal'nyaeva (1964, 1966) was continued (Dzyuba, 2004, 2011; and others). As a result, the Callovian–Upper Jurassic zonation was reworked considerably. The first belemnite zonation of the entire Callovian and Oxfordian was offered (Dzyuba, 2000, 2004). This is the only interval in the stratigraphic scale for the Jurassic sediments of the Siberia which uses West Siberian belemnite succession. Northern East Siberia is the reference locality for establishing all the other biostratigraphic successions.

Now nine biostratigraphic units are distinguished within the Kimmeridgian and Volgian of Siberia (Dzyuba, 2004, 2011). It has become customary to distinguish two parallel continuous belemnite successions (Fig. 3): this ensures a very detailed subdivision of the sediments and correlation of sections formed under different conditions.

As compared with the previous scale, which is part of the set of parallel scales from the Boreal zonal standard (Zakharov et al., 1997, 2005), the renewed belemnite scale has a higher correlation potential. On the basis of finds in West Siberia, it came to include Subextensoides beds (Dzyuba, 2004), which had been found in the Lower Callovian of Central Russia (Nal'nyaeva, 1989). The Siberian Tehamaensis Zone, distinguished in the Jurassic–Cretaceous boundary sediments on the Nordvik Peninsula, was recognized in northern California (Dzyuba, 2010). Many other biostratigraphic units may be suitable for distant interregional correlations with Eastern and northwestern Europe (Beaumontianus beds, Panderiana beds, Explanata beds, Russiensis Zone), eastern Greenland (Cuspidata beds, Ingens Zone), the Upper Amur region (Cuspidata beds). Such correlations are impeded by the fact that belemnite scales for these territories have not been developed enough (or at all).

The Jurassic belemnite scale for Siberia now comprises 24 biostratigraphic units: zones, subzones, and belemnite beds.

By the late 1970s, the stratigraphic significance of the Jurassic macro- and microbenthos of Siberia had been underestimated. Assemblages of different groups constraining stages, substages, or ammonite biostratigraphic units had been usually described. Actually, more or less identifiable units of general or local (formations, members) stratigraphic scales were described paleontologically. Only for the Upper Jurassic of West Siberia, independent foraminiferal biostratigraphic units were distinguished (Regional..., 1981; and others). In the following nearly two decades, the unified foraminiferal scale for the Callovian and Upper Jurassic did not change much: only the biostratigraphic units rose in rank from beds with characteristic species to zones; the index species were replaced; the boundaries of some biostratigraphic units were refined (Atlas, 1990).

A new stage in the development of Jurassic benthic scales for Siberia began in the late 1970s–early 1980s. First, a buchia parallel zonal (phylozonal) scale was developed for the Upper Jurassic (Zakharov, 1981), and then a bivalve parallel bioevent zonal scale was developed for the Lower and Middle Jurassic (Shurygin, 1986, 2005). The Jurassic microfaunal scales in current use were developed by the same principles (Nikitenko, 1992, 2009).

Modern Jurassic scales for Siberia based on benthic groups (bivalves, foraminifers, ostracods) and palynomorphs are, as a rule, the most efficient tool for the rapid subdivision and correlation of sections, especially those penetrated by wells. The entire diversity of parallel biostratigraphic zones is regarded as an operational combination of bioevent scales. It is used for identifying various types of datums (reference points) in well logging and regional and interregional correlations of the Siberian Jurassic (Nikitenko, 2009; Shurygin, 2005; Shurygin et al., 2000). Note that the entire diversity of independent methods for section subdivision and correlation is also used for cross checking (feedback).

Zonal scales for parastratigraphic groups were developed by tracing various types of datums (corresponding to the leveling of the Boreal biota) and comparing the zones squeezed in between the datums (Shurygin et al., 2000). The zones for parastratigraphic groups most often correspond in content to ecozones (section intervals characterized by a certain conjugation of recurring facies and assemblages). In principle, a complete paleontologic description of such zones is contained in an elementary cyclothem. The boundaries (usually lower) of such zones are marked by the appearance of new assemblages and taxa (as a result of both phylogeny and migrations) and as boundaries of the intervals with coinciding epiboles of the characteristic species (from paleocommunity cores) (Nikitenko, 2009; Shurygin, 2005).

