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BOREAL ZONAL STANDARD AND BIOSTRATIGRAPHY OF THE SIBERIAN MESOZOIC

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We offer a boreal zonal standard scale providing an effective panboreal correlation and current geological dating of Mesozoic boreal sediments. The need for establishment of a boreal standard is brought about by the fact that most boreal stratigraphic sections cannot be correlated directly, zone by zone, with Mesozoic type sections located in Western Europe. The standard section of boreal Mesozoic represents the most complete sequence of mollusk (mainly ammonite) zones known on the territory of the boreal realm. It is compiled from fragments of zonal sequences established in more than 30 Triassic, Jurassic, and Cretaceous sections of Northern Eurasia, North America, and Greenland. The boreal standard of the Triassic system comprises 36 ammonoid zones and 2 bivalve zones; Jurassic, 70 ammonite zones; Cretaceous, 37 ammonite zones, subzones, and beds, 6 bivalve zones, and 11 belemnite zones and subzones. Siberia and Northeastern Asia provide stratigraphic sections, many of which are the best in the boreal realm regarding their stratigraphic completeness and detailed zonal subdivision. They include the type section of the Olenekian and one of the most complete boreal sections of the Induan stage. Infrazonal scales are constructed for both Induan and Olenekian stages as well as for the Middle Anisian and Upper Anisian. Sequences of ammonite zones from Hettangian, Sinemurian, Toarcian, and Upper Pliensbachian sections, located in Northeastern Asia, as well as the Lower Oxfordian substage from North Siberia and Kimmeridgian stage of the Subpolar Urals are chosen as boreal standards. The ammonite zonal scale of the Upper Volgian substage in the north of Siberia is more complete than that of the Gorodishche type section on the Volga. The most complete and continuous successions of ammonite zones in boreal Berriasian and Valanginian are established in North Siberia. They are adopted as a composite boreal standard. Studies of the North-Siberian Upper Cretaceous sections in a stratigraphic range from the Upper Cenomanian to the Santonian/Campanian boundary revealed analogs of all East- and West-European inoceramid zones. In addition to ammonoid zones for all the Mesozoic systems in Siberia and Northeastern Asia we used the same sections to compile independent parallel zonal scales on parastratigraphic groups of fauna and flora. We also compiled an almost "through" scale, based on bivalves, and some of its intervals entered the boreal standard (Upper Jurassic, Upper Cretaceous). We offer a zonation on nautiloids for the entire Triassic and zonations on conodonts and foraminifers for some other intervals. A set of scales were developed for the Jurassic interval: on belemnites, foraminifers, ostracods, dinocysts, spores, and pollen. The Cretaceous was characterized with dinocyst and foraminifer scales. Taken together, these scales may ensure close correlations, mainly regional. However, many of them, like the zonal bivalve-based scale, allow direct panboreal and even boreal-peritethyan correlations for the Upper Triassic, Lower Liassic, Upper Jurassic, Neocomian, and Upper Cretaceous. The proposed boreal Mesozoic standard should be improved. This is particularly true for a greater part of the zonal scale of the Cretaceous system. Nevertheless, even in its present version it may be used for improvement of panboreal and boreal-tethyan correlations, as well as for current stratigraphic studies of boreal sections in particular regions.

Zonal standard, boreal Mesozoic, Siberia, Northeastern Asia, ammonoidea, bivalves, foraminifers, dinocysts

INTRODUCTION

The last edition of the International Stratigraphic Code does not regard zone as a geochronological straton [1]. Stage is adopted as the smallest geochronological unit. This approach is hardly a step forward. Biostratigraphic zonal scales rest on phyletic ground and provide a tool for the most detailed chronostratigraphic constructions. Zones are elementary correlation units. Nothing but zonal correlations allow us to judge about the stratigraphic volume of stages in various provinces and their relationships with the type sections.

From the very beginning the stratigraphy of the boreal Mesozoic of Siberia manipulated with zone as a stratigraphic unit for practical purpose. Emphasis was placed on zones and stages of the international scale at the sacrifice of the Jurassic and Neocomian lithostratigraphy best supported with zonal scales. However, just the preferential orientation to zone allowed development of the ammonite scale for the Siberian Jurassic and Neocomian in almost as great detail as the West-European scale and as fast as for 20 years [2]. Bad mistakes in developing the West-Siberian petroleum province were escaped owing to previous studies in zonal biostratigraphy of East Siberia. As shown by drilling, Jurassic and Cretaceous beds in West Siberia contain the same sequences of faunistic and floristic complexes as in northern Siberia. This imparts more importance to the parallel scales on parastratigraphic groups of fauna and flora, developed for the north of West Siberia and for the Subpolar Urals, and shows that their potential has not been exhausted yet.

The modern line in the biostratigraphy of boreal deposits involves development of panboreal zonal correlation. The ultimate goal of these investigations is in agreement with current problems of the International Commission on Stratigraphy, involved with the refinement of the global stratigraphic scale by means of establishment of global stratotype sections and points, both within and beyond the type localities of stages [3, 4]. In this case stage remains a universal chronostratigraphic unit and maintains its nomenclature over the globe. The geography and nomenclature of a biostratigraphic zone, even orthofaunistic, is limited [5]. This can be exemplified by difficulties in zonal boreal-tethyan correlation of Mesozoic beds: few of 200 ammonite zones established in sections of boreal Mesozoic deposits can be directly correlated with tethyan zones. Obviously the ammonite tethyan standard cannot be efficiently applied to current stratigraphic examinations of particular sections of boreal deposits. Just for this reason students of boreal deposits use as a standard a sequence of boreal rather than tethyan biostratigraphic zones. The boreal zonal standard has been in actual use for many Mesozoic stages for a long time. This paper is the first to present a complete and continuous orthozonal scale from the bottom of the Triassic to the roof of the Maastrichtian.

NATURE AND CONSTRUCTION OF ZONAL SCALES

Division of fossils into ortho- and parastratigraphic, proposed by O. Shindevolf and reflecting their importance for stratigraphic purposes determined two types of scales: top-priority (based on ortho-groups of fossils) and autonomous, or parallel (based on para-groups) [7, 8]. It should be emphasized that this classification is conventional, since some scales of either group are known to be inverted. For instance, the inoceram zonal scale of the Upper Cretaceous, once considered top-priority in a global scale, is now replaced by the ammonite-based scale in areas of occurrence of tethyan deposits, but remains top-priority in boreal and peritethyan deposits. The Paleozoic provides another example: the conodont scale competes with the graptolite and cephalopod scales in a number of stratigraphic ranges, but is regarded as autonomous in the Triassic, where the priority is held by ammonoid zonal scale. More examples can be given, if necessary.

Autonomous zonal scales (AZS) can be classified, according to their nature in two groups: (1) phylostratigraphic or, rather, evolutionary-migrational, and (2) ecostratigraphic, or facies-migrational. The former type AZS's are similar to top-priority zonal scales (PZS). Nearly all types of zones established with the use of orthostratigraphic taxa are observed for parastratigraphic fossil groups. Sections in which PZS's had been established were preferentially used in the development of AZS's in Siberia. This allowed a more effective use of parazones for correlation and determination of the geological age of deposits. However, establishment of parazones and their boundaries was done independently of orthozones and their boundaries. Match or mismatch of the boundaries of ortho- and parazones cannot be assessed unambiguously from the practical point of view. AZS's are used in stratigraphy in the same way as PZS's. Methods of interregional and interfacies correlation with the use of AZS's rest on fundamental stratigraphic principles: homotaxy and chronotaxy [9].

BOREAL STANDARD AND PANBOREAL CORRELATION

The need for a boreal zonal standard arises from the fact that the boreal type sections cannot be correlated

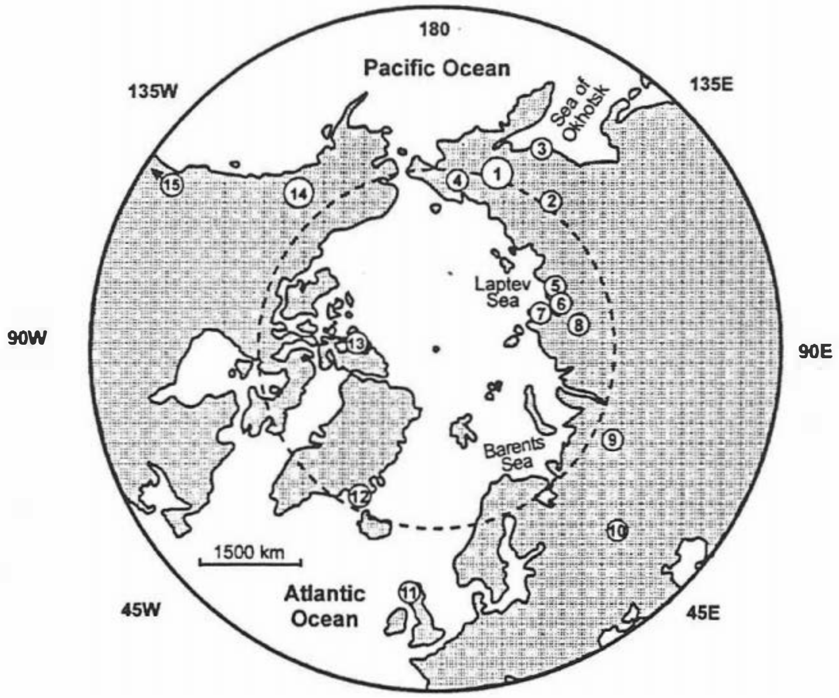


Fig. 1. Location map of type sections of the boreal zonal standard. 1–4 — northeastern Russia: 1 — Omolon Massif and Alazei Plateau (Rhaetian Stage, zone *Tosapecten efimovae*: Kedon R., near the mouth of the Omkuchan R. [32]); Hettangian Stage: left bank of Kedon [31]; Sinemurian Stage: Kedon and Vizualnaya Rivers [31]; Upper Pliensbachian: Brodnaya, Bulun, and Russkaya Rivers [31]; Toarcian Stage: Lower Toarcian: Levyi Kedon R. [31]; Upper Toarcian: Levyi Kedon R. (Saturn Stream) [79]; Bajocian Stage: Lower Bajocian: Sededema basin, Alazei Plateau, Anadyr R. [31], 2 — Yana-Indigirka interfluve (Norian Stage, zone *Monotis ochotica* — Adycha R., Yana basin) [32], 3 — Near-Okhotsk region (Aalenian Stage — Viliga basin) [31], 4 — Chukchi Peninsula (Lower Pliensbachian — upper reaches of the Bol'shoi Anyui R.) [31], 5–8 — northern Siberia: 5 — Lena-Olenek interfluve (Olenek Stage — lower reaches of the Olenek) [19], 6 — Anabar-Khatanga interfluve (Berriasian Stage — Nordvik Peninsula, shore of the Laptev Sea) [30, 121], 7 — Eastern Taimyr (Lower Oxfordian, the Chernokhrebetnaya R., northeastern Taimyr) [31], 8 — Kheta basin (Valanginian Stage, Boyarka R., Kheta basin, northern East Siberia) [26, 46], Subpolar Urals (Kimmeridgian Stage, Lopsiya R., Severnaya Sos'va basin) [87, 108], 10 — East-European Plain (uppermost zone of the Callovian — Volga basin, near Saratov) [47], Volgian Stage — Gorodishche Village, near Ulyanovsk, on Volga) [88]; Lower Hauterivian Substage — Kresty Village, near Yaroslavl; Upper Hauterivian Substage — Volga, near Saratov [131]; Barremian, Aptian, Albian, Cenomanian, Turonian, Coniacian, Santonian, Campanian, Maastrichtian Stages, southeastern West-Siberian Plain [75], 11 — Scotland (Middle Oxfordian and Upper Oxfordian, islands of Skye and Shtaffin) [85, 86], 12 — Eastern Greenland (Induan Stage, zone *Ophiceras commune*) [71]; Upper Bathonian and Callovian, Northeastern Greenland [40, 81, 82]. 13 — Arctic Canada (Induan Stage, zones *Otoceras concavum* and *Otoceras boreale* — Axel Heiberg Island) [48]; Induan Stage, zones *Proptychites candidus* and *Vavilovites sverdrupi* — Ellesmere Island) [48]. 14 — Western Canada (Anisian, Ladinian, Carnian, and Norian Stages — British Columbia) [48, 71]; Carnian Stage, zones *Austrotrachiceras obesum* and *Sirenites nanseni* — British Columbia [48]; Norian Stage, to the zone *Monotis ochotica* — British Columbia [48]; Bathonian Stage, Lower and Middle Bathonian — Porcupine and Northern Yukon Rivers [83]. 15 — southwestern USA (Carnian Stage, zone *Trachyceras desatoyense* — New Pass Range, Nevada [71]; Carnian Stage, zones *Tropites dilleri* and *Tropites welleri* — California [71]; Carnian Stage, zone *Klamatites macrolobatus* — Shoshone Mts, Nevada [71]).

directly with those of the west-tethyan (Mediterranean) type, where stratotypes of most Mesozoic stages are located. The standard boreal zonal scale is compiled on the same principles as the tethyan. It is combined from zone sequences of either entire stages or, sometimes, of their fragments, most completely appearing in specific (type) sections within the region of occurrence of boreal deposits (Fig. 1). Hence, the synthetic scale of the boreal standard demonstrates the most complete sequence of biostratons of the zonal level, known in the boreal region (Figs. 2–4). In some ranges it also contains fragments of zonal scales constructed on sections of the intermediate boreal-tethyan type (regions of a paleobiogeographical ecotone). Occurrence of boreal deposits is limited in the south, as a rule, by a latitude of 50° N. The chief objective of the standard boreal zonal scale is to enable a direct panboreal correlation in the region of occurrence of boreal-type deposits. The standard boreal scale is located in stratigraphic schemes between the tethyan standard and the regional (provincial) scale. So it serves as a link in practical determinations of geological ages of boreal-type deposits.

