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Ordovician Corals of the Siberian and Mongolian Basins: Taxonomic Diversity, Morphogenesis, and Occurrence

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Abstract—Taxonomic diversity, structural peculiarities, and occurrence of the Ordovician corals Tabulatoidea, Heliolitoidea, Rugosa, and Cyrtophyllida from the Siberian and Mongolian basins are analyzed. The corals settled in the Siberian basin almost for 1.5 million of years earlier than in the Mongolian basin. First corals in the Siberian basin were found in the lowermost Muktei Horizon (Llanvirn, i.e. Darriwilian Stage) while first corals in the Mongolian basin are known from the lower part of the Bairim Horizon (Late Caradoc, i.e. lower part of the Katian Stage). First corals in both basins belonged to the subclass Tabulatoidea.

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INTRODUCTION

The Siberian and Mongolian basins belonged to the Siberian-Canadian zoogeographical region. They were located in the equatorial and borderline climatic zones. The Siberian basin (more precisely Middle Siberian) was wide marine epicontinental basin located to the north of the Angara Continent; its area and borders coincided with the Siberian Platform (Fig. 4). Geosynclinal Mongolian marine basin was located to the south of the Angara Continent and its area and borders correspond to the Mongolian folded belt. Fig. 4 shows only containing corals shelf part of the Mongolian basin. The connection between Siberian and Mongolian basins occurred through the Altai-Tuva basin and straits, which from time to time cut through the Angara Continent. Possibly it was an insular arc, not a continuous continent (A.V. Dronov, personal communication).

Three variously independent and separated Ordovician paleobasins may be distinguished within the Siberian basin: Tunguska Sea coinciding with the Tunguska syneclise, Irkutsk Sea coinciding with the Irkutsk amphitheater, and Vilyui Sea coinciding with the Vilyui syneclise. Mongolian basin is traditionally divided into the following parts: West, South, East, and Central Mongolia. The sedimentation in the Siberian and Mongolian basins often slowed down and sometimes interrupted up to the erosion. The Ordovician deposits with corals in both basins consist of the shallow terrigenous and terrigenous-carbonate, greenish-gray, and sometimes variegated facies.

Here we accept for the Siberian basin the stratigraphic scheme of the Ordovician proposed by Kh.S. Rozman (1977), A.V. Kanygin, etc. (*Zonal Stratigraphy of the Russian Phanerozoic*, 2006) and for Mongolian basin we accept scheme from the *Atlas of fauna*… (1981) and *Paleontology of Mongolia* (2003), with some changes. The correlation of the regional stages with stages of the global and international geochronological scales is in the table (GSS, ISS). The ages in millions of years are given after the International stratigraphic scale (*Stratigraphic Code of Russia*, 2006; *Zonal Stratigraphy of the Russian Phanerozoic*, 2006). In the description of the biodiversity of corals we used geochronological category "age" (for stages of GSS) and "time" (for regional horizons and subhorizons).

The paper is composed on the base of own investigations and analysis of the literary data. Table 1 and Figs. 1–4 are compiled for the first time by the authors of the paper.

DISCUSSION

Taxonomic Diversity

Four groups of corals existed in the Siberian and Mongolian basins: tabulatoids, heliolitoids, rugoses, and cyrtophyllids (Table 1; see also note and references). The taxonomic rank and volume of the groups are debatable, from subclass to superorder and order, up to the debatableness of the referring of some genera to the certain order (Sokolov, 1962; Ivanovskii, 1963; Sytova, 1979; Hill, 1987; Sytova et Ulitina, 1983; Bondarenko, 1982, 2003; Ulitina, 2003). Here we accept Tabulatoidea, Heliolitoidea, and Rugosa as subclasses and Cyrtophyllida as an order of the uncertain

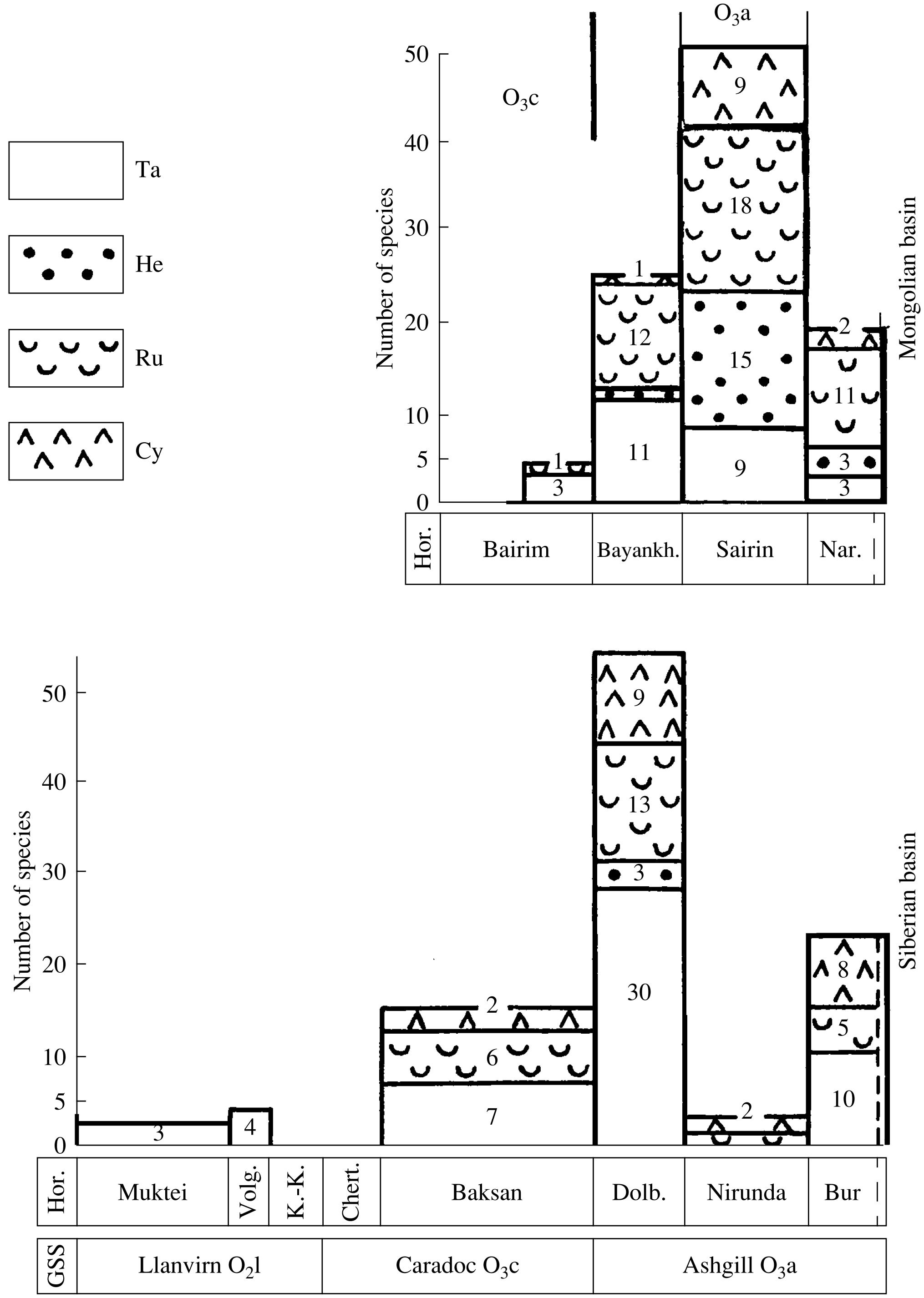


Fig. 1. Dynamics of changes of species number of the Ordovician corals in the Siberian and Mongolian basins by the horizons and stages (correlation and proportions of horizons and stages by *Zonal Stratigraphy*…, 2006). Designations: (Ta) Tabulatoidea, (He) Heliolitoidea, (Ru) Rugosa, (Cy) Cyrtophyllida, (Bayankh.) Bayankhongor, (Volg.) Volgina, (Hor.) Horizon, (K.-K.) Kirensk–Kudrin, (Nar.) Nariingol, (GSS) Global stratigraphic scale, (Chert.) Chertovo.

