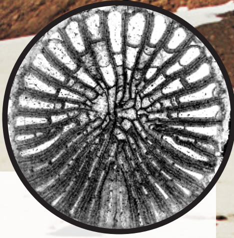
Edward Chwieduk

Palaeogeographical and palaeoecological significance of the Uppermost Carboniferous and Permian rugose corals of Spitsbergen



WYDAWNICTWO NAUKOWE UAM

Palaeogeographical and palaeoecological significance of the Uppermost Carboniferous and Permian rugose corals of Spitsbergen

UNIWERSYTET IM. ADAMA MICKIEWICZA W POZNANIU
SERIA GEOLOGIA NR 23

EDWARD CHWIEDUK

Palaeogeographical and palaeoecological significance of the Uppermost Carboniferous and Permian rugose corals of Spitsbergen

WYDAWNICTWO NAUKOWE

POZNAŃ 2013

Abstract. Chwieduk Edward, *Palaeogeographical and palaeoecological significance of the Uppermost Carboniferous and Permian rugose corals of Spitsbergen* [Paleograficzne i paleoekologiczne znaczenie permo-karbońskich koralowców Rugosa spitsbergenu]. Poznań 2013. Adam Mickiewicz University Press. Seria Geologia nr 23. Pp. 270. ISBN 978-83-232-2556-0. ISSN 0239-7560. Tekst in English with a summary in Polish.

The Carboniferous and Permian rugose corals of the Cordilleran-Arctic-Uralian (C-A-U) Realm, belong to the best known group of animals of those periods. Spitsbergen, situated at that time on the northern margin of the drifting supercontinent Pangea, stands out from the entire C-A-U Realm for its exceptionally large accumulation of their fossils. The climate obtaining in the Carboniferous and Early Permian was favourable to their development. At that time today's Svalbard Archipelago lay roughly just above the Tropic of Cancer and in those periods and later kept moving northwards until it had reached its present location between the 75th and 80th parallels in the northern subpolar zone. The corals described in this monograph come from three areas: the Hornsund region, a Polakkfjellet hill, and the Grønfjorden region. They belong to both, known and new species. Thus, on the one hand, they attest to the affinity of the Spitsbergen rugosans with the rest of the C-A-U Realm, corroborating their connection with the faunas of Alaska, the Urals, the Central European Basin, and Arctic Canada (Sverdrup Basin). On the other hand, however, they can be indicative of limited communication possibilities, or perhaps of the presence on Spitsbergen environmental conditions determining such a taxonomic composition.

Edward Chwieduk, Institute of Geology, Adam Mickiewicz University, ul. Maków Polnych 16, 61-606 Poznań, Poland; chwieduk@amu.edu.pl

Reviewer/Recenzent: prof. dr hab. Ewa Roniewicz

Publikacja dofinansowana przez
Rektora Uniwersytetu im. Adama Mickiewicza w Poznaniu
oraz Wydział Nauk Geograficznych i Geologicznych UAM

Wydano na podstawie maszynopisu gwarantowanego

Cover design/Projekt okładki: Edward Chwieduk
Production editor/Redakcja techniczna: Dorota Borowiak
Typesetting and formatting/Łamanie komputerowe: Reginaldo Cammarano

ISBN 978-83-232-2556-0
ISSN 0239-7560

WYDAWNICTWO NAUKOWE UNIWERSYTETU IM. ADAMA MICKIEWICZA W POZNANIU
61-701 POZNAŃ, UL. FREDRY 10
www.press.amu.edu.pl
Sekretariat: tel. 61 829 46 46, faks 61 829 46 47, e-mail: wydnauk@amu.edu.pl
Dział sprzedaży: tel. 61 829 46 40, e-mail: press@amu.edu.pl

Wydanie I. Ark. wyd. 17. Ark. druk. 16,875

DRUK I OPRAWA: UNI-DRUK s.j., LUBOŃ, UL. PRZEMYSŁOWA 13

CONTENTS

INTRODUCTION

The Permian-Carboniferous rugose corals of the Cordilleran-Arctic-Uralian (C-A-U) Realm, *sensu* Fedorowski (1986), belong to the best known group of animals of those periods, and Spitsbergen stands out from the entire C-A-U Realm for its exceptionally large accumulation of their fossils. The climate obtaining in the Carboniferous and Early Permian was favourable to their development, as well as that of brachiopods, echinoderms, bryozoans and sponges that co-occurred with them. At that time today's Svalbard Archipelago lay roughly just above the Tropic of Cancer (Golonka and Ford 2000, Scotese 2000) and in those periods and later kept moving northwards (Beauchamp 1994, Reid et al. 2007) until it had reached its present location between the 75th and 80th parallels in the northern subpolar zone. As a result, Svalbard, situated at that time on the northern margin of the drifting supercontinent Pangea, experienced a change in climatic conditions from tropical and humid in the Early Carboniferous to temperate in the Late Permian (Beauchamp 1994, Beauchamp and Desrochers 1997, Beauchamp and Baud 2003, Stemmerik 1997, 2000). Rocks of the Lower Permian are still similar to those from the upper Carboniferous (Wordiekammen and Treskelodden Formations, Kasimovian to Sakmarian in age) because in both cases they developed in a similar environment of shallow water, locally passing into dry land. By the end of the Early Permian, intensive evaporation had led to the formation of gypsums, anhydrites and dolomites (Gipshuken Formation; Sakmarian/Artinskian). In the Middle (Fig. 1) and Late Permian, Pangea's northern shelves reached the sub-Arctic, and perhaps also Arctic regions (Beauchamp 1994, Reid et al. 2007). The dominant types of rock of those series are siliceous limestones containing numerous sponge spicules and shells, mostly of brachiopods, as well as sandstones and limestones restricted to isolated highs (Stemmerik and Worsley 2005).

Rocks formed in the Permian-Carboniferous are exposed on all the major islands of the Svalbard Archipelago. They have been most extensively examined on Spitsbergen Island, north and east of Isfjorden. They can mostly be

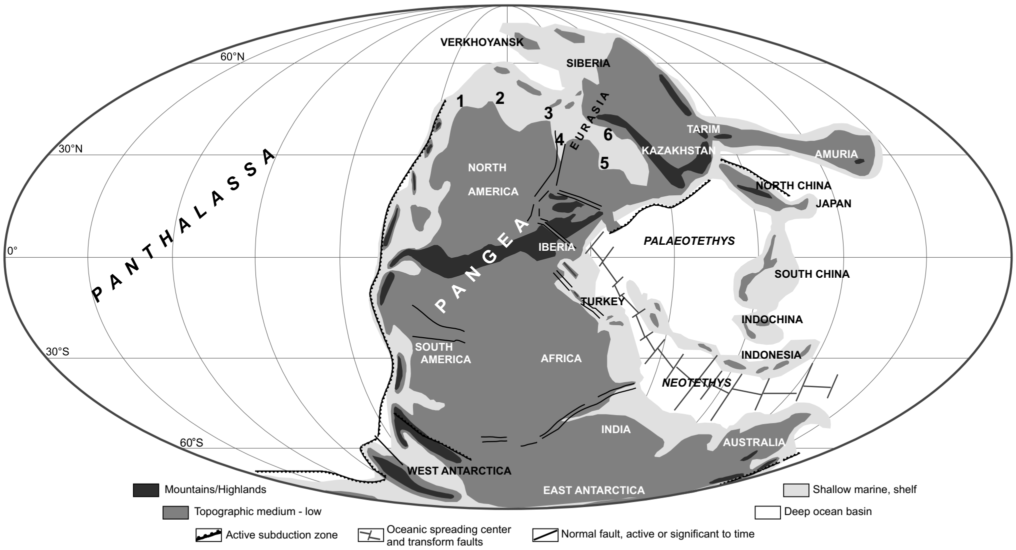


Fig. 1. Wordian-Capitanian palaeogeographical map (after Golonka and Ford 2000, Fedorowski and Bamber 2001) showing coral localities in the Cordilleran-Arctic-Uralian Realm: 1 – Alaska, 2 – Sverdrup Basin, 3 – Svalbard Archipelago, 4 – East Greenland, 5 – Central European Basin, 6 – Urals and Timan.

found in the north of Spitsbergen, while in the south and centre they only extend in a relatively narrow belt along the western coast. Towards the east, they sink so that in the central Spitsbergen basin they disappear under the Meso-Cenozoic cover and emerge only on the islands of Edgeoya, Barentsoya and Nordaustlandet (Fig. 2B). The exposures of Permian rocks observed today are mostly connected with Palaeogene tectonic movements (Birkenmajer 1972, Steel and Worsley 1984, Stemmerik and Worsley 1995).

The corals described in this monograph come from eight exposures located in three areas of the mentioned narrow belt of outcropping Permian-Carboniferous rocks (Fig. 2C-E): the Hornsund region (Treskelen, Kruseryggen), a Polakkfjellet hill, and the Grønfjorden region (exposures in Linnédalen and Blendadalen, and on Kapp Starostin). Those corals make up a substantial proportion of the faunas found in the Treskelodden, Wordiekammen and Kapp Starostin Formations (Fig. 3). They belong to both, known and new species. Thus, on the one hand, they attest to the affinity of the Spitsbergen rugosans with the rest of the C-A-U Realm (Fig. 1), corroborating their connection with the faunas of Alaska, the Urals, the Central European Basin, and Arctic Canada (Sverdrup Basin). On the other hand, however, they can be indicative of limited communication possibilities, or perhaps of the presence on Spitsbergen the environmental conditions determining such a taxonomic composition.

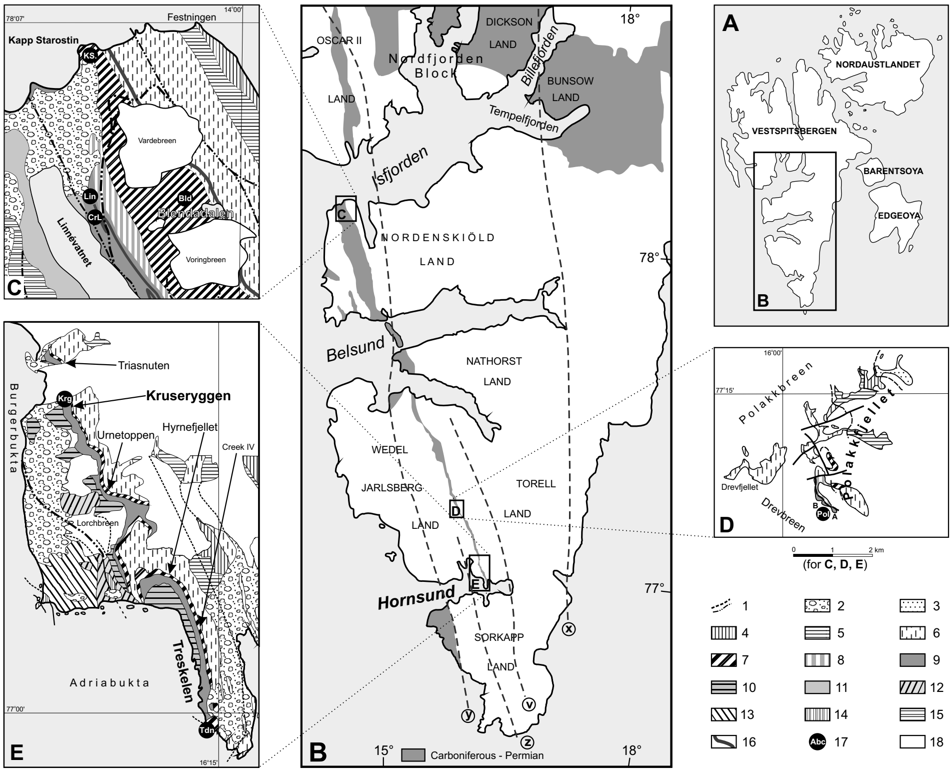


Fig. 2. A – Map of Spitsbergen. B – Sketch map of part of Spitsbergen showing outcrops of Carboniferous and Permian rocks after Harland (1997). C-E – Geological maps with marked collecting sites of the Linnédalen region (C), Polakkfjellet Mt. (D) and Inner Hornsund area (E), after (respectively) Dallmann et al. (1992), Ohta and Dallmann (1999), Birkenmajer (1990). 1 – faults, 2 – Quaternary cover, 3 – Palaeogene, 4-6 – Mesozoic rocks (respectively: Cretaceous, Jurassic, Triassic), 7 – Permian, Kapp Starostin Fm., 8 – Permian, Gipshuken Fm., 9 – Carboniferous/ Permian, Treskelodden Fm./Wordiekammen Fm., 10 – Carboniferous, Hyrnefjellet Fm., 11 – Carboniferous, Orustdalen Fm., 12 – Carboniferous, Adriabukta, 13 – Devonian, Marietoppen Fm., 14 – Proterozoic, Gashamna Fm., 16 – Middle Proterozoic?, Areno-argillaceous phyllite, 16 – dolerite, 17 – collecting sites, 18 – glaciers (Figs 2C-E), x – Billefjorden Fault Zone, y – Kongresbreen-Hansbreen Fault, z – Adriabukta Fault, v – Inner Hornsund Fault.

Of the three sites under study, the southernmost one is the Treskelodden exposure with the youngest Palaeozoic rocks containing Middle Permian (Wordian or Capitanian) solitary corals. Coming from the Kapp Starostin Formation, they are also the youngest rugosans found on Treskelen, closing the Lower Permian succession in this area (Chwieduk 2007).

The oldest solitary and colonial corals of the area in question come from Polakkfjellet. They have not been reported from this region of Spitsbergen earlier. On the basis of fusulinids, the age of rocks from the lower part of the exposure was determined as Gzhelian (Lin Rui 2004, unpublished data; Błażejowski et al. 2006) – the lower part of the Treskelodden Formation.

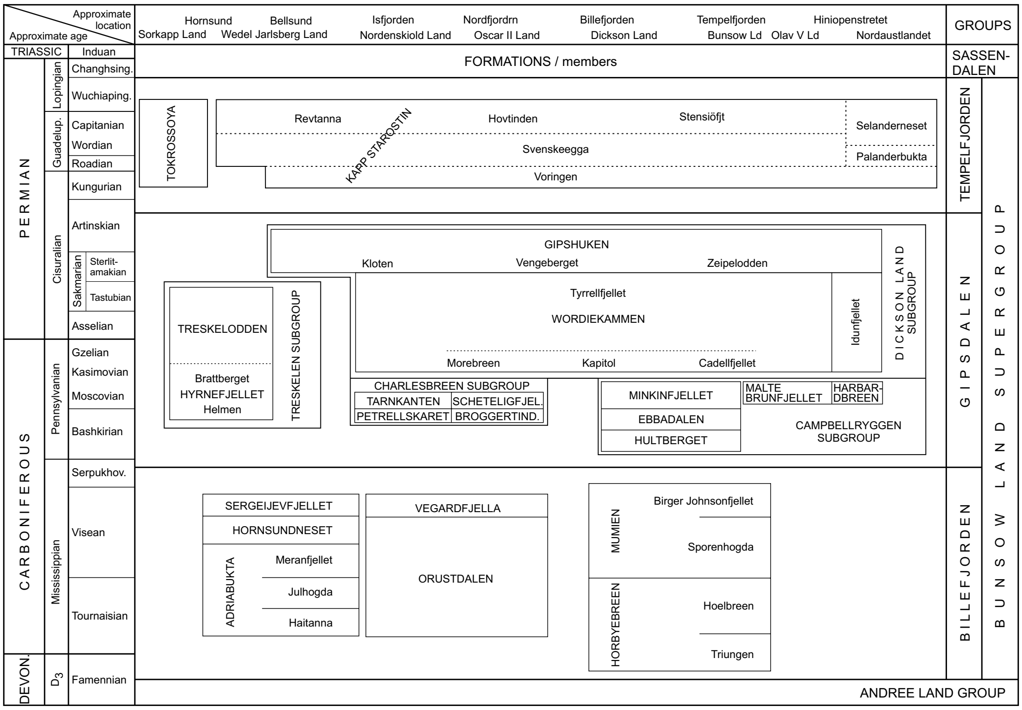


Fig. 3. Lithostratigraphic diagram of Carboniferous and Permian formations of the Bünsow Land Supergroup, simplified and slightly modified from Harland 1997.

Solitary and colonial forms of Rugosa were also found on Kruseryggen. This hill, built mainly of rocks of the upper Treskelodden Formation, corresponds to the Lower Sakmarian (Fedorowski 1982*a*, Fedorowski et al. 2007). The coral associations collected here turned out to be highly significant for ecological and tectonic issues in the Inner Hornsund area.

The rugosans of the western part of Nordenskiöld Land (the Linnédalen area, west of Grønfjorden) are of similar age as the Kruseryggen ones. Like the Polakkfjellet corals, they are presented in this work for the first time. The rich Rugosa collection obtained from this site comes from two formations: the Permian-Carboniferous one – Wordiekammen, dominated by solitary forms, and the Middle Permian one – Kapp Starostin, represented exclusively by solitary forms.

1 MATERIAL AND METHODS

The research material presented in this monograph is one I collected during three expeditions to Spitsbergen that I made in the summer seasons of 2003-2005. The first two were funded by the Committee for Scientific Research under project no. 0421/P04/2003/24; the third was organised under a project entitled "Structure, evolution and dynamics of the lithosphere, cryosphere and biosphere in the European sector of the Arctic and in Antarctica". My part in this last expedition was co-financed by the Rector of Adam Mickiewicz University. The collection of corals I accumulated during those expeditions is now kept in the Institute of Geology in Poznań. It embraces some 1,200 rock samples with Rugosa corals. Regrettably, the state of preservation of the fossils differs widely. Most coral skeletons are more or less recrystallized (dolomitised or silicified), in a lot of cases to an extent making it impossible even to establish their generic status. Hence, for detailed analysis a selection was made of 429 specimens (Table 1A, B) whose diagenetic transformation did not hinder their taxonomic identification. This fact, however, determined the way microscopic preparations were made. It was practically impossible to use easily made peels; they had to be replaced with thin sections, nearly 1,600 of which were prepared for the purposes of this monograph. Owing to various mechanical and chemical types of damage to the internal structure of coral skeletons (abrasion, solution, recrystallization, indentation and crushing) revealed only after the microscopic preparations had been made, a total of 1,371 thin sections from transverse sections and 85 from longitudinal sections were used for taxonomic determinations.

It was possible to prepare a small number of peels from best-preserved corals, mostly obtained from rocks of the Permian-Carboniferous Treskelodden Formation on Kruseryggen and Polakkfjellet. Only a few corals from those areas had been slightly dolomitised, or sporadically silicified. Rather, they tended to suffer abrasion, solution and/or crushing resulting mainly from the pressure of the overlying rocks. Usually those taphonomic processes did

Table 1A. Distribution and frequency of the Late Carboniferous and Permian solitary rugose corals studied in Spitsbergen; n. – number of specimens, * - percentage of solitary corals, ** - percentage of total number of corals, (x) – after Chwieduk 2009*a*.

	Taxa	number of specimens and percentage value			Kruseryg.			Polakkfjellet									Linnedalen																
					Krg.												Lin.			CrL					KS					Bld			
		n.	%*	%**	III	IV	V	II	VI	B I	B II	B III	B IV	B V	B VI	B VII	I	II	III	I/4	I/5	I/6	I/7	I/8	IA	IB	IC	II	III	I	II	II/v	III
	***Arctophyllum* (CYATHOPSIDAE)**	**34**	**10,0**	**7,9**																													
1	*Arctophyllum intermedium*	21	6,2	4,9						8			13																				
2	*Arctophyllum spitsbergensis* sp.nov.	13	3,8	3,0						5	1		6								1												
	Alekseeviella	**1**	**0,3**	**0,2**																													
3	*"Alekseeviella" sp. A*	1	0,3	0,2						1																							
	Caninia	**6**	**1,8**	**1,4**																													
4	*"Caninia" nikitini*	6	1,8	1,4									4		1						1												
	***Bothrophyllum* (BOTHROPHYLLIDAE)**	**8**	**2,4**	**1,9**																													
5	*Bothrophyllum baeri*	1	0,3	0,2		(x)	(x)										1																
6	*Bothrophyllum permicum*	1	0,3	0,2													1																
7	*Bothrophyllum cf. okense*	3	0,9	0,7					1												2												
8	*Bothrophyllum cf. pseudoconicum*	3	0,9	0,7							2											1											
	Gen. nov.	**1**	**0,3**	**0,2**																													
9	Gen. et sp. nov.	1	0,3	0,2													1																
	Caninophyllum	**3**	**0,9**	**0,7**																													
10	*Caninophyllum belcheri*	2	0,6	0,5											2																		
11	*C.b. var. magnum*	1	0,3	0,2			(x)								1																		
	Gshelia	**10**	**2,9**	**2,3**																													
12	*Gshelia rouilleri*	10	2,9	2,3						1	2				1		4	1	1														
	Hornsundia	**5**	**1,5**	**1,2**																													
13	*Hornsundia lateseptata*	5	1,5	1,2	(x)		(x)											4				1											
	Pseudotimania	**100**	**29,5**	**23,3**																													
14	*Pseudotimania arctica* sp. nov.	17	5,0	4,0									1				7	6		1		2											
15	*Pseudotimania borealis* sp. nov.	19	5,6	4,4	4		3								3		6						3										
16	*Pseudotimania longiseptata* sp. nov.	64	18,9	14,9	3		2							1	9		25	13	2		6	3											
	Siedleckia	**28**	**8,3**	**6,5**																													
17	*Siedleckia bjornoyana*	1	0,3	0,2											1																		
18	*Siedleckia longiseptata*	4	1,2	0,9						1											3												
19	*Siedleckia mutafii*	15	4,4	3,5						1	3		3		4					2	1		1										
20	*Siedleckia sp. A*	2	0,6	0,5									1		1																		

21	*Siedleckia sp. B*	6	1,8	1,4						1					2		2				1												
	Svalbardphyllum	**8**	**2,4**	**1,9**																													
22	*Svalbardphyllum pachyseptatum*	8	2,4	1,9	5				1						2																		
	***Krusenella* gen. nov. (ANTIPHYLLIDAE)**	**14**	**4,1**	**3,3**																													
23	*Krusenella pachyseptata* gen. et sp. nov.	14	4,1	3,3			12										2																
	Lytvolasma	**5**	**1,5**	**1,2**																													
24	*Lytvolasma asymetrica*	5	1,5	1,2													5																
	***Allotropiochisma* (HAPSIPHYLLIDAE)**	**4**	**1,2**	**0,9**																													
25	*Allotropiochisma exzentrica*	4	1,2	0,9																					1	1				1		1	
	Euryphyllum	**8**	**2,4**	**1,9**																													
26	*Euryphyllum troldfjordense*	7	2,1	1,6																					2	1	1	2	1				
27	*Euryphyllum sp. A*	1	0,3	0,2																											1		
	***Amygdalophylloides* (GEYEROPHYLLIDAE)**	**1**	**0,3**	**0,2**																													
28	*Amygdalophylloides ivanovi*	1	0,3	0,2											1																		
	***Yakovleviella* (AULOPHYLLIDAE)**	**37**	**10,9**	**8,6**																													
34	*Yakovleviella tschernyschewi*	9	2,7	2,1													5	2	1		1												
35	*Yakovleviella spitsbergensis* sp. nov.	28	8,3	6,5													8	12	2	2	2		2										
	***Gronfjordphyllum* gen. nov.**	**18**	**5,3**	**4,2**																													
31	*Gronfjordphyllum minor* gen. et sp. nov.	7	2,1	1,6													4	3															
32	*Gronfjordphyllum parvum* gen. et sp. nov.	11	3,2	2,6													5	6															
	***Barentsburgia* gen. nov.**	**6**	**1,8**	**1,4**																													
33	*Barentsburgia crinisphyllia* gen. et sp. nov.	6	1,8	1,4													6																
	***Linnephyllum* gen. nov. (*INCERTAE SEDIS*)**	**4**	**1,2**	**0,9**																													
29	*Linnephyllum spitsbergensis* gen. et sp. nov.	2	0,6	0,5													2																
30	*Linnephyllum longiseptatum* gen. et sp. nov.	2	0,6	0,5													2																
	***Calophyllum* (POLYCOELIDAE)**	**7**	**2,1**	**1,6**																													
36	*Calophyllum columnare*	7	2,1	1,6																					3	2						1	1
	Sochkineophyllum	**4**	**1,2**	**0,9**																													
37	*Sochkineophyllum turgidiseptatum*	4	1,2	0,9																										1	2	1	
	***Fedorowskites* gen. nov.**	**26**	**7,7**	**6,1**																													
38	*Fedorowskites spitsbergensis* sp. nov.	26	7,7	6,1																					2		1	3	1		14	5	
	Gen. indet.	**1**	**0,3**	**0,2**																													
39	Gen. and sp. indet.	1	0,3	0,2	1																												
	TOTAL	**339**	**100**	**79,0**	13		17		2	18	8		28	1	28		86	47	6	5	18	7	6		8	4	2	5	2	2	17	8	1
					30			85									175								49								

Table 1B. Distribution and frequency of the Late Carboniferous and Permian colonial rugose corals studied in Spitsbergen; n. – number of specimens, * - percentage of colonial corals, ** - percentage of total number of corals.

	Taxa	number of specimens and percentage value			Kruseryg.			Polakkfjellet									Linnedalen																
					Krg.												Lin.			CrL					KS					Bld			
		n.	%*	%**	III	IV	V	II	VI	B I	B II	B III	B IV	B V	B VI	B VII	I	II	III	I/4	I/5	I/6	I/7	I/8	IA	IB	IC	II	III	I	II	II/v	III
	***Pararachnastraea* (DURCHAMINIDAE)**	**2**	**2,2**	**0,5**																													
1	*Pararachnastraea gracilis*	2	2,2	0,5			2																										
	***Fomichevella* (KLEOPATRINIDAE)**	**7**	**7,8**	**1,6**																													
2	*Fomichevella hoeli*	4	4,4	0,9				4																									
3	*Fomichevella borealis* sp. nov.	3	3,3	0,7												3																	
	Heintzella	**25**	**27,8**	**5,8**																													
4	*Heintzella borealis*	12	13,3	2,8													10	1	1														
5	*Heintzella breviseptata* sp. nov.	2	2,2	0,5													1	1															
6	*Heintzella poljarica* sp. nov.	2	2,2	0,5												2																	
7	*Heintzella* cf. *davydovi*	4	4,4	0,9								3					1																
8	*Heintzellqa sp. A*	5	5,6	1,2													3		1			1											
	Paraheritschioides?	**1**	**1,1**	**0,2**																													
9	*Paraheritschioides? californiense*	1	1,1	0,2		1																											
	Kleopatrina	**22**	**24,4**	**5,1**																													
10	*Kleopatrina arcturusensis*	1	1,1	0,2																			1										
11	*Kleopatrina ftatateeta*	13	14,4	3,0			3															1	3	6									
12	*Kleopatrina grinnellensis*	1	1,1	0,2																		1											
13	*Kleopatrina uralensis*	4	4,4	0,9		2	1										1																
14	*Kleopatrina rozkowskae*	3	3,3	0,7													3																
	Protowentzelella	**14**	**15,6**	**3,3**																													
15	*Protowentzelella columellata*	2	2,2	0,5			2																										
16	*Protowentzelella hyporiphaea*	2	2,2	0,5			2																										
17	*Protowentzelella kunthi*	5	5,6	1,2			1															2	1	1									
18	*Protowentzelella longiseptata*	1	1,1	0,2																				1									
19	*Protowentzelella variabilis*	4	4,4	0,9		1	3																										
	***Tschussovskenia* (LITHOSTROTIONIDAE)**	**19**	**21,1**	**4,4**																													
20	*Tschussovskenia captiosa*	11	12,2	2,6		9	2																										
21	*Tschussovskenia dilata*	2	2,2	0,5															2														
22	?*Tschussovskenia columellata* sp. nov.	3	3,3	0,7			3																										
23	*Tschussovskenia borealis* sp. nov.	3	3,3	0,7					3																								
	TOTAL	**90**	**100**	**21,0**		13	19	4	3			3				5	19	2	4			5	5	8									
					32			15									43																

not change the morphological structure of corals in a significant way to affect their taxonomy. In sum, out of the 150 Polakkfjellet specimens and nearly 100 Kruseryggen ones, 100 and 62 specimens were chosen, respectively, for a detailed palaeontological analysis (Table 1A, B), of which about 180 peels were made. Still, here too thin sections were necessary in many cases; 425 of them were made from transverse sections and 56 from longitudinal ones.

The corals most heavily transformed diagenetically are definitely those from the Middle Permian Kapp Starostin Formation. In many cases they display highly advanced recrystallization and mineralization (mostly silicified, to a lesser extent dolomitised), often leading to a complete disappearance of diagnostic features, very poorly visible in thin sections in a transmission microscope. That is why out of the nearly 200 specimens collected from this formation, only 49 could be used for taxonomic purposes (Table 1A). 153 thin sections were made from transverse sections of those corallites, and one from a longitudinal section.

From the Wordiekammen Formation in the Linnédalen area, 218 specimens were selected for taxonomic studies (Table 1A, B), with 793 thin sections made from transverse sections and 28 from longitudinal ones. To illustrate some transverse sections of those corallites, drawings were made, or photos taken in reflected light, because it was observed that details of the morphological structure of silicified specimens were more readily visible in photos of polished surfaces taken in the light reflected at a low angle from the surface photographed than in transmitted light.

2 GEOLOGICAL SETTING

The oldest geological studies of Svalbard were connected with mining carried out there in the early 1900s. They were summed up by Hoel (1925) and Horn (1928). Those unrelated with mining, both of its Precambrian crystalline basement (Holtedahl 1913) and its mostly post-Caledonian rock sequences (Nathorst 1910; Hoel and Orvin 1937; Frebold 1928, 1937, 1939; Frebold and Stoll 1937), were summarised by Orvin in 1940. This enduring interest in the geology of the archipelago has persisted until today. Of the many works that appeared in the 1990s (e.g. Nakrem et al. 1992, Hjelle 1993, Harland 1997, Dallmann 1999), the one worthy of special attention is a comprehensive presentation of its geology by Harland (1997). He divided the stratigraphic succession of Svalbard rocks into two Groups of sequences separated by a distinct unconformity. In the first he included the pre-Carboniferous succession, in the second, younger rocks up to and including the Quaternary, which he called a cover complex.

Harland (1997) accounts for the complicated tectonic structure of rocks older than Carboniferous by multi-stage folding and metamorphism that ended in the Silurian (Caledonian orogenesis), and for the mosaic nature of the facies of those systems, by their belonging to different micro-plates: the Eastern, Central and Western Svalbard Terranes. The boundaries of those terranes are usually pre-Carboniferous faults running NNW-SSE. In his opinion, the pre-Caledonian history of Svalbard greatly affected the deposition, erosion and deformation of sediments of the second rock cycle. As he states in his monograph, the rocks overlying the unconformity separating the two cycles form sequences of basins and platforms. On Spitsbergen, he called them the East Svalbard Platform and the Spitsbergen and Bjørnøya (Bear Island) Basins, with the term 'basin' applied in the structural sense possible to interpret as a brachysyncline. In lithological terms, the post-Caledonian sedimentary cover is generally built of Lower Carboniferous sandstones, Middle Carboniferous conglomerates, Upper Carboniferous and Permian carbonaceous rocks with a minor share of evaporites, as well as of Mesozoic, Palaeogene and Neogene sandstones and shales. The deposition of Lower and Middle Carboniferous sediments was limited to tectonic trenches and depressions, while Upper Carboniferous, Permian and Mesozoic deposits cover a greater part of Svalbard (Harland 1997). Rocks of the Upper Permian and Mesozoic have been found to occur mostly on the southern coast of Isfjorden, from Kapp Starostin to Festningen (Dallmann et al. 1992, Dallmann 1999, Ezaki 1997, Harland 1997), while Palaeogene and Neogene rocks, it seems, were not deposited in a wider area than found at present (Harland 1997). With Early Palaeogene tectonic movements on the western Barents Shelf, the deposits of the Carboniferous to Neogene Systems became part of the great syncline-shaped structure extending from the Isfjorden area towards the south of the island (Hjelle 1993).

The best known in geological and palaeontological terms is the Spitsbergen Basin. Cut by a number of faults running N-S and NNW-SSE, some of them active in the Carboniferous and Permian, it was divided by Harland (1997: fig. 17.4) into smaller basin areas: Eastern, Central and Western. In the Late Carboniferous, there appeared elevated zones ('highs') and troughs within the basins. Predominant in the troughs are Lower Carboniferous deposits, often of substantial thickness (the Billefjorden Trough contains sequences of Carboniferous rocks that are about 1,500 m thick), while the blocks, e.g. Ny Friesland or Nordfjorden, were source areas of the sedimentary material. In the Tournaisian and Viséan the latter were still partly negative landforms; in the Serpukhovian, however, the situation was reversed and during the Bashkirian and Moscovian the blocks became positive landforms separating the Eastern Basin from the Western one (Harland 1997). In the Late Permian, the Nordfjorden Block dropped a bit in relation to the basins (Harland 1997). The Western Basin, which contrasts with this block in terms of facies, has folded and faulted rocks overlying a mostly pre-Devonian basement (Harland 1997).

In the topography of the southern part of Spitsbergen, in turn, in the Carboniferous there appeared the Inner Hornsund Trough and the Sørkapp-Hornsund High. The depression was probably part of the Bjørnøya Basin situated farther south, from the Famennian to Bashkirian forming the south-western part of a tectonic rift or trench that extended NNW-SSE (Harland 1997). The Sørkapp-Hornsund High, in turn, formed in the Bashkirian on the western coast of the Inner Hornsund Trough (Harland 1997).

2.1. Carboniferous and Permian lithostratigraphy of the study area

The Rugosa corals I collected come from the Western Basin and the Inner Hornsund Trough. The Permian-Carboniferous succession in those areas makes up four Groups. Starting with the oldest, those are: the Billefjorden Group, built mostly of continental sandstones and shales with coal; the Gipsdalen Group, dominated by marine carbonates and evaporites; and the Tempelfjorden and Sassendalen Groups containing mostly marine shales. Those formal lithostratigraphic units are members of two Supergroups: Bünsow Land and Nordenskiöld Land (Fig. 3).

The Bünsow Land Supergroup is a readily distinguishable unit in the entire Svalbard Archipelago since it is delimited by unconformities: in the Upper Devonian (Lower Famennian) and the Upper Permian (Wuchiapingian). Those unconformities are emphasised by stratigraphic gaps connected with local uplifting movements and with marine regression (Harland 1997).

2.1.1. *Billefjorden Group*

This Group mostly embraces rocks belonging to the Tournaisian and Viséan (Nathorst 1920, Harland 1997). The facies that occur there reflect the variable conditions of sedimentation in a continental environment at the boundary of land and sea, with marshes and small, isolated, periodically inundated areas. They are dominated by clastic rocks, rich in plant fossils and beds of hard coal indicative of the humid climate of that epoch (Forbes et al. 1958, Birkenmajer and Turnau 1962, Playford 1962, 1963, Birkenmajer 1964). In the current nomenclature, this Group in its typical area of occurrence (the Billefjorden region) is made up of two Formations: Mumien and Horbyebreen. In turn, in the area I examined (from Hornsund to Isfjorden) it embraces the Formations: Adriabukta – terrestrial and fresh-water, grey conglomerates and sandstones with cross-stratification, towards the top passing into black shales containing sporomorphs of the Upper Tournaisian and Viséan (Birkenmajer and Turnau 1962, Birkenmajer 1964); Hornsundneset – sandy deposits of alluvial fans and floodplains; Sergeijevfiellet – sandstones, mudstones and shales with hard coal in the top; Orustdalen – sandstones and coarse-grained rocks which, like those of the Adriabukta Formation, lie unconformably on a folded Caledonian basement; and Vegard – reddish, thin-bedded quartzitic sandstones and shales.

2.1.2. *Gipsdalen Group*

The typical area of occurrence of this unit extends around Billefjorden, in Bünsow Land and Dickson Land, and in central Spitsbergen (Cutbill and Challinor 1965). It contains four Subgroups: Campbellryggen, Charlesbreen, Dickson Land, and Treskelen (Fig. 3). The Gipsdalen Group is separated from the overlying Tempelfjorden Group by a stratigraphic gap spanning the Upper Artinskian and Lower Kungurian (Harland 1997).

The deposition of sediments belonging to the Subgroups: Campbellryggen, Charlesbreen and the lower part of Treskelen, occurred from the Bashkirian to the Kasimovian under a very dry climate, on land and on the margin of a sea basin, probably as a result of an accumulation of river sediments in the form of deltas on which sebkhas and lagoons had developed. The facies are highly diversified, with fairly widespread lateral lithological variability. Deposits characteristic of those Subgroup are red clastics: conglomerates, sandstones and shales, towards the top passing into marine coastal facies with carbonates (dolomite, sandy and marly limestones as well as breccias of calcareous rocks and oolites), gypsum-anhydrite facies and evaporites, as well as black shales co-occurring with sandstones (Harland 1997). At places, e.g. in the Billefjorden region (the Hultberget Formation), they also feature thin layers of siderites which probably come from limonite muds. In turn, the Ebbadalen Formation (one of the better known lithostratigraphic units in the entire Svalbard), stands out for its numerous alluvial cones.

Among the commonest fossils found in the Campbellryggen and Charlesbreen Subgroups are crinoids, corals, brachiopods, and fusulinids. This fauna occurs mostly in limestones built of biomicrite or biosparite, in dolomite limestones, and in shales (Gobbett 1963, Harland 1997).

Predominant in the rocks belonging to the upper part of the Treskelen Subgroup (the Treskelodden Formation) and the lower and central parts of the Dickson Land Subgroup (the Wordiekammen Formation) are relatively uniform, widespread carbonaceous facies passing into evaporites, with a secondary occurrence of sandstones and sulphates. The deposition of those formations probably took place in a warm, shallow sea occupying this region from the Kasimovian to the Sakmarian (Harland 1997). From the palaeontological point of view, they belong to the most interesting ones in the entire Gipsdalen Group (see below).

The Gipshuken Formation, which crowns the Dickson Land Subgroup and mostly occurs in central and western Spitsbergen, is largely built of carbonates, evaporites (which form rhythmical sequences of limestone/dolomite and gypsum/anhydrite) and a small amount of sandstones (Cutbill and Challinor 1965). In the opinion of Harland (1997) as well as Samuelsberg and Pickard (1999), it is a record of a regressive cycle and intertidal sedimentation taking place in a warm, shallow sea with a limited circulation. The few fossils of foraminifers and brachiopods found in this unit (Forbes et al. 1958, Gobbett 1963, Burov et al. 1965, Sosipatrova 1967) indicate their age to be the Upper Sakmarian – Lower Artinskian (Harland 1997).

Wordiekammen Formation (Fig. 3). The first to use the term 'Wordiekammen' were Gee et al. (1953). The Wordiekammen Limestones they distinguished were assigned in 1965 by Cutbill and Challinor to the Nordenskiöldbreen Formation, in which they also included the Passage Beds underlying the Wordiekammen Limestones. After the Permian-Carboniferous units had been redefined by Dallmann et al. (1996 – Proposal by the Committee on the Stratigraphy of Svalbard, *fide* Harland 1997), the name Wordiekammen was restored to the upper part of the Nordenskiöldbreen Formation, which was given the rank of a formation by itself.

The Wordiekammen Formation together with the Gipshuken Formation form the Dicksonland Subgroup, a characteristic feature of which is a relative uniformity of facies development on Spitsbergen. In the area of the best documented occurrence of the Wordiekammen Formation (Dickson and Bünsow Lands), its thickness attains up to 350 m. It is mostly built of marine carbonates, limestones and dolomites (Dallmann 1999), often with intercalations containing large concentrations of kerogen and pyrite with pseudomorphs after weathered minerals (Skaug et al. 1982).

In the lower part of the formation, three coeval Members can be distinguished: Cadellfjellet, occurring in the central and north-eastern parts of Spitsbergen, Kapitol, known from the Nordfjorden and Billefjorden areas, and Morebreen, documented in Nordenskiöld Land. They are largely composed of limestones, usually of the micrite type, deposited under stable shelf conditions and at normal salinity; a small proportion of this rock sequence goes to dolomites, sandy limestones and calcareous sandstones (Cutbill and Challinor 1965, Harland 1997). In the base of the upper part of this formation (the Lower Tyrrellfjellet Member, distinguished by Cutbill and Challinor 1965), there is a thin sandstone horizon with locally developed conglomerates, breccias and gypsums (Bates and Schwarzacher 1958). Surfaces of unconformity and small-scale shifts in the underlying layers are indicative of a slight uplift of this area at the Carboniferous /Permian boundary. After this event came a transgression and the restoration of shelf conditions (Harland 1997). The upper part of the Tyrrellfjellet Member is mostly composed of Lower Permian (Asselian/Sakmarian) organodetrital limestones, dolomitic limestones and arenites, with local intercalations of clastic rocks, gypsums and cherts. The last only rarely occur in bigger accumulations, and never in such quantities as in the Tempelfjorden Group. It is believed (Harland 1997) that sediments of the upper part of the Wordiekammen Formation were deposited in lagoon and open-sea basins with a rich organic world. Their typical stratigraphic section can be found in Tyrrellfjellet (the Billefjorden region) where the Tyrrellfjellet Member attains a thickness of 160 metres.

Found in abundance within the Wordiekammen Formation are brachiopods, molluscs, corals, trilobites, bryozoans, sponges, echinoderms, fusulinids and plant remains which, in the opinion of Skaug et al. (1982), come from algal bioherms. An important element of the fauna is foraminifers, the index fossil. While occurring sporadically, in the lower part of the Formation they indicate the Late Carboniferous, Kasimovian-Gzhelian, and possibly Moscovian (Cutbill 1968); those found in the upper part of the Formation point to the Asselian-Sakmarian (Cutbill and Challinor 1965, Ross 1965, Sosipatrova 1967). The Early Permian age of the upper part of the Wordiekammen Formation, apart fusulinids, is also corroborates by diversified macrofauna (Forbes et al. 1958, Forbes 1960, Gobbett 1963, Cutbill and Challinor 1965, Cutbill 1968, Somerville 1997). Treskelodden Formation (Fig. 3). It was defined by Cutbill and Challinor (1965), who formed this unit by renaming Treskelodden "beds" *sensu* Birkenmajer (1959, 1964). Its lower part, some 1/3 of the stratigraphic section, decidedly continental, is built of conglomerates, sandstones (usually compact and well sorted, often calcareous) and mudstones. In the upper part there is a systematic increase in the proportion of marine carbonaceous rocks. As a result, what we have here is an alternation of alluvial and shallow-sea rocks with secondary intercalations of limestones. The total thickness of the Treskelodden Formation varies across the area of its occurrence, i.e. from Sørkapp Land to Bellsund (Birkenmajer 1964, 1984*a*, Nysaether 1977, Fedorowski 1982*a*, Dallmann 1999, Chwieduk 2009*a*) from 115 m in Austjokultinden (Sørkapp Land), through about 100 m in the south of the Treskelen Peninsula, 129 m in creek IV (the central part of the Treskelen Peninsula), 150 m in Kruseryggen, and 185 m in Triasnuten (northern Burgerbukta), to 180 m in Polakkfjellet.

The Treskelodden Formation, especially its upper two-thirds, contains numerous Rugosa and Tabulata (Fedorowski 1965, 1967, 1982*a*; Birkenmajer and Fedorowski 1980; Nowiński 1982, 1991) as well as brachiopods (Birkenmajer and Czarniecki 1960, Czarniecki 1969, Birkenmajer and Logan 1969). Other animals found and described in this formation include foraminifers (Liszka 1964), trilobites (Osmólska 1968), bivalves and gastropods (Karczewski 1982), and sponges and bryozoans (Czarniecki 1964). Judging by the presence and state of preservation of a considerable part of the fauna, it must have been redeposited (Fedorowski 1965, 1967, 1982*a*; Birkenmajer and Fedorowski 1980). The lower part of the Treskelodden Formation does not contain other fossils except unidentifiable plant remains.

The first to deal with the stratigraphy of rocks assigned today to the Treskelodden Formation were Birkenmajer and Czarniecki (1960), and later Birkenmajer (1964). On the basis of brachiopods they determined the age of the lower part of this formation to be Upper Carboniferous. In 1969 Czarniecki reported that brachiopod associations belonged to the Gzhelian. Also trilobites indicated a similar age (Osmólska 1968). On examination of foraminifers (Liszka 1964) and corals from Treskelen (Fedorowski 1964, 1965, 1982*a*), the age of the upper part of this unit was established as Early Permian – Asselian/Sakmarian. On the basis of an analysis of the fauna of the C-A-U Realm (Fedorowski et al. 1999, Fedorowski and Bamber 2001, Fedorowski et al. 2007), this part of the formation was dated more precisely to the Early Sakmarian.

2.1.3. *Tempelfjorden Group*

The Tempelfjorden Group (Fig. 3) is a record of shallow-sea sedimentation taking place from the Late Artinskian to the Wuchiapingian. On Spitsbergen it is defined by two formations: Kapp Starostin (Cutbill and Challinor 1965) and Tokrossøya (Siedlecki 1964), overlying the Gipsdalen Group with a considerable stratigraphic gap (Cutbill and Challinor 1965, Harland 1997). North of Sørkapp Land (Figs 2B, 3), it is only represented by the Kapp Starostin Formation.

Kapp Starostin Formation, was defined by Cutbill and Challinor (1965) and is an exact equivalent of the Brachiopod Cherts of Gee et al. (1953). It is the main unit of the Tempelfjorden Group. It is exposed most completely in the central part of the island (the northern coast of Isfjorden down to Nordaustlandet and in the vicinity of Tempelfjorden). Along the western coast it runs in a narrow belt of outcrops extending to the Hornsund depression. It was also found in small exposures on Barents and Edge Islands (Harland 1997), so its range roughly coincides with the Permian-Carboniferous on Spitsbergen (Fig. 2). A typical stratigraphic section can be found in Nordenskiöld Land (Fig. 2C), on Kapp Starostin, where the formation attains 380 metres in thickness. Some 50 km north, in St. Jonsfjorden in Oscar II Land, its thickness increases to 460 m (Dallmann 1999). Towards the south the Formation gets thinner, slightly exceeding 4 m in the Hornsund region. The sequence of rocks show an onlap sequence (transgressive), and the lithological boundaries are diachronic until there appear open-sea facies with cherts. The boundaries, both lower and upper, are emphasised by distinct unconformities and stratigraphic gaps (Fig. 3).

The Kapp Starostin Formation shows a variety of lithofacies (Cutbill and Challinor 1965, Biernat and Birkenmajer 1981, Nakamura et al. 1987, Stemmerik 1988, Harland 1997, Dallmann 1999, Chwieduk 2007). It is mostly composed of massive, silicified, very hard, dark-grey or black weathering-resistant rocks, and is similar throughout the entire zone of its occurrence. Its characteristic is gradational silicification of limestones, shales and mudstones up to pure cherts, which make up about a half of the formation.

In the area from Hornsund to Isfjorden, within the Kapp Starostin Formation, three Members have been distinguished (Fig. 3). In its lower part lies the Vøringen Member (Cutbill and Challinor 1965), composed of sandy bioclastic limestones. The middle part is occupied by the Svenskeegga Member (Cutbill and Challinor 1965), which is a mosaic of facies: mudstones, cherts, silicified limestones, and glauconite limestones and sandstones. And in the upper part, there is the Hovtinden Member (Cutbill and Challinor 1965) with mudstones, cherts and glauconite sandstones (Harland 1997). In Sørkapp Land, the equivalent of the Kapp Starostin Formation is the Tokrossøya Formation (Fig. 3).

Rocks of the Kapp Starostin Formation contain numerous accumulations of animal remains, mostly spicules of sponges, silicified brachiopods, bryozoans, bivalves, corals, echinoderms, gastropods, and foraminifers. Unfortunately, most of the species have long stratigraphic ranges, which makes an exact correlation with the other regions of Pangea impossible. Still, in the lower part of this Formation the Kungurian stage was identified (Gee et al. 1953, Nysaether 1977, Ustritskiy 1979). On the basis of foraminifers with glauconite facies on Edge Island, its central part was dated to the Ufimian (Pchelina 1977), and the upper boundary of the Formation, on the basis of brachiopods (Gee et al. 1953) and a correlation with its stratigraphic equivalent in Greenland, was established as the Kazanian-Tatarian (Stemmerik 1988) – according to the new division, the Upper Wuchiapingian. Later dating made by conodonts (Szaniawski and Małkowski 1979) confirmed this age of the Formation. Its Kungurian age was also confirmed by many studies of brachiopods carried out in the 1980s (Biernat and Birkenmajer 1981, Nakamura et al. 1987, Stemmerik 1988).

2.2. Characteristics of the study areas

2.2.1. *Hornsund area*

This is an area in the northern part of the Sørkapp-Hornsund region, which is situated in the south of Spitsbergen (Fig. 2B). The large, well-studied tectonic units of the Sørkapp-Hornsund region include, from west to east: the Hornsund Fault Zone, Lidfjellet-Øyrlandsodden Fold Zone, Øyrlandet Graben, Sørkapp-Hornsund High and Inner Hornsund Fault (Fig. 2B), as well as the Palaeogene Fold-and-Thrust Belt (Dallmann 1992, Dallmann et al. 1993, Winsnes et al. 1993). The rock associations of those units present an almost complete rock succession from the Early Proterozoic up to and including the Quaternary (Birkenmajer 1984*b*, 1990, Dallmann 1992, Dallmann et al. 1993). The tectonic structures document both pre – and post-Caledonian foldings and overthrusts, dominated by

Palaeogene tectonism (Birkenmajer 1972, Lowell 1972, Kellogg 1975, Steel et al. 1985, Dallmann 1992, Dallmann et al. 1993, Bergh and Grogan 2003) during which heavily deformed older rocks were included into the Palaeogene fold chain. Dallmann (1992) and Bergh and Grogan (2003) are of the opinion that in the Sørkapp-Hornsund region one can find numerous clues as to the nature and relative age of those events, and that its multi-phase tectonic history can reflect the post-Caledonian tectonic history of the entire Svalbard Archipelago and the western margin of the Barents platform.

There were four events that had a great impact on the post-Caledonian/pre-Mesozoic history of the Sørkapp-Hornsund region. (1) The formation of a Devonian basin and its shallowing towards the end of the Devonian (Birkenmajer 1964, Dallmann 1992); (2) Early Carboniferous NNW-SSE-oriented folding and faulting, as well as a local transpression forming major basins and highs, including the Sørkapp-Hornsund High (Birkenmajer 1964, 1975, 1981; Gjelberg and Steel 1981; Steel and Worsley 1984; Dallmann 1992; Bergh and Grogan 2003), which divided this region into the Inner Hornsund Trough and the Basin of Western Sørkapp Land (Harland 1997). The presence of Lowermost Carboniferous strata in the central part of the Sørkapp-Hornsund High, covered by Triassic rocks lying unconformably on the lower Carboniferous and the pre-Cambrian basement, suggests that terrestrial conditions persisted in this area throughout most of the Carboniferous, the Permian, till the early Triassic (Bergh and Grogan 2003). (3) Synsedimentary faulting with a record of syntectonic sedimentation occurring along older tectonic fault zones – the so-called Adriabukta Phase (Fig. 2B) – correlated with Svalbard block movements dated to the Serpukhovian and Bashkirian (Birkenmajer 1964, 1975); in the Hornsund region, movements connected with this phase made the Upper Carboniferous and the Lower Permian differ in thickness (Fedorowski 1982*a*). (4) A sedimentary break and slight angular unconformity corresponding to the Saalic Phase uplift (Birkenmajer 1964) separates the Treskelodden Formation from the overlying Kapp Starostin Formation (Birkenmajer 1990).

In the Triassic sedimentation conditions stabilised, with the exception of local gaps caused by vertical movements. A continuous lithological transition between the Permian and the Triassic can be observed in the east of Sørkapp Land. In the Inner Hornsund Trough, the upper part of the Lower Triassic is separated from the Permian by a short gap in sedimentation. Jurassic and Cretaceous sedimentation, interrupted by vertical movements and marine regressions, left many hiatuses not only in the Hornsund region, but in the whole of Spitsbergen (Birkenmajer 1990). Younger deposits, lying unconformably on Aptian-Albian rocks, accumulated mostly in the eastern part of the Hornsund area and in smaller tectonic trenches. In the Palaeogene there occurred a contractional-transpressional and extensional tectonic process (Birkenmajer 1972, Lowell 1972, Kellogg 1975, Steel et al. 1985, Dallmann 1992, Dallmann et al. 1993, Winsnes et al. 1993, Bergh and Grogan 2003). Heavily deformed older rocks were included into the Palaeogene fold chain.

Carboniferous and Permian. In the Early Carboniferous the Hornsund area became part of the Barents Sea-Karski Sea continental platform (Birkenmajer 1990). The basement of the post-Caledonian rock complex in Hornsund consists of clastic rocks of the Adriabukta Formation (the Billefjorden Group) mostly featuring deposits of alluvial cones, anastomosing streams, and floodplains. They developed in a depression whose boundaries were delineated by earlier dislocation zones (Birkenmajer 1990). Its probable alimentation area was the Sørkapp-Hornsund High being uplifted in the west (Birkenmajer 1964, 1975, Gjelberg and Steel 1981; Steel and Worsley 1984).

The overlying Upper Carboniferous and Lower Permian rocks of the Gipsdalen Group are already connected with the diminishing tectonic movements. Partly coming from the erosion of the Sørkapp-Hornsund High, they were deposited in the east, in the Inner Hornsund Trough (Steel and Worsley 1984, Bergh and Grogan 2003). Additionally, in the Late Carboniferous eustatic sea-level changes caused by glacial factors made the Hornsund area turn slowly into an environment with shallow-sea and terrestrial sedimentation. The rocks that developed at that time have been classified as belonging to the Hyrnefjellet and Treskelodden Formations. While the Hyrnefjellet Formation (ca. 60 m thick) is built of red conglomerates, breccias, sandstones and mudstones deposited in the conditions of a warm and dry climate, the Treskelodden Formation, in its lower part still decidedly continental, towards the top shows a larger contribution of marine deposits (Fig. 4). In the typical stratigraphic section situated on Treskelen (creek IV), in the upper part of this Formation, Birkenmajer (1964) found distribution channels with cross-bedding. In his opinion, sedimentation occurred on the margin of a marine basin; thin, poorly sorted or graded beds fineing upwards and lenses of conglomerates were transported by rivers and creeks from shallow water environments, uplifted during the Adriabukta Phase, that extended along the Inner Hornsund Trough and the Sørkapp-Hornsund High (Birkenmajer 1964, 1984*b*, 1990). Also Kleinspehn et al. (1984), Birkenmajer (1984*a*) and Steel and Worsley (1984) think that the conglomerates and sandstones in the lower member of the Treskelodden Formation could have accumulated as a result of the transport of river deposits towards the sea from the margin of the Sørkapp-Hornsund High. Detailed stratigraphic sections and descriptions of the Treskelodden Formation rocks are presented in Birkenmajer (1964), Birkenmajer and Fedorowski (1980), and Fedorowski (1982*a*).