Operationally, the sections contain not the surfaces with the changing taxonomic composition of the assemblages but successions of beds (strata) different in the taxonomic composition of fossils, the structure of their assemblages, and the patterns of assemblage change in the recurring facies. The boundaries between the biostratigraphic units in the succession always have an uncertainty interval, whose size varies depending on the facies recurrence. In fact, the zonal volume is determined by recording the succession and combined results of different events (chorologic ones, migration; ecosystem ones, changing community structure, changing dominant species, thriving taxa or life forms; phylogenetic ones, the autochthonous appearance of a new taxon) (Shurygin et al., 2000).

In parallel, narrow and broad zones are distinguished, with different assemblages for various facies. The bivalve and microfaunal zonal charts of the Lower and Middle Jurassic are most detailed for the sections of the northern and eastern framing of the Siberian Platform. The Lower and Middle (without the Callovian) Jurassic sections of Siberia contain 27 bivalve, 25 foraminiferal, and 15 ostracod zones (Nikitenko, 2009; Shurygin, 2005). In distant interregional correlations, the benthic zonal scales of this interval can be regarded as bioevent scales, where the datums are characterized by a unique succession of the results of combined biologic events of different (independent) nature (phylogenetic, chorologic, ecosystem). Exactly a fixed succession of independent events, apparently, has the highest probability of isochronism when identified in different regions.

The parallel zonal scales developed for the Lower and Middle Jurassic of Siberia are quite a reliable tool for regional and, partly, interregional correlation. The stratigraphic volume of the biostratigraphic units distinguished corresponds to a part of or 1–2 ammonite zones (less often, a substage). The scales were used successfully for the detailed subdivision and