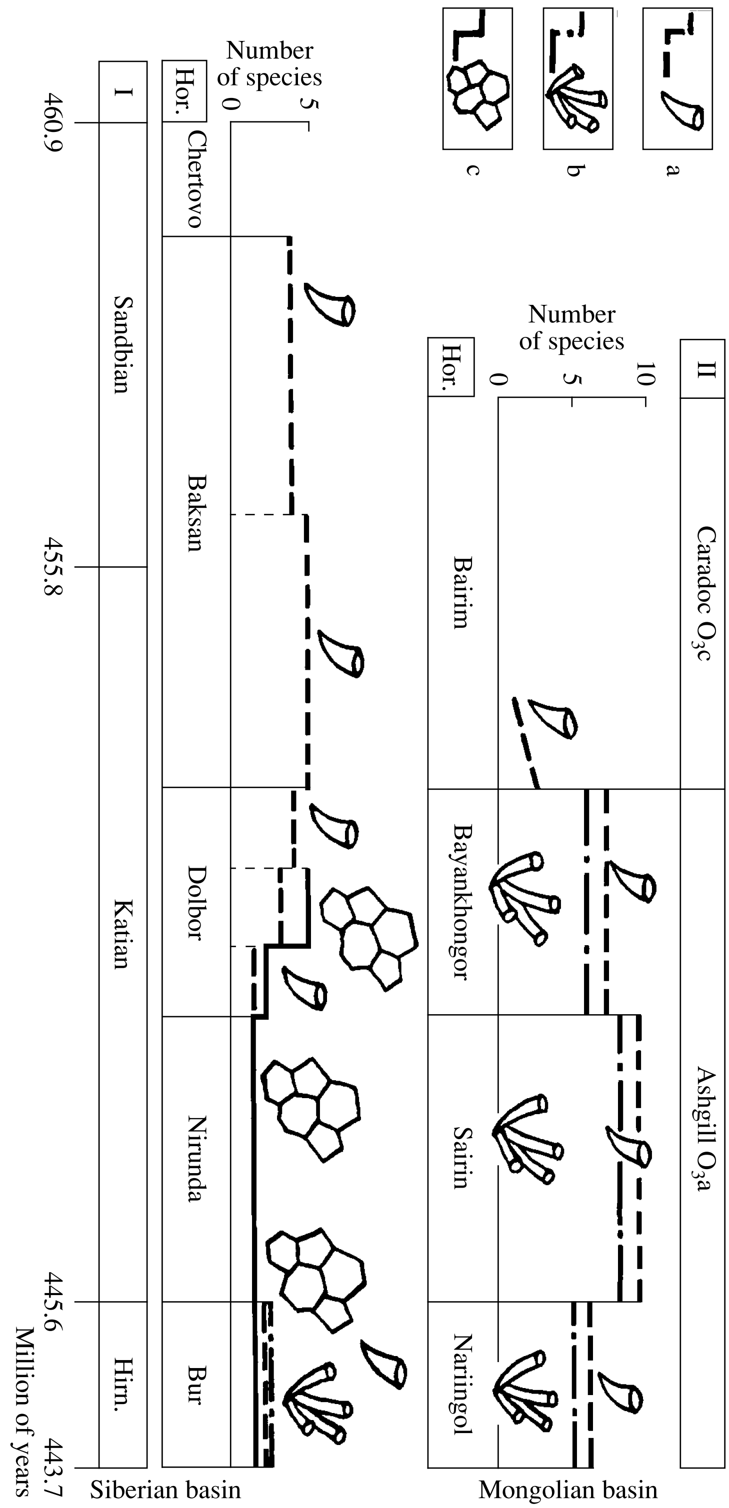


Fig. 2. Dynamics of changes of species number of singular and colonial rugoses in the Ordovician Siberian and Mongolian basins. Designations: (a) singular, (b) colonial branchy, (c) colonial massive, (Hor.) Horizon, (Hirn.) Hirnantian Stage, (1) stages of the International stratigraphic scale, (2) stages of the Global stratigraphic scale.

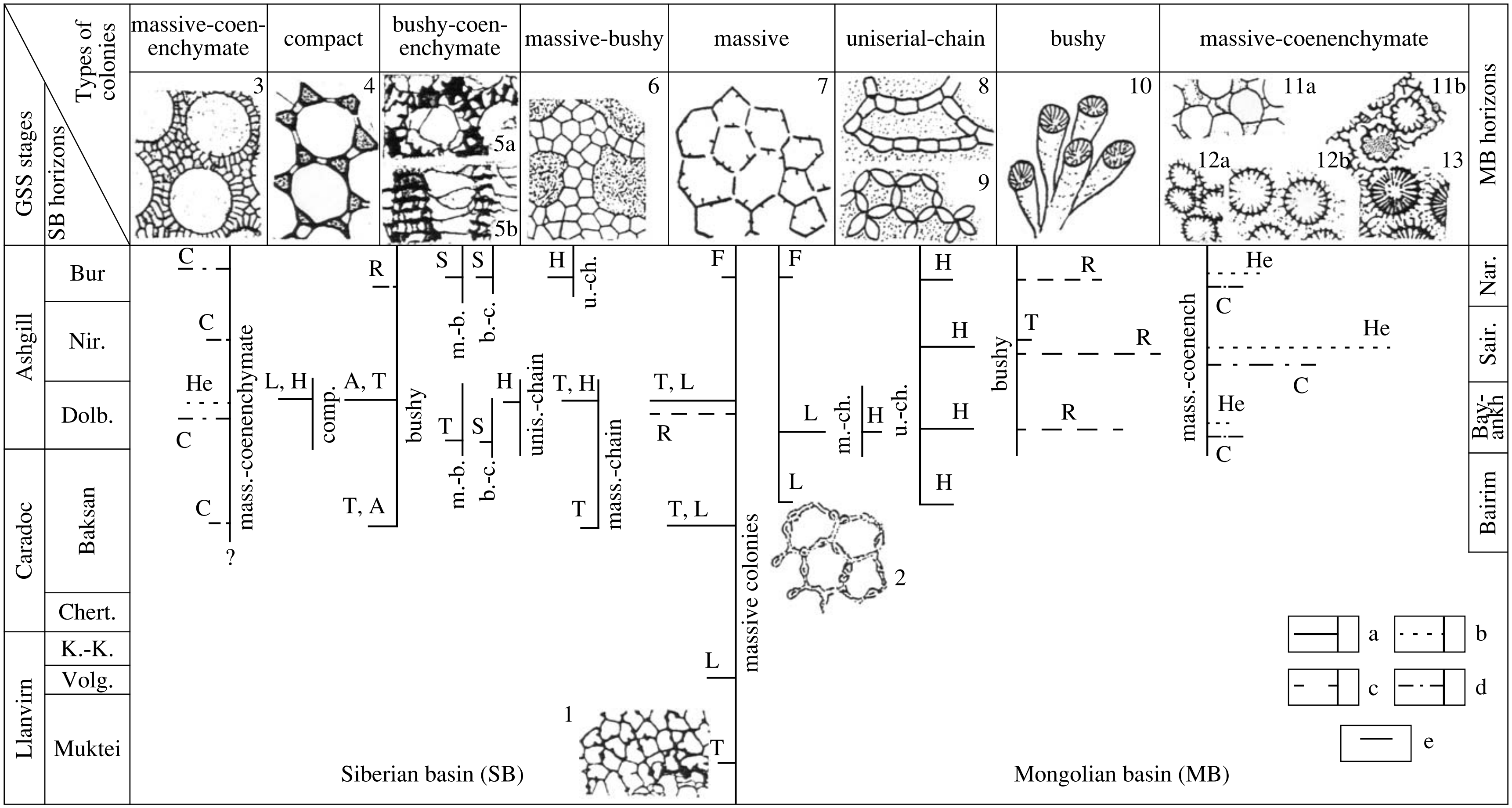


Fig. 3. Types of colonies of the Ordovician corals, their geochronological distribution and distribution by taxa in the Siberian and Mongolian basins. Designations: (a) Tabulatoidea, (b) Heliolitoidea, (c) Rugosa, (d) Cyrtophyllida; (e) length of the horizontal line corresponds to three genera, (A) Auloporida, (C) Cyrtophyllida, (F) Favositida, (H) Halysitida, (He) Heliolitoidea, (L) Lichenariida, (R) Rugosa, (S) Sarcinulida, (T) Tetradiida, (Baksan) Baksan, (Bair.) Bairim, (Bayan.) Bayankhongor, (Bur) Bur, (Volg.) Volgina, (Dolb.) Dolbor, (comp.) compact, (b.-c.) bushy-coenenchymate, (m.-b.) massive-bushy, (mass.) massive, (mass.-coen.) massive-coenenchymate, (mass.-chain) massive-chain, (Muktei) Muktei, (Nar.) Nariingol, (Nir.) Nirunda, (GSS) Global stratigraphic scale, (unis.-ch.) uniserial-chain, (Sair.) Sairin, (coen.) coenenchymate, (chain) chain, (1) *Cryptolichenaria*, (2) *Transitolites*, (3) *Cyrtophyllum*, (4) *Labyrinthites*, (5a, 5b) *Sarcinula* in cross and longitudional sections, (6) *Tollina*, (7) *Palaeofavosites*, (8) *Catenipora*, (9) *Procatenipora*, (10) *Rugosa*, (11a, 11b) *Khangailites* in astogeny, (12a, 12b) *Karagemia* in astogeny, (13) *Khadzhingia*.

The taxonomical composition of the Ordovician corals of Siberian (SB) and Mongolian (MB) basins (see notes in the end of the Table)

Order	Suborder	Family	System	Ordovician							
			Series	Middle			Upper				
			Stages: ISS	Darriwilian			Sandbian		Katian		Hirn.
			Stages: GSS-2	Llanvirn			Caradoc		Ashgill		
			Horizons: SB	Muktei	Volg.	K.–K.	Ch.	Baksan	Dolb.	Nir.	Bur
			Species / MB					Bair.	Bayan.	Sair.	Nar.
1	2	3	4	5	6	7	8	9	10	11	12
			Tabulatoidea								
Favositida	Favositina	Favositidae	*Palaeofavosites argutus* Ivanov, 1950 (STS, CM)								× —
			P. carinatus Sokolov et Tesakov, 1963 (STS)								—
			P. ivanovi Sokolov, 1951 (STS, VS)								—
			P. kanuensis Sokolov et Tesakov, 1963 (STS)								—
			P. alveolaris Goldfuss, 1826 (VS)								cf.
Sarcinulida		Calap.	*Calapoecia canadensis* Billings, 1865 (STS)						—		
			C. anticostiensis Billings, 1865 (VS)						—		
		Syringophyllidae	*Parasarcinula spinosa* Sokolov et Tesakov, 1963 (STS)								—
			P. trabeculata Sokolov et Tesakov, 1963 (STS)								—
			Columnoporella compacta Sokolov et Tesakov, 1963 (STS)								—
			C. acerosa Sokolov et Tesakov, 1963 (STS)								—
Auloporida		Fletcheriidae	*Fletcheriella evankiana* Sokolov, 1955 (STS)						—		
			Eofletcheria sp. I (STS)						—		
			E. sp. II (STS)					—			
Halysitida		Halysitidae	*Tollina keyserlingi* (Toll, 1889) (STS)						—		
			T. evenkiana Sokolov, 1955 (STS)y						—		
			Manipora tsagandelensis Minzhin, 1981 (CM)						×		
			Procatenipora baidragensis Minzhin, 1981 (CM)						×		
			P. appraximatoforma Minzhin, 1981 (CM)						×		
			P. tsetsegense Minzhin, 1981 (WM)						×		
			P. sp. (WM)							×	
			Catenipora bumbugurica Minzhin, 1981 (CM)					×			
			C. minima (Tchernyshev, 1937) (STS, CM)						× —		
			C. pulchella (Wilson, 1926) (CM)						×		
			C. workmanae Flower, 1961 (WM)							×	
			C. obliquaforma Minxhin, 1981 (WM)							×	
			C. ex gr. *C. robusta* (Wilson, 1926) (WM)							×	
			C. libera Kovalevsky, 1972 (SM)							×	
			C. admira Preobrazhensky, 1968 (EM)							×	
			C. darjiganga Minzhin, 1981 (EM)							×	
			C. sp. (?STS)						—		
			Halysites praecedens Webby et Semeniuk, 1969 (CM)						×	×	×
			H. ex gr. *H. ipraecedens* Webby et Semeniuk, 1969 (WM)					×			

Table (Contd.)