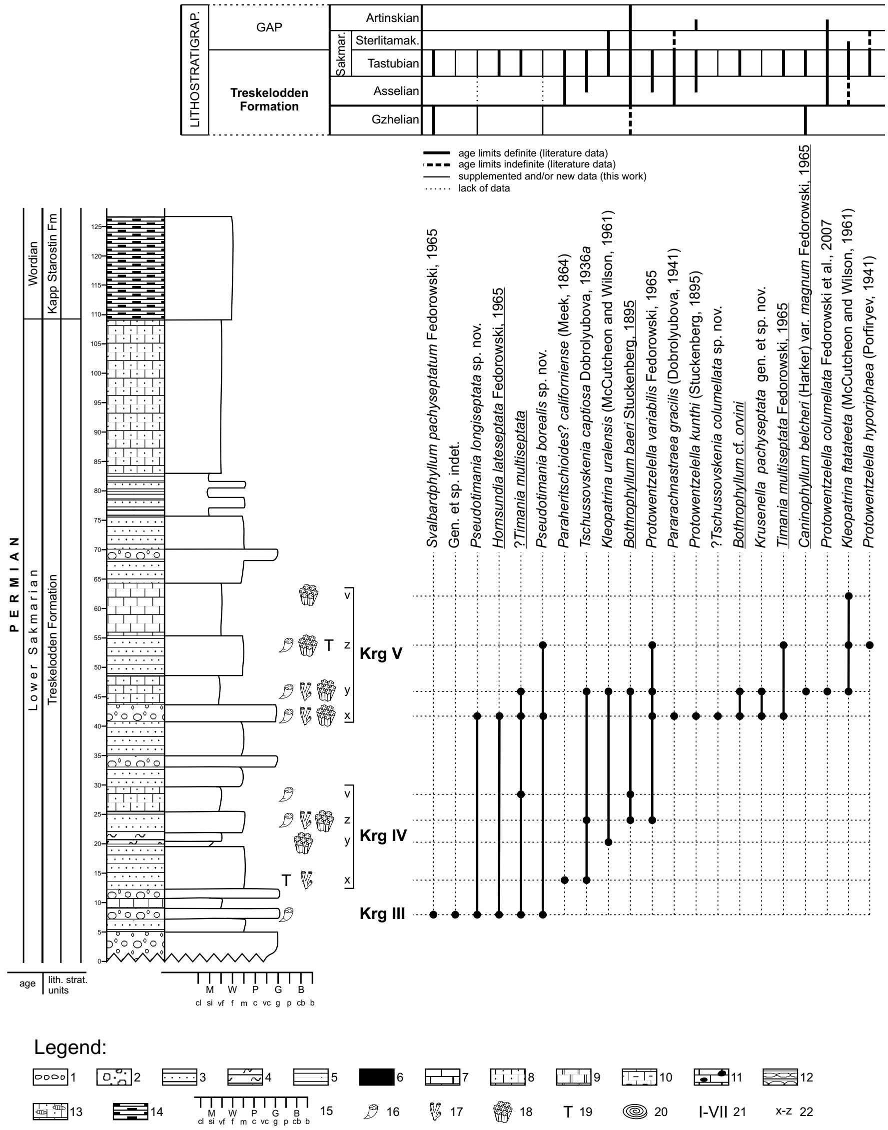


Fig. 4. Stratigraphic section of Kruseryggen (77°03.833′ N, 16°05.092′ E, 250 m above sea level) and occurrence of coral specimens of coral horizons III-V and subhorizons x, y, z, v. Underlying taxa described in Chwieduk (2009*a*).

1 – conglomerate, 2 – pebbly sandstone, 3 – sandstone, 4 – mudstone, 5 – shale, 6 – clay, 7 – limestone, 8 – sandy limestone, 9 – dolomite, 10 – marl, 11 – limestone with chert nodules, 12 – nodular limestone, 13 – cavernosal limestone, 14 - siliciclastic sediment with cherts, 15 – grain size scale: cl – clay, si – silt, vf – very fine sandstone, f – fine sandstone, m – medium sandstone, c – coarse sandstone, vc – very coarse sandstone, g – gravel, p – pebbles, cb – cobbles, b – boulders, M – mudstone, W – wackestone, P – packstone, G – grainstone, B – bundstone, 16 – solitary rugose corals, 17 – dendroid and phaceloid colony of rugose corals, 18 – cerioid colony of rugose corals, 19 – Tabulata, 20 – Foraminifera, 21 – coral horizons, 22 – coral subhorizons, Bld. – Blendadalen area, CrL – Linnédalen Creek, Krg. – Kruseryggen Hill, KS – Kapp Starostin, Lin. – Linnédalen, Pol. - Polakkfjellet.

The distribution of Rugosa corals in five cycles (coral horizons *sensu* Birkenmajer 1964) in the Permian part of the Treskelodden Formation (Fig. 4) shows there to be additionally a local tectonic control of sedimentation within the Inner Hornsund Trough. Thus, in this region the Gipsdalen Group reflects the changing sedimentation conditions connected, on the one hand, with the progradation of the delta on which sebkhas and lagoons had developed, and on the other, with the changing relief of the margins of the basin shaped by relative (block tectonics) and eustatic fluctuations in sea-level. North of Hornsund, shallow-sea sedimentation connected with a eustatic lowering of sea-level is corroborated by evaporite episodes representing the Gipshuken Formation. This formation, absent from the Hornsund region, attains a thickness of abut 70 m in Torell Land in the Drevbreen region (Cutbill and Challinor 1965), while in Dickson Land, in a typical place of its occurrence, it has 245 m (Dallmann 1999).

The unit standing out for its resistance to weathering, built of siliceous rocks and belonging to the Middle and Upper Permian, is the Kapp Starostin Formation (Upper Kungurian-Wuchiapingian). On Treskelen it lies with a slight angular unconformity and a stratigraphic gap directly on the Treskelodden Formation. On the basis of Rugosa corals, the age of the Kapp Starostin Formation has been dated to the Wordian (Chwieduk 2007), or possibly the Roadian (Kossovaya 2009), which corresponds to the Svenskeegga and/or Vøringen Member(s) documented in the Isfjorden region. Thus, those data disprove the earlier suppositions by Harland (1997) and Dallmann (1999) that rocks of this formation in the Hornsund area were of Capitanian age and belonged to the Revtanna Member.

In the Hornsund region, the bed thickness of the Kapp Starostin Formation grows from less than 5 m on Treskelen (Chwieduk 2007) to at least 18 m on Kruseryggen (Fig. 4). In comparison with the most complete stratigraphic section in Oscar II Land, those quantity are not large. The differences in thickness are due to a near-bottom gap and possibly some inner gaps as well as various thicknesses of the stratigraphic levels. Birkenmajer (1990) assumes that those gaps and unconformities are a result of uplifting movements in the southern part of Spitsbergen, probably connected with the fault zones of Kongsfjorden-Hansbreen and Hornsund. The Mesozoic rocks covering the Kapp Starostin Formation and represented in the Hornsund region by all, though incomplete, systems, are separated from the Palaeozoic ones by another stratigraphic gap embracing the uppermost Permian and the lowest Triassic (e.g. Birkenmajer 1964, Harland 1997).

The Permian-Carboniferous fauna of the Hornsund region was very rich. It has supplied material for numerous palaeontological studies (Birkenmajer and Czarniecki 1960; Birkenmajer 1964; Liszka 1964; Czarniecki 1964, 1969; Osmólska 1968; Birkenmajer and Logan 1969; Szaniawski and Małkowski 1979;

Karczewski 1982; Nowiński 1982, 1991). An especially large accumulation of fossils can be found in the upper layers of the Treskelodden Formation. The Rugosa corals that come from it belong to the best studied groups of Spitsbergen fossils (Fedorowski 1964, 1965, 1967, 1982*a*; Birkenmajer and Fedorowski 1980; Fedorowski et al. 1999; Fedorowski et al. 2007; Chwieduk 2009*a*). Apart from a great number of palaeontological descriptions, those works have also supplied new taxa, presented in statistical terms by Chwieduk (2009*b*).

Rugosans allowed Birkenmajer (1964) to distinguish five coral horizons on Treskelen. On the basis of taxonomic differences, Fedorowski (1965, 1967, 1982*a*) characterised the coral associations of those horizons. He established, among other things, that the Treskelodden corals were shallow-water and thermophilic ones. On the basis of preliminary sedimentological observations, he also demonstrated that the coral fauna of the horizons, with the exception of horizon V, was redeposited, with transport distance diminishing towards the top of stratigraphic section (Fedorowski 1982*a*).

A characteristic of the overlying Kapp Starostin Formation, less abundant in Rugosa fossils (Chwieduk 2007), is a large accumulation of (mostly silicified) brachiopods, bryozoans, bivalves, sponges, echinoderms, gastropods, and foraminifers. On the basis of conodonts, Szaniawski and Małkowski (1979) identified here two coeval associations of organisms, one of high-energy, shallow coastal waters, and another, of low-energy, deeper waters in which conodonts were accompanied by sponges, bryozoans and thin-shell brachiopods.

2.2.2. *Polakkfjellet range*

Polakkfjellet lies between Torell Land and Wedel Jarlsberg Land (Fig. 2B). It is a range of several elevations separated by faults (Fig. 2D). Its facies are a mosaic of systems, from the Carboniferous to the Palaeogene. Regrettably, this is a poorly known area, among other things owing to its mountainous topography and an extensive cover of glaciers, greatly restricting access to exposures. The earliest work concerning this area (Różycki 1959), describing the results of a 1934 expedition, characterized the Kopernikusfjellet region (some 8 km NW of Polakkfjellet) up to Bellsund as built of varicoloured clastic rocks, carbonates and siliceous rocks belonging to the Carboniferous and Permian. Nysaether (1977), on the example at the southern margin of Polakkfjellet (the Drevbreen stratigraphic section) reports that the basement underlying Upper Palaeozoic rocks is built of metamorphic Precambrian rocks and sedimentary Cambrian-Silurian rocks deformed during the Caledonian orogenesis. In turn, rocks of the Carboniferous and Permian systems are the basement of the post-Caledonian rock complex.

C a r b o n i f e r o u s a n d P e r m i a n. When describing the lithology of the Drevbreen stratigraphic section, Nysaether (1977) presented the tripartite nature of Permian-Carboniferous rocks in this area. The section starts with a 180-m thick carbonate-sandstone series, overlain by a 69-m thick carbonate-evaporite sequence, and ends with a 95-m thick rock package containing carbonates, sandstones and silicified rocks. The last two sequences are correlated with the Gipshuken and Kapp Starostin Formations. The lower series, which Nysaether (1977) called Drevbreen layers, today is classified as belonging to the Treskelodden Formation (Dallmann 1999, Błażejowski et al. 2006). Rocks younger than the Permian are poorly known from this area.

Outcrops of the Treskelodden Formation can best be studied in the southern part of the Polakkfjellet range (Fig. 2D). Here they are visible already at the boundary with the Drevbreen (Drev glacier), whose surface in this place lies about 450 m above sea-level. The rock sequence in this unit displays a pattern of alternating sandstones, siliceous rocks, limestones and dolomites, with a secondary occurrence of conglomerates and shales, a decided majority of which, 75% according to Nysaether (1977), are terrigenous clastics; carbonates contribute 20%, and the remaining 5% are silicified rocks. On the basis of the types of carbonates, Nysaether divided the Drevbreen layers (=Treskelodden Formation) in the Polakkfjellet region into three units: (1) the lowest, calcareous-sandy one with intercalations of conglomerates, ca. 70 m thick, with a wealth of the organic world of that time as expressed by an abundance of Rugosa, Tabulata, Fusulinida, Gastropoda, Brachiopoda, Bryozoa, and Crinoidea; (2) central, 83 m thick, with no limestones but mostly dolomites containing just a few Tabulata fossils; and (3) the highest, 27 m thick, built of limestones, a small proportion of them bituminous, with only a few bivalves and gastropods. The sporadic appearance of silica in the form of small cherts in all the units is indicative of the primary presence also of siliceous organic material.

The Rugosa corals presented for the first time in this monograph come from the first, lowest unit *sensu* Nysaether (1977), corresponding to the lower part of the Treskelodden Formation. The collection containing solitary and colonial forms (Table 1A, B) comes from two exposures designated in Fig. 2D by letters "A" and "B". Stratigraphic section "A", on the southern part of the hill, lies at 77°13.326′ N and 16°03.199′ E. Stratigraphic section "B" comes from an exposure lying at 77° 13.498′ N and 16° 01.933′ E, i.e. north-west of "A". The rock complexes presented in those sections (Fig. 5) are built of terrigenous siliciclastic rocks and carbonates. Both types of rock contain an abundant and rich in species rugose corals, deposited at some time intervals, i.e. separated by unfossiliferous beds. Thus, as on Treskelen, it was possible to identify layers with corals. To distinguish them from the Lower Permian

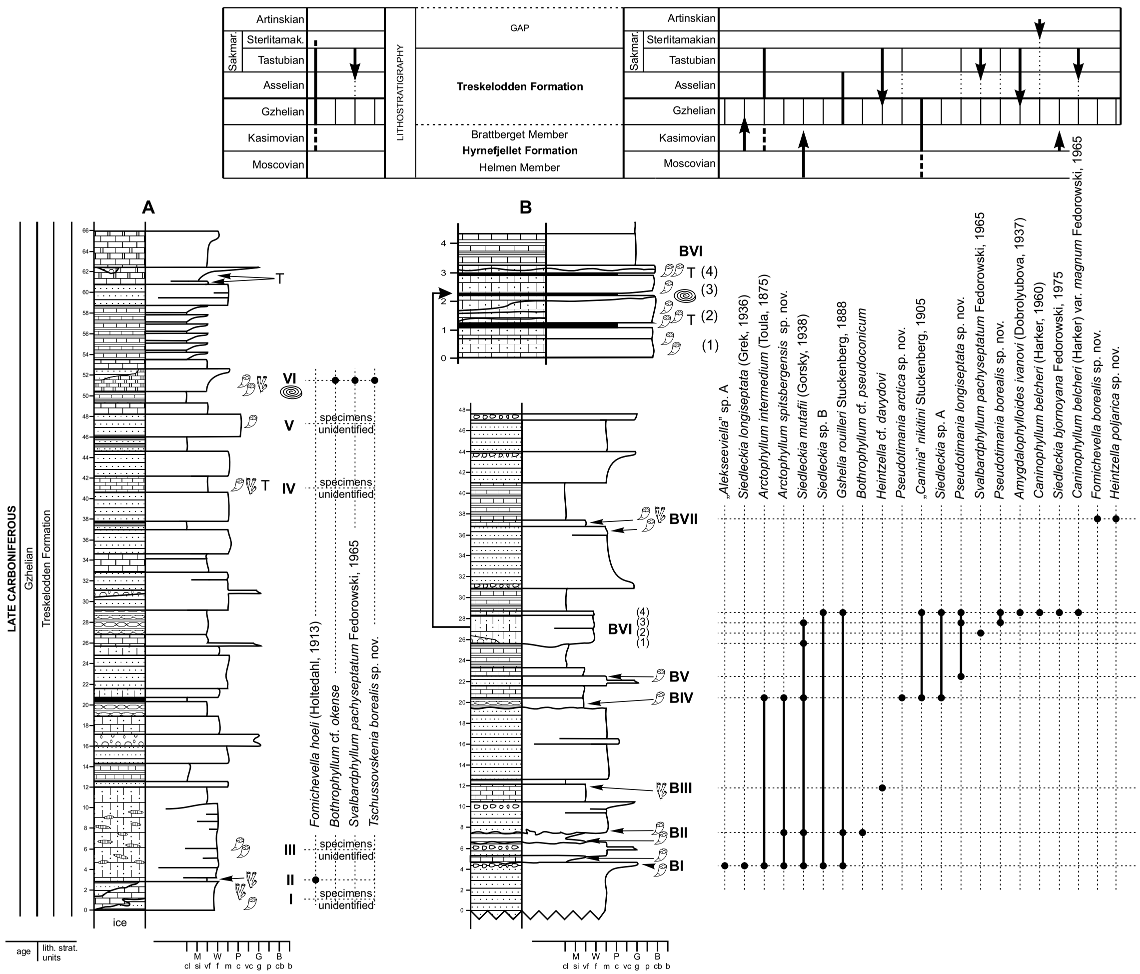


Fig. 5. Stratigraphic section of Polakkfjellet. A – southern mountain slope (77°13.326′ N, 16°03.199′ E, 453 m above sea level), B – south-western mountain slope (77°13.498′ N, 16°01.933′ E, 434 m above sea level). For explanations see Fig. 4.

(Lower Sakmarian) Treskelen coral horizons, they were termed levels. The fusulinids determined by Lin Rui (2004, unpublished data) which I collected from dark-grey limestones of the Treskelodden Formation on Polakkfjellet in stratigraphic sections "A" (Fig. 5A, level VI) and "B" (Fig. 5B, level BVI), are indicative of the highest Carboniferous (Gzhelian) – ?lowest Permian (?Asselian). Apart from Rugosa corals and the fusulinids, the calcareous rocks of the two sections have also preserved Tabulata, Crinoidea, Bivalvia, Gastropoda and Brachiopoda.

In stratigraphic section "A" six levels with Rugosa corals were identified and designated by Roman numerals from I to VI (Fig. 5A). The lowest (first) occurs in light-grey limestone about 2 m thick. The solitary and phaceloid rugosans found here are in a very good state of preservation. Equally well preserved is the fauna of the second level, ca. 15 cm thick, lying directly on the first and containing very numerous colonies of phaceloid rugose corals (Fig. 5A). The overlying complex of dark-grey, compact sandy limestones , ca. 7 m thick, has numerous, solitary Rugosa corals of the third level. The next, fourth level, separated from the preceding one by a layer of mostly clastic rocks more than 30 m thick, is dominated by non-bedded, grey calcareous sandstones, claystones, less often conglomerates and limestones. Here solitary and colonial Rugosa corals are accompanied by an abundance of Tabulata. The overlying sandy rocks, some 6 m thick, contain in the top a few solitary rugosans of the fifth level. The richest coral association, marked as the sixth level, was found in the limestones and dolomites covering clastic rocks of the fifth level. In the remaining part of the section, nearly 50 m long, no Rugosa corals were identified. Ten metres above the sixth level only some Tabulata were found in a great accumulation in a light, sometimes dolomitised, limestone.

In stratigraphic section "B", richer in fossils than section "A" (Fig. 5B), seven coral levels were identified. To distinguish them from those of stratigraphic section "A", they were designated by Roman numerals from I to VII preceded by the letter B. The first level (BI) includes only a few solitary Rugosa corals, poorly preserved in a conglomerate a dozen or so centimetres thick (occurring in the top of a sandstone) and in the overlying limestone. Although the rocks differ widely, the taxonomic similarity of the corals they contain is big enough to include them in a single coral level, which runs about 4 m above a glacier adjacent to those rocks. Level BII was distinguished within an overlying, 1.5-m thick mudstone and in the bottom part of the sandstone that covers it. The numerous corals found here are exclusively solitary forms. The first colonial corals forming phaceloid colonies included in level BIII were found in the top part of limestones covering clastics that separate this level from the underlying BII. Phaceloid and solitary rugosans were also found to occur in calcareous sandstones and limestones of level BVII. Within the remaining levels, from BIV to BVI, only solitary Rugosa forms were identified. A large accumulation of Rugosa and Tabulata in sandy limestones separated by shales at level BVI provided a basis for distinguishing four associations here, which were denoted by numerals 1 to 4 (Fig. 5B).

A feature common to both sections "A" and "B" is a great similarity of their terrigenous clastics in terms of composition, structure and colour. Brown, yellowish or grey sandstones and mudstones are usually well sorted. The dominant detritic component is quartz. The thickness of sandstone beds varies from tens of centimetres to a few metres, with medium-scale cross-bedding in some cases. Conglomerates occur in the form of lenses or laminae and are composed of well-rounded quartz grains, cherts and quartzitic pebbles which usually do not exceed a few centimetres in diameter. The whole is embedded in a sand-clay matrix. Thin, very numerous laminae of shales are usually almost black, less often greenish and light-grey.

2.2.3. *Grønfjorden area*

This area lies south of Isfjorden, in the western part of Nordenskiöld Land (Fig. 6). Permian-Carboniferous outcrops extend there in a 7-km wide belt as far as Bellsund (Fig. 2B). Glaciers in this part of Spitsbergen occur in small cirques on moderately inclined mountain slopes with a northern and a north-eastern exposure. Hence ice-free valleys are very good places for fieldwork and sampling. One of such places – an open Linnédalen valley (Fig. 6B) cutting across Upper Palaeozoic layers – was the site of my research. From the west it is bounded by a series of elevations composed of Precambrian rocks, and from the east, by mountains built of weathering-resistant rocks, dominated by the siliceous rocks of the Kapp Starostin Formation, with the highest peak of Vøringen (675 m). Within those rocks and the ones lying north of western Isfjorden, Dallmann et al. (1992) have distinguished four structural units (Fig. 6A): I – the Palaeogene Forlandsundet Graben, in the western part represented by Precambrian rocks and in the east by Carboniferous ones; II – the horst of a Precambrian crystalline basement, built mostly of phyllites, with cracks caused probably by Caledonian folding and some faults reactivated during Palaeogene deformation events; III – a deformation zone running NNW-SSE, forming an 8-km wide belt of outcrops of mostly Upper-Palaeozoic and Mesozoic rocks, highly folded and faulted in the Middle Palaeogene, as a result of which today we have repeating layers in the mountains between Grønfjorden and Linnédalen; and IV – almost undeformed, flat-lying Cretaceous, Palaeogene and Neogene rocks forming a plateau east of Grønfjorden.

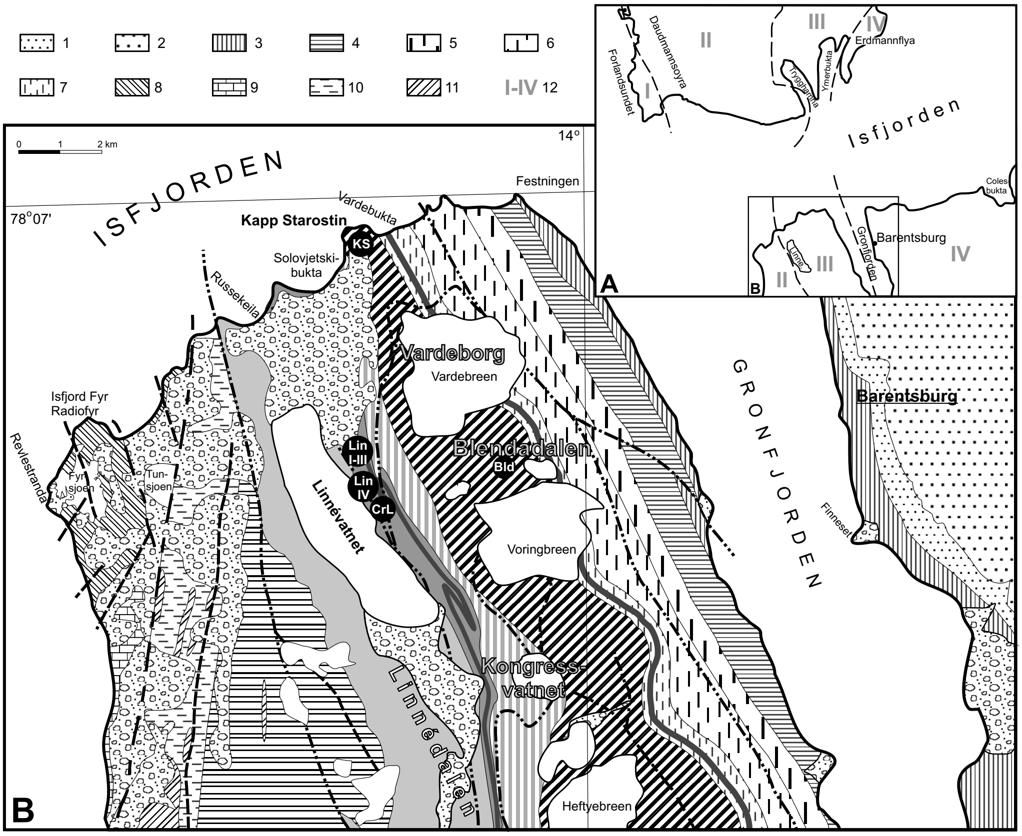


Fig. 6. A: Structural division of the western part of Isfjorden. B: geological map of N-W part of Nordenskiöld Land (after Ohta et al. 1992, simplified). 1 – Palaeogene, Firkanten Fm., 2 – Palaeogene, Basilica Fm., 3 – Lower Cretaceous, Helvetiafjellet and Carolinefjellet Fm, 4 – Jurassic, Janusfjellet Fm., 5 – Upper Triassic, De Geerdalen and Wilhelmøya Fm., 6 – Lower and Middle Triassic, Bravaisberget and Tvillingodden Fm., 7 – Lower Triassic, Vardebukta Fm., 8 – Vendian, diamictite, 9 – Upper Proterozoic, carbonate rocks, 10 – Middle Proterozoic? Phyllite, 11 – Middle Proterozoic? Carbonate rocks, 12 – Forlandsundet (I), Precambrian basement high (II), Tertiary fold-and-thrust belt (III), – weakly deformed basin strata (IV). For more explanation see Fig. 2.

The rocks of the western part of the Isfjorden region, from Carboniferous to Neogene, were studied earlier by Frebold (1928, 1937, 1939), Frebold and Stoll (1937), and Hoel and Orvin (1937). In the 1950s to '80s, this area was visited by geologists from Birmingham and Cambridge (Baker et al. 1952; Weiss 1958; Dineley 1958; Gee et al. 1953), Oslo (Hellem 1980, *fide* Dallmann et al. 1992), Trondheim (Mork et al. 1982), and Hokkaido (Nakamura et al. 1987). When Maher et al. (1989) mapped the structural-tectonic conditions in this part of Isfjorden on the basis of their works, they revealed two systems of folds, one within the Carboniferous (the Orustdalen Formation) and one within the Triassic (the Sassendalen Group).

Carboniferous and Permian. Out of the formal lithostratigraphic units, the following were identified in the western part of the Isfjorden region: the Billefjorden Group with the Orustdalen and Vegard Formations, the Gipsdalen Group with the Petrellskaret, Tarnkanten, Wordiekammen and Gipshuken Formations, and the Tempelfjorden Group with the Kapp Starostin Formation. However, most of the basic stratigraphic ranges are still being examined. The most abundant palaeontological material, the best part of which is presented in a later section of this work, was gathered in the Lake Linné valley neighbouring with the Permian-Carboniferous rocks of the Billefjorden and Gipsdalen Groups. In my study area, the former Group includes deposits of alluvial cones, anastomosing streams, and floodplains. The Orustdalen Formation belonging to this Group is represented by sandstones and coarse-grained rocks attaining a thickness of up to 759 m in the typical stratigraphic section in Orustdalen (Nordenskiöld Land, ca. 10 km south of Lake Linné; Cutbill and Challinor 1965). This formation lies unconformably on a folded Caledonian basement. Dominated by light-grey, mostly cross-bedded quartzitic sandstones, it contains plant fossils. Best exposed along the western Spitsbergen coast, it had its alimentation area in the west (Gjelberg and Steel 1981, Steel and Worsley 1984). Palaeobotanical studies of the Orustdalen Formation (Nathorst 1920) as well as palynological studies of the equivalent Hornsundneset Formation distinguished in the south of Isfjorden (Siedlecki and Turnau 1964), together with palaeo-environmental correlations (Gjelberg and Steel 1981; Steel and Worsley 1984), show the Orustdalen Formation to be Lower Carboniferous (Tournaisian-Viséan) in age.

The overlying Vegardfjella Formation documented in Nordenskiöld Land, named so by Dineley (1958) and later redefined by Cutbill and Challinor (1965), attenuates towards Linnédalen. Its thickness in a typical locality in Orustdalen amounts to 358 m (Cutbill and Challinor 1965), though tectonism in that area makes thickness estimates unreliable; lithologies are light-grey, pinkish or reddish, thin-bedded sandstones and shales. As follows from lithological and palaeo-environmental correlations, the rocks of this formation belong to the Upper Viséan (Harland 1997).

The rocks of the Gipsdalen Group overlie the Billefjorden Group usually with an angular unconformity. Moving from bottom to top layers of the Group, they reflect a stratigraphic development from clastic red alluvial beds to delta-fan facies in the lower part (the Petrellskaret and Tarnkanten Formations), through a fine-grained clastic and carbonate facies (the Wordiekammen Formation) to gypsiferous dolomitic deposits (the Gipshuken Formation) in the upper part. The red beds rich in quartz or carbonates, cross-bedded, with ripple marks and erosion surfaces as well as sporadic transformed fossils of brachiopods, crinoids and corals, do not occur everywhere. Their continuation into the western part of Nordenskiöld Land, suggested by Cutbill and Challinor (1965), was not confirmed by later studies (Hjelle et al. 1986; Maher et al. 1989). This does not hold for the overlying formations (Wordiekammen and Gipshuken), which occur throughout the entire Isfjorden area (Cutbill and Challinor 1965, Dallmann 1999, Somerville 1997). Probably within the down-faulted tectonic block along the western coast of Oscar II Land (Fig. 2), in the St. Jonsfjorden Trough, sedimentation is supposed to have been more or less continuous in the Wordiekammen Formation (Dineley 1958). South of Isfjorden, this formation transgressed onto the sandy Billefjorden Group after a major Middle to Late Carboniferous hiatus (Hjelle et al. 1986). East of Linnédalen (stratigraphic section CrL., Fig. 6B), the accessible thickness of this formation amounts to 90 m (Fig. 7A); by comparison, in Kongressvatnet, south-east of Linnévatnet (Fig. 6B), its thickness attains 200 m (Tangen 1981). Lithologies are sandstones, grey shales as well as alternating dolomites and limestones, which are high in sand or silica at places (Fig. 7A-B). Sandstones and sandy limestones are usually limited to the transitional lower part of the formation. The overlying dolomites and limestones contain a great accumulation of fossil fusulinids, corals, crinoids, bryozoans, brachiopods, sponges, and ostracods; also frequent are bioturbations. Forbes et al. (1958), Forbes (1960) and Winsnes (1966) report that fusulinids show the age of this formation to be Late Carboniferous – Early Permian.

The Gipshuken Formation in the Isfjorden region conformably overlies the Wordiekammen Formation and occurs continuously from Linnédalen to Vermlandryggen (east of Trygghamna). South of Isfjorden it attains about 250 m in thickness. It consists mainly of limestones, dolomites and dolomite breccia. North of the fiord, in the Trygghamna region, it is dominated by anhydrite-dolomite alternations with intercalations of shales and marly limestones (Cutler 1981 *fide* Dallmann et al. 1992, Knag 1980 *fide* Dallmann et al. 1992; Tangen 1981). Its documented thickness in this region exceeds 300 m; according to Dallmann et al. (1992), this increase in thickness towards the north is probably of tectonic genesis.

The Tempelfjorden Group, represented by the Kapp Starostin Formation, is usually well exposed and forms the tops of the highest mountain peaks. In the exposure on Kapp Starostin (here a stratotype) and in the Blendadalen region (ca. 7 km south of the place of a typical occurrence of the Kapp Starostin Formation) the thickness of this formation amounts to 305 m and 115 m, respectively (Figs 6, 8A-B). The Vøringen Member (not documented in Fig. 8), which attains 22 m on Kapp Starostin, is consists of bioclastic limestones with numerous silicified brachiopods, bryozoans, crinoids and other fossils. The overlying Svenskeegga Member (165 m thick on Kapp Starostin), is composed of arenaceous cherts, spiculite shales, and partly silicious limestones with

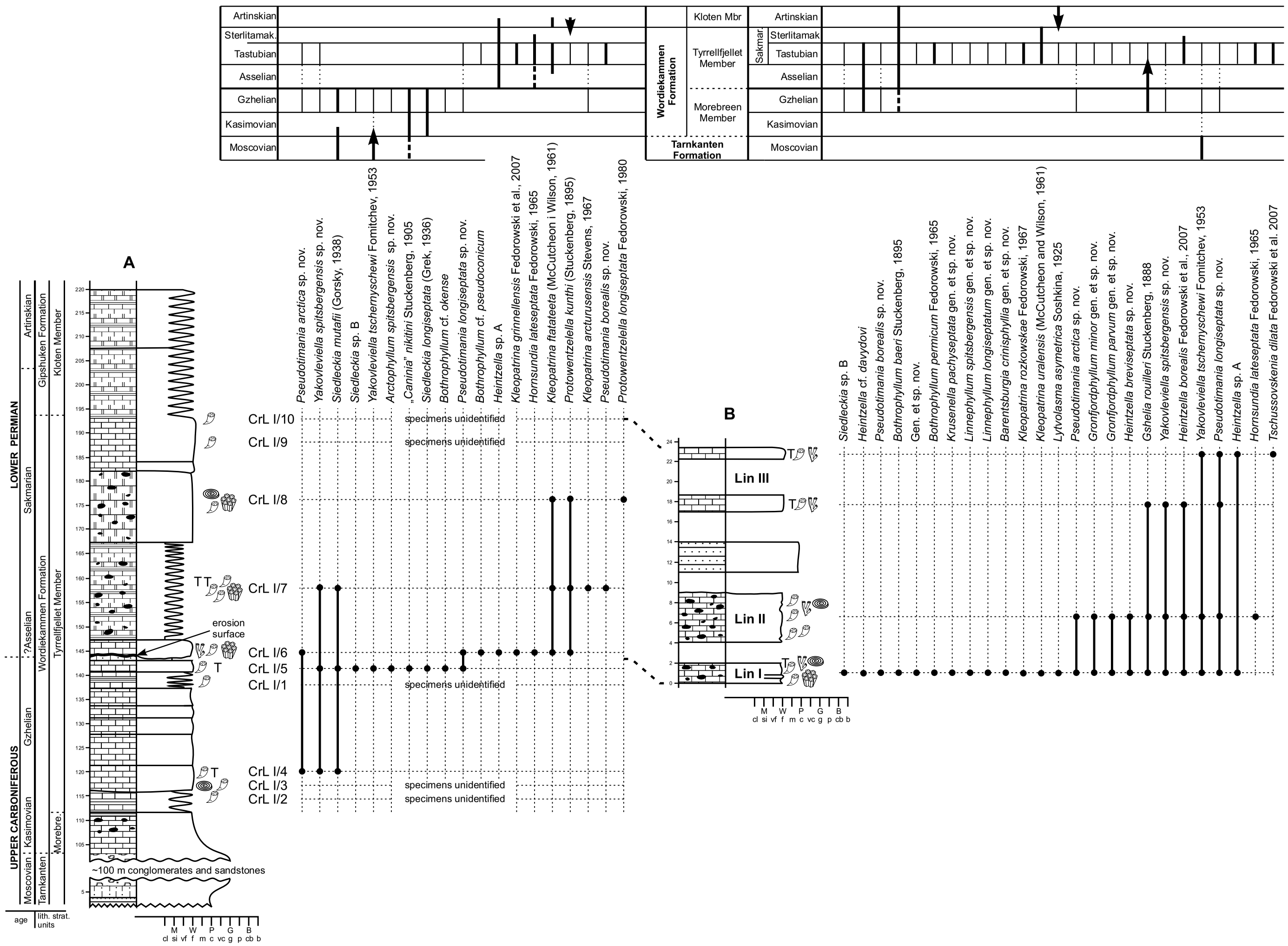


Fig. 7. Stratigraphic sections of Linnédalen; A – section from creek near Linnévatnet (78°03.607′ N, 13°48.424′ E, 31 m above sea level), B – section made 1.5 km north of A (78°03.865′ N, 13°48.144′ E, 46 m above sea level). For explanations see Fig. 4.

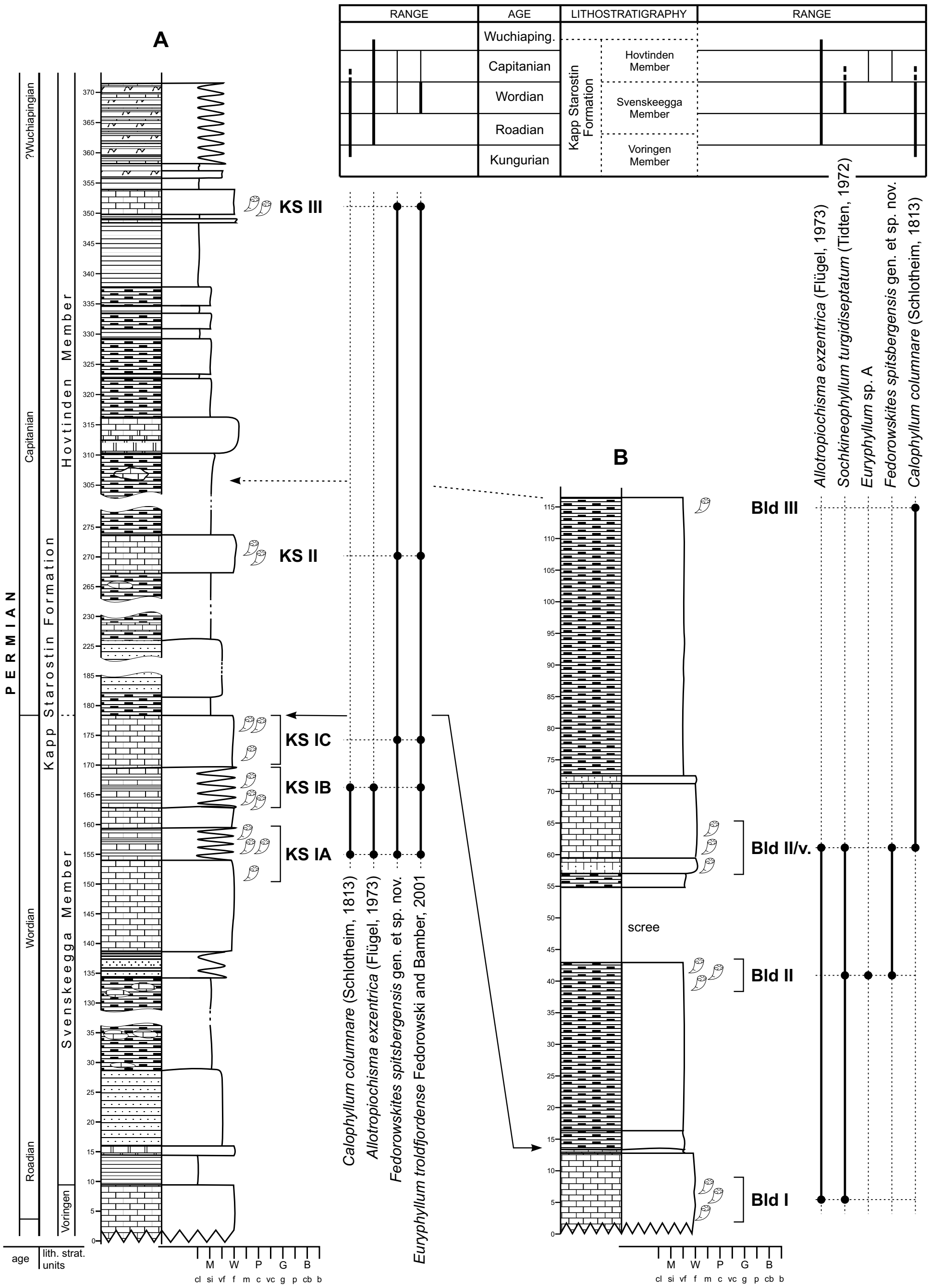


Fig. 8. Stratigraphic sections of Kapp Starostin (A – 78°05.644′ N, 13°48.601′ E, 1.0-14.0 m above sea level) and Blendadalen (B – 78°03.221′ N, 13°56.368′ E, 133 m above sea level). For explanations see Fig. 4.

sponges and sponge spicules, brachiopods, bryozoans, Rugosa corals, and trace fossils (e.g. *Zoophycos*). In the KS stratigraphic section (Fig. 8A) I documented 80 m thick of this unit. The overlying Hovtinden Member on Kapp Starostin attains 196 m in thickness. It consists of silica-cemented clastic (shales, siltstones, sandstones), limestones and thin intercalations of dolomite. The fauna found here compares with that of the Svenskeegga Member. In the KS stratigraphic section the thickness of this unit exceeds 220 m.

3 PREVIOUS TAXONOMIC STUDIES OF SVALBARD RUGOSA

The first mentions of Rugosa corals on Spitsbergen come from 1875. It was then that Toula published a paper with descriptions and illustrations of two species from central Spitsbergen, at least one of which ("*Clisiophyllum Geinitzii*") may have been derived from the Kapp Starostin Formation in Nordenfjorden. Later works on collections accumulated at random by 19th – and 20th-century Norwegian expeditions (Heritsch 1929, 1939) were doomed from the very start to be of little use because they lacked an established stratigraphic position. They cannot be verified today because they were lost during the Second World War. Of no more use are also the illustrated works by Padget (1954) and Forbes et al. (1958) – both require a revision. In another study (Tidten 1972) there are only descriptions of a lot of taxa of solitary corals and plocoid colonies, without any litho – and biostratigraphic suggestions. More recent works on rugosans from the Isfjorden area (Ezaki and Kawamura 1992, Ezaki et al. 1994, Ezaki 1997, Somerville 1997) are only confined to preliminary determinations of five species, four taxa left in an open nomenclature and seven taxa of indeterminate species and/or generic status. Those studies, with no taxonomic descriptions and only a few illustrations, largely limit themselves to information about the occurrence of Rugosa in the Kapp Starostin and Wordiekammen Formations.

The great interest in central Spitsbergen shown by the above-mentioned palaeontologists is probably due to the fact that in this part of the archipelago there are extensive exposures in which the Permian-Carboniferous stratigraphic division is the most complete and contains the richest, most diversified fauna, including rugose corals. South Spitsbergen (the Hornsund region), in turn, less diversified in faunal terms and with considerable stratigraphic gaps, has so far been visited mostly by Polish geologists and palaeontologists. An exception is the Norwegian collections worked over by Heritsch (1939) and Fedorowski (1967). Still, Hornsund's Lower and Middle Permian rocks of the Treskelodden and Kapp Starostin Formations have been definitely among the best studied in terms of corals (Fedorowski 1964, 1965, 1967, 1975, 1982*a*, 1997; Fedorowski et al. 1999; Fedorowski and Bamber 2001; Fedorowski et al. 2007; Birkenmajer and Fedorowski 1980; Nowiński 1982, 1991; Chwieduk 2007, 2009*a*). One can also state that Poland is among the most active states conducting palaeontological research in this part of Spitsbergen.

4 TAXONOMY

Despite the efforts of many specialists, the systematics of Rugosa has not yet been satisfactorily worked out and, in many respects, there are differences of opinion. The present writer has, in principle, based his taxonomy of Upper Carboniferous and Lower Permian corals on Hill's (1981) and Fedorowski's (1991) classifications. Therefore, the taxons Rugosa Milne-Edwards and Haime, 1850 and Dividocorallia Fedorowski, 1991, are treated as subclasses of the class Anthozoa Ehrenberg, 1834. An alternative division applied by, *inter alia*, Olivier (1996) and Scrutton (1997), classifies Rugosa and Heterocorallia as separate orders of the class Anthozoa. The reason for this different treatment of the major taxa is an ambiguous identification of Calyxcorallia Fedorowski, 1991, a taxon which some authors have placed in the order Rugosa rather than the subclass Dividocorallia.

Following Hudson (1936) and Fedorowski (1997), the term 'protosepta' is applied in this dissertation only with reference to cardinal and counter septa; thus, it is not applied to alar and counter-alar septa. Following Hill (1981) and Fedorowski (many papers), the term "corallite" is applied here to the skeleton of a solitary polyp and that of a single individual in a colony.

Abbreviations:

UAMIG.Tc-C.Bld. I/1/1 – catalogue number: UAMIG – place where the collection is kept (Adam Mickiewicz University, Institute of Geology), Tc – Tetracorallia, C – first letter of the collector's surname (in this instance Chwieduk), Bld., CrL., Krg., KS., Lin., Pol. – abbreviations of geographical areas from which the specimens derive (respectively, Blendadalen, a creek in the Linné valley, Kruseryggen, Kapp Starostin, Linnédalen, Polakkfjellet), I-III/1-n/1-n – corallite number.

n/d – septal index, ratio of the number of major septa (n) to corallite diameter (d).

Phylum: Coelenterata Frey and Leuckart, 1847
Class: Anthozoa Ehrenberg, 1834

Subclass: Rugosa Milne-Edwards and Haime, 1850
Order: Stauriida Verrill, 1865
Suborder: Caniniina Wang, 1950
Family: Cyathopsidae Dybowski, 1873
Genus: *Arctophyllum* Fedorowski, 1975

Type species: *Campophyllum intermedium* Toula, 1875.

Diagnosis: See Fedorowski (1975), p. 43.

Arctophyllum intermedium (Toula, 1875)
Figs 9, 10, 11B

1875. *Campophyllum intermedium* n. sp.; Toula: pp. 576-577, pl. 5, figs 13-14.
1939. *Caninia intermedia* (Toula); Heritsch: pp. 70-71, pl. 5, figs 5-7, pl. 13, fig. 19, pl. 14, figs 4, 11, 12, pl. 17, fig. 11.
1948. *Gshelia rouilleri breviseptata* sp. nov.; Dobrolyubova and Kabakovitsch: pp. 21-23, pl. 12, figs 1-4, pl. 14, figs 1-2.
1975. *Arctophyllum intermedium* (Toula); Fedorowski: pp. 44-47, text-fig. 4, pl. 3, fig. 1, pl. 5, fig. 3.
1992. *Arctophyllum intermedium* (Toula); Ezaki and Kawamura: pl. 1, fig. 1.

Diagnosis: See Fedorowski (1975), p. 44.

Material: 21 incomplete, slightly silicified corallites (UAMIG.Tc-C.Pol. BI/1, 2, 3, 10; BI/10/1, 6; BI/11/1; BI/15; BIV/6, 8, 13, 14, 16, 17, 19, 26, 27, 29, 32; BIV/15/1, 3); fragments of external wall preserved in some. 26 peels and 43 transverse thin sections and two peels and two longitudinal thin sections.

Description: The preserved fragments present immature (Figs 9$A_{1,2}$, 10D, 11$B_{1,2}$), early mature (Figs 9A_3, C, 10A_1, B, 11$B_{3,4}$) and mature growth stages (Figs 9$A_{4\text{-}7}$, $B_{1,2}$, 10$A_{2,3}$, C, E, $F_{1,2}$, $G_{1\text{-}4}$, 11$B_{5\text{-}9}$). Major septa straight, in immature growth stages thickened and of varying length, with shortened counter protoseptum, elongated alar septa and long cardinal protoseptum; in mature growth stages septa grow thinner, starting with counter protoseptum towards cardinal protoseptum; they are also thin in dissepimentarium; except shortened cardinal protoseptum, remaining ones grow equal in length leaving free space at the corallite axis embracing ca. one-half its diameter. Septal indices range from 18/4 through 26-29/10-13 to 42-43/20-35 (Fig. 12). At maturity shortened cardinal protoseptum lies in open, deep tabular fossula, with lateral walls usually formed by 1-2 pairs of neighbouring major septa (Figs 9$A_{5\text{-}7}$, $B_{1,2}$, 10A_3, C, E). Minor septa very short; poorly visible in preserved fragments, limited to narrow dissepimentarium, built of 1-5 rows of irregular, herringbone and pseudo-herringbone dissepiments. In ontogeny dissepiments appear early; visible as single vesicles already in corallite 12 mm in diameter (Figs A_3, $11B_2$). Tabulae in early growth stages complete, asymmetrically raised, with highest point at counter protoseptum, gently inclining to the corallite axis towards cardinal protoseptum where their steeply downturned edges emphasise considerable depth of cardinal fossula (Fig. $9B_3$, right side). In later growth stages (Fig. $10G_5$, top of section) apart from complete, convex tabulae, fairly abundant accessory tabellae.

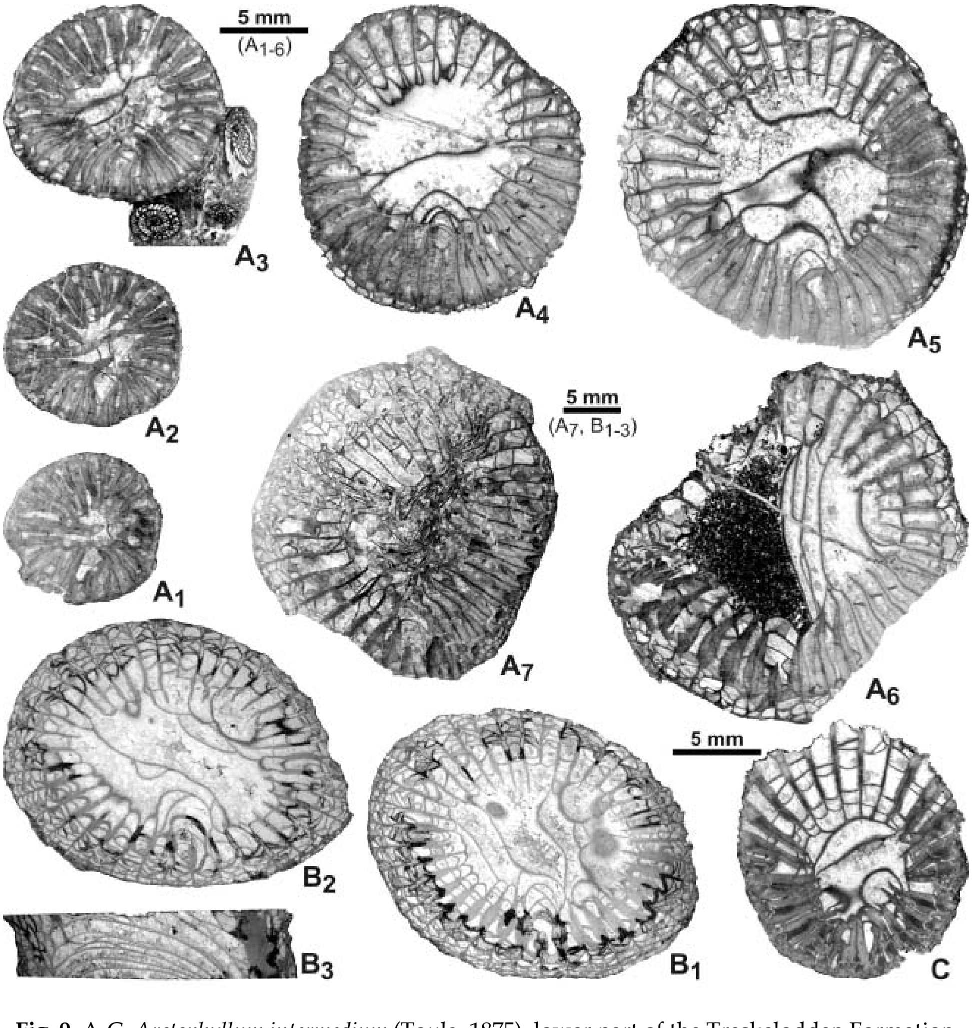


Fig. 9. A-C. *Arctophyllum intermedium* (Toula, 1875), lower part of the Treskelodden Formation.

A – UAMIG.Tc-C.Pol. BIV/15/1; $A_{1\text{-}3}$ – transverse thin sections from immature growth stage, $A_{4\text{-}7}$ – transverse thin sections from mature growth stage.

B – UAMIG.Tc-C.Pol. BI/11/1; $B_{1,2}$ – transverse thin sections from mature growth stage; B_3 – longitudinal thin section;

C – UAMIG.Tc-C.Pol. BI/2; transverse thin section from mature growth stage.

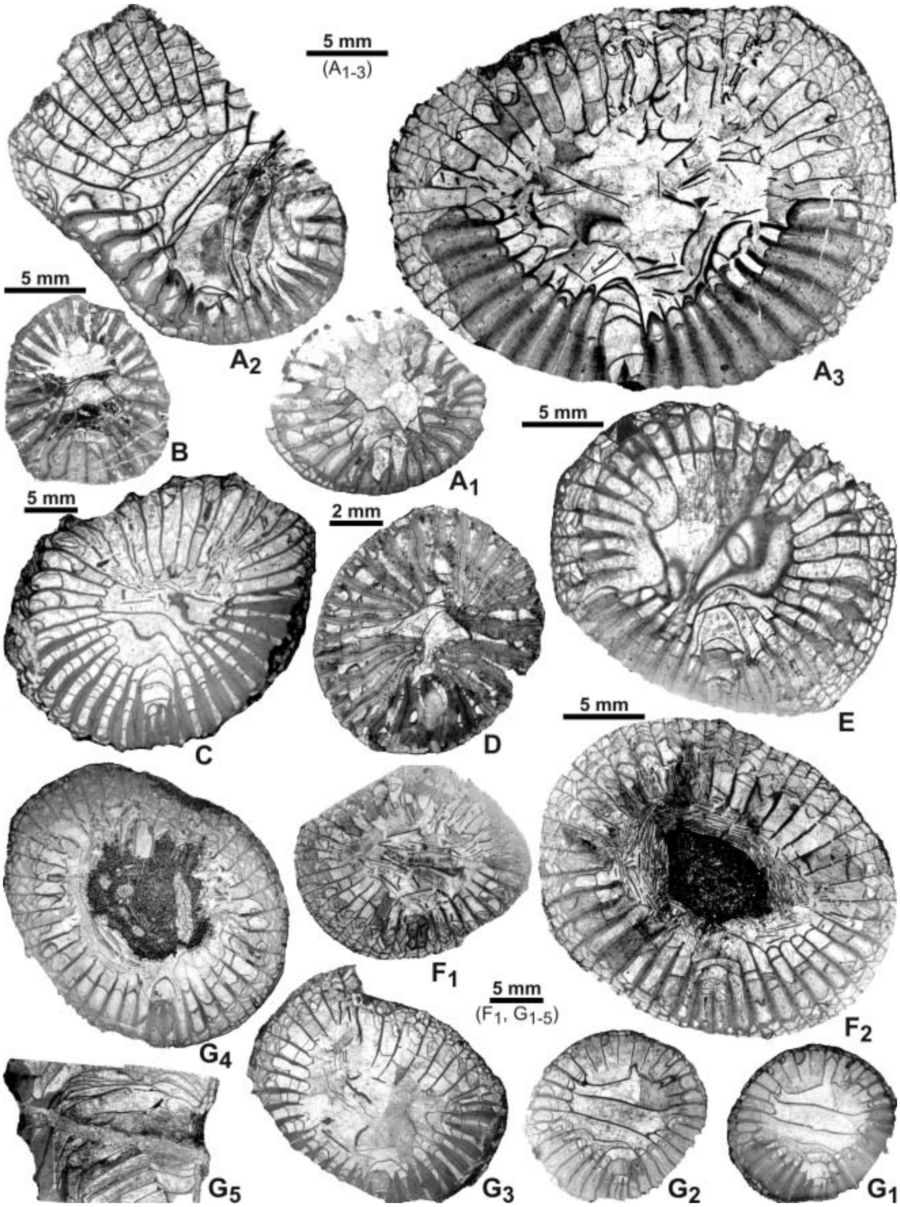


Fig. 10. A, C, D. *Arctophyllum spitsbergensis* sp. nov., lower part of the Treskelodden Formation.