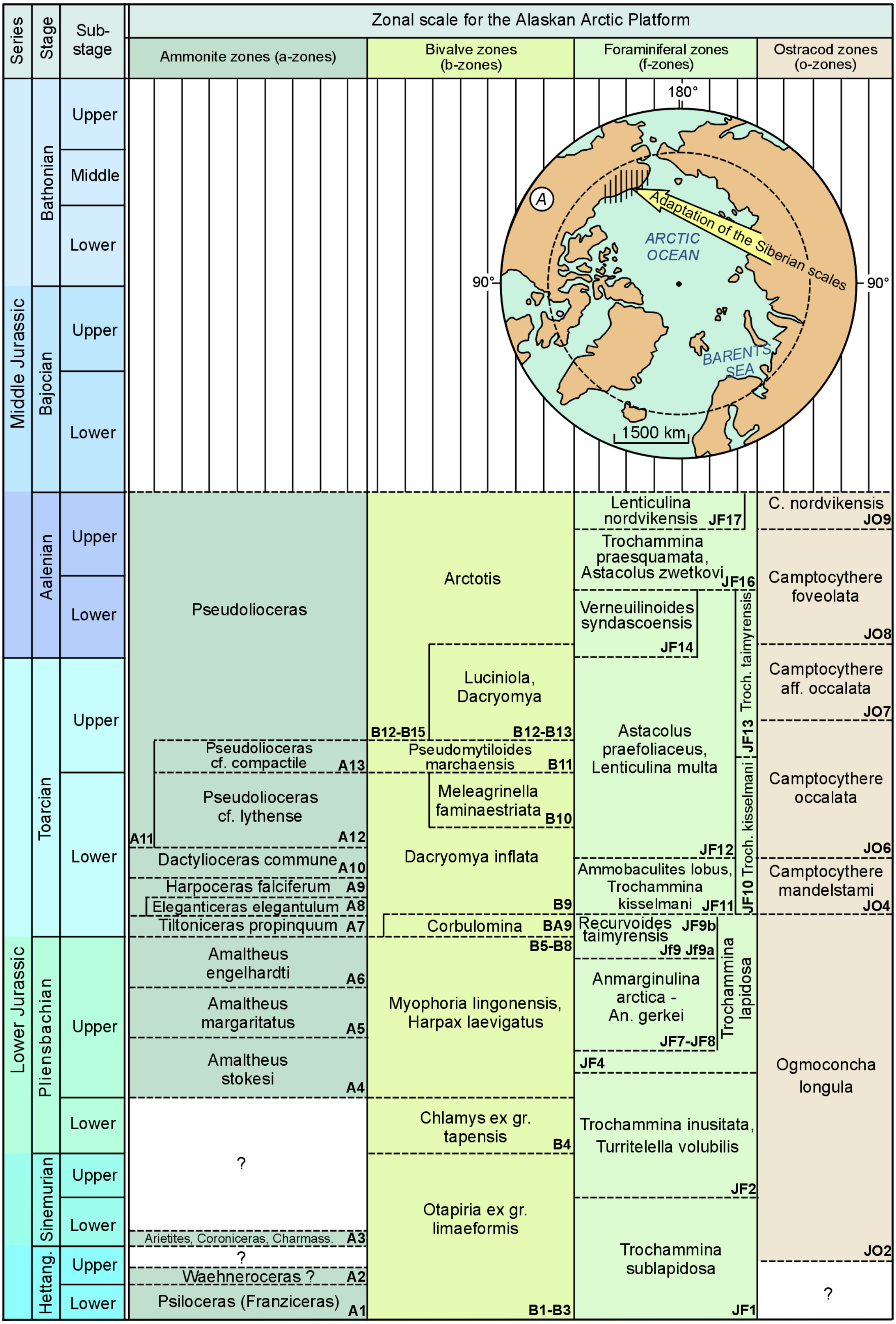
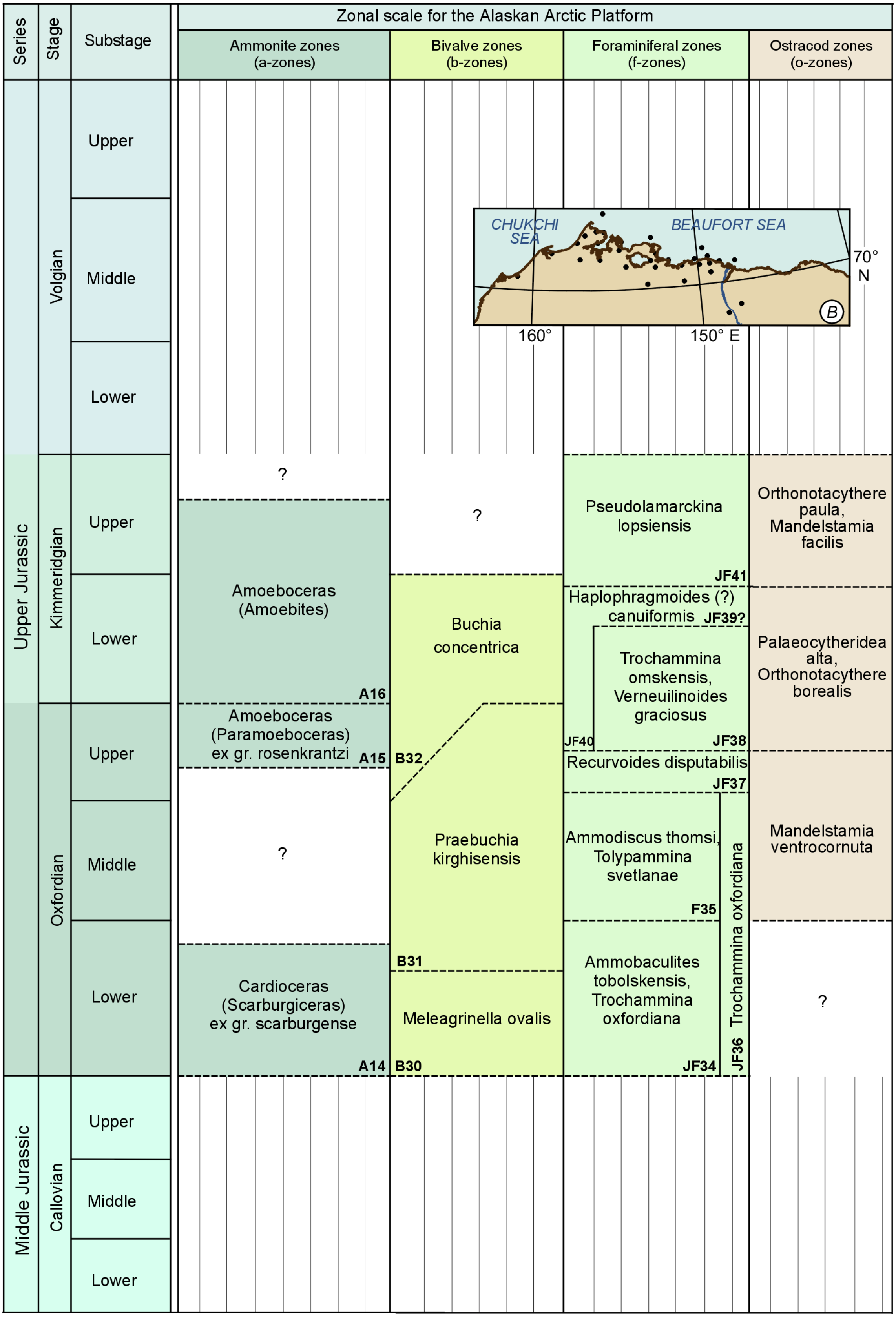


