

MIDDLE ARTINSKIAN (EARLY PERMIAN) ECOLOGICAL EVENT: A CASE STUDY OF THE URALS AND NORTHERN TIMAN

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Abstract. Biotic and abiotic changes established in the middle Artinskian of several sections of the northern Timan and the western slope of the Central Urals are discussed. Data on the distribution of corals, composition of the biota as a whole, palaeotemperature and microfacies changes are presented for the first time. The determination of the stratigraphic levels is based on the new and revised biostratigraphic data. The palaeotemperature decline coincides with the maximal flooding surface and is considered as a possible cause of the ecological event triggering the turnover or extinction of many faunal groups. The event level was recognized in the coeval deposits along the Pangea shelves.

Key words: middle Artinskian event, biota turnover, sequence stratigraphy, oxygen and carbon isotopes.

INTRODUCTION

The end of the Early Permian was a time of distinctive abiotic and biotic changes, previously discussed in Gorsky et al. (1984), Beauchamp et al. (1987, 1989), Beauchamp & Theriault (1994), Kossovaya (1994), and Leven et al. (1996). Selective disappearance and replacement of different faunal groups, especially great changes in rugose corals, have been recorded from the Late Sakmarian to Late Artinskian.

The goal of this paper is to show the evolution of rugose corals before and after the mid-Artinskian event and possible ecological triggers for the biotic crisis within the Urals–Cordillera–Arctic province (name of the province after Fedorowski 1986a). Earlier data on the pre-crisis evolution of rugose corals

(Kossovaya 1993, 1994, 1996, 1997) were considered in order to assess the range and scale of coral turnover and extinction. Abiotic causes of the crisis are interpreted based on comparative analysis of the biostratigraphic, sedimentological, microfacies, and isotopic data.

MATERIALS AND METHODS

For this study several Artinskian sections were investigated in the northern part of the Central Urals, including the Most and Karpikha sections (Fig. 1). Additionally, the Irgina section (Fig. 1) of the lowermost Kungurian, and the Lower Permian sections on the eastern slope of the northern Timan (northeastern part of the Russian Platform; Fig. 2) were studied. Both regions correspond to the northeastern marginal basin of the Pangea palaeocontinent.

New data on ^{18}O and ^{13}C from brachiopod shell carbonates, Ca/Mg ratio, and microfacies analyses were used to determine the ecological nature of the changes within the middle Artinskian. In addition to microfacies analysis, the insoluble residues of samples consisting of the silicified micro- and, partly, macrofossils were examined. The data received by both methods allowed us to reconstruct the biotic changes near the crisis level.

BIOSTRATIGRAPHIC DATA

Biostratigraphic subdivision of the Lower Permian of the Urals was established long ago. Recent changes in the Artinskian part of it are shown in Fig. 3.

The data obtained have been used for creating and improving the ostracode and coral zonal charts. Considering the data by E. Guseva (in Gorsky et al. 1984), we could redetermine the age of the deposits in the Upper Artinskian portion (Sargian Substage) of the Most and Karpikha sections (Figs. 1, 3). According to our findings, the event level coincides with the base of the *Bairdia aculeata* ostracode Zone in the carbonate-siliciclastic rocks of the Sargian Substage or with the upper boundary of the *Eoparafusulina lutugini*–*Pseudofusulina juresanensis* fusulinid Zone in the shallow reef deposits of the Irginian Substage. The post-crisis ostracode assemblage, appearing at the Lower/Upper Artinskian boundary in the Most and Karpikha sections, includes *Healdia arcuata* Coryell & Osario, *Bairdia magna* Kotsch., *B. cf. B. kaschewarovae* Mart., *B. perlonga* Kash., and *B. aculeata* Coope. The coral community of this part of the sections, considered as holdover type I (Figs. 1, 4), contains *Soshkineophyllum artiense* Soshk., *Ufimia carbonaria* Stuck., *Ufimia* sp. 1, *Paralleynia permiana* Soshk., ? *Lophocarinophyllum ilitshense* Soshk., *Cyathocarinia multituberculata* Soshk., *Cyathaxonia* ex gr. *C. cornu* Mich., *C. dobrolyubovae* Sim., *Pseudo-*