A – UAMIG.Tc-C.Pol. BIV/25; $A_{1,2}$ – transverse thin sections from immature growth stage.
C – UAMIG.Tc-C.Pol. BIV/28; $C_{1\text{-}3}$ – transverse thin sections from immature growth stage.
D – UAMIG.Tc-C.Pol. BIV/30; $D_{1,2}$ – transverse thin sections from mature growth stage, D_3 – longitudinal thin section.
B. *Arctophyllum intermedium* (Toula, 1875), lower part of the Treskelodden Formation. UAMIG.Tc-C.Pol. BIV/26; $B_{1,2}$ – transverse thin sections from immature growth stage, $B_{3\text{-}9}$ – transverse thin sections from mature growth stage.

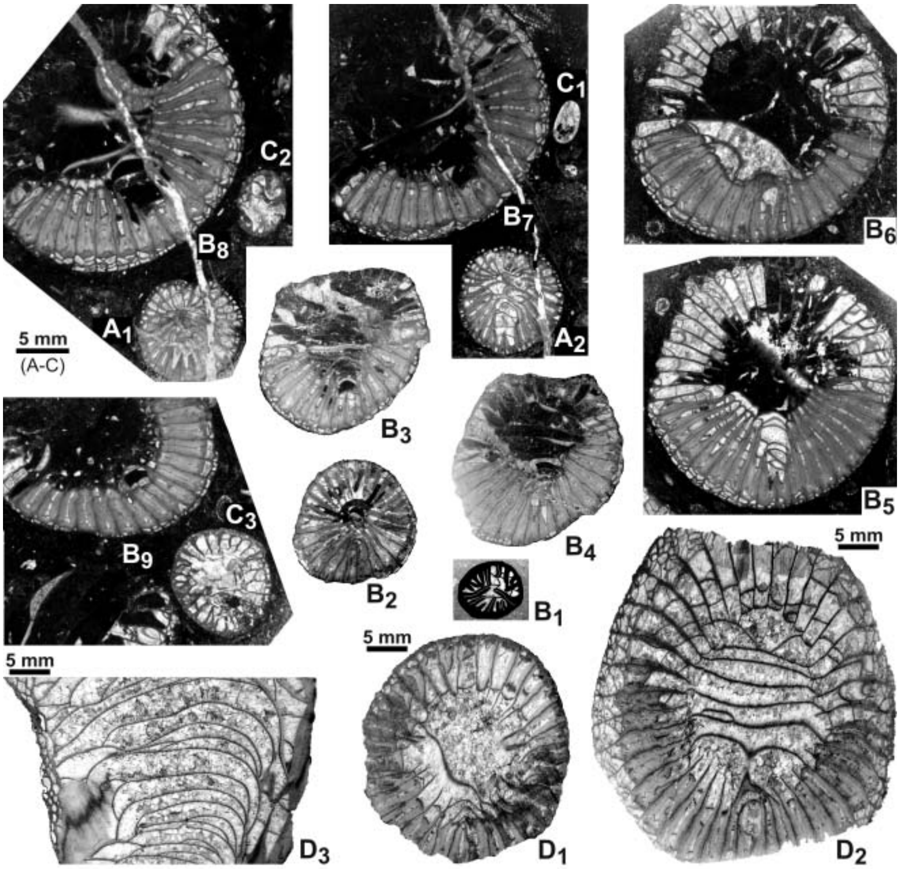


Fig. 11. A-G. *Arctophyllum intermedium* (Toula, 1875), lower part of the Treskelodden Formation.

A – UAMIG.Tc-C.Pol. BIV/17; $A_{1,2}$ – transverse thin sections from immature growth stage, A_3 – transverse thin section from mature growth stage.
B – UAMIG.Tc-C.Pol. BIV/15/3; transverse thin section from immature growth stage.
C – UAMIG.Tc-C.Pol. BI/10; transverse thin sections from mature growth stage.
D – UAMIG.Tc-C.Pol. BI/1; transverse thin sections from immature growth stage.
E – UAMIG.Tc-C.Pol. BIV/14; transverse thin section from mature growth stage.
F – UAMIG.Tc-C.Pol. BIV/8; $F_{1,2}$ – transverse thin section from mature growth stage.
G – UAMIG.Tc-C.Pol. BIV/6; $G_{1,2}$ – transverse thin section from immature growth stage, $G_{3,4}$ – transverse thin section from mature growth stage, G_5 – longitudinal thin section.

Remarks: In comparison with the Bellsund specimens described by Fedorowski (1975), dated to Gzhelian-Lower Permian, those from Polakkfjellet have a slightly longer cardinal protoseptum in early mature stages (compare Fig. 9C with fig. 4f in Fedorowski 1975). In this feature the corallites here examined resemble immature growth stages of specimens from Bellsund and Skansen (Central Spitsbergen) described by Ezaki and Kawamura (1992). Their remaining features, including septal numbers and corallite diameters, match the diagnosis of the species.

Occurrence: Russia, Novaya Zemlya – Upper Carboniferous, Moscow Basin – Upper Carboniferous (recently considered by Russian geologists to be rather Lower Permian); Spitsbergen: Bellsund – Gzhelian-Lower Permian, Polakkfjellet – Gzhelian.

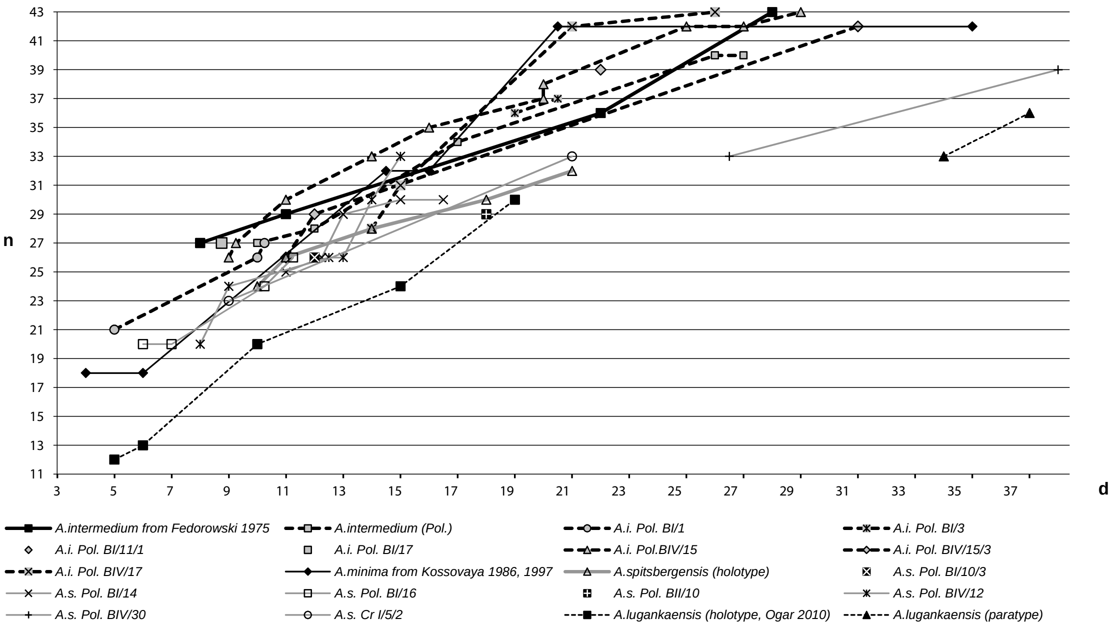


Fig. 12. Plot of the number of major septa (n) *vs*. diameters (d) of *Arctophyllum*. Symbols joined by lines represent values taken from individual specimens.

Arctophyllum spitsbergensis sp. nov.
Figs 11A, C, D, 13, 14A, B

Holotype: UAMIG.Tc-C.Pol. BI/10/5 (Fig. 14A), three peels and six transverse thin sections and one longitudinal thin section.

Type locality: Polakkfjellet (N 77° 13.498'; E 16° 01.933'), south Spitsbergen (Fig. 2D).

Type horizon: Lower part of Treskelodden Formation, Gzhelian.

Derivation of name: *spitsbergensis* – after Spitsbergen.

Diagnosis: *Arctophyllum* with n/d value of 30-33/15-21 in lower part of calice; cardinal fossula narrow, bordered by bent inner ends of 1-2 pairs of major septa of cardinal quadrants; tabularium formed by slightly convex or trapezoid tabellae in inner part of tabularium and few accessory tabellae at periphery.

Material: Besides the holotype, 12 incomplete corallites, mostly with corroded external wall (UAMIG.Tc-C.Pol. BI/8, 14, 16; BI/10/3; BII/10; BIV/12, 15/2, 22, 25, 28, 30; UAMIG.Tc-C.CrL. I/5/2), 11 from the type locality, one from Linnédalen. 18 peels and 30 transverse thin sections and five longitudinal thin sections.

Description: The longest preserved part of corallite is trochoid, 40 mm long, with calice about 15 mm deep. Thickness of external wall from 0.1 to 0.2 mm (Fig. $14A_{4,5}$). Septal indices reach 24-33/9-21, in one case 33/26.5 – 39/38 (Figs $11D_{1,2}$, 12). Major septa differing in size; in the ontogenetically earliest preserved parts of the specimens, equally (Fig. $13D_{1,2}$), or variously (Figs $13C_{1,2}$, $14A_{1,2}$) thickened in all quadrants, the longest reaching corallite axis; they may be thickened to lateral contiguity. In later growth stages major septa usually grow thinner from counter protoseptum towards cardinal protoseptum (Figs $11A_{1,2}$, 13B, D_3, $14A_{3,4}$, B_1), or are of similar thickness in all quadrants (Figs $11C_3$, $13A_{1,2}$), differentiated in thickness only below the calice bottom (Fig. $13A_{3,4}$). In lower part of calice (Figs $13C_3$, $14A_{4-6}$) length of major septa attains one-half to two-thirds corallite radius; some septa in cardinal quadrants remain distinctly thicker than the rest.

Cardinal protoseptum always on convex side of corallite; in early growth stages only slightly shorter than remaining major septa, in late growth stages usually markedly shortened to ca. one-half length of major septa. In one case major septa shortened to ca. one-third corallite radius, and cardinal protoseptum equal to major septa of cardinal quadrants in length, but twice as thick (Fig. $13A_2$). Cardinal fossula tabular, open, bordered by bent inner ends of 1-3 pairs of major septa of cardinal quadrants. Counter protoseptum amplexoid, in earlier growth stages shortened, in later stage, in sections made near tabula, equal to major septa (Fig. $13A_3$), above tabula shortened (Figs $13A_4$, B, C_3, $14B_1$); usually the thinnest of all major septa; can occur in the open, tabular pseudofossula (Fig. $13A_4$). Alar septa in early growth stages slightly longer than remaining major septa, in later stages do not differ in length. Minor septa appear very early in ontogeny, discernible already at corallite diameter of ca. 6.0 mm (Fig. $13D_1$), a stage when dissepiments have not formed yet. At this growth stage their length is 0.5 mm. Later in ontogeny, their length increases to 1.0 mm, or ca. one-seventh the length of major septa; they do not enter into tabularium. Dissepimentarium variable in width; appears at corallite diameter of ca. 13.0 mm (Fig. $13A_2$, D_3). At calice bottom, in counter quadrants, composed of 2-4 rows of irregular dissepiments, forms a zone 1.5 mm wide (Fig. $14A_5$); in cardinal quadrants becomes narrower and disappears at cardinal protoseptum. In lower part of calice, dissepimentarium built of straight and herringbone dissepiments increases to 3.0 mm in counter quadrants and ca. 1.0

mm in cardinal quadrants (Fig. 14A_6). Tabularium bi-zonal with asymmetric surface. In longitudinal section along C-K line (set by cardinal and counter protosepta) axial tabellae flat or convex with downturned edges, short on the side of counter protoseptum and usually much longer on the side of cardinal protoseptum. As a result, tabularium surface drops gently towards counter protoseptum and steeply at cardinal protoseptum; cardinal fossula deep (Figs 11D_3 – right side, 14A_7, B_2 – right sides). Along straight sections of corallite, axial tabellae more closely spaced (ca. 24 per 10 mm corallite length) than along arching ones (ca. 12 per 10 mm). In outer zone of tabularium, peripheral tabellae vesicular, variously oriented and more widely spaced than in axial area, 7 per 10 mm corallite height. In early growth stages (Fig. 14A_7, lower part of specimen) tabularium formed mostly by trapezoid axial tabellae.

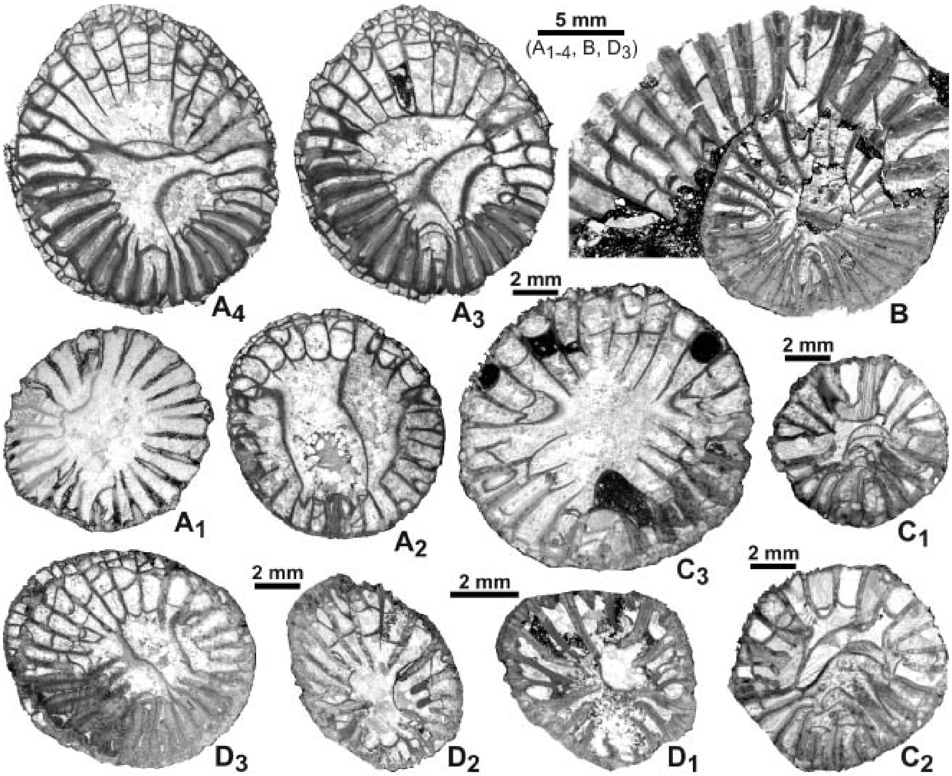


Fig. 13. A-D. *Arctophyllum spitsbergensis* sp. nov., lower part of the Treskelodden Formation.

A – UAMIG.Tc-C.Pol. BI/14; A_{1-4} – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Pol. BI/8; transverse thin sections from mature growth stage.
C – UAMIG.Tc-C.Pol. BIV/12; $C_{1,2}$ – transverse thin sections from immature growth stage, C_3 – transverse thin section from mature growth stage.
D – UAMIG.Tc-C.Pol. BI/16; D_{1-3} – transverse thin sections from immature growth stage.

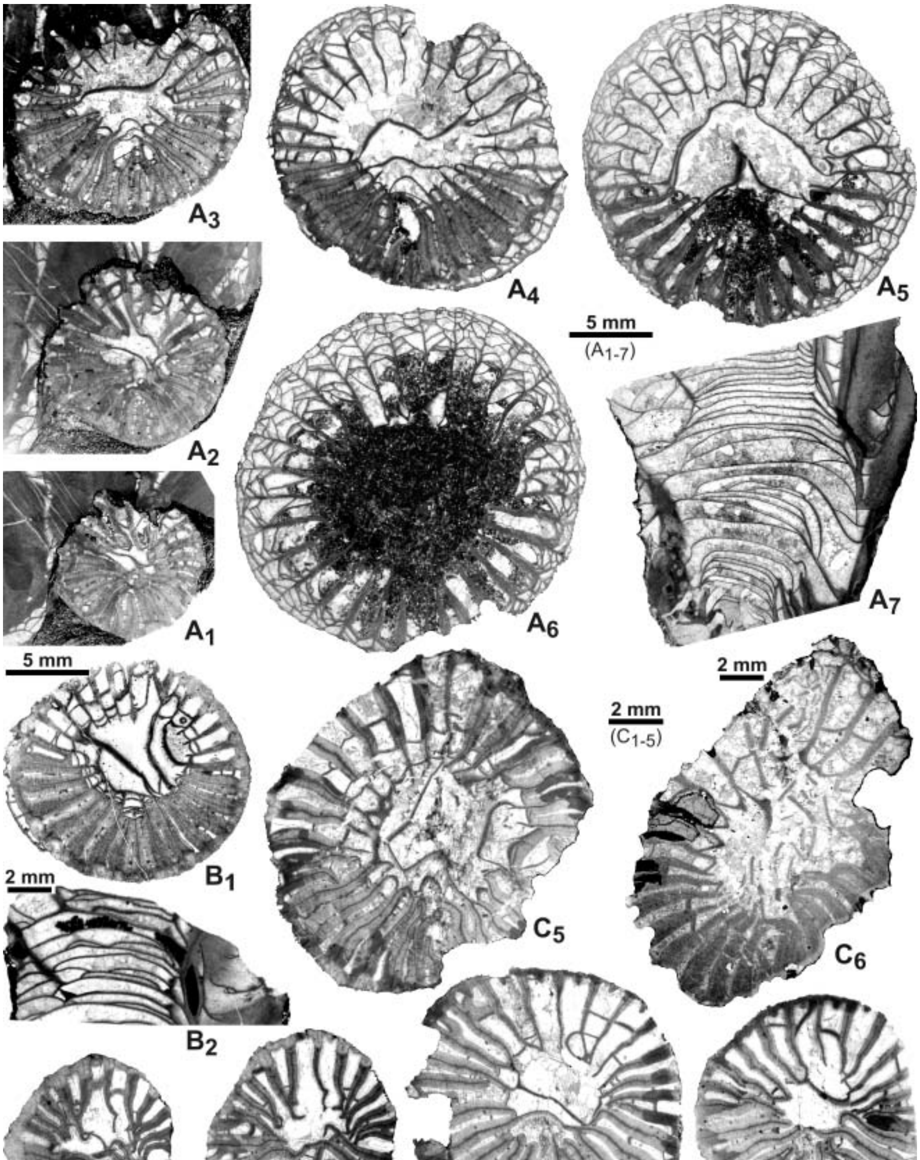


Fig.14. A, B. *Arctophyllum spitsbergensis* sp. nov., lower part of the Treskelodden Formation.

A – UAMIG.Tc-C.Pol. BI/10/5; $A_{1\text{-}3}$ – transverse thin sections from immature growth stage, $A_{4\text{-}6}$ – transverse thin sections from mature growth stage, A_7 – longitudinal thin section.

B – UAMIG.Tc-C.Pol. BII/10; B_1 – transverse thin section from immature growth stage, B_2 – longitudinal thin section.

C. "*Alekseeviella*" sp. A., lower part of the Treskelodden Formation. UAMIG.Tc-C.Pol. BI/6; $C_{1\text{-}4}$ – transverse thin sections from immature growth stage, $C_{5,6}$ – transverse thin sections from mature growth stage.

Intraspecific variability: The paratypes show considerable variability of ontogenetic stages. Individual growth stages differ in the thickness and length of major septa (Fig. 13$A_{1, 2}$, $D_{2, 3}$). In early growth stages also minor septa are variable length (Fig. 13C_1, D_1), as well as cardinal protoseptum, which can be equal to major septa (Fig. 13C_2) or shorter (Fig. 13D_1). In later stages the cardinal protoseptum also varies in length and can be as long as the remaining major septa of cardinal quadrants (Fig. 13D_3), or shorter (Figs 13$A_{3, 4}$, 14B_1). Usually thinner and shorter counter protoseptum can occur in the pseudofossula.

All paratypes have the following features in common: deep cardinal fossula on the convex side of corallite, very short minor septa, dissepiments at corallite diameter of ca. 13.0 mm, tabularium, and usually similar septal numbers and corallite diameters (Fig. 12). In the specimen presented in Fig. 11D, these features greatly differ from typical ones. Still, the remaining features of this specimen are indicative of advanced growth stages of *A. spitsbergensis* rather than of any other species.

Remarks: In comparison with *A. intermedium* from Bellsund (Fedorowski 1975), or Polakkfjellet (described above), *A. spitsbergensis* sp. nov. has a generally smaller number of septa at similar corallite diameters (Fig. 12), shorter minor septa limited to the outer zone of the dissepimentarium, a deeper main fossula, and a unique form of the tabularium. The latter in *A. intermedium* is built of convex, irregular tabellae, similar in number in the axial part of the corallite and in the peripheral part of the tabularium. Besides, in *A. spitsbergensis* sp. nov. tabellae and tabulae are trapezoid, while in early growth stages of *A. intermedium* the surface of the tabularium is inclined towards the cardinal protoseptum. The variable spacing of tabellae throughout ontogeny, especially in axial parts (Fig. 14A_7), was probably caused by different growth rates of corallite connected with changed direction of growth: greater density of tabellae along straight sections of corallites and smaller density along arching ones.

The *A. spitsbergensis* sp. nov. differs from *A. lugankaensis* from the Lower Gzhelian of the Donetsk Basin (Ogar 2010), the following features: longer and thickened major septa in early growth stages, a amplexoid counter protoseptum which is differ from the remaining major septa in terms of thickness, longer alar septa in early growth stages, n/d indices ranging from 24-26/10-11 to 30-33/15-21 (*vs.* 20-24/10-15 to 30/19; Fig. 12), and a dissepimentarium appearing later in ontogeny (at corallite diameter of 13 mm, *vs.* 6.5 mm in *A. lugankaensis*), which attains a maximum of 4 rows of dissepiments (*vs.* 8-10 in *A. lugankaensis*). The differently formed tabularium surface was intentionally omitted in the above comparison because it seems that the longitudinal section of *A. lugankaensis* was not performed along the C-K line, and so the bi-zonal tabularium in this species is almost symmetric (see Ogar 2010: fig. 6L).

Occurrence: Spitsbergen: Polakkfjellet, Linnédalen – Gzhelian.

Genus: *Alekseeviella* Kossovaya, 2001

Type species: *Caninia irinae* Gorsky, 1939 [in: Fomitchev 1939].

Diagnosis: See Kossovaya (2001), p. 152.

Remarks: In proposing a new genus, Kossovaya (2001) gives several features, including a "vermicularis" stage in early ontogeny and the thickening of all major septa in early growth stages. However, we cannot observe those features in the type species, because Gorsky (1939) described *Caninia irinae* on the basis of mature growth stages. Kossovaya (2001) described the ontogeny of *Alekseeviella* on the basis of separate sections coming from several specimens representing various growth stages (Kossovaya 2001: the table on p. 154), omitting early growth stages of the *C. irinae* holotype. This raises the question of whether a series of sections from different specimens, really describes the same species.

In the present author's opinion this name should only be applied conditionally. That is why also incomplete specimens from Polakkfjellet for the time being are described as "*Alekseeviella*". The significant features of this genus include a long cardinal protoseptum present in ontogeny from the immature to early mature stages, a counter protoseptum unremarkable as to length, a narrow, interseptal dissepimentarium, and convex tabulae.

"*Alekseeviella*" sp. A
Fig. 14C

Material: One incomplete, partly corroded corallite (UAMIG.Tc-C.Pol. BI/6). Three peels and six transverse thin sections.

Description: The preserved fragment presents immature (Fig. 14$C_{1\text{-}3}$) and mature (Fig. 14$C_{4\text{-}6}$) growth stages. In the earliest ontogenetic stage available, at n/d = 20/6.5, major septa are varying in length, in cardinal quadrants longer and thicker than those in counter quadrants. Cardinal protoseptum equal in length to metasepta of the second pair of cardinal quadrants, which are the longest in late immature and early mature growth stages; in some sections their inner ends can fuse (Fig. 14$C_{2,3}$; in C_4 they are connected by tabula). Those septa can be markedly shortened at the mature stage, together with remaining major septa of cardinal quadrants (Fig. 14C_5), the cardinal protoseptum including. Counter protoseptum thin, similar to neighbouring major septa in length, in early growth stage in open pseudofossula. Alar septa in all growth stages equal to major septa of cardinal quadrants in length (an exception is immature growth stages with elongated metasepta of the second pair). Minor septa discernible in external wall as early as at corallite diameter of 7.0 mm (Fig. 14C_2), and in corallite lumen at corallite diameter of 8.5 mm; better developed in counter quadrants than in cardinal ones. Dissepiments observed below the calice bottom (Fig. 14C_6).

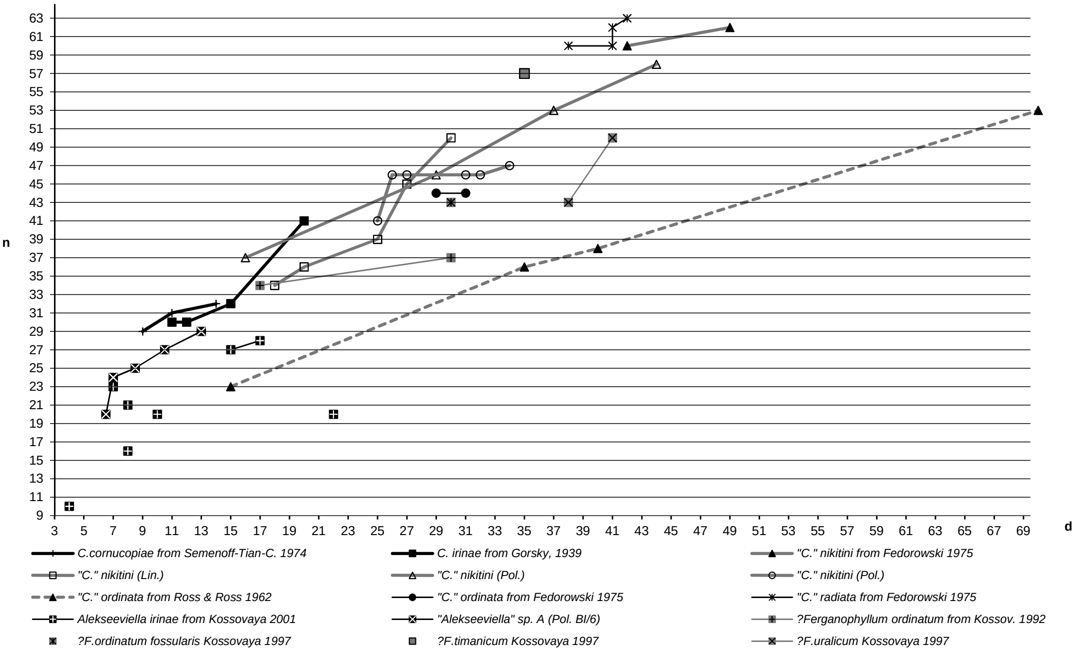


Fig. 15. Plot of the number of major septa (n) *vs*. diameters (d) of *Caninia*, "*Caninia*", *Alekseeviella*, *?Ferganophyllum*. Symbols joined by lines represent values taken from individual specimens.

Remarks: The specimen examined has many features in common with *Alekseeviella* (*sensu* Kossovaya 2001), especially an elongated cardinal protoseptum, long persisting in ontogeny, thin counter protoseptum of unremarkable length, and a narrow dissepimentarium appearing late in ontogeny. Unfortunately, since the earliest growth stages are lacking, it is impossible to state if this specimen had, from the very beginning of its growth, a "vermicularis" stage (*sensu* Carruthers 1908: 161) – in the opinion of Kossovaya (2001), characteristic of this genus.

Occurrence: Spitsbergen, Polakkfjellet – Gzhelian.

Genus: *Caninia* Michelin in Gervais, 1840

Type species: *Caninia cornucopiae* Michelin in Gervais, 1840.

Diagnosis: See Hill (1981), p. F339.

Discussion: The genus *Caninia* has been discussed for more than 100 years. The ontogenesis of the type species was closely studied already at the start of the previous century by Carruthers (1908) and Saleé (1910). Carruthers (1908: 158-171) observed four growth stages in the ontogeny of *Caninia cornucopiae*. Starting with the earliest, those were: 1) "vermicularis", with protosepta reaching corallite axis, deep, narrow cardinal fossula with parallel walls, long major septa, and no minor septa; 2) "dumonti", with shortened cardinal protoseptum but still elongated counter protoseptum, slightly shortened major septa bordering inner part of cardinal fossula, and with first minor septa; 3) "nystiana", with amplexoid major septa shorter than in previous growth stage, shortened and dilated cardinal fossula, but still elongated counter protoseptum; and 4) "cornu-bovis", with amplexoid major septa shortened to ca. one-half corallite radius, equally short, deep cardinal fossula with shortened cardinal protoseptum, the first dissepiments; counter protoseptum, elongated so far, at this growth stage becomes equal in length to the remaining major septa of counter quadrants.

In spite of the fairly accurate description of the genus and the type species, over the decades various authors have assigned many forms to *Caninia*, most of which showed a resemblance to this genus only in adult growth stages. Later studies demonstrated that the error in determinations resulted from an insufficient examination of early growth stages of *Caninia*-like corals. A thorough re-examination of their ontogeny has caused many of those specimens to be included in new genera. For example, *Caninia longiseptata* Grek, 1936 or *C. mutafii* Gorsky, 1938, since 1975 have been reassigned to *Siedleckia* Fedorowski, 1975; *Campophyllum intermedium* Toula, 1875 to *Arctophyllum* Fedorowski, 1975; *Pseudozaphrentoides ordinatus* Ross & Ross, 1962 to *Ferganophyllum* Kossovaya, 1987 (*fide* Kossovaya 1992); *Caninia irinae* (Gorsky, 1939) to *Alekseeviella* Kossovaya, 2001.

When comparing his new genus *Siedleckia* against *Caninia*, Fedorowski (1975) recalls and complements the list of features of the latter in which he includes, the following features: a zaphrentoid arrangement of septa in the immature growth stage, the presence of an amplexoid stage, an elongated counter septum in early growth stages, and a very narrow dissepimentarium with a tendency to form lonsdaleoid vesicles. The significance of this last *Caninia* feature, visible in mature growth stages of the type species, is also emphasised by Poty (1981). The dominant role of lonsdaleoid dissepiments in the ontogeny of *Caninia* is also noted by Kossovaya (2001); who in defining a new genus *Alekseeviella*, indicated the absence of lonsdaleoid dissepiments as one of the main features differentiating it from *Caninia*.

Fedorowski (2010) the permanent elongation of the counter protoseptum in *Caninia cornucopiae* Michelin, claims to be the key feature of *Caninia*, differentiating this genus from the other caninoid forms that have not an elongated counter protoseptum in their ontogeny. Carruthers (1908) and Fedorowski (1975, 2010) oblige students to perform a detailed ontogenetic examination of all caninoid forms.

Because of the relative paucity of material and/or impossibility to trace ontogeny in all *Caninia*-like corals in the collection examined, I labelled some specimens temporarily as "*Caninia*", including e.g. *"Caninia" ordinata* (Ross and Ross, 1962) *sensu* Fedorowski (1975). It means I do not agree with the separation of *Ferganophyllum* Kossovaya, 1987 (*fide* Kossovaya 1992), a genus based on *Pseudozaphrentoides ordinatus* Ross and Ross, 1962.

"Caninia" nikitini Stuckenberg, 1905
Fig. 16

1905. *Caninia nikitini* Stuckenberg; Stuckenberg: pp. 19-20, pl. 2, fig. 15.
1975. *"Caninia" nikitini* Stuckenberg, 1905; Fedorowski: p. 39, pl. 1, fig. 4, pl. 2, fig. 4 (cum synon.)

Diagnosis: Corallites cylindrical with n/d index from 37/16 to 58-62/44-49; metasepta from one-half to two-thirds of corallite radius, slightly thickened at tabularium; cardinal protoseptum shortened in open, tabular fossula, bordered by 2-3 pairs of major septa; minor septa attain one-fourth length of major septa; width of dissepimentarium reaching one-third corallite radius; dissepiments interseptal, regular and herringbone; tabularium bi-zonal, axial tabulae wide, on the side of cardinal protoseptum with sharply downturned edges, peripheral tabellae globose.

Material: Six corallites preserved in fragments, locally abraded, without earliest parts (UAMIG.Tc-C.Pol. BIV/1, 3, 4, 5; BVI(4)/11; UAMIG.Tc-C.CrL. I/5/3). Nine peels and 17 transverse thin sections and one peel and one longitudinal thin section.

Description: The fragments under study are up to 5 cm long and represent advanced growth stages; n/d ratio from 34/18 through 45/27 to 50/30 for Linnédalen specimens, and from 37/16 through 41-47/25-34 to 58/44 for Polakkfjellet specimens (Fig. 15). Fragmentarily preserved external wall very thin, up to a mere 0.2 mm. In ontogenetically earliest preserved part of corallite (Fig. 16C_1) major septa of cardinal quadrants greatly thickened. Owing to deformation of axial part of corallite, total length of the septa at this growth stage difficult to estimate, but counter protoseptum clearly longer than at least two pairs of neighbouring major septa, and cardinal protoseptum is as long as most septa of cardinal quadrants. In later growth stages (Fig. 16$A_{1,2}$,

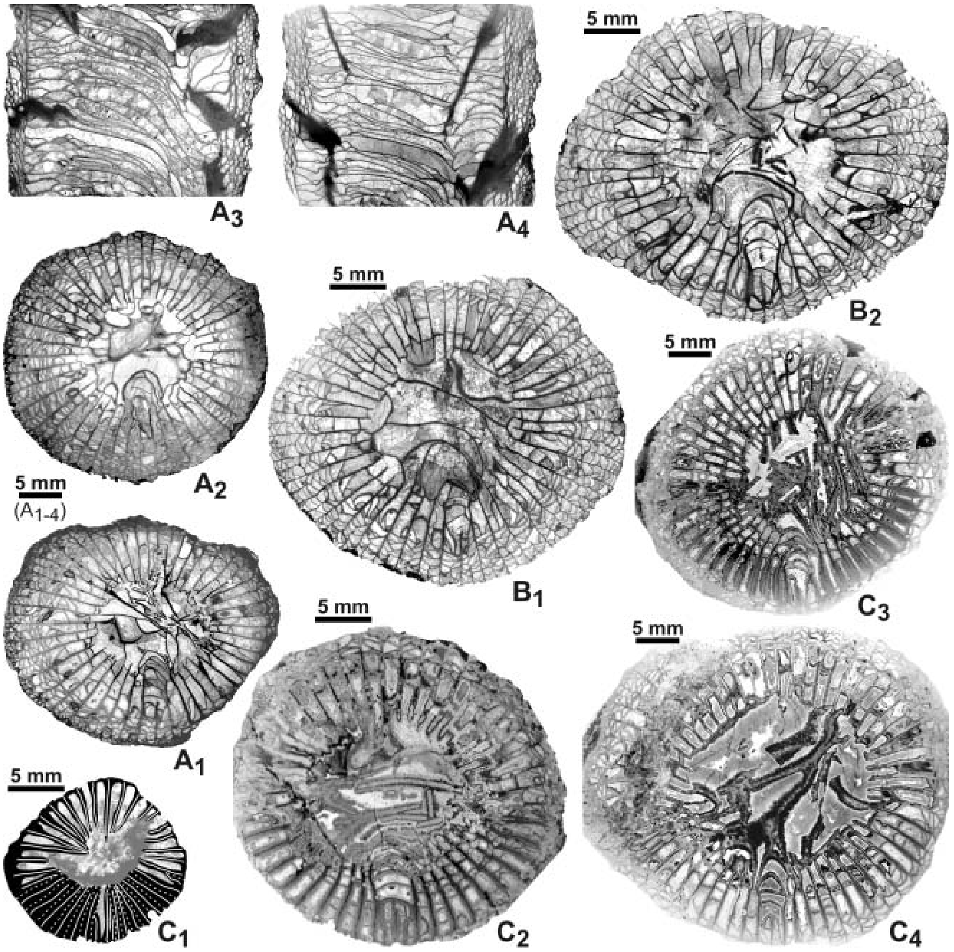


Fig. 16. A-C. "*Caninia*" *nikitini* Stuckenberg, 1905, lower part of the Treskelodden Formation.

A – UAMIG.Tc-C.Pol. BIV/3; $A_{1,2}$ – transverse thin sections from mature growth stage, $A_{3,4}$ – longitudinal thin sections.

B – UAMIG.Tc-C.Pol. BIV/5; $B_{1,2}$ – transverse thin sections from mature growth stage.

C – UAMIG.Tc-C.Pol. BIV/4; C_1 – transverse thin section from immature growth stage, $C_{2\text{-}4}$ – transverse thin sections from mature growth stage.

$B_{1,2}$, $C_{2\text{-}4}$), mostly thin major septa attain two-thirds corallite radius, in cardinal quadrants can be thickened; below calice bottom septa of similar thickness in all quadrants (Fig. 16C_4). Shortened cardinal protoseptum no longer than half length of other major septa, and may be thickened; it always occurs in open, deep tabular fossula, which attains three-fourths corallite radius (Fig. 16$A_{1\text{-}3}$, $B_{1,2}$, $C_{2\text{-}4}$). Fossula bordered by the shortening 2-3 pairs of neighbouring major septa, the pairs joined by means of the traverses of the tabulae. Minor septa reach about 2.0 mm in length, do not extend to full width of dissepimentarium (commonly up to one-half of its width). Dissepimentarium up to one-third corallite radius and mostly built of 8 rows of globose and herringbone dissepiments (Fig. 16$A_{3,4}$, $B_{1,2}$); in external zone of dissepimentarium (containing minor septa) dissepiments are more frequent and dominated by pseudo-herringbone dissepiments. In longitudinal sections (Fig. 16$A_{3,4}$), dissepiments vary in size; bi-zonal tabularium in those sections attains up to three-fourth corallite diameter. Depending on whether the section was made along the C-K line (Fig. 16A_3), or beside it (Fig. 16A_4), tabularium surface is more or less asymmetric. In the first case, in axial zone tabellae of variable morphology, strongly inclined towards cardinal protoseptum, emphasising considerable depth of fossula; tabellae of peripheral zone usually convex, more numerous in counter quadrants than in cardinal quadrants, mostly vesicular; in cardinal quadrants slightly convex at dissepimentarium with downturned edges within fossula and at boundary with axial tabellae. In the latter case, in a section made slightly beside the C-K line, tabularium less asymmetric. Axial tabellae inclined at low angle towards cardinal protoseptum; tabellae in peripheral zone, in counter quadrants of variable morphology, in cardinal quadrants usually convex. Axial tabellae numbering about 13 per 10 mm.

Remarks: The absence of the earliest growth stages precludes a precise determination of the genus. Still, a long cardinal protoseptum and an elongated counter protoseptum in the early growth stage, with preserved *Caninia*-like morphology at maturity, are indicative of *Caninia*. Those stages in Spitsbergen specimens display a close similarity to *"Caninia" nikitini* from Bjørnøya (Fedorowski 1975) dated to the Gzhelian (Fedorowski 1997). It shows comparable n/d indices, development of major septa, presence of a shortened cardinal protoseptum and neighbouring major septa, open cardinal fossula hollowed into dissepimentarium, vesicular tabellae in marginal part of tabularium, and dissepimentarium structure in transverse sections. The Spitsbergen corallites differ from those from Bjørnøya only in having slightly shorter minor septa. This is a feature they share with another species also known from Bjørnøya – *"Caninia" ordinata*, which differs, however, in having a slightly smaller number of septa at similar corallite diameters (Fig. 15), a dissepimentarium attaining one-half corallite radius, and a symmetric tabularium in the longitudinal section, where the axial zone is composed of long tabellae slightly concave in the middle, while those in the peripheral zone are flat-concave and usually placed slightly diagonally towards the top.

Occurrence: Russia, Ural Mts. – Upper Carboniferous; China – Lower to Middle Carboniferous; Carnic Alps – lower part of Upper Carboniferous; Svalbard:

Bjørnøya – Gzhelian (after Fedorowski 1997), Linnédalen, Polakkfjellet – Gzhelian.

Family Bothrophyllidae Fomitchev, 1953
Genus: *Bothrophyllum* Trautschold, 1879

Type species: *Turbinolia conica* Fischer, 1830; *Bothrophyllum conicum* Trautschold, 1879 (by original designation).

Emended diagnosis: See Fedorowski (2004), p. 97.

Discussion: *Bothrophyllum* occurs from the Viséan to the Lower Permian, being typical of the Upper Carboniferous. Fomitchev (1953) placed it, together with *Yakovleviella*, in the new family Bothrophyllidae that he introduced. Hill (1956) included this genus within Cyathopsidae, while Semenoff-Tian-Chansky (1974) classified *Bothrophyllum* into Aulophyllidae on the basis of its axial structure. Fedorowski (1975), in a broad discussion of this genus, agreed with Fomitchev's (1953) decision, and also completed the diagnosis of the genus by adding that "in early ontogenetic stages the arrangement of septa is zaphrentoid with cardinal, counter and some metasepta joined in the axis; in the mature growth stage counter septum typically elongated and cardinal septum shortened, but caninoid stage often developed; microstructure lamello-trabecular". Poty (1981), while recognising the classification and features listed by Fomitchev (1953) and Fedorowski (1975), adds the absence of a median lamella typical of Aulophyllidae in the axial structure of *Bothrophyllum*, and of radial septal lamellae. Also Hill (1981) accepted this classification. In one of the latest studies discussing this genus, Flügel (1993) unquestionably places *Bothrophyllum* in Bothrophyllidae.

Until the appearance of Fedorowski's (1975) work, the insufficient precision in the choice of diagnostic features, among others of *Bothrophyllum*, brought about an excessive multiplication of species and genera, more rarely their synonymisation. When categorising the features of the morphological structure of bothrophylloids, Fedorowski (1975) divided them into variable, hence of little significance for classification, and permanent, of diagnostic significance. In consequence, he classed as *Bothrophyllum* several species from various genera (Fedorowski 1975: 57-58).

Bothrophyllum baeri Stuckenberg, 1895
Fig. 17B

1895. *Bothrophyllum baeri* sp. nov.; Stuckenberg: p. 56, pl. 17, fig. 6.
1937. ?*Bothrophyllum baeri* Stuckenberg; Dobrolyubova: pp. 105-106, fig. 31.
1965. *Bothrophyllum baeri* Stuckenberg; Fedorowski: pp. 29-31, text-fig. 5, pl. 4, figs 1a-b.

Diagnosis: *Bothrophyllum* with n/d value of 61-66/50-58; major septa long with the longest reaching corallite axis; cardinal protoseptum short; counter protoseptum may be elongated; weak axial structure; minor septa attain one-seventh length of major septa; dissepimentarium more than one-third corallite radius in width; tabulae incomplete, inclined towards cardinal protoseptum. [On the basis of descriptions by Stuckenberg (1895), Dobrolyubova (1936*b*), Fedorowski (1965) and own observations].

Material: One specimen (UAMIG.Tc-C.Lin. I/1/6), partly destroyed by recrystallization. Two transverse thin sections.

Description: The specimen under study represents a mature growth stage. Its septal index attains 66/56-58 (Fig. $17B_{1,2}$). Major septa long, some of them reach the corallite axis; in cardinal quadrants, within tabularium strongly dilated. Cardinal protoseptum shortened to ca. one-half length of major septa, in narrow fossula, bordered by five pairs of major septa gradually shortening towards cardinal protoseptum; inner parts of these septa slightly bent over fossula, embracing cardinal protoseptum. Counter protoseptum may be longer than other major septa of counter quadrants (Fig. $17B_1$). Axial structure loose in the axial zone, consisting of sections of tabulae and inner parts of some major septa. Minor septa short, straight, attaining ca. one-tenth corallite radius. Dissepimentarium occupies nearly one-half corallite radius in counter quadrants and ca. one-third corallite radius in cardinal quadrants; built of several series of flat and herringbone dissepiments.

Remarks: This specimen shows a great similarity to the one described by Fedorowski (1965), coming from Lorchbreen (the Hornsund region), from coral horizon V. A difference can only be noticed in the structure of the cardinal fossula. In the specimen described above, it is narrower, and the inner ends of septa that border it are bent only slightly. The minor difference in n/d indices (61/50 for the specimen from Lorchbreen *vs.* 66/56 for the Linnédalen one) may be due to the growth stages being slightly later in the material examined.

Occurrence: Russia: Moscow Basin – ?Carboniferous (recently considered by Russian geologists to be rather Lower Permian); northern and central Urals – Sakmarian-Artinskian; Spitsbergen: Hornsund, Linnédalen – Lower Sakmarian.

Bothrophyllum permicum Fedorowski, 1965
Fig. 18A

1965. *Bothrophyllum permicum* n. sp.; Fedorowski: pp. 31-37, text-fig. 6, pl. 3, fig. 4, pl. 4, figs 2-3.

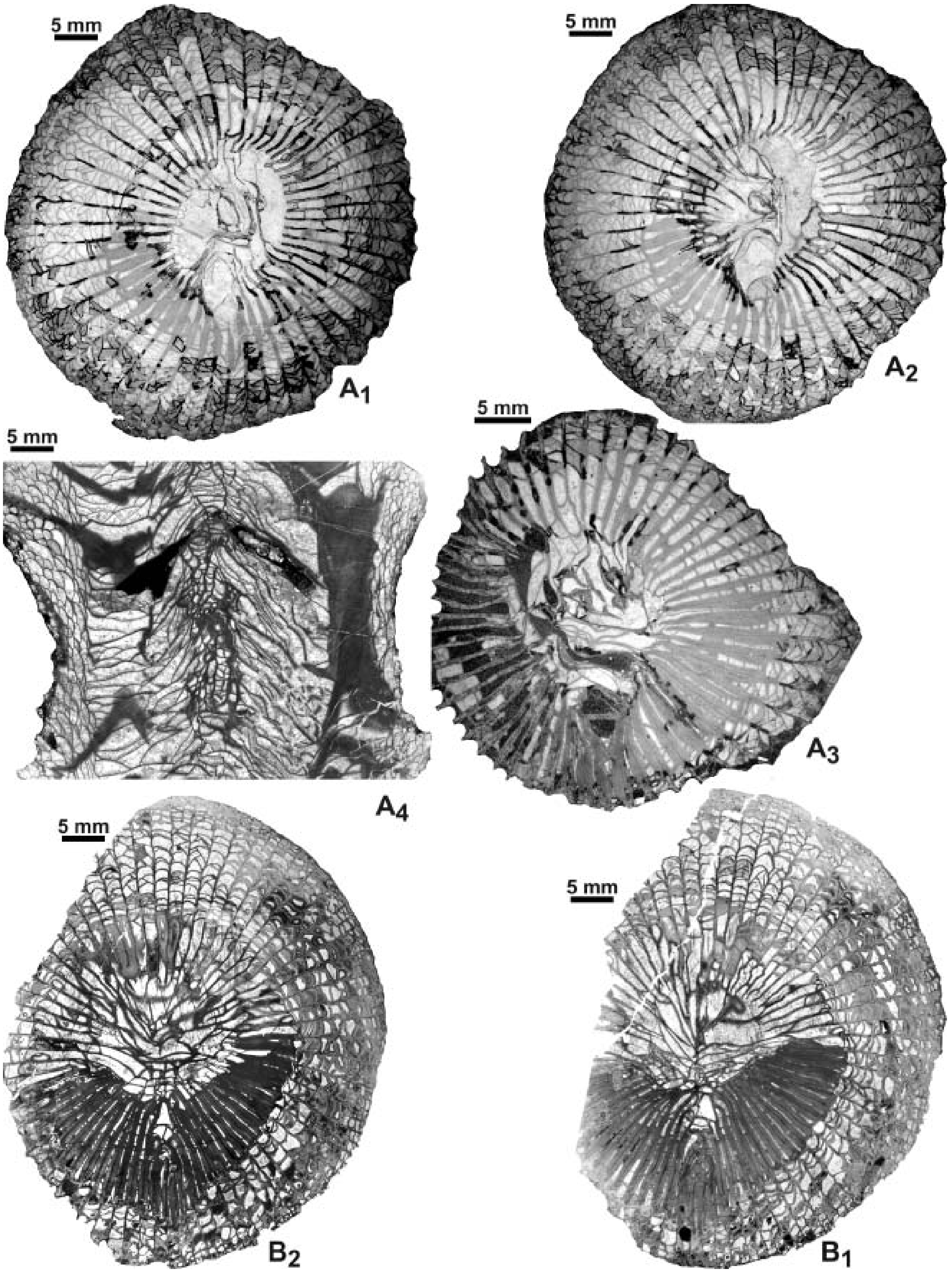


Fig. 17. A. *Bothrophyllum* cf. *pseudoconicum* Dobrolyubova, 1937, lower part of the Treskelodden Formation. UAMIG.Tc-C.Pol. BII/8; $A_{1\text{-}3}$ – transverse acetate peels from mature growth stage, A_4 – longitudinal thin section. B. *Bothrophyllum baeri* Stuckenberg, 1895, Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.Lin. I/1/6; $B_{1,2}$ – transverse thin sections from mature growth stage.

Diagnosis: See Fedorowski (1965), p. 34.

Material: One partly silicified specimen (UAMIG.Tc-C.Lin. I/1/45), preserved without proximal end. External parts of corallites slightly damaged by abrasion. Five transverse thin sections.

Description: The specimen under study is trochoid and represents a mature growth stage. Depth of calice reaches 20 mm. External wall does not exceed 0.2 mm in thickness. In proximal part of mature corallite (Fig. $18A_1$), n/d index attains 31/14; below calice bottom (Fig. $18A_{2,3}$), 36/22-25; in calice (Fig. $18A_4$), 43/33. Major septa long; in the earliest growth stage available, mostly reaching corallite axis. In cardinal quadrants pinnately arranged, in counter quadrants, radially; below calice bottom slightly shortened. Axial zone of corallite, free from septa and ca. 3 mm in diameter. In calice, axial zone free from septa, ca. 5 mm in diameter, shifted towards counter quadrants; major septa of those quadrants are shorter than those of cardinal quadrants. Cardinal protoseptum in all sections shortened to nearly one-half length of major septa. Cardinal fossula open; below the calice bottom it is narrow, bordered by successively shortening 4-5 pairs of major septa of cardinal quadrants; in calice keyhole-shaped, bordered by six pairs of major septa, of which 2-4 outer pairs limit it with their bent inner ends. Counter protoseptum equal in length to remaining major septa of counter quadrants, but below calice bottom slightly thinner. Minor septa, with the exception of the earliest growth stage available, penetrate into tabularium. Below the calice bottom their length is one-fifth that of major septa; in calice, up to one-fourth length of major septa. Owing to abrasion and considerable recrystallization of corallite, dissepimentarium preserved only in fragments; in the section from the earliest growth stage available, one-row type, 0.5 mm in width. Below the calice bottom it attains 2.0 mm in width; in calice, 4.0 mm.

Remarks: When compared with specimens from the Hornsund region, the morphological structure of the preserved corallite fragment suggests that the Linnédalen specimen probably represents earlier growth stages of this species. This is indicated by long, thickened major septa almost reaching corallite axis, a narrow dissepimentarium, and minor septa being one-fourth of major septa in length. Those features, which in this specimen occur in the calice and just below its bottom, in the holotype are observed in the lower segment of the corallite. The supposition that the specimen in question did not attain maturity is also corroborated by its n/d indices, similar to those of the comparable growth stages of the Hornsund corallites: 31/14 *vs.* 32/14x16, 36/22 *vs.* 36/22.5 and 43/33 *vs.* 44/32x37 (for the Linnédalen and Hornsund specimens, respectively). In mature growth stages of typical representatives of the species, major septa are shortened to ca. two-thirds corallite radius and thinner, the dissepimentarium widens to ca. one-third corallite radius, and minor septa, limited to the dissepimentarium zone, constitute ca. one-half length of major septa (Fedorowski 1975: text-fig. 6e). The absence of those features in the specimen under study can be taken as another indication of its incomplete development.

Occurrence: Spitsbergen: Lorchbreen (upper part of Treskelodden Formation) – Lower Permian, Linnédalen (Wordiekammen Formation) – Lower Permian.

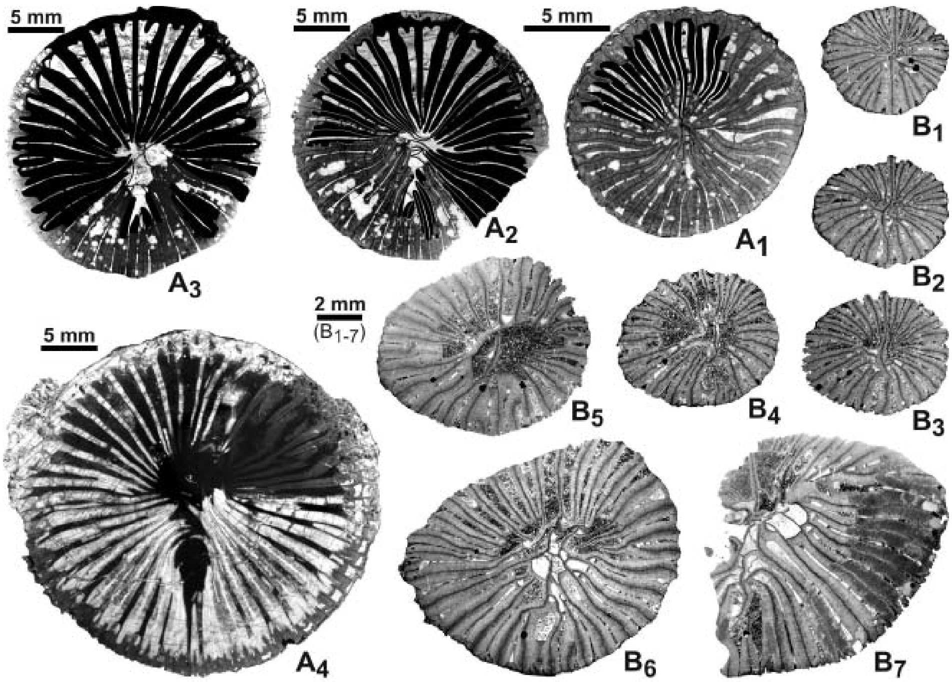


Fig. 18. A. *Bothrophyllum permicum* sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.Lin. I/1/45; A_1 – transverse thin section from immature growth stage, A_{2-4} – transverse thin sections from mature growth stage. B. *Bothrophyllum* cf. *okense*, Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.CrL. I/5/16; B_{1-4} – transverse thin sections from immature growth stage, B_{5-7} – transverse thin sections from mature growth stage.