PROBLEMS OF BOREAL-TETHYAN CORRELATION

The severe requirements for a special zonal scale for the boreal type deposits does not mean that those who investigate boreal deposits should work for this scale only. The unified scale of geological time is of common interest for all stratigraphers round the world. Therefore zonal boreal-tethyan correlation is a vital problem of boreal stratigraphy.

Regions with mixed fauna associations play key roles for detailed north—south correlation. Zonal complexes in these regions contain natives of both boreal and tethyan seas. Therefore they can be used as a link in boreal-tethyan correlations. This makes the boreal zonal standard even more important as a geochronological reference for the boreal type deposits. The region of the paleobiogeographical ecotone — a space with mixed boreal-tethyan fauna associations — is located now between 45 and 55° N [10, 11].

A direct zone-by-zone correlation of boreal, subtethyan, and tethyan sections can be done by comparing zone sequences, characterized by a considerable similarity of the associations and retain index species, as well as by comparing individual zones. This can be exemplified by sequences of ammonite zones of the Lower Induan, Lower Olenekian, Hettangian, Upper Pliensbachian, Lower Oxfordian, Upper Kimmeridgian, as well as by inoceram zones of the Upper Cenomanian, Turonian, and Santonian (Figs. 2–4). The zones *Neoprotrachyceras seimkanense* (Upper Triassic, Lower Carnian) and *Cardioceras cordatum* (Upper Jurassic, Oxfordian) provide brilliant examples of direct boreal-tethyan correlation between individual zones. Boreal and peritethyan sections of the Jurassic and Cretaceous can be directly correlated using inoceramid and *Buchia* zones.

However, considerable stratigraphic ranges on the Mesozoic boreal zonal scale are not correlated directly with the international geochronological standard. Examples are the Volgian Stage and the boreal Berriasian. Of 24 ammonite zones and subzones recognized within these stages only one level, at the bottom of the Volgian, can be directly correlated with type sections in Western Europe. Boreal-tethyan correlation of the Rhaetian, Lower Pliensbachian, Upper Toarcian, Aalenian, Bajocian, and most Cretaceous stages presents notable difficulties. A significant homotaxy of the ammonite assemblages should be taken into account when performing zone-by-zone correlation of the listed stages. The time discrepancy between the boundaries of equally named stages may reach one or two ammonite zones. The chief concern of students of boreal deposits in the nearest future is to make boreal-tethyan correlations more accurate.

HISTORY OF CONCEPTS OF SIBERIAN MESOZOIC ZONAL SCALES

The development of the Mesozoic zonal scale in Siberia, as in Europe, started with the Jurassic system. The first biostratigraphic scale for Jurassic deposits in the north of East Siberia was proposed in V. I. Bodylevskii and D. D. Kiparisova's communication at the 27th session of the International Geological Congress, Moscow, 1987. This scale was far from being perfect, but it demonstrated potentialities of the evolutionary paleontological method in development of chronostratigraphy of the boreal Mesozoic: the sequence of zones was established "at a desk", but all these zones were confirmed thereafter by field stratigraphic studies.

V. N. Saks was the first to question the validity of application of the general (international) stratigraphic scale to the subdivision of Siberian Jurassic deposits [12]. He demonstrated that, in spite of the boreal fauna being provincial in some time ranges, the Jurassic fauna of Arctic and Siberia, on the one hand, and of Europe, on the other, had in common a sufficient quantity of genera and species. So all the stages — from the Hettangian to Kimmeridgian, as well as the boreal Volgian — could be reliably established in the Jurassic system of Siberia. In the same year 1968 V. N. Saks and N. I. Shul'gina proposed a stage and zonal subdivision of the Cretaceous system of Siberia [13]. The staging of the Cretaceous system in Siberia according to the International Geochronological Scale was not as reliable as that of the Jurassic, because many stratigraphic ranges lacked orthostratigraphic mollusk groups: ammonites, bivalves, or belemnites.

The first biostratigraphic schemes of the Triassic were reported by Kiparisova [14, 15], Kiparisova and Popov [16], and Popov [17]. These schemes are based on L. Spaeth's concept of genozones for the boreal Triassic [18]. Zonal scales for particular stages of the Siberian Triassic appeared later [19–24]. Tuchkov was the first to reveal the sequence of zones *Otapiria ussuriensis-Monotis ochotica* in Norian deposits [25].

Stage and zonal scales of the Mesozoic in Siberia suffered from many drawbacks.

The Upper Induan is one of the least clear stratigraphic ranges in the Lower Triassic. One zone, *Vavilovites* spp., characterized by species of the only genus *Vavilovites*, was recognized within the stage. Interpretation of the *Vavilovites* sequences in sections was rather contradictory. To draw the boundary between the Lower and Upper Olenek substages is also difficult, because stages of the ammonoid faunas had not been sufficiently studied, and correlations of this stratigraphic range were tentative. The chief unsolved problems in the biostratigraphy of the Middle Triassic were: correlation of upper horizons of the Anisian, ambiguity of the boundary between the Anisian and Ladinian Stages in boreal regions, imperfection of the zonal scale of the Ladinian Stage, need for search for zonal levels of correlation. The correlation of the zonal scale of the boreal Upper Triassic remained tentative, and all but few Siberian zones were compared on the basis of their stratigraphic location.

Concerning the Jurassic system, detailed biostratigraphy of the Lower Jurassic and Middle Jurassic presented some difficulties. There were so many gaps (see the chart in [12]) that some individual stages, like Domerian (Lotharingian), Aalenian, and Bajocian could not be established at all, and other stages were established by fragments of ammonite zones. Only Upper Jurassic stages, except the Upper Volgian, were established by zone sequences more or less convincingly. Many Cretaceous stages (Hauterivian, Albian, Campanian, Maastrichtian) were established by findings of few taxa. These findings were of boreal origin, and it was difficult to correlate the stages with West-European standards, located in regions of tethyan deposits. Recognition of the Barremian, Aptian, and Cenomanian was not supported by findings of marine fauna. Even the Berriasian (established in the north of Siberia as an individual stage for the first time in the USSR) and Valanginian had no zonal level providing a direct correlation between sections of Siberia and Western Europe, in spite of the fact that they were the richest in fauna and were subdivided into ammonite zones [13, 26]. Later several Valanginian levels were found, thus permitting the volume of the Valanginian in the north of East Siberia to be established through sections of Lower Saxony (Germany) [27, 28].

Development of zonal scales of the Mesozoic and improvement of staging were greatly contributed by combined stratigraphic studies carried out in the 1960–70s. Research teams from institutes of the Ministry of Geology (Research Institute of Arctic Geology and All-Union Geological Survey Institute, Leningrad; Siberian Research Institute of Geology, Geophysics, and Raw Materials, Novosibirsk; West-Siberian Institute of Oil Geology, Tyumen') and of the Siberian Division of the USSR Academy of Sciences (Institute of Geology and Geophysics, Novosibirsk; Geological Institute of the Yakutsk Branch) investigated reference sections in the northeast (East Upper Yana region, basin of the Yana, Omolon Massif, North Near-Okhotsk region) and north of East Siberia (basins of the Kheta, Khatanga, Anabar, Olenek, Lena Rivers; the Taimyr Peninsula; coast of the Laptev Sea); in West Siberia (Subpolar Urals, basin of the Severnaya Sos'va R.). At this stage emphasis was placed on the description of reference sections, zonal scales of individual stages, panboreal and boreal-tethyan correlation. The Triassic and Jurassic systems and the Neocomian Stage were studied most comprehensively [29–33]. Studies on zonal stratigraphy of the Jurassic and Neocomian of the boreal belt were reported in the late 1970s [2, 32]. The parallel zonal scale on bivalves for all series of the Jurassic and Neocomian appeared in zonation charts for the first time. The state of the biostratigraphy and paleontology of the Siberian Mesozoic in the early 1980s is described in [34].

At the end of the 1980s the zonal scale of the Siberian Jurassic contained 61 ammonite-based and 33 bivalve-based levels. Also, a sequence of beds with spores and pollen was traced within the Jurassic in both marine and continental deposits in various regions of Siberia [35–37]. The ammonite scale of the Lower Jurassic was refined considerably. Its zonation allowed reliable establishment of all, but the Pliensbachian, stages of the standard scale, and the Toarcian was approximated to the type section. Bivalve zones and beds were traced not only in the north, but also in the northeast of Asia. The Middle Jurassic ammonite zonation was developed in more detail than before, but less than the boreal standard [37–40]. The parallel inoceramid scale, comprising 10 biostratons, allowed correlation of marine boreal deposits throughout Asia [37]. By the end of the 1980s the sequence of Upper Jurassic zones was the most complete in all the system. This was the most detailed

Series (1)	Stage (2)	S/stage (3)	Standard (4)	Boreal standard (5)	Zonal scales of Triassic of Northern Siberia and northeastern Russia: On Ammonoidea (6)		On Nautiloidea (7)		On Bivalvia (8)	
Upper	Rhaet.		Choristoceras marshi	Tosapecten efimovae	Scale on Ammonoidea undeveloped		Grypoceras bytschkovi		Tosapecten efimovae	Campt. nanus
										T. efimovae
	Norian	Upper	Rhabdoceras suessi	Monotis ochotica			Yakutionautilus kavalerovae		Monotis ochotica	M. subcircularis
										M. zabaikalica
		Middle	Himavatites columbianus	Himavatites columbianus					Monotis scutiformis	M. pinensis
										M.daonellaeformis
									Otapiria ussuriensis	Otapiria annulata
			Cyrtopleurites bicrenatus	Drepanites rutherfordi						O. ussuriensis
		Lower	Juvavites magnus	Juvavites magnus	Pinacoceras verchojanicum		Proclydonautilus seimkanensis		Zittelihalobia indigirensis	Halobia aotii
			Malayites paulckei	Malayites dawsoni						
			Stikinoceras kerri	Stikinoceras kerri						Halobia kawadai
	Carnian	Upper	Anatropites spp. beds	Klamathites macrolobatus	Sirenites yakutensis		Proclydonautilus pseudoseimkanensis		Zittelihalobia asperella	Z. kudleyi
			Tropites welleri	Tropites welleri	Yakutosirenites pentastichus					Z. omkutchanica
			Tropites dilleri	Tropites dilleri					Zittelihalobia subfallax	
			Sirenites spp. beds	Sirenites nanseni			Cosmonautilus polaris	Proclydonautilus goniatites		
		Lower	Austrotrach. austriacum	Austrotrachyceras obesum	Neoprotrachyceras seimkanense				Zittelihalobia popowi	
			Trachyceras aonoides	Trachyceras desatoyense	"Protrachyceras" omkutchanicum			C. polaris	Zittelihalobia talajaensis	
			Trachyceras aon		Stolleyites tenuis		Proclydonautilus anianiensis		Zittelihalobia zitteli	
Middle	Ladinian	Upper	Frankites regoledanus	Frankites sutherlandi	Nathorstites lindstroemi				Daonella subarctica	
					Nathorstites mcconnelli		Gryponautilus kegalensis			
			Protrachyceras archelaus	Maclearnoceras maclearni	Nathorstites maclearni					
				Meginoceras meginae	Jndigirites krugi				Bakevellia ladinica	
					Tsvetkovites neraensis					
				Tuchodiceras poseidon	Tsvetkovites constantis					
		L.	Eoprotrachyceras curionii	Eoprotrachyceras matutinum	Eonathorstites oleshkoi					
	Anisian	Upper	Nevadites reitzi	Frechites chischa	Frechites nevadanus	P. sublaqueatus	Arctonautilus egorovi	Paranautilus smithi	Daonella dubia	
			Aplococeras avisianum	Eogymnotoceras deleeni		F. nevadanus				
						P. dzeginense			Daonella americana	
					Gymnotoceras rotelliforme	G. olenekense		Arctonautilus egorovi		
			Paraceratites trinodosus			P. asseretoi			Bakevellia arctica	