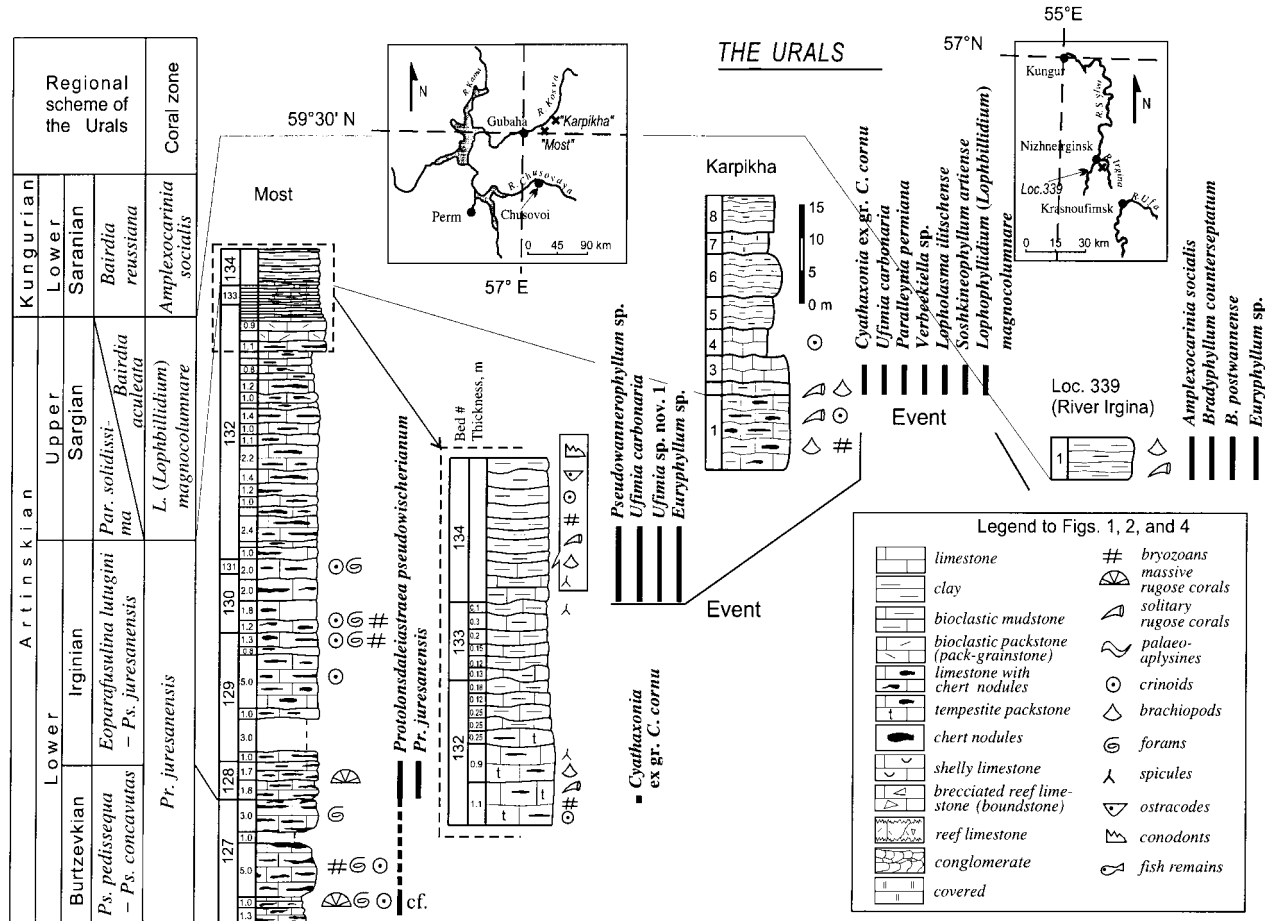


Fig. 1. Correlation of the Central Urals sections (Most, Karpikha, and Irgina).

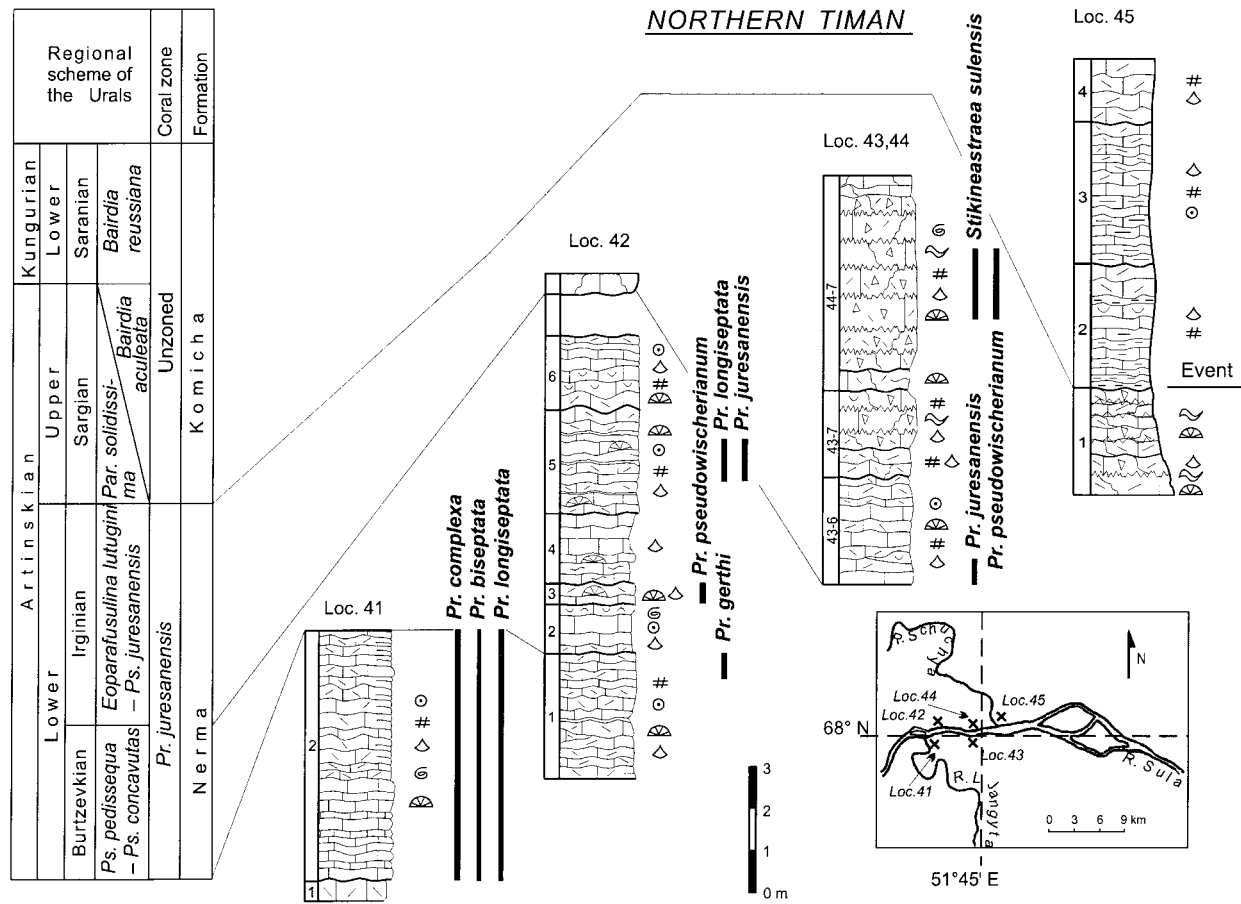


Fig. 2. Correlation of the Sula River localities (Sula section) of the northern Timan. For legend see Fig. 1.