Bothrophyllum cf. *okense* Kossovaya, 2001

Fig. 18B

Material: Three dolomitised specimens (UAMIG.Tc-C.Pol. VI/9; UAMIG.Tc-C. CrL. I/5/8, 16), preserved without proximal and distal ends. External parts of corallites damaged by abrasion. 16 transverse thin sections.

Description: The specimens under study have ca. 30 mm in length. Dissepimentaria almost completely damaged by abrasion. In immature stage (Fig. $18B_{1-5}$), corallite diameters (= tabularia) are 5.0 to 8.0 mm. Number of major septa changes from 22 to 27. At maturity (Fig. $18B_{6,7}$), the ratio of the number of septa to tabularium diameter changes to 31/12. In proximal parts of corallites major septa much thickened; they fill almost entire corallite lumen; the longest ones, including protosepta and alar septa, fused at the corallite axis (Fig. $18B_1$). In sections of higher parts of specimens (Fig. $18B_{2,3}$), at the corallite axis there are joined protosepta and one major septum from each, cardinal and counter quadrants, or only from cardinal quadrant. In the section illustrated in Fig. $18B_4$, there are major septa shortened to ca. three-fourths tabularium radius; cardinal protoseptum shortened to ca. one-half length of major septa; at the corallite axis inner part of counter protoseptum and thickened section through tabula are to be observed. Another section (Fig. $18B_6$) presents the longest major septa reaching corallite axis; together with tabulae they form a weak axial structure. Protosepta as long as neighbouring major septa; counter protoseptum slightly thinner than remaining major septa. Minor septa penetrate into tabularium to a depth of at least 0.5 mm. At calice bottom, cardinal protoseptum shortened to ca. one-third length of major septa (Fig. $18B_7$). Cardinal fossula, poorly visible in early growth stages, in late stages open, bordered by 2-3 pairs of successively shortening major septa, the inner ends of which can bend towards its interior (Fig. $18B_7$).

Remarks: Specific determination uncertain due to almost complete destruction of dissepimentaria and minor septa; skeletal structures altered diagenetically. It seems, that the cardinal protoseptum (Fig. $18B_4$) is secondarily substantially shortened.

Still, the protosepta fused at the corallite axis and preservation of some metasepta in early growth stages, a long counter protoseptum and a shortened cardinal protoseptum at maturity, as well as an axial structure formed by axial tabellae and inner ends of the longest major septa, are all indicative of *Bothrophyllum*. Of the known species of this genus, the specimens here described show the greatest similarity to *Bothrophyllum okense* Kossovaya, 2001 from the Moscovian of the Moscow Basin in Russia – in the diameters of their tabularia, length of major septa, axial structure, and shape of the cardinal fossula. Unfortunately, incomplete preservation of the skeleton does not allow the specimens under study to be classified as *B. okense*.

In comparison with the other species of this genus known from Spitsbergen (*Bothrophyllum permicum* Fedorowski, 1965; *Bothrophyllum orvini* Fedorowski, 1967 and *Bothrophyllum baeri* Stuckenberg, 1895), the Polakkfjellet and Linnédalen specimens stand out primarily for their decidedly smaller tabularium diameters and a smaller number of septa. What makes them additionally different from *B. permicum* is a better developed axial structure, despite the damage.

Occurrence: Spitsbergen: Polakkfjellet, Linnédalen – Gzhelian.

Bothrophyllum cf. *pseudoconicum* Dobrolyubova, 1937
Fig. 17A

Material: Three specimens (UAMIG.Tc-C.CrL. I/6/17; UAMIG.Tc-C.Pol. BII/7, 8), preserved without proximal ends, abraded to various degrees. Nine acetate peels, four transverse thin sections and one longitudinal thin section.

Description: The specimens under study represent variously advanced mature growth stage. Septal indices of ontogenetically more advanced specimens are 52/47 (Fig. 17$A_{1,2}$) and 55/~40 (Fig. 17A_3). Length of major septa up to four-fifths corallite radius. Cardinal protoseptum thickened and shortened to ca. one-half corallite radius. Cardinal fossula tabular, can reach the corallite axis; it is bordered by 1-3 pairs of successively shortening major septa. Counter protoseptum usually thinner than remaining major septa and can also be longer. Axial structure built of few inner margins of the longest major septa and numerous axial tabellae. Minor septa short and/or weakly developed, only few reach 5.0 mm in length (Fig. 17A_2). Dissepimentarium zone mostly built of herringbone and pseudo-herringbone dissepiments; in counter quadrants occupying ca. one-half corallite radius; in cardinal quadrants narrowing to ca. one-third corallite radius; at external wall dissepiments very small (Fig. 17$A_{1,2}$, left sides). Tabularium bi-zonal. Axial tabellae steeply upturned, longer on the side of cardinal protoseptum than at counter protoseptum, indicating deep fossula. Peripheral tabellae at counter protoseptum flat or convex, inclining at a low angle towards dissepimentarium; tabellae in fossula vesicular, at boundary with dissepimentarium upturned (Fig. 17A_4, right, lower part of the picture). Number of tabellae in peripheral zone at counter protoseptum, 8-10/10 mm.

Remarks: The specimens from Polakkfjellet are very similar to *Bothrophyllum pseudoconicum* from the Upper Bashkirian of the Moscow Basin in Russia described by Dobrolyubova (1937, 1940), especially to specimen no. 469 from her collection (1937: pl. 16, figs 1-3, pl. 17, figs 1-2). The similarity is observed in the formation of a bi-zonal dissepimentarium (with small dissepiments near the external wall and larger, straight and herringbone ones in the interior zone), usually poorly developed minor septa limited to the outer zone of the dissepimentarium, major septa of similar length and thickness, and an axial structure looking similar in transverse sections. However, the largest specimens from the Moscow Basin attain at most 36 mm in diameter, while those from Spitsbergen have diameters 10 mm or more. Some differences are also visible in the structure of the tabularium. While in transverse sections the image of the axial structure formed by interior tabellae is similar in both cases, in longitudinal section of the Spitsbergen specimens the bi-zonality of the tabularium has a different shape. Here axial tabellae are steeply upturned (tent-shaped), short on the side of the counter protoseptum and elongated on that of the cardinal protoseptum, and the outer zone of the tabularium is built of tabellae either declining (counter quadrants) or rising (cardinal quadrants) to the dissepimentarium, features we do not observe in longitudinal sections of specimens illustrated by Dobrolyubova (1937).

In terms of corallite sizes and the number of septa, the specimens under study are close to *B. timanioides timanioides*, described for the first time by Fedorowski (1975) from the Gzhelian of Bjørnøya. What makes them similar, apart from n/d indices (55/40 *vs.* 56/39 in the Bjørnøya specimens), is also the development of dissepimentaria and minor septa. There is a distinct difference, in turn, in the structure of the tabularium (wide, simple, with contratingent tabellae in the peripheral areas in *B. t. timanioides*) and in a more developed axial structure still present at the calice bottom in Polakkfjellet specimens, which disappears at maturity in the Bjørnøya specimens.
Occurrence: Spitsbergen: Polakkfjellet – Gzhelian, Linnédalen – Sakmarian.

Gen. et sp. nov.
Fig. 19

Material: One specimen (UAMIG.Tc-C.Lin. I/1/7), preserved without proximal end. External parts of corallite locally abraded and recrystallized; combined with strong thickening of septa and local deformation of corallite, this makes elements of its morphological structure hardly to observable in longitudinal section. 12 transverse thin sections and one longitudinal thin section.

Description: The specimen under study represents advanced immature and mature growth stages. Its n/d indices are 32-35/11-14 (Fig. $19A_{1-4}$); at calice bottom 39/20x30 (Fig. $19A_5$). Major septa attain about three-fourths corallite radius and reach oval axial structure; strongly thickened, with median part of some septa free from stereoplasmatic thickening (Fig. $19A_5$, lower, right side of the picture). Shortened cardinal protoseptum attains one-third length of major septa. Cardinal fossula open, narrow, bordered by one pair of major septa. Counter protoseptum does not differ from remaining major septa. Axial structure built of several inner margins of the longest major septa and numerous tabulae, it has a structure of fine, irregular net surrounded by thickened tabulae which form a sort of external wall (Fig. $19A_7$). Minor septa

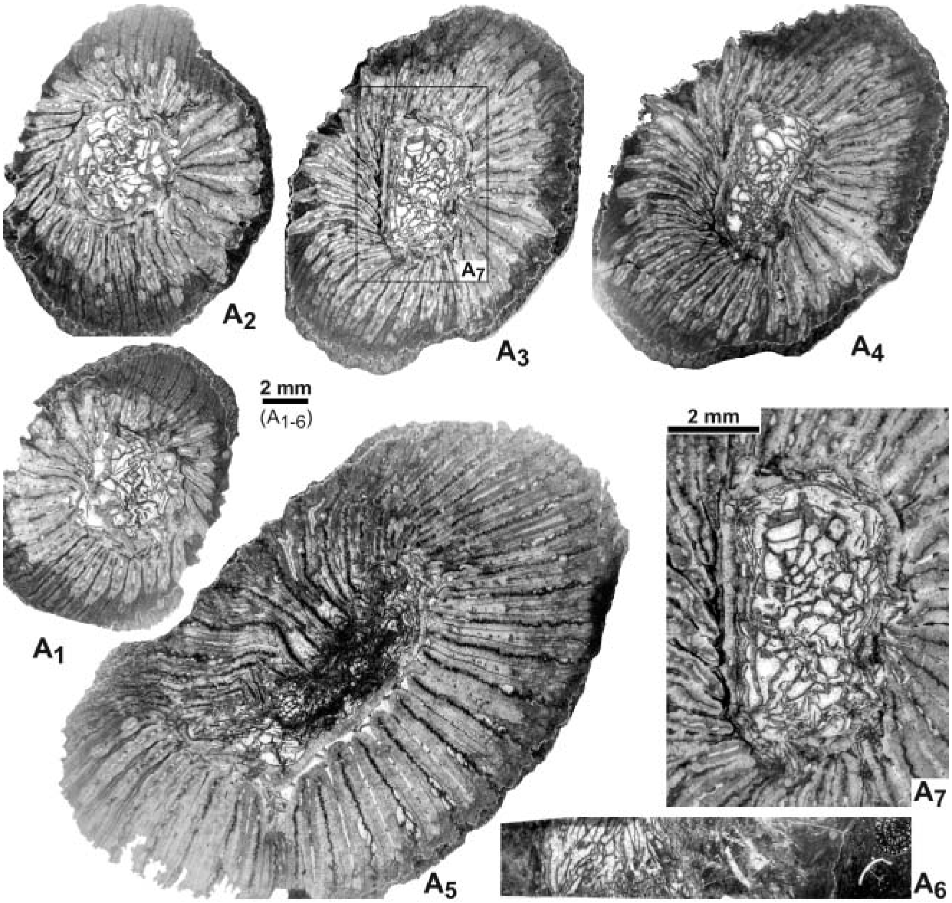


Fig. 19. A. Gen. et sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG. Tc-C.Lin. I/1/7; $A_{1,2}$ – transverse thin sections from immature growth stage, $A_{3\text{-}5}$ – transverse thin sections from mature growth stage, A_6 – longitudinal thin section, A_7 – enlarged fragment of axial part of section illustrated in A_3.

short and poorly developed (Fig. 19$A_{4,5}$). Small dissepiments observable along non-thickened by stereoplasma parts of septa, occupying about one-fourth corallite radius (Fig. 19A_5).

In longitudinal section along the C-K line (Fig. 19A_6), in axial zone of tabularium, very numerous tabellae, varying in size and upturned at steep angle.

Remarks: The Linnédalen specimen is similar to *Bothrophyllum pseudoconicum* described by Dobrolyubova and Kabakovitsch (1948: pl. 3, figs 11-13) from the Kasimovian of the Moscow Basin. The similarity is observed in the axial structure, the occurrence of short minor septa, and the development of major septa in early growth stages. Owing to the deformation of the Linnédalen specimen, it is hard to tell whether at maturity its major septa would also have been similar to those observed in the specimens described by Dobrolyubova and Kabakovitsch (1948). Marked differences, in turn, can be noted in corallite diameters; although only estimated in the case of the Spitsbergen specimen owing to its deformation, and possibly also underestimated (ca. 30 mm below the calice bottom), they clearly exceed the diameters of the Moscow Basin corallites, which attain 20 mm at calice rim.

It is possible that the specimens described by Dobrolyubova and Kabakovitsch (1948) do not belong to *Bothrophyllum*. The authors themselves noted that their specimens showed a similarity to *Aulophyllum*. Regrettably, sparse occurrence (only 4 such specimens are known, together with the one described above) and incomplete preservation of those specimens do not allow for a separate taxon to be created. Still, if a richer material should appear, this is certainly a possibility because the unique axial structure together with the remaining features of the morphological structure are good grounds to do this.

Occurrence: Spitsbergen: Linnédalen – Sakmarian.

Genus: *Caninophyllum* Lewis, 1929

Type species: *Cyathophyllum archiaci* Milne Edwards and Haime, 1852.

Diagnosis: See Hill (1981), pp. F346-348.

Caninophyllum belcheri (Harker, 1960)
Fig. 20B

1960. *Caninia belcheri* n. sp.; Harker: pp. 43-44, pl. 12, figs 1-5.

Emended diagnosis: *Caninophyllum* with n/d index 55-57/40-45; major septa up to three-fourths corallite radius; cardinal protoseptum about half as long as major ones; counter protoseptum usually equal in length to adjacent major septa, may be slightly longer; minor septa about one quarter length of major septa; dissepimentarium occupies about one-half length of major septa; tabulae incomplete, tabellae almost flat with downturned edges.

Material: Two specimens (UAMIG.Tc-C.Pol BVI(4)/12, 14), without proximal and distal ends. Six transverse thin sections.

Description: The illustrated corallite was ca. 50 mm in length and represented a mature growth stage (Fig. $20B_{1\text{-}3}$). External wall, preserved only at places, attains 0.2 mm in thickness. Major septa reaching ca. two-thirds corallite radius, in tabularium of cardinal quadrants thickened to 1.5 mm, in counter quadrants ca. 0.2 mm thick. Septal indices range from 57/36 to 57/45. Cardinal protoseptum shortened to ca. one-half length of major septa. Cardinal fossula narrow, open, bordered by 1-3 pairs of neighbouring major septa, can be slightly longer than major septa of cardinal quadrants. Counter protoseptum can be slightly longer and thinner than remaining major septa of counter quadrants (Fig. $20B_1$). Alar septa similar in length to remaining major septa. Minor septa straight, reaching one-fifth length of major septa. Width of dissepimentarium in proximal part of preserved specimen, ca. one-fifth corallite radius at corallite diameter 35 mm, and in distal part, ca. one-third corallite radius at corallite diameter 45 mm; at cardinal protoseptum slightly narrower. Dissepiments straight, herringbone and sporadically pseudo-herringbone.

Remarks: The specimen described above is morphologically very similar to those described by Harker (1960) from the Grinnell Peninsula (Belcher Channel Formation, Devon Island, Canadian Arctic Archipelago). The similarity is observed in comparable n/d indices (55/40 for the holotype *vs.* 57/40), the structure of the cardinal fossula, the length of the cardinal protoseptum, as well as the width and structure of the dissepimentarium. Some minor differences are visible in the length of major and minor septa. In the specimen from Polakkfjellet, those septa are slightly shorter. Major septa amount to two-thirds corallite radius (*vs.* three-fourths), and minor septa, to one-fifth (*vs.* one-fourth) length of major septa.

Of the remaining species of this genus known from the Arctic area, the feature distinguishing *Caninophyllum ovibos* (Salter, 1855) from the Grinnell Peninsula is the presence of a pseudocolumella (Fedorowski 2010, oral information). The *Caninophyllum calophylloides* [*ad interim*] (Holtedahl, 1913) from the Wordiekammen Formation in Oscar II Land (West Spitsbergen) have smaller corallite diameters and a smaller number of septa than specimens from Polakkfjellet (their n/d indices = 47-50/27-30), a narrower dissepimentarium occupying ca. one-fifth corallite radius, and complete, widely spaced tabulae. Included at present in synonymy with *C. ovibos*, *Caninophyllum calophylloides* should be restored to its original name because the specimens described and illustrated by Holtedahl (1913: 32-33, pl. 10, figs 9-12) probably do not have an axial structure. To resolve the question of the lack/presence of the axial structure a revision of Holtedahl's original material is required. In turn, *Caninophyllum kokscharowi* (Stuckenberg, 1895) known from south Spitsbergen (Treskelen Peninsula) has smaller corallites and/or a smaller number of major septa than *C. belcheri*. The largest specimens of *C. kokscharowi* attain n/d indices of 46/40, and have shorter minor septa reaching one-seventh length of major septa (Dobrolyubova 1936*b*). What distinguishes *Caninophyllum belcheri* (Harker) var. *magnum* Fedorowski, 1965 described below is primarily its larger corallite diameters up to 54 mm (diameters of tabularia to 40 mm) and the number of septa ranging from 61 to 74.

Occurrence: Canadian Arctic Archipelago (Devon Island) – Lower Artinskian; Spitsbergen, Polakkfjellet – Gzhelian.

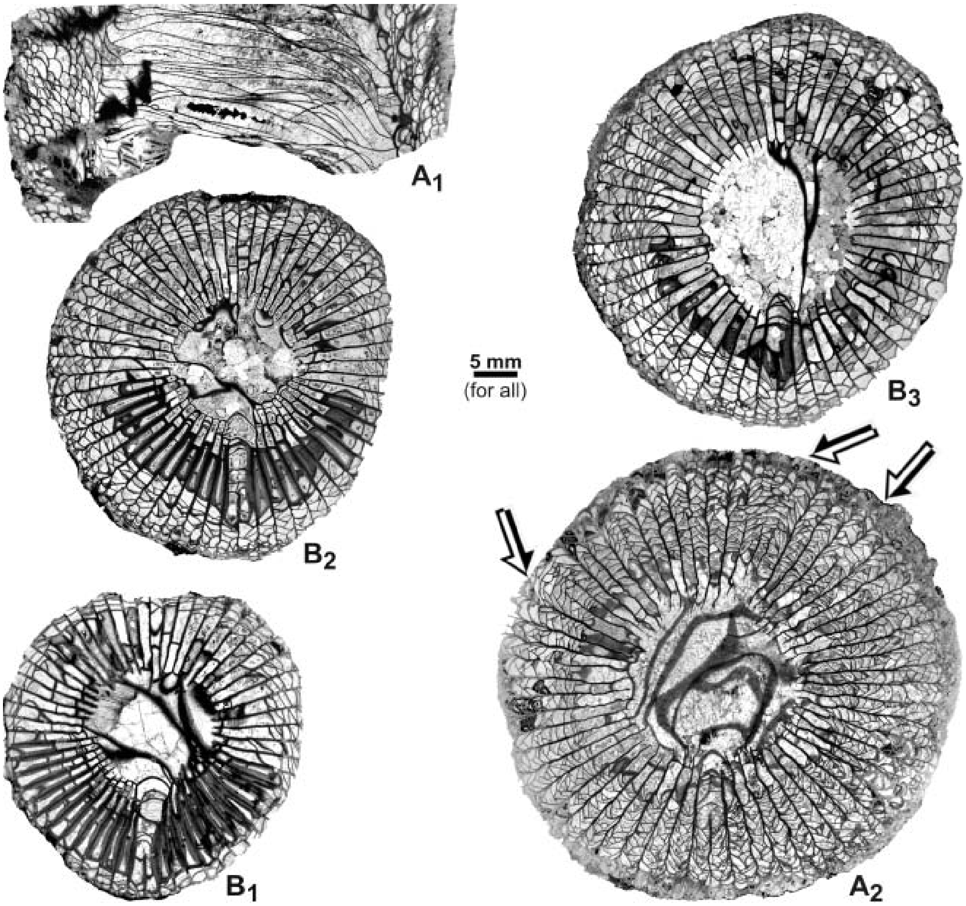


Fig. 20. A. *Caninophyllum belcheri* (Harker) var. *magnum* Fedorowski, 1965, lower part of the Treskelodden Formation. UAMIG.Tc-C.Pol. BVI(4)/2; A_1 – longitudinal thin section, A_2 – transverse thin section from mature growth stage, arrows show lonsdaleoid dissepiments. B. *Caninophyllum belcheri* (Harker, 1960), lower part of the Treskelodden Formation. UAMIG.Tc-C.Pol. BVI/5; $B_{1\text{-}3}$ – transverse thin sections from mature growth stage.

Caninophyllum belcheri (Harker) var. *magnum* Fedorowski, 1965
Fig. 20A

1965. *Caninophyllum belcheri* (Harker) var. *magnum*; Fedorowski: pp. 18-22, pl. 2, fig. 1, text-fig. 2.

Diagnosis: See Fedorowski (1965), p. 18.

Material: One 3-cm long corallite fragment (UAMIG.Tc-C.Pol. BVI/5), preserved without the earliest and latest parts. One transverse and one longitudinal thin sections.

Description: Septal n/d index attains 61/54. Major septa thin, slightly undulated, up to two-thirds corallite radius. Cardinal protoseptum 6.5 mm shorter than major septa, penetrates 3 mm into tabularium (Fig. 20A_2). Cardinal fossula tabular, extensive, open, slightly hollowed into dissepimentarium; deep between the bordering major septa, becoming shallower towards corallite axis. Minor septa in full number, thin, reach at most one-seventh length of major septa (at most one-fifth of width of dissepimentarium). Dissepimentarium occupies nearly one-half corallite radius; slightly narrower at cardinal protoseptum. Dissepiments generally herringbone and pseudo-herringbone, less frequently regular, sporadically lonsdaleoid (Fig. 20A_2, see arrows). In longitudinal section (Fig. 20A_1) dissepiments of varying sizes, generally small, convex, smaller at external wall. Tabularium occupies about two-thirds of corallite diameter. In axial part of corallite, tabulae slightly concave, rarely convex or flat, numbering 14/10 mm; at cardinal protoseptum, at dissepimentarium bent downwards, forming there a deep, tabular fossula (Fig. 20A_1, right side); at counter protoseptum a few additional tabellae upturned towards dissepimentarium.

Remarks: The specimen described above differs from the specimens from the lower Sakmarian of Hornsund described by Fedorowski (1965) in the following features: in a smaller number of major septa (61 *vs.* 70-74) while having similar corallite diameters, shorter minor septa attaining one-fifth (*vs.* one-third) width of the dissepimentarium, and a wider dissepimentarium occupying ca. one-half (*vs.* ca. one-third) corallite radius. Those differences are considered herein to be from the range of variability of this variety, while lonsdaleoid dissepiments, not documented in known *Caninophyllum* specimens, may be an effect of small pathological changes (in one place they co-occur with two shortened major septa, Fig. 20A_2, upper arrow). As incidental, they are therefore of no taxonomic significance. The remaining features, including the length of the cardinal protoseptum, the shape and size of the cardinal fossula, the length of major septa, and the structure of the tabularium, are almost identical with those observed in specimens from the Hornsund area.

Occurrence: Spitsbergen: Treskelen, Hyrnefjellet, Urnetoppen, Lorchbreen, Kruseryggen – Lower Sakmarian; Polakkfjellet – Gzhelian.

Genus: *Gshelia* Stuckenberg, 1888

Type species: *Gshelia rouilleri* Stuckenberg, 1888.

Diagnosis: See Dobrolyubova (1940), pp. 38-39.

Gshelia rouilleri Stuckenberg, 1888
Figs 21, 22A, B

1888. *Gshelia rouilleri* n. sp.; Stuckenberg: pp. 24-25, pl. 3, figs 27-33.
1940. *Gshelia rouilleri* Stuckenberg; Dobrolyubova: pp. 41-49, pl. 9, figs 1-2, pl. 13, figs 11-17, pl. 14-19, pl. 20, fig. 1, pl. 22-25.
1948. *Gshelia rouilleri* Stuckenberg; Dobrolyubova and Kabakovitsch: pl. 1, figs 2-4, pl. 5, figs 4-10.
1973. *Gshelia rouilleri* Stuckenberg; Fedorowski and Gorianov: pp. 52-54, text-fig. 19, pl. 11, fig. 1.
1992. *Gshelia* sp. aff *G. rouilleri*; Ezaki and Kawamura: pl. 2, figs 1a-e.

Emended diagnosis: *Gshelia* with n/d indices from 21/5 through 28-38/10-21 to 50/47x30; major septa reaching corallite axis or terminating within short distance from it; protosepta fused at the corallite axis in immature growth stages, at maturity cardinal protoseptum shortened, counter protoseptum and alar septa may be shortened; pseudocolumella present only in early ontogenetic stages; minor septa apparently not exceeding one-third of length of major septa; dissepimentarium up to one-sixth corallite radius in width, dissepiments small, interseptal.

Material: Ten specimens 2-5 cm in length, partly or wholly silicified [UAMIG. Tc-C.Pol. BI/10/2, BII/1, BII/1/14, BVI(4)/13; UAMIG.Tc-C.Lin. I/1/15, 23, 97, 103, II/1/62, III/1/7]. Five acetate peels and 43 transverse thin sections.

Description: Septal n/d index from 26-32/10.5-18 to 34/20 for the illustrated specimen from Linnédalen (Fig. 22B$_{1-4}$) and from 28/8x11, 33/11x15 to 39/16 for the Polakkfjellet one presented in Fig. 22A$_{1-4}$. Major septa varying in length. In cardinal quadrants pinnately arranged and slightly thicker and longer (to three-fourths corallite radius) than in counter quadrants, where they reach one-half corallite radius (Fig. 22A$_{3,4}$). Major septa in counter quadrants arranged radially in all growth stages. Protosepta joined at the corallite axis in early growth stages; in later ones, cardinal protoseptum shortened to two-thirds /one-half length of major septa in cardinal quadrants, counter protoseptum, initially combined with pseudocolumella, shortens and becomes as long as remaining major septa of counter quadrants. Cardinal fossula open; in growth stages with elongated counter protoseptum can extend to the corallite axis (Fig. 22A$_3$); in the latest growth stage available, shortened and narrowed (Fig. 22A$_4$, B$_4$), in length equalling major septa of cardinal quadrants and bordered by one or 2-3 pairs of neighbouring major septa. Pseudocolumella visible in early growth stages disappears below calice bottom (Fig. 22A$_4$, B$_4$). Alar septa no different from remaining major septa. Minor septa appear early in ontogeny (Fig. 22B$_1$), but are poorly visible owing to almost complete recrystallization of outer corallite surface; in non-recrystallized parts of corallites preserved in fragments, restricted to dissepimentarium zone occupying not more than one-sixth corallite radius (Fig. 22B_5).

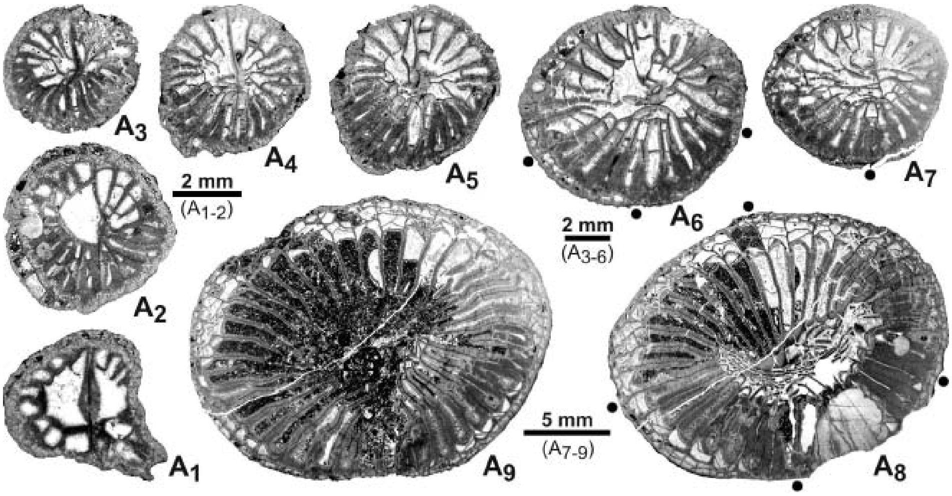


Fig. 21. A. *Gshelia rouilleri* Stuckenberg, 1888, Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.Lin. III/1/7; A_{1-5} – transverse thin sections from immature growth stage, A_{6-9} – transverse thin sections from mature growth stage.

Ontogenesis: The best preserved specimen (UAMIG.Tc-C.Lin. III/1/7; Fig. 21) was ca. 3 cm in length. The earliest growth stage available for study (Fig. 21A_1), protosepta are fused at the corallite axis, with considerable thickening in point of fusion. This feature is additionally emphasised by remaining major septa, diagenetically shortened to ca. one-third corallite radius, which are mostly joined by tabellae.

In slightly later growth stages (Fig. 21$A_{2,3}$), n/d indices are 19-21/5-6. Protosepta joined at the corallite axis. Major septa in cardinal quadrants longer and thicker than in counter quadrants; the longest reach the corallite axis. In the next section (Fig. 21A_4) n/d index is 23/6.5. Protosepta reach the corallite axis, but do not fuse. Metasepta in cardinal quadrants longer and thicker than in counter quadrants; the longest reach the corallite axis. One-row dissepimentarium.

In sections from the next growth stages (Fig. 21$A_{5,6}$) n/d indices amount to 24-25/7-9.5. Major septa in counter quadrants thinner and shorter (their length being ca. one-half corallite radius) than major septa in cardinal quadrants, attaining ca. three-fourths corallite radius. Cardinal protoseptum as long and thick as remaining major septa in cardinal quadrants, counter protoseptum slightly longer than major septa of counter quadrants. Pseudocolumella formed from inner part of counter protoseptum (this feature also visible in specimens illustrated in Fig. 22$A_{1,2}$, $B_{1,2}$). Dissepimentarium narrow, comprises two rows of interseptal dissepiments. Minor septa attain ca. one-tenth length of major septa, limited to dissepimentarium zone.

In mature growth stage, immediately below the calice, septal index equals 26/10 (Fig. 21A_7). Major septa varying in length, in cardinal quadrants generally longer and thicker than in counter quadrants. Cardinal protoseptum shortened to three-fourths length of major septa in cardinal quadrants; counter protoseptum no different from major septa of its quadrants. In corallite axis sections through axial tabellae and median lamella, visible also in Fig. 22A_2; instead of median lamella, in corallite axis there can be an oval (1.5 mm x 3 mm) pseudocolumella, a few sections of tabellae and the longest major septa (Fig. 22B_3). Two-row dissepimentarium built of straight interseptal dissepiments.

At calice bottom (Fig. 21A_8) septal index is 37/16.5. Major septa in cardinal quadrants thicker than in counter quadrants. Cardinal protoseptum or equal in length to major septa of cardinal quadrants, or shortened to ca. two-thirds length of major septa of cardinal quadrants (Fig. 22B_4). Cardinal fossula narrow, open, tabular, bordered by 4 pairs of neighbouring septa whose inner ends are bent towards cardinal protoseptum. Counter protoseptum no different in length from remaining major septa of counter quadrants, but one-half their width, which is also visible in Fig. 22B_4. Dissepimentarium of variable width, in counter quadrants attaining one-fourth corallite radius, in cardinal quadrants narrowing, to disappear completely at cardinal protoseptum. Minor septa attain 0.5 mm in length, which is ca. one-tenth length of major septa; limited to outer zone of dissepimentarium.

In calice (Fig. 21A_9) n/d index is 40/17.5. Major septa in cardinal quadrants longer and thicker than in counter quadrants. Cardinal protoseptum shortened to ca. one-half length of major septa in cardinal quadrants. Counter protoseptum does not differ from remaining major septa of counter quadrants. Dissepimentarium and minor septa developed similarly as at calice bottom. Fragmentarily preserved external wall, from earliest to latest growth stages not exceeding 0.1 mm in thickness.

Fig. 22. A, B. *Gshelia rouilleri* Stuckenberg, 1888. C, D. *Hornsundia lateseptata* Fedorowski, 1965.

A – UAMIG.Tc-C.Pol. BVI(4)/13, lower part of the Treskelodden Formation; $A_{1,2}$ – transverse thin sections from immature growth stage, $A_{3,4}$ – transverse thin sections from mature growth stage.

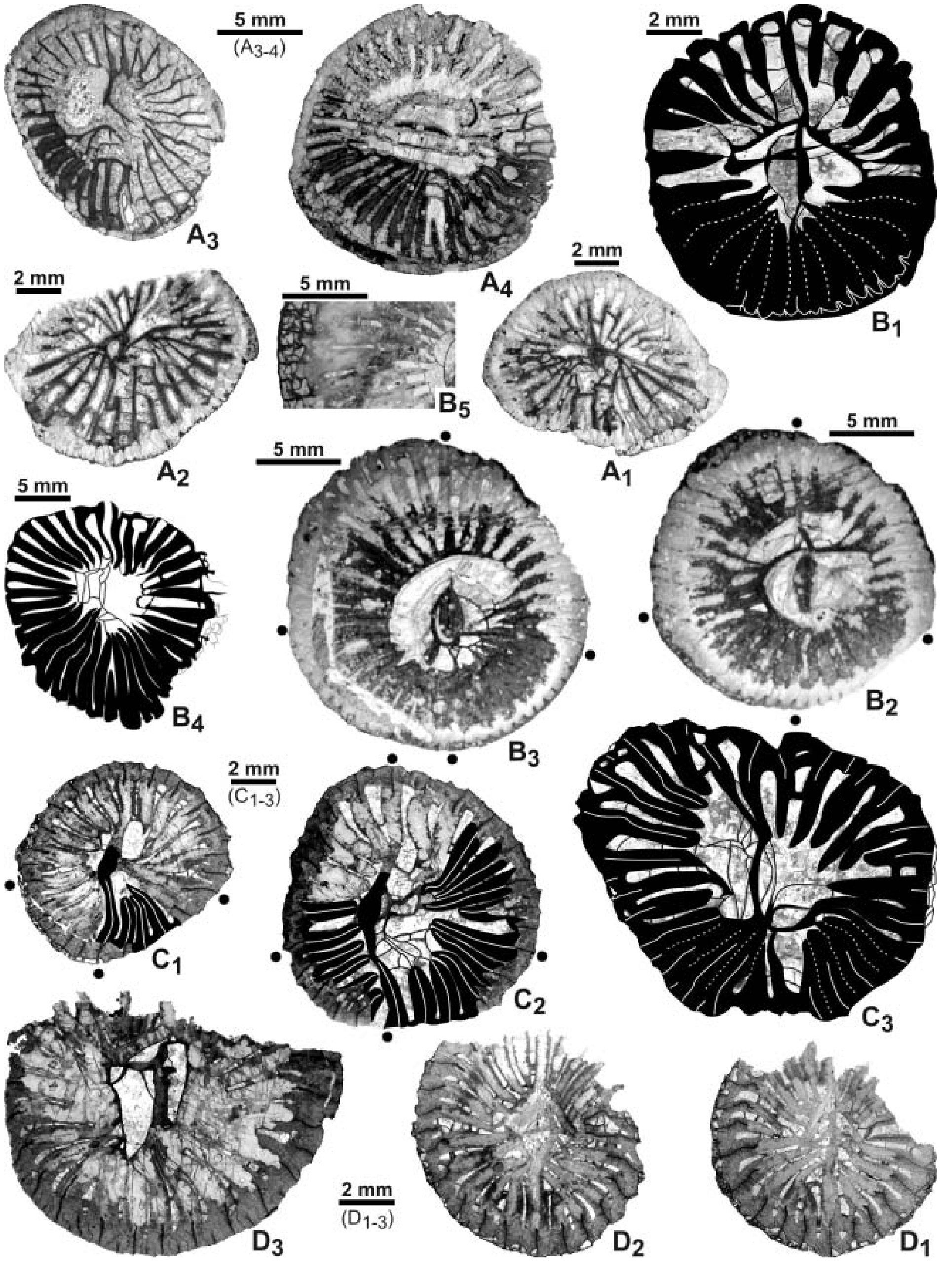
B – UAMIG.Tc-C.Lin. II/1/62, Tyrrellfjellet Member of the Wordiekammen Formation; $B_{1\text{-}3}$ – transverse thin sections from immature growth stage, B_4 – transverse thin section from mature growth stage, B_5 – part of transverse section showing dissepimentarium.

C – UAMIG.Tc-C.Lin. II/1/48, Tyrrellfjellet Member of the Wordiekammen Formation; $C_{1,2}$ – transverse thin sections from immature growth stage, C_3 – transverse thin section from mature growth stage.

D – UAMIG.Tc-C.Lin. II/1/15, Tyrrellfjellet Member of the Wordiekammen Formation; $D_{1,2}$ – transverse thin sections from immature growth stage, D_3 – transverse thin section from mature growth stage.

Protosepta and alar septa marked by dots; cardinal protoseptum, with the exception of colonial specimens, always at the bottom of the illustration – this holds for all figures.

Remarks: A comprehensive description of this species, based on a rich collection (112 specimens from the upper Carboniferous of the Moscow Basin, from the localities of Gzhel and Rusavkino), was made by Dobrolyubova (1940). After a careful examination of the best preserved specimens, she showed their



wide variability. It manifests in sizes and shapes of corallites (from wide cones to cylindrical forms, and the outlines of transverse sections which can be irregular, elliptical or round even in a single specimen), in the variable length of the cardinal protoseptum in different and the same specimens, in a more or less distinct or undeveloped fossula, and in a varying size of an oval or irregular pseudocolumella. Specimens from Polakkfjellet and Linnédalen display the same variability in their morphological structure as those from Russia. Other similarities they share include n/d indices, varying length of major septa, an axial structure disappearing at maturity, fused protosepta in early growth stages, a thin counter protoseptum in mature growth stages, short minor septa, and an early appearance of dissepiments.

The specimens under study (Fig. 22A) differ from the known *G. rouilleri* in a well-developed cardinal fossula in all the observed growth stages (in typical specimens it is usually poorly developed, and in comparably early ontogenetic stages it is mostly lacking), and in longer major septa in cardinal quadrants than in counter quadrants. In other cases the specimens described above differ in an axial structure long lasting in ontogeny. In a few specimens an axial structure could still be found below the calice bottom either as an elliptic pseudocolumella (Fig. 22B_3), or a median lamella (Fig. 21A_7), co-occurring with axial tabellae. Those features, having not been described in *G. rouilleri* so far, can be treated as intraspecific variability.

The occurrence in Spitsbergen of a coral affiliated with *G. rouilleri* was reported earlier by Ezaki and Kawamura (1992). They determined their specimen, coming from the Wordiekammen Formation in the Skansen region (Dickson Land, central Spitsbergen), as *Gshelia* sp. aff *G. rouilleri*. It is a pity they only limited themselves to illustrations of a few transverse sections, without supplying a description, which makes it impossible to compare this specimen with the Linnédalen and Polakkfjellet specimens with any accuracy. Still, given the illustrations, it was possible to state, that the specimen shares the features of corals I examined. The early growth stages of the specimen from Dickson Land (Ezaki and Kawamura 1992: pl. 2, figs 1a-d), with long major septa, a distinct cardinal fossula, and a lamellar axial structure, are closer to the Polakkfjellet specimen, while the adult stage growth (Ezaki and Kawamura 1992: pl. 2, fig. 1e), with long major septa and numerous transverse sections through tabellae in the axial zone is closer to the comparable stage of the Linnédalen specimen (Fig. 22B_4). Keeping in mind the great infraspecific variability of *G. rouilleri*, it is highly probable that the specimen illustrated by Ezaki and Kawamura (1992) belongs to this species, especially that, like the Linnédalen and Polakkfjellet corals, it has an entire set of the remaining features of *G. rouilleri*, including short minor septa, a narrow dissepimentarium, and an elongated counter protoseptum connected with the axial structure in early ontogenetic stages. Also its septal n/d indices (21/7, 25-29/9-13 and 33-36/16-17.5) are comparable with both, those of the specimens I examined, and of some specimens from the Moscow Basin (22/6-8, 25/7-8, 29/10-15, 34/17).

Occurrence: Russia, Moscow Basin – ?Carboniferous (recently considered by Russian geologists to be rather Lower Permian); Spitsbergen: Skansen, Linnédalen (Wordiekammen Formation) – Lower Permian, Polakkfjellet – Gzhelian

Genus: *Hornsundia* Fedorowski, 1965

Type species: *Hornsundia lateseptata* Fedorowski, 1965

Diagnosis: See Fedorowski (1965), p. 37.

Hornsundia lateseptata Fedorowski, 1965
Fig. 22C, D

1965. *Hornsundia lateseptata* n. sp.; Fedorowski: pp. 37-42, text-fig. 7, pl. 2, fig. 8.
2009*a*. *Hornsundia lateseptata* Fedorowski; Chwieduk: pp. 71-72, text-fig. 8A-B.

Diagnosis: See Fedorowski (1965), p. 40.

Material: Five specimens (UAMIG.Tc-C.Lin. II/1/7, 15, 37, 48; UAMIG.Tc-C.CrL. I/6/7), representing small fragments abraded to a considerable degree. 17 transverse thin sections.

Description: The preserved fragments represent immature (Fig. $22C_{1,2}$, $D_{1,2}$) and mature growth stages (Fig. $22C_3$, D_3). Septal indices from 24/9 to 34/14. In immature growth stage major septa thickened, differing in length, with the longest reaching corallite axis; protosepta fused at the corallite axis. In mature growth stage, major septa vary in length and thickness, but do not attain corallite axis; protosepta no different from remaining major septa of their quadrants, at the corallite axis connected by thickened, arching section of tabula. Moderately broad and open cardinal fossula best developed in advanced growth stage (Fig. $22C_3$). Alar septa do not differ in length from long major septa in cardinal quadrants. Minor septa 0.5 mm in length. Two-row dissepimentarium, ca. 1.0 mm wide, appearing fairly early in ontogeny (Fig. $22C_1$, D_1).

Remarks: Although the corallites described above are not complete, the preserved features of their morphological structure indicate early growth stages of *H. lateseptata*. In comparison with representatives of this species known from the Hornsund region, the specimens from Linnédalen are closely similar to the *Hornsundia lateseptata* from Urnetoppen collected from horizon V and described by Fedorowski (1965). Only an earlier appearance of dissepiments, visible in the examined specimens already at corallite diameters of ca. 9.0 mm, differentiate them from those of the Hornsund region (Fedorowski 1965: text-fig. 7), where dissepiments appear at corallite diameter of ca. 16 mm.

Occurrence: Spitsbergen: Hyrnefjellet, Urnetoppen, Kruseryggen, Linnédalen – Lower Sakmarian.

Genus: *Pseudotimania* Dobrolyubova and Kabakovitsch, 1948

Type species: *Timania mosquensis* Dobrolyubova, 1937.

Diagnosis: See Dobrolyubova and Kabakovitsch (1948), p. 8.

Pseudotimania arctica sp. nov.
Figs 23, 24

1992. *Pseudotimania* sp. A; Ezaki and Kawamura: pl. 2, fig. 2.

Holotype: UAMIG.Tc-C.Pol. BIV/21 (Fig. $23A_{1\text{-}11}$). 11 transverse thin sections and one longitudinal thin section.

Type locality: Polakkfjellet (N 77° 13.498′; E 16° 01.933′), south Spitsbergen (Fig. 2D).

Type horizon: Lower part of Treskelodden Formation, Gzhelian.

Derivation of name: *arctica* – from the Arctic region.

Diagnosis: *Pseudotimania* with septal indices from 25-42/8-25 to 56/45; major septa may reach corallite axis; in early growth stages protosepta fused at the corallite axis; at calice bottom cardinal protoseptum shortened; cardinal fossula distinct; minor septa short and not extending throughout the width of dissepimentarium, the latter attaining one-fifth corallite radius; dissepiments generally normal and herringbone; tabulae incomplete.

Material: Paratypes – 16 corallites, abraded and silicified to various degrees, representing adult growth stages (UAMIG.Tc-C.Lin. I/1/22, 70, 89, 94, 98, 116, 120; UAMIG.Tc-C.Lin. II/1/1, 4, 17, 35, 42, 49; UAMIG.Tc-C.CrL. I/4/3; UAMIG.Tc-C.CrL. I/6/14, 15). 56 transverse thin sections.

Description of holotype: Corallite trochoid. The examined sections are from immature (Fig. $23A_{1\text{-}4}$), early mature (Fig. $23A_{5\text{-}7}$) to late growth stages (Fig. $23A_{8\text{-}10}$). Septal indices at calice bottom (Fig. $23A_{8,\,9}$) are 37-40/19-20. Major septa varying in length and thickness, the longest, including counter protoseptum, reaching corallite axis. In cardinal quadrants thicker than in counter quadrants; in earlier growth stages thickened in all quadrants. At maturity major septa of neighbouring (cardinal – counter) quadrants can combine, thus emphasising bilateral symmetry of corallite (Fig. 23A$_{5-9}$). Minor septa poorly developed, limited to outer zone of narrow dissepimentarium (Fig. 23A$_{10}$). Surface of tabularium domed (Fig. 23A$_{11}$), tabulae incomplete, vesicular, in counter quadrants more numerous (7/5 mm) than in cardinal quadrants (3/5 mm), at the corallite axis declining, with long outer edges downturned almost vertically and short interior edges inclining gently; at boundary with dissepimentarium, in cardinal quadrants additional, straight tabellae slightly upturned towards inner part of corallite.

Ontogeny of holotype: In the earliest section available, septal index = 25/6 (Fig. 23A$_1$). Major septa of varying length; protosepta and alar septa join at the corallite axis. Owing to recrystallization, this feature is poorly visible in enclosed illustration. External wall and peripheral intraseptal spaces silicified.

In section made ca. 2 mm above previous one, septal index is 26/8 (Fig. 23A$_2$). Major septa of varying length. Protosepta, alar septa and one major septum of each, cardinal and counter quadrants fused at the corallite axis. Minor septa attain 0.3 mm in length. Single-row dissepimentarium. Fragmentarily preserved external wall does not exceed 0.1 mm in thickness.

In the next section, with septal index of 28/10 (Fig. 23A$_3$), protosepta, middle septa of all quadrants and one alar septum combine at the corallite axis. Cardinal fossula, bordered by 3 pairs of shortening major septa of cardinal quadrants, reaches corallite axis. Minor septa short, visible only in the vicinity of counter protoseptum. Because of corallite abrasion along its entire circumference and partial silicification of its peripheral part, it was impossible to measure thickness of external wall.

At septal index of 31/11 (Fig. 23A$_4$), all major septa of similar thickness, but varying in length. Counter protoseptum the longest, slightly crossing corallite axis. Its inner part touches the longest major septa, including hooked inner end of cardinal protoseptum. Silicification and/or abrasion of outer part of corallite makes minor septa and dissepimentarium impossible to observe. External wall abraded.

In next sections made at intervals of ca. 3 mm, n/d indices amount to 32/14 and 36/15 (Fig. 23A$_{5,6}$). Major septa of varying length, thinner in counter quadrants than in cardinal ones. They can fuse near/at the corallite axis. Cardinal protoseptum elongated, but not extending to the corallite axis. Cardinal fossula narrow, triangular, bordered by two pairs of neighbouring major septa. Counter protoseptum elongated; in section illustrated in Fig. 23A$_6$ it combines with 5th septum major of cardinal quadrant. Peripheral part of corallite silicified. Preserved transverse sections through tabellae indicative of "biformly reduced" tabularium (*sensu* Fedorowski 1987: 10).

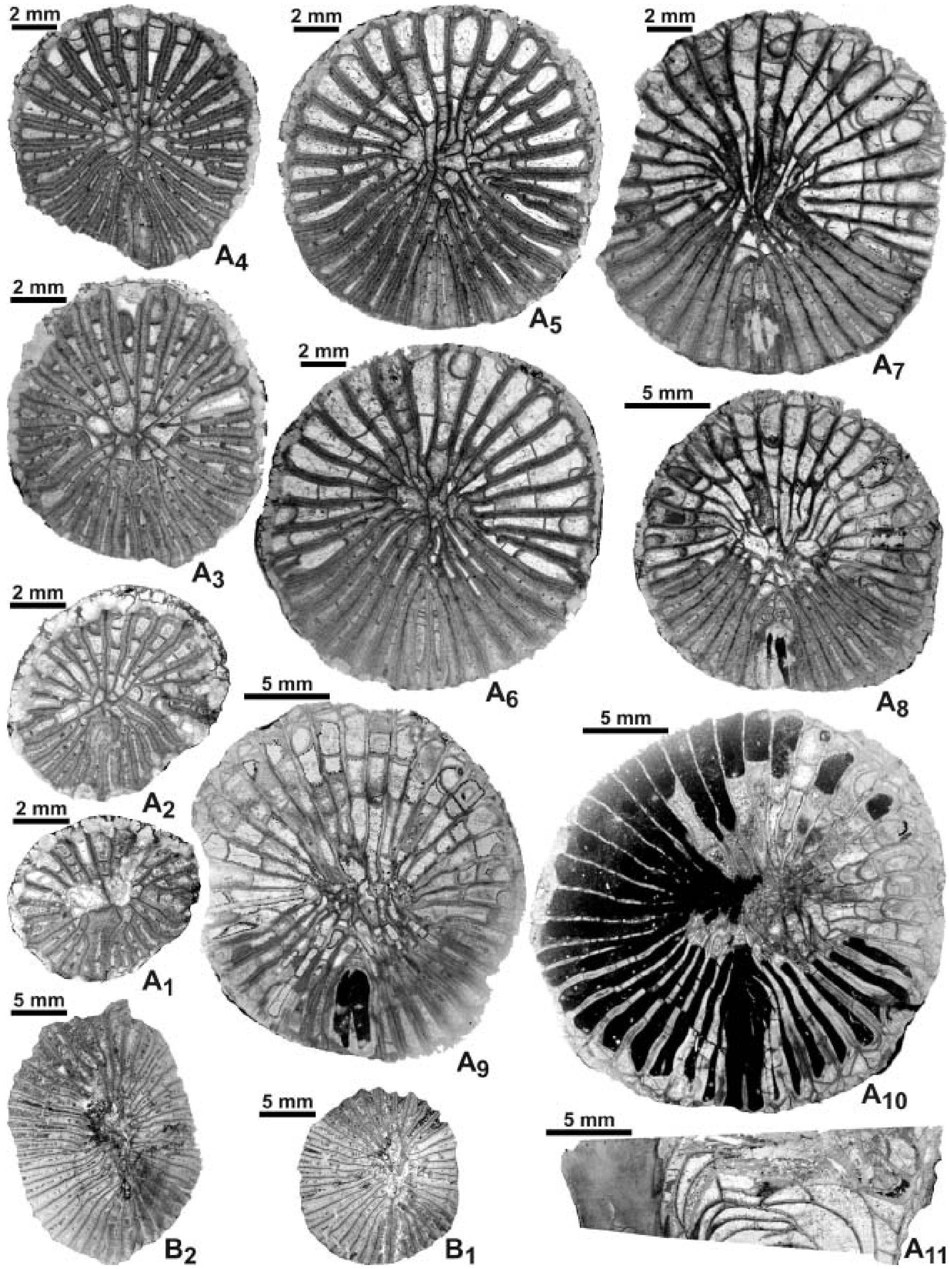


Fig. 23. A, B. *Pseudotimania arctica* sp. nov.

A – UAMIG.Tc-C.Pol. BIV/21, lower part of the Treskelodden Formation; $A_{1\text{-}4}$ – transverse thin sections from immature growth stage, $A_{5\text{-}10}$ – transverse thin sections from mature growth stage, A_{11} – longitudinal thin section.

B – UAMIG.Tc-C.Lin. I/1/87, Tyrrellfjellet Member of the Wordiekammen Formation; $B_{1,2}$ – transverse thin sections from mature growth stage.

In sub-calice part (Fig. 23A_7), n/d index is 37/17. Major septa of varying length, the longest, including counter protoseptum, reaching corallite axis, but not fused. Of remaining major septa, some merge near corallite axis. Cardinal protoseptum shortened to ca. two-thirds the corallite radius, equal in length to neighbouring 2nd pair of major septa. Cardinal fossula open, bordered by three pairs of successively shortening major septa. Because of heavy abrasion of corallite, minor septa and external wall not visible. Preserved dissepimentarium built of regular and herringbone dissepiments.

In next sections made through calice bottom ca. every 2 mm, n/d indices equal 37/19 and 40/20 (Fig. 23$A_{8, 9}$). Here, major septa of variable length can fuse in near-axial zone; counter protoseptum elongated. At fossula bottom, cardinal protoseptum almost reaches corallite axis (Fig. 23A_8); slightly above the bottom it shortens to one-fourth the corallite radius (Fig. 23A_9). Cardinal fossula deep, oval, bordered by 2-3 pairs of successively shortening major septa. Fragmentarily preserved external wall attains 0.1 mm in thickness. Dissepimentarium widest at counter protoseptum where it occupies ca. one-sixth corallite radius; towards cardinal protoseptum it gradually narrows, to disappear completely; built of regular and herringbone dissepiments.

In calice (Fig. 23A_{10}) septal index amounts to 42/25. Major septa, although mostly long, do not reach corallite axis. Cardinal protoseptum shortened to 2 mm, or ca. one-fifth the corallite radius. Counter protoseptum does not differ from remaining major septa of counter quadrants. Poorly developed minor septa attain 0.5 mm in length and occupy peripheral part of narrow, ca. 2-mm wide dissepimentarium, built of regular and herringbone dissepiments.

Description of paratypes: The specimens under study represent immature (Fig. 23B_1) to mature growth stages (Figs 23B_2, 24A-F). Although they are all silicified to a greater or lesser extent, they have kept the features of the new species (long major septa, elongated cardinal protoseptum long persisting in ontogeny, narrow cardinal fossula, and narrow dissepimentarium). Slight deviations can be observed in the number of septa, which is usually smaller than in the holotype at the same corallite diameters (Fig. 25). In three specimens (Fig. 24$A_{1, 2}$, C, $E_{1, 2}$), at more advanced growth stages, corallite diameters greatly exceed those of the holotype and the remaining paratypes. Notable among other features are a thin counter protoseptum (Fig. 24$A_{1, 2}$, C), a thickened cardinal protoseptum (Figs 23$B_{1, 2}$, 24F), and a wide dissepimentarium attaining at least (abraded specimens) one-fourth corallite radius (Fig. 24E_2). Septa longer in cardinal quadrants than in counter ones, as observed in some sections (Figs 23B_1, 24D_2, F), are due to an uneven abrasion of corallites and/or slightly oblique sections.