Order	Suborder	Family	System / Series / Stages / Horizons / Species	Ordovician							
			Series	Middle			Upper				
			Stages: ISS	Darriwilian			Sandbian		Katian		Hirn.
			Stages: GSS-2	Llanvirn			Caradoc		Ashgill		
			Horizons / SB	Muk-tei	Volg.	K.–K.	Ch.	Baksan	Dolb.	Nir.	Bur
			Species / MB					Bair.	Bayan.	Sair.	Nar.
1	2	3	4	5	6	7	8	9	10	11	12
Halysitida		Hexis	*Labyrinthites* sp. (STS)						—		
Lichenariida		Lyoporidae	*Lyopora crassa* Sokolov et Tesakov, 1963 (IS)		—						
			L. flexibilis Sokolov et Tesakov, 1693 (IS)		—						
			Baikitolites alveolitoides Sokolov, 1955 (STS)						—		
			B. magnus Sokolov et Tesakov, 1963 (STS)						—		
		Billingsaridae	*Billingsaria lepida* Sokolov, 1955 (STS)		—						
			B. sp. (TS)		—						
			Nyctopora nicholsoni (Radugin, 1963) (STS)					—	—		
			N. denticulata Sokolov et Tesakov, 1963 (STS)						—		
			N. sp. (?STS)						—		
			Saffordophyllum sibiricum Sokolov, 1955 (STS)						—		
			?*S.* sp. (STS)								- - -
			Foerstephyllum acer Sokolov, 1955 (STS)						—		
			F. ex gr. F. vacuum (Foerse, 1924) (?STS)						—		
			Vacuopora prisca (Sokolov, 1955) (STS)						—		
			V. crenata Sokolov et Tesakov, 1963 (STS)						—		
			Transitolites transitus Minzhin, 1981 (CM)						×		
			T. hongorensis Bondarenko et Minxhin, 1977 (CM)						×	–	
			T.(?) sp. (WM)					×			
			Trabecuvallum altaicum (Dziubo, 1967) (CM)						×		
			Bajnolites buriduingolensis Minzhin, 1981 (CM)						×		
		Lich.	*Lichenaria carterensis* (Safford, 1856) (TS)					—			
Tetradiida		Cryptolichenariidae	*Cryptolichenaria miranda* Sokolov, 1955 (STS, TS)	—							
			C. baikitica Sokolov et Tesakov, 1963 (STS, TS)	—					–		
			C. sp. (?IS)	—							
			Amsassia sp. (STS)					—			
		Tetradiidae	*Tetradium* sp. (STS)				—	—			
			T. subfibratum Sokolov et Tesakov, 1963 (TS)					—			
			T. fibratum Safford, 1856 (STS, TS)				—	—			
			Paratetradium mangaseicum Sokolov, 1955 (STS, TS)				—	—			
			P. quadrilobatum Sokolov et Tesakov, 1963 (STS)					—			
			P. saffordi Bassler, 1950 (?STS)					—			
			Rhabdotetradium nobile Sokolov, 1955 (STS)					—			

Table (Contd.)

Order	Suborder	Family	System		Ordovician							
			Series		Middle			Upper				
			Stages	ISS	Darriwilian			Sandbian		Katian		Hirn.
				GSS-2	Llanvirn			Caradoc		Ashgill		
			Horizons	SB	Muk-tei	Volg.	K.–K.	Ch.	Baksan	Dolb.	Nir.	Bur
			Species	MB					Bair.	Bayan.	Sair.	Nar.
1	2	3	4		5	6	7	8	9	10	11	12
Tetradida		Tetradiidae	*Rh. apertum* (Safford, 1856) (STS)						—	—		
			Rh. floriforme Sokolov et Tesakov, 1963 (?*Rh. petalliforme*) (STS)							—		
			Rh. tubifer (Troedsson, 1929) (?STS)							—		
			Rh. elegans Zhizhina, 19 (?STS)							—	—	
			Rh. sp. (WM)								×	
			Phytopsis cellulosum Hall, 1847 (?STS)						—			
Heliolitoidea												
Proporida		Proporidae	*Propora spesiosa* (Bullings, 1865) (CM)									×
Khangailitida			*Khangailites sinkiangensis* (Yü, 1960) (CM)									×
			Kh. parallelus Bondarenko et Minzhin, 1981 (CM, WM)								×	
			Kh. heteromorphosus Bondarenko et Minzhin, 1980 (CM, WM, SM, EM)								×	
			Kh. karasuensis (Dzuibo, 1960) (WM, SM)								×	
			Pseudokhangailites abitus Bondarenko et Minzhin, 1981 (EM)								×	
			Dilites rosa Bondarenko et Minzhin, 1981 (WM, EM)								×	
		Innaeporidae	*D. multihabitus* Bondarenko et Minzhin, 1981 (WM, SM)								× ×	
			Concavites mongolicus (Kovalevsky in B.et M., 1981) (WM, EM)								×	
			C. incertus Bondarenko et Minzhin, 1981 (EM)								×	
			Sibiriolites sibiricus mongolicus Bondarenko et Minzhin, 1981 (WM)								×	
			S. sibiricus Sokolov, 1955 (STS, NSP)						- - -	—		
			S. elegans Sokolov et Tesakov, 1963 (STS)							—		
Heliolitida		Hel.	*Paolites* (?) *dumbites* (Bondarenko et Minzhin, 1981) (WM)								×	
			P. (?) *obolites* (Bondarenko et Minzhin, 1981) (SM, EM)								×	
		Ps.	*Pseudoplasmoporra cargoensis* (Hill, 1957) (WM)								×	
		Stel.	*Derivatolies* (?) *archaeus* (Bondarenko et Minzhin, 1981) (WM, SM)								×	
Coccoseridida		Taeniolitidae	*Granulina grandis* (Bondarenko, 1975) (SM, EM)								×	
			Sibiriolitella reticulata Sokolov, 1955 (STS, TS)							—		
			Mongoliolites pearadoxides Bondarenko et Minzhin, 1977 (CM)							×	×	×

Table (Contd.)

Order	Suborder	Family	System		Ordovician							
			Series		Middle			Upper				
			Stages	ISS	Darriwilian			Sandbian		Katian		Hirn.
				GSS-2	Llanvirn			Caradoc		Ashgill		
			Horizons	SB	Muk-tei	Volg.	K.–K.	Ch.	Baksan	Dolb.	Nir.	Bur
			Species	MB					Bair.	Bayan.	Sair.	Nar.
1	2	3	4		5	6	7	8	9	10	11	12
Rugosa												
		Pali.	*Paliphyllum primarium* Soshkina, 1955 (STS)							—		
Staurida	Streptelasmatina	Streptelasmatidae	*Bighornia* sp. (VS)									—
			Helicelasma sp. (WM)								×	
			Grewingkia altaica (Tcherepnina, 1960) (WM, SM)							– –	×	– –
			G. anquinea (Scheffen, 1933) (SM, CM)							– –	×	– –
			G. parva McLean, 1974 (WM, SM)							– –	×	– –
			G. venusta Ulitina, 1983 (CM)							×		
			G. contexta Neuman, 1969 (CM)							×		
			G. sp. (EM)								×	
			Rectigrewingkia antelion Dybowski, 1873 (SM)							– –	×	– –
			Streptelasma duncani (Dybowski, 1873) (CM)								×	×
			S. ostrogothicum Neuman, 1969 (WM, SM)							– –	×	
			S. primum (Wedekind, 1927) (WM, SM)							– –	×	
			?*S. cyrtum* Neuman, 1969 (WM)								×	
			S. tesakovi Sytova, 1979 (STS)						—	—		
			Reimanelasma elegans Sytova, 1979 (STS)						—	—		
			Kenelasma sibiricum Sytova, 1979 (STS)						—	—		
			K. holophagmoides (Ivanovsky, 1961) (STS)						—	—		
			Dimelasma gratum Sytova, 1979 (STS)						—	—		
			?*Pterophrentis allae* Ivanovsky, 1963 (STS)							—		
	Stauriina	Stauriidae	*Palaeophyllum* sp. (VS, WM)								×	—
			P. thomi (Hall, 1847) (STS, WM)							×	×	—
			P. crassum Webby, 1972 (SM)							– –	×	– –
			P. lebediensis (Tcherepnina, 1960) (SM)							– –	×	– –
			P. virgultum (Tcherepnna, 1960) (SM)							– –	×	– –
			P. patulum McLean et Webby, 1976 (SM)							– –	×	– –
			Modesta gobiensis Ulitina, 1983 (Wm, SM)							– –	×	– –
			M. sp. (EM)								×	
			Cyathophylloides dybowskii (Soshkina, 1955) (STS)							—	—	
			Favistina breviseptata (Sokolov, 1955) (STS)							—		
			F. stellata (Hall, 1847) (STS)							—		
			F. rozmanae Sytova, 1979 (STS)							—		
			Proterophyllum simplex (Sokolov, 1955) (STS, VS)							—		
Cystiphyllida		Holaranthe	*Cantrillia andreevae* Sytova, 1979 (STS, VS)							—		
			Rugosa (imprints of solitary forms) (WM)						×			

Table (Contd.)