A r t i n s k i a n				Kungurian	Stage	Regional scheme of the Urals (Antsygin et al. 1993)
Burtzevkian	Irginian	Sargian	Saranian	Horizon		
		<i>Bairdia aculeata</i>	<i>Bairdia reussiana</i>	Ostracode zone	Regional substage	Chuvashov & Nairn (1993)
<i>Pseudofusulina pedissequa-juresanensis-concavatas</i>	<i>Pseudofusulina juresanensis-Eoparafusulina lutugini</i>	<i>Parafusulina solidissima</i>		Fusulinid zone		
Burtzevkian					Regional substage	Pnev (1974)
Aktastian					Regional substage	
A r t i n s k i a n				Kungurian	Stage	Chuvashov et al. (1996), Chuvashov (1997)
<i>Pseudofusulina pedissequa-concavatas</i>	<i>Pseudofusulina juresanensis-Parafusulina lutugini</i>	<i>Parafusulina solidissima</i>	<i>Bairdia reussiana</i>	Zonal sub-division	Ostracode/fusulinid zone	Authors' data
<i>Pseudofusulina pedissequa-concavatas</i>	<i>Pseudofusulina juresanensis-Eoparafusulina lutugini</i>	<i>Bairdia aculeata</i>	<i>Bairdia reussiana</i>			
<i>Protolonsdaleiastraea juresanensis</i>	<i>Lophophylidium (Lophbillidium) magnocolumnare</i>		<i>Amplexocarinia socialis</i>	Zone and bed with corals		

Fig. 3. Comparison of the biostratigraphic schemes of the Central Urals based mainly on the Karpikha, Most, and Irgina sections. Subdivisions of the Most and Karpikha sections framed with the solid line. Subdivisions of the Irgina sections framed with diagonal stripes.

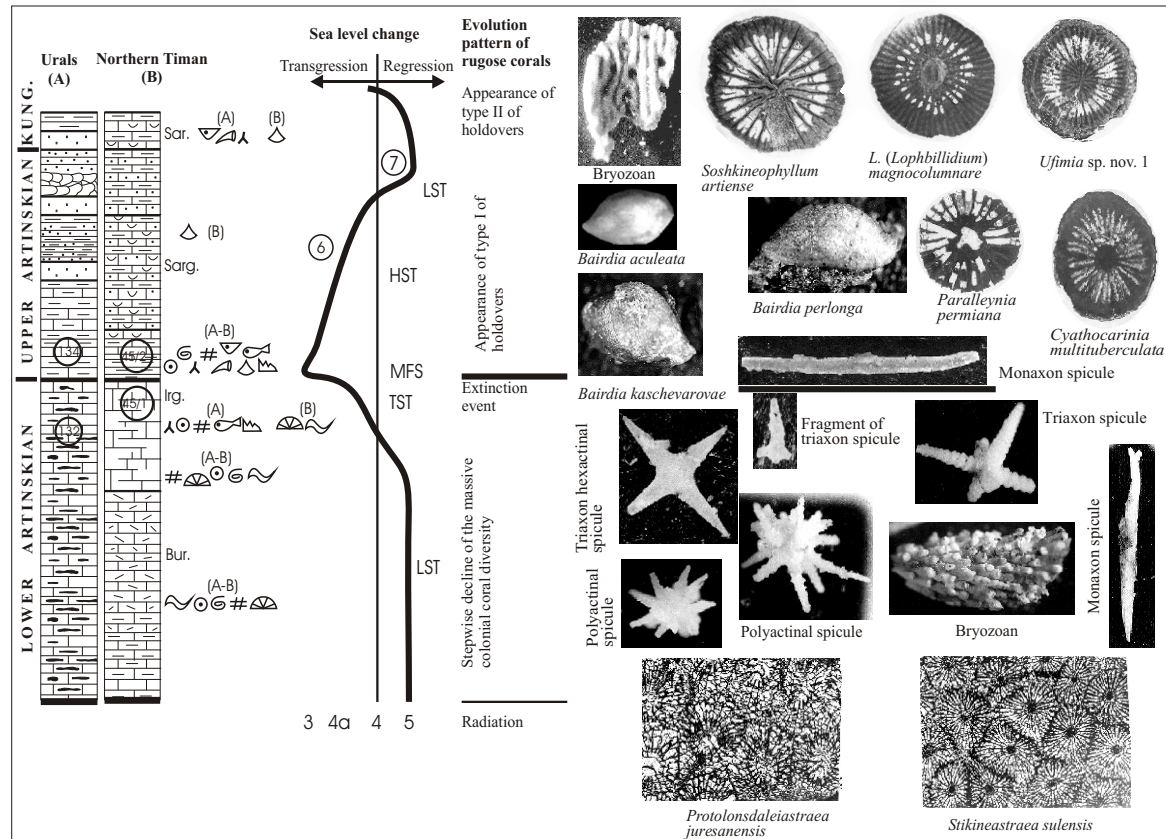


Fig. 4. Correlation of the sequence-stratigraphic subdivisions of the Artinskian and lowermost Kungurian deposits of the Central Urals and northern Timan, and biotic composition: 3, deep shelf margin facies; 4, foreslope facies of carbonate platform; 4a, tempestites; 5, organic reef of platform margin; 6, turbidites; 7, open marine platform facies with terrigenous fans. Abbreviations: Sar., Saranian; Sarg., Sargian; Irg., Irginian; Bur., Burtzevkian; LST, lowstand system tract; HST, highstand system tract; MFS, maximal flooding surface; TST, transgressive system tract. For legend see Fig. 1.

wannerophyllum sp. 1, and *Verbeekiella* sp., together with the Upper Leonardian species *Lophophyllidium* (*Lophbillidium*) *magnocolumnare* (Fedor.), and *L. (L.) cyathaxoniforme* Fedor. The pre-crisis assemblage consists of massive colonial corals, such as *Protolonsdaleiastraea juresanensis* Dobr. and *Stikineastraea sulensis* Koss., occurring in *Palaeoaplysina*–coral buildups of the Sula River section (northern Timan, localities 43–45, Fig. 2). *Eoparafusulina lutugini* (Grozd.) has been recorded by Barkhatova (1970) in the upper part of locality 44. The post-crisis assemblage, occurring in the packstones and wackestones intercalated with thin clay layers (locality 45), contains the brachiopods *Sowerbina sulaensis* Barch., *Linoproductus* ex gr. *L. cora* (Orb.), *Spiriferella timanica* Barch., and *Spiriferella polaris* Barch. (Goreva et al. 1997).