1	2	3	4	5	6	6	7	7	8	8
Middle	Anisian	Middle	Balatonites balatonicus	Arctohungarites kharaulakhensis	Arctohungarites kharaulakhensis	C. gastroplanus	Arctonautilus migayi		Bakevellia arctica	
			Anagymnot. ismidicum			A. laevigatus				
			Nicomedites osmani	Czekanowskites decipiens	Czekanowskites decipiens	A. triformis				
						A. ventroplana				
		Lower	Aegeiceras urga	Taimyrites immutabilis	Lenotropites caurus		Arctonautilus ljubovae			
				Lenotropites solitarus	Grambergia taimyrensis	L. solitarus				
				Stenopopanoceras mirabile		S. mirabile				
						K. evolutus				
						K.? arkhipovi				
Lower	Olenekian	Upper	Olenekites spiniplicatus	Olenekites spiniplicatus	Olenekites spiniplicatus		Phaedrysmocheilus involutus		Claraia aranea	
			Parasibirites grambergi	Parasibirites grambergi	Parasibirites grambergi	P. efimovae	Phaedrysmocheilus nestori		Peribositria sibirica	"Streblopteria" jakutica
						P. mixtus	Phaedrysmocheilus evolutus			
						P. kolymensis				
			Nordophiceras contrarium	Nordophiceras contrarium	Nordophiceras contrarium	P. egorovi				"Streblopteria" newelli
						P. tuberculatus				
						B. lenaense				
			Bajarunia euomphala	Bajarunia euomphala	Bajarunia euomphala	B. apostolicum	Phaedrysmocheilus ornatus			
						B. planorbis				
						B. eiekitensis				
		Lower	Anawasatchites tardus	Anawasatchites tardus	Anawasatchites tardus		Trematoceras boreale	T. boreale	Claraia occidentalis	
			Lepiskites kolymensis	Lepiskites kolymensis	Lepiskites kolymensis			P. pulchrum	Peribositria mimer	
			H. hedenstroemi	Hedenstroemia hedenstroemi	Hedenstroemia hedenstroemi		No Nautiloidea		Atomodesma errabunda	A. errabunda
	Induan	Upper	Prionolobus rotundatus	Vavilovites sverdrupi	Kingites korostelevi					Promyalima schamarae
					Vavilovites turgidus	V. umbonatus				
						V. subtriangularis				
			Gyronites frequens		Vavilovites sverdrupi					
				Proptychites candidus	No diposits					
		Lower	Ophiceras tibeticum	Bukkenites strigatus	Wordioceras decipiens					
				Ophiceras commune	Tompophiceras morpheos		Tomponautilus setorymi			
					Tompophiceras pascoi					
			Otoceras woodwardi	Otoceras boreale	Otoceras boreale					Nuculopsis setorymensis
				Otoceras concavum	Otoceras concavum					

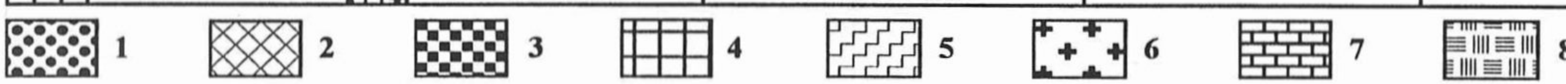


Fig. 2. Zonal stratigraphy of the Triassic System of Siberia and northeastern Russia. Location of zones of the boreal standard is shown with filling: *1* **— northern Siberia,** *2* **— East Greenland,** *3* **— southwestern USA,** *4* **— East-European Plain,** *5* **— northeastern Russia,** *6* **— Canada,** *7* **— Subpolar Urals,** *8* **— Scotland.**

scale, allowing direct correlation of the Oxfordian and Kimmeridgian with the West-European type sections at a number of stratigraphic levels. The Volgian stage of Siberia was closely correlated with the type section on the Volga (Gorodishche Village) [31, 41, 42].

Only in the lower part of the Neocomian the zonal stratigraphy of the Cretaceous system was nearly as close as that of the Jurassic. The "middle" Jurassic had not been zonated at all because of the absence of marine deposits from Siberia. Stages of the "middle" Jurassic — Upper Hauterivian, Barremian, Aptian, Albian, and Cenomanian — were established mainly by palynological evidence and rare findings of Jurassic foraminifers in core samples [43]. The zonal stratigraphy of the marine Upper Jurassic had little changed since the late 1950s. Occasional ammonite findings were not enough to construct a zonal scale according to this mollusk group. Only two important zones, at the boundary of the Turonian and Coniacian, had appeared in the inoceram scale by the end of the 1970s [44].

Since the last generalizations the work on refinement and improvement of zonal stratigraphic scales of Siberia on various fauna and flora groups has been in progress. Emphasis has been placed on stratigraphic ranges, in which the morphogenetic potential of orthostratigraphic groups has not been exhausted. In doing so, zonal ammonite scales of the Ladinian, Berriasian, and Valanginian have been developed in much more detail by establishing subzones. The zonal ammonite scale of the East-Siberian Bathonian has been approached to the boreal standard [45–47]. During the last 15 years autonomous (parallel) zonal scales have been developed: on bivalves for the Triassic, Lower and Middle Jurassic, Upper Cretaceous; on belemnites for the Jurassic and Neocomian: on foraminifers for all systems of the Mesozoic; on conodonts and Nautiloidea for the Triassic; on dinocysts for the Jurassic and Cretaceous; on spores and pollen for the Lower Jurassic and Middle Jurassic. New data concerning zonal scales of the boreal Triassic, Jurassic, and Cretaceous of Siberia, obtained for the last 15 years is reported here.

TRIASSIC SYSTEM

Triassic deposits are widespread in the north of East Siberia and northeast of Asia. The bulk of them comprises terrigenous siltstone-mudstone rocks of marine origin. They formed in basins inhabited generally by similar faunas. For this reason, in spite of the fact that the sections are spaced far apart from west to east, a unified scheme of detailed stratigraphy is adopted for this region. The sections are extremely complete and abundantly supplied with organic remains, including an orthostratigraphic group, Ammonoidea. The absence of stratigraphic condensation, common in the Tethys, allows us to establish a real sequence of faunas and to develop detailed zonal and infrazonal scales of the boreal Triassic, as detailed as those of the best investigated regions of the world.

The boreal standard. Comparison of regional zonal scales of the boreal Triassic indicates that the best of them is ammonoid scale of Canada, developed on sections of British Columbia and containing mixed boreal-tethyan complexes [48]. At some zonal levels it ensures a direct boreal-tethyan correlation of the Triassic. Dagis and Tozer were the first to propose the boreal standard based on these sections [49]. We follow this standard with next to no changes. The Olenekian stage is an exception; its sequence of ammonite zones is adopted as the boreal standard as it appears in the type section in the lower reaches of the Olenek R. in northern Siberia (Figs. 1, 2) [50].

During the last decade progress has been made in improvement and refinement of the ammonoid zonal scale of the Lower and Middle Triassic of northeast Asia. Evidence from most complete sections in several key regions in the north of Central Siberia, the upper reaches of the Yana R., the midstream of the Kolyma and the Okhotsk coast, including monographs on Ammonoidea, has allowed development of close zonal and infrazonal scales of the Lower Triassic [50], Middle and Upper Anisian Substages [51, 52], and Ladinian Stage [53]. Several books have been dedicated to paleontological justification of zonal scales [54–57]. The ammonoid scale of the Lower and Middle Triassic comprises 43 biostratons and is the closest to the boreal paleogeographic region and even to some time ranges: the Induan, Olenekian, Lower Anisian. The biostratigraphy of the Upper Triassic is much poorer; it has not enjoyed considerable upgrading during the last 15–20 years, because all the Late Triassic fauna groups are poorly studied. Ammonoidea are still abundant and diverse in the Carnian and Lower Norian, but become rare and occasional in younger deposits. For this reason the zonal scale of the Middle-Upper Norian and Rhaetian is based on bivalves. Fourteen biostratons are recognized now within the Upper Triassic, mainly on Bivalvia.

Parallel scales. A set of autonomous (parallel) biostratigraphic scales of bivalves [58–62], conodonts [18], nautiloids [63, 64], and foraminifers [65, 66] have been developed on Siberian sections. This provides additional correlation opportunities to the Triassic biostratigraphy of Siberia. In some ranges the autonomous zonal scales of nautiloids and bivalves are no less detailed than the ammonoid scale. So they are of great importance for both intra- and interregional correlations, and even for boreal-tethyan ones at some stratigraphic levels.

The nautiloid scale was first developed in the early 1990s [63, 64]. It comprises 19 biostratons (Fig. 2). The scale is based on stages of development of particular nautiloid taxa. For example, zonation of the Upper Olenekian is based on the evolution of the genus *Phaedrysmocheilus* and zonation of the Anisian, on *Arctonautilus*. The Carnian stage was subdivided into zones on the basis of evolution of the genera *Proclydonautilus* and *Cosmonautilus*. The stratigraphic volume of the nautiloid zones corresponds to the ranges of occurrence of index species. Nautiloid zones can be determined as biozones of species. The zones are generally of wide geographical occurrence and in most cases provides a detailed correlation throughout North-Asian Russia. Broader correlations are now hampered because of a poor knowledge of nautiloid faunas beyond Siberia and considerable paleobiogeographic differentiation of nautiloids at low and high latitudes, existing in the Triassic. In some biostratigraphic ranges (subzones *Paranautilus smithi* and *Proclydonautilus goniatitus*), however, boreal-tethyan correlations can be done.

The autonomous zonal scale of the boreal Triassic on bivalves is based on developmental stages of mainly pelagic groups and those closest to them in evolution rates: halobiids, posidoniids, monotides, pectinids, and others. This scale has been developed for the Lower Triassic and Middle Triassic on sections in the north of Middle Siberia, where 15 biostratons have been established (Fig. 2) [60, 61, 67]. General trends in phylogenesis of the genus *Daonella* have been outlined, allowing establishment of seven *Daonella* zones in the Upper Anisian and Ladinian. The scale for the Upper Triassic has been developed on sections of Northeastern Asia [58, 59, 68]. It has been developed more closely over the past few years; its nomenclature has been modified [57, 62]. Now the scale comprises 19 biostratons: zones, subzones, and beds. The entire autonomous scale on bivalves comprises 32 biostratons and is inferior in details only to the ammonoid scale. Further progress in detailed biostratigraphy of the Triassic on bivalves centers around the revision of pelagic posidoniids and halobiids and some rapidly evolving benthic groups: monotides and pectinids.

The panboreal correlation of the Triassic presents no serious difficulties owing to weakly pronounced provincial specificity of the fauna within the boreal region. Correlation of the Siberian Triassic scale with those of other boreal regions have been considered in several papers [49, 50, 56, 69, 70].

The zone *concavum* in Siberia matches the zone of the same name in Arctic Canada. The zone *boreale* in Arctic Canada, Greenland, and Spitzbergen contains a species in common, *Tompophiceras* ex gr. *pascoei.* This zone is correlated with two zones in Siberia, *boreale* and *pascoei.* Representatives of the genus *Ophiceras* appear in the zone *morpheos*, justifying the correlation of this zone with the Canadian zone *commune*. Comparison of upper zones of the Lower Induan in Siberia, Spitzbergen, and Canada is based on common genera and species *Wordieoceras* and *Bukkenites*. Correlations of the Upper Induan present more problems. Analogs of the Canadian zone *candidus* are absent from Siberia. In western parts of the boreal region the overlying zone *sverdrupi* is likely to correspond to three zones of the Upper Induan in Siberia, for the terminal subzone of this zone, *Kingites discoidalis*, established by Tozer [71], seems to be coeval with the zone *Kingites korostelevi* in Siberia. The panboreal zonal correlation of the Lower Olenek substage is beyond question due to cosmopolitan ammonoid taxa, but the Siberian zone *hedenstroemi* has been established only in one locality of Arctic Canada [49]. The most advanced and detailed scale of the Upper Olenekian in Siberia comprises four zones and nine subzones. On the contrary, only analogs of the subzone *kolymensis* and zone *spiniplicatus* are found in Canada, and analogs of the zone *spiniplicatus* alone in Spitzbergen.