	System			Ordovician							
Order		Series		Middle			Upper				
	Suborder		Stages: ISS	Darriwilian			Sandbian	Katian			Hirn.
		Family	Stages: GSS-2	Llanvirn			Caradoc		Ashgill		
			Horizons: SB	Muk-tei	Volg.	K.–K.	Ch.	Baksan	Dolb.	Nir.	Bur
			Species: MB					Bair.	Bayan.	Sair.	Nar.
1	2	3	4	5	6	7	8	9	10	11	12
			Cyrtophyllida								
Cyrtophyllida		Cyrtophyllidae	*Cyrtophyllum* s.l. (STS, SM)					—	— ▬	× ▬	× ▬
			C. orthis Sokolov, 1950 (STS)								- - - -
			C. simplicatum Sokolov. 1950 (STS)								- - - -
			C. densum Lindström, 1882 (STS)						— ▬	—	—
			C. byringiesnum Barskaja, 1958 (STS)						▬		
			C. sibiricum Sokolov, 1950 (STS)						▬		
			C. lambeiformum Sokolov, 1950 (?1949) (STS, TS)						— ▬		—
			C. laxum Sokolov, 1950 (STS)								- - - -
			C. ex gr. *C. lambei* (Schuchert, 1900) (STS)					—			
			Karagemia sp. (WM)							×	×
			K. tsaganbulakiensis Minzhin, 1981 (SM)							×	
			K. altaica Dziubo, 1960 (STS, TS, SM, EM)						▬	×	—
			K. gobialtaica Minzhin, 1981 (SM)							××	
			K. baragashiensis Dzuibo, 1960 (WM, SM)							×	
			Rhaphidophyllum ex gr. *Rh. lindströmi* Preobrazhensky, 1964 (WM)							×	
			Rh. histrum Preobrazhensky, 1964 (STS, TS)						— ▬		—
			Rh. bellum (Ivanov, 1950) (STS)						—		
			Rh. constellatum Lindström, 1882 (STS, TS)						—		
			Khadzhingia khadzhingica Minzhin, 1981 (WM, SM)							× ×	
			Genera now. I, II, nom. nud. (in *Guide Book…*, 2001) (SM)						×	× ×	

Notes: (1) The Table is composed by data of Sokolov, 1962; Sokolov and Tesakov, 1963; Ivanovskii, 1963, 1965; Fomin, 1971; Rozman, 1977, 1979; Ulitina et al., 1979; Sytova, 1979; Sytova and Ulitina, 1985; *Atlas of Fauna…*, 1981; Bondarenko and Minjin, 1981; Minjin, 1981; Bondarenko, 1992, 2003; *Guide…*, 2001; Bolshakova et al., 2003; Minjin and Bondarenko, 2003; *Paleontology of Mongolia*, 2003; Ulitina et al., 2009.

(2) Abridgements: (Baksan) Baksan Horizon (H.), (Bair.) Bairim H., (Bayan.) Bayankhongor H., (Bur) Bur H., (Volg.) Volgina H., (EM) East Mongolia, (VS) Vilyui Sea (Vilyui syneclise), (Darriwilian) Darriwilian Stage, (Dolb.) Dolbor H., (WM) West Mongolia, (IS) Irkutsk Sea (Irkutsk amphitheater), (Katian) Katian Stage, (K.-K.) Kirensk–Kudrin H.; (MB) Mongolian basin; (ISS-1) International stratigraphic scale; (Muktei) Muktei H.; (Nar.) Nariingol H., (Nir.) Nirunda H., (GSS-2) Global stratigraphic scale, (M) Middle, (Sandb.) Sandbian Stage, (Sair.) Sairin H., (SB) Siberian basin, (NSP) northern Siberian Platform, (TS, STS) Tunguska Sea (Tunguska syneclise), northeastern and southwestern regions, (Hirn.) Hirnantian Stage, (CM) Central Mongolia, (Ch.) Chertovo H., (SM) South Mongolia, (Calap.) Calapoeciidae, (Cyst.) Cystiphyllida, (Hel.) Heliolitida, (Hexis.) Hexismiidae, (Hol.) Holacanthiidae, (Lichen.) Lichenariidae, (Pal.) Paliphyllidae, (Ps.) Pseudoplasmoporidae, (Stel.) Stelliporellidae, (Syr.) Syringophyllidae; (▬, —) findings in the Siberian basin, frequent and rare, (×, ×) findings in the Mongolian basin, frequent and rare, (----) supposed occurence.

belonging (subclassis incertae sedis): Heliolitoidea (?) or Rugosa (?).

Tabulatoids. The tabulatoids have four main types of colonies: massive, chain, bushy, and compact (for details see pp. 00–00). The shape of colonies varied from disciform and hemispherical to nodular, cylindrical, and branchy with various transitions between them.

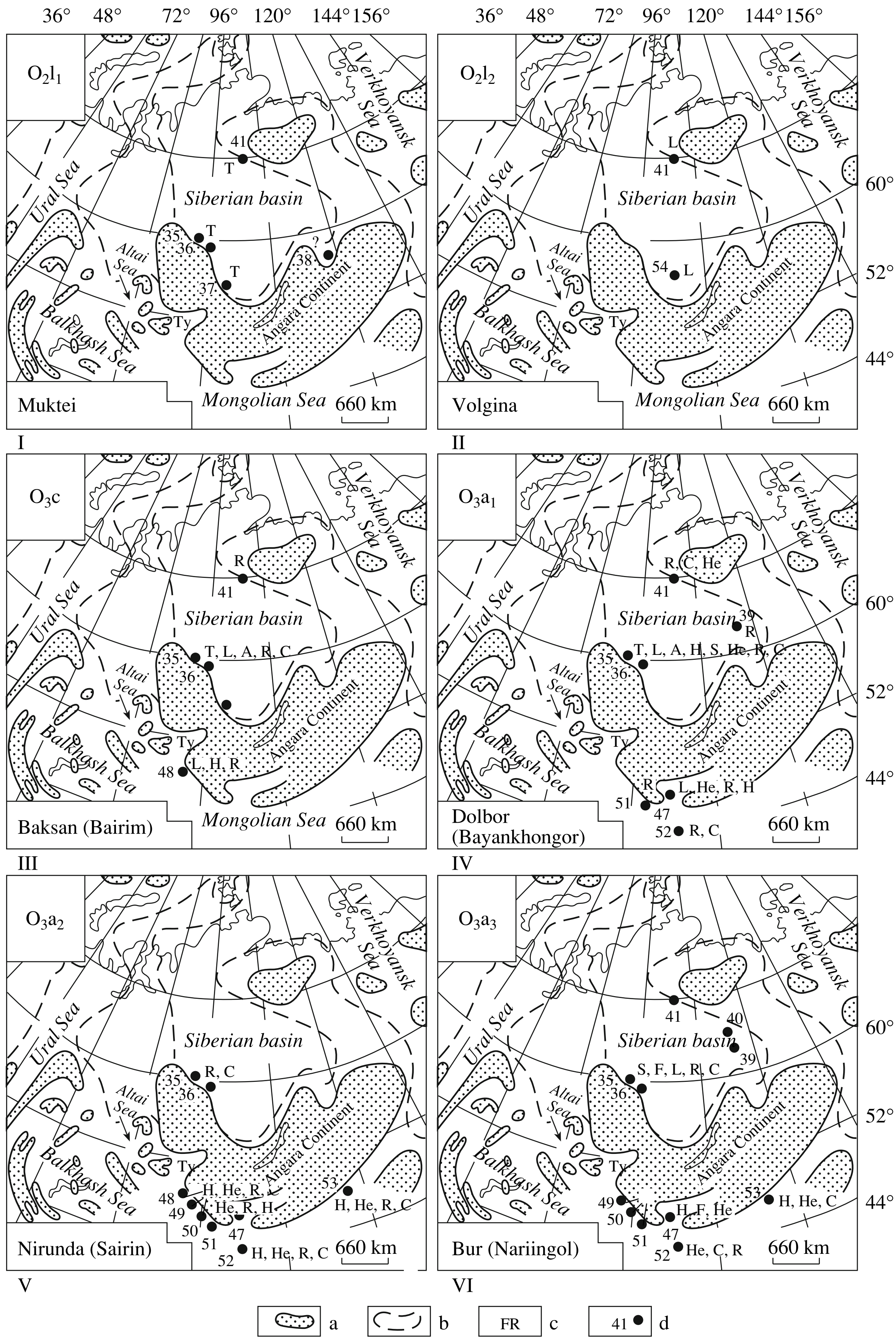
Siberian basin (SB). The auloporids were found in the SB as early as in the Ordovician (Sokolov and Tesakov, 1963). But first reliable tabulatoids from the order Tetradiida appeared in SB in the Middle Ordovician, in the beginning of Llanvirn, Muktei Time. They were three species of *Cryptolichenaria*, which appeared almost simultaneously in the Tunguska, Irkutsk, and ?Vilyui Seas (Figs. 1 and 4a, nos. 35–37). Their numerous massive colonies were found in the variegated terrigenous and terrigenous carbonate shallow rocks. Presence of Auloporida in the Early Ordovician of the Irkutsk Sea needs revision. The taxonomic diversity of tabulatoids in the beginning of Llanvirn is scanty: one order Tetradiida, one family Cryptolichenariidae, one genus *Cryptolichenaria*, and three species. First tabulatoids of the order Lichenariida appeared in the Late Llanvirn (Volgina Time): *Billingsaria lepida* from the family Billingsariidae in the Tunguska Sea and *Lyopora crassa* and *L. flexibilis* from the family Lyoporidae in the Irkutsk Sea (Fig. 4b, nos. 41 and 54). Their taxonomical composition sharply changed in comparison with the Early Llanvirn: the order Lichenariida with families Billingsariidae and Lyoporidae, two genera *Billingsaria* and *Lyopora*, and three species appeared.