Fig. 5. Regional stratigraphic scales for the Jurassic units of northern Alaska (inset A) as the Siberian scales adapted for the sections of the North Alaskan Platform. Ruling in inset A shows the northern platform, where the major studied wells (inset B) which penetrated the Jurassic units of northern Alaska are located.



Series	Stage	Substage	Ammonite zones (a-zones)	Bivalve zones (b-zones)	Foraminiferal zones (f-zones)	Ostracod zones (o-zones)
Upper Jurassic	Volgian	Upper				
		Middle				
		Lower				
	Kimmeridgian	Upper	? Amoeboceras (Amoebites)	?	Pseudolamarckina lopsiensis **JF41**	Orthonotacythere paula, Mandelstamia facilis
		Lower	Amoeboceras (Amoebites) **A16**	Buchia concentrica	Haplophragmoides (?) canuiformis **JF39?** **JF40** Trochammina omskensis, Verneuilinoides graciosus	Palaeocytheridea alta, Orthonotacythere borealis
	Oxfordian	Upper	Amoeboceras (Paramoeboceras) ex gr. rosenkrantzi **A15** ?	Buchia concentrica **B32** Praebuchia kirghisensis	Trochammina omskensis, Verneuilinoides graciosus **JF38** Recurvoides disputabilis **JF37**	Palaeocytheridea alta, Orthonotacythere borealis Mandelstamia ventrocornuta
		Middle	?	Praebuchia kirghisensis	Ammodiscus thomsi, Tolypammina svetlanae **F35** Trochammina oxfordiana	Mandelstamia ventrocornuta
		Lower	? Cardioceras (Scarburgiceras) ex gr. scarburgense **A14**	Praebuchia kirghisensis **B31** Meleagrinella ovalis **B30**	Ammobaculites tobolskensis, Trochammina oxfordiana **JF34** **JF36** Trochammina oxfordiana	?
Middle Jurassic	Callovian	Upper				
		Middle				
		Lower				

Fig. 5 (*continued*).