Lower Anisian deposits are zoned most closely in the north of Siberia, where they comprise five biostratons. They are also known in Spitzbergen and Eastern Greenland, but there are no analogs of the oldest beds with *Karangatites* of the Siberian Anisian. The zones *mulleri* and *caurus* of Canada, taken together, correspond to two upper subzones of the zone *taimyrensis* and the zone *caurus* of Siberia, since they have the species *Lenotropites caurus* and the genus *Stenopopanoceras* in common. The zone *caurus* of Spitzbergen is correlated in a similar way. Beds with *Stenopopanoceras*, *Groenlandites*, and *Pearylandites* in Eastern Greenland [72] seem to correspond to the upper part of the zone *taimyrensis.* It is difficult to correlate boreal Middle Anisian deposits, because Siberian Ammonoidea are too specific. One zone *Frechites laqueatus* is recognized in the Upper Anisian of Spitzbergen [73]. It corresponds in its ammonoid complex to the zone *chischa* of British Columbia, beds with *Frechites laqueatus* of Arctic Canada, and the subzone *sublaqueatus* of the Siberian zone *nevadanus*. The zone *rotelliforme* and two lower subzones of the zone *nevadanus* correspond to the zone *deleeni* of British Columbia and the upper part of beds with *Anagymnotoceras*, *Hollandites*, and *Gymnotoceras* of Spitzbergen.

Correlation of the Ladinian stage of boreal regions is based on evolutionary sequence of genera, species, and close forms of *Natgorstitides.* The panboreal correlation of the Upper Triassic presents considerable difficulties and is arbitrary even at the level of substages. In Spitzbergen only bottom beds of the Carnian (zone *zitteli* or zone *tenuis*) [69, 74] and Norian (beds with *Pterosirenites*) stages are characterized with Ammonoidea. They are correlated with Siberian zones *tenuis* and *verchojanicum*, respectively. The Carnian of the Arctic Canada contains the zone *nanseni* and analogs of the zone *welleri* of British Columbia; the Norian contains only some parts of the zone *columbianus* [71].

Parallel scales are of great use for panboreal correlation of Triassic deposits. Zones and beds with bivalves can be easily correlated. This correlation is the most reliable in the north of Central Siberia, in East Siberia, northeastern Russia, and on the New Siberian Islands. Some Siberian bivalve biostratons are recognized in the Franz Joseph Land, Spitzbergen, East Greenland, and, most clearly, in Arctic Canada. They can also be traced in some regions of Tethys.

Lower Triassic zones on bivalves occur in the boreal region, and some of them even go beyond it. The zone *errabunda* is well correlated with the Induan stage in the northeast of Asia, as well as in Spitzbergen, Eastern Greenland, and Primorye owing to wide occurrence of the index species. Zones of the Olenekian Stage — *mimer*, *occidentalis*, *sibirica*, and *aranea* — are clearly traceable within the area of occurrence of boreal deposits; the zone *occidentalis* has been recognized in inner regions of the USA (states of Nevada and Idaho). Age analogs of the zones *mimer* and *occidentalis* have been established in some regions at the low latitudes (Timor, the Himalayas) [61, 62].

Middle Triassic zones are confined to the boreal region. The Lower-Middle Anisian zone *arctica* is traceable only in shelf facies of the north of Middle and East Siberia. The Upper Anisian *Daonella* zones *americana* and *dubia* are noticed in numerous regions of Northeastern Asia, in Spitzbergen, Arctic Canada, and in the west of North America [57]. Owing to the index species, *Daonella* complexes established in the Ladinian are clearly traceable mainly in the northeast of Asia and, to a lesser extent, in the Franz Joseph Land, Spitzbergen, and Arctic Canada.

The Upper Triassic Halobia zones are not only reliably correlated in northeastern Russia, but even go beyond it. The zone *zitteli* is recognized in Spitzbergen, the Alps, and, maybe, on Timor. The zones *talajaensis*, *subfallax*, *asperella*, *indigirensis*, and others, or their age analogs, are traceable in Primorye, on the Pacific coast of North America, in Japan, Crimea, Malaysia, and so on [59]. The zones *ussuriensis*, *scutiformis*, and *ochotica* have the largest areal occurrence and are traceable in regions of boreal-type deposits on their index species. The zone *scutiformis* can also be correlated with the lower part of the local Warepan stage in New Zealand. Analogs of *Monotis* zones are established in numerous regions of Tethys on wide occurrence of vicarious species of genera *Eomonotis* and *Monotis*. The Rhaetian zone *efimovae* with two subzones is well correlated only in the north of Siberia and in northeastern Russia [32].

The boreal-tethyan correlation of the Triassic deposits seems to be the most successful in the boreal Mesozoic. The tethyan scale and the Siberian scale, the closest in the region of occurrence of boreal deposits, are linked through the scale of the Triassic of North America, whose Pacific areas were an ecotone region in the Triassic and were characterized by mixed complexes of tethyan and boreal genera and species of ammonoids. The Siberian and Canadian scales are fairly precisely correlated at the zonal level with respect to the presence of the same genera and species of ammonoids for the bulk of the Lower Triassic and Middle Triassic, excluding the Upper Induan and Middle Anisian [49]. A more detailed correlation does not yet seem possible, since most of the subzones of the Canadian scale have been recognized from distribution of ammonoids of tethyan groups in sections [71]. A direct correlation of boreal and tethyan scales of the Triassic can be done only in some ranges, probably corresponding to eustatic sea rises, accompanied by equalization of faunas of various biochores (Fig. 2). In the Lower Triassic such ranges are *Otoceras* beds, the zones *Lepiskites kolymensis* and *Anawasatchites tardus*; in the Upper Triassic the zone *Monotis ochotica* and, somewhat arbitrarily, the zone *Neoprotrachyceras seimkanense*. Comparison of the zonal scale of the Carnian, Lower Norian, lower Middle Norian, and Rhaetian of the boreal and tethyan regions is hampered by enhanced geographical differentiation and endemic occurrence of ammonoids in the Late Triassic. So the boreal-tethyan correlation of the Upper Triassic appears arbitrary even at the level of substages.

Boreal-tethyan zonal correlations can be done with respect not only to ammonoids, but also to bivalves. The zones *mimer*, *occidentalis*, *zitteli*, and others are found both in regions of occurrence of boreal deposits and in many peritethyan and tethyan regions [61]. Some of them (*scutiformis*, *ochotica*) occur even in the Notal region (New Zealand). Halobia zones, widely occurring in the northeast of Asia, are quite reliably correlated with zones in central Western Europe (the Alps), in North America, Japan, and so on [59]. Phylozones of monotides of the Norian occur most widely and can be easily traced throughout the globe [57].

JURASSIC SYSTEM

Of all Mesozoic systems Jurassic deposits are the most widespread in Siberia. Being typical boreal marine sediments, they have essentially terrigenous composition. Pure carbonate rocks are almost absent. All sections of the Jurassic system in the vast expanses of Siberia are classified in two groups. The first, western group of sections presents thin (hundreds and thousands of meters) rocks of various origin of the platform and near-platform type. It is located west of the Yana upper reaches. The second, eastern group consists of thick (thousands and tens of thousands of meters) terrigenous-volcanogenous rocks, mainly of marine origin, of the subgeosyncline and geosyncline type. It is located east of the Yana upper reaches [31, 37]. Deposits of marine origin are generally rich in diverse macro- and microfossils. Owing to this fact, close biostratigraphic scales on ammonites, belemnites, bivalves, foraminifers, and dinocysts have been developed during the last 30 years.

The boreal standard is a combined zonal ammonite scale, reflecting taxonomic peculiarities of the boreal paleobiochore divisions in the Jurassic (of the provincial rank in the Early Jurassic and regional starting from the Middle Jurassic, the intraregional biogeographic differentiation tending to increase). The boreal standard includes also zones from sections in areas with mixed boreal and tethyan ammonoids. Paleobiogeographic ecotone associations are the most important for comparison of sequences of typical boreal ammonite zones with standard ammonite sequences, located in Western Europe. The presence of zones with taxa varying in biogeographic origin within the unified scale excludes chronological gaps when boreal sedimentation is reconstructed throughout the Jurassic.

The boreal zonal standard of the Hettangian, Sinemurian, Pliensbachian, Toarcian, Aalenian, and Lower Bajocian is based primarily on sections of Northeastern Asia (Fig. 1). The zonal ammonite scale constructed there is the most detailed for deposits of the boreal type. It also provides a standard for northern Central Siberia, since the North-Siberian zonal ammonite scale matches it almost perfectly [75, 76]. We substitute the North-Siberian zone *Dactylioceras commune* for the northeastern zone *D. athleticum* in the boreal standard of the Lower Toarcian, because it is directly correlated with the European standard [77] (Fig. 3). Two scales, based on the evolution of the genus *Pseudolioceras* and differing only in zone nomenclature have been proposed for the Upper Toarcian [78, 79]. We include V. G. Knyazev's zonal scheme, developed on sections of both West Siberia and northeastern Russia, into the boreal standard of the Upper Toarcian, in spite of some controversial points: poor choice of *Pseudolioceras compactile* as a zone index species and abandoned validity of the species *P. rosenkrantzi*. An advantage of the chosen zonal scale is its good alignment with parallel scales on parastratigraphic groups developed in the same sections.

Ammonite sequences of the Aalenian and Lower Bajocian in northern East Siberia and northeastern Russia are the most complete in areas of boreal deposits [75, 76]. So they are proposed as standard ones with a minor change in nomenclature in the Upper Aalenian: substitution of *Pseudolioceras whiteavesi* for one of the index species [80] (Figs. 1, 3). A zonal ammonite sequence constructed on sections of Eastern Greenland was chosen as the boreal standard for the Upper Bajocian, Upper Bathonian, and Callovian [81, 82], and a sequence on sections of Northern Yukon and Western Canada for the Lower and Middle Bathonian [83] (Figs. 1, 3).

The most detailed zonal scale constructed on sections in Eastern Taimyr and the Anabar R. in East Siberia [84] is proposed as the boreal zonal standard for the Lower Oxfordian (Figs. 1, 3). The boreal zonal standard for the Middle Oxfordian and Upper Oxfordian, previously constructed on sections in Scotland (Fig. 1), represents the evolution of *Cardioceratidae ammonites*. The same zonal sequence has been established in East Greenland [85, 86] (Fig. 3).

The Kimmeridgian boreal zonal standard comprises the most complete ammonite scale established in a single section on the Lopsiya R. on the eastern slope of the Subpolar Urals [87]. The type sections of the Volgian Stage are located in the East-European Plain in the Volga basin (Fig. 1). The most prominent and complete sequences of Lower- and Middle-Volgian ammonite assemblages in the boreal region have been established near Gorodishche Village, not far from the city of Ulyanovsk; sequences of the Upper Volgian substage have been found near Kashpir Village, not far from Syzran, the Samara Region [88]. They are chosen for the zonal standard of the terminal stage of the boreal Jurassic (Fig. 3).

The parallel scales are based on various parastratigraphic groups. The scales are related to each other and to the Siberian ammonite zonal standard (Fig. 3). Scales of polytaxon zones on bivalves, foraminifers, ostracods, dinocysts, and others are important for zonation and current correlation of Jurassic deposits within individual paleobasins. The scales involve zones of joint occurrence, teil-zones, ecozones, sets of parallel phylozones, and so on [8, 89–92]. Actually determination of the volumes of zones involves elucidation of the sequence and combination of events of various nature: chorological (penetration of migrants), ecosystemic (rearrangement of associations, change of dominants, acme of a particular taxon or form), phylogenetic (autochthonous emergence of a novel taxon). Hence, in long-distance interregional correlations zonal scales on benthos may be regarded as "bioevent" scales. In these scales reference ranges are characterized by unique sequences of combined results of mutually independent biological events varying in nature: phylogenetic, chorological, and ecosystemic [90, 92]. Zones of narrow and wide ranges with different features of assemblages from different facies are established simultaneously. There is much evidence for circumboreal occurrence of individual reference levels on paragroups. Some of the biostratons established in Siberia can be clearly recognized in Jurassic sections of Western Europe, Canada, Alaska, and so on [93].