In the Late Ordovician the tabulatoids developed more successfully. Their taxonomical diversity in the Caradoc (Baksan Time) increased up to three orders (Tetradiida, Lichenariida, Auloporida), four families (Tetradiidae, Lichenariidae, Billingsariidae, Fletcheriidae), seven genera (*Tetradium, Paratetradium, Rhabdotetradium, Phytopsis, Lichenaria, Nyctopora, Eofletcheria*), and seven species. “Burst” of the taxonomical diversity of tabulatoids occurred in the Early Ashgill of SB (Dolbor Time) and was especially strong in the Tunguska Sea. Assemblages especially rich in these corals were found in the dark bituminous limestones, which were referred by B.S. Sokolov and Yu.I. Tesakov (1963) to the base of the Dolbor Horizon and by Rozman (1977) to the Middle Dolbor Subhorizon. The maximum diversity was in the existence of five orders (Tetradiida, Lichenariida, Auloporida, Halysitida, Sarcinulida), seven families (Cryptolichenariidae, Tetradiidae, Billingsariidae, Halysitidae, Heximiidae, Fletcheriidae, Calapociidae), thirteen genera (*Amsassia, Tetradium, Paratetradium, Baikitolites, Nyctopora, Saffordophyllum, Foerstephyllum, Vacuopora, Fletcheriella, Eofletcheria, Calapoecia*), and thirty species. Tetradiids (and particularly bushy colonies of *Rhabdotetradium*) were especially numerous. The orders Halysitida and Sarcinulida first appeared in the Dolbor Time. Five genera and five species (*Eofletcheria* sp., *Nyctopora nicholsoni, Tetradium fibratum, Paratetradium mangaszicum, Rhabdotetradium apertum*) are common for the Dolbor and Baksan tabulatoids. The quantity and diversity of tabulatoids decreased by the end of the Early Ashgill (Late Dolbor Time).

The tabulatoids are unknown in the Middle Ashgill (Nirunda Time). Four orders (Favositida, Sarcinulida, Halysitida, ?Lichenariida), five families (Favositidae, Syringophyllidae, Columnoporidae, Halysitidae, ?Billingsariidae), six genera (*Palaeofavosites*, *Parasarcinula*, *Columnoporella, Catenipora s.l.*, ?*Halysites*, ?*Saffordophyllum*), and more than ten species are know from the Late Ashgill (Bur Time). The Late Ashgill (Bur) and Early Ashgill (Dolbor) tabulatoids differ not only in the number of taxa but also in the sharp change of the composition of orders, families, and genera. The order Favositida first appeared in the Bur Time (five species of *Palaeofavosites*); family Syringophyllidae prospered in the order Sarcinulida (two species of *Parasarcinula* and two species of *Columnoporella*); family Calapoeciidae, orders Tetradiida and Lichenariida, and massive chain *Tollina* of the order Halysitida became extinct, and uniserial chain *Catenipora s.l.* and ?*Halysites* remained few in number. Thus tabulatoids qualitatively renewed in the Bur Time of the Late Ashgill due to the first appearance of typical for the Silurian and Devonian Favositida and extinction of the typical for the Ordovician orders Tetradiida and Lichenariida. The tabulatoids are unknown from the Ordovician–Silurian boundary deposits of SB.

Conclusions. The Middle–Late Ordovician (Muktei–Bur Time) tabulatoids in SB consisted of six orders (Auloporida, Lichenariida, Tetradiida, Halysitida, Sarcinulida, Favositida); eleven families (Fletcheriidae,

Fig. 4. Succession of appearing of the Ordovician corals in the Siberian and Mongolian basins. Designations: (a) land, (b) borders of the plain areas occasionally covered by the sea, the other are the marine basins, (c) indexes of the orders and subclasses, (d) number of the locality with findings, (A) Auloporida, (C) Cyrtophyllida, (F) Favositida, (H) Halysitida, (He) Heliolitoidea, (L) Lichenariida, (T) Tetradiida, (R) Rugosa, (S) Sarcinulida; (O_2l_1) Middle Ordovician, Early Llanvirn, (O_2l_2 Late Llanvirn, (O_3c) Late Ordovician, Caradoc, (O_3a_1) Early Ashgill, (O_3a_2) Middle Ashgill, (O_3a_3) Late Ashgill, (nos. 35, 36, etc.) numbers of localities with corals (by Bondarenko, 1989; 2003): (nos. 35, 36) southwestern Tunguska Sea: Podkamennaya Tunguska, Stolbovaya, B. Nirunda, N. Chunku, Chunya and other rivers, (no. 37) Irkutsk Sea, Angara zone, (nos. 38–40) Vilyui Sea: (no. 38) Kalar zone, (no. 39) Vilyui zone, (no. 40) Morkoka zone; (no. 41) northeastern Tunguska Sea, basin of the Moiero River, Moierokan Stream, (nos. 47–53) Mongolia: (no. 47) Central Mongolia, Khangai Ridge, Tsagaan-del Section, (nos. 48–51) West Mongolia, (no. 52) South Mongolia, Shine Jinst Ridge, (no. 53) East Mongolia, to the south of Baruun-urt; (no. 54) Middle Siberia, Irkutsk amphitheater. Names of the Siberian horizons are without brackets, Mongolian horizons are in brackets; paleogeographical scheme by *Paleogeography of the USSR*, 1974, simplified.


36° 48° 72° 96° 120° 144° 156°
60°
52°
44°
O_2l_1
Muktei
I
O_2l_2
Volgina
II
O_3c
Baksan (Bairim)
III
O_3a_1
Dolbor (Bayankhongor)
IV
O_3a_2
Nirunda (Sairin)
V
O_3a_3
Bur (Nariingol)
VI
Verkhoyansk Sea
Ural Sea
Siberian basin
Altai Sea
Balkhash Sea
Angara Continent
Mongolian Sea
660 km
Ty
T, L, A, R, C
L, H, R
R, C, He
T, L, A, H, S, He, R, C
L, He, R, H
R, C
H, He, R, C
H, He, R, C
S, F, L, R, C
H, F, He
H, He, C
He, C, R
a
b
FR
c
41
d

Tetradiidae, Lyoporidae, Billingasariidae, Cryptolichenariidae, Halysitidae, Hexismiidae, Syringophyllidae, Calapoeciidae, Favositidae); twenty-one genera (*Fletcheriella*, *Eofletcheria*, *Lyopora*, *Baikitolites*, *Billingsaria*, *Nyctopora*, *Saffordophyllum*, *Foerstephyllum*, *Vacuopora*, *Cryptolichenaria*, *Amsassia*, *Tetradium*, *Paratetradium*, *Rhabdotetradium*, *Tollina, Catenipora s.l.*, ?*Halysites*, *Calapoecia, Labyrinthites, Parasarcinula, Columnoporella, Palaeofavosites*), and more than forty species (Table 1).

The taxonomical diversity of the Middle Ordovician tabulatoids of SB (Muktei–Volgina Time) is low that was probably caused by the initial stages of the tabulatoids evolution and uniformly shallow conditions of the Tunguska, Irkutsk, and ?Vilyui Seas. Muktei and Volgina tabulatoids lacked common species, genera, families, and orders. The taxonomical diversity of the Late Ordovician tabulatoids of SB (Dolbor–Bur Time) was high, especially in the Dolbor Time in the southwestern Tunguska Sea.

Baksan and Dolbor tabulatoids have five common species, five genera, two families, and two orders; Dolbor and Bur have only one order in (Table 1; Figs. 1, 4).

Mongolian basin (MB). First tabulatoids appeared in the West Mongolia in the Late Ordovician (end of Caradoc, Late Bairim Time). They consisted of three species *Transitolites (?)* sp., *Procatenipora* sp., *Halysites* ex gr. *H. praecedens* from the orders Lichenariida and Halysitida. The tabulatoids became widely spread in the western and central parts of MB in the Early Ashgill (Bayankhongor Time), especially in the central part, where then existed half-closed bay (Tsagandel area). Eleven species and six genera (*Manipora, Procatenipora, Halysites, Transitolites, Trabecuvallum, Bajnolites*) existed in the Bayankhongor Time. They also belong to the orders Lichenariida and Halysitida, which appeared in MB in the Late Caradoc in the Bairim Time. The taxonomical diversity of tabulatoids gradually decreased up to nine species and four genera (*Procatenipora, Catenipora, Halysites, Rhabdotetradium*) in the Middle Ashgill (Sairin Time); order Lichenariida disappeared; order Halysitida preserved; order Tetradiida (*Rhabdotetradium?*) appeared for the short time in the western part of MB. The species diversity of the genera *Catenipora* and *Halysites* (order Halysitida) decreased in the Late Ashgill (Nariingol Time) but their two former species preserved and one cosmopolitan species *Palaeofavosites argutus* Ivanov from the order Favositida appeared (Table 1). The tabulatoids are unknown from the Ordovician–Silurian boundary deposits of MB.

Conclusions. The Late Ordovician (Bairim–Nariingol Time) tabulatoids in MB consisted of four orders (Lichenariida, Tetradiida, Halysitida, Favositida), four families (Billingsariidae, Tetradiidae, Halysitidae, Favositidae), nine genera (*Trabecuvallum, Transitolites, Bajnolites, Rhabdotetradium (?), Manipora, Procatenipora, Catenipora, Halysites, Palaeofavosites*), and nineteen species. The order Halysitida existed throughout Late Caradoc–Ashgill with maximum species and generic diversity in the Early Ashgill. The order Lichenariida is known in MB only from the Late Caradoc and Early Ashgill; the order Favositida first appeared in the Late Ashgill.

Heliolitoids. The heliolitoids have massive-coenenchymate, variously shaped from disciform and hemispherical to nodular and from cylindrical to branchy colonies.