The ostracode assemblage found in the lower part of the Saranian Substage of the Kungurian Stage in the Irgina River section includes species of the *Bairdia reussiana* Zone, such as *Paraparchites kamajicus* Guss., *P. sylvaensis* Guss., *Healdia distributa* Guss., *Bairdia cultrataeformis* Guss., and *B. reussiana* Guss. The rugose coral assemblage is poor, containing *Amplexocarinia socialis* Sosh. (dominant), *Amplexocarinia* sp., *Euryphyllum* sp. 1, *Euryphyllum* sp., *Bradyphyllum* aff. *postwannense* Fedor., *Lytvolasma* sp., *Bradyphyllum* aff. *counterseptatum* Fedor., and *Euryphyllum* aff. *profundum* Fedor.

Only a few occurrences of the coeval corals are known in the northern shelves of the Pangea palaeocontinent. *Euryphyllum* sp. A and *Euryphyllum* sp. B, which show a wide range of intraspecific and interspecific morphological variations, are known from unit 1 at the base of the Kapp Starostin Formation of Spitsbergen (Ezaki & Kawamura 1992; Ezaki 1997).

SEQUENCE STRATIGRAPHY AND FACIES

The pre-event (Burtzevkian–Irginian) interval in the Most section (the Central Urals) is represented by the carbonate facies of the upper part of the foreslope (Wilson 1980). Two sequences are recognized in the Artinskian deposits (Fig. 4).

The lowstand system tract is represented by the succession from the reef facies to crinoid–foraminiferal packstones of the inner platform foreslope. In the Most section the reef facies of the platform margin (facies 5) is constituted by the coral–*Palaeoaplysina*–algal boundstone framework or algal–coral–*Palaeoaplysina* packstones (bed 127, Fig. 1). This interval is determined as the *Pseudofusulina pedissequa*–*Ps. concavutas* fusulinid Zone, or the lower part of the *Protolonsdaleiastraea juresanensis* coral Zone (Figs. 3, 5; Kossovaya 1996), which corresponds to the Burtzevkian Substage (Chuvashov & Nairn 1993). Corals are represented by *Protolonsdaleiastraea juresanensis* (Dobr.) and *Pr. pseudowischerianum* (Porf.).

The foreslope facies of the carbonate platform, observed in the Most section in bed 128 (Fig. 1) is formed by wacke-packstone composed of bryozoans, crinoids, colonial corals (sporadically), and *Palaeoaplysina* debris (Fig. 4; facies 4 by

Cisuralian				International scale (Waterhouse 1997)	Urals and Russian Platform (Antsygin et al. 1993 with authors' additions)	Spitsbergen (Malkowski & Szaniawski 1975; Ezaki & Kawamura 1992; Ezaki 1997; Somerville 1997)	Canada	
Sakmarian		Artinskian					Kungurian	Saranian
Tastubian	Sterlitamakian	Burtzevkian	Irginian	Sargian	Fusulinid and ostracode zones	Formation	Formation	Formation
<i>Ps. verneuilli</i> – <i>Ps. uralica</i>	<i>Pseudofusulina urdatensis</i>	<i>Ps. pedissequa</i> – <i>Ps. concavatus</i>	<i>Ps. juresa-nensis</i>	<i>Pseudofusulina solidissima</i>	<i>Bairdia reussiana</i>	Coral morphoeocotype	Coral morphoeocotype	Coral morphoeocotype
<i>Sweetognathus inornatus</i> – <i>Sw. spp.</i>		<i>Sweetognathus whitei</i>	<i>Mesogondolella bisselli</i> – <i>Sw. whitei</i>	<i>Bairdia aculeata</i>	<i>Neostreptognathodus pnevi</i>	Conodont zone	Conodont zone	Conodont zone
<i>Protolonsdaleiastraea bisepitata</i>	<i>Protolonsdaleiastraea longiseptata</i>	<i>Protolonsdaleiastraea juresanensis</i>		<i>Lophophylidium (L.) magnocolumnare</i>	<i>Amplexocarinia socialis</i>	Coral zone	Coral zone	Coral zone
Nordenskioldbreen				Gipshuken	Kapp Starostin	Formation	Formation	Formation
Morphoeocotypes II–IV				Barren interval	Coral assemblage I	Coral morphoeocotype	Coral morphoeocotype	Coral morphoeocotype
Belcher Channel					<i>Neostreptognathodus pnevi</i>	Conodont zone	Conodont zone	Conodont zone
Morphoeocotypes II–IV				Great Bear Cape	Interruption	Formation	Formation	Formation
				Morphoeocotypes II–IV (transported)	No data	Coral morphoeocotype	Coral morphoeocotype	Coral morphoeocotype
Morphoeocotypes III and IV				Ambition		Formation	Formation	Formation
				Corals of morphoeocotypes II–IV	No data	Coral morphoeocotype	Coral morphoeocotype	Coral morphoeocotype
				Morphoeocotypes II and III		Formation	Formation	Formation
						Coral morphoeocotype	Coral morphoeocotype	Coral morphoeocotype

Fig. 5. Correlation chart of the Sakmarian–Artinskian deposits of the northern and eastern shelves of the Pangea palaeocontinent.

Wilson 1980). The age was determined by the occurrence of *Pseudofusulina juresanensis* – one of the fusulinid zonal species of the Irginian Substage.

Coeval deposits (analogues of facies belts 4 and 5) form the lower part of the Nerma Formation of the northern Timan sections. In the Sula River section they are represented by crinoid–foraminiferal packstone interbedded with foraminiferal grainstone bearing numerous colonial corals (Fig. 2, locality 42, beds 2–5). The age of these sediments is dated by the co-occurrence of the corals *Protolonsdaleiastraea juresanensis* and *Pr. gerthi*, and the fusulinids *Pseudofusulina urdalensis* and *Ps. concavutas* (fusulinids identified by Barkhatova 1970).