The Lower-Middle Jurassic and Upper Jurassic differ in the nature of their bivalve zones. The Upper Jurassic scale consists of phylozones, which have been established on phylogenetic stages of eurybiontic genera and species of the family Buchiidae, autochtonously developing in the boreal basin (Fig. 3) [94, 95]. The scale comprises 10 *Buchia* zones. The circumboreal occurrence of most index species of *Buchia* allows direct panboreal and sometimes boreal-peritethyan correlations. In the boreal Lower and Middle Jurassic there are no bivalves of autochthonously developing euryfacies groups except for inocerams. The scales on bivalves for the Lower and Middle Jurassic are composed of polytaxon zones of various types. Thirty biostratons of zonal rank and beds with bivalves are established in the Lower-Middle Jurassic scale. They allow recognition of up to 26 stratons differing in facies settings (Fig. 3) [8, 89, 90].

The scales on foraminifers and ostracods are constructed on the same principles as the Lower-Middle Jurassic scale on bivalves [90, 96, 97]. In the Lower-Middle Jurassic range they contain 31 zones on foraminifera and 15 zones on ostracods, allowing recognition of up to 22 and 14 stratons respectively in sections differing in facies settings. The Upper Jurassic zones on foraminifers, first developed for unexposed territories of West Siberia [98], have been considerably modified by now on sections in the margins of West Siberia, and there are as many as 14 of them (Fig. 3).

Belemnites is one of the most widespread and well-preserved groups of fossils in Jurassic deposits. They are distributed unevenly both within the section and over the area. Being abundant in the Toarcian, they decrease in number in the Aalenian, are rare in the Bajocian and widespread in the Bathonian, Callovian, and Upper Jurassic. The Lower- and Middle-Jurassic scales on belemnites are composed of complex zones and comprise 11 biostratons. The Upper Jurassic scales comprise six biostratons, established mainly on developmental stages of two genera: *Pachyteuthis* and *Cylindroteuthis* [99, 100].

The pollen stratigraphic scale of the Siberian Jurassic is developed in key sections of the margins of the Siberian Plate, where the Jurassic is well characterized by complexes of various mollusks and microfauna [91, 101–103]. Pollen zones and spore-and-pollen beds are established in this scale mainly as acme zones of one or several characteristic species with regard to the appearance, disappearance, and evolutionary level of specific taxa (Fig. 3). The sequence of the Lower- and Middle-Jurassic pollen zones is the most reliable; it comprises 10 biostratons, some of which, such as pollen zone 6, are excellent references within Asian Russia [91, 101]. Here we propose an improved version of this scale.

The scale on dinocysts is still under development for most stratigraphic ranges, because dinocysts are unevenly distributed over the Siberian Jurassic. First dinocysts appear in the upper Pliensbachian. They are abundant in the Toarcian and disappear almost entirely from the Aalenian. The subsequent rise in abundance of dinocysts and their expansion to northern paleobasins of Russia falls on the Callovian. Biostratons on dinocysts (dinozones) have been established in the Siberian regional scale on appearance of new taxa, acme zones, ranges of common occurrence and levels of disappearance of particular characteristic species [91, 101, 104]. A sequence of two dinozones with five subzones has been established in the north of Siberia in the upper Pliensbachian and in the Toarcian. In the same area six biostratons ranked as dinocyst beds have been established in the Callovian and Upper Jurassic. Their boundaries are most precisely established and verified with ammonites in the Lower Callovian and Upper Volgian (Fig. 3). The Toarcian sequences of dinocyst assemblages match very well with those of sections in the north of England, northwest of Germany, in Spitzbergen and Arctic Canada [91, 103]. Boreal dinocyst biostratons are traceable only in Arctic regions of Europe and North America [103, 104]. It is worth mentioning that beds with *Crussolia dalei* and *Paragonyaulacystaretifragmata* of the Lower Callovian are reliably correlated with the coeval biostraton of the Pechora basin, whose assemblages contain both boreal and boreal-atlantic dinocyst species.

The panboreal correlation of Jurassic deposits is done mainly by means of ammonite zones, though some reference levels on paragroups — bivalves and foraminifers (Middle Jurassic) [93] and *Buchia* (Upper Jurassic) have also been established. Correlations of ammonite scales of North Siberia, Northeastern Asia, Spitzbergen, East Greenland, northern Canada, and northern Alaska are the most reliable. A number of ammonite zones of the Lower Jurassic provide not only panboreal, but even boreal-tethyan zonal correlation. For example, zones of the Hettangian (*Psiloceras planorbis*, *Alsatites liasicus*, *Schlotheimia angulata*), Upper Pliensbachian (*Amaltheus stokesi*, *A. margaritatus*), Lower Toarcian (*Harpoceras falciferum*, *Dactylioceras commune*, *Zugodactylites monestieri*) are directly correlated. Zones of the Upper Toarcian, Aalenian, and Lower Bajocian have their own nomenclature in the boreal standard because of a significant difference in the composition of zonal ammonite assemblages as compared with the standard. Their correlation with zones of the European standard is done through intermediate sections in North America, whose zonal assemblages contain both boreal and peritethyan ammonite taxa.

A satisfactory correlation is obtained for zones of the Upper Bajocian, Bathonian, and Lower Callovian within the regions of occurrence of boreal deposits (East Greenland, Spitzbergen, and North America). However, the correlation with the European ammonite standard is somewhat arbitrary. One of the reference levels for correlation is the zone *Boreiocephalites borealis* at the bottom of the boreal Upper Bajocian. It is correlatable through the zone *Megasphaeroceras rotundum* of Southern Alaska with the lower zone of the Upper Bajocian of the standard. Another reference is provided by Siberian Lower Callovian zones *Cadoceras falsum* and *C. anabarense*. Owing to related species of *Cadoceras* in zonal complexes they are well correlated with Eastern Greenland zones *C. calyx* and *C. apertum*. These zones, in turn, correspond to the lower zone of the Callovian in the English standard [83]. Notice that both Siberian zones are no less reliably correlated with the lower zone of the standard through sections in the Pechora basin, too [105].

The standard-oriented zone-by-zone panboreal correlation can be done for the Middle Callovian and Upper Callovian, the upper Lower Oxfordian, the Middle Oxfordian, and, to a lesser extent, Upper Oxfordian and Kimmeridgian (Fig. 3). The possibility of panboreal zone-by-zone correlation of this stratigraphic range has been considered in several studies in West Siberia and East Siberia and on the East-European Plain [47, 84, 87, 106–111]. Reliable panboreal zone-by-zone correlation on ammonites within West Siberia [112] and East Siberia [87, 113], East Greenland [114, 115], and Canada [116] have been reported for the Volgian Stage. *Buchia* zones provided a less detailed panboreal correlation of the Volgian and direct boreal-peritethyan correlation of the Tithonian [94, 95, 117–121].

The boreal-tethyan or, rather, **boreal-peritethyan correlation** of Jurassic deposits presents few difficulties. The reason is that most type sections of Jurassic stages are located within the occurrence of peritethyan deposits. Some stages and substages of the Lower Jurassic (Hettangian, Sinemurian, Upper Pliensbachian, Lower Toarcian) and Upper Jurassic (Oxfordian, Kimmeridgian) in the boreal zonal scale have the same nomenclature of many ammonite zones as the West-European standard. Zones of Middle Jurassic stages of the boreal standard are reasonably correlated with zonal sequences of West-European key sections through sections with mixed ammonite assemblages or by comparison of scales on parastratigraphic fossil groups. The zone-by-zone correlation of the Volgian and Tithonian still presents a problem. Of a dozen of Tithonian zones and nearly the same quantity of Volgian ones only one horizon, with *Gravesia*, ensures direct correlation of the lowermost zone (*Hybonoticeras hybonotum*) of the Tithonian, border Kimmeridgian-Portlandian beds and the bottom zone (*Ilowaiskya klimovi*) of the Volgian Stage. Versions of correlations of other zones of the Volgian Stage with zones of the Tithonian, assuming correlation of the top of the Tithonian with the bottom of the Upper Volgian Substage are open to debates [108, 122].

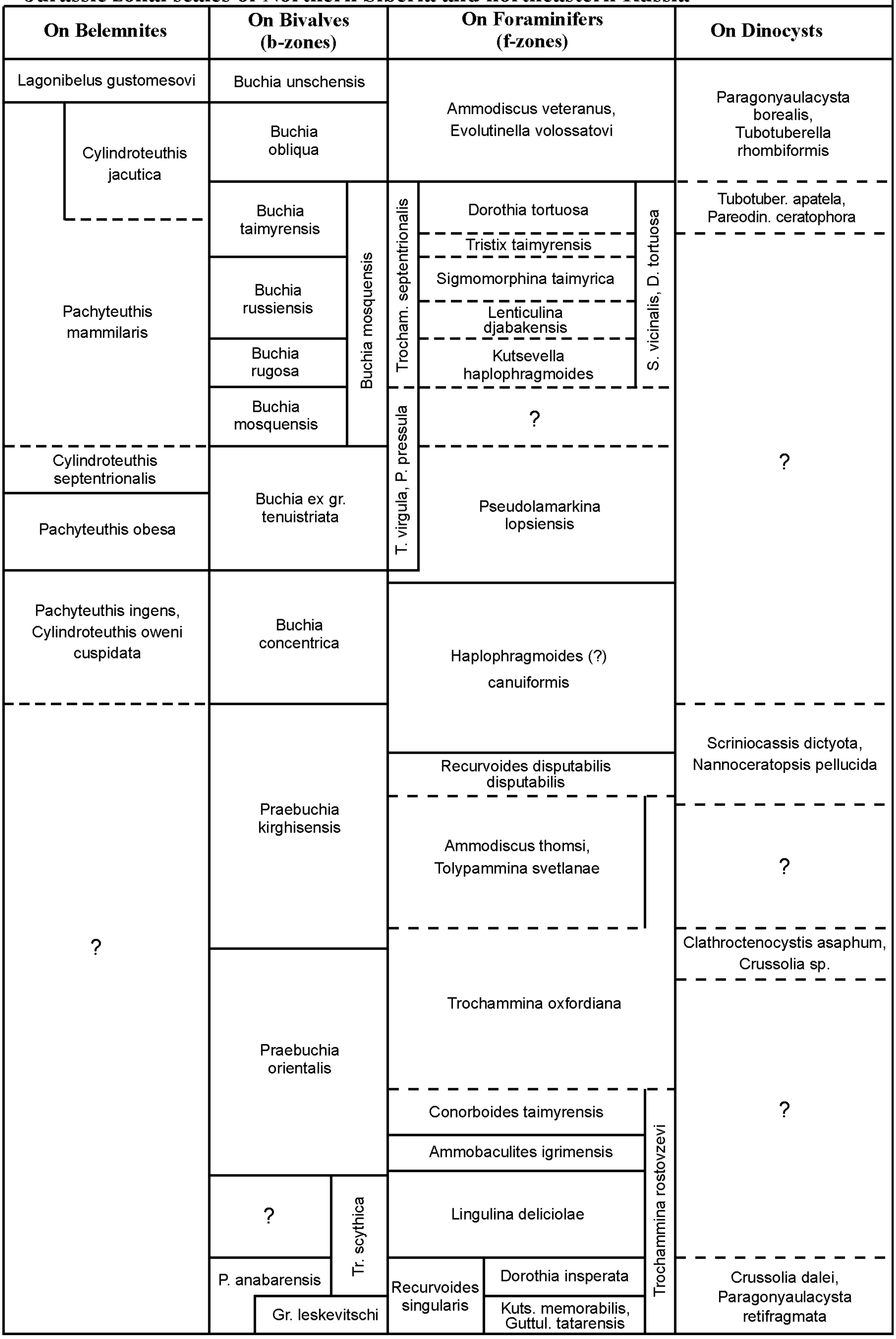
CRETACEOUS SYSTEM

Deposits of Cretaceous age occupy over one third of Siberia. They contain both marine and, much more, continental formations. The marine Lower Cretaceous (the lower Neocomian) is the most widespread. The Berriasian and Valanginian Stages are related to the Upper Jurassic, especially to the Volgian Stage, in origin and occurrence. The Upper Hauterivian, Barremian, Aptian, Albian, and Cenomanian are formed mainly by non-marine sediments. The marine Upper Cretaceous is confined mainly to the West-Siberian Plain, where it is overlain by much younger deposits [43].