Siberian basin (SB). The heliolitoids are partially studied. Two species *Sibiriolites sibiricus* and *S. elegans* of the order Khangailitida and one species *Sibiriolitella reticulate* of the order Coccoseridida were described from the Early Ashgill (Dolbor Time). The genus *Sibiriolites* possibly appeared already in the end of the Caradoc in the Late Baksan Time. Numerous branchy and cylindrical colonies together with the other corals played a considerable part in the forming of bituminous coral-stromatopore and coral-bryozoan thick-plate limestones in the southwestern Tunguska Sea and in the forming of organogenous aleurite middle- and thin-plate limestones in the northeastern Tunguska Sea.

Mongolian basin (MB). First heliolitoids appeared in the Central Mongolia in the Early Ashgill (Bayankhongor Time) and consisted of one neoendemic species *Mongoliolites paradoxides* from the order Coccoseridida. Two heliolitoid species (*Khangailites karasuensis, Dilites multihabitus*) from two families of the order Khangailitida appeared in the beginning of the Middle Ashgill (beginning of the Sairin Time) in the West and South Mongolia. In the second half of the Middle Ashgill (middle and end of the Sairin Time) the diversity and habitat of heliolitoids in all parts of MB sharply increased: fifteen species, ten genera, eight families, and three orders Khangailitida, Coccoseridida, and Heliolitida (Table 1; Fig. 2). In the Late Ashgill (Nariingol Time), the heliolitoids preserved only in the Central Mongolia. Their taxonomical diversity sharply decreased at all taxonomical levels. Only three species of three genera of three families preserved. The composition of orders qualitatively changed: Heliolitida disappeared, Proporida first appeared, and singular representatives of the orders Khangailitida and Coccoseridida preserved. Their genera *Khangailites* and *Mongoliolites* were living out. *Propora* appeared here for the first time and consisted of one cosmopolitan species *P. speciosa*. The heliolitoids are unknown from the Ordovician–Silurian boundary deposits of MB.

Conclusions. The Ashgill (Bayankhongor–Nariingol Time) heliolitoids in MB consisted of four orders (Khangailitida, Coccoseridida, Proporida, Heliolitida), nine families, eleven genera (*Khangailites, Pseudokhangailites, Dilites, Concavites, Sibiriolites, Mongoliolites, Granulina, Propora, Paolites (?) Derivatolites (?), Pseudoplasmopora*) and seventeen species.

Rugoses. The rugoses are the only group of the Paleozoic corals with two forms of life: singular and colonial. Two types of colonies are known: bushy and massive (Fig. 2).

Siberian basin (SB). First rugoses appeared in the southwestern Tunguska Sea in the beginning of the Late Ordovician (Caradoc, Early Baksan Time) and consisted of four species from three genera *Reimanelasma, Kenelasma*, and *Dimelasma* from the family Streptelasmatidae, order Stauriida (Table 1). One more singular coral *Streptelasma tesakovi* appeared in this family by the end of the Middle Caradoc (Late Baksan Time) in the Tunguska Sea. The taxonomical diversity of rugoses sharply increased in the Early Ashgill (Dolbor Time): eleven species, eight genera, three families, and two orders. In the beginning of the Early Ashgill (Early Dolbor Time) existed the same species as in the end of the Late Caradoc (Table 1). Qualitative leap was in the middle of the Early Ashgill (Middle Dolbor Time) and was connected with the appearance of the colonial rugoses and singular vesicular forms. The rugoses became widely spread in the Tunguska Sea in the Middle Dolbor Time and part of them penetrated the Vilyui Sea (*Cantrillia andreevae, Propterophyllum simplex*). One species of singular rugoses *Paliphyllum primarium* and two colonial species *Cyathophylloides dybowskii* and *Favistina breviseptata* preserved in the Tunguska Sea by the end of the Early Ashgill (Late Dolbor Time). One species of massive rugoses *Cyathophylloides dybowskii*, which had appeared in the Early Ashgill, preserved in the Middle Ashgill (Nirunda Time). Five species from four genera of two families and two orders existed in the Late Ashgill (Bur Time). Of them, the order Cystiphyllida consisted only of singular rugoses *Cantrillia andreevae*, which had appeared in the Early Ashgill; the order Stauriida consisted of singular *Bighornia* sp., colonial massive *Proterophyllum simplex*, and first bushy rugoses *Palaeophyllum thomi* and *P.* sp. It is notable that in the Vilyui Sea in the Late Ashgill existed two species *Cantrillia andreevae* and *Propterophyllum simplex*, which had appeared in the Early Ashgill.

Conclusions. The Late Ordovician (Baksan–Bur Time) rugoses in SB consisted of two orders (Stauriida, Cystiphyllida), four families (Streptelasmatidae, Paliphyllidae, Stauriidae, Holacantridae), twelve genera (*Bignornia, Streptelasma, Reimanelasma, Kenelasma, Dimelasma, Paliphyllum, Palaeophyllum, Cyathophylloides, Favistina, Proterophyllum, Cantrillia*), and fifteen species. The taxonomical diversity of rugoses in the Tunguska Sea was higher than in the Vilyui Sea.

First rugoses appeared in SB in the Middle Caradoc (Early Baksan Time), prospered in the Early Ashgill (Middle Dolbor Time), and became extinct in the end of the Late Ashgill (Bur Time; Table 1; Fig. 1).

Mongolian basin (MB). First rugoses appeared in the end of Caradoc (end of Bairim Time; West Mongolia, Lake basin). They are represented by single imprints of singular rugoses in the carbonate-terrigenous deposits. Numerous and various singular and colonial rugoses (thirteen species of four genera) existed in the Early Ashgill (Bayankhongor Time). They were spread throughout MB and especially in its western and southern areas. Singular rugoses consisted of one order Stauriida and its family Streptelasmatidae with three genera *Grewingkia* (five species), *Rectigrewingkia* (one species), and *Streptelasma* (two species). Colonial rugoses belong to the same order Stauriida but to its another family Stauriidae with two genera *Palaeophyllum* (four species) and *Modesta* (one species), which have bushy colonies. The same genera preserved in the Middle Ashgill (Sairin Time) but the number of species increased up to eighteen (ten species of singular rugoses and eight species of colonial rugoses). The Stauriida with its former two families, four genera, and about ten species continued to exist in the Late Ashgill (Nariingol Time) (Table 1).

Conclusions. The Late Ordovician (Bairim–Nariingol Time) rugoses in MB consisted of one order Stauriida, two families (Streptelasmatidae, Stauriidae), six genera (*Helicelasma, Grewingkia, Rectigrewingkia, Streptelasma, Palaeophyllum, Modesta*), and eighteen species. First rugoses appeared in MB in the end of Caradoc (end of the Bairim Time), prospered in the Early–Middle Ashgill (Bayankhongor–Sairin Time), and died out in the end of the Late Ashgill (Nariingol Time). The maximum diversity of rugoses was in the western and southern areas of MB.

Cyrtophyllida (?subclass Heliolitoidea or ?subclass Rugosa). The order consists of one nominative family. The colonies have massive-coenenchymate structure and are variously shaped (but not branchy).

Siberian basin (SB). First cyrtophyllids appeared in the Caradoc Age (Baksan Time) in the southwestern part of the Tunguska Sea with one or two species of the genus *Cyrtophyllum*. The taxonomical diversity of cyrtophyllids increased in the Early Ashgill (Dolbor Time) up to nine species and three genera (*Cyrtophyllum, Karagemia, Rhaphidophyllum*). However, S.Yu. Tesakov (1995) supposes that cyrtophyllids in the Dolbor Time consisted of one genus *Cyrtophyllum* and its type species *C. densum* Lindstrŏm. In the Dolbor Time the number of cyrtophyllid colonies in the SB increased so strongly that they formed meadows, banks, and biostromes, which became the base for the forming of coral-stromatopore and coral-bryozoan limestones. Two species of the genus *Cyrtophyllum* are known from the Middle Ashgill (Nirunda Time) of the southwestern part of the Tunguska Sea. The same as in the Early Ashgill three genera *Cyrtophyllum, Rhaphidophyllum*, and *Karagemia* existed in the Late Ashgill (Bur Time) in both parts of the Tunguska Sea but the number of species decreased up to five.

Conclusions. The cyrtophyllids existed in SB throughout Late Ordovician (Baksan–Bur Time). In the Ashgill, the genus *Cyrtophyllum* dominated in the southwestern part of the Tunguska Sea and the genus *Rhaphidophyllum* dominated in the northeastern part. The species composition in the southwest of this sea was richer (twelve species) than in the northeast of the sea (four species).

Mongolian basin (MB). First cyrtophyllids appeared in the South Mongolia in the Early Ashgill (Bayankhongor Time). They belong to the new undescribed genus (*Guide Book…*, 2001). In the Middle Ashgill (Sairin Time) the taxonomical diversity of cyrtophyllids increased up to nine species and six genera (*Cyrtophyllum, Karagemia, Rhaphidophyllum, Khadzhingia* and two new undescribed genera). They were spread throughout MB except its central part and were especially numerous and various in the western and southern parts of MB. One species of *Karagemia* and possibly genus *Cyrtophyllum* s.l. preserved in the Late Ashgill (Nariingol Time).

Conclusions. Of cyrtophyllids from the Middle Ashgill of MB, the genus *Karagemia* prevailed in number of species and their specimens and genera *Khadzhingia, Rhaphidophyllum*, and two new undescribed genera prevailed in number of specimens. Rare colonies of *Cyrtophyllum* (?) are known from the end of the Middle and Late Ashgill of South Mongolia.