In the Most section, tempestites of the lower part of the foreslope are represented by wavy-bedded wacke-packstones with numerous sponge spicules (facies 4a) and are considered as the transgressive system tract. The spicule association includes monaxon, triaxon, and tetraaxon spicules. They were found together with crinoids, brachiopods, and bryozoan debris (samples 132-1 and 132-2 from bed 132). Fossil fragments often form thin parallel layers. Clasts of bryozoans, crinoids, tabulate corals, and rare fusulinids are scattered on wavy bed surfaces. In the upper part of this unit, the abundance of spicules increases and the monaxon spicules dominate (sample 132-4). Only one specimen of deep-water *Cyathaxonia* sp. has been found in this part of the section. The age of this unit corresponds to the *Eoparafusulina lutugini*–*Pseudofusulina juresanensis* fusulinid Zone of the Irginian Substage. The beginning of the transgression is marked by tempestites which contain the deeper nektoplanktic fossils, such as fish remains, conodont fragments, and rare radiolarians, also abundant bryozoan debris. The coeval deposits of the Sula River section are represented by *Palaeoaplysina*–coral buildups with *Stikineastraea sulensis* Koss., *Protolonsdaleiastraea juresanensis* Dobr. (Kossovaya 1997), and rare *Eoparafusulina lutugini* (Barkhatova 1970) in the upper part of the Nerma Formation (Fig. 2, localities 43, 44).

The overlying deposits (from the base of layer 134) are characterized in the Most and Karpikha sections by the alternation of thin-bedded green-grey bioclastic packstone, mudstone, and siltstone which are considered as the high-stand system tract. Packstone contains monaxon spicules, ostracode debris, conodonts (*Neostreptognathodus* sp.), some bryozoans, small crinoid fragments, and fish remains. Sometimes the monaxon spicules form spiculites. In this case spicules show subparallel orientation. A new post-crisis fossil community contains bryozoans, well-preserved small solitary corals, and brachiopods. This unit corresponds to the *Bairdia aculeata* Zone (Sargian Substage) and *Lophophyllidium* (*Lophbillidium*) *magnocolumnare* coral beds (Fig. 1). *Cyathaxonia* and *Cyathocarinia* are considered as the indicators of deep-water facies. Fish remains belonging to nektic *Acanthodus* sp. and *Palaeonisci* sp. were found here (identified by A. O. Ivanov). The base of bed 134 (sample 134-1) is interpreted as the maximum flooding surface according to the microfacies changes and appearance of the deep-water coral assemblage, pelagic, and neritic

fauna. The development of transgression is reflected in the Sula River section by abrupt onlap of the thin layer of clay and wackstone of the Komicha Formation on the *Palaeoaplysina*-coral reef boundstone of the upper part of the Nerma Formation (Fig. 2, locality 45).

The diversity of benthic and nekto planktic fauna decreases gradually towards the Upper Artinskian turbidites formation, followed by coarse-grained clastic sediments represented by conglomerates and sandstones of terrigenous fans (Rassolnyi section, the Urals). The latter sediments are considered to be formed in the lowstand system tract.

Proceeding from the microfacies and biota composition, the sea level change may be regarded as a gradual increase in transgression until the maximal flooding surface (the level of coral turnover, Fig. 4). It is followed by the filling of the basin with sediments of terrigenous fans.

Coeval transgressive sedimentological changes occur in the upper part of the Gipshuken Formation (West Spitsbergen), where brachiopods, bryozoans, and sponge spicules give evidence of the more open marine influx (Keilen 1992). The Great Bear Cape Formation (Sverdrup Basin) comprises a shallowing succession of bioclastic carbonates with turned over colonial corals and reworked fusulinids, interpreted as tempestites resulting from high-energy events on an open, wave-swept shelf (Beauchamp & Theriault 1994). The event level, which is mostly based on transition to colder temperature, approximately coincides with the middle part of the Great Bear Cape Formation (Beauchamp et al. 1989; Beauchamp & Theriault 1994) (Fig. 5).

The appearance of rugose holdover assemblage II in the earliest Kungurian (Irgina section, Fig. 1) during an ingression seems to be a result of the next transgression (new sequence) (Fig. 2). The Lower Kungurian deposits (Sarian Substage) in the Irgina River section were formed in the interreef environment resulting from ingression. These are represented by mudstone with ostracodes and a taxonomically impoverished coral assemblage. The beginning of a significant sea level rise was noted also in the Voringen Member of the lowermost Kapp Starostin Formation, West Spitsbergen (Keilen 1992).

RESULTS OF OXYGEN AND CARBON ISOTOPIC ANALYSIS

The analysis of ^{18}O and ^{13}C isotopes was performed with calcite taken from the shells of brachiopods found in the Sula River section. The $\delta^{13}\text{C}$ values increase from +3.1‰ to +3.5‰ from sample 42/1 to 45/2 in this section. The fluctuation of oxygen isotope ratio within the same stratigraphical interval has the same short-term trend from -8.5‰ to -8‰ PDB with a further decrease to -8.2‰ (sample 47/1; Goreva et al. 1997). The increase in $\delta^{18}\text{O}$ values is interpreted as a result of the temperature fall at the event level. The palaeotemperature data based on the Ca/Mg ratio show the average value between +15°C and

+17°C in the northern Timan section (samples 45/1 and 45/2) and +19°C in the Central Urals section (sample 134/1) (Fig. 4). A temperature of +13°C in the Upper Carboniferous–Permian, determined from primary carbonates in the Sverdrup Basin of the Canadian Arctic, was interpreted as characterizing deep-water sediments (Beauchamp et al. 1987). The maximum temperature in the Late Sakmarian approximately coincided with the sea level drop, while the maximum flooding coincided with the temperature decline at the mid-Artinskian event level in the Central Urals and northern Timan basins.