The boreal standard of the Cretaceous System has been developed by now to the least extent because of the lack of specialized investigations and to some unfavorable conditions in the north of the Siberian and Russian Platforms, as well as in the whole circumboreal region. This is especially true with regard to the upper and middle Cretaceous. As mentioned above, the middle part of the Cretaceous is represented in Siberia mainly by continental facies, and the Upper Cretaceous is either overlain by Cenozoic deposits or strongly distorted by glaciers moving southwards in the Quaternary time. Cretaceous sections on the Russian Platform contain many stratigraphic gaps (see Fig. 6 in [123]). The best biostratigraphic scales have been developed for the boreal Berriasian and Valanginian on sections of North Siberia (Fig. 1). The most complete sequences of ammonite zones known in the region of occurrence of boreal deposits have been established for the Berriasian

Series	Stage	Sub-stage	Standard	Boreal standard			Middle and Upper: On Ammonites
Upper	Tithonian	Upper	"Durangites"	Volgian	Upper	Craspedites nodiger	Craspedites chetae Craspedites taimyrensis
			Paraulacosphinctes transitorius			Craspedites subditus Kashpurites fulgens	C. okensis: Subcraspedites originalis C. okensis: Craspedites okensis C. okensis: Virgatosphinctes exoticus
		Middle	Microcantoceras ponti		Middle	Paracrasp. opressus Epivirgatites nikitini	Epilaugeites vogulicus / E. variabilis Laugeites groenlandicus
			Semiformiceras falluxi			Virgatites virgatus	Taimyrosphinctes excentricus Dorsoplanites maximus
			Semiformiceras semiforme			Dorsoplanites panderi	Dorsoplanites ilovaiskii Pavlovia iatriensis
		Lower	Danubisphinctes palatinum Franconites vimineus		Lower	Ilovaiskya pseudoscythica	Pectinatites pectinatus
			Usseliceras parvinodosum Dorsoplanitoides triplicatus Usseliceras tagmersheimense			Ilovaiskya sokolovi	Subdichotomoceras
			Hybonoticeras hybonotum			Ilovaiskya klimovi	Eosphinctoceras
	Kimmeridgian	Upper	Aulacostephanus autissiodorensis	Aulacostephanus autissiodorensis			Oxydiscytes taimyrensis
			Aulacostephanus eudoxus	Aulacostephanus eudoxus			Aulacostephanus eudoxus
			Aulacostephanus mutabilis	Aulacostephanus acanthicus			Aulacostephanus mutabilis
		Lower	Rasenia cymodoce	Amoeboceras kitchini		Rasenia borealis	Amoeboceras kitchini: Rasenia borealis
			Pictonia baylei			Pictonia involuta	Pictonia involuta
	Oxfordian	Upper	Ringsteadia pseudocordata	Amoeboceras rosenkrantzi Amoeboceras regulare			A. ex gr. rosenkrantzi beds Amoeboceras regulare
			Decipia decipiens	Amoeboceras serratum			Amoeboceras serratum
			Perisphinctes cautisnigrae	Amoeboceras glosense			Amoeboceras glosense
		Middle	Gregoriceras transversarium	Cardioceras tenuiserratum			Cardioceras tenuiserratum
			Perisphinctes plicatilis	Cardioceras densiplicatum			Cardioceras densiplicatum
		Lower	cordatum: Cardioceras cordatum	Cardioceras cordatum			Cardioceras cordatum
			cordatum: Cardioceras percaelatum	Cardioceras percaelatum			Cardioceras percaelatum
			cordatum: Cardioceras bukowskii	Cardioceras gloriosum			Cardioceras gloriosum Cardioceras praecordatum
			Vertumniceras mariae	Cardioceras obliteratum			C.obliteratum, C.scarburgense
Middle	Callovian	Upper	Quenstedtoceras lamberti	Quenstedtoceras lamberti			Eboraciceras subordinarum
			Peltoceras athleta	Peltoceras athleta			Longaeviceras keyserlingi
		Middle	Erymnoceras coronatum	Erymnoceras coronatum			Rondiceras milaschevici & Erymnoceras beds
			Kosmoceras jason	Kosmoceras jason			
		Lower	Sigaloceras calloviense	Sigaloceras calloviense			Cadoceras emelianzevi
			Proplanulites koenigi	Cadoceras nordenskjoelde			
			Macrocephalites herveyi	Cadoceras apertum Cadoceras calyx			Cadoceras anabarense Cadoceras falsum

Jurassic zonal scales of Northern Siberia and northeastern Russia



Series	Stage	Substage	Standard	Boreal standard	Lower and Middle On Ammonites
Middle	Bathonian	Upper	Clydoniceras discus	Cadoceras variabile	Cadoceras variabile beds
			Oxycerites orbis		Cadoceras barnstoni
			Procerites hodsoni	Arcticoceras (?) cranocephaloide	Arcticoceras (?) cranocephaloide
		Middle	Tulites subcontractus	Arcticoceras ishmae	Arcticoceras ishmae
			Procerites progracilis	Arcticoceras harlandi	Arcticoceras harlandi
		Lower	A. tenuiplicatus	Arctocephalites frami	Paracephalites (?) belli beds
				Arctocephalites amundseni	Arctocephalites aff. greenlandicus
			Zigzagiceras zigzag	Arctocephalites porcupinensis	Arctocephalites arcticus
				Arctocephalites spathi	Oxycerites jugatus
	Bajocian	Upper	Parkinsonia parkinsoni	Cranocephalites pompeckji	Cranocephalites carlsbergensis
			Garantiana garantiana	Cranocephalites indistinctus	Cranocephalites gracilis
			Strenoceras niortense	Boreiocephaltes borealis	Boreiocephaltes borealis
		Lower	Stephanoceras humriesianum	Chondroceras cf. marshalli beds	Chondroceras cf. marshalli beds
			Otoites sauzei	Arkelloceras tozeri	Arkelloceras tozeri
			Witchella laeviuscula	Ps. (T.) fastigatus	Ps. (T.) fastigatus
			Hyperlioceras discites		
	Aalenian	Upper	Graphoceras concavum	Pseudolioceras (Tugurites) whiteavesi	Pseudolioceras (Tugurites) whiteavesi, P.(T.) tugurensis
			Ludwigia murchisonae		
		Lower	Leioceras opalinum	Pseudolioceras maclintocki	Pseudolioceras maclintocki
				Pseudolioceras beyrichi	Pseudolioceras beyrichi
Lower	Toarcian	Upper	Dumortieria levesquei	Pseudolioceras falcodiscus	Pseudolioceras falcodiscus
			Grammoceras thouarsense	Pseudolioceras wurttenbergeri	Pseudolioceras wurttenbergeri
			Haugia variabilis	Pseudolioceras compactile	Pseudolioceras compactile
		Lower	Hildoceras bifrons	Porpoceras spinatum	Porpoceras spinatum
				Zugodactylites monestieri	Zugodactylites monestieri
				Dactylioceras commune	Dactylioceras commune
			Harpoceras falciferum	Harpoceras falciferum	Harpoceras falciferum
				Eleganticeras elegantulum	Eleganticeras elegantulum
			Dactylioc. tenuicostatum	Tiltoniceras propinquum	Tiltoniceras propinquum
	Pliensbachian	Upper	Pleuroceras spinatum	Amaltheus viligaensis	Amaltheus viligaensis
			Amaltheus margaritatus	Amaltheus margaritatus	Amaltheus margaritatus
			Amaltheus stokesi	Amaltheus stokesi	Amaltheus stokesi
		Lower	Prodact. davoei	?	?
			Tragophyl. ibex		
			Uptonia jamesoni	Polymorphites	Polymorphites
	Sinemur.	Upper	Echioceras raricostatum	Angulaticeras colymicum	Angulaticeras colymicum
			Oxynoticeras oxynotum		
			Asteroceras obtusum	Coroniceras siverti	Coroniceras siverti
		Lower	Caenisites turneri		
			Arnioceras semicostatum		
			Arietites bucklandi	Arietites libratus	Arietites libratus
	Hett.	Upper	Schlotheimia angulata	Schlotheimia angulata	Schlotheimia angulata
			Alsatites liasicus	Alsatites liasicus	Alsatites liasicus
		Lower	Psiloceras planorbis	Psiloceras planorbis	Psiloceras planorbis
					Primasiloceras primulum