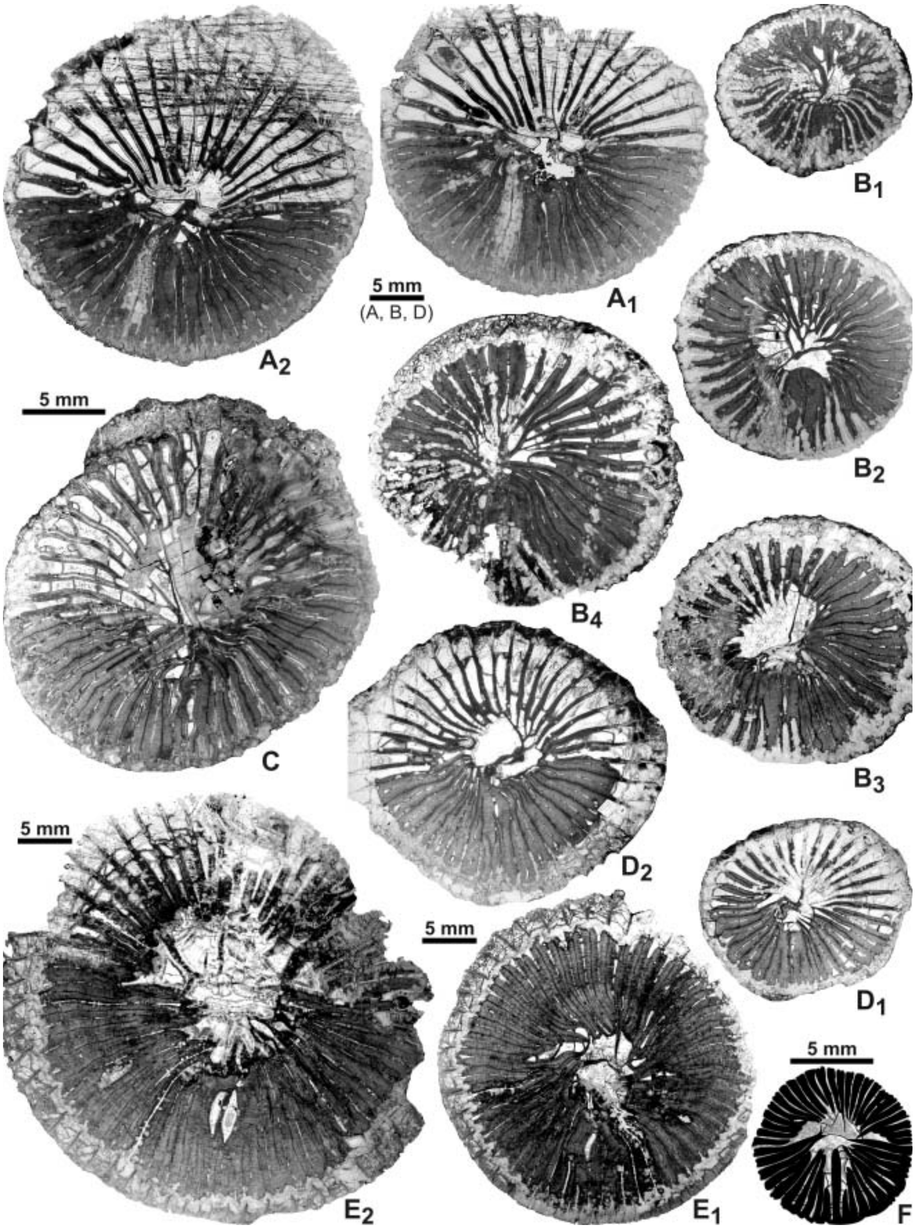


Fig. 24. A-F. *Pseudotimania arctica* sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.Lin. II/1/42; $A_{1,2}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Lin. I/1/94; B_1 – transverse thin section from immature growth stage, B_{2-4} – transverse thin sections from mature growth stage.
C – UAMIG.Tc-C.CrL. I/6/15; transverse thin section from mature growth stage.
D – UAMIG.Tc-C.Lin. II/1/1; $D_{1,2}$ – transverse thin sections from mature growth stage.
E – UAMIG.Tc-C.Lin. II/1/49; $E_{1,2}$ – transverse thin sections from mature growth stage.
F – UAMIG.Tc-C.CrL. I/4/3; transverse thin section from mature growth stage.

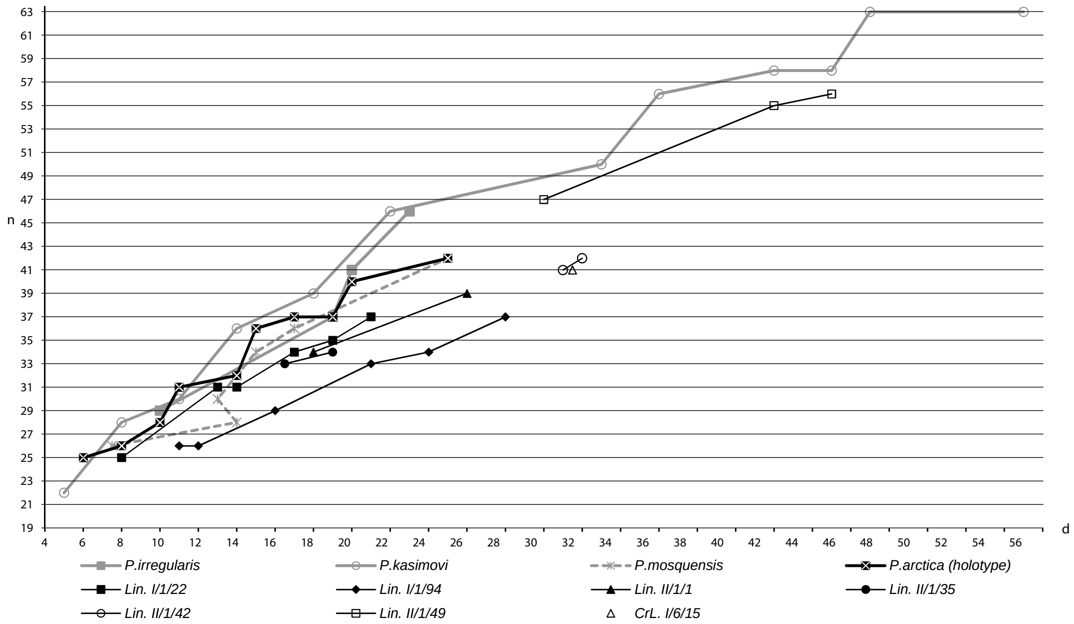


Fig. 25. Plot of the number of major septa (n) *vs*. diameters (d) of *Pseudotimania arctica* sp. nov. as compared with the remaining species of *Pseudotimania*: *P. irregularis, P. kasimovi, P. mosquensis,* Symbols joined by lines represent values taken from individual specimens.

Remarks: When compared with other species of the genus, in early growth stages the specimens described above have n/d indices similar to *P. mosquensis* (Fig. 25), later stages both species have the following features in common: major septa of varying length and thickness, a thin external wall, and thin counter protosepta. However, *P. mosquensis* has shorter major septa in early growth stages, a cardinal protoseptum shortened early in ontogeny, distinct alar fossulae, and a wide dissepimentarium at maturity.

A strongly elongated cardinal protoseptum has so far been characteristic of *P. kasimovi* (Dobrolyubova and Kabakovitsch 1948). Corallites of this species also have thickened and elongated major septa, especially in early growth stages. The presence of those features in *P. arctica* sp. nov. makes those two species very similar in immature ontogenetic stages. Slight differences at this stage of growth can be found in the development of the counter protoseptum, which is not always elongated in *P. kasimovi*, and in the absence of dissepiments, which become noticeable in this species only at 25 mm corallite diameter. More pronounced differences between the species can be observed in mature growth stages. *P. kasimovi* attains a generally greater size and always has a greater number of septa, even in comparison with the largest *P. arctica* sp. nov. (Fig. 25). Besides, in mature *P. kasimovi* major septa shorten to ca. one-half corallite radius, leaving a wide, free axial zone, and the cardinal protoseptum is the longest major septum throughout the entire ontogeny, while in *P. arctica* sp. nov., major septa remain long over the entire ontogeny, and the cardinal protoseptum, while long below the calice bottom, at the bottom itself becomes markedly shorter.

When comparing the new species with *P. irregularis* described by Gorsky (1978), one can note similar n/d indices in some growth stages (Fig. 25), variable thickness of major septa, poorly developed minor septa, and joined protosepta at the corallite axis in early growth stages. However, *P. arctica* sp. nov. differs from the species known from Novaya Zemlya and the Urals in the fusion of major septa at the corallite axis, an early appearance of the dissepimentarium, and first of all, in alar septa being long in all growth stages, while in *P. irregularis* they are very short and thickened, thus determining the generic attribution of this species.

The specimens I described, and especially the growth stages of the holotype illustrated in Fig. 23$A_{3, 4, 6}$, bear a close similarity to the specimen from the Permian-Carboniferous Wordiekammen Formation in the Skansen region in Dickson Land, illustrated by Ezaki and Kawamura (1992: pl. 2, fig. 2). Identified by those authors as *Pseudotimania* sp. A. , it features, like *Pseudotimania arctica* sp. nov., an elongated cardinal protoseptum, some major septa fused in or near the corallite axis, a long counter protoseptum crossing the corallite axis, major septa of varying length and thickness, and a similar structure and shape of the cardinal fossula. For those reasons the specimen collected by Ezaki and Kawamura (1992) is treated in synonymy with *Pseudotimania arctica* sp. nov.

Occurrence: Spitsbergen: Polakkfjellet – Gzhelian; Linnédalen – Gzhelian-Sakmarian.

Pseudotimania borealis sp. nov.
Figs 26, 28, 29

Holotype: UAMIG.Tc-C.Krg. III/16 (Fig. 26). Two acetate peels and 11 transverse thin sections.

Type locality: Kruseryggen (N 77° 04.567; E 16° 05.100; 250 m above sea level), south Spitsbergen (Fig. 2E).

Type horizon: Treskelodden Formation, Lower Sakmarian.

Derivation of name: *borealis* – northern; for occurrence in boreal (northern) area.

Diagnosis: *Pseudotimania* with n/d indices from 36/16 to 67/45; major septa long in early growth stages, in later shortened to two-thirds – one-half coral-

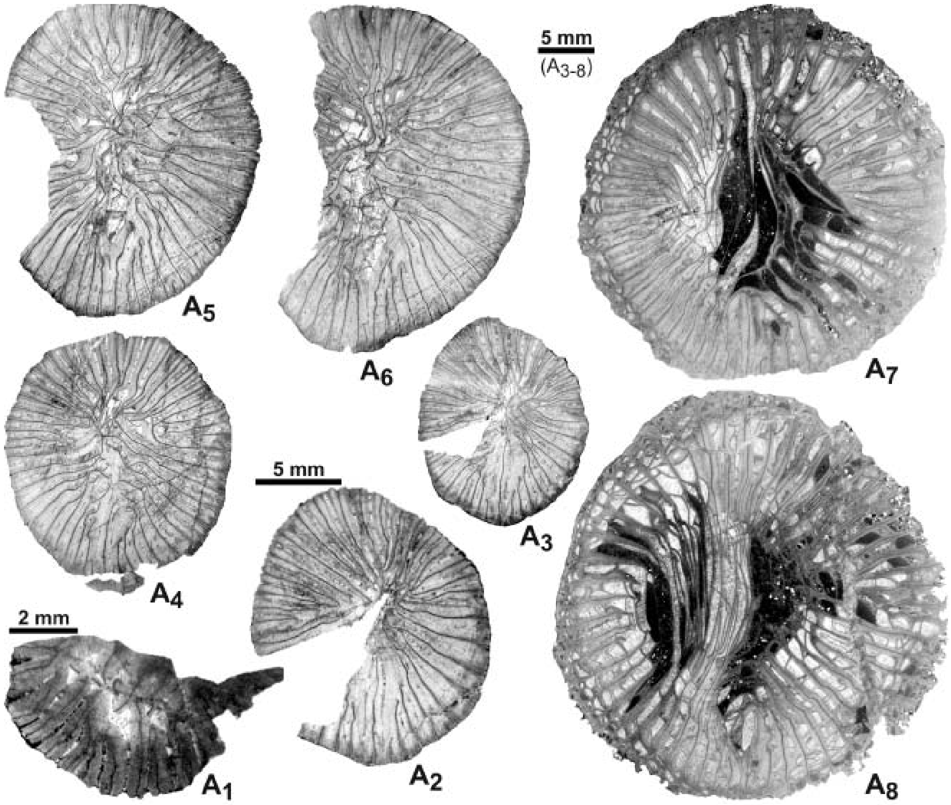


Fig. 26. A. *Pseudotimania borealis* sp. nov., upper part of the Treskelodden Formation. UAMIG. Tc-C.Krg. III/16; $A_{1\text{-}3}$ – transverse thin sections from immature growth stage, $A_{4\text{-}8}$ – transverse thin sections from mature growth stage.

lite radius; cardinal protoseptum long, in calice shortened to one-third length of major septa; cardinal fossula distinct; alar septa as long as other majors or slightly longer; minor septa up to one-eighth corallite radius; width of dissepimentarium attains one-third corallite radius; tabularium bi-zonal.

Material: Paratypes – 18 specimens, about 30 to 80 mm long, in fragments, abraded to a considerable degree (UAMIG.Tc-C.Krg. III/14, 17, 19, Krg. Vx/11, Krg. Vz/16, 18; UAMIG.Tc-C.Pol. BVI/1, BVI(3)/3; BVI(4)/1; UAMIG.Tc-C. Lin. I/1/11, 25, 32, 38, 58, 87; UAMIG.Tc-C.CrL. I/7/1, 9, 13). 61 transverse thin sections and one longitudinal section.

Description of holotype: Corallite ceratoid, 80 mm long, without proximal end, with concave cardinal side. Calice approximately 35 mm deep. Arrangement of major septa pinnate in all quadrants in immature growth stage; pinnate in cardinal quadrants and radial in counter quadrants at maturity; in calice shortened, leaving open axial area 12 mm wide, which is ca. one-third corallite

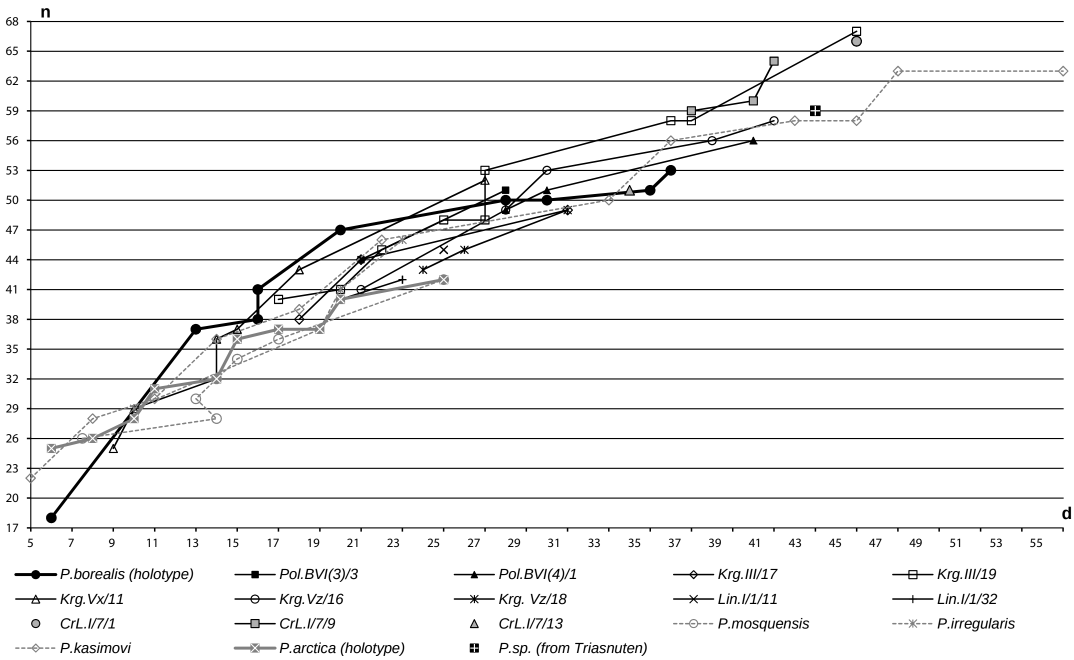


Fig. 27. Plot of the number of major septa (n) *vs.* diameters (d) of *Pseudotimania borealis* sp. nov. as compared with the remaining species of *Pseudotimania*: *P. irregularis, P. kasimovi, P. mosquensis, P. arctica* sp. nov. Symbols joined by lines represent values taken from individual specimens.

diameter. Cardinal protoseptum in early growth stage elongated, becoming shorter at maturity, but up to calice bottom still longer than 3-4 adjacent major septa (Fig. 26A_{1-7}). At calice bottom it has ca. 10 mm in length, and above it shortens to 5.0 mm (Fig. 26A_8), which is about one-third length of major septa of cardinal quadrants. Cardinal fossula open, outlined by successively shortening major septa of cardinal quadrants. Counter protoseptum longer than other major septa in all growth stages.

Minor septa appear at corallite diameter of ca. 14 mm and attain a maximum of 0.5 mm in length (Fig. 26A_2). In later growth stage their length increases to 1.5 mm. At calice bottom, with appearance of dissepiments, they are limited to outer dissepimentarium zone (Fig. 26$A_{7,8}$).

Ontogeny of holotype: The ontogenetically earliest skeleton is missing. In the earliest growth stage available for study (Fig. 26A_1) n/d ratio attains ~15/~5.0; major septa thick, of different sizes, protosepta being the longest, and due to deformation of this part of corallite, they overlap each other and cross the corallite axis. Cardinal fossula open; alar pseudo-fossulae not developed. External wall abraded.

In section cut approximately 10 mm above the previous one n/d ratio attains 38/16 (Fig. 26A_2). Major septa pinnately arranged in all quadrants.

Cardinal protoseptum slightly shorter than the longest major septa of cardinal quadrants. Cardinal fossula slightly longer than cardinal protoseptum, open, bordered by successively shortening major septa of cardinal quadrants. Counter protoseptum longer than neighbouring major septa. Alar septa as long as the other long metasepta. Short minor septa (about 0.5 mm long) appear in counter quadrants.

In later growth stage (Fig. 26A_3) n/d ratio attains 41/15×19. Major septa varying in length, with the longest reaching corallite axis. Cardinal protoseptum slightly shorter than the longest metasepta. Counter protoseptum reaches corallite axis. Cardinal fossula open, elliptic, bordered by successively shortening major septa of cardinal quadrants. Minor septa not developed in full number, 1.0 mm long. External wall 0.1 mm thick.

In section at the mid-length of corallite (Fig. 26A_4) n/d index is 47/20. Major septa vary in length; the longest extend to corallite axis where they fuse. Cardinal protoseptum long, in open fossula bordered by shortening major septa of cardinal quadrants. Counter protoseptum long, but not reaching corallite axis. Alar septa not different from remaining major septa. Minor septa not developed in full number and poorly visible.

At maturity, in sections below the calice bottom (Fig. 26$A_{5, 6}$) n/d indices equal 50/28 and 52/30. Major septa varying in length, the longest, together with counter protoseptum, join at the corallite axis. Cardinal protoseptum long, in fossula widely open adaxially and bordered by successively shortening major septa of cardinal quadrants. Alar septa not differ from remaining major septa. Minor septa 1.5 mm long, visible only in cardinal quadrants.

In lower part of calice (Fig. 26$A_{7, 8}$) n/d index is 51/35. Major septa of varying length, but not exceeding one-third corallite diameter. Counter protoseptum slightly longer than remaining major septa. Alar septa as long as other major septa. Minor septa reach 1.5 mm in length. Dissepimentarium of variable width. In the widest part, in counter quadrants, it occupies one-fifth the corallite radius. Dissepiments straight and herringbone. External wall 0.1 mm thick. In the section taken near calice bottom (Fig. 26A_7) the cardinal protoseptum is only slightly shorter than the longest septa of cardinal quadrants, while in the one made a few mm higher it is shortened to ca. one-third length of major septa of cardinal quadrants. In both sections it lies in a wide, open fossula bordered by 4-5 pairs of neighbouring, successively shortening major septa.

Intraspecific variability: Septal indices of paratypes in most specimens oscillate around those of the holotype (Fig. 27); in a specimen at the most advanced growth stage (UAMIG.Tc-C.Krg. III/19; Fig. 28A_{1-10}), it attains ~67/~45. What differentiates this specimen from the remaining paratypes is its uniquely developed cardinal fossula. Its structure undergoes some modifications in the

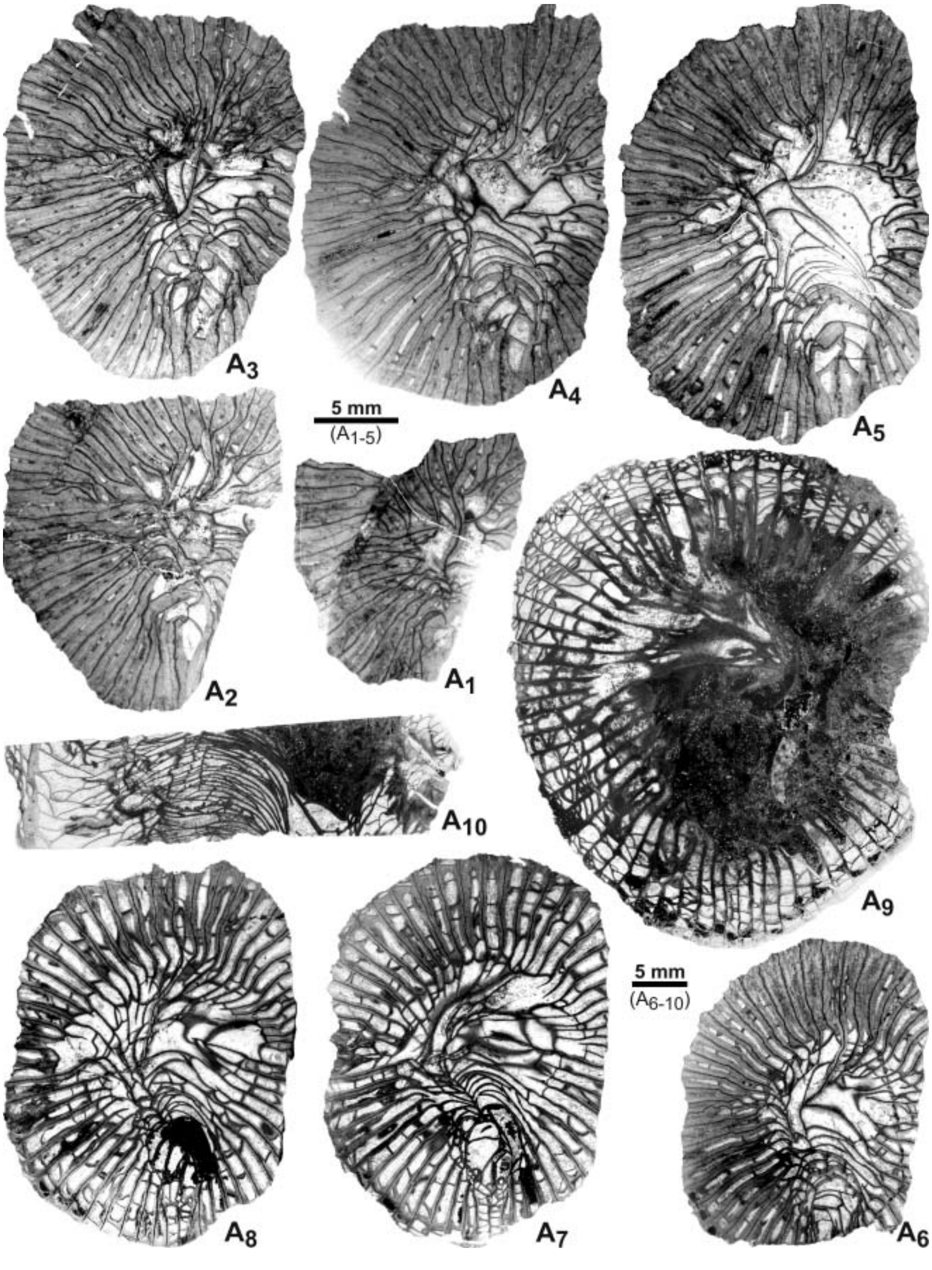


Fig. 28. A. *Pseudotimania borealis* sp. nov., upper part of the Treskelodden Formation. UAMIG. Tc-C.Krg. III/19; $A_{1\text{-}4}$ – transverse thin sections from immature growth stage, $A_{5\text{-}9}$ – transverse thin sections from mature growth stage, A_{10} – longitudinal thin section.

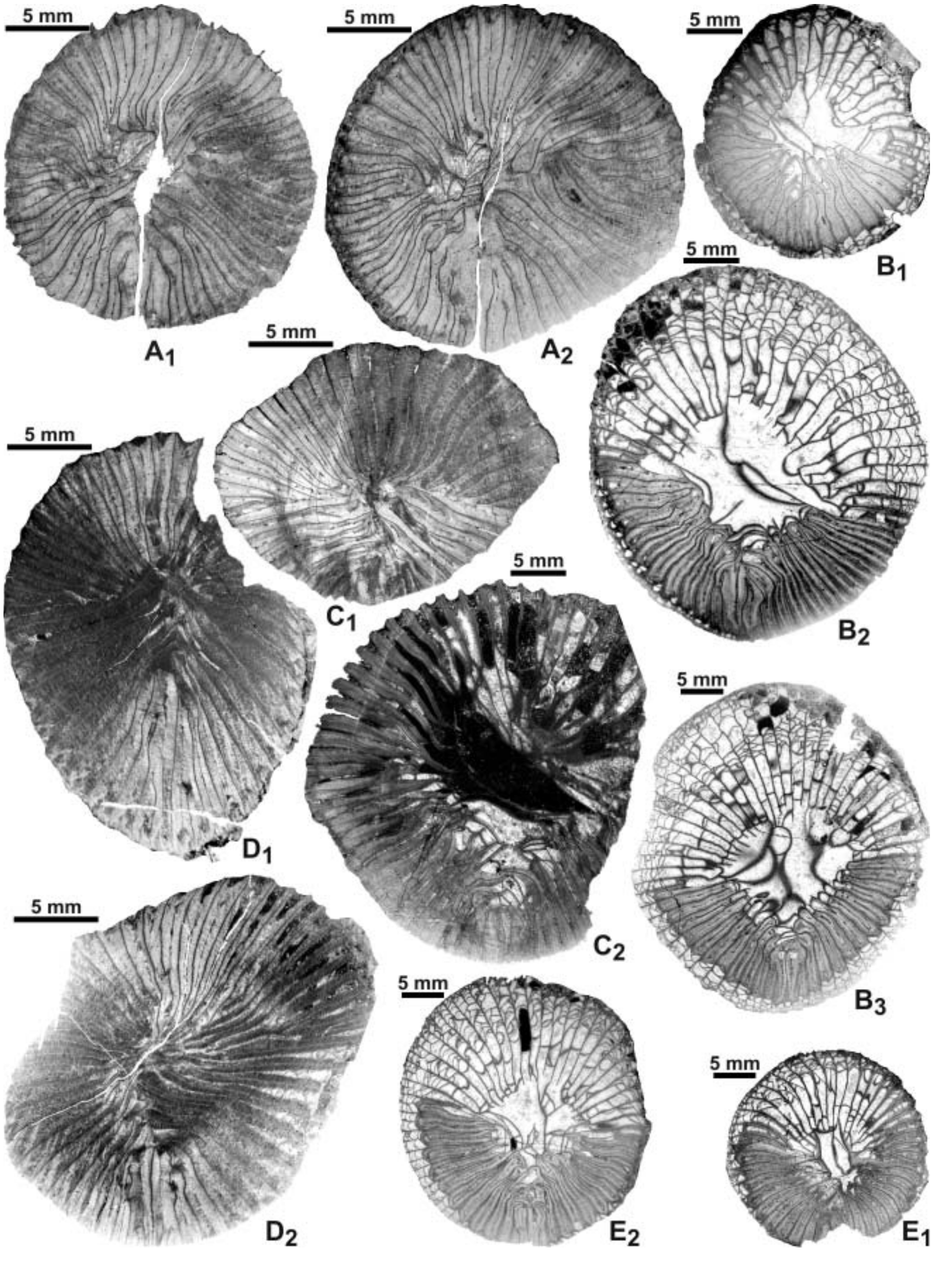


Fig. 29. A-E. *Pseudotimania borealis* sp. nov., upper part of the Treskelodden Formation.

A – UAMIG.Tc-C.Krg. III/17; $A_{1,2}$ – transverse thin sections from immature growth stage.
B – UAMIG.Tc-C.Krg. Vz/16; $B_{1\text{-}3}$ – transverse thin sections from mature growth stage.
C – UAMIG.Tc-C.Krg. III/14; C_1 – transverse thin section from immature growth stage, C_2 – transverse thin section from mature growth stage.
D – UAMIG.Tc-C.Krg. Vx/11; $D_{1,2}$ – transverse thin sections from immature growth stage.
E – UAMIG.Tc-C.Krg. Vz/18; $E_{1,2}$ – transverse thin sections from mature growth stage.

course of ontogeny. In early growth stages it is long and widening towards corallite axis (Fig. 28A_{2-6}), with inner ends of major septa on tabellae (Fig. 28$A_{3,5}$); in later growth stages it becomes trough-shaped, arched, bordered by inner ends of its neighbouring major septa strongly bent towards its interior (Fig. 28$A_{7,8}$); as in early growth stages, so in later ones it almost reaches corallite axis. In this specimen cardinal protoseptum, in contrast to the holotype, is clearly thinner below the calice bottom and in the calice than the remaining major septa (Fig. 28A_{7-9}), while an elongated counter protoseptum in some sections crosses corallite axis (Fig. 28$A_{1,3,6,8}$) and can meet the cardinal fossula. Notable is also the occurrence of major septa in the sub-calicular part that are thicker in counter quadrants than in cardinal ones (Fig. 28$A_{7,8}$). A longitudinal section known only from this specimen (Fig. 28A_{10}), shows the cardinal fossula to be deep and the tabularium bi-zonal. Axial tabellae are convex and very numerous (ca. 17/10 mm), inclining steeply towards the cardinal fossula and gently towards the counter protoseptum. In the outer zone of the tabularium, tabellae are less numerous, in counter quadrants of variable morphology, in the cardinal fossula strongly concave, and at the boundary with the dissepimentarium vesicular. In the holotype, axial tabellae are densely arranged which is observable in a slightly oblique section illustrated in Fig. 26A_8. Because of the abrasion of the outer part of the corallite, neither its diameter, nor total width of its dissepimentarium can be determined. Still, when observing relicts of the preserved parts of the outer skeleton, it seems that the dissepimentarium, as in the holotype, appears late in ontogeny (Fig. 28A_7) and is wide – abrasion notwithstanding, it occupies ca. one-fourth corallite radius in the calice (Fig. 28A_9).

A few new features not observed in the holotype of *Pseudotimania borealis* sp. nov. are also supplied by specimens illustrated in Fig. 29A-E. Two of them (UAMIG.Tc-C.Krg. Vz/16, Vz/18; Fig. 29B, E) differ from the holotype in the variable thickness of their major septa, which attain 1.5 mm in cardinal quadrants and ca. 0.2 mm in counter quadrants, and in a cardinal protoseptum lying in a closed fossula, and earlier shortened in ontogeny (Fig. 29$E_{1,2}$). The presence of a dissepimentarium in the specimen UAMIG.Tc-C.Krg. Vz/16 at corallite diameter of 22 mm (Fig. 29B_1) shows that dissepiments can appear earlier in ontogeny than in the holotype, and the dissepimentarium in later growth stages can have variable width ranging from one-fifth to ca. one-third corallite radius.

The next two specimens (Fig. 29C, D) expand the scope of variability of the species to include greater differences in length of major septa; in addition, in cardinal quadrants they are pinnately arranged with respect to the cardinal protoseptum, and in counter quadrants pinnately arranged with respect to alar septa, which can be longer than the remaining major septa. The last of the illustrated paratypes (Fig. 29A), differs from the holotype in having a much more elongated counter protoseptum in the early growth stage and a distinctly pinnate arrangement of septa in cardinal quadrants.

Remarks: Specimens included in *Pseudotimania borealis* sp. nov. display a great infraspecific variability. It involves changes in the length and thickness of major septa in the course of ontogeny, their more or less pinnate arrangement, a variable length of alar septa and the counter protoseptum, no uniform structure of the cardinal fossula, and a variable width of the dissepimentarium. The *Pseudotimania borealis* sp. nov. from Spitsbergen shows therefore a unique combination of characteristics not observed in the known *Pseudotimania* and *P. arctica* sp. nov. described above. While some of those characteristics occur in *Pseudotimania* species known earlier (Table 2), none of them shows this particular combination.

The newly described species shares the greatest number of features with *P. kasimovi* created by Dobrolyubova and Kabakovitsch (1948). The specimens described above have in common with this species, known from the Bashkirian of the Moscow Basin, the following features: n/d indices in early growth stages (Fig. 27), a long cardinal protoseptum, thickened and elongated major septa in early growth stages filling almost the entire corallite lumen, short minor septa, and late appearance of the dissepimentarium in ontogeny. *P. kasimovi*, however, has elongated major septa in early growth stages, a pinnate arrangement of major septa only in cardinal quadrants, a permanently elongated cardinal protoseptum, which is the longest septum at maturity, sparsely spaced and mostly small tabellae, long minor septa crossing the entire dissepimentarium zone and often penetrating into the tabularium, and a wide dissepimentarium, which can attain 10 mm in counter quadrants in specimens 40 mm in diameter, i.e. one-half corallite radius.

Some features of early growth stages of the specimens described above, including n/d indices (Fig. 27), an elongated cardinal protoseptum and early appearance of minor septa, resemble those of the Carboniferous *T. mosquensis* (Dobrolyubova, 1937), typical of this genus. *T. mosquensis*, however, has shortened alar septa, a cardinal protoseptum shortening very early in ontogeny (at 10 mm corallite diameter it is equal to ca. one-half length of major septa), dissepiments appearing very early, already at corallite diameter of 7.5 mm, and major septa retreating early from the corallite axis.

As to the *Pseudotimania* known from Spitsbergen, *P. borealis* sp. nov., and in particular the Kruseryggen specimen UAMIG.Tc-C.Krg. Vz/16 (Fig. $29B_{13}$), shares many features with the *Pseudotimania* sp. from the Sakmarian of Triasnuten (the Hornsund area) described by Fedorowski (1980, in: Birkenmajer and Fedorowski 1980). Both specimens have similar n/d indices (Fig. 27), thickened major septa in cardinal quadrants, a similar width of the dissepi-

Table 2. Morphological differentiation of species of *Pseudotimania* Dobrolyubova & Kabakovitsch, 1948

Taxa	n/d	Cardinal protoseptum	Cardinal fossula	Counter protoseptum	Alar septa	Major septa	Minor septa	Dissepimentarium	Tabulae	Range
Timania mosquensis Dobrolyubova, 1937	26/7.5 28/14 34/15 42/25	in early growth stage long, in late growth stage shortened	narrows, closed	longer and thinner than other major septa	shortened	vary in length; within dissepimentarium thin; in cardinal quadrants successively shortened toward cardinal protoseptum	appear early in ontogeny; short, confined to dissepimentarium	in early growth stage with one row of dissepiments; 4-5 rows (3.0 mm of wide) in late growth stage, in cardinal quadrants narrower than in counter quadrants; dissepiments globose	complete and incomplete, with downturned edges	Moscow Basin – Upper Moscovian
Pseudotimania mosquensis (Dobrolyubova, 1937)	30/13 32/14 36/17	shortened	in early growth stage closed	longer and thinner than other major septa		in cardinal quadrants pinnately arranged; microstructure fibro-normal	very short	appear early in immature growth stage, dissepiments commonly herringbone		Svalbard, Bjørnøya - Gzhelian
P. kasimovi Dobrolyubova and Kabakovitsch, 1948	30/11 36/14 39/18 46/22 56/36	elongated, also in mature growth stage	open	in young growth stage vary in length, in mature growth stage always elongated	elongated	in young growth stage elongated and thickened; in mature growth stage reaching about 1/2 corallite radius in length	very short	appear late in ontogeny; in cardinal quadrants narrower than in counter quadrants, at corallite diameter 40 mm reach 10 mm of width	complete and/or incomplete, with downturned edges, widely spaced	Moscow Basin - C4II – Bashkirian
P. irregularis Gorsky, 1951	29/10 41/20 46/23	elongated, joined with counter protoseptum	open	elongated	very short	thickened; in cardinal quadrants pinnately arranged, longer than in counter quadrants	appear late in ontogeny	appear late in ontogeny, poorly developed		Novaya Zemlya, Urals – Upper Carboniferous
P. sp. Fedorowski 1980	59/43	shortened	closed, bordered by 2-3 pairs of major septa gradually shortening towards the cardinal protoseptum		slightly shorter than other major septa	long, but do not reach corallite axis, in tabularium of cardinal quadrants thickened; microstructure multitrabecular	very short	in cardinal quadrants narrower than in counter quadrants, dissepiments thin, herringbone		Spitsbergen, Triasnuten, III i V coral horizon - Sakmarian

P. arctica sp. nov.	25/6 28/10 37/19 47/30 56/45	elongated, in young growth stage joined with counter protoseptum	narrow, closed, bordered by inner ends of major septa of cardinal quadrants	elongated, may be thinner than other major septa	elongated in young growth stage	elongated; pinnately arranged in cardinal quadrants, radially arranged in counter quadrants	short, restricted to dissepimentarium	narrow, in calice may attain at most 1/5 of coralite radius in width	incomplete, with strongly declined edges; 7 tabellae per 5 mm of coralite length	Spitsbergen, Polakkfjellet, Linnédalen – Gzhelian-Sakmarian
P. borealis sp. nov.	18/6 38/16 47/20 53/36 67/45	elongated, does not connect with counter protoseptum; in mature growth stage may be shortened	commonly open, may extend to corallite axis, bordered by successively shortened major septa of cardinal quadrants	elongated	as long as other major septa	in young growth stage elongated, in all quadrants pinnately arranged; in calice shortened, reaching 2/3-1/2 corallite radius in length	very short	appear late in ontogeny, up to 1/3 coralite radius in width; dissepiments regular and herringbone	bi-zonal, axial tabellae convex (17 per 10 mm of coralite length), peripheral tabellae globose, in cardinal fossula strongly concave	Spitsbergen, Kruseryggen, Polakkfjellet – Gzhelian-Sakmarian
P. longiseptata sp. nov.	20/5 33/11 44/20 57/66	shortened, in earliest growth stage joined with counter protoseptum	commonly open, narrowing or extending adaxially; bordered by successively shortened major septa of cardinal quadrants	elongated, may cross corallite axis; thinner than other major septa; in calice as long as other major septa	as long as other major septa	long, in early growth stages reach corallite axis; in mature growth stage reaching from 2/3 to more than 3/4 corallite radius in length	attain 1/6 of major septa length	appear early in ontogeny, in mature growth stage up to 1/3 coralite radius in width; dissepiments regular, herringbone	incomplete, globose, axial and peripheral tabellae elevated, between these zones concave	Spitsbergen, Kruseryggen, Polakkfjellet – Gzhelian-Sakmarian

mentarium, short minor septa, and the structure of the cardinal fossula. There are slight differences in the length of major septa and in the structure of the axial zone. In a section illustrated by Birkenmajer and Fedorowski (1980: pl. 1, fig. 5a), major septa of *Pseudotimania* sp. are longer than in the Kruseryggen specimen, and in the Triasnuten specimen, the axial zone is occupied by numerous transverse sections through tabellae and inner ends of the longest major septa, while in the corallite from Kruseryggen (Fig. $29B_{2,3}$) is free from skeletal structures with the exception of a few transverse sections through tabellae. Those features could be regarded as intraspecific variability, but since no comparison can be made of early growth stages, missing in the Triasnuten specimen, this taxon cannot be assessed fully.

In comparison with the *Pseudotimania arctica* sp. nov. described earlier, representatives of *P. borealis* sp. nov. generally attain greater sizes and have a greater number of septa (Figs 25, 27), and in early growth stages its long cardinal protoseptum, does not extend to the counter protoseptum. Besides, major septa in the calice of *P. borealis* sp. nov. are nearly half the length of, and the cardinal protoseptum nearly twice as long as, those in *P. arctica* sp. nov. at corresponding growth stages.

Occurrence: Spitsbergen: Kruseryggen, Polakkfjellet (Treskelodden Formation) – Gzhelian-Lower Sakmarian, Linnédalen (Wordiekammen Formation) – Sakmarian.

Pseudotimania longiseptata sp. nov.
Figs 30, 31

1992. *Pseudotimania* sp. B; Ezaki and Kawamura: pl. 2, fig. 3.

Holotype: UAMIG.Tc-C.Pol. BVI(4)/7 (Fig. 30A). Eight transverse thin sections.

Type locality: Polakkfjellet (N 77° 13.498'; E 16° 01.933'; 434 m above sea level), south Spitsbergen (Fig. 2D).

Type horizon: Treskelodden Formation, Gzhelian.

Derivation of name: *longiseptata* – after long major septa.

Diagnosis: *Pseudotimania* with n/d indices from 30-31/11 to 57/66; in early growth stages major septa reach corallite axis, in later attain from two-thirds to three-fourths corallite radius; protosepta joined in early growth stages, in later, cardinal protoseptum shortened; alar septa as long as other majors or slightly longer; minor septa up to one-sixth corallite radius; dissepimentarium appears very early in ontogeny, in mature growth stages its width attains one-third corallite radius; tabulae incomplete; external wall 0.2 mm thick.

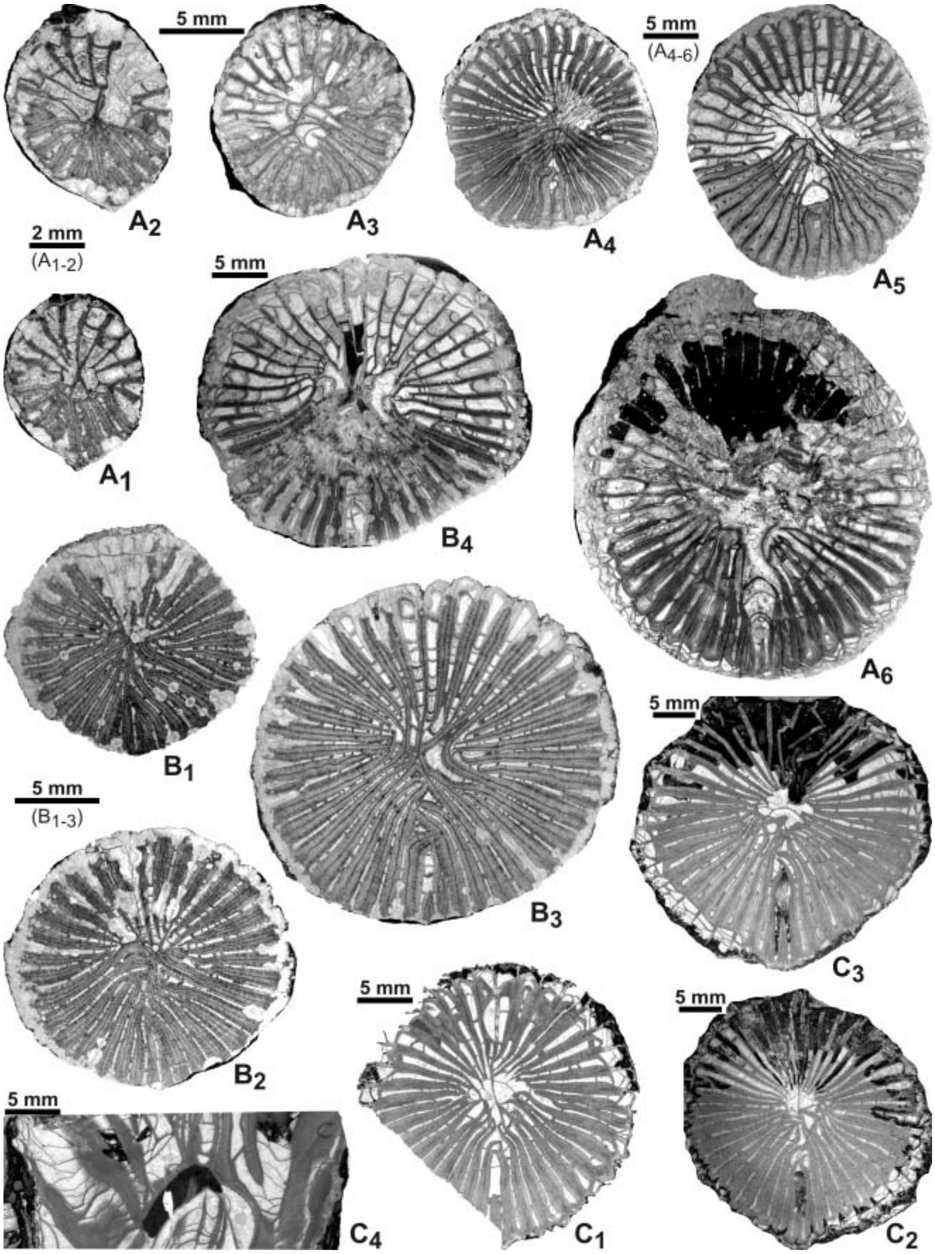


Fig. 30. A-C. *Pseudotimania longiseptata* sp. nov., lower part of the Treskelodden Formation.

A – UAMIG.Tc-C.Pol. BVI(4)/7; $A_{1\text{-}3}$ – transverse thin sections from immature growth stage, $A_{4\text{-}6}$ – transverse thin sections from mature growth stage.

B – UAMIG.Tc-C.Pol. BVI(4)/5; $B_{1,2}$ – transverse thin sections from immature growth stage, $B_{3,4}$ – transverse thin sections from mature growth stage.

C – UAMIG.Tc-C.Pol. BV/2; $C_{1\text{-}3}$ – transverse thin sections from mature growth stage, C_4 – longitudinal thin section; cardinal protoseptum on right side.

Material: 63 fragmentarily preserved, partly abraded and/or recrystallized corallites, mostly without proximal and distal ends and with damaged dissepimentarium (UAMIG.Tc-C.Krg. III/7, 8, 18; Krg. Vx/17, 18; UAMIG.Tc-C. Pol BV/2; UAMIG.Tc-C.Pol BVI/3; UAMIG.Tc-C.Pol. BVI(3)/1, 2, 5; BVI(4)/4, 5, 16, 21; UAMIG.Tc-C.Lin. I/1/5, 17, 27, 29, 30, 39, 40, 41, 43, 47, 50, 52, 53, 73, 80, 81, 82, 84, 86, 88, 99, 109, 117, 121, 129; UAMIG.Tc-C.Lin. II/1/8, 16, 18, 20, 24, 26, 31, 32, 50, 53, 56, 66, 89; UAMIG.Tc-C.Lin. III/1/1, 11; UAMIG.Tc-C. CrL. I/5/6, 13, 15, 17, 19, 22; UAMIG.Tc-C.CrL. I/6/1, 19, 20). 185 transverse thin sections and two longitudinal sections.

Description of holotype: Corallite strongly corniculate. In section of the earliest stage available, septal index attains 20/5 (Fig. 30A_1). Major septa of varying length, in cardinal quadrants thicker than in counter ones. Protosepta, one alar septum and second metaseptum of counter quadrant reaching corallite axis. Despite abrasion and recrystallization of outer part of corallite, there are visible first dissepiments and short minor septa. In section made ca. 3 mm higher, septal index is 22/7 (Fig. 30A_2). Major septa of varying length and thickness, with protosepta joined at the corallite axis. Minor septa limited to one-row dissepimentarium. In next section, with septal index of 33/12 (Fig. 30A_3), most major septa attain ca. three-fourths corallite radius, only a few (including counter protoseptum) reach its axis. Cardinal protoseptum equal in length to major septa of cardinal quadrants. Cardinal fossula closed, bordered by neighbouring major septa. External wall abraded along entire circumference. Minor septa and dissepiments invisible.

At septal index of 40/20 (Fig. 30A_4), major septa fill almost entire corallite lumen; the longest, including counter protoseptum, reach the corallite axis. In cardinal quadrants they shorten successively towards cardinal protoseptum, in counter quadrants gradually shorten towards alar septa. Cardinal protoseptum shortened to ca. one-third the corallite radius, in closed narrow fossula. Because of recrystallization of outer part of corallite, one-row dissepimentarium and minor septa poorly visible.

In next section made ca. 10 mm higher than the preceding one, septal index is 44/23 (Fig. 30A_5). Major septa of varying length, in cardinal quadrants generally longer and thicker than in counter quadrants. Counter protoseptum elongated, thinner than remaining major septa; cardinal protoseptum shortened to ca. one-third the corallite radius, in closed fossula bordered by three pairs of neighbouring major septa.

An oblique section from the latest available part of corallite (Fig. 30A_6), presents a fragment of calice (counter quadrants) with radially arranged major septa, and of sub-calice part (cardinal quadrants) with pinnately arranged major septa. Septal index n/d equals 51/33. Below calice bottom major septa shortened to ca. three-fourths the corallite radius, thickened; cardinal protoseptum shortened to ca. one-fourth corallite radius, in open, more than twice as long fossula widening towards corallite axis. Above calice bottom major septa shortened to ca. one-half corallite radius; counter protoseptum no different from remaining major septa of cardinal quadrants. Dissepimentarium narrow, one-fifth the corallite radius in width below calice bottom and ca. one-fourth the corallite radius at its bottom. Minor septa very short, limited to outer zone of dissepimentarium.

Description of paratypes: In comparison with the holotype, paratypes (Figs $30B_{1\text{-}4}$, $C_{1\text{-}3}$, $31B_{1,2}$), except the longest ones nos. UAMIG.Tc-C.Pol. BVI(4)/16 and UAMIG.Tc-C.Lin. I/1/121 (Fig. $31A_{1\text{-}4}$, $C_{1\text{-}4}$), have slightly smaller number of septa at similar corallite diameters (in some cases slightly underestimated because of abrasion of outer part of corallite), or at the same diameters (Fig. 32); narrower and longer cardinal fossula (Fig. $30C_{1\text{-}3}$); protosepta still joined at corallite diameter of 14.0 mm (Fig. $30B_1$); cardinal protoseptum shortened to one-fifth length of major septa in mature growth stages (Fig. $30B_3$); long major septa exceeding three-fourths the corallite radius at calice bottom (Fig. $30B_4$, $C_{2,3}$); and some major septa of counter quadrants fused below calice bottom. Also notable is regular thinning of major septa from cardinal to counter protoseptum without clear division into thin septa in counter quadrants and thick ones in cardinal quadrants (Fig. $30C_{1\text{-}3}$).

The large sizes of specimens UAMIG.Tc-C.Pol. BVI(4)/16 and UAMIG.Tc-C. Lin. I/1/121 (50 mm in length, n/d = 57/50-55 and 57/66) probably result from the fact that they represent more advanced growth stages. In earlier growth stages (Fig. $31A_{1,2}$, $C_{1,2}$) those specimens have characteristics observed in the holotype (cf. Fig. $30A_5$ and Fig. $31A_{1,2}$) and the paratype UAMIG.Tc-C.Pol. BVI(4)/5 (cf. Fig. $30B_{2\text{-}4}$ and Fig. $31C_{1\text{-}3}$), and slightly differ from the holotype only in their distal part. Some features, like 3.0-mm long minor septa, which equals ca. one-sixth length of major septa, and a wide dissepimentarium exceeding one-fourth the corallite radius just below the calice bottom and in the calice, can be a natural result of a more advanced growth stage. Other features, like major septa either slightly longer, attaining more than three-fourths corallite radius (Fig. $31C_4$), or shorter, of ca. two-thirds corallite radius (Fig. $31A_{3,4}$), as well as wide differences in the number of septa in cardinal quadrants characteristic of specimen UAMIG.Tc-C.Lin. I/1/121 [at n/d 48/~38 (Fig. $31C_3$) the distribution of septa is $\frac{9}{10} | \frac{8}{15}$, and at n/d = 54/~44 (Fig. $31C_4$) it is $\frac{11}{12} | \frac{8}{17}$], can be treated as part of intraspecific variability. In turn, the different thicknesses of major septa, which are either thickened in all quadrants of the

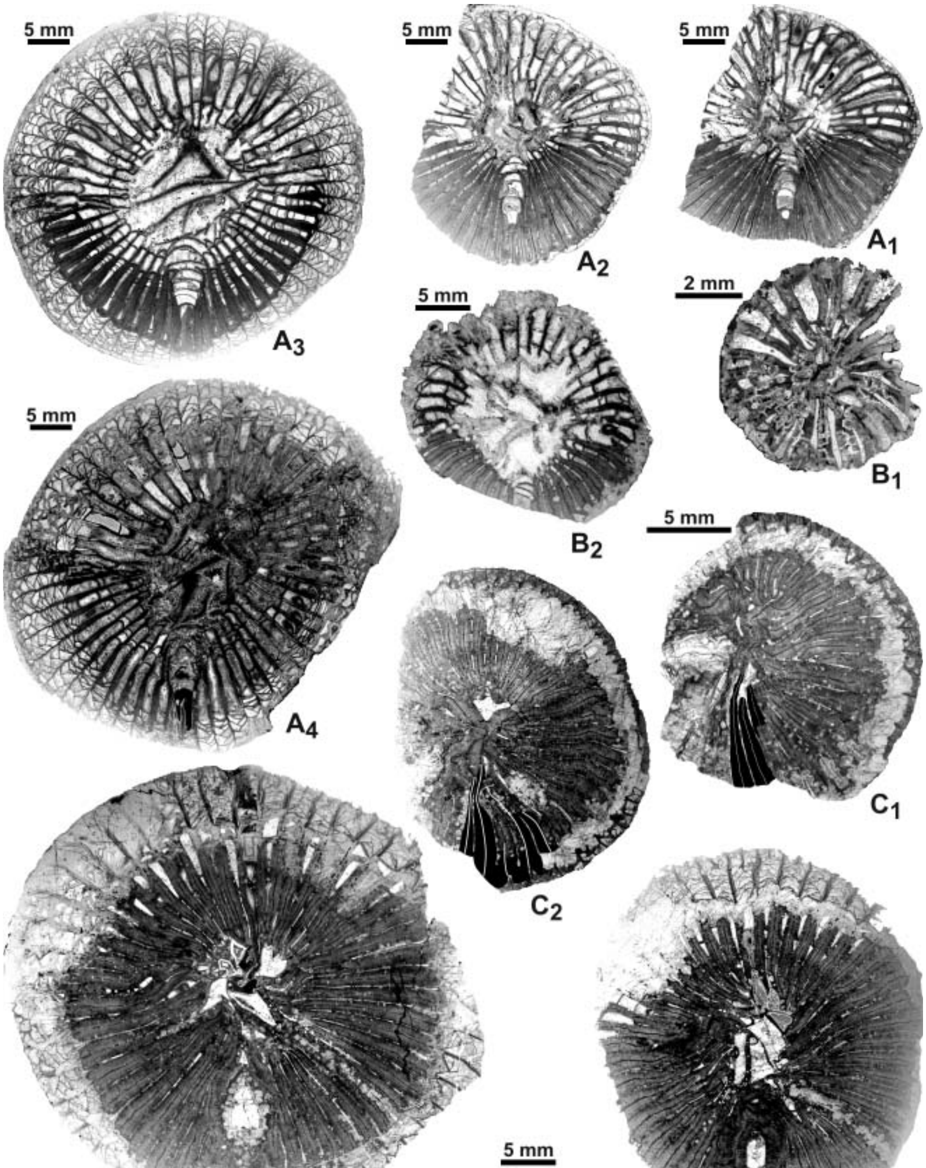


Fig. 31. A-C. *Pseudotimania longiseptata* sp. nov.