CHANGES IN FAUNA AND FLORA

Taxonomic diversity of different faunal groups within the uppermost Sakmarian–lower Artinskian is well studied (Bogoslovskaya 1986; Aristov 1994; Leven et al. 1996). In the following, an attempt will be made to show the intensity of the mid-Artinskian extinction.

Rugose corals. The pre-crisis rugose coral assemblage shows a gradual taxonomic and quantitative decrease in genera and species of the widespread family Durhaminidae. This phenomenon was typical of the climax phase of the *Protolonsdaleiastraea* ecological succession (Kossovaya 1997). The above-mentioned family is specific to reefs, reef slopes, and buildups of the Asselian, Sakmarian, and Early Artinskian age.

Just before the *Parafusulina solidissima* fusulinid Zone (= *Bairdia aculeata* ostracode Zone) the final disappearance of most of the fasciculate and massive colonial Rugosa, as well as the solitary corals with dissepiments, takes place.

Following the crisis, the assemblage of the rugose corals (type I of holdovers) reappears at the beginning of the Late Artinskian. It consists of simple primitive ahermatypic diaphragmatophoral corals, the so-called *Cyathaxonia* fauna, and is represented in the sections studied by solitary corals bearing axial structures of different types (Flügel 1972, 1973). Among these a pseudoseptal columella (*Cyathaxonia* and *Cyathocarinia*), septa-formed columella (*Pseudowannerophyllum* and *Verbeekiella*), and septal column (*Lophophyllidium* (*Lophbillidium*)) (coral assemblage I, Fig. 6) should be noted. In some cases, the pseudoaxial structure formed from the parts of septa existed for a rather long time in the neanic stage, but not until the maturity stage (*Paralleynia* type). The corals identified in the Most and Karpikha sections include *Lophophyllidium* (*Lophbillidium*) *magnocolumnare* Fedor., *Pseudowannerophyllum* sp. 1, *Cyathaxonia* ex gr. *C. cornu* Mich., *Cyathocarinia multituberculata* Soshk., *Paralleynia permiana* Soshk., *Ufimia carbonaria* Stuck., *Ufimia* sp. nov. 1, *Soshkineophyllum artiense* (Soshk.), and *Verbeekiella* sp. All together 15 species from 10 genera were identified; most of them were immigrants. Most probably, this assemblage inhabited deep-water facies (Flügel 1973; Kullmann 1997) in the northern, central, and southern parts of the Urals (see fauna lists in Sochkine 1925; Soschkina 1928; Soshkina 1932; Soshkina et al. 1941; Simakova 1986).

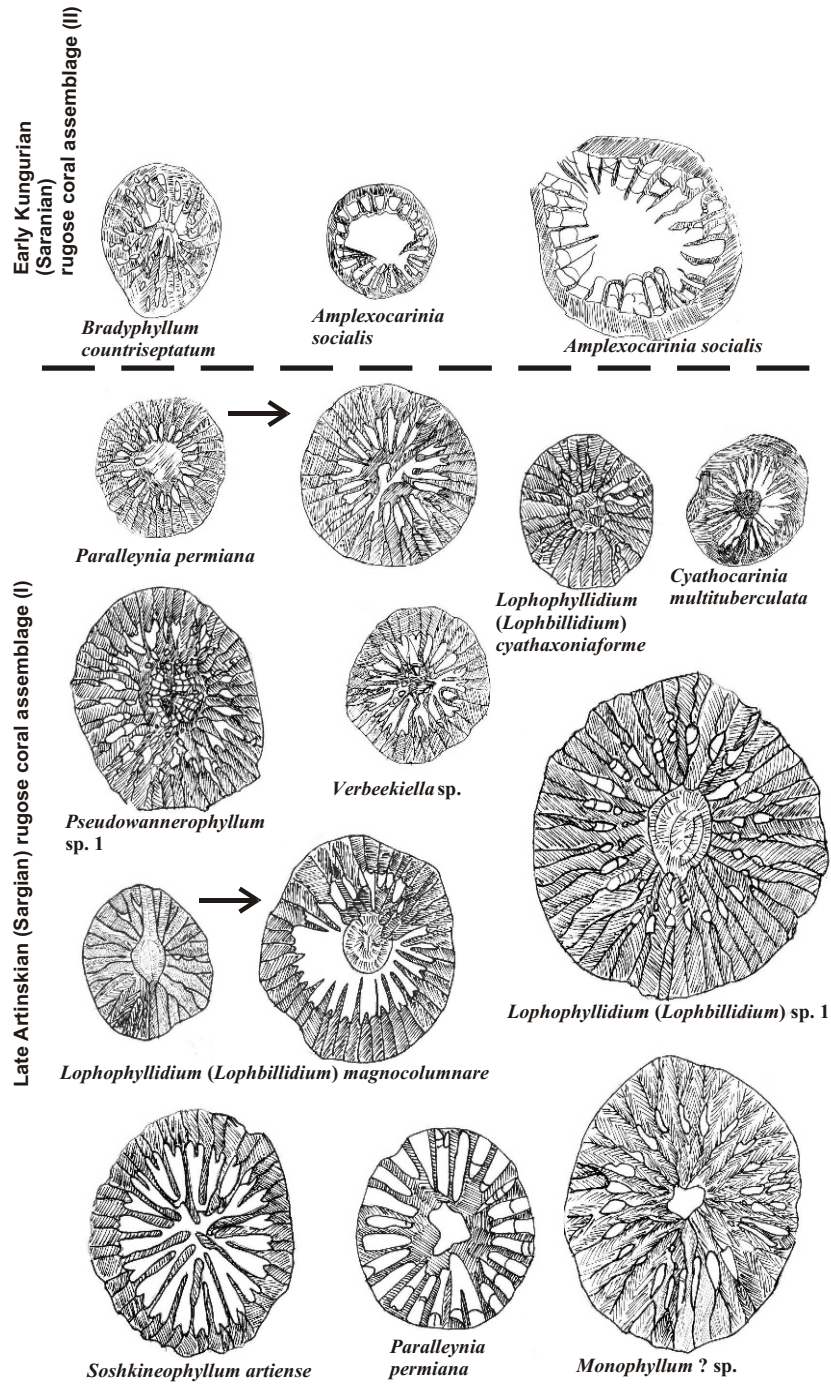


Fig. 6. Lowermost Late Artinskian deep cool-water assemblage (I) and lowermost Kungurian warm-water assemblage (II).