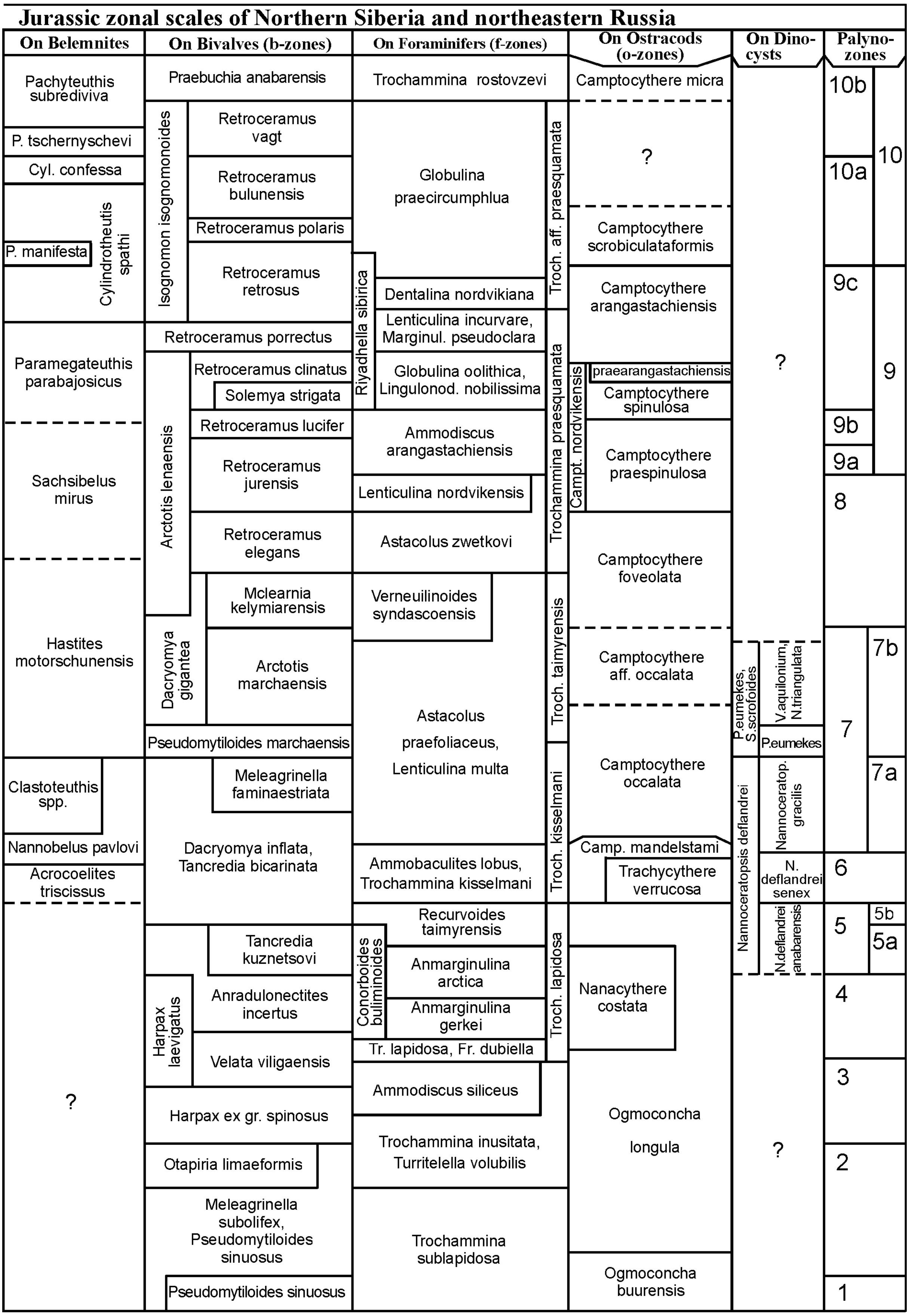

Jurassic zonal scales of Northern Siberia and northeastern Russia
On Belemnites
Pachyteuthis subrediviva
P. tschernyschevi
Cyl. confessa
P. manifesta
Cylindrotheutis spathi
Paramegateuthis parabajosicus
Sachsibelus mirus
Hastites motorschunensis
Clastoteuthis spp.
Nannobelus pavlovi
Acrocoelites triscissus
?
On Bivalves (b-zones)
Praebuchia anabarensis
Isognomon isognomonoides
Retroceramus vagt
Retroceramus bulunensis
Retroceramus polaris
Retroceramus retrosus
Retroceramus porrectus
Arctotis lenaensis
Retroceramus clinatus
Solemya strigata
Retroceramus lucifer
Retroceramus jurensis
Retroceramus elegans
Mclearnia kelymiarensis
Dacryomya gigantea
Arctotis marchaensis
Pseudomytiloides marchaensis
Meleagrinella faminaestriata
Dacryomya inflata, Tancredia bicarinata
Tancredia kuznetsovi
Harpax laevigatus
Anradulonectites incertus
Velata viligaensis
Harpax ex gr. spinosus
Otapiria limaeformis
Meleagrinella subolifex, Pseudomytiloides sinuosus
Pseudomytiloides sinuosus
On Foraminifers (f-zones)
Trochammina rostovzevi
Globulina praecircumphlua
Troch. aff. praesquamata
Riyadhella sibirica
Dentalina nordvikiana
Lenticulina incurvare, Marginul. pseudoclara
Globulina oolithica, Lingulonod. nobilissima
Trochammina praesquamata
Ammodiscus arangastachiensis
Lenticulina nordvikensis
Astacolus zwetkovi
Verneuilinoides syndascoensis
Troch. taimyrensis
Astacolus praefoliaceus, Lenticulina multa
Troch. kisselmani
Ammobaculites lobus, Trochammina kisselmani
Recurvoides taimyrensis
Conorboides buliminoides
Anmarginulina arctica
Anmarginulina gerkei
Troch. lapidosa
Tr. lapidosa, Fr. dubiella
Ammodiscus siliceus
Trochammina inusitata, Turritelella volubilis
Trochammina sublapidosa
On Ostracods (o-zones)
Camptocythere micra
?
Camptocythere scrobiculataformis
Camptocythere arangastachiensis
Campt. nordvikensis
praearangastachiensis
Camptocythere spinulosa
Camptocythere praespinulosa
Camptocythere foveolata
Camptocythere aff. occalata
Camptocythere occalata
Camp. mandelstami
Trachycythere verrucosa
Nanacythere costata
Ogmoconcha longula
Ogmoconcha buurensis
On Dino-cysts
?
P.eumekes, S.scrofoides
V.aquilonium, N.triangulata
P.eumekes
Nannoceratopsis deflandrei
Nannoceratop. gracilis
N. deflandrei senex
N.deflandrei anabarensis
?
Palyno-zones
10b
10a
10
9c
9
9b
9a
8
7b
7
7a
6
5b
5
5a
4
3
2
1

Fig. 3. Zonal stratigraphy of the Jurassic System of Siberia and northeastern Russia. Designations as in Fig. 2. Palynozones and beds: 1 — *Dipterella oblatinoides*, *Allsporites pergrandis*, *Camptotriletes cerbriformis*, *Dipteridaceae*, *Quadraeculina anellaeformis*; 2 — *Cycadopites medius*, *C.* spp., *Stereisporites infragranulatus*, *Polycingulatisporites triangularis*, *Quadraeculina anellaeformis*, *Protopicea cerina*; 3 — *Cycadopites* spp., *Uvaesporites argentaeformis*, *Dipterella oblatinoides*, *Paleoconiferus asaccatus*; 4 — *Stereisporites* spp., *Uvaesporites argentaeformis*, *Cycadopites dilucidus*; 5 — *Tripartina variabilis*; 5a — *Osmundacidites*, *Cycadopites dilucidus*, *Stereisporites*, *Quadraeculina limbata*; 5b — *Cyathidites minor*, *Obtusisporis junctus*, *Dipteridaceae*, *Marattisporites scabratus*; 6 — *Cyathidites*, *Dipteridaceae*, *Marattisporites scabratus*, *Klukisporites variegatus*, *Classopollis*; 7 — *Piceapollenites variabiliformis*, *Cyathidites minor*, *Osmundacidites* spp., *Dipteridaceae*, *Marattisporites scabratus*; 8 — *Cyathidites minor*, *Osmundacidites jurassicus*, *Piceapollenites variabiliformis*, *Sterisporites* spp., *Sciadopityspollenites multiverrucosus*; 9 — *Neoraistrickia rotundiformis*, *Lycopodiumsporites intortivallus*, *Dicksonia densa*, *Pinus divulgata*; 9a — *Cyathidites minor*, *C. coniopteroides*, *Osmundacidites* spp., *Lycopodiumsporites* spp., *Leiotriletes adiantiformis*; 9b — *Cyathidites australis*, *Microlepidites crassirimosis*, *Hemitelia parva*, *Neoraistrickia truncata*, *N.* spp., *Podocarpidites rousei*, *Monolites couperi*; 9c — *Neoraistrickia* spp., *Lycopodiumsporites* spp., *Osmundacidites* spp., *Stereisporites*, *Cyathidites minor*, *Alisporites bisaccus*; 10 — *Lophotriletes torosus*, *Gleichenidites*, *Quadraeculina limbata*, *Sciadopityspollenites macroverrucosus*; 10a — *Cyathidites* spp., *Piceapollenites* spp., *Gleichenidites*, *Quadraeculina limbata*, *Sciadopityspollenites macroverrucosus*, *Marattisporites scabratus*, *Classopollis*; 10b — *Perotrilites zonatoides*, *Leiotriletes pallescens*, *Osmundacidites* spp., *Perinopollenites elatoides*.

in a section on the Nordvik Peninsula, at the coast of the Laptev Sea [124, 125]; for the Valanginian, in the basin of the Boyarka R. [46, 126]. These sequences are proposed as standards for the Berriasian and Valanginian in the Mesozoic boreal zonal scale [127, 128] (Fig. 4).

Continuous sections of the marine boreal Hauterivian have been found neither in Siberia nor on the Russian Platform. Therefore the standard sequence of ammonite zones we have proposed is a combination of a number of sections on the Russian Platform. The Lower Hauterivian zonal sequence is based on sections near the village of Krest, not far from Yaroslavl (Fig. 1). Though being a glacial erratic rock mass, it is the only locality where the most complete known sequence of beds with boreal ammonites of the lower Hauterivian (*Homolsomites bojarkensis* and *Pavlovites polyptychoides*) is observed (Fig. 4) [129, 130]. The lacking Hauterivian zones *Speetoniceras versicolor* (Lower substage) and *Simbirskites decheni* (Upper substage) are chosen from sections at the Volga River near Ulyanovsk and Saratov [131]. It should be emphasized that the temporal relations of these beds with *Pavlovites* and *Speetoniceras* are still under question [132, 133].

The sequence of mollusk zones constructed mainly on sections in the southeast of the West-European Plain has been adopted as a boreal standard for the upper part of the Lower and the entire Upper Cretaceous [75]. This standard, however, lacks some zones on ammonites, for example, in the Barremian and, partly in the Lower Aptian. There are also many gaps in the ammonite sequences of the Aptian and Albian, making the standard vulnerable to criticism. The belemnite zonal standard of the Santonian, Campanian, and Maastrichtian does not ensure reliable correlation with Arctic sections (Fig. 4).

Parallel scales for the Lower and Upper Cretaceous have been developed on bivalves (*Buchia* and inocerams) and dinocysts (Fig. 4). Scales on foraminifers and belemnites (only for the lower Neocomian) are still under development.

The Neocomian scale on bivalves is based on the evolution of a single genus *Buchia* and is typically phylozonal [95]. The scale has been developed on the same sections as the ammonite scales for the Berriasian and Valanginian (Fig. 1). Owing to the circumboreal occurrence of the vast majority of index species for *Buchia* zones and penetration of some important species of *Buchia* into peritethyan regions the scale provides direct panboreal and even boreal-tethyan correlations at some levels.

The inoceram zonal scale of the Upper Cretaceous has been constructed by Khomentovsky on sections of the Ust'-Yenisei Depression [134–137]. The scale covers a stratigraphic range from the top of the Cenomanian to the bottom of the Campanian and comprises 10 inoceram zones (Fig. 4). This scale is categorized as evolutionary-migrational. Most of them are of panboreal occurrence, and some penetrate directly into tethyan regions of Western Europe [138].

The Neocomian scale on dinocysts is based on studies of this microplancton group done by N. K. Lebedeva on a section at the Yatriya R. (Subpolar Urals, see Fig. 4). This scale covers a wider stratigraphic range than the previous sequence of beds with dinocysts (Fig. 2 in [139]). Correlation of the proposed scale with dinocyst

Series	Stage	S/stage	Tethian standard	Boreal standard	Cretaceous zonal scales of Northern Siberia: On Ammonites	On Bivalves	On Dinocysts
1	2	3	4	5	6	7	8
Upper	Maastrichtian	Upper	N.kazimiroviensis / Sph. binkhorsti	Neobelemnitella kazimiroviensis	Ammonite scale undeveloped	No Inocerams	Cerodinium sp.A
			Belemnitella junior				Formea chytra-Palaeocystodinium sp.
		Lower	occidentalis: Belemnella fastigata	Acanthoscaphites tridens: Belemnella sumensis			Operculodinium centrocarpum - Cerodinium diebelii
			occidentalis: Belemnella cimbrica				
			occidentalis: B. sumensis / P. neubergicus	Belemnella lanceolata			
			lanceolata: B. obtusa / Sph. ubaghsi				
			lanceolata: B. pseudoobt.	Belemnella licharewi			
			lanceolata: B. lanceolata				
	Campanian	Upper	Bostrichoceras polyplocum	Belemnitella langei			Chatangella niiga
			H. marroti	Belemnitella mucronata			
		Lower	Delawarella campaniensis	Gonioteuthis quadrata gracilis			Isabelidinium spp.
			Placenticeras bidorsatum	G. quadrata quadrata		Sph. patootensiformis beds	
	Santon.	Upper	Placenticeras polyopsis / E. austriacum	Actinocamax laevigatus		Sphenoceramus patootensis	Alterbidinium daveyi
			?	Gonioteuthis granulata			
		L.	Tex. gallicus	Sphenoceramus cardissoides		Sphenoceramus cardissoides	Chatangella chetiensis
	Coniacian	Upper	P. serratomarginatus	Volviceramus involutus		Inoceramus (Haenleinia) russiensis	Canningia macroreticulata
			Gauthiericeras margae				
		M	Peroniceras tridorsatum				
		Lower	Forresteria (Harleites) petrocoriensis	Inoceramus schloenbachi		I. (I.) schulginae jangodaensis / Volviceramus subinvolutus	Spinidinium sverdrupianum
	Turonian	Upper	Subprionoceras neptuni / C. woollgari	Inoceramus costellatus		Volviceramus inaequivalvis	Chatangiella spectabilis
			R. deverianum				Cyclonephelium vannophorum
		Middle	R. ornatissimum	Inoceramus lamarcki		Inoceramus (Inoceramus) lamarcki	Chatangiella victoroensis
			Romaniceras kallesi				
			K. turoniensis				
		Lower	Mammites nodosoides	Mytiloides labiatus		Inoceramus (Mytiloceramus) labiatus	Chlamydophorella nyei
			Watinoceras coloradoensis				
	Cenoman.	Upper	Neocardioceras juddi	Praeactinocamax plenus triangulus		Inoceramus pictus	Euridinium saxoniense
			Metoicoceras geslinianum	Sciponoceras gracile			
			Calycoceras guerangeri	Eucalycoceras pentagonum			Geiselodinium cenomanicum

1	2	3	4	4	5	5	6	7	8
Upper	Cenomanian	Upper	A.jukesbrownei		A.jukesbrownei		**Nonmarine deposits**	**Nonmarine deposits**	**Nonmarine deposits**
			Acanthoceras rhotomagense	T. acutus	Turrilites acutus	Inoceramus oripssi			
				T.costatus	Turrilites costatus				
		Lower	Mantelliceras dixoni		Mantelliceras mantelli				
			Mantelliceras mantelli	M.saxbii					
				N. carcitaensis					
Middle	Albian	Upper	Stoliczkaia dispar		Stoliczkaia dispar				
			Mortoniceras inflatum		?				
		Middle	Dipoloceras cristatum						
			Hoplites dentatus		A. intermedius beds				
			Euhoplites lautus		Hoplites dentatus				
		Lower	Otohoplites raulinianus		? Arcthoplites jachromensis		Arcthoplites sp.		Palaeoperidinium cretaceum beds
			Sonneratia dutempleana						
			Leymeriella tardefurcata						
	Aptian	Upper	Hypacanthoplites jacobi		Hypacanthoplites jacobi		**Nonmarine deposits**		
			D.subnodosocostatum		?				**Nonmarine deposits**
			Epicheloniceras tschernyschewi		Parahoplites melchior				
					E.tschernyschewi				
		Lower	Tropaeum boverbanki		?				
			Deshayesites weissi		Deshayesites deshayesi				
			Roloboceras hambrovi		Deshayesites weissi				
			Ancyloceras matheroni						
			Deshayesites consobrinus		?				
			Pseudocrioceras coquandi						
			Prodeshayesites sp.						
	Barremian	Upper	Colchidites sp.		Oxytoma jasikowi				
			Heteroceras astieri						
			Hemihoplites feraudi						
			"Emericeras" barremense						
		Lower	Moutoniceras sp.						
			Pulchellia compressissima						
			Spitidiscus hugii						