A – UAMIG.Tc-C.Pol. BVI(4)/16, lower part of the Treskelodden Formation; $A_{1\text{-}4}$ – transverse thin sections from mature growth stage.

B – UAMIG.Tc-C.Pol. BVI/3, lower part of the Treskelodden Formation; B_1 – transverse thin section from immature growth stage, B_2 – transverse thin section from mature growth stage.

C – UAMIG.Tc-C.Lin. I/1/121, Tyrrellfjellet Member of the Wordiekammen Formation; $C_{1,2}$ – transverse thin sections from immature growth stage, $C_{3,4}$ – transverse thin sections from mature growth stage.

entire corallite (Fig. $31C_{1\text{-}4}$), or only in its cardinal quadrants, where they attain ca. 1.5 mm in comparison with 0.5 mm in counter quadrants (Fig. $31A_3$), are perhaps an effect of ecological variability.

A slightly oblique longitudinal section from specimen UAMIG.Tc-C.Pol. BV/2 (Fig. $30C_4$), shows tabellae to be incomplete, vesicular, upturned at corallite axis and declining towards protosepta, slightly raised at the boundary with the dissepimentarium.

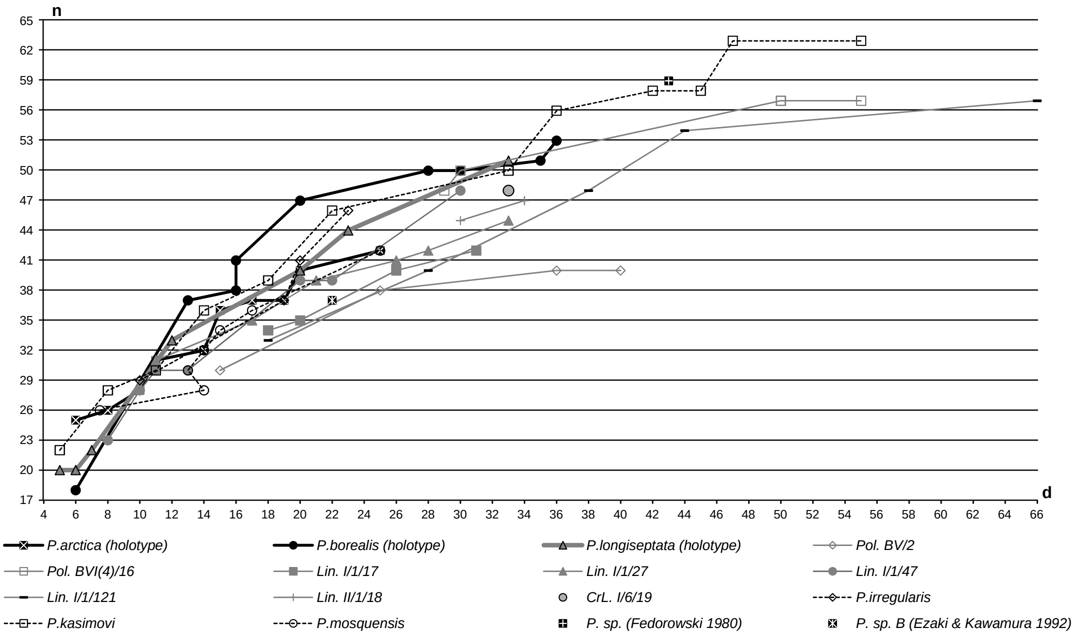


Fig. 32. Plot of the number of major septa (n) *vs*. diameters (d) of *Pseudotimania longiseptata* sp. nov. as compared with the remaining species of *Pseudotimania*: *P. irregularis, P. kasimovi, P. mosquensis, P. arctica* sp. nov., *P. borealis* sp. nov. Symbols joined by lines represent values taken from individual specimens.

Remarks: The unique set of features of *Pseudotimania longiseptata* sp. nov. makes it incomparable with any known *Pseudotimania* species described by Dobrolyubova (1937), Dobrolyubova and Kabakovitsch (1948) and Gorsky (1951, *fide* Gorsky 1978), or with the *P. arctica* sp. nov. and *P. borealis* sp. nov. described above (Table 2, Fig. 33). *P. longiseptata* sp. nov. stands out for its dissepimentarium appearing early in ontogeny and exceeding one-fourth corallite radius in width at maturity. It has a shortened cardinal protoseptum except in early growth stages, when it is elongated and connected with the counter protoseptum. It also differs in having long major septa exceeding three-fourths corallite radius throughout most of ontogeny (their smaller length in the section illustrated in Fig. $31B_2$ is due to recrystallization of the axial part of the corallite) and a generally smaller number of septa in corallite diameters comparable with those of other species of this genus (Fig. 32).

Some of those features resemble the new species described above. Long major septa and the fusion of some of them near corallite axis as well as the fusion of protosepta in early growth stages have already been found in *P. arctica* sp. nov. In turn, shortened major septa and a wide, regular dissepimentarium observed in mature paratypes of *P. longiseptata* sp. nov. make them similar to *P. borealis*. However, specimens of *P. arctica* sp. nov. are generally smaller and keep an elongated cardinal protoseptum long in ontogeny, while a characteristic of *P. borealis*, also with an elongated cardinal protoseptum long persisting in ontogeny, is the absence of fusion of protosepta in early growth stages.

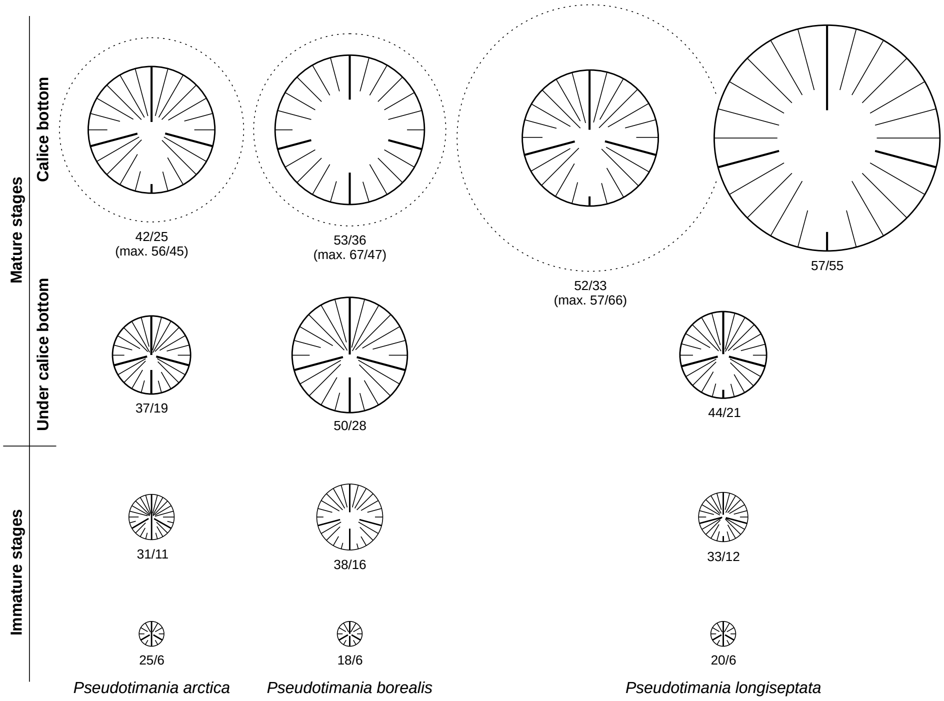


Fig. 33. Ontogeny of *Pseudotimania arctica* sp. nov, *P. borealis* sp. nov. and *P. longiseptata* sp. nov.

The specimens of *P. longiseptata* sp. nov. described above, especially the one illustrated in Fig. 30C, are similar in general features to the *Pseudotimania* sp. B specimen (Ezaki and Kawamura 1992: pl. 2, fig. 3) from the Permian-Carboniferous Wordiekammen Formation (the Skansen region in Dickson Land, north Spitsbergen). The taxa have the following features in common: (1) a long counter protoseptum crossing corallite axis; (2) a shortened cardinal protoseptum; (3) variable length and thickness of major septa; (4) similar n/d indices (Fig. 32); and (5) a similarly developed dissepimentarium. In this specimen only the cardinal fossula is built a bit differently in mature growth stages. In Ezaki and Kawamura (1992: pl. 2, fig. 3b), it is short, widening towards the corallite axis and bordered by bent inner ends of major septa, two pairs of which are joined. In the specimens of *P. longiseptata* sp. nov. the cardinal fossula is usually longer, while the ends of major septa that border it do not bend at such a great angle and do not fuse. However, assuming that the fusion of major septa in the newly introduced species is possible, this feature falls within the range of intraspecific variability, like the length of the cardinal fossula. Hence *Pseudotimania* sp. B (Ezaki and Kawamura 1992) was placed in synonymy with *P. longiseptata* sp. nov.

Occurrence: Spitsbergen: Polakkfjellet – Gzhelian; Triasnuten, Kruseryggen (Treskelodden Formation) – Sakmarian; Skansen (Wordiekammen Formation) – probably Sakmarian; Linnédalen (Wordiekammen Formation) – Sakmarian.

Genus: *Siedleckia* Fedorowski, 1975

Type species: *Siedleckia bjornoyana* Fedorowski, 1975.

Diagnosis: See Fedorowski (1975), p. 47.

Siedleckia bjornoyana Fedorowski, 1975
Fig. 34

1975. *Siedleckia bjornoyana* n. sp.; Fedorowski: pp. 48-50, text-fig. 5, pl. 4, fig. 4, pl. 8, fig. 5.

Diagnosis: See Fedorowski (1975), p. 48.

Material: One specimen, largely silicified (UAMIG.Tc-C.Pol. BVI(4)/15). Three peels and five transverse thin sections.

Description: The specimen under study represents early mature (Fig. 34A_{1-3}) and mature growth stages (Fig. 34A_4). Septal indices attain from 32/15 to 43/20. Major septa of varying length. In proximal part of specimen the longest exceed three-fourths corallite radius, but do not reach its axis; below calice bottom, in cardinal quadrants they attain ca. three-fourths corallite radius, in counter quadrants ca. one-half radius (Fig. 34A_4). In tabularium, cardinal quadrants strongly thickened, with thinning inner ends. Cardinal protoseptum in early mature growth stage equal in length to longer major septa of cardinal quadrants (Fig. 34A_2), or shorter (Fig. 34$A_{1,3}$); in adult stage shortened (Fig. 34A_4); in tabularium attaining ca. one-half length of major septa. Cardinal fossula narrow,

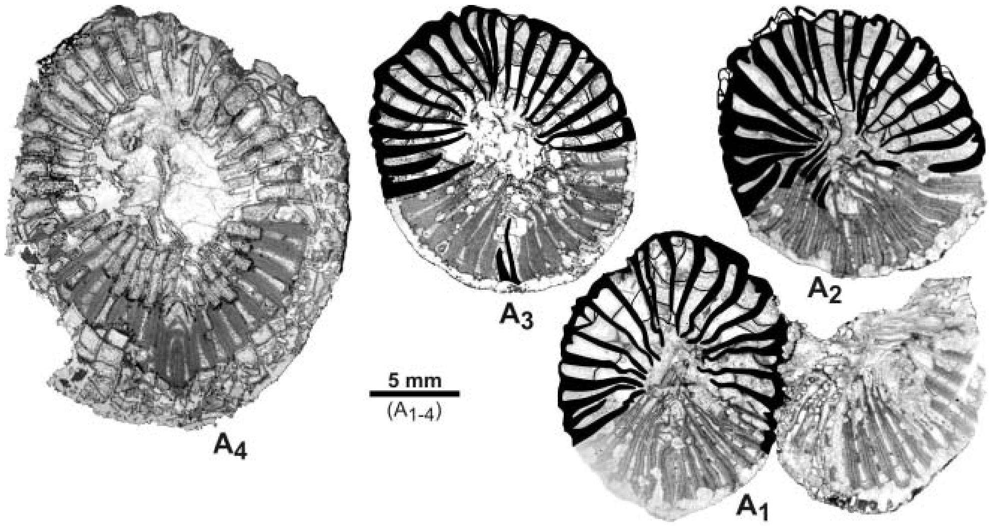


Fig. 34. A. *Siedleckia bjornoyana* Fedorowski, 1975, lower part of the Treskelodden Formation. UAMIG.Tc-C.BVI(4)/15; $A_{1,2}$ – transverse thin sections from immature growth stage, $A_{3,4}$ – transverse thin sections from mature growth stage.

open, bordered by successively shortening major septa. Counter protoseptum of variable length. Because of heavy recrystallization of outer corallite surface, minor septa very poorly visible; in sections from early mature growth stage, locally penetrating into tabularium. Dissepimentarium occupies ca. one-fourth corallite radius; built mostly of regular dissepiments, sporadically of herring-bone ones.

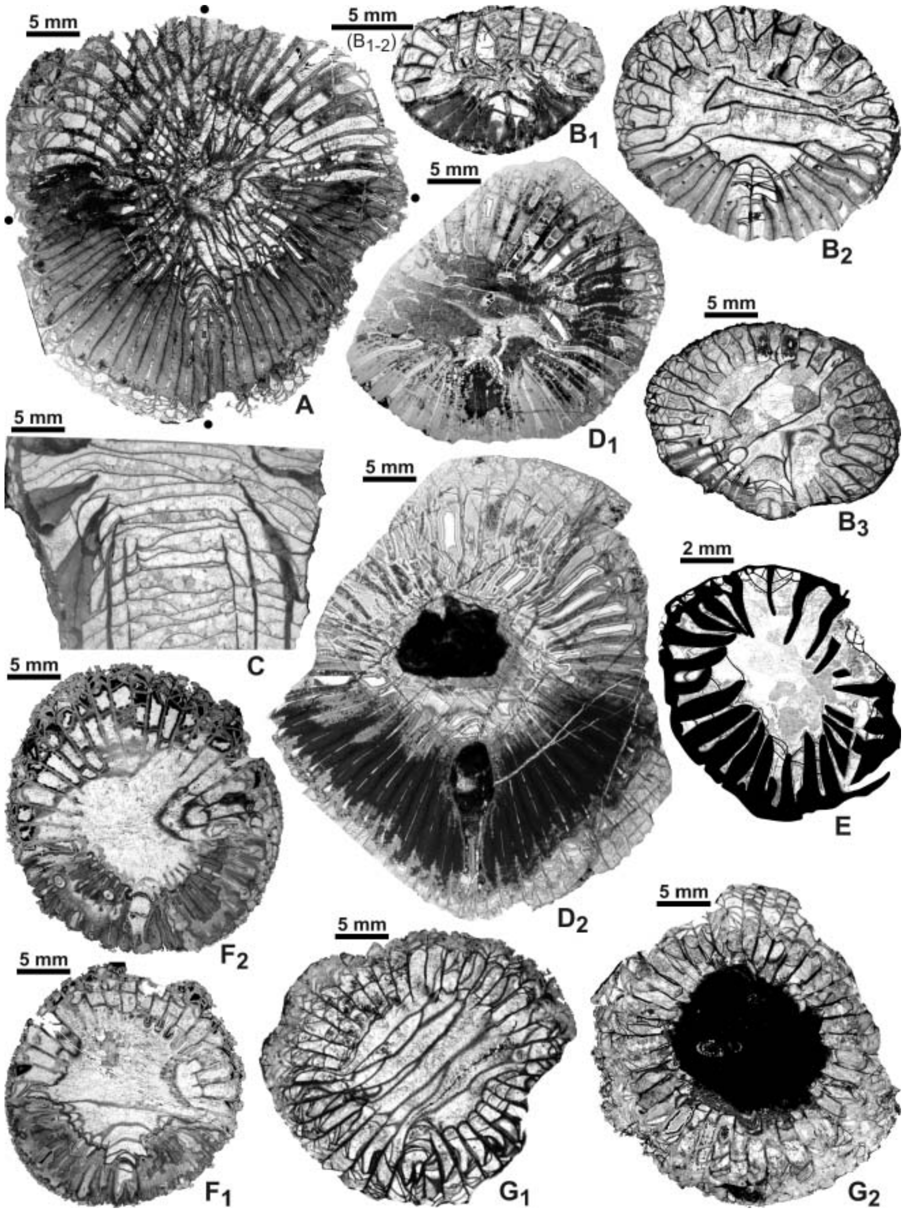
Remarks: The n/d indices, major septa elongated in early growth stages and shortened in adult ones, a similar width and structure of dissepimentarium, and minor septa in early growth stages crossing the dissepimentarium are features connecting the Spitsbergen specimen with the holotype from Bjørnøya. Only

Fig. 35. A, D. *Siedleckia longiseptata* (Grek, 1936), Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.CrL. I/5/4; transverse thin section from mature growth stage.
D – UAMIG.Tc-C.Lin. I/1/88; $D_{1,2}$ – transverse thin sections from mature growth stage.
B, E. *Siedleckia* sp. A., lower part of the Treskelodden Formation.
B – UAMIG.Tc-C.Pol. BIV/18; $B_{1,2}$ – transverse thin sections from immature growth stage, B_3 – transverse thin section from mature growth stage.
E – UAMIG.Tc-C.Pol. BVI(4)/9; transverse thin section from immature growth stage.
C, F, G. *Siedleckia mutafii* (Gorsky, 1938), lower part of the Treskelodden Formation.
C – UAMIG.Tc-C.Pol. BI/13; longitudinal thin section.
F – UAMIG.Tc-C.Pol. BVII/1; $F_{1,2}$ – transverse thin sections from mature growth stage.
G – UAMIG.Tc-C.Pol. BVI(3)/6; $G_{1,2}$ – transverse thin sections from mature growth stage.

major septa slightly longer in cardinal than in counter quadrants and a shorter cardinal protoseptum at maturity differentiate the specimen under study from the holotype.

Occurrence: Svalbard: Bjørnøya (Ambigua Limestone) – Gzhelian, Polakkfjellet – Gzhelian.



Siedleckia longiseptata (Grek, 1936)
Fig. 35A, D

1936. *Caninia longisepta* Grek; Grek: pp. 12-13, pl. 2, figs 1-9, pl. 3, fig. 14.
1975. *Siedleckia longiseptata* (Grek, 1936); Fedorowski: pp. 50-51, pl. 4, figs 2-3, pl. 7, fig. 2a-b.

Diagnosis: *Siedleckia* with n/d ratio commonly 50-60/40-50; major septa up to two-thirds length of corallite radius; minor septa reaching one-fourth major septa in length; dissepimentarium of variable width, from 1.0 mm in cardinal quadrants to one-half length of major septa in counter quadrants; tabulae flat, mostly incomplete, numbering 12/10 mm; microstructure lamello-trabecular; external wall 0.3 mm thick. [Based on specimens from Bjørnøya (Fedorowski 1975) and those described by the present author].

Material: Four fragmentary specimens, from 10 to 50 mm in length (UAMIG. Tc-C.Pol. BI/9; UAMIG.Tc-C.CrL. I/5/4, 5, 18). Six peels and six transverse thin sections.

Description: The specimens under study represent immature (Fig. 35D_1) and mature growth stages (Fig. 35A, D_2). Their n/d indices are ~38/~30 (at tabularium diameter of 25 mm) and 55/~40 (at tabularium diameter of 32 mm); at tabularium diameter of 35.0 mm, major septa number 51. Major septa attain about two-thirds to three-fourths corallite radius; in tabularium of cardinal quadrants strongly thickened, with thinning inner ends. Cardinal protoseptum below calice bottom exceeds one-third corallite radius (Fig. 35A); in early growth stages equal in length to neighbouring major septa (Fig. 35D_1); above calice bottom shortened to ca. one-fourth corallite radius (Fig. 35D_2). Cardinal fossula open, exceeding one-half corallite radius in length, bordered by 2-4 pairs of major septa. Counter protoseptum shortened; in specimen illustrated in Fig. 35A, some 6.0 mm shorter than neighbouring major septa. Owing to abrasion and recrystallization of external parts of corallites, minor septa poorly visible, only a few reaching 3.0 mm in length (Fig. 35$D_{1,2}$). Dissepimentarium about 5 mm wide (crushed and diminished by abrasion).

Remarks: The specimens under study show most morphological features of the *S. longiseptata* described by Fedorowski (1975) from the Gzhelian of Bjørnøya. Significant features that the Spitsbergen specimens share with those from Bjørnøya include long major septa in mature growth stages, a similar number of septa at comparable diameters of tabularia, and a cardinal protoseptum shortened in the calice and below its bottom. Only a slightly less shortened cardinal protoseptum below the calice bottom differentiates them from the Bjørnøya specimens, while making them similar to *S. bjornoyana*. This species, however, has smaller diameters of corallites and tabularia than *S. longiseptata*, as well as longer major septa in early growth stages and shorter ones at maturity. It seems, therefore, that in this case the extent of shortening of the cardinal protoseptum is indicative of a variability of this feature in *S. longiseptata* rather than of a different taxonomic attribution of the specimens examined.

Occurrence: Russia, the Urals – Upper Carboniferous; Svalbard: Bjørnøya (Ambigua Limestone) – Gzhelian, Polakkfjellet (Lower Treskelodden Formation) – Gzhelian, Linnédalen (Wordiekammen Formation) – Gzhelian.

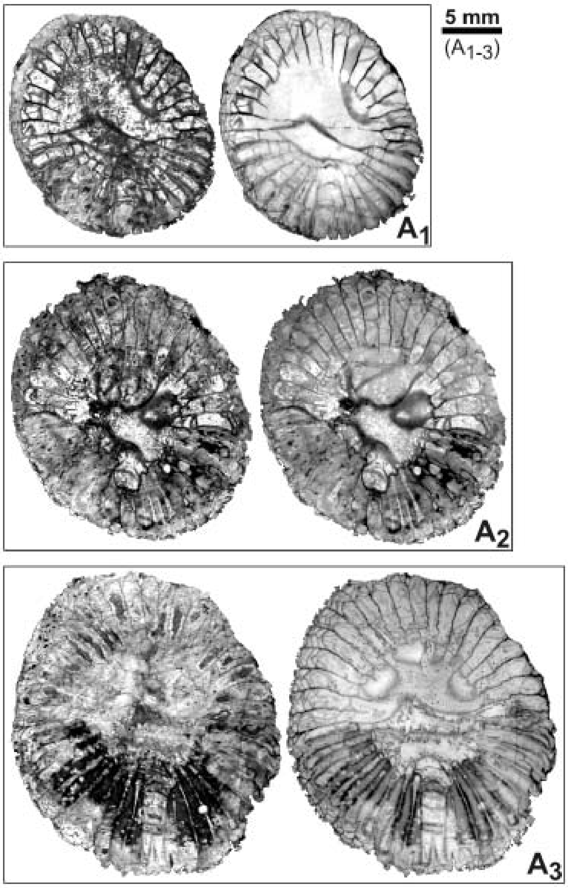


Fig. 36. A. *Siedleckia mutafii* (Gorsky, 1938), lower part of the Treskelodden Formation. UAMIG. Tc-C.Pol. BVI(3)/4; A_{1-3} – transverse thin sections from mature growth stage. In the pairs of photos, those on the right are taken in reflected light, those on the left, in transmitted light.

Siedleckia mutafii (Gorsky, 1938)
Figs 35C, F, G, 36

1938. *Caninia mutafii* sp. nov.; Gorsky: p. 37, text-fig. 21a, pl. 5, figs 2-6.
1975. *Siedleckia mutafii* (Gorsky, 1938); Fedorowski: pp. 51-52, pl. 5, figs 1-2.
1978. *Caninia mutafii* Gorsky, 1938; Gorsky: pp. 81-83, pl. 9, figs 1-4, pl. 10, figs 1-2.

Diagnosis: *Siedleckia* with n/d of 27-38/10-21; major septa attain two-thirds corallite radius, in tabularium of cardinal quadrants slightly curved towards cardinal protoseptum; shortened counter protoseptum commonly placed asymmetrically; minor septa attain one-fourth length of major septa; dissepimentarium occupies about one-fourth corallite radius.

Material: 15 fragmentarily preserved specimens [UAMIG.Tc-C.Pol. BI/13; BII/4, 5, 9; BIV/19, 20, 34; BVI(1)/1, 2; BVI(3)/4, 6; UAMIG.Tc-C.CrL. I/4/1, 2; UAMIG.Tc-C.CrL. I/5/10; UAMIG.Tc-C.CrL. I/7/7)], all without proximal ends, abraded to various degrees, partly deformed and silicified. Eight peels and 25 transverse and two longitudinal thin sections.

Description: The specimens under study represent mature growth stages. Their n/d indices range from 27/10 to 35/18. Major septa attain one-half to two-thirds corallite radius in length (Figs 35$F_{1, 2}$, $G_{1, 2}$, 36A_{1-3}); in tabularium of cardinal quadrants thickened; right below calice bottom and in calice thin in all quadrants (Fig. 35$G_{1, 2}$). Cardinal protoseptum shortened (5 mm in length), in open fossula elongated to ca. three-fourths corallite radius. Counter protoseptum from short (Figs 35F_2, G_1, 36A_3), through no different in length from major septa (Fig. 36A_1), to slightly elongated (Fig. 36A_2); can be thinner than remaining major septa. Minor septa 1.4 mm in length and limited to peripheral part of dissepimentarium (Fig. 36A_3), which attains from ca. one-fifth to ca. one-third corallite radius in width. Dissepiments mostly herringbone. Tabulae incomplete, at the corallite axis flat with downturned edges, numbering 10/10 mm (Fig. 35C), in outer zone with additional, mostly convex tabellae inclining towards dissepimentarium.

Remarks: The corallites described above are comparable with Gorsky's (1978) specimens from the Uppermost Bashkirian of Bashkir and Novaya Zemlya in their n/d indices, thick major septa in cardinal quadrants, short minor septa, a wide dissepimentarium, and the form of the tabularium. They differ from those specimens in having shorter major septa and a lower density of tabellae at the corallite axis.

Among 20 specimens collected in Spitsbergen there is one [UAMIG.Tc-C. Pol BVI(3)/4], presented in Fig. 36A_{1-3}, which has a variable length of its counter protoseptum. This feature does not occur in the Russian specimens, but is present in *S. mutafii* from Bjørnøya described by Fedorowski (1975) with which it shares the remaining features of the species, including similar n/d indices.

Occurrence: Russia: Bashkir and Novaya Zemlya – Moscovian; Svalbard: Bjørnøya – Gzhelian, Polakkfjellet – Gzhelian, Linnédalen – Gzhelian-Sakmarian.

Siedleckia sp. A
Fig. 35B, E

Material: Two partly abraded and deformed fragments (UAMIG.Tc-C.Pol. BIV/18; BVI(4)/9). Three peels and six transverse thin sections.

Description: The specimens under study represent immature (Fig. 35$B_{1,2}$, E) and mature growth stages (Fig. 35B_3). Their n/d indices are 27/13, 34/18 and 37-38/24. Length of major septa in early growth stages from two-thirds to three-fourths corallite radius; in tabularium of cardinal quadrants thickened; in adult stage shortened to one-half corallite radius. Cardinal protoseptum elongated in early growth stages, in later ones shortened. Cardinal fossula open, slightly longer than cardinal protoseptum, bordered by 2-3 pairs of major septa. Counter protoseptum shorter than remaining major septa of counter quadrants. Minor septa poorly visible, ca. 1.5 mm in length. Dissepimentarium occupies ca. one-sixth corallite radius, attaining at most 2 mm width; dissepiments mostly herringbone.

Remarks: The specimens described above have n/d indices in early growth stages similar to *S. bjornoyana* (28/14 *vs.* 27/13). At maturity their n/d indices are close to those of *S. mutafii* (39/25 *vs.* 37-38/24), especially the ones from Polakkfjellet. However, an elongated cardinal protoseptum in early growth stages, a narrow dissepimentarium and very short minor septa preclude the possibility of their attribution to any of those species. What makes it especially difficult to classify them into the known species of *Siedleckia* is the fact that for the greater part of ontogeny they have an elongated cardinal protoseptum, which, as follows from the diagnosis of the genus, should be shortened from early ontogenetic stages on. The set of features of the Polakkfjellet *Siedleckia* sp. A corallites is therefore specific, but owing to the scarcity of material no new species was distinguished.

Occurrence: Spitsbergen, Polakkfjellet – Gzhelian.

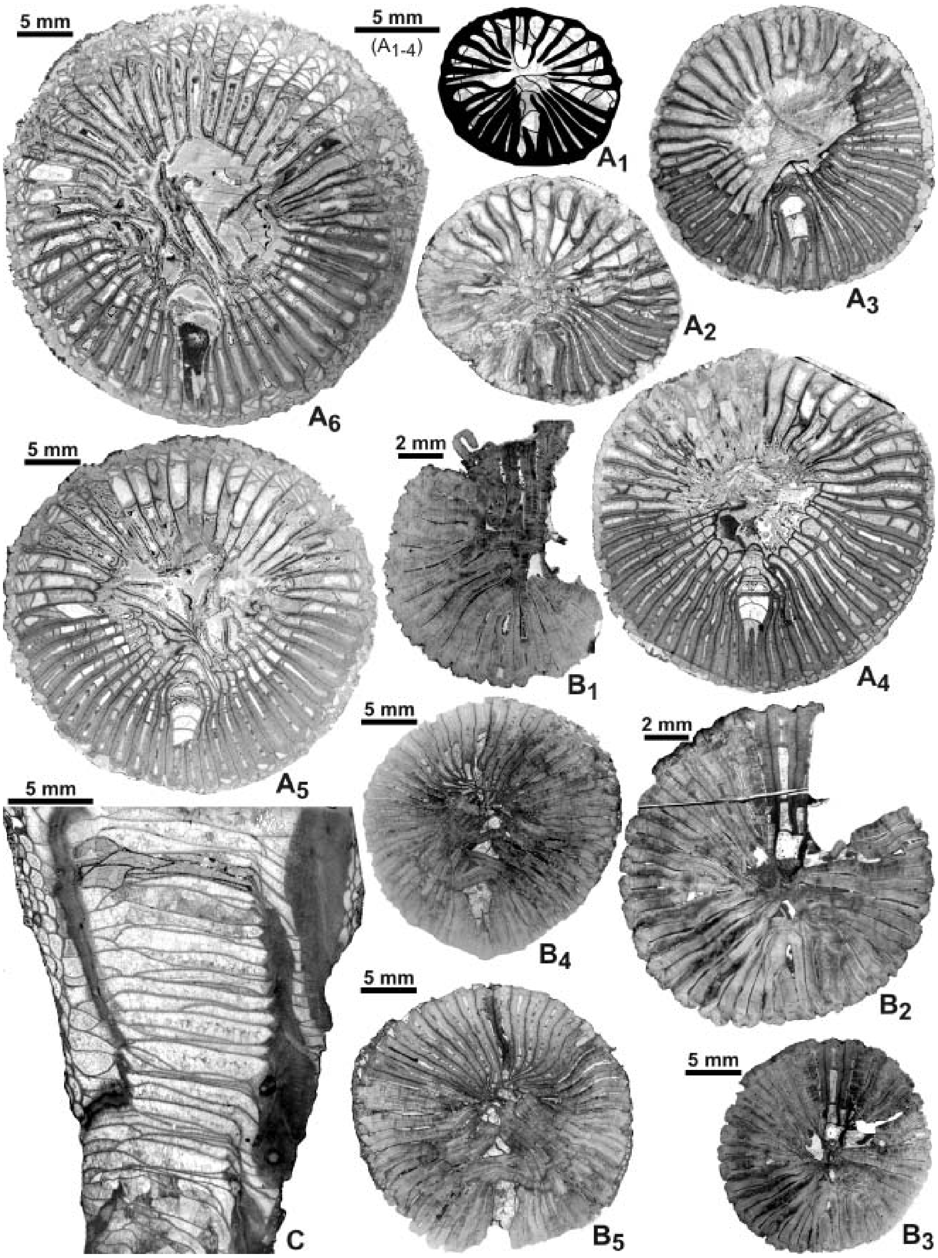


Fig. 37. A-C. *Siedleckia* sp. B.

A – UAMIG.Tc-C.Pol. BVI(4)/6, lower part of the Treskelodden Formation; $A_{1,2}$ – transverse thin sections from immature growth stage, $A_{3\text{-}6}$ – transverse thin sections from mature growth stage.

B – UAMIG.Tc-C.Lin. I/1/10, Tyrrellfjellet Member of the Wordiekammen Formation; $B_{1\text{-}3}$ – transverse thin sections from immature growth stage, $B_{4,5}$ – transverse thin sections from mature growth stage.

C – UAMIG.Tc-C.Pol. BIV/24, lower part of the Treskelodden Formation; longitudinal thin section.

Siedleckia sp. B
Fig. 37A-C

Material: Six partly or almost entirely silicified specimens, without proximal and distal parts (UAMIG.Tc-C.Pol. BI/11/2, BVI(4)/6; BVI/24; UAMIG.Tc-C. Lin. I/1/10, 26; UAMIG.Tc-C.CrL. I/5/1). 22 transverse and one longitudinal thin sections.

Description: The longest specimens under study have 60 mm in length. Their n/d indices are 29-35/10-13, 42-49/20-27 and 50-55/32-40. In early growth stages, either all major septa are thickened and elongated (Fig. 37B_{1-5}), or only those in cardinal quadrants (Fig. 37A_1). In mature growth stages major septa attain from two-thirds (in counter quadrants) to three-fourths (in cardinal quadrants) corallite radius in length; in cardinal quadrants thickened (Fig. 37A_{2-5}). At calice bottom major septa are similar in length in all quadrants, at ca. two-thirds corallite radius (Fig. 37A_6). Cardinal protoseptum in early growth stage long (Fig. 37B_1), in later one shortened to ca. one-third length of major septa in cardinal quadrants. Cardinal fossula open, tabular, in early growth stages with parallel walls, in later ones key-hole shaped, bordered by 3-4 pairs of neighbouring major septa with inner ends slightly bent towards cardinal protoseptum. Counter protoseptum shortened to a greater or lesser degree, can be thinner than neighbouring major septa (Fig. 37A_2). Alar septa do not differ from remaining major septa of cardinal quadrants. Minor septa appear together with dissepiments at n/d = 42/20 (Fig. 37A_3); in mature growth stages limited to outer zone of dissepimentarium. In initial stage of development of dissepimentarium (Fig. 37$A_{3,4}$) its width amounts to ca. 1/10 corallite radius; in later growth stages it is wider in counter quadrants than in cardinal ones (Fig. 37A_6); in the widest place (at counter protoseptum) 6 mm wide, which is more than one-fourth corallite radius; towards cardinal protoseptum narrowing to 1 mm; built of regular and herringbone dissepiments. External wall 0.1 mm in thickness . Tabularium bi-zonal; tabellae at corallite axis mostly flat or slightly convex with gently declining edges, ca. 12/10 mm; at boundary with dissepimentarium of variable morphology, mostly concave (Fig. 37C).

Remarks: With their long cardinal protoseptum, longer major septa in cardinal quadrants than in counter ones, and a narrow dissepimentarium in early growth stages, the specimens are similar to *S. bjornoyana*. However, they differ from this species in the morphological structure of later growth stages. Then they have a cardinal protoseptum attaining one-third length of major septa (*vs.* slightly shorter one in *S. bjornoyana*), a shortened counter protoseptum (*vs.* one not differing in length), shorter minor septa limited to the outer zone of a narrow dissepimentarium (*vs.* ones crossing the entire dissepimentarium), larger corallite diameters with a greater number of major septa, which raise their n/d index to 55/40 (*vs.* 51/27x31 in *S. bjornoyana*), and a differently formed tabularium, which in *S. bjornoyana* is built of S-shaped peripheral tabellae and long, arching axial tabellae enriched with a few fine accessory tabellae.

In comparison with *S. longiseptata*, *S.* sp. B. has smaller corallite diameters at a similar number of septa. In the Russian specimens of *S. longiseptata*, n/d indices amount to 34/22 and 42-53/34-52 (Grek 1936), in specimens from Bjørnøya – 54-56/44-46, with a maximum of 61/50 (Fedorowski 1975). Adult growth stages of *S.* sp. B also have shorter major septa, a longer cardinal protoseptum, a narrower dissepimentarium with minor septa limited to its outer zone, and usually flat, widely spaced axial tabellae, which in *S. longiseptata* are arched and densely spaced.

The specimens described above as *Siedleckia* sp. B probably belong to a new species, but one cannot preclude the possibility that the differences listed above may be examples of intraspecific variability of *S. bjornoyana* or *S. longiseptata*. Regrettably, the poorly preserved material (specimens mostly silicified, without the earliest and latest parts) makes it impossible to corroborate any of those theses.

Occurrence: Spitsbergen: Polakkfjellet – Gzhelian, Linnédalen – Gzhelian-Sakmarian.

Genus: *Svalbardphyllum* Fedorowski, 1965

Type species: *Svalbardphyllum pachyseptatum* Fedorowski, 1965.

Diagnosis: See Chwieduk (2009*a*), p. 72.

Remarks: With its long counter protoseptum, *Svalbardphyllum* cannot belong to the family Polycoeliidae. The set of features occurring in this genus, together with the long counter protoseptum, can be found in the Pseudoclaviphyllinae. The problem is, however, that the appertaining of this subfamily to the family Antiphyllidae from the suborder Stereolasmatina is dubious, because of its having dissepimentarium, a feature alien to this suborder (Hill 1981: F308). Hence, I suggest to transmit this genus to the Bothrophyllidae representing the suborder Caniniina. While this suborder includes taxa with rather wide dissepimentaria, the remaining diagnostic features of Bothrophyllidae match *Svalbardphyllum* better than those found in the Polycoeliidae. Besides, the Bothrophyllidae include *Hornsundia*, a genus also described from Spitsbergen, with *H. lateseptata*, which, like *S. pachyseptatum*, has a narrow dissepimentarium appearing late in ontogeny.

Svalbardphyllum pachyseptatum Fedorowski, 1965
Fig. 38A-F

1965. *Svalbardphyllum pachyseptatum* n. sp.; Fedorowski: pp. 45-49, text-fig. 9a-f.
1980. *Svalbardphyllum pachyseptatum* Fedorowski; Birkenmajer and Fedorowski: pp. 14-15, pl. 1, fig. 3.
2009*a*. *Svalbardphyllum pachyseptatum* Fedorowski; Chwieduk: p. 72, fig. 8 C, D.

Emended diagnosis: *Svalbardphyllum* with 22-50 major septa at tabularium diameter of 7-25 mm; protosepta in early growth stages can meet at the corallite axis; at maturity major septa of counter and/or the same quadrants can fuse too.

Material: Eight specimens (UAMIG.Tc-C.Krg. III/1, 3, 4, 6, 21; UAMIG.Tc-C. Pol. VI/13, BVI/6, 10) abraded to various degrees. 22 transverse thin sections.

Description: Since all specimens are more or less abraded, the n/d indices are approximate and refer to the diameters of tabularia. In specimens from Kruseryggen the indices are: 28/11, 29/12, 33/14, 40/21, 42/23 and 45/24; those from Polakkfjellet are: 22/7, 26/9, 29/12.5 and 44/18. In immature and early mature growth stages, thickened major septa are of various length, almost filling whole corallite diameter (Fig. 38A_{1-3}, B, $D_{1,2}$); at maturity shortened, and in counter quadrants also thinner (Fig. 38C, E). Cardinal protoseptum in early growth stages can join counter protoseptum (Fig. 38A_1), or some major septa of counter quadrants (Fig. 38D_1); in later growth stages shortened, lying in closed fossula, restricted by successively shortening major septa of cardinal quadrants, one pair of which can fuse (Fig. 38B, D_2). Counter protoseptum can merge with one or more major septa of cardinal and/or counter quadrants (Fig. 38$A_{2,3}$, B). Alar septa prolonged and can merge at corallite axis with the longest major septa (Fig. 38$A_{2,3}$). Dissepimentarium poorly preserved (Fig. 38E, F), in visible fragments built of 1-4 rows of straight and herringbone dissepiments.

Remarks: Specimens of *Svalbardphyllum pachyseptatum* have so far been described from Treskelen (Fedorowski 1965), Triasnuten (Birkenmajer and Fedorowski 1980) and Kruseryggen (Chwieduk 2009*a*). Because of a considerable abrasion of corallites, in their n/d indices the number of septa is usually measured against the diameter of tabularium. Also in our case it was only possible to measure the width of tabularia, except in the early growth stages of specimens from Polakkfjellet.

The Kruseryggen and Polakkfjellet specimens described above differ from those known so far in having a slightly smaller number of septa at the same and similar tabularium diameters, which are equal to 32/12, 36/14, 40/19, 42/21 and 45/23 in the specimens from Treskelen and Kruseryggen (Fedorowski 1965, Chwieduk 2009*a*), *vs*. 29/12, 33/14, 38-40/21 and 42/23 for the Kruseryggen specimens described in this paper. Also notable is the fusion of protosepta in

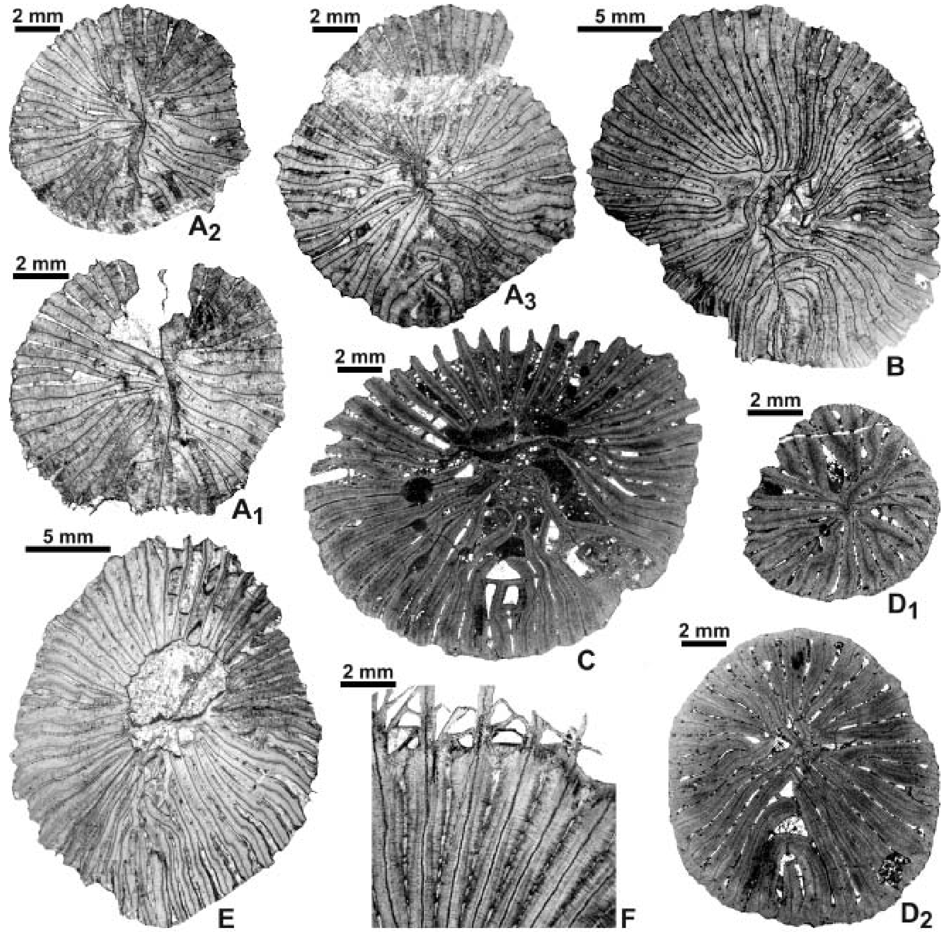


Fig. 38. A-F. *Svalbardphyllum pachyseptatum* Fedorowski, 1965.

A – UAMIG.Tc-C.Krg. III/1, upper part of the Treskelodden Formation; $A_{1,2}$ – transverse thin sections from immature growth stage, A_3 – transverse thin section from mature growth stage.
B – UAMIG.Tc-C.Krg. III/6, upper part of the Treskelodden Formation; transverse thin section from mature growth stage.
C – UAMIG.Tc-C.Pol. BVI/6, lower part of the Treskelodden Formation; transverse thin section from mature growth stage.
D – UAMIG.Tc-C.Pol. BVI/13, lower part of the Treskelodden Formation; D_1 – transverse thin section from immature growth stage, D_2 – transverse thin section from mature growth stage.
E – UAMIG.Tc-C.Krg. III/3, upper part of the Treskelodden Formation; transverse thin section from mature growth stage.
F – UAMIG.Tc-C.Krg. III/4, upper part of the Treskelodden Formation; part of dissepimentarium.

early growth stages, not observed so far. This feature was not observed earlier by Fedorowski (1965), Fedorowski and Birkenmajer (1980) and Chwieduk (2009*a*), because those authors had no examples of early growth stages of this species. In the material I examined, connected protosepta are visible in a section at tabularium diameter of ≤12 mm, while the earliest growth stages of the specimens described by the above authors had tabularia of 12.7 mm in diameter and larger.

The remaining features of morphology of the Kruseryggen and Polakkfjellet specimens, including a long counter protoseptum, long alar septa and long major septa that can join at corallite axis, and a very narrow dissepimentarium, do not differ from those of the specimens described earlier. Only a greater number of major septa at similar diameters of tabularia in the mature specimens from Polakkfjellet (44/18 *vs*. 40/19 for the specimens from Treskelen and 38/21 for the one from Triasnuten) distinguishes them from the remaining *S. pachyseptatum*, the differences which can be treated as intraspecific variability.

Occurrence: Spitsbergen: Treskelen, Triasnuten, Kruseryggen – Lower Sakmarian; Polakkfjellet – Gzhelian.

Suborder: Stereolasmatina Hill, 1981
Family: Antiphyllidae Ilina, 1970
Subfamily: Antiphyllinae Ilina, 1970

Genus: *Krusenella* gen. nov.

Derivation of name: named after small-sized corallites from Kruseryggen.

Type species: *Krusenella pachyseptata* gen. et sp. nov.

Diagnosis: Antiphyllinae with major septa varying in length, pinnately grouped in cardinal quadrants, the longest extending to axis; cardinal protoseptum long, shortened above calice floor; counter protoseptum reaches corallite axis, may link with metasepta in cardinal quadrants; alar septa commonly equal in length to adjacent major septa, may be slightly longer; minor septa very short.

Remarks: Most Antiphyllinae genera described are Carboniferous in age. Only *Lytvolasma* known from the Ural Mts are Early Permian. However, both Permian and Carboniferous genera differ from the Kruseryggen specimens in their unique combination of generic characteristics (Table 3).

Krusenella gen. nov. from the Treskelodden Formation (Lower Sakmarian) of Kruseryggen is represented by small, trochoid corallites, at most 16.0 mm in diameter. In some sections they resemble immature growth stages of *Svalbardphyllum pachyseptatum*, which is a fairly common species on Spitsbergen, known from coral horizon III on Triasnuten (Birkenmajer and Fedorowski 1980), coral horizon IV on Treskelen (Fedorowski 1965), coral horizon III on Kruseryggen (Chwieduk 2009*a* and this study), and Polakkfjellet (this study). The similarity between *Krusenella* gen. nov. and early growth stages of *S. pachy-*

septatum is shown in their n/d indices, fusion of some major septa at the corallite axis, long alar septa and a long cardinal protoseptum, and absence of dissepiments, which appear in *S. pachyseptatum* only at maturity.

All those similarities notwithstanding, it is impossible to treat the *Krusenella pachyseptata* gen. et sp. nov. described below as immature growth stages of *S. pachyseptatum*. The chief reason is the presence in *Krusenella* gen. nov. of a long cardinal protoseptum, which shortens only above the calice bottom (in *S. pachyseptatum* it is usually shorter than the remaining major septa). Against treating *Krusenella pachyseptata* gen. et sp. nov. as immature stages of *Svalbardphyllum* is a lack of adult representatives of *Svalbardphyllum* in coral horizon V, even though in coral horizon III, all growth stages of *S. pachyseptatum* can be found. The absence of adult specimens of *S. pachyseptatum* in coral horizon V cannot be due to selection because there various growth stages of such different corals as: *Bothrophyllum baeri*, *B.* cf. *orvini, Caninophyllum belcheri* var. *magnum*, *Hornsundia lateseptata*, or *Timania multiseptata* (Chwieduk 2009*a*), as well as *Pseudotimania borealis* sp. nov. and *P. longiseptata* sp. nov. were described in an earlier part of this study.

Distribution of genus: Spitsbergen: Kruseryggen, Linnédalen – Sakmarian.

Krusenella pachyseptata gen. et sp. nov.
Figs 39, 41

Holotype: UAMIG.Tc-C.Krg. Vx/34 (Fig. 39A). Eight transverse thin sections.

Type locality: Kruseryggen (N 77° 07’; E 16° 10’), south Spitsbergen, Hornsund area (Fig. 2E).

Type horizon: Upper part of Treskelodden Formation, Lower Sakmarian.

Derivation of name: *pachyseptata* – having thickened major septa.

Diagnosis: *Krusenella* with n/d ratio of 23-31/8-16; major septa vary in length, the longest reaching corallite axis, thickened to contiguity in early growth stages; protosepta long, connected at corallite axis in early growth stages; in calice, cardinal protoseptum shortened and counter protoseptum extending to axis; in all growth stages alar septa as long as other majors.

Material: Paratypes – 13 specimens (UAMIG.Tc-C.Krg. Vx/5, 7, 9, 12, 14-18; Krg. Vy/16, 17; UAMIG.Tc-C.Lin. I/1/56, 118), in small fragments, abraded to a considerable degree. 46 transverse thin sections.

Description of holotype: In the earliest growth stage available for study (Fig. 39A$_1$) the n/d index equals 12/4. This sharply oblique section shows that the first to appear are protosepta merged at corallite axis – in Fig. 39A$_1$ visible on the left side of section; ten slightly higher (right side of section) metasepta are present. This shows the increment of septa in the early growth stage to be relatively fast.

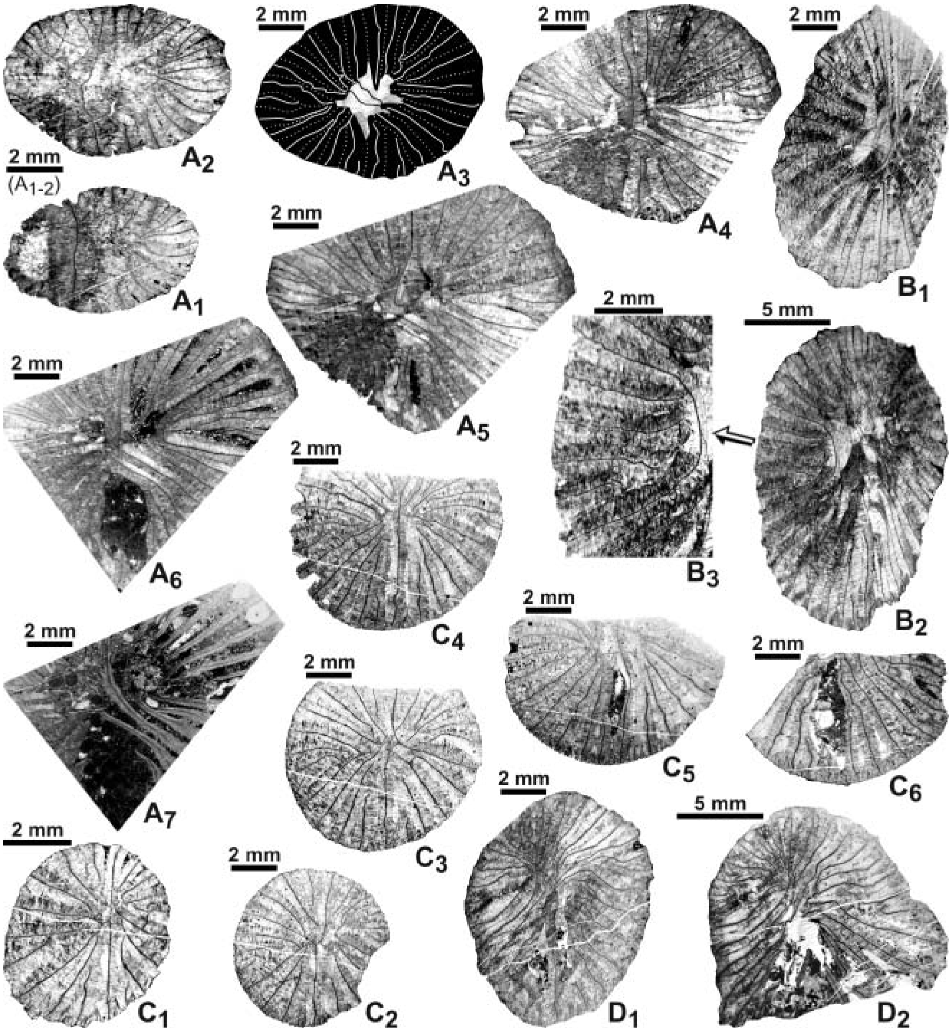


Fig. 39. A-D. *Krusenella pachyseptata* gen. et sp. nov., upper part of the Treskelodden Formation.