Further changes in the taxonomic composition of the holdover assemblage (coral assemblage II, Fig. 6) occurred in the Early Kungurian. Only three genera survived: *Bradyphyllum countriseptatum*, *Br.* aff. *Br. postwannense*, *Amplexocarinia socialis*, and *Euryphyllum* sp. All of them had a pseudoaxial structure in the early stage of ontogeny. This assemblage occupied the Early Kungurian restricted basins, and thus morphological changes in it coincided with the increase in water temperature. The preliminary isotopic data show the fall of the $^{18}\text{O}/^{17}\text{O}$ ratio in the Sula River section at this level.

Fusulinids. The fusulinids of the western and eastern Pangea marginal basins are very much alike. Their impoverished community is represented by the *Pseudoschwagerina*–*Paraschwagerina* assemblage in the western part and by the *Praeparafusulina*–*Parafusulina* assemblage in the eastern part of Pangea. The beginning of Yachtash time (Tethys realm), corresponding approximately to the beginning of the Artinskian, shows taxonomic diversification (Leven et al. 1996).

Ammonoids. Abrupt diversification of species and genera occurred in the middle of the Artinskian (Bogoslovskaya 1986). The lower Artinskian Substage (Aktastian Regional Substage) was marked by the appearance of Eothinitidae (*Eothinites*), *Aktubinskia*, *Artioceras*, *Daraelites*, and *Neoshumardites*. The Late Artinskian ammonoid assemblage includes *Propinacoceras*, *Waagenina*, *Neocrimites*, and diverse *Uraloceras* and *Paragastrioceras* (Bogoslovskaya 1986; Leven et al. 1996).

Conodonts. A well-known Early Permian crisis among conodonts (Ritter 1987; Aristov 1994) continues from the end of the Sakmarian to the middle of the Artinskian. The mid-Artinskian event coincides with the final phase of the conodont crisis and leads to ultimate extinction of the last typically Carboniferous taxa: *Adetognathus lautus* Gunnell, *Streptognathodus elongatus* Gunnell, and *Streptognathodus artinskensis* (Kozur & Movshovitch). At the same time, it could have triggered the radiation within the *Sweetognathus*–*Neostreptognathodus* and neogondolellid lineages. The crisis association consisted of the tolerant and nonspecialized species such as *Sweetognathus whitei* (Rhodes) and *Mesogondolella bisseli* (Clark & Behnken).

Late Artinskian time shows the diversification of species and appearance of *Pseudosweetognathus*, *Rabeignathus*, and *Vjalovognathus* (Leven et al. 1996).

Ostracodes. The Late Artinskian ostracode assemblage consists of 43 species of 14 genera. Among them, 31 species appear for the first time. Most of them are characteristic of the *Bairdia aculeata* ostracode Zone of the Sargian Substage (Gorsky et al. 1984). This association is followed by a much more diverse one, which seems to be evidence of the emergence of the Kungurian ostracode assemblage (the base of the *Bairdia reussiana* ostracode Zone; Fig. 4).

Flora. The middle of the Lower Permian is characterized by the immigration of the cordaite flora into the Subangarian regions (the Urals and Central Kazakhstan), as a response to temperature gradient decrease (Durante 1994).

CORRELATION

In a few regions along the Pangea marginal shelves the event level seems to have valuable correlation potential. The main diagnostic features include coral fauna turnover, change in biota composition and facies, and the small isotopic shift. Besides the eastern shelf basins of Pangea (Central Urals, northern Timan), the event level has been identified in the Aidaralash Creek section (Southern Urals), where it coincides with the Aktastian–Baigendzhinian boundary (Davydov et al. 1997).

The last massive colonial corals of Durhaminidae and some other families were found in Spitsbergen in the Sakmarian Tyrellfjellet Formation (? Limestone B). The predominance of the bun-shaped cerioid rugose coral colonies points to relatively quiet-water subtidal and open-marine shelf environments (Somerville 1997). This facies and the coral composition are close to the Sakmarian ones (possibly Tastubian) of the western Urals and northern Timan. Contemporaneous early Artinskian deposits of the lowermost part of the Gipshuken Formation are represented by gypsum-anhydrite intercalating with dolomite and marls. Oolite limestone or dolomite beds occur as well. These sediments are interpreted as deposited in the restricted marine environment (Nakamura 1992).

The beginning of the next transgressive sedimentation cycle in the uppermost Lower Artinskian could be correlated with the upper part of the Gipshuken Formation, where brachiopods (*in situ*), bryozoans, and sponge spicules give evidence of open marine influx of temperate water conditions (Ezaki & Kawamura 1992). The lower Sargian boundary (event level) can be indentified somewhere within the uppermost Gipshuken Formation (Fig. 5). Based on the appearance of shallower-water corals, Coral Unit 1 of the Kapp Starostin Formation, Festningen, Spitsbergen (Ezaki & Kawamura 1992; Ezaki 1997), coincides with the Saranian impoverished coral assemblage of the beds with *Amplexocarinia socialis*.

In the Sverdrup Basin (Canada), the event level may be established at the lower boundary of the Great Bear Cape Formation based on the biotic change. The Great Bear Cape Formation contains bryozoans, echinoderms, and brachiopods, which are associated with locally abundant fusulinaceans and colonial rugose corals. This biota, referred to as a Bryonoderm-extended assemblage, indicates much colder temperate conditions than those evidenced by the abundant algae and foraminifers (Chlorofoam assemblage) of the older Raanes Formation and Belcher Channel Formation. The rocks of the Great Bear Cape Formation are interpreted as tempestites, formed in the high-energy environments on an open, wave-swept shelf (Beauchamp & Theriault 1994).