1	2	3	4	4	5	5	6	6	7	7	8
Lower	Hauterivian	Upper	Pseudothurmannia angulicostata		Simbirskites decheni		Nonmarine deposits		Nonmarine deposits		Nonmarine deposits
			Balearnites balearnis								
			Subsaynella sayni								
		Lower	Cruasiceras cruasense		Speetoniceras versicolor		Speetoniceras versicolor		Buchia crassicollis		Canningia americana - Gardodinium trabeculosum
			Lyticoceras nodosoplicatum								
			Crioceratites loryi		Pavlovites polyptychoides						
			Acanthodiscus radiatus		Homolsomites bojarkensis		Homolsomites bojarkensis				
	Valanginian	Upper	Techenites callidiscus		Dichotomites bidichotomus	Selandites kotschetkovi	Dichotomites bidichotomus	Selandites kotschetkovi	Buchia sublaevis		Dingodinium cerviculum
			Himantoceras trinodosum			Dichotomites bidichotomoides		Dichotomites bidichotomoides			
			Saynoceras verrucosum			Prodichotomites triplodiptychus		Prodichotomites triplodiptychus			
		Lower	Thurmanniceras campylotoxum		Siberites ramulicosta	Polyptychites beani	Siberites ramulicosta	Polyptychites beani			Muderongia simplex - Cribroperidinium muderongensis
						Siberites ramulicosta		Siberites ramulicosta	Buchia keyserlingi		
			Thurmanniceras pertransiens		Euryptychites astieriptychus		Euryptychites astieriptychus				
					Euryptychites quadrifidus		Euryptychites quadrifidus				
			Thurmanniceras otopeta		Neotollia klimovskiensis		Neotollia klimovskiensis		Buchia inflata		Dingodinium albertii - Ambonosphaera delicata
	Berriasian	Upper	Fauriella boissieri	Tirnovella alpillensis	Tollia tolli		Tollia tolli			Buchia volgensis	
				Picteticeras picteti	Bojarkia mesezhnikowi		Bojarkia mesezhnikowi		Buchia tolmatschowi		
				Malbosiceras paramimou-num	Surites analogus	Surites analogus	Surites analogus	Surites analogus	Buchia jasikovi		Paragonyaulacysta borealis
						Surites subquadratus		Surites subquadratus			
		Middle	Tirnovella occitanica	Dalmasiceras dalmasi	Hectoroceras kochi	Surites praeanalogus	Hectoroceras kochi	Surites praeanalogus	Buchia okensis		
				Berriasella privasensis		Borealites constans		Borealites constans			
				Tirnovella subalpina		Hectoroceras kochi		Hectoroceras kochi	Buchia unschensis		
		Lower	Berriasella jacobi	Pseudosubpl. grandis	Chetaites sibiricus	Chetaites sibiricus	Chetaites sibiricus	Chetaites sibiricus			
				Berriasella jacobi		Praetollia maynci		Praetollia maynci			
J.	T.	U.	Durangites spp.		Chetaites chetae		Chetaites chetae				

Fig. 4. Zonal stratigraphy of the Cretaceous System of Siberia and northeastern Russia (The symbols follow Fig. 2).

scales of Northern Europe and Arctic Canada has revealed elements of boreal and tethyan algae in Yatriya complexes, making it even more important for panboreal correlation. The Upper Cretaceous dinocyst scale is based on sections of the Ust'-Yenisei Depression [134, 135]. The combined section of marine deposits comprises a total of 13 dinocyst-based scales [91]. They are mainly of combined justification: their index species are chosen either by domination or just by appearance in associations. The current state of the development of dinocyst scales imposes regional confinements on their correlation potential, though there are some levels where panboreal correlation is possible (the Cenomanian/Turonian and Santonian/Campanian boundaries and some others) [140, 141].

Zones and beds with belemnites are established on succession of assemblages of species belonging to various genera. They pertain to the category of multifossil range biozones. Five zones and beds with belemnites have been established within a range from the Upper Volgian Substage to the bottom of the Hauterivian on sections of the north of East Siberia [142].

The latest version of the foraminifer scale for the Upper Cretaceous of West Siberia has been proposed by Podobina [143]. Beds with foraminifers in the Lower Neocomian have been established by Bulynnikova [144] as well as by Bokova and Ivanova [145].

Panboreal correlation of Cretaceous sections presents no difficulties for marine deposits. Quite reliable direct zonal correlations of Berriasian, Valanginian, and, partly, Hauterivian have been done with the use of ammonite and *Buchia* zones. Some ammonite zones (*Praetollia maynci*, *Hectoroceras kochi*) allow a direct correlation between sections in East Siberia and West Siberia, the Subpolar Urals, in the Pechora basin, in England, Northeastern Greenland, and on Arctic islands [26, 30, 94, 114, 120, 146–154].

No consideration is given here to the correlation of boreal deposits of the middle Cretaceous: Barremian, Aptian, Albian, and Lower Cenomanian, since the bulk of the Siberian territory is devoid of marine deposits of this age.

Problems of detailed correlation of the boreal Upper Cretaceous are discussed here in terms of zonal scales on inocerams and dinocysts (Fig. 4). The inoceram scale allows direct correlation between sections of the Upper Cretaceous of Siberia and the Russian Platform at the level of substages, since these regions have zones in common: *Inoceramus (Inoceramus) pictus* in the Upper Cenomanian; *I. (Mytiloceramus) labiatus*; I. *(I.) lamarcki* in the Turonian; *Sphenoceramus cardissoides* and *Sph. patootensis* in the Santonian. Zonal inoceram complexes of the Coniacian stage also contain species occurring in sections of both Siberia and the Russian Platform, allowing reliable correlation of deposits of this age. The three lowermost inoceram zones (Upper Cenomanian—Middle Turonian) are correlated directly with Upper Cretaceous sections of Western Europe and Eastern Europe, too; the others are reasonably correlated via sections on the Russian Platform [141, 155–157]. The species *Sphenoceramus patootensiformis*, occurring in Western Europe at the top of the Santonian and bottom of the Campanian, has been found in bordering Santonian-Campanian beds of East Siberia. Hence, these levels can be directly correlated [141]. Inocerams have not been found in stratigraphically higher stages of Siberia, the Campanian and Maastrichtian, and this hampers correlation of the deposits with the adjacent regions.

The dinocyst scale allows an interregional correlation between North Siberia, Great Britain, North America (Eastern Canada) at the Cenomanian/Turonian border and between North Siberia, North America (New Jersey and, probably, Eastern Canada), and Great Britain at the Santonian/Campanian border [141].

The boreal-tethyan correlation is done through intermediate peritethyan regions. However, no level of direct correlation between the boreal Berriasian and the West-Mediterranean standard has yet been established. The most suitable for boreal-tethyan correlation of the Berriasian are sections in Northern California (USA) [158] and in Primorye (Russia) [159]. Both regions contain tethyan ammonites together with boreal *Buchia*, allowing direct correlation of these sections with the boreal standard [120]. Preference should be given to North-American sections, because stratigraphically they are much more complete than those of Primorye; the sequence of *Buchia* zones recognized there is complete and contiguous [160]. Versions of correlation through sections of Primorye are not adequately justified and cannot be adopted unconditionally [161].

The boreal standard of the Valanginian quite reliably correlates with the tethyan standard through sections of Lower Saxony, Germany. Four reference levels have been established: at the bottom and in the middle part of the Lower Valanginian, at the bottom and in the middle part of the Upper Valanginian. They allow zonal correlation of the boreal standard of the Valanginian with the hypostratotype in the Voconian Depression, France [46, 149, 162–164]. Location of the boundary between the Valanginian and Hauterivian is under question, since the occurrence of the zone *Homolsomites bojarkensis* at the bottom of the boreal Hauterivian is still unproved [165]. The uncertainty of the location of this zone prevents it from being correlated with *Homolsomites* beds in Northern California, where they are placed into the Upper Valanginian [158].

We leave beyond consideration boreal-tethyan correlation of a large part of the Lower Cretaceous and Cenomanian because of the absence of marine deposits of this age in Siberia. The potential of the inoceram zone scale in boreal-tethyan correlation of Upper Cretaceous deposits was discussed on considering problems of panboreal correlation.

DISCUSSION

The boreal zonal standard proposed in this paper will likely be an issue of much controversy. We ourselves see many vulnerable points in it. They are most evident in the priority scale of the Cretaceous system, which, on the one hand, has gaps in zone sequences; on the other hand, it combines biostratons of phylogenetically different groups of mollusks: ammonite zones are mixed there with bivalve and belemnite zones. The reason is that ammonites are poor in diversity and abundance in Cretaceous boreal deposits over a significant stratigraphic range from Barremian to Maastrichtian. In the vast expanses of Northern Eurasia current stratigraphic tasks are solved mainly by means of widespread parastratigraphic groups of fauna and flora. The same is true for the Upper Triassic. The only way to make the priority scale of the Norian and Rhaetian closer, enabling also correlation of deposits of this age over the enormous northeast of Asia is to go from ammonoid- to bivalve-based zones.

Some important ammonoid findings can be made within the mentioned stratigraphic ranges in the nearest future, but they will hardly improve the situation. We have no grounds to expect that the ammonite standard will soon be used in the most Cretaceous and in final stages of the Triassic. Obviously, these ranges demand refinement of zonal scales based on parastratigraphic groups of mollusks and on microfossils. To oppose priority and autonomous zonal scales would be unreasonable. While the priority scales form the most detailed chronostratigraphic framework, the zonal scales, speaking in terms of genetics, "transcribe the temporal trait of the priority scale and translate it in the space", enabling the temporal tagging of sedimentary deposits lacking fossils of ortho-groups. Examples of greater significance of an autonomous zonal scale as compared with a priority one during current geological studies can be provided by Middle and Upper Jurassic and Neocomian deposits on either side of the Northern Pacific. The most detailed geochronology is based there on a *Buchia* zonal scale, because ammonite fossils are extremely scarce in these rocks. The importance of autonomous scales for deposits of the boreal Mesozoic is proven long ago by studies of core samples. Since experts on parastratigraphic groups sometimes have to solve stratigraphic problems by themselves for some reasons, every autonomous scale should have a boreal zonal standard of its own.

Hence, the boreal zonal standard of the Mesozoic will be a system of combined parallel zonal scales on various flora and fauna groups, in which the priority scale should bear the principal geochronological information.

CONCLUSIONS

The present biostratigraphic review illustrates progress in development of zonal scales of the Boreal Mesozoic of Siberia and the northeast of Russia during the last 15 years. Along with refinement of the ammonoid scale, autonomous (parallel) scales on parastratigraphic groups of fossils — bivalves, belemnites, nautiloids, foraminifers, ostracods, conodonts, dinocysts, spores, pollen — have been developed and refined. A pioneering attempt to construct a boreal zonal standard based mainly on ammonoids was made. The need for a boreal standard stems from the fact that tethyan ammonoid zonal sequences cannot be directly invoked to date geological beds within the vast expanses of the Northern Hemisphere where deposits of the boreal type occur. The set of parallel zonal scales proposed in this paper allows the most reliable circumboreal correlation of marine Mesozoic deposits. Since tethyan and sometimes global zones (e.g., *Psiloceras planorbis*) are included into boreal sequences at some stratigraphic levels, these reference levels offer a good means for global zonal correlations.

The most important innovations in the proposed combined zonal standard of the boreal Mesozoic are: (1) a closer ammonoid scale containing new zones in various stages; (2) newly developed parallel zonal scales on parastratigraphic groups: nautiloids and bivalves in the Triassic; bivalves, foraminifera, ostracods and dinocysts in the Jurassic; dinocysts in the Cretaceous; (3) a novel version of the standard zonal sequence for the Lower Triassic; (4) newly proposed standard scales on mollusks for the boreal Jurassic and Cretaceous.

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