A – UAMIG.Tc-C.Krg. Vx/34; $A_{1,2}$ – transverse thin sections from immature growth stage, A_{3-7} – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Krg. Vx/12; $B_{1,2}$ – transverse thin sections from mature growth stage, B_3 – fragment B_2 showing alar septum combined with major septum of counter quadrant.
C – UAMIG.Tc-C.Krg. Vz/18; C_{1-4} – transverse thin sections from immature growth stage, $C_{5,6}$ – transverse thin sections from mature growth stage.
D – UAMIG.Tc-C.Krg. Vy/16; $D_{1,2}$ – transverse thin sections from mature growth stage.

Table 3. Morphological differentiation of genera in Antiphyllinae Ilina, 1970.

Genus	Cardinal protoseptum	Cardinal fossula	Counter protoseptum	Alar septa	Major septa	Minor septa	Tabular floor	Occurrence
Actinophrentis Ivanovsky, 1967	thin, somewhat short	narrow, its axial end reaching to or almost to corallite axis	equal in length to adjacent major septa	as long as other major septa	thickened to contiguity in early growth stages, radially arranged, reaching to or almost to axis; in late growth stages contiguous in peripheral stereozone and wide axial structure	very short	domed	Upper Carboniferous (Donbas)
Bradyphyllum Grabau, 1928	vary from long to short	distinct	vary from long to short	equal in length to adjacent major septa	in early growth stages straight, long, axial parts somewhat thickened and contiguous; in late growth stages withdrawn from axis, rhopaloid	very short	domed	Middle-Upper Carboniferous (Asia, N. America)
Clavilasma Weyer, 1975	like *Claviphyllum* but septa with metriophylloid flanges							Lower Carboniferous Viséan (Scotland)
Claviphyllum Hudson, 1942	short	on convex side	rhopaloid, longer and thicker than others, extending to axis	short	straight, different size, Cl, first counter metasepta short; second and third counter metasepta and first and second cardinal metasepta longer and rhopaloid	if long contratingent	domes depressed axially with edges declined abaxially	Lower Carboniferous Viséan (Great Britain)
?*Lytvolasma* Soshkina, 1925	in early growth stages long, in late stages slightly shortened	open, narrows midlength, widens into axial space; in late growth stages weakly marked	as other major septa	as long as other major septa	long, thickened, laterally contiguous over much of their length, somewhat curved and almost reaching axis, in cardinal quadrants grouped about fossula; axial ends of septa of counter quadrants join	very short, confined to narrow peripheral stereozone	convex	Lower Permian Artinskian (Ural)
Pseudobradyphyllum Dobrolyubova, 1940	shortest	distinct in late growth stages	shortest	longest	in early growth stages long, reach corallite axis; in late growth stages their axial ends become somewhat rhopaloid, and they are unequal; Cl, alar and first cardinal metasepta longest; insertion in counter quadrants accelerated	very short	convex, may be incomplete	Upper Carboniferous Gzhelian (Moscow Basin)

Rotiphyllum Hudson, 1942	may withdraw from center of axial structure	narrowing adaxially, may extend to corallite axis	longer than other	as long as other major septa	dilated, with extra thickening in inner third of their length, joined to form dense axial structure	short	conical	Lower Carboniferous Tournaisian (Poland), Viséan (Great Britain, Kazakhstan) Upper Carboniferous Moscow (Donbas)
Krusenella gen. nov.	in early growth stages long, joined with counter protoseptum; in late growth stages slightly shortened	narrowing adaxially, may extend to corallite axis	longer than other; in late growth stages connect with major septa of cardinal quadrants	as long as other major septa	vary in length, longest one reaching to or almost to axis; thickened to contiguity in early growth stages; in upper part of calice withdrawn from axis	very short		Lower Permian Sakmarian (Kruseryggen, Treskelodden Fm.)

In section cut approximately 1.0 mm above previous one (Fig. 39A_2) n/d index is 23/6; major septa of varying length, but not reaching corallite axis, strongly thickened, filling entire corallite lumen. Protosepta joined at corallite axis.

In later growth stages n/d indices are 28/8 and 30/9 (Fig. 39$A_{3,4}$). Metasepta developed as in previous section. Cardinal protoseptum equal in length to major septa of cardinal quadrants; counter protoseptum elongated, crossing corallite axis (Fig. 39A_4). Alar septa not distinguished among remaining metasepta.

Septal index in adult growth stage (in calice bottom) equals 31/12 (Fig. 39A_5). Major septa of varying length, with the longest reaching corallite axis. Counter protoseptum crosses corallite axis. Cardinal protoseptum slightly shortened, longer than two adjacent pairs of major septa, at ca. one-half corallite radius. Cardinal fossula narrow, bordered by shortening major septa of cardinal quadrants, closed by bent inner ends of elongated major septa of third and fourth pairs of cardinal quadrants.

In lower part of calice n/d index is 32/~16 (Fig. 39A_6). Major septa of varying length, with the longest reaching corallite axis. Estimated length of cardinal protoseptum – ca. one-third length of major septa. Cardinal fossula about twice as long, bordered by shortening major septa of cardinal quadrants, the longest of which have inner ends bent towards cardinal protoseptum. Counter protoseptum elongated, at corallite axis meets (but does not merge with) the longest major septa of cardinal quadrants. Alar septa may join with major septa of counter quadrant. Free spaces appear between septa, and minor septa (0.3 mm long) start to be noticeable for the first time.

In the upper part of the calice (Fig. 39A_7) the morphological structure cannot be described with any accuracy because of the damage to the specimen. It is impossible to determine, e.g., its n/d index, minor septa, or the external wall. Still, one can note that major septa become thin and shorter, leaving in corallite axis only the counter protoseptum fused with one septum of the third pair of metasepta of the cardinal quadrant. The cardinal protoseptum is shortened so strongly as to be invisible in the incompletely preserved calice.

Intraspecific variability: 13 paratypes were used to supplement the description of *Krusenella pachyseptata* gen. et sp. nov. They have n/d indices slightly differing from those of the holotype (Fig. 40). It was also found that in later growth stages the counter protoseptum could merge with any major septum of cardinal quadrants (Figs 39B_1, $D_{1,2}$, 41$A_{1,2}$), not necessarily the same with which it merges in the holotype. An alar septum can fuse with any major septum of the counter quadrant (Fig. 39$B_{2,3}$), and any septum of the cardinal quadrant can fuse with any septum of the counter quadrant (Fig. 41B_2). When

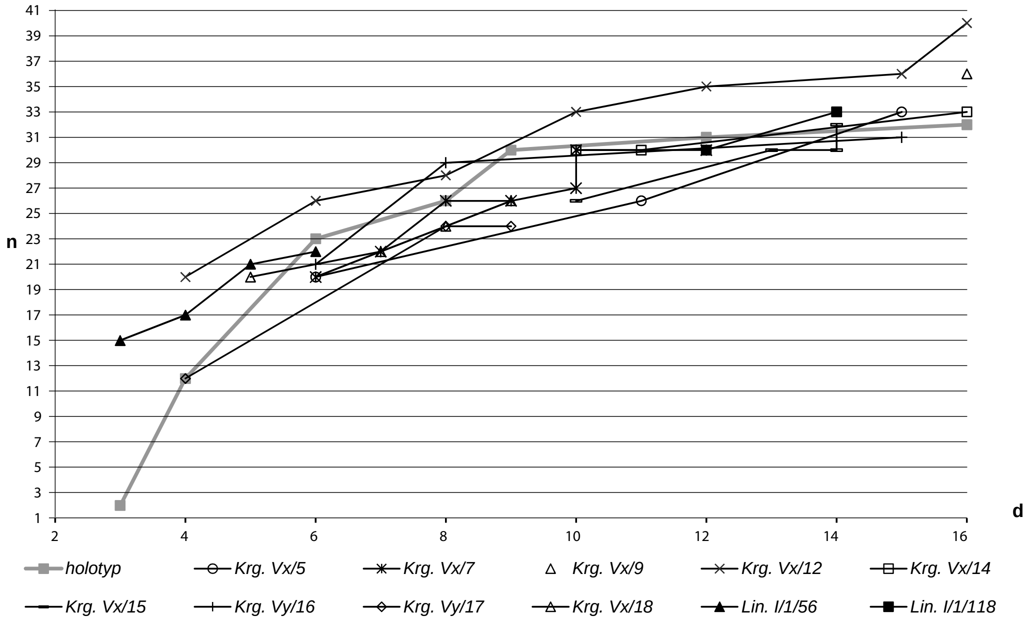


Fig. 40. Plot of the number of major septa (n) *vs*. diameters (d) of *Krusenella pachyseptata* gen. et sp. nov. Symbols joined by lines represent values taken from individual specimens.

tracing the arrangement of septa in the calice (Fig. 41A$_{2,3}$), it was only in its upper part that all major septa were found to retreat from the corallite axis. Then they become thin and similar in length, attaining ca. two-thirds corallite radius. The sections made near the calice floor and in the calice (Figs 39C$_{4-6}$, 41B$_2$, C$_{1,2}$), show a deep cardinal fossula and cardinal protoseptum shortened above the calice floor. The fragmentarily preserved external wall has 0.3 mm in thickness (Fig. 41A$_{2,3}$). Minor septa, poorly visible in the holotype, in specimen UAMIG.Tc-C.Krg. Vx/14 (Fig. 41C$_2$) appear below the calice bottom, where they attain one-fifth corallite radius, while in specimen UAMIG.Tc-C. Krg. Vx/15 (Fig. 41A$_{2,3}$) they appear only in the calice, attaining ca. one-tenth corallite radius.

Occurrence: Spitsbergen: Kruseryggen, Linnédalen (Treskelodden Formation) – Lower Sakmarian.

Genus: *Lytvolasma* Soshkina, 1925

Type species: *Lytvolasma asymetrica* Soshkina, 1925.

Diagnosis: See Fedorowski (1987), p. 57.

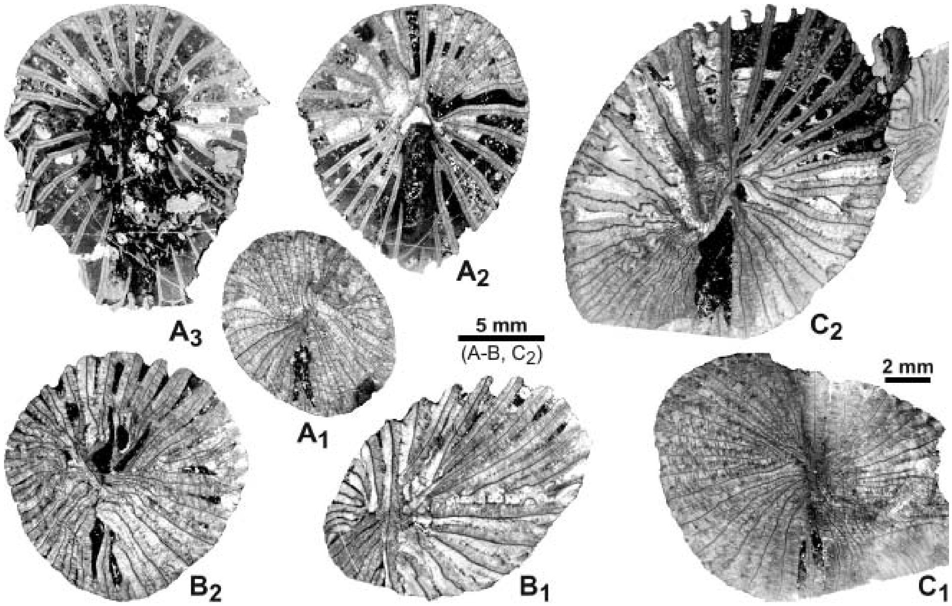


Fig. 41. A-C. *Krusenella pachyseptata* gen. et sp. nov., upper part of the Treskelodden Formation.

A – UAMIG.Tc-C.Krg. Vx/15; A_1 – transverse thin section from immature growth stage, $A_{2,3}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Krg. Vx/5; B_1 – transverse thin section from immature growth stage, B_2 – transverse thin section from mature growth stage.
C – UAMIG.Tc-C.Krg. Vx/14; $C_{1,2}$ – transverse thin sections from mature growth stage.

Lytvolasma asymetrica Soshkina, 1925
Fig. 42A, B

1925. *Lytvolasma asymetricum* [sic] Soshkina; Soshkina: pp. 82-83, pl. 1, figs 1, 1a, 1b.

Material: Five specimens (UAMIG.Tc-C.Lin. I/1/46, 48, 59, 77, 96), with early growth stages heavily silicified or mechanically damaged. 37 transverse thin sections.

Description: Corallites strongly corniculate, small in size, with cardinal protoseptum perpendicular to plane of curvature. N/d ratio ranges from 18-21/4-5 to 24/7 for immature growth stages (Fig. $42A_{1-3}$, B_{1-5}) and 23-26/8-14 at maturity (Fig. $42A_{4-8}$, B_6). Major septa of varying length; except of a few elongated septa at concave side of corallite, remaining septa usually attain three-fourths corallite radius. Bent inner ends of major septa join to form an incomplete aulos, open on the side of alar septum throughout most of ontogeny.

In the earliest growth stage available, altered by biostratinomic processes, the axial part of the corallite and most of its external wall have been damaged.

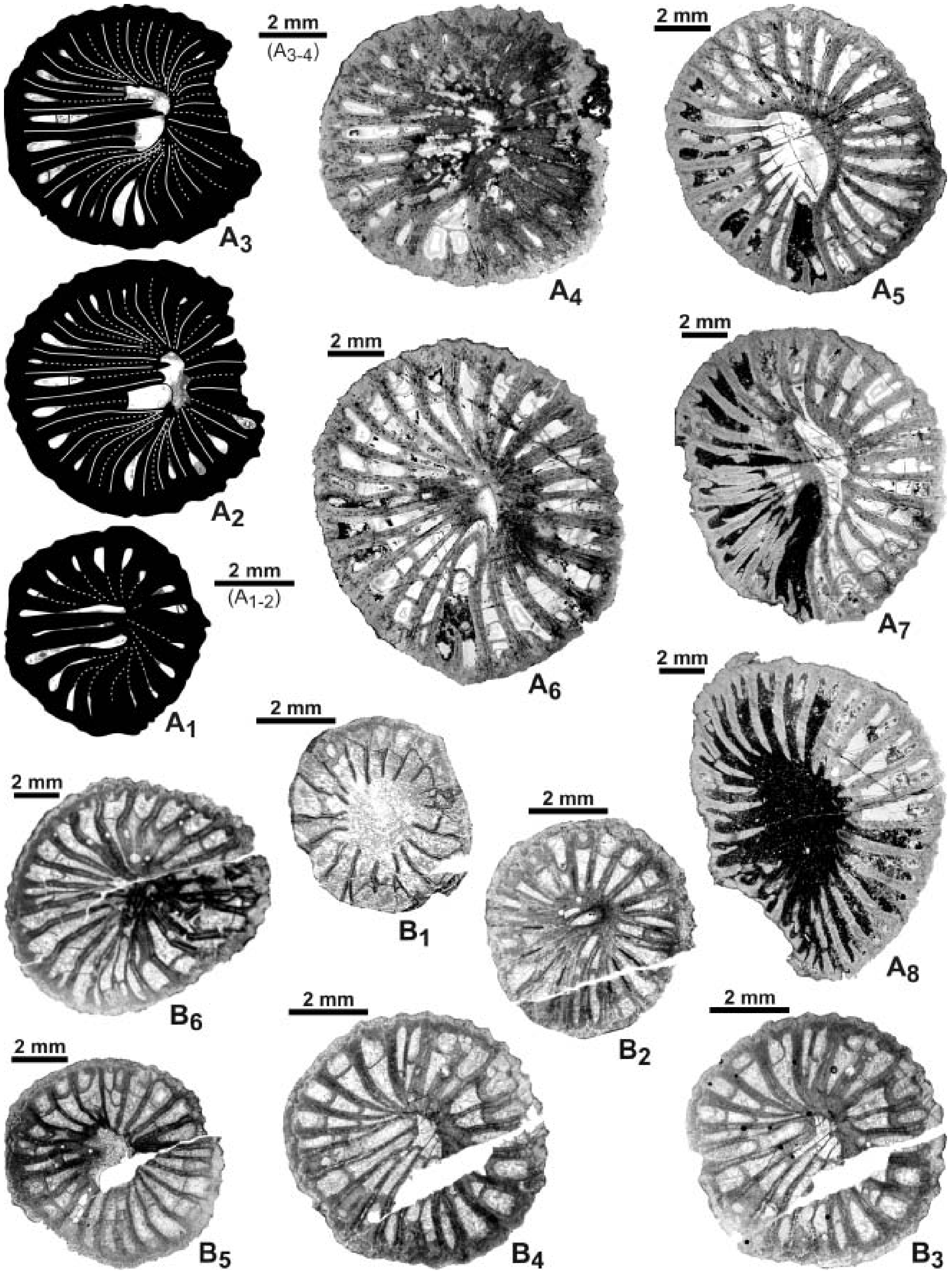


Fig. 42. A, B. *Lytvolasma asymetrica* Soshkina, 1925, Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.Lin. I/1/77; A_{1-3} – transverse thin sections from immature growth stage, A_{4-8} – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Lin. I/1/48; B_{1-6} – transverse thin sections from immature growth stage.

From the preserved relics of major septa, one can conclude that they were arranged radially (Fig. $42B_1$).

At mature growth stages major septa slightly withdraw from axis; free axial space occupies about one-fourth corallite diameter (the fusion of major septa at corallite axis, illustrated in Fig. $42B_6$, is caused by light crushing of the specimen). As follows from a series of transverse sections, the incomplete aulos disintegrates below calice bottom (Fig. $42A_{5-7}$ – right side of specimen, B_{3-5}). Initially it embraces three quadrants, then two, and then disappears (Fig. $42B_5$); hence it is lacking in the calice (Fig. $42A_8$). Cardinal protoseptum perpendicular to plane of curvature; in early ontogenetic stages equal in length to remaining major septa of cardinal quadrants; in later ones, shortened to one-third length of major septa. In specimen UAMIG.Tc-C.Lin. I/1/48 (Fig. $42B_6$), cardinal protoseptum shortens to at least three-fourths length of major septa. Cardinal fossula deep and arched, in early growth stages triangular and closed, in later stages narrow, elongated, reaching corallite axis, bordered by 1-2 pairs of adjacent major septa and half-aulos. Counter protoseptum does not differ from remaining major septa of counter quadrants. Minor septa of varying length and not developed in full number, visible in corallite lumen only below calice bottom, at corallite diameter of 7.0-9.0 mm (Fig. $42A_5$, B_5); ultimately attaining from 0.2 to 2.0 mm in length, which is ca. one-tenth to ca. one-third length of major septa. Traces of tabulae at minor septa indicate tabularium to be "biformly reduced" (Fig. $42A_{5,6}$). External wall 0.3 mm thick, with distinct septal furrows.

Remarks: The type species of *Lytvolasma* is represented by a small, 15-mm fragment of a specimen coming from the Artinskian of the Urals. No topotype of *L. asymetrica* has been described either. This makes it difficult to compare the morphology of the Spitsbergen specimens with that of the Ural specimen. Still, such features as: radial organisation of major septa in early growth stages, similar n/d indices (21/6.5 and 23/8 for the Spitsbergen specimens *vs*. 20/7-9 for the Ural one), long cardinal protoseptum in early growth stages, corniculate bending perpendicular to the C-K line, half-aulos open on the side of alar septum, and appearance of minor septa at corallite diameters of 7.0-9.0 mm (*vs*. 9.0 mm for the holotype), make the specimens under study close to the type species of this genus. A difference can only be found in the size of minor septa, which are longer in the examined specimens than in those from the Urals. However, Soshkina (1925) had at her disposal only a small corallite fragment with the adult growth stage not preserved, hence she may have found no fully formed minor septa in her material. In the Spitsbergen specimens, in sections with diameters smaller than 9.0 mm, minor septa are hardly visible, and those long enough to be perceptible in corallite lumen, appear at diameters of 9.5-10.0 mm and larger.

When compared with other species of this genus, the Spitsbergen specimens of *L. asymetrica* were also found to share some features with *L. aucta*. The similarity with this species, which was described by Fedorowski (1987: text-fig. 17) from the Asselian of southern Texas and which shows great intraspecific variability, is expressed in the n/d indices of early growth stages (18/6.3 – 22/7.8 for the Texas specimens, 18/5.0 – 22/7.5 for the Spitsbergen ones), in the length of the cardinal protoseptum at comparable growth stages, and in the appearance of minor septa at a corallite diameter of ca. 7.0 mm. However, at maturity the Spitsbergen specimens attain greater sizes. Their n/d indices amount then to 26/11-12 at the calice bottom and 26/14 higher up in the calice, as against 21-22/8-9 in *L. aucta*. Besides, in *L. aucta* the cardinal protoseptum is found on the concave side of the corallite, the counter protoseptum and alar septa can be elongated, and major septa withdraw from the corallite axis slightly later than in the Spitsbergen specimens. The most significant fact, however, is a zaphrentoid organisation of major septa in early growth stages of *L. aucta*. For Fedorowski (1987) this feature in the Texas corallites was the chief reason for distinguishing *L. aucta* from among specimens similar to *L. asymetrica*.

In relation to *L. canadensis* Fedorowski and Bamber, 2001, known from the Canadian Arctic Archipelago, the specimens under study differ in having a smaller, and in adult stages a constant, number of major septa at growing corallite diameters (26/9.5-14, *vs*. 26-30/12.5 for specimens from Ellesmere Island) and an unremarkable counter protoseptum, which is elongated in *L. canadensis* in the calice and below its bottom.

Occurrence: Russia: the Urals – Artinskian; Spitsbergen: Linnédalen – Sakmarian.

Family: Hapsiphyllidae Grabau, 1928
Subfamily: Hapsiphyllinae Grabau, 1928
Genus: *Allotropiochisma* Fedorowski, 1982*b*

Type species: *Amplexizaphrentis longiseptata* Flügel, 1973.

Diagnosis: See Fedorowski and Bamber (2001), p. 44.

Allotropiochisma exzentrica (Flügel, 1973)
Fig. 43A

1973. *Amplexizaphrentis exzentrica* n. sp.; Flügel: pp. 35-37, pl. 3, fig. 4, text-figs 15-16.
1982*b*. *Allotropiochisma exzentrica* (Flügel, 1973); Fedorowski: pl. 4, figs 3-4.

Diagnosis: See Flügel (1973), p. 36.

Material: Four specimens (UAMIG.Tc-C.Bld. I/2; II/v./6; KS. IA/14; KS. IB/18/2). 17 transverse thin sections.

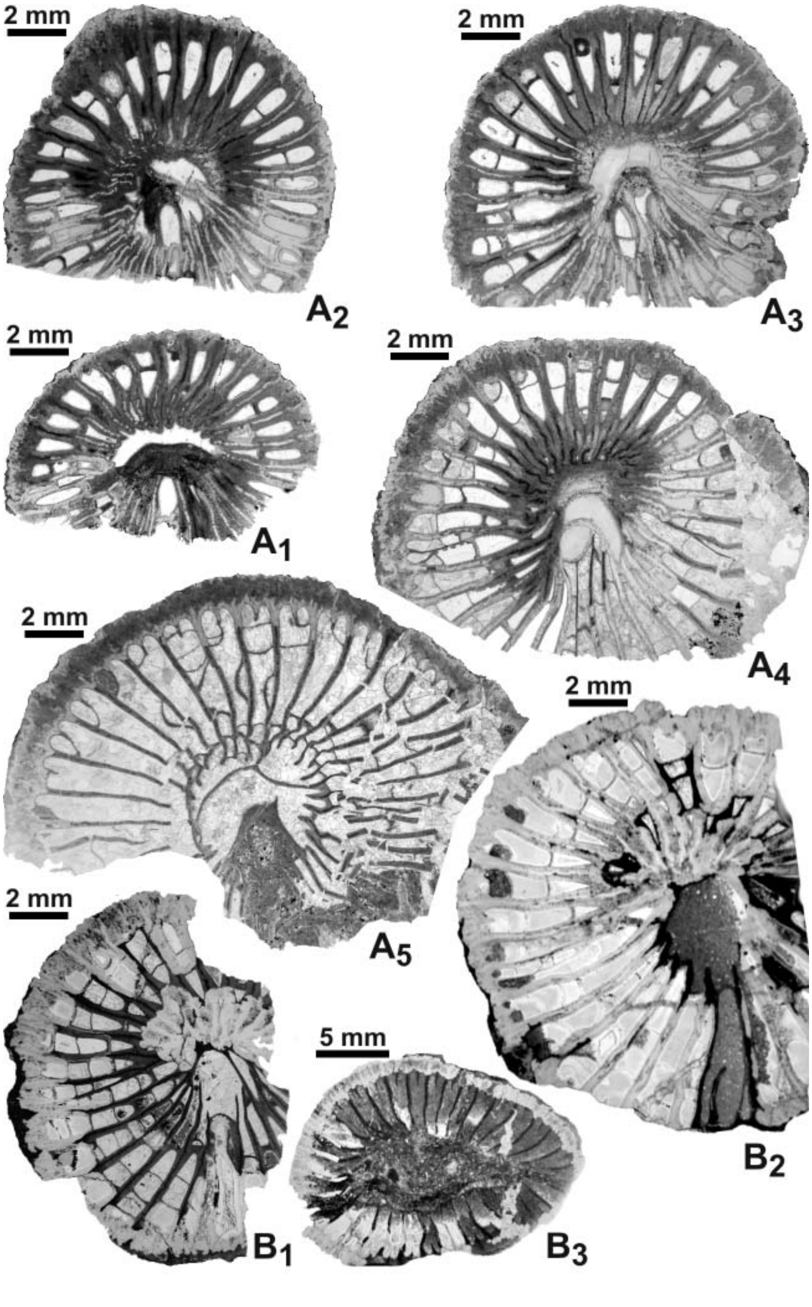


Fig. 43. A. *Allotropiochisma exzentrica* (Flügel, 1973). UAMIG.Tc-C.Bld. I/2, Svenskeegga Member of the Kapp Starostin Formation; $A_{1\text{-}5}$ – transverse thin sections from mature growth stage. B. *Euryphyllum troldfiordense* Fedorowski and Bamber, 2001. UAMIG.Tc-C.KS. II/2/4, Hovtinden Member of the Kapp Starostin Formation; $B_{1\text{-}3}$ – transverse thin sections from mature growth stage.

Description: Corallite trochoid, with concave cardinal side. Septal indices from ~30/~10 through 33-36/11-14 to 40/17 (Fig. $43A_{1-5}$). Major septa in mature growth stages thin, generally long, but do not meet at corallite axis; open axial area is 4 mm wide. In early growth stages cardinal protoseptum much shortened, remaining major septa of varying length – in cardinal quadrants generally longer than in counter quadrants (Fig. $43A_{1-4}$). Arranged pinnately in cardinal quadrants, they shorten gradually towards cardinal protoseptum; in counter quadrants almost equal in length and radially distributed. Inner halves of major septa thickened to join laterally around axial part of corallite; the resulting ring of septa opens only at axial margin of cardinal fossula. All major septa thicken at periphery to form septotheca. Cardinal fossula in early growth stage closed (Fig. $43A_1$), in later open (Fig. $43A_{2-4}$); may extend beyond corallite axis into counter quadrants; bordered by major septa of cardinal quadrants and periaxial margins of almost equally long major septa of counter quadrants. Counter protoseptum no different from remaining major septa of counter quadrants. Alar septa may be slightly longer than other majors (Fig. $43A_{2,4}$). Minor septa distinguishable in microstructure of external wall already in early growth stages; they penetrate corallite lumen only near and within calice (Fig. $43A_{4,5}$), where they attain 1.0 mm in length. Tabularium "biformly reduced". External wall about 1.0 mm thick (Fig. $43A_{4,5}$).

Remarks: The examined specimens differ from those from Greenland described by Flügel (1973) only in n/d indices at maturity: the Spitsbergen specimens have smaller corallite diameters at similar numbers of septa (36-38/14-18 *vs*. 36-37/18-25); in early growth stages those indices can be identical (32-33/11-12 for the Spitsbergen specimens *vs*. 33/12 for the Greenland ones). As to major septa being longer in cardinal than in counter quadrants, this seems to be only apparent. Such an image is often produced when transverse sections through a corallite are not perpendicular to its growth direction. That such oblique sections were made from a specimen illustrated in this study is indicated by traverses of tabulae, which grow in number from the counter protoseptum towards the cardinal one (Fig. $43A_{3,4}$). It is possible that the sections made by Flügel (1973: text-figs 15, 16), also illustrated by Fedorowski (1982*b*: pl. 4, figs 3b, 4a-b), were slightly inclined towards the counter protoseptum, as shown by the different number of sections through tabulae in the various quadrants. The section illustrated by Fedorowski (1982*b*) in pl. 4, fig. 3a may be perpendicular to growth direction. Here the length of septa in all quadrants seems to be comparable.

As to other species of this genus found on Spitsbergen, *Allotropiochisma treskelense*, known from the Kapp Starostin Formation on Treskelen (Chwieduk 2007), differs from the Blendadalen and Kapp Starostin *A. exzentrica* in a cardinal protoseptum shortening earlier in ontogeny, a cardinal fossula bordered by successively shortening major septa of cardinal quadrants, an elongated counter protoseptum at all growth stages, and the presence of alar fossulae. In comparison with *A. euryphylloides*, also known from Treskelen, *A. exzentrica* has a larger number of septa in early growth stages (~30-34/~10-12.5 *vs*. 26-28/10-12), smaller corallite diameters at similar numbers of major septa at maturity (36/14 *vs*. 35/17and 36/18-20), longer minor septa, and shorter major septa (the major septa in *A. euryphylloides* commonly reach the corallite axis below the calice bottom, forming a compact axial structure still visible above the bottom).

The specimens I described also show some similarity to *A.(A.)longiseptata* and *A. birkenmajeri*. However, *A. exzentrica* has shorter major septa, long cardinal protoseptum early in ontogeny, and a much larger number of major septa at comparable growth stages (31/10, 36/14, ~40/~17 *vs*. 23/9, 28/14, 30-31/17). What differentiate the specimens in question from the other species, in turn, are a narrower axial space free from septa, much shorter minor septa, and smaller sizes accompanied by a greater number of major septa (~40/~17 *vs*. 32/22).

Occurrence: Northeast Greenland: Kap Stosch ["Productus-Kalk" (Flügel 1973)] – Wordian or Lower Capitanian; Spitsbergen: Kapp Starostin, Blendadalen (Kapp Starostin Formation) – Wordian and/or Capitanian.

Genus: *Euryphyllum* Hill, 1938

Type species: *Euryphyllum reidi* Hill, 1938.

Emended diagnosis: See Fedorowski and Bamber 2001, p. 36.

Euryphyllum troldfiordense Fedorowski and Bamber, 2001
Figs 43B, 44A-C

2001. *Euryphyllum troldfiordense* sp. n.; Fedorowski and Bamber: pp. 42-44, text-fig. 6, pl. 2, figs 1-2.

Diagnosis: See Fedorowski and Bamber (2001), p. 42.

Material: Seven specimens (UAMIG.Tc-C.KS. IA/1/1, 2; KS. IB/16; KS. IC/4/1; KS. II/2/4, 22; KS. III/1/2). 28 transverse thin sections.

Description: Septal indices of almost completely preserved specimen UAMIG. Tc-C.KS. IA/1/2 Fig. 44$A_{1\text{-}6}$) are 24/6, 28-29/8-9, 35-37/14-15 and 38/~18; in the remaining illustrated specimens (Figs 43$B_{1\text{-}3}$, 44$B_{1,2}$, $C_{1,2}$), they are 28-31/7-9, 35/14-16 and 37/15-17. Major septa, at calice bottom and below, thinner in cardinal quadrants than in counter quadrants; their thickened inner ends

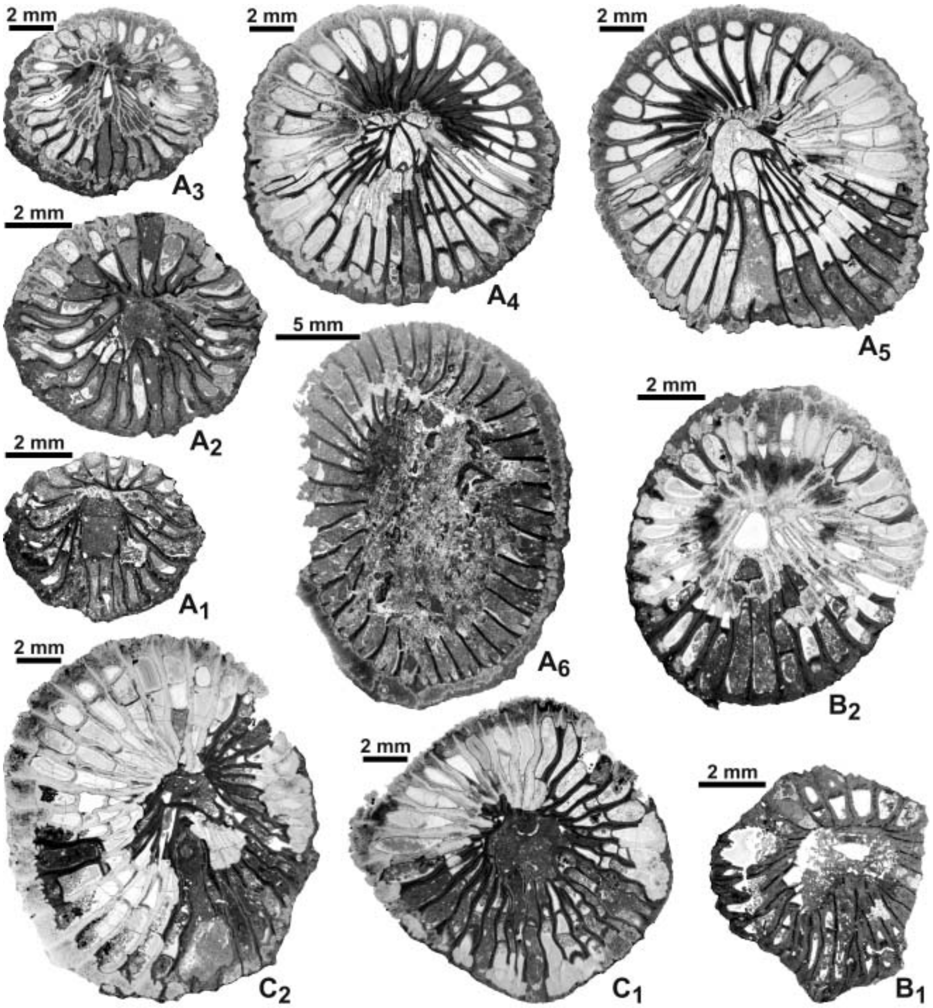


Fig. 44. A-C. *Euryphyllum troldfiordense* Fedorowski and Bamber, 2001.

A – UAMIG.Tc-C.KS. IA/1/2, Svenskeegga Member of the Kapp Starostin Formation; $A_{1,2}$ – transverse thin sections from immature growth stage, A_{3-6} – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.KS. II/2/22, Hovtinden Member of the Kapp Starostin Formation; B_1 – transverse thin section from immature growth stage, B_2 – transverse thin section from mature growth stage.
C – UAMIG.Tc-C.KS. IB/16, Svenskeegga Member of the Kapp Starostin Formation; $C_{1,2}$ – transverse thin sections from mature growth stage.

laterally contiguous, forming extensive axial structure which disintegrates near calice bottom. Cardinal protoseptum in available sections from early growth stages either as long as remaining major septa of cardinal quadrants (Fig. 44A_{2-4}, B_1), or slightly shorter (Fig. 44A_1), or longer (Fig. 44B_1); at calice bottom long (Fig. 44A_4, B_2), but slightly above bottom shortening even to one-fifth length of major septa of cardinal quadrants (Fig. $44A_5$). Its extremely small size visible in Fig. $44C_2$ results from damage to this part of corallite; apart from cardinal protoseptum, also damaged is adjacent major septum. Above calice bottom major septa shortened to ca. one-half corallite radius; cardinal protoseptum of ca. one-fifth length of major septa, slightly longer than minor septa (Figs $43B_3$, $44A_6$], in those sections visible for the first time in corallite lumen; right below and at calice bottom, minor septa restricted to septotheca. Counter protoseptum not differing in length from remaining major septa of counter quadrants. Cardinal fossula key-hole shaped, crossing corallite axis, bordered by successively shortening major septa of cardinal quadrants and inner ends of major septa of counter quadrants. Alar pseudofossulae better visible in early growth stages (Fig. $44A_{3,4}$). External septothecal wall from 0.5 to 1.0 mm thick.

Remarks: Specimens from the Kapp Starostin area have several main characteristics of *E. troldfiordense* known from Ellesmere Island. They include: similar n/d indices, non-compact stereocolumn disintegrating early, cardinal protoseptum shortening at calice bottom, long counter protoseptum commonly equal in length to adjacent major septa, major septa shorter in counter quadrants, and minor septa visible only at calice bottom and calice itself.

The n/d indices of specimens UAMIG.Tc-C.KS. IA/1/2 and KS. II/2/22 (Fig. 44A and 44B, respectively), at 28-29/8-9, 35/14 and 37/15, make them similar to *E. boreale* with n/d indices of 29/8.5, 35/13 and 36/14. However, the early disintegration of the stereocolumn, already near the calice bottom, rules out classifying them as *E. boreale*, in which the stereocolumn extends right up to the rim of the calice.

Occurrence: Sverdrup Basin: Ellesmere Island (Trold Fiord Formation) – Wordian; Spitsbergen: Treskelen, Kapp Starostin (Kapp Starostin Formation) – Wordian.

Euryphyllum sp. A
Fig. 45A

Material: One specimen (UAMIG.Tc-C.Bld. II/3). Five transverse thin sections.

Description: The ontogenetically earliest preserved growth stage has an n/d ratio of 38/17 (Fig. $45A_1$); major septa in cardinal quadrants generally longer than in counter quadrants; every other septum of cardinal quadrants shortened, starting with the second metaseptum. Cardinal protoseptum and alar septa equal in length to the longer major septa of cardinal quadrants. Alar pseudofossulae distinct, closed. Minor septa not visible in corallite lumen, but present in septothecal structure of external wall, which attains ca. 1.5 mm in thickness.

In later growth stages (Fig. $45A_{2, 3}$, A_3 – section directly in calice floor) diameters of transverse sections are 25.0 and 31.0 mm; number of major septa, 43 and 45, respectively; laterally contiguous major septa meet at corallite axis forming stereocolumn; the longest reach corallite axis. Cardinal protoseptum shortened to ca. one-third to one-fourth length of major septa. Cardinal fossula narrow, bordered by one pair of elongated major septa adjacent to cardinal protoseptum. Counter protoseptum slightly longer than adjacent major septa. Alar septa are the longest septa in cardinal quadrants. Minor septa do not protrude from external wall.

In calice (Fig. $45A_4$) n/d index is 46/~42. Major septa long, with thickened inner ends forming massive stereocolumn; arranged pinnately in cardinal quadrants, radially in counter quadrants. Cardinal protoseptum shortened so much that it cannot be found in preserved (undamaged) part of calice. Cardinal fossula narrow, elongated, reaching inner ends of major septa of counter quadrants. Minor septa protrude ca. 1.0 mm from external wall. Their total length (with the part in external wall) is one-sixth length of major septa. External wall 1.5 mm thick and septothecal.

Remarks: The feature differentiating the specimen described above from the remaining *Euryphyllum* species is its n/d indices, in which both the number of septa and the diameters of transverse sections much exceed the figures documented so far (36/15.5 for *E. boreale*, 28/17 for *E. profundum*, 33/23 for *E. robustum*, and 37/20 for *E. troldfiordense*). Besides, the specimen has well developed alar pseudofossulae that only occur in the earlier growth stages, and minor septa which are generally confined to the external wall; at the corallite lumen, they only appear in the calice.

In spite of its considerable size, the specimen was identified as *Euryphyllum* on the basis of its: a) long major septa, reaching corallite axis, arranged pinnately along the long, closed cardinal fossula and radially in the counter quadrants; b) a counter protoseptum and alar septa longer than the remaining major septa; and c) a distinct, compact stereocolumn extending up to the calice floor. The last feature, as well as the appearance of minor septa at the corallite lumen only in the calice, make this Blendadalen specimen similar to *E. boreale*. However, with no sections from higher parts of the calice at our disposal, it is impossible to find whether the stereocolumn extends up to its rim, as can be observed in *E. boreale*. Hence there are not enough grounds to treat the specimen in question, almost triple the size of *E. boreale*, as its more advanced growth stage.

Occurrence: Spitsbergen: Blendadalen (Kapp Starostin Formation) – Wordian and/or Capitanian.

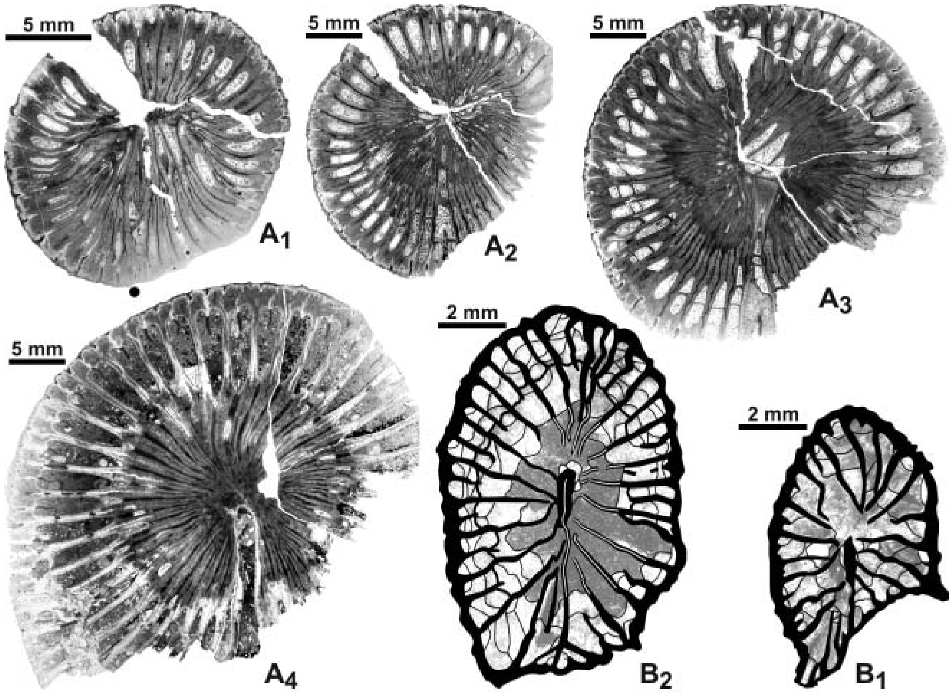


Fig. 45. A. *Euryphyllum* sp. A. UAMIG.Tc-C.Bld. II/3, Hovtinden Member of the Kapp Starostin Formation; A_1 – transverse thin section from immature growth stage, A_{2-4} – transverse thin sections from mature growth stage. B. *Amygdalophylloides ivanovi* (Dobrolyubova, 1937). UAMIG. Tc-C.Pol. BVI(4)/20, lower part of the Treskelodden Formation; $B_{1,2}$ – transverse thin sections from mature growth stage.

Suborder: Lonsdaleiina Spasskiy, 1974
Family: Geyerophyllidae Minato, 1955
Genus: *Amygdalophylloides* Dobrolyubova and Kabakovitsch, 1948

Type species: *Amygdalophyllum ivanovi* Dobrolyubova, 1937.

Diagnosis: See Dobrolyubova and Kabakovitsch (1948), p. 23.

Amygdalophylloides ivanovi (Dobrolyubova, 1937)
Fig. 45B

1937. *Amygdalophyllum ivanovi* sp. nov.; Dobrolyubova: pp. 60-62, pl. 19, figs 15-20.
1940. *Amygdalophyllum ivanovi* Dobrolyubova; Dobrolyubova: pp. 51-53, pl. 20, figs 2-11.
1948. *Amygdalophylloides ivanovi* (Dobrolyubova); Dobrolyubova and Kabakovitsch: pp. 24-26, pl. 8, figs 5-11.
1992. *Amygdalophylloides ivanovi* (Dobrolyubova); Ezaki and Kawamura: pl. 1, fig. 3.

Emended diagnosis: *Amygdalophylloides* with septal index n/d from 14/4 to 26/10-14; cardinal protoseptum thickened at inner end; axial structure consisting of thick oval pseudocolumella, inner ends of major septa, and tabulae; minor septa attaining one-half to two-thirds length of major septa; dissepimentarium up to half corallite radius, consisting of small interseptal and sporadically lonsdaleoid dissepiments; tabulae almost horizontal or raised towards the centre [on the basis of descriptions of Dobrolyubova (1937, 1940) and own observations].

Material: One incomplete, mostly silicified corallite [UAMIG.Tc-C.Pol. BVI(4)/20]. Two transverse thin sections.

Description: The preserved fragment presents an adult growth stage, with n/d indices of 20/5x7 (below calice bottom) and 22/7x10 (in calice). Major septa thin, of varying length, with the longest reaching oval pseudocolumella formed from inner part of cardinal protoseptum (Fig. $45B_{1,2}$). Minor septa straight, of varying length; below calice bottom not developed in full number, attaining from one-sixth to ca. one-fourth length of major septa; in calice the longest exceeding half the length of major septa. Owing to recrystallization of axial structure, its visible details represent widened inner part of cardinal protoseptum and single sections through tabulae. Dissepimentarium narrow below the calice bottom, restricted to single dissepiments, in calice occupying ca. one-third corallite radius, built of straight interseptal dissepiments, with inner dissepiments having markedly thickened walls.

Remarks: *Amygdalophylloides ivanovi* are known from the Moscow Basin (Dobrolyubova 1937, 1940) and Spitsbergen, from the Wordiekammen Formation of the Skansen region (Ezaki and Kawamura 1992). The Polakkfjellet specimen described above has many features in common with both, typical specimens of the Middle and Upper Carboniferous (today considered by Russian geologists to be the Lower Permian) of the Moscow Basin and with the specimen from the Permian-Carboniferous Wordiekammen Formation of north Spitsbergen. The similarity shown in comparable n/d indices (21-23/6-10 for the Moscow Basin specimens, 23/10x13 for the Skansen specimen), a wide dissepimentarium with a thickened inner wall, and long major and minor septa. Different features between the holotype and paratypes can be found in the axial structure, which is slightly narrower in the specimen under study. However, because of the total silicification of the pseudocolumella, its size could have been changed by diagenesis, and so could its morphological structure, with no inner ends of major septa that are visible in type specimens. Apart from the narrower axial structure, the specimen in question differs from the Skansen corallite from the Wordiekammen Formation also in a lack of lonsdaleoid dissepiments. The last feature, however, sporadically also found in the type material, can be treated as falling within the range of ecological or genetic variability of the species, and therefore of no taxonomic significance.

Occurrence: Russia: Moscow Basin – Upper Carboniferous (recently considered by Russian geologists to be rather Lower Permian); Spitsbergen: Skansen (Wordiekammen Formation) – (?)Upper Carboniferous-Lower Permian, Polakkfjellet (Treskelodden Formation) – Gzhelian

Suborder: Aulophyllina Hill, 1981
Family: Aulophyllidae Dybowski, 1873
Subfamily: Dibunophyllinae Wang, 1950

Genus: *Yakovleviella* Fomitchev, 1953

Type species: *Yakovleviella tschernyschewi* Fomitchev, 1953.

Diagnosis: Solitary corals; protosepta joined in early growth stages; axial structure built of lamellar pseudocolumella on the basis of cardinal protoseptum and axial tabellae; in mature growth stages cardinal protoseptum shortened, axial structure disappears; major septa of varying length; minor septa restricted to dissepimentarium zone; tabularium bi-zonal, with flat tabellae at the corallite axis and vesicular ones on periphery [after Fomitchev (1953): 318-319].

Yakovleviella tschernyschewi Fomitchev, 1953
Figs 46A, 47

1953. *Yakovleviella tschernyschewi* sp. nov.; Fomitchev: pp. 320-323, pl. 21, figs 1-7.

Diagnosis: *Yakovleviella* with up to 44 major septa at corallite diameter of 32.0 mm above calice floor; major septa attain three-fourths corallite radius; axial structure consists of median lamella and numerous axial tabellae; cardinal fossula narrow; minor septa reach one-tenth major septa in length; dissepimentarium below calice bottom attains ca. one-half corallite radius, built mainly of herringbone dissepiments; tabulae incomplete, axial tabellae upturned, peripheral ones vesicular [after Fomitchev (1953) and own observations].

Material: Nine incomplete, slightly or completely silicified corallites (UAMIG. Tc-C.Lin. I/1/13, 16, 93, 106; I/6/2; II/1/10, 43; III/1/6; UAMIG.Tc-C.CrL. I/5/18). 47 transverse thin sections.

Description: Corallites trochoid. In specimen UAMIG.Tc-C.Lin. I/1/93 (Fig. $46A_{1-12}$), almost complete, though lightly crushed and at places recrystallized, in the ontogenetically earliest section n/d index attains 14/3. Major septa of different length, with the longest reaching corallite axis. Protosepta joined at the corallite axis. In slightly later growth stage (Fig. 46$A_{2,3}$), n/d index equals 15-18/3.5-4.0. Major septa of varying length. Minor septa attain ca. one-fifth length of major septa. At corallite diameter of 5.0 mm (Fig. 47A_1), number of major septa is 21; their arrangement is almost radial; they are long, but do not reach corallite axis; it is possible that inner ends of at least some of them have been damaged by recrystallization that can be observed in axial part of corallite. Cardinal fossula poorly developed. Single dissepiments, visible in spite of corrosion of outer part of corallite, suggest the presence of a dissepimentarium (Fig. 47A_1 see arrows].

In successive sections (Figs 46$A_{4,5}$, 47$A_{2,3}$), n/d indices are 24/6.5-8.0 and 19-21/5.5-7.0. Major septa arranged radially in counter quadrants and pinnately in cardinal ones. Protosepta fused at the corallite axis. Length of minor septa attains ca. one-sixth corallite radius. Sparse dissepiments visible only in counter quadrants. External wall, preserved at places, has a thickness of 0.3 mm (Fig. 47A_2) and 0.1 mm (Fig. 47A_3).

In later growth stages [n/d = 28-32/12-16, Fig. 47A_{4-6}; 26-29/9.0-11, Fig. 46A_{6-8}) metasepta long, but do not meet at corallite axis, leaving open axial area 1-2 mm wide. Protosepta connected at the corallite axis; their fusion disrupted at corallite diameters of 15.0 and 17.0 mm (Fig. 46A_9 and Fig. 47A_7, respectively). Cardinal protoseptum in this section crosses corallite axis; counter protoseptum meets cardinal protoseptum, but does not merge with it. At corallite diameters of 17 and 20 mm (Fig. 46A_{10} and Fig. 47A_8, respectively) cardinal protoseptum shortens to ca. three-fourths length of major septa of cardinal quadrants, thus breaking its connection with axial structure. Still present at the corallite axis are median lamella and sections through axial tabellae. Minor septa very short; in sections from adult growth stages, restricted to outer zone of 1.5-mm wide dissepimentarium, built of fine interseptal dissepiments. External wall 0.1 mm thick.

In transverse sections cut partly beneath the calice floor (Fig. 47A_9), n/d index equals 39/23. Major septa long, but only some reach axial structure. Cardinal protoseptum attains one-third length of major septa. Cardinal fossula narrow, open, bordered by successively shortening major septa of cardinal quadrants. Counter protoseptum no different in length from remaining major septa of counter quadrants. In corallite axis a few sections through tabulae and probably median lamella are observable, but owing to recrystallization of axial part of corallite this cannot be stated for certain. Alar septa slightly longer than other septa. Minor septa do not exceed dissepimentarium zone and attain less than one-tenth corallite radius. Dissepimentarium not fully developed, being widest at alar septum, where it attains ca. one-tenth corallite radius; towards cardinal and counter protosepta gradually narrowing, to disappear completely at those septa.

In the lower part of calice (Fig. $46A_{11}$) major septa of varying length, mostly attaining two-thirds corallite radius. Cardinal protoseptum shortened to ca. one-half – one-third length of major septa of cardinal quadrants. Still remaining in axial zone are median lamella and axial tabellae. The shortened counter protoseptum visible in this and the previous section (Fig. $46A_{10}$) results from damage to this part of corallite and is not a feature of *Y. tschernyschewi*. In section made above this damage (Fig. $46A_{12}$), major septa in counter quadrants, though crushed, are of similar length; most of them reach axial structure.

Above calice bottom (Fig. $47A_{10}$) n/d index equals 45/~28. Major septa attain two-thirds corallite radius, cardinal protoseptum has one-fourth the length of major septa. Due to corrosion of outer corallite surface, it is not possible to determine total width of dissepimentarium and length of minor septa. In less corroded places minor septa do not cross dissepimentarium zone, having ca. one-tenth the corallite radius in width.

Remarks: The *Y. tschernyschewi* from Linnédalen differ from the Donets Basin specimens described by Fomitchev (1953) in having less developed dissepimentarium. In the remaining features, the specimens here described are similar to those from the Donets Basin: they have protosepta fused in early growth stages; in later stages they have a similarly built axial structure, dissepiments appearing very early in ontogeny (at n/d = 20/5 *vs*. 22/6 in the Donets Basin specimens), and short minor septa never penetrating into the tabularium. All specimens have also comparable septal numbers and corallite diameters (Fig. 48). Very narrow dissepimentaria of the specimens under study (Fig. $46A_{12}$), may be due to their being at ontogenetic stages with adult features not fully developed.

Considering the fact that this species has so far been known only from the Upper Carboniferous (Moscovian), we cannot exclude that the Sakmarian specimens in question represent homeomorphy resulting from parallel evolution and/or convergence. A narrow dissepimentarium could then be a unique feature of the Spitsbergen homeomorph of *Y. tschernyschewi*.

Occurrence: Russia: Donets Basin – Moscovian; Spitsbergen: Linnédalen – Gzhelian, Sakmarian.

Yakovleviella spitsbergensis sp. nov.
Figs 46B, 49A-D

Holotype: UAMIG.Tc-C.Lin. II/1/3 (Fig. 49B). 12 transverse thin sections.