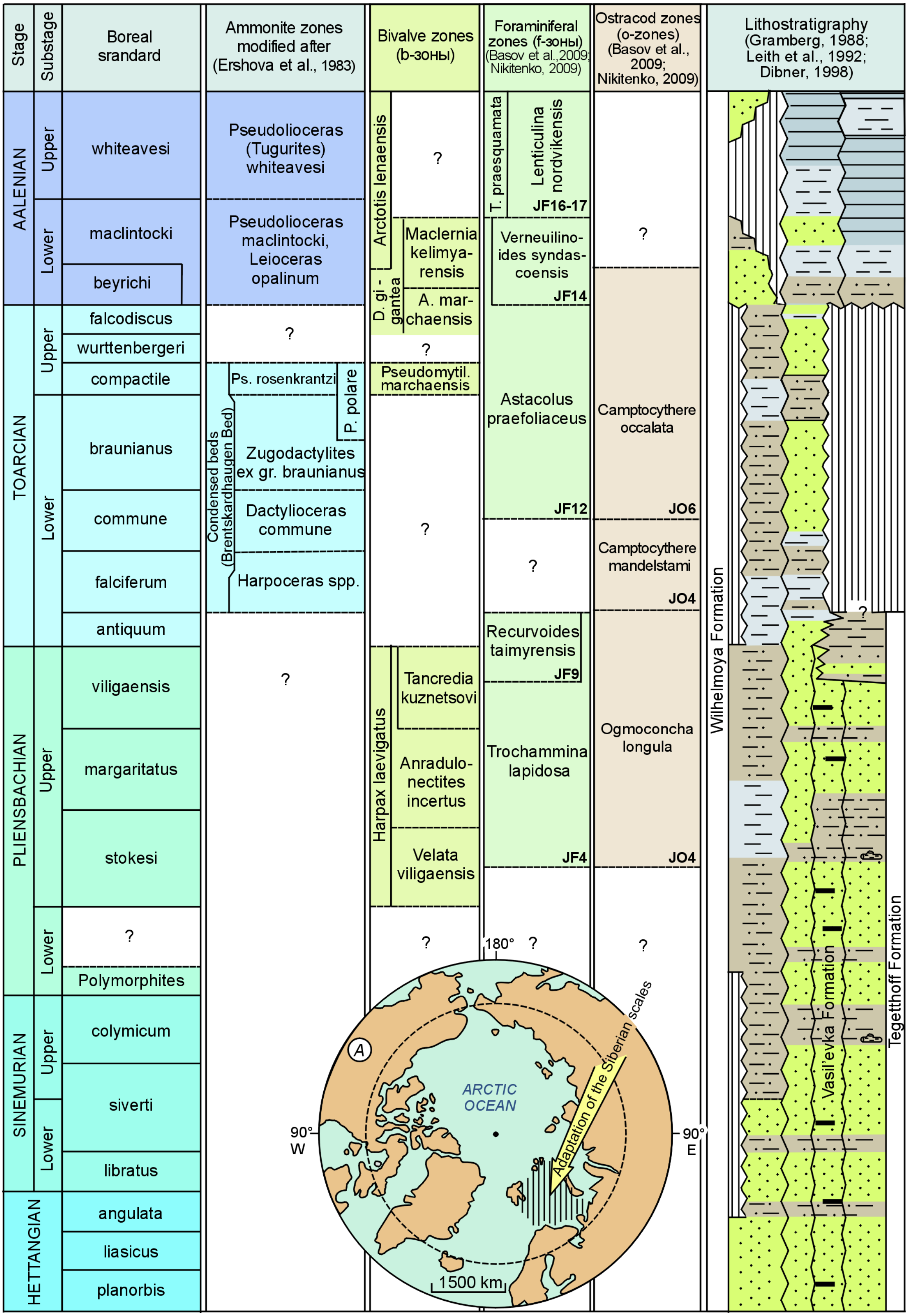


Fig. 6. Regional stratigraphic scales for the Lower Jurassic and Aalenian units of the Barents shelf (inset *A*) as the Siberian scales adapted for the shelf sections and outcrops of the framing land. Ruling in inset *A* shows the location of the major sections and outcrops used. See Fig. 2 for the rest of the legend.