As a whole, the coral fauna of the Sakmarian–Artinskian (Lower Artinskian ?) deposits of the Sverdrup Basin includes *Heritschioides*, *Kleopatrina*, *Protolonsdaleiastraea*, and *Stylastraea* (Gunning et al. 1994). These genera are widespread in the coeval deposits of the Urals, Volga–Urals region, and northern Timan (Soshkina et al. 1941; Kossovaya 1996).

The mid-Artinskian event is less reflected in the Ambition Formation in northwestern Stikina, British Columbia, where more abundant fasciculate (morphoecotype III) and solitary corals (morphoecotype II) were found together with *Neostreptognathodus pequopensis* (Gunning et al. 1994). This interval correlates with the upper part of the Sargian Substage (Fig. 5). Also, a weak reflection of the event is seen in the coeval deposits of Nevada, where the massive colonial corals *Kleopatrina (Porfirievella) illipahensis* (Easton) and *Permastraea (?) hudsoni* (Wils. & Long.) were found in the Pequop Formation, Nevada (Stevens 1967). The latter could be correlated with the upper Sargian Substage based on the occurrence of *Neostreptognathodus pequopensis* (Behnken 1975). The underlying deposits, containing *Kleopatrina (K.) arcturensis* Stevens and *Durhamina cordillerensis* (Easton), have been assigned to the upper part of the *Mesogondolella bisseli*–*Sweetognathus whitei* Zone (Ritter 1987). They may be preliminarily correlated with the lower part of Sargian Substage. Massive colonial corals disappeared in this area in Late Leonardian time (Stevens 1967).

The occurrence of similar rugose coral species *Lophophyllidium (Lophbillidium) magnocolumnare* (Fedor.) and *Lophophyllidium (L.) cyathaxoniformis* Fedor. (Fedorowski 1987) permits us to correlate the Sargian Substage with the Lower Bone Spring Formation (Upper Leonardian, Texas), the Bitauini Beds of Timor (Schindewolf 1942; Schoupe and Stacul 1955; Fedorowski 1986b), and the Lower Permian Calceolispongia Stage of Australia (Hill 1942).

We can suggest that in the temperate belt of the eastern and northern shelves of Pangea fauna displays a stronger influence of the temperature decline (Urals, Canadian Arctic (part), Spitsbergen). In the tropical belt of the western shelf of Pangea (Nevada, Utah), the crisis is reflected in the moderate decrease in biodiversity only in comparison with the temperate belt.

CONCLUSIONS

The mid-Artinskian biotic event is characterized by an abrupt coral turnover. The Early Artinskian pre-event assemblage corresponds to the elimination phase of massive colonial corals. The Upper Artinskian post-event assemblage is characterized by the appearance of the opportunistic taxa (holdovers) consisting of small primitive corals. This crisis is accompanied by remarkable changes in the other groups of fauna.

The following causes of the biota turnover may be suggested:

1. The beginning of the transgression led to gradual replacement of the *Palaeoaplysina*–coral–fusulinid association by the bryozoan–spicules–ostracode association. A specific ecological community appeared at the maximum flooding surface. This community was represented by sponges with monaxon spicules, ostracodes, and small solitary corals, considered as post-crisis holdovers. One of the possible reasons for cooling could be the influx of cold oceanic water

carried by oceanic currents (Beauchamp et al. 1987). The influence of cold water decreased towards the inner part of the remaining Uralian Ocean.

2. The taxonomic composition of this assemblage reflects the temperature decrease, determined in reference sections of the northern Timan and western Urals. Coeval temperature fall was also recognized in the uppermost part of the Gipshuken Formation of West Spitsbergen and approximately contemporaneous deposits of the Sverdrup Basin of the Canadian Arctic (Beauchamp et al. 1987; Beauchamp & Theriault 1994).

It seems that the area of the mid-Artinskian ecological event is restricted by western (partly), northern, and eastern marginal basins of Pangea. The geographical extension of the event is estimated as provincial or subglobal. The combination of similar abiotic and biotic features raises the potential of the Lower and Upper Artinskian boundary for interregional correlation.

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KESK-ARTINSKI (VARA-PERMI) ÖKOLOOGILISE SÜNDMUSE UURING UURALI JA PÕHJA-TIMAANI LÄBILÕIGETES

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On uuritud biotilisi ja abiotilisi muutusi, mis ilmnesid reas Kesk-Artinski vanusega kivimite läbilõigetes Põhja-Timaanil ja Kesk-Uurali läänenõlval. Esmakordselt on kirjeldatud korallide levikut, elustiku terviklikku taksonoomilist koostist, paleotemperatuuri ja mikrofaatsieste muutusi. Stratigraafiliste tasemete määrangute aluseks on võetud uued ja revideeritud biostratigraafilised andmed. Temperatuuri langus Kesk-Artinski eal korreleerub mere maksimaalse transgressiooni tasemega ning seda käsitletakse põhjusena, mis algatas paljude faunarühmade koosseisu muutumise ja/või väljasuremise. See ökoloogilise sündmuse tase tuvastati ka Pangea šelfi samaealistes settekivimites.

СРЕДНЕАРТИНСКОЕ (РАННЯЯ ПЕРМЬ) ЭКОЛОГИЧЕСКОЕ СОБЫТИЕ НА ПРИМЕРЕ УРАЛА И СЕВЕРНОГО ТИМАНА

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Рассмотрены биотические и абиотические изменения в середине артинского века на примере ряда конкретных разрезов Северного Тимана и западного склона Среднего Урала.

Данные по стратиграфическому распределению кораллов, изменению состава биоты, изменениям палеотемпературы и микрофаций получены впервые. Установленное понижение палеотемпературы совпадает с максимальным углублением бассейна (поверхностью максимального затопления) и рассматривается как возможная причина экологического события, вызвавшего перестройку или вымирание многих фаунистических групп. Событийный уровень был распознан в одновозрастных отложениях шельфов Пангеи.