Some Peculiarities of the Morphogeny of the Siberian and Mongolian Ordovician Corals

Eight main types of coral colonies are known: massive, massive-coenenchymate, massive-chain, uniserial-chain, compact, bushy-coenenchymate, and massive-bushy (Fig. 3). The massive colonies consisted of densely spaced prismatic corallites. In the massive-coenenchymate colonies, the corallites and interstitial skeletal elements are also densely packed. In the massive-chain colonies, the massive areas were combined with multiserial and uniserial chains. The uniserial-chain colonies were composed of variously accreted loops of uniserial chains. The bushy colonies consisted of usually cylindrical isolated corallites, which were connected in the areas of budding. Due to the development of the horizontal connective tubes (canals), the structure of corallites of the bushy-coenenchymate colonies is dense and almost massive. The corallites of the massive-bushy colonies could be densely spaced or diverge in different areas of the colony. The compact colonies are characterized by the accretion of the neighboring corallites with 4–6 or more sides with forming of interstitial tubes and lacunas (gaps) between them and the corallites. The compact colonies may be considered as pseudomassive by some features and by another as pseudobushy. The listed above colonial structures (types) developed independently in different orders and families; their appearance is connected with the specificity of the asexual reproduction, i.e. processes of cloning.

Siberian basin (SB). Only massive tabulatoids existed in Llanvirn, Middle Ordovician (*Cryptolichenaria* in Muktei Time; *Lyopora* and *Billingsaria* in Volgina Time). All types of colonies are known from the Late Ordovician. Massive (*Nyctopora, Lichenaria, Tetradium, Phytopsis*), massive-chain (*Paratetradium*), and bushy colonies lacking connective tubes (*Eofletcheria, Rhabdotetradium*) are known from Caradoc (Baksan Time). The Early Ashgill tabulatoids (Dolbor Time) had maximally diverse colonies: massive (*Nyctopora, Saffordophyllum, Foerstephyllum, Tetradium*), bushy-coenenchymate (*Calapoecia*), massive-bushy (*Amsassia*), massive-chain (*Paratetradium, Tollina, Baikitolites*), compact (*Vacuopora, Labyrinthites*), uniserial-chain (*Catenipora s.l.*), and bushy (*Eofletcheria, Fletcheriella, Rhabdotetradium*). In the Late Ashgill (Bur Time) existed massive colonies (*Palaeofavosites, ?Saffordophyllum*), massive-bushy (*Columnoporella*), uniserial-chain (*Catenipora s.l., ?Halysites*), and bushy-coenenchymate (*Parasarcinula*). The massive colonies (thirteen genera) and their variations (five genera) were most widespread among the tabulatoids of SB; second-best were bushy (four genera) and their variations (two genera), and also compact colonies (two genera). All of them were builders of coral banks, ridges, horizons, biostromes, and biogermes.

First colonies of tabulatoids were mainly small, rare up to 10 cm in cross section and up to 3.5 cm in height, and usually nodular and hemispherical in shape. Connective pores and canals connecting inner cavities of corallites appeared in tabulatoids of SB in the Early Ashgill (Dolbor Time). The structure of the skeletal tissue of the corallites and septae walls changed from cryptocrystalline and fibrous to trabecular; the trabecular structure became especially apparent in the Dolbor Time of the Early Ashgill. The asexual reproduction (cloning) in the majority of the Ordovician tabulatoids of SB was proceeded by the longitudinal division.

The heliolitoids had massive-coenenchymate colonies of various shape. The Early Ashgill heliolitoids of SB (Dolbor Time) had small and middle-sized cylindrical, irregularly branchy, nodular, and disciform colonies (genera *Sibiriolites* and *Sibiriolitella*) with peripherally thickened skeleton and other structural peculiarities.

The rugoses of SB consisted of singular and colonial forms. First singular rugoses appeared already in the Caradoc, Early Baksan Time (Fig. 2). They were small and middle-sized straight conic, rare cylindrical corals with deep calyxes and relatively rare platforms (unizonalia rugoses). The dissepiments in the singular corals of SB appeared in the Early Ashgill, Dolbor Time (bizonalia rugoses). The colonial rugoses appeared in the Middle Dolbor Time (Early Ashgill), almost for eight millions of years later than singular rugoses. First colonial rugoses had massive colonies; bushy forms appeared only in the Late Ashgill (Bur Time). The structure of the skeleton complicated from lamellar to trabecular. L.M Ulitina described (1980) some regularities of the colonial development of rugoses.

The cyrtophyllids had variously shaped (except branchy) massive-coenenchymate colonies. First colonies of *Cyrtophyllum* sp. appeared in the Tunguska Sea of SB in the Caradoc (Baksan Time) but were rare. They were small, up to 1 cm in cross section, with poorly developed interstitial skeletal elements between the corallites. In the Early Ashgill (Dolbor Time), the cyrtophyllids became numerous and various, especially in the northeastern Tunguska Sea. The colonies enlarged up to 30–40 cm in cross section; the spaces between the corallites and skeletal elements, the diameter of corallites, number of septae, and their differentiation in long and short septae also increased. In the Dolbor Time of the Early Ashgill, the number cyrtophyllids became so large that they formed meadows, banks, and biostromes that became the basement for formation of coral and coral-bryozoan limestones.

Mongolian basin (MB). First tabulatoids of MB had small massive and uniserial-chain colonies. They appeared in the Caradoc in the end of the Bairim Time. The massive-chain colonies appeared in the Early Ashgill in the Bayankhongor Time. Then prevailed chain tabulatoids (seven species), not massive (four species). The morphological diversity of the uniserial-chain colonies was both in the arrangement of corallites in chains and in the types of accretion of chains. Then corallites began to differentiate into small and large. The structure of walls and septae of corallites of massive colonies sharply changed from granular and fibrous to trabecular. In the Middle Ashgill (Sairin Time), massive and massive-chain colonies disappeared in MB and sharply increased number of uniserial-chain tabulatoids (eight species). In the Late Ashgill (Nariingol Time), uniserial-chain type of colonies preserved (two species) and one species with massive colonies appeared. These massive colonies of the order Favositida are independent and lack phylogenetic connections with the Early Ashgill massive tabulatoids Lichenariida of MB.

The heliolitoids had variously shaped massive-coenenchymate colonies. Different types of heliolitoid morphogeny were described by Bondarenko in 1975 and later. The heliolitoids first appeared in MB in the Early Ashgill (Bayankhongor Time) and had small colonies consisting of closely spaced corallites and poorly developed interstitial skeletal elements, the heteroliths (*Mongoliolites*). The Middle Ashgill genus *Khangailites* (Sairin Time) had the same structure but larger colonies. The colonies of such morphotype prevailed. Nevertheless, in the Middle Ashgill also existed heliolitoids with almost equally developed corallites and heteroliths. Heliolitoids with cylindrical and branchy colonies (*Pseudokhangailites, Sibiriolites*) appeared in the Middle Ashgill. In the Late Ashgill (Nariingol Time), number of heteroliths in colonies increased in comparison with the Early–Middle Ashgill heliolitoids.

First rugoses in MB were singular and had conic and cylindrical shape (Caradoc, Bairim Time). The bushy colonies appeared beginning with the Early Ashgill. Both types of colonies flourished in the Middle Ashgill (Sairin Time) and almost in equal proportions lived up to the end of the Ashgill (Nariingol Time). First singular rugoses were small but by the end of the Ashgill their sizes increased.

The cyrtophyllids with massive-coenenchymate colonies appeared in MB in the Early Ashgill and became especially numerous and various in the Middle Ashgill. First colonies were small with densely arranged corallites. During the Ashgill the sizes of colonies increased and their corallites became more spacious arranged. The septal apparatus had been strengthened and complicated.

The Occurrence of the Ordovician Corals in the Siberian and Mongolian Basins

The settlement of corals in the Siberian (SB) and Mongolian (MB) basins was not simultaneous (Figs. 1–4; Table 1). The corals appeared in SB probably in the Early Ordovician (tabulatoids Auloporida); it is still not proved that reliable tabulatoids appeared in the Middle Ordovician (Early Llanvirn, Muktei Time). They were primitive tabulatoids from the genus *Cryptolichenaria* of the order Tetradiida, which appeared almost simultaneous in the Tunguska, Irkutsk, and probably Vilyui Seas (Fig. 4 I, T). In the second half of the Llanvirn, during the Volgina transgression, more complicated tabulatoids of the genera *Lyopora* and *Billingsaria* (order Lichenariida) appeared almost in the same regions (Fig. 4, II, L). However, during the regression in the following Kirensk–Kudrin Time and deep erosion in the Chertovo Time, the corals disappeared.

New qualitative stage of settlement of corals in SB coincided with the beginning of the Late Ordovician. In the Caradoc (Baksan Time), the southwestern part of the Tunguska Sea was settled by the tabulatoids Tetradiida, Lichenariida, and Auloporida and also by Rugosa and Cyrtophyllida (Fig.4, III, T, L, A, R, C). Simultaneously the rugoses penetrated the northeastern Tunguska Sea. In the Early Ashgill, Dolbor Time, the corals of SB reached maximal taxonomical and morphological diversity: 55 species, 26 genera, 14 families, and 9 orders (Table 1; Figs. 1, 2, 4, IV: T, L, A, H, S, He, R, C). The density of settlement was so thick that reef structures appeared, which are especially typical for the southwestern Tunguska Sea (Fig. 4, IV, nos. 35, 36) and less typical for the northeastern part (Fig. 4, IV, no. 41). The corals were rare in the Vilyui Sea and consisted mainly of rugoses (no. 39). The area, diversity, and number of corals of SB sharply decreased in the Middle Ashgill (Nirunda Time); only rare rugoses and cyrtophyllids preserved in the southwestern Tunguska Sea (Fig. 4, V, nos. 35, 36). In the Late Ashgill (Bur Time), the corals inhabited the same regions of SB as in the

Dolbor Time of the Early Ashgill but their taxonomical diversity decreased and simultaneously the new order Favositida appeared (Fig. 4, VI: S, F, L, R, C).