correlation of the Lower and Middle Jurassic in outcrops and well sections in the Russian and foreign Arctic (Figs. 5, 6) (Nikitenko, 2009; Nikitenko and Mickey, 2004; Shurygin, 2005; Shurygin et al., 2000; and others). The set of markers in the circumboreally traced benthic scales permits interregional correlations and good correlations between spatially isolated sections within the Boreal–Arctic Realm (Mickey et al., 1998; Shurygin et al., 2000; and others).

The bivalve zonal scale for the Callovian and Upper Jurassic of Siberia was originally developed on different principles than that for the Lower and Middle Jurassic. The Lower–Middle Jurassic scale can be regarded as a mostly bioevent one, which consists of polytaxon zones, whereas the Upper Jurassic scale has a typical phylozonal structure. The Upper Jurassic of Siberia are rich in various Buchiidae species, which are euryfacies and abundant in the fossil assemblages throughout the strata and develop autochthonously to a considerable extent. This bivalve group has been well studied to date, and its stratigraphic significance has been assessed (Zakharov, 1981; Zakharov et al., 1997; and others). The detailed sections of Siberian Upper Jurassic outcrops were used to develop a buchia zonal scale for this interval. It comprises 12 biostratigraphic units and is widely used in the geologic study and stratigraphic charting of individual Siberian regions. The Callovian and Upper Jurassic foraminiferal scale comprises up to 32 zones, which permit identifying up to 19 stratigraphic intervals of different ages depending on the facies characteristics of the sections.

The set of parallel scales developed together with the ammonite scale is used as a Jurassic Boreal zonal standard (Shurygin et al., 2000; Zakharov et al., 1997) and ensures Circum-Arctic section correlations.

The boundaries of biostratigraphic units distinguished for different fossil groups often diverge. When sections are subdivided and correlated with the help of the entire set of parallel zonal scales, the divergent boundaries permit identifying and tracing very narrow intrazonal intervals (intervals with overlapping zonal boundaries on different scales (cointervals)) (Nikitenko, 2009; Nikitenko and Shurygin, 1994; Shurygin, 2005; and others).

Conclusions

Studying the Jurassic key sections of northern Central Siberia has shown that exactly these sections should be used for developing sets of mutually correlated parallel zonal scales based on different fossil groups, which can ensure a zone-by-zone regional and interregional correlation of the Arctic Jurassic, especially in closed territories with commercial petroleum accumulations. According to the stratigraphic analysis of the distribution of ammonite, belemnite, bivalve, foraminiferal, and ostracod assemblages in different Arctic regions (Siberia, northeastern Russia, the Barents Sea shelf, northern Alaska, and Arctic Canada), the biostratigraphic units on the zonal scales developed for northern East Siberia are found throughout the Arctic Realm. Also, a whole range of datums permits correlating the micro- and macrobenthic zonation of the Arctic Jurassic with that for Western Europe and eastern Eastern Europe.

The stratotype region for this standard must have a typical Boreal (Arctic rather than mixed) fauna (Fig. 4). A possible candidate is Siberia (and the Arctic biochorema), which is located in the center of the Panboreal Superrealm, where the set of interrelated scales for various fossil groups is the most complete.

Using a complete set of Siberian Jurassic scales (or their constituents) in different Arctic regions (Barents Sea shelf, Canadian Arctic, Arctic Alaska) (Figs. 5, 6) permits substantially refining the stratigraphic position of the boundaries and the volume of the lithostratigraphic units containing them. Also, it permits constructing consistent models for Circum-Arctic lithostratigraphic correlation. A comprehensive analysis of biotic and abiotic events along with a good biostratigraphic base (the possibility of assessing the event isochronism or anisochronism) permit constructing reliable paleogeographic charts of the Arctic.

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