The settlement of MB by corals began in the Caradoc, almost for eight millions of years later than of SB. The fragments of the Caradoc tabulatoids from the orders Lichenariida, uniserial-chain Halysitida, and imprimnts of singular Rugosa were found in the northwestern part of MB (Fig. 4, III, no. 48, L, H, R). In the Early Ashgill (Bayankhongor Time), the number of species in MB increased up to 25 and their area widened; colonial rugoses first appeared. The settlements of corals concentrated in the Central and South Mongolia (Figs. 2, 4, IV, nos. 47, 51, 52, L, H, He, R, C). In the Middle Ashgill (Sairin Time) the area and diversity of corals in MB reached their maximum. All four groups of corals were present: tabulatoids, heliolitoids, rugoses, and cyrtophyllids (totally 51 species, 24 genera, 9 families, and 7 orders). Most of the Sairin corals inhabited West and South Mongolia (Table 1, Fig. 4, V, nos. 47–53: T, H, He, R, C). During the Late Ashgill (Nariingol Time) the area of corals distribution in MB remained the same but Lichenariida became extinct and cosmopolitan species *Palaeofavosites argutus* of the order Favositida (tabulatoids) and *Propora speciosa* of the order Proporida (heliolitoids) appeared that indicates the last impulse of transgression (Fig. 4, IV, nos. 47, 49–53: H, F, He, C, R).

Thus the origin of corals (tabulatoids, heliolitoids, rugoses, and cyrtophyllids) occurred during the Ordovician. The Cambrian findings are doubtful and need revision. The oldest tabulatoids of SB are known from the Middle Ordovician (Llanvirn). Their structure is similar to the Early–Middle Ordovician tabulatoids of the North America from the Canadian, Chazy, and Black River and they also had common species (Bassler, 1950; Sokolov, 1962; Sokolov and Tesakov, 1963; Hill, 1981). The basins of the North America (especially of Canada), Russian Arctic, and Siberia were closely connected and probably were parts of the vast general Paleoocean. First tabulatoids in SB were probably immigrants. Their further development and settlement in the Middle and Late Ordovician are connected both with independent evolution and moving of some forms from other basins. The repeated mutual exchange occurred between the corals of the Altai-Sayany and Mongolian basins. The connections of MB and SB were rather weaker (Table 1). The heliolitoids, rugoses, and cyrtophyllids appeared in SB and MB later than tabulatoids almost for twelve millions of years. Their morphotypes are similar to the even-aged groups from the other basins. The ancient heliolitoids had densely spaced corallites and poorly developed interstitial elements between them; the number of the latter increased in the morphogeny. They differ also in the other features and form separate genera in different paleozoogeographical regions and provinces. The each case needs analysis of such categories as provenance, neoendemic, polyregional, polyprovincial, cosmopolitan, postendemic, etc., that exceeds the problems of the present paper.

CONCLUSIONS

(The comparative characteristic of the corals from Siberian and Mongolian basins)

(1) The subclasses Tabulatoidea, Heliolitoidea, Rugosa, and Cyrtophyllida (subclassic insertae sedis) inhabited Siberian (SB) and Mongolian (MB) basins. 103 species and 49 genera from 18 families and 10 orders are known from the Muktei–Bur Time in SB (Table 1, Fig. 1). 99 species and 31 genera from 16 families and 10 orders are known from the end of the Bairim up to the Nariingol Time in MB. The numbers of taxa differ first of all due to the different time of appearance and existence of corals in SB (Middle–Late Ordovician, Llanvirn–Ashgill; 23 millions of years) and MB (Late Ordovician, Late Caradoc–Ashgill; 13 millions of years). The comparison of the periods of existence of corals in both basins from the Late Caradoc up to the Late Ashgill reveals the following quantity of taxa: number of species is 94 in SB and 99 in MB; number of genera is 46 in SB and 31 in MB; number of families is 18 in SB and 16 in MB; number of orders is 10 in SB and 10 in MB. The qualitative characteristic is almost similar but the qualitative analysis of taxa reveals that SB and MB corals belonged to the different provinces. They differ in the time of the first appearance of subclasses (Llanvirn in SB and Late Caradoc in MB), time of maximums of the taxonomical diversity (Early Ashgill (Dolbor Time) in SB and Middle Ashgill (Sairin Time) in MB), and taxa composition, especially at the species and generic levels. Only 6 or 7 species of 193 species are common for SB and MB (Table 1). Of cyrtophyllids, Late Ordovician *Cyrtophyllum* s.l., (Late Baksan–Bur Time in SB and Sairin–Nariingol Time in MB) and genus *Cyrtophyllum* occur almost all over the Siberian-Canadian Region. The Ashgill species *Karagemia altaica* is known from the Dolbor–Bur Time of SB and Sairin Time of MB; outside SB and MB it was found in the Chakyr Horizon of Gorny Altai. Of tabulatoids, the Early Ashgill *Catenipora minima* is known from the Dolbor Time of SB and Bayankhongor Time of MB; outside SB and MB they were found in Taimyr. Of heliolitoids, the Early–Middle Ashgill *Sibiriolites sibiricus* is known from the Dolbor Time of SB and Sairin Time of MB; outside SB and MB it was found in Canada. Of rugoses, the Middle–Late Ashgill *Palaeophyllum sp.* is known from the Bur Time of SB and Sairin Time of MB; Ashgill *P. thomi* is known from the Bur Time of SB and Bayankhongor–Sairin Time of MB; outside SB and MB they were found in Canada, United States (New Mexico). Of tabulatoids, the Late Ashgill cosmopolitan species *Palaeofavosites argutus* is known from the Bur of SB and Nariingol Time of MB. The appearance of

common species is connected with the maximums of transgressions and development of connections between SB, MB, and other basins.

Eight of 77 genera are common for SB and MB: tabulatoids *Rhabdotetradium, Catenipora, Palaeofavosites*; heliolitoids *Sibiriolites*, rugoses *Palaeophyllum*; cyrtophyllids *Cyrtophyllum, Rhaphidophyllum, Karagemia*. Number of families and orders in SB and MB almost coincides, but their diversity, taxa composition, and presence or absence differ. In SB, tabulatoid orders Tetradiida (16 species of 6 genera) and Lichenariida (16 species of 8 genera) prevail; less widespread are Sarcinulida, Auloporida, Favositida, Halysitida; of heliolitoids, the order Khangailitida prevails; of rugoses, the orders Stauriida and Cystiphyllida prevail. Auloporida, Sarcinulida, and Tetradiida are absent in MB (except single finding of the fragment of *(?)Rhabdotetradium* in the West Mongolia), Favositida are rare, and Halysitida prevails; the heliolitoids are highly variable (four orders); one rugose order Stauriida with both singular and colonial bushy forms is present. Hence corals successfully existed in SB and MB beginning with the Caradoc but preserved their specificity, especially at the species and generic levels.

Thus the Siberian and Mongolian basins compose two provinces of one Siberian-Canadian paleozoological region. Its characteristic orders were Cyrtophyllida and Tetradiida. The taxonomical diversity of corals of SB is higher than that of Mongolian due to the size of the basin, abundance of food, relatively quiet tectonic conditions, and favorable physical-hydrological conditions during the Middle–Late Ordovician.

(2) The colonial corals of SB and MB have eight types of colonies: massive, massive-coenenchymate, massive-chain, uniserial-chain, compact, bushy, bushy-coenenchymate, and massive-bushy. These types developed independently in different taxa and their appearance is connected with the specificity of the asexual reproduction, i.e. cloning. All eight types of colonies are known from SB, the most common are massive colonies. Five types of colonies existed in MB, of them the most common types are uniserial-chain, massive-coenenchymate, and massive (Table 1, Fig. 3).

The singular corals are known only for rugoses; they appeared in the beginning of Caradoc in SB and in the end of Caradoc in MB (Fig. 2). First singular rugoses were small, mostly conic, and had small number of platforms. The colonial rugoses appeared later than singular, in the Early Ashgill, almost simultaneously in SB and MB. However, in SB they had massive colonies; bushy forms appeared only in the end of Ashgill. Only bushy colonies are known from MB.

(3) Four biotic stages may be distinguished in the development of corals from SB (Figs. 1, 4). First stage is characterized by scanty taxonomical diversity of tabulatoids, which appeared there for the first time while heliolitoids, rugoses, and cyrtophyllids were absent (Llanvirn, Muktei–Volgina Time). Second stage is characterized by the increase of the taxonomical diversity of tabulatoids and first appearance of rugoses, cyrtophyllids, and possibly of heliolitoids (Caradoc, Baksan Time). Third stage corresponds to the maximum of the taxonomical diversity of tabulatoids, rugoses, and cyrtophyllids and first appearance of reliable heliolitoids (Early Ashgill, Dolbor Time). Then the corals were widely spread and reefing was maximal for the Ordovician of SB. On the fourth stage (Late Ashgill, Bur Time) the taxonomical composition of corals qualitatively changed due to the extinction of some groups, sharp decrease of the other groups, and first appearance of tabulatoids from the order Favositida, typical for the following Silurian and Devonian periods. The area of corals in the Bur Time remained almost the same as in the Dolbor Time.

Three biotic stages may be distinguished in the development of the corals of MB, which do not coincide in time with the stages of SB but are similar in the trend of the diversity changes (Figs. 1, 4). First stage is characterized by the first appearance of scanty tabulatoids and rugoses (Late Caradoc, end of the Bairim Time) and beginning of the intensive colonization of the western, central, and southern parts of MB (Lower Ashgill, Bayankhongor Time). Second stage in MB corresponds to the maximum of corals biodiversity (Middle Ashgill, Sairin Time). Simultaneously the diversity corals sharply, almost catastrophically decreased in SB. On the third stage (Late Ashgill, Naringol Time), the taxonomical diversity decreased in MB but the area remained almost the same as in the preceding maximum. It is noteworthy that tabulatoid order Favositida with common species *Palaeofavosites argutus* and rugose common species *Palaeophyllum* first appeared in the Late Ashgill in MB and SB.

The connection of the biotic coral stages with abiotic factors is especially evident with taken into account of sequences and transgressive-regressive cycles, their rates and duration (Dronov, 2008).

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