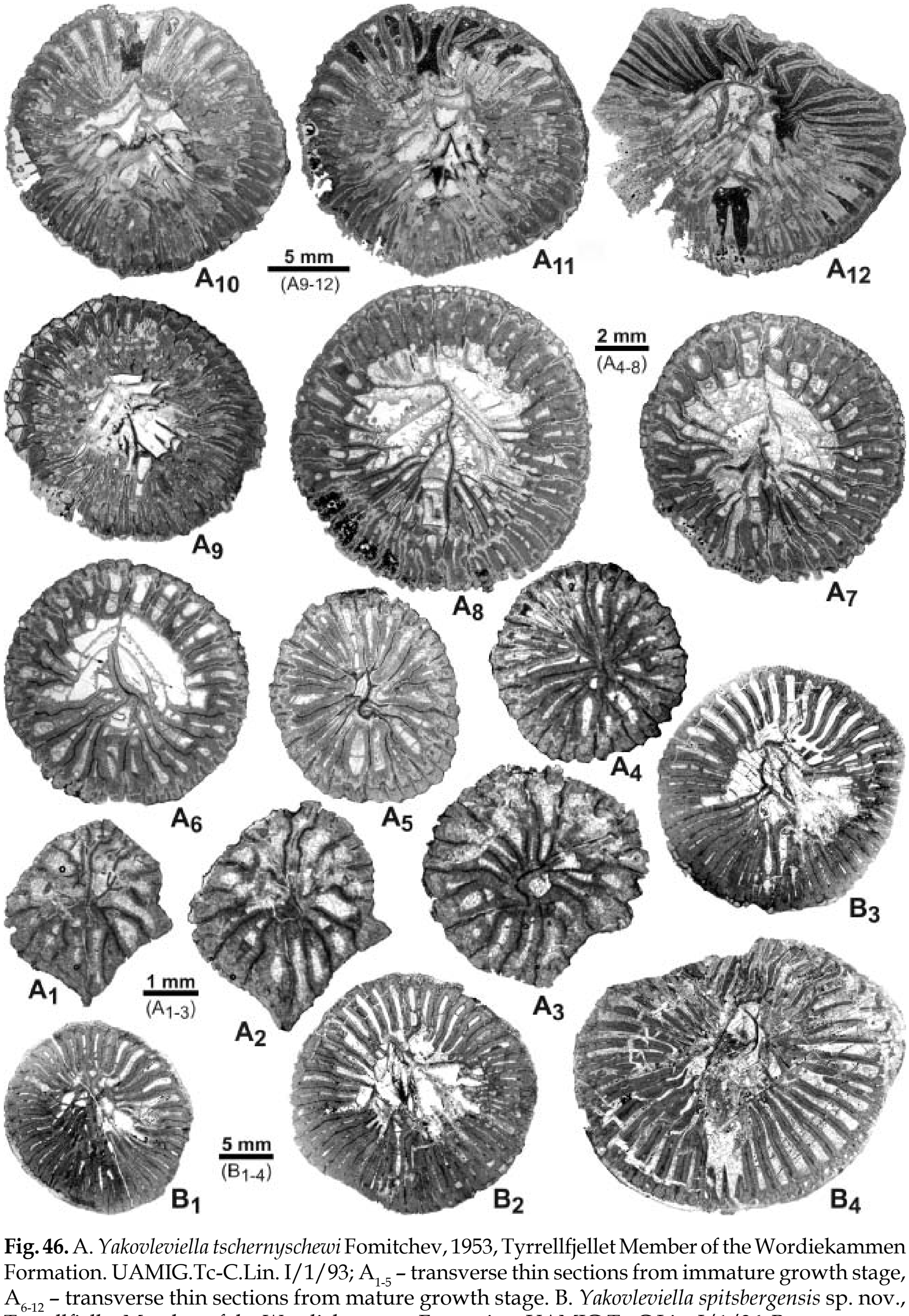


Fig. 46. A. *Yakovleviella tschernyschewi* Fomitchev, 1953, Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.Lin. I/1/93; A_{1-5} – transverse thin sections from immature growth stage, A_{6-12} – transverse thin sections from mature growth stage. B. *Yakovleviella spitsbergensis* sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.Lin. I/1/36; B_1 – transverse thin section from immature growth stage, B_{2-4} – transverse thin sections from mature growth stage.

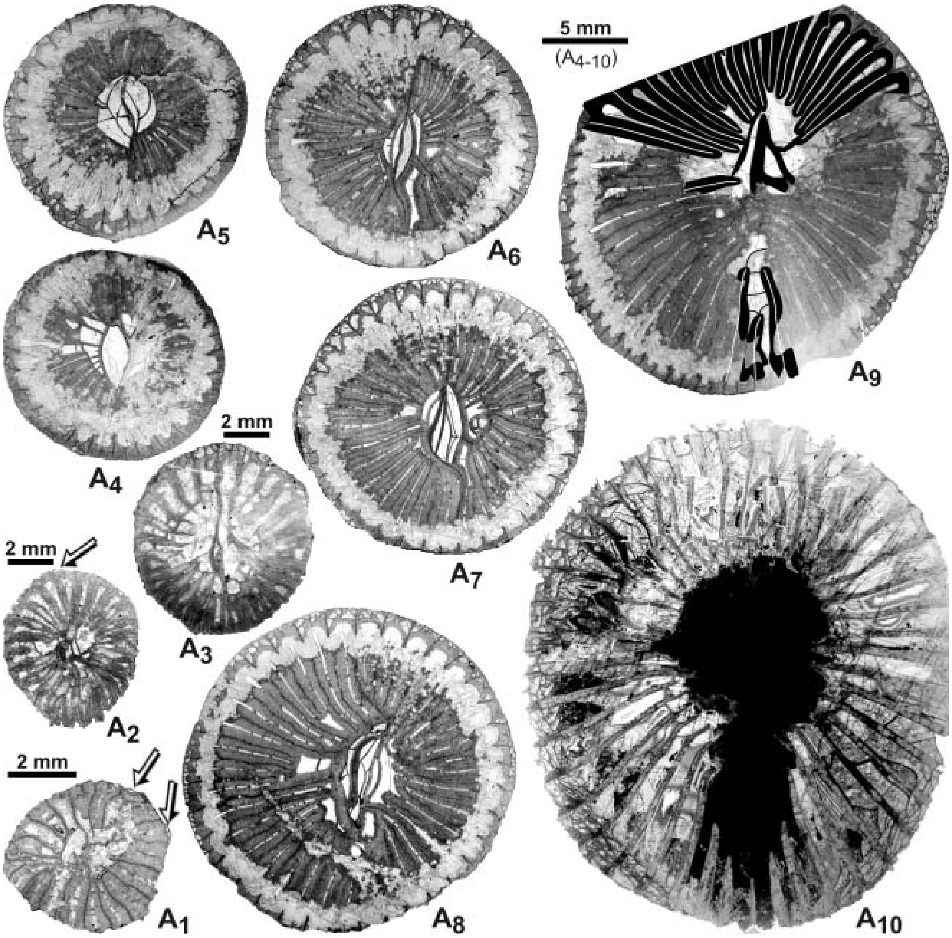


Fig. 47. A. *Yakovleviella tschernyschewi* Fomitchev, 1953, Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.Lin. I/1/13; A_{1-4} – transverse thin sections from immature growth stage, arrows in $A_{1,2}$ show dissepiments, A_{5-10} – transverse thin sections from mature growth stage.

Type locality: Linnédalen (N 78°03.865; E 13°48.144; ~46 m above sea level), central Spitsbergen (Figs 2C, 6).

Type horizon: Wordiekammen Formation, Gzhelian-Sakmarian.

Derivation of name: *spitsbergensis* – described from Spitsbergen.

Diagnosis: *Yakovleviella* with up to 43 major septa at corallite diameter of 30.0 mm below calice floor; major septa attain three-fourths corallite radius; cardinal protoseptum shortens at calice bottom; cardinal fossula narrow, outlined by 1-3 pairs of major septa; axial structure consists of median lamella and a few

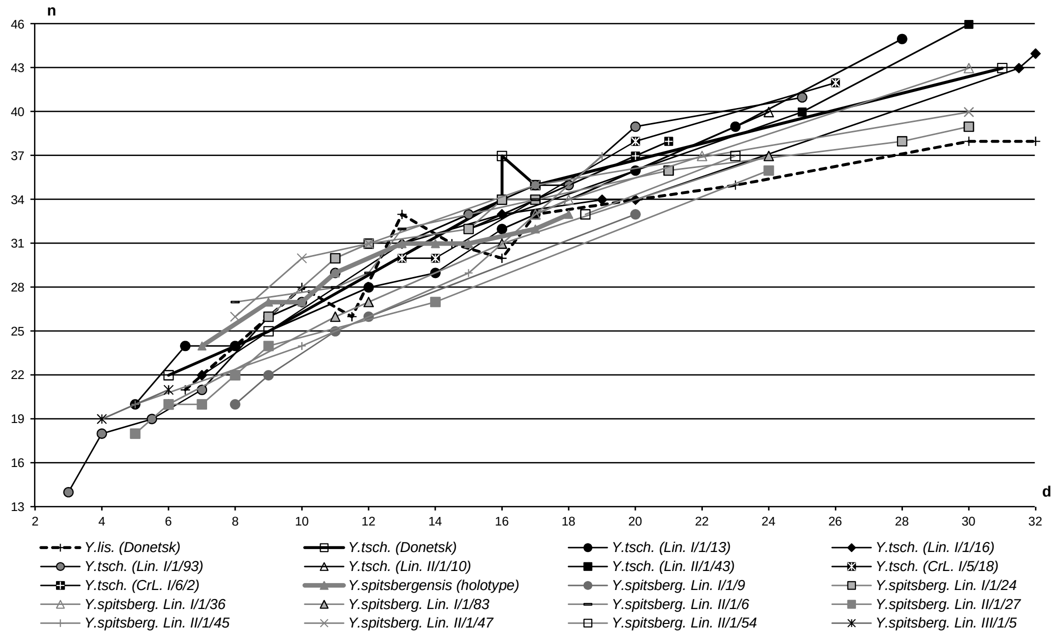


Fig. 48. Plot of the number of major septa (n) *vs*. diameters (d) of *Yakovleviella spitsbergensis* sp. nov. as compared with *Y. tschernyschewi* and *Y. lissitzini*. Symbols joined by lines represent values taken from individual specimens.

axial tabellae; minor septa attain one-tenth corallite radius; dissepimentarium below calice bottom occupies ca. one-eighth corallite radius; external wall 0.2 mm thick.

Material: Paratypes – 27 incomplete, slightly or completely silicified corallites (UAMIG.Tc-C.Lin. I/1/9, 14, 21, 24, 36, 42, 83, 130; II/1/3, 6, 8, 26, 27, 28, 40, 45, 47, 54, 63; III/1/3, 5; UAMIG.Tc-C.CrL. I/4/4, 5; CrL. I/5/4, 9; I/7/10, 12). 65 transverse thin sections.

Description of holotype: Corallite trochoid. In the earliest growth stage available, n/d index = 25/7 (Fig. 49B_1). Protosepta joining at corallite axis. Visible between major septa are regular traces of sections through tabulae. Two-row dissepimentarium occupying ca. one-seventh corallite radius, separated from tabularium by thickened walls of inner dissepiments. Minor septa restricted to dissepimentarium zone. Cardinal fossula poorly developed. External wall 0.1 mm thick.

In section made 5.0 mm above previous one (Fig. 49B_2), n/d index = 27/10. Major septa arranged radially, long, with the longest reaching corallite axis. Protosepta touching at corallite axis. Minor septa very short, restricted to two-row dissepimentarium, occupying ca. one-seventh corallite radius.

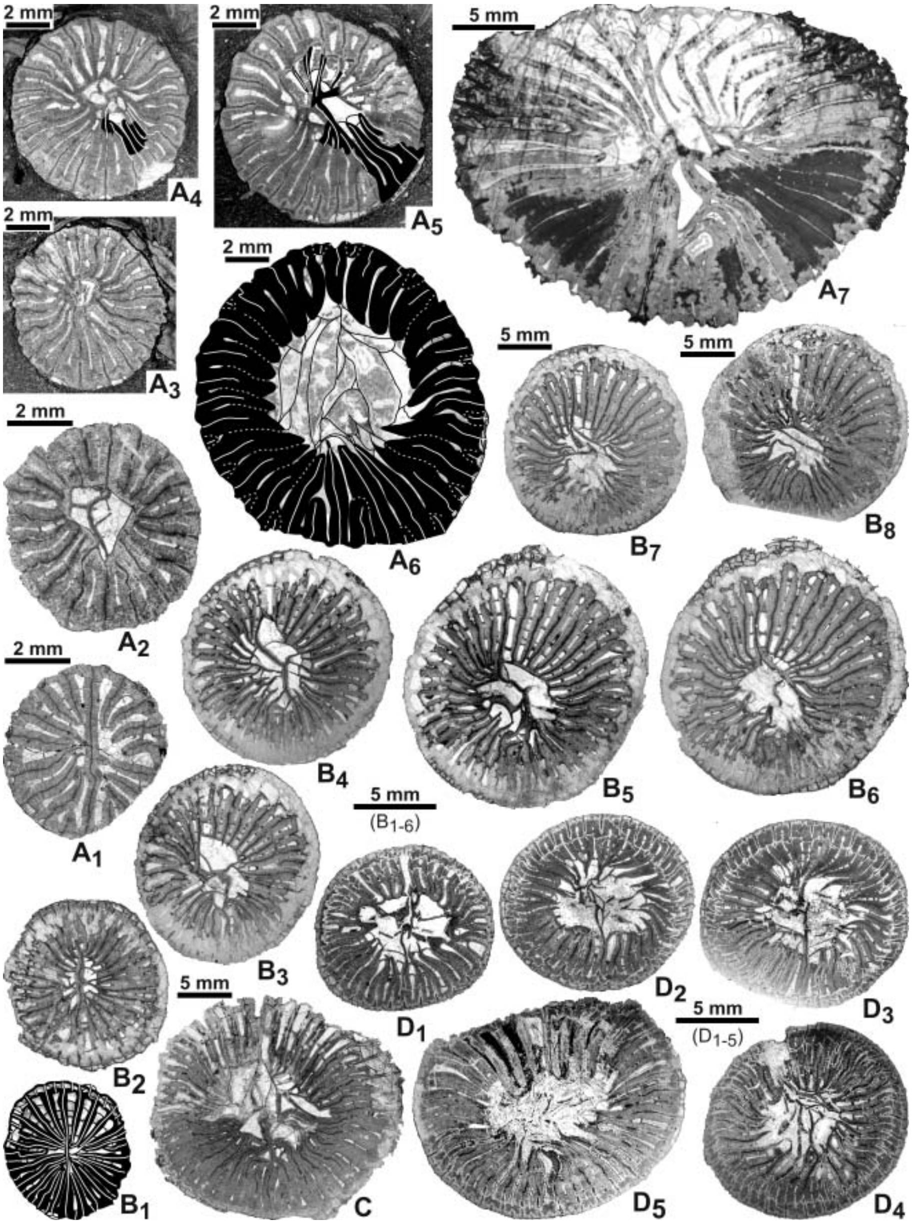


Fig. 49. A-D. *Yakovleviella spitsbergensis* sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.Lin. II/1/27; A_{1-5} – transverse thin sections from immature growth stage, $A_{6,7}$ – transverse thin sections from mature growth stage.

B – UAMIG.Tc-C.Lin. II/1/3; $B_{1,2}$ – transverse thin sections from immature growth stage, B_{3-8} – transverse thin sections from mature growth stage.

C – UAMIG.Tc-C.Lin. II/1/54; transverse thin section from mature growth stage.

D – UAMIG.Tc-C.Lin. II/1/6; D_{1-5} – transverse thin sections from mature growth stage.

In sections from successively later growth stages, n/d indices attain 29-31/11-14 (Fig. 49B$_{3-5}$). Major septa usually attain three-fourths corallite radius in length, only few reach corallite axis, including cardinal protoseptum. Minor septa restricted to 2-3-row dissepimentarium occupying ca. one-fifth corallite radius, built mainly of pseudo-herringbone dissepiments. External wall 0.1 mm thick.

In section made ca. 5.0 mm higher (Fig. 49B$_6$), septal index n/d equals 31/15. Cardinal protoseptum divides into two parts; its inner part forms a median lamella; cardinal protoseptum equals to major septa of cardinal quadrants in length. Remaining major septa shortened to ca. three-fourths corallite radius. In axial zone free of septa. Median lamella of 2.0 mm length. Dissepimentarium of variable width; in counter quadrants of 3-4 rows, occupying ca. one-fifth corallite radius; towards cardinal protoseptum narrowing to one-tenth corallite radius, built of one row of dissepiments. Minor septa restricted to dissepimentarium zone.

In sections made below calice bottom (Fig. 49B$_{7,8}$) n/d indices attain 32/17 and 33/18. Major septa developed similarly as in sections from previous growth stage. Cardinal protoseptum slightly shorter than remaining major septa of cardinal quadrants. Short, median lamella visible in Fig. 49B$_7$ disappears in section made 3.0 mm higher (Fig. 49B$_8$). Because of recrystallization of outer part of corallite, minor septa and dissepiments poorly visible.

Intraspecific variability: Although the number of specimens included in this species is large, because of their considerable, almost complete recrystallization, only four best preserved corallites were chosen, apart from the holotype, to illustrate transverse sections (Figs 46B$_{1-4}$, 49A, C, D). However, it was possible to trace changes in n/d indices in the course of ontogeny (Fig. 48) in eleven specimens, together with those illustrated.

A growth stage earlier than in the holotype and preserved in one of the paratypes shows that dissepiments appear already at corallite diameter of 5.0 mm (Fig. 49A$_1$). A fusion of protosepta at the corallite axis could be observed from the earliest growth stages available until the corallite diameter of 17.0 mm (Fig. 46B$_1$). The cardinal protoseptum extending to the corallite axis, remains to be elongated at corallite diameter of 23.0 mm (Fig. 49C), but below the calice bottom it is as long as the remaining major septa of cardinal quadrants; it shortens markedly only in the calice (Figs 46A$_4$, 49D$_5$). Major septa, as in the holotype, usually attain three-fourths corallite radius; shorter septa are due to damage and/or recrystallization of the axial part of corallites (Fig. 49A$_6$, D$_{1-3}$). In the specimen illustrated in Fig. 49A$_6$, below and above the presented section, the septa are long.

Remarks: In early growth stages *Yakovleviella spitsbergensis* sp. nov. from Linnédalen has many features in common with *Yakovleviella lissitzini* Fomitchev, 1958. In both species dissepiments appear early; the dissepimentarium is separated from the tabularium by a thickened inner wall; most major septa reach the corallite axis; and n/d indices are similar (25/7 for *Y. spitsbergensis* sp. nov. *vs*. 21/6.5 for *Y. lissitzini*). The differences are greater in slightly later growth stages. While quantitative features are still similar – *Y. spitsbergensis* sp. nov. has 27 major septa at corallite diameter of 10.0 mm and *Y. lissitzini* 26 at corallite diameter of 11.5 mm – the length of those septa in the compared species is different. In *Y. lissitzini*, they shorten gradually in the course of ontogeny, finally attaining one-half to one-third corallite radius (in the calice and below its bottom). In the newly described species, major septa remain long in the later growth stages. Their mean length is ca. three-fourths radius, and the longest ones reach the corallite axis. At maturity major septa of *Y. spitsbergensis* sp. nov. are at least twice as long as in *Y. lissitzini* at comparable growth stages. Besides its, dissepimentarium is at least twice as wide as in *Y. lissitzini*, and minor septa are shorter. The only feature common to all ontogenetic stages of the compared species is a long cardinal protoseptum, which shortens markedly only in the calice.

When compared with *Y. tschernyschewi*, *Yakovleviella spitsbergensis* sp. nov. has a cardinal protoseptum that shortens late in ontogeny, a less complicated axial structure, and a narrower dissepimentarium.

Occurrence: Spitsbergen: Linnédalen – Gzhelian-Sakmarian.

Genus: *Gronfjordphyllum* gen. nov

Derivation of name: Described from the Grønfjorden area (central Spitsbergen).

Type species: *Gronfjordphyllum minor* gen. et sp. nov.

Diagnosis: Solitary Aulophyllidae with complex axial structure, sharply bounded, consisting of thick median lamella, few septal lamellae and few, commonly thick, axial tabellae; major septa of varying length; cardinal protoseptum in early growth stages elongated, at calice bottom shortened; cardinal fossula tabular, open; counter protoseptum linked with axial structure; minor septa attaining one-fourth length of major septa; dissepimentarium up to one-fourth corallite radius in width, dissepiments very fine, interseptal; tabellae vesicular, dissepiment-like.

Remarks: The unique set of features found in the specimens described below is without doubt indicative of a new genus. Among the characteristics that cause those corals to have no counterparts among the genera described in the literature so far are the presence of dissepiments, short minor septa and an elongated counter protoseptum throughout their entire ontogeny and a cardinal protoseptum during most of it, a fusion of those septa in early growth stages and the formation of a pseudocolumella at the point of fusion, then the transformation of this part into a median lamella, and finally an enrichment of the axial structure thus developed with a few septal laminae and traverses of axial tabellae, combined with a small size of the corallites (the maximum n/d index equals 28/11).

When compared with the known genera of Dibunophyllinae, the specimens in question are close in their general look and morphological structure of some growth stages to *Yakovleviella*. However, this genus, known from the Moscovian of the Donets Basin, has a shortened counter protoseptum and an elongated cardinal protoseptum as well as an axial structure built on the basis of the inner part of the latter. But the ontogeny of the specimens from the Lake Lenné region shows their axial structure to be linked with the counter protoseptum at all growth stages available, while the cardinal protoseptum shortens at maturity. Besides, this structure is more extensive in the Spitsbergen specimens than in those from the Donets Basin, since apart from the median lamella and axial tabellae, which also occur in *Yakovleviella*, it can additionally contain sporadic septal lamellae. A significant feature of the new genus is also an early in ontogeny appearance of minor septa and dissepiments. They are visible already at corallite diameters of ca. 5 mm.

The complexity of the axial structure and its growth complication resemble the development of the axial structure in *Axolithophyllum* Fomitchev, 1953. However, as in *Yakovleviella*, in *Axolithophyllum* it rests on the cardinal protoseptum, which shortens only in mature growth stages. Besides, as most genera in the family Geyerophyllidae, *Axolithophyllum* has lonsdaleoid dissepiments, never found in any of the growth stages of the newly established genus.

The occurrence of this unique combination of features in as many as 18 specimens, all in a relatively good state of preservation, has inclined the author to distinguish a new genus and two new species.

Gronfjordphyllum minor gen. et sp. nov.
Figs 50, 51A, B

Holotype: UAMIG.Tc-C.Lin. I/1/63 (Fig. 50). 11 transverse thin sections.

Type locality: Linnédalen (N 78° 03.697'; E 13° 48.437'), central Spitsbergen (Figs 2C, 6).

Type horizon: Wordiekammen Formation, Sakmarian.

Derivation of name: *minor* – smaller, smaller than the next species – *G. parvum* gen. et sp. nov. (*parvus* = small).

Diagnosis: *Gronfjordphyllum* with septal n/d indices from 14-21/2-3 to 28/7-11; major septa can reach axial structure; protosepta linked in early growth

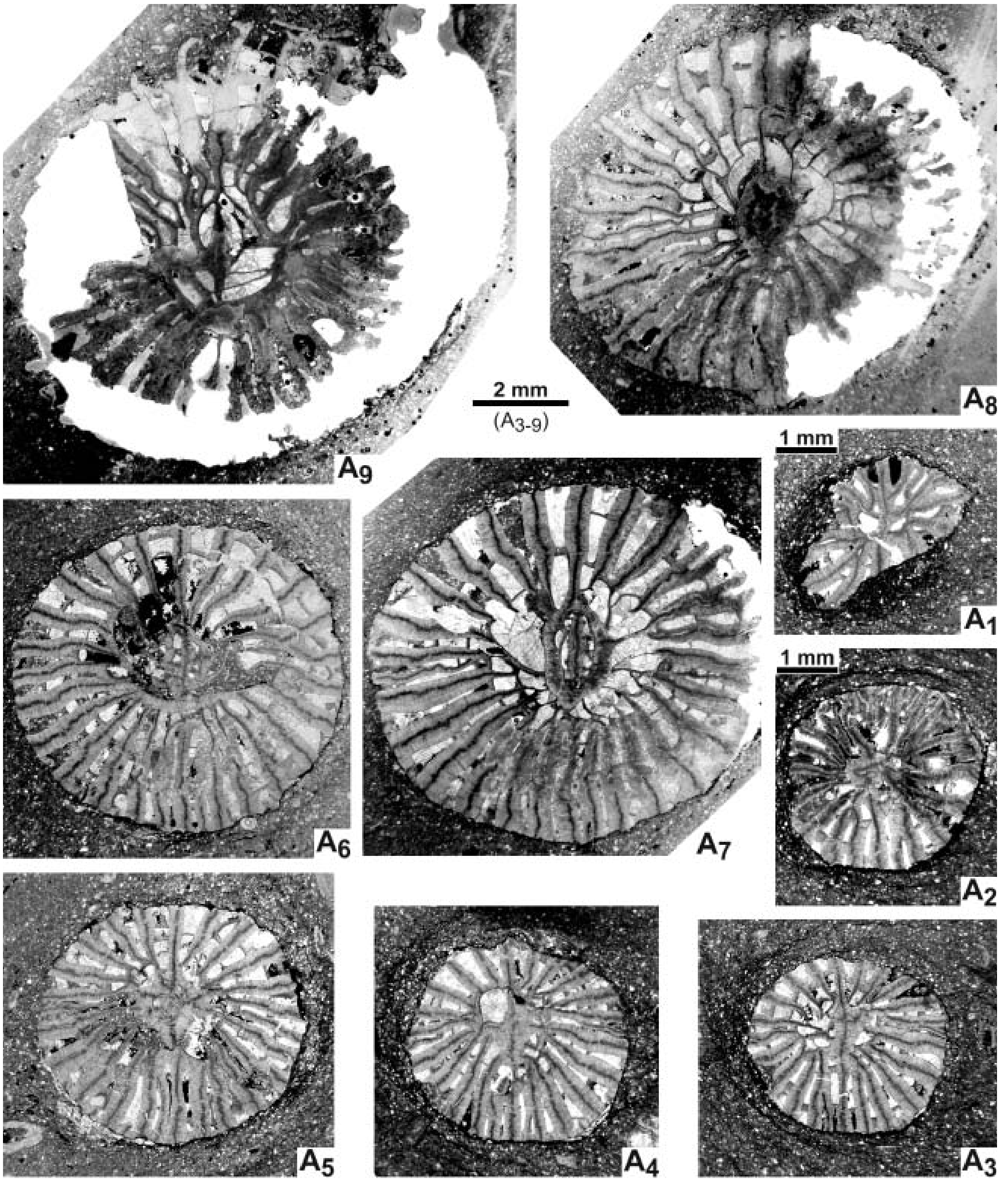


Fig. 50. A. *Gronfjordphyllum minor* gen. et sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.Lin. I/1/63; A_{1-4} – transverse thin sections from immature growth stage, A_{5-9} – transverse thin sections from mature growth stage.

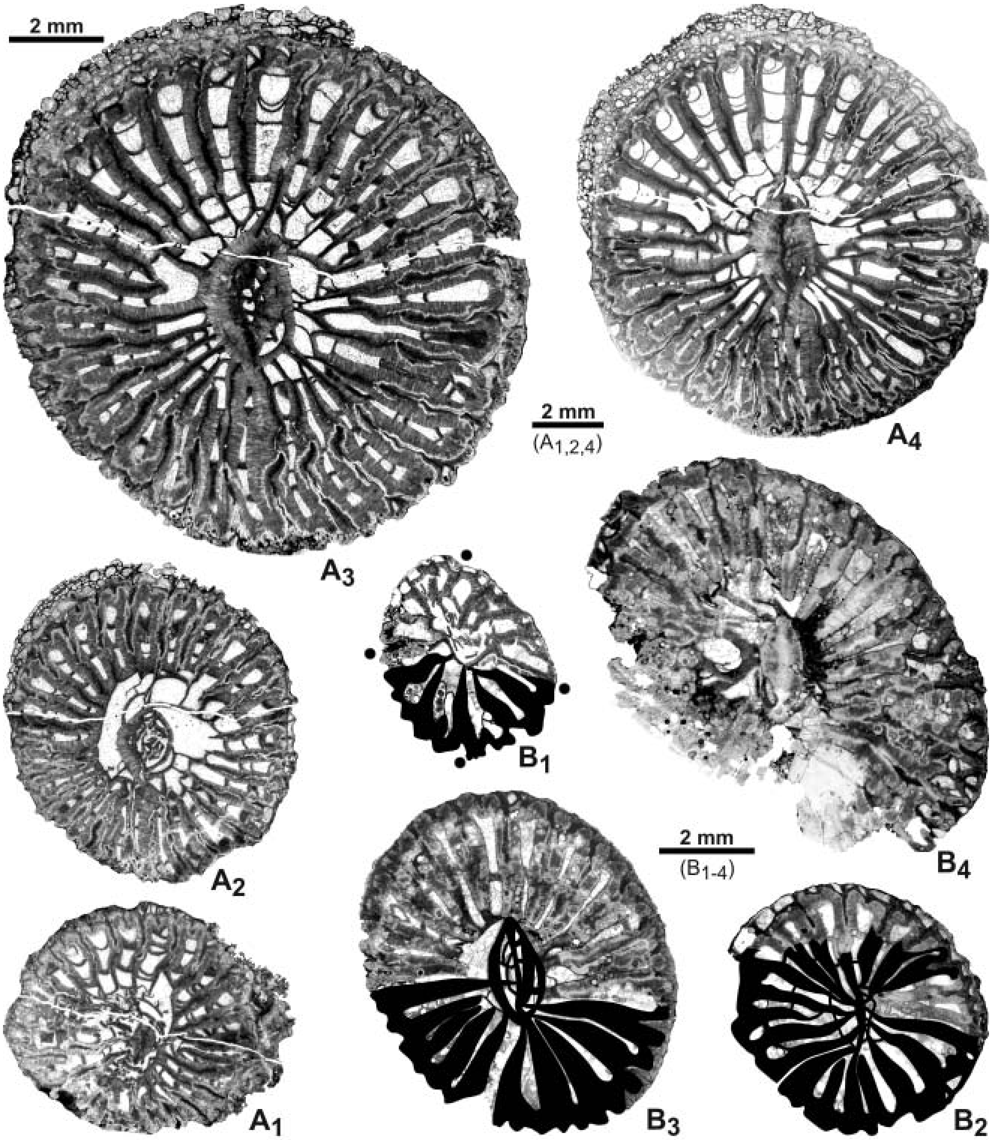


Fig. 51. A, B. *Gronfjordphyllum minor* gen. et sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.Lin. I/1/7; A_1 – transverse thin section from immature growth stage, $A_{2\text{-}4}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Lin. II/1/19; $B_{1,2}$ – transverse thin sections from immature growth stage, $B_{3,4}$ – transverse thin sections from mature growth stage.

stages, in later stages counter protoseptum can connect with axial structure; minor septa attain ca. one-fifth length of major septa; width of dissepimentarium, built of fine interseptal dissepiments, does not exceed one-fifth length of major septa; external wall 0.1 mm thick.

Material: Paratypes – six specimens, one in part overgrown with bryozoans, in part abraded (UAMIG.Tc-C.Lin. I/1/71), remaining ones (UAMIG.Tc-C. Lin. I/1/31, 67; II/1/13, 21, 19) partly silicified, partly abraded and corroded. 28 transverse thin sections.

Description of holotype: Corallite ca. 20 mm long, in mature growth stages attaining 7-10 mm in diameter, with major septa numbering 28. Because of corrosion and abrasion, the diameters given in all n/d indices of the holotype refer as a rule to those of tabularia. Given the small dissepimentarium width, ca. 1.0 mm in the paratypes, the error is negligible.

In the earliest growth stage available (Fig. 50A_1), in oval transverse section (2 mm x 3 mm) 14 major septa are visible. The longest, including protosepta, fuse at the corallite axis, remaining ones vary in length. In section made 2 mm above previous one septal n/d index is 21/3 (Fig. 50A_2), while length and arrangement of septa are similar.

Next sections (Fig. 50$A_{3,4}$) were made ca. every 2 mm. Septal indices equal 23/4.0 and 25/4.5. Protosepta fused; in place of fusion, at the corallite axis, lenticular pseudocolumella. Cardinal fossula narrow, closed, its sides bordered by 2-3 pairs of adjacent major septa, inner side bordered by axial structure. Remaining major septa of varying length, with the longest reaching axial structure. Minor septa 0.25 mm long.

In section made 3 mm above latter ones (Fig. 50A_5), septal index attains 25/5. Axial structure more complicated, formed by few thickened septal laminae, two sections through strongly thickened tabulae, and inner part of elongated and thickened counter protoseptum. The thickening of elements makes the axial structure compact. Elongated cardinal protoseptum loses contact with axial structure.

In next section made 2 mm above previous one (Fig. 50A_6), septal index is 26/6. Axial structure openwork. Cardinal protoseptum as long as remaining septa of cardinal quadrants. Cardinal fossula open, bordered by two pairs of adjacent major septa. Counter protoseptum linked with axial structure. Remaining major septa of varying length, with the longest reaching axial structure.

In section made ca. 3 mm above previous one, septal index attains 28/7 (Fig. 50A_7). Major septa long, with thin inner ends, most of them reaching axial structure. Cardinal protoseptum as long as remaining major septa of cardinal quadrants. Counter protoseptum connected with outer tabula bordering axial structure. Apart from strongly thickened tabulae bordering axial structure from the outside, it is also composed of thin inner tabulae, few septal laminae, and thickened median lamella.

Because of advanced corrosion of outer corallite surface, septal indices of next sections illustrated in Fig. 50$A_{8, 9}$ are approximate, at ?28/8 and ?28/10, respectively. Major septa of varying length, with the longest, including cardinal protoseptum, reaching axial structure. Initially compact, resembling a pseudocolumella (Fig. 50A_8), axial structure becomes loose ca. 5.0 mm higher, with lenticular median lamella surrounded by several traverses of thin tabulae (Fig. 50A_9). Cardinal protoseptum becomes slightly shortened, losing contact with axial structure. Cardinal fossula narrow, equal in length to major septa of cardinal quadrants, bordered by ?two pairs of shortening major septa; on the inside bordered by tabula to which extends thin inner end of cardinal protoseptum. Counter protoseptum in both sections joined with axial structure. Dissepiments few, interseptal. When observed in uncorroded fragment counter quadrants, the dissepimentarium extends over one-fourth corallite radius.

Intraspecific variability: Two illustrated paratypes (Fig. 51$A_{1\text{-}4}$, $B_{1\text{-}4}$) differ from the holotype in having a smaller number of septa at comparable corallite diameters (Fig. 52). Owing to the "coating" of one of the corallites by a colony of bryozoans (Fig. 51$A_{2\text{-}4}$), it was possible to supplement the diagnosis of the species with the following features: the external wall is very thin and has 0.1 mm in thickness; dissepimentarium below the calice bottom occupies ca. one-sixth corallite radius and is built of straight and pseudo-herringbone dissepiments; septa in dissepimentarium are thin, and minor septa restricted to dissepimentarium zone. An analysis of the preserved proximal parts of the paratypes also shows that dissepiments and minor septa appear very early in ontogeny. They are clearly visible already at corallite diameters of 3.5-5.0 mm (Fig. 51$B_{1, 2}$) and 7.0 mm (Fig. 51A_1). The axial structure, as in the holotype, appears at a corallite diameter of 5.0 mm (Fig. 51A_2); at the calice bottom (Fig. 51A_4) it has the form of a pseudocolumella connected with the counter protoseptum.

Occurrence: Spitsbergen: Linnédalen (Wordiekammen Formation) – Sakmarian.

Gronfjordphyllum parvum gen. et sp. nov.
Figs 53A-E, 54A, B

Holotype: UAMIG.Tc-C.Lin. I/1/64 (Fig. 53A1-7). 15 transverse thin sections.

Type locality: Linnédalen (N 78° 03.697′; E 13° 48.437′), central Spitsbergen (Figs 2C, 6).

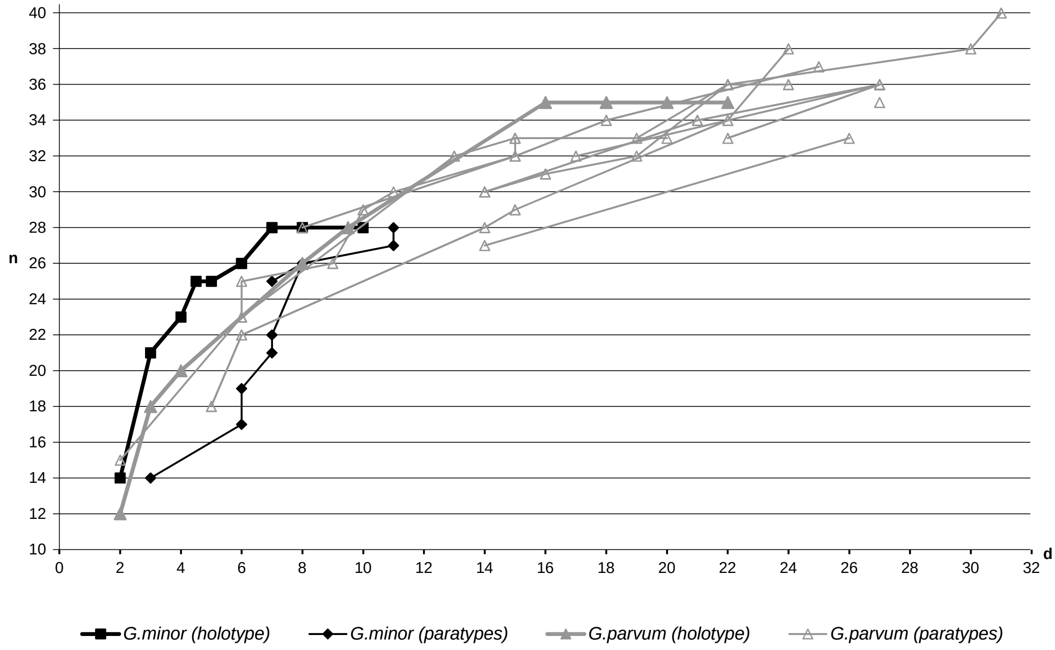


Fig. 52. Plot of the number of major septa (n) *vs*. diameters (d) of species of *Gronfjordphyllum* gen. nov. Symbols joined by lines represent values taken from individual specimens.

Type horizon: Wordiekammen Formation, Sakmarian.

Derivation of name: *parvum* – small dimensions.

Diagnosis: *Gronfjordphyllum* with septal n/d indices from 12/2 to 36-40/16-31; major septa of varying length; cardinal protoseptum shortened, except in the earliest growth stages; minor septa present in corallite lumen in calice, attaining one-fourth length of major septa; dissepimentarium occupies one-fifth length of major septa, built of fine, vesicular interseptal dissepiments.

Material: Paratypes – ten, a few centimetres in size, partly abraded and strongly silicified fragmentary coralla (UAMIG.Tc-C.Lin. I/1/18, 20, 69, 107; UAMIG. Tc-C.Lin. II/1/2, 25, 29, 30, 38, 60). 55 transverse thin sections.

Description of holotype: In the earliest growth stage available, n/d index attains 12/2 (Fig. 53A_1). Alar septa and protosepta fused at corallite axis, remaining major septa of varying length; all equally thickened. In section made ca. 3 mm above previous one (Fig. 53A_2), septal index is ca. 18/3; alar septa and protosepta still fused at corallite axis. Remaining major septa long, but not reaching corallite axis. In next growth stage n/d index = 26/8 (Fig. 53A_3). Major septa of varying length, the longest ones, including alar and counter

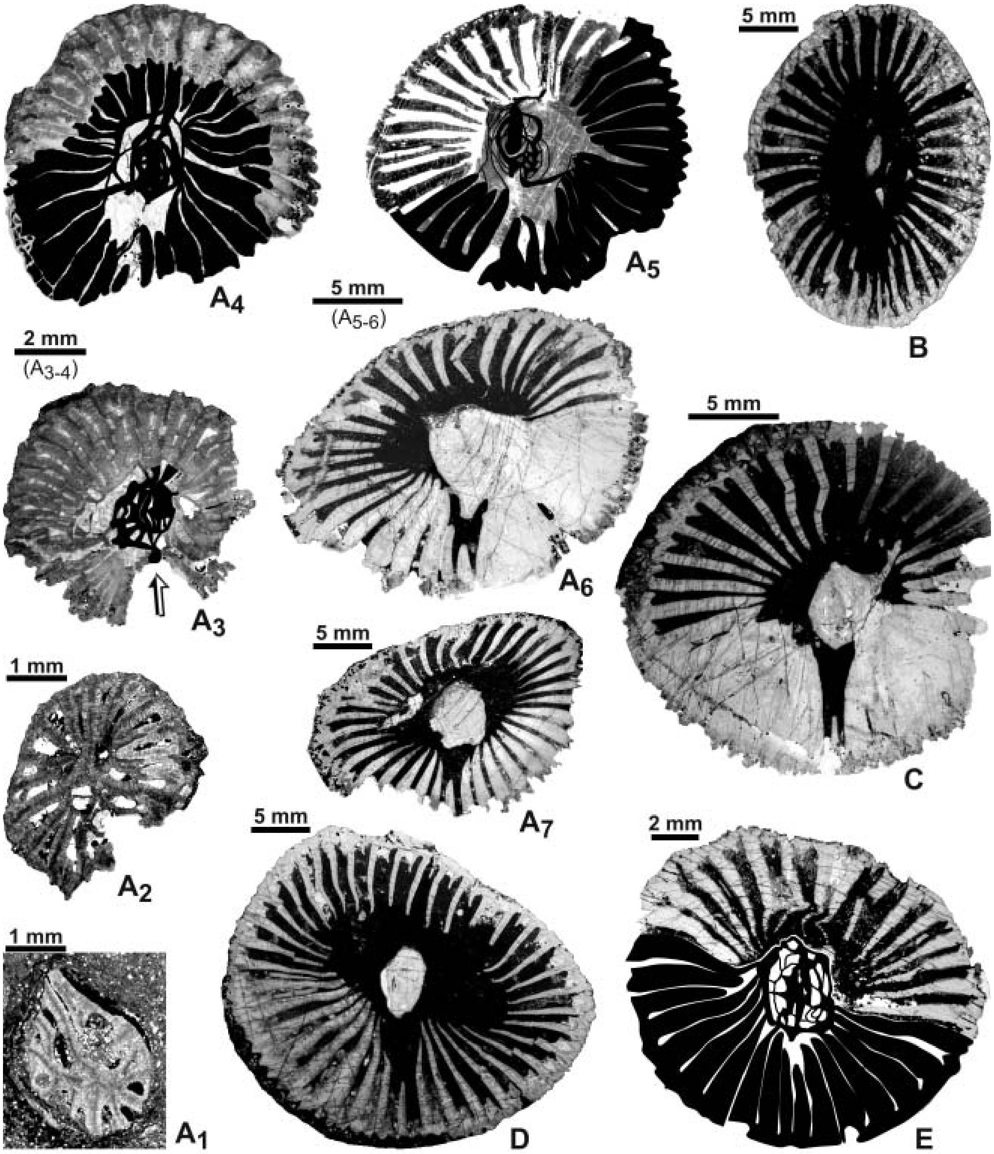


Fig. 53. A-E. *Gronfjordphyllum parvum* gen. et sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.Lin. I/1/64; A_{1-3} – transverse thin sections from immature growth stage, A_{4-7} – transverse thin sections from mature growth stage; arrow in A_3 points to inner end of cardinal protoseptum.
B – UAMIG.Tc-C.Lin. I/1/69; transverse thin section from mature growth stage.
C – UAMIG.Tc-C.Lin. II/1/25; transverse thin section from mature growth stage.
D – UAMIG.Tc-C.Lin. I/1/20; transverse thin section from mature growth stage.
E – UAMIG.Tc-C.Lin. II/1/2; transverse thin section from mature growth stage.

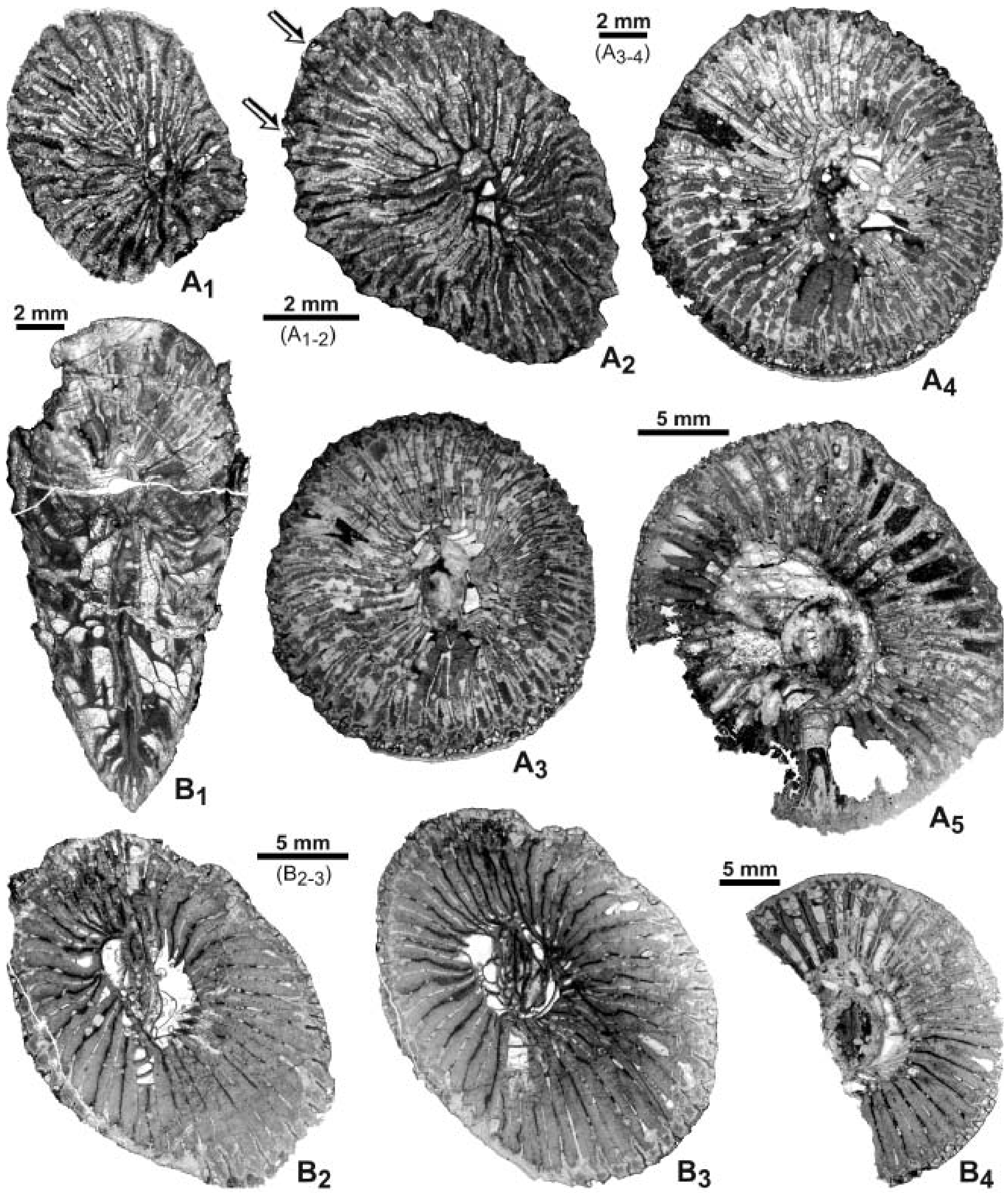


Fig. 54. A, B. *Gronfjordphyllum parvum* gen. et sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.Lin. II/1/60; $A_{1,2}$ – transverse thin sections from immature growth stage, $A_{3\text{-}5}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Lin. I/1/18; B_1 – transverse thin section from immature growth stage, $B_{2\text{-}4}$ – transverse thin sections from mature growth stage.

protoseptum, connected with openwork axial structure built of median lamella, septal lamellae and axial tabellae. Because of considerable damage to cardinal quadrants, one can only suppose that the fragment of a septum joined with the axial structure, indicated by an arrow in Fig. 53A_3, belongs to the cardinal protoseptum. Minor septa, visible in counter quadrants, attain at most one-fifth length of major septa. Fusion of axial structure with counter protoseptum can still be observed in successive sections (Fig. 53$A_{4,5}$), with septal n/d indices of 28/9.5 and 35/18.0, respectively. In those sections cardinal protoseptum is slightly shortened, but longer than adjacent pair of major septa; axial structure built of thick median lamella, several septal lamellae and axial tabellae; dissepimentarium occupies ca. one-sixth length of major septa; minor septa slightly penetrate into tabularium. At calice bottom septal index equals 35/20 (Fig. 53A_6). At this growth stage contact of axial structure with counter protoseptum is broken; cardinal protoseptum shortens to ca. one-half length of major septa. Because of heavy silicification of this part of corallite, details of axial structure are poorly visible. One can only find that is it sizeable (3.0 x 6.5 mm), with tip pointing towards cardinal fossula ("cuspidate"). Above calice bottom (Fig. 53A_7), n/d index equals 35/~22; major septa attain ca. two-thirds corallite radius; counter protoseptum does not differ from remaining major septa of counter quadrants; cardinal protoseptum shortens to ca. two-thirds length of major septa; cylindrical axial structure has ca. 5.0 mm in diameter; minor septa, ca. one-sixth length of major septa, penetrate into outer tabularium; dissepimentarium is built of fine interseptal dissepiments.

Intraspecific variability: A series of transverse sections made from the paratypes (Figs 53B-E, 54$A_{1\text{-}5}$, $B_{2\text{-}4}$) show their close similarity to the holotype. It can be seen in the structure of the cardinal fossula and the axial structure, the development of major septa (including protosepta) and minor septa, as well as in a narrow dissepimentarium. Sections from early growth stages corroborate early appearance of the axial structure, which starts to form already at an n/d index of 22/6 (Fig. 54A_2; in the holotype at a corallite diameter of 7.5 mm).

Some differences, in turn, can be noted in the size of the axial structure, which can be wide (Fig. 53E), as in the holotype, but also narrow and elliptic (Fig. 53D), and in the upper part of the calice elongated, built only of dilated median lamella (Fig. 53B). The preserved advanced growth stages of most of the paratypes show that corallites can attain up to 31 mm in diameter, and their number of septa can be up to 40. It was also noted that in the paratypes the number of major septa are usually smaller than in the holotype at similar growth stages (Fig. 52).

Notable among other features is an early appearance of dissepiments. They are visible as single structures already at an n/d index of 22/6 (Fig. 54A_2, see arrows). At maturity the dissepimentarium can attain from ca. one-twelfth corallite radius in cardinal quadrants to one-fifth in counter quadrants (Fig. 54A$_4$).

Tabulae, observed only in one oblique section (Fig. 54B$_1$), are incomplete, vesicular, at corallite axis upturned. The columella-like structure visible in this section at the corallite axis is an obliquely cut cardinal protoseptum, which at 10 mm corallite diameter (upper part of section) is still connected with the axial structure; in the holotype, it lies at a considerable distance from it at 9.5 mm corallite diameter.

Remarks: The species described above differs from *Gronfjordphyllum minor* gen. et sp. nov. primarily in having diameters almost three times as large (Fig. 52) as well as in its cardinal protoseptum shortening earlier in ontogeny and its axial structure being more extensive in mature growth stages, usually with the tip turned towards the cardinal fossula.

Occurrence: Spitsbergen: Linnédalen (Wordiekammen Formation) – Sakmarian.

Genus: *Barentsburgia* gen. nov.

Derivation of name: Name coined from Barentsburg village in central Spitsbergen.

Type species: *Barentsburgia crinisphyllia* gen. et sp. nov.

Diagnosis: Solitary Aulophyllidae with axial structure consisting of thick, elliptic pseudocolumella with few commonly thin axial tabellae; major septa long, usually anastomozing; protosepta fused in early growth stage, in later one, cardinal protoseptum shortened to two-thirds length of major septa of cardinal quadrants, counter protoseptum not differing from remaining major septa of counter quadrants; cardinal fossula open, narrow; minor septa attaining one-fourth length of majors; width of dissepimentarium up to one-third corallite radius, dissepiments interseptal, mostly herringbone and pseudo-herringbone.

Remarks: In comparison with the known genera of Aulophyllidae, the specimens in question show some similarity with *Yakovleviella* and *Fedorowskiphyllum*. In the first case, common features include fused protosepta at very early growth stages, an axial structure than can be composed of a pseudocolumella and axial tabellae, and a dissepimentarium appearing relatively early in ontogeny. In turn, what they share with *Fedorowskiphyllum* are a similar axial structure in early growth stages as well as an elongated counter protoseptum and a shortened cardinal protoseptum at maturity.

However, from a set of features of *Yakovleviella* the specimens from Linnédalen lack an elongated cardinal protoseptum in early-mature growth stages that would join the axial structure built on the basis of this septum, a widely open cardinal fossula, and a shortened counter protoseptum. In turn, features precluding their inclusion within *Fedorowskiphyllum* are: a pseudocolumella still present at least at mid-depth of the calice (in *Fedorowskiphyllum*, in mature growth stages the axial structure is clisiophylloid), and a wide dissepimentarium (in *Fedorowskiphyllum*, 3-4 rows).

In comparison with *Gronfjordphyllum* gen. nov., the specimens classed as *Barentsburgia* gen. nov. differ in having a wider dissepimentarium in mature growth stages, attaining one-third corallite radius, longer minor septa, although also limited to the outer dissepimentarium zone, and an absence of septal lamellae in the axial structure.

A unique feature of the newly described genus differentiating it from those compared above is the occurrence of anastomozing septa in the dissepimentarium zone. It has never been noted in this family so far. Similarly developed septa have been observed in *Axophyllum cylindricum* from the family Axophyllidae. Significant differences, however, are that this Carboniferous species coming from the Moscow Basin has an extensively developed axial structure, a wide dissepimentarium occupying more than one-half corallite radius, and long minor septa which can penetrate into the tabularium.

Barentsburgia crinisphyllia gen. et sp. nov.
Fig. 55

Holotype: UAMIG.Tc-C.Lin. I/1/126 (Fig. 55). 12 transverse thin sections.

Type locality: Linnédalen (N 78° 03.697′; E 13° 48.437′), central Spitsbergen (Figs 2C, 6).

Type horizon: Wordiekammen Formation, Sakmarian.

Derivation of name: *crinisphyllia* – lat. *crinis* – plait, referring to anastomozing septa, gr. *φύλλο* **(plural** *φύλλα***)** – leaf, septum.

Diagnosis: *Barentsburgia* with n/d index at calice bottom of 37/30; length of major septa attaining three-fourths corallite radius, in dissepimentarium zone thin, anastomozing; minor septa in mature growth stages attaining one-fourth length of major septa; dissepimentarium occupying ca. one-third corallite radius; dissepiments regular, herringbone and pseudo-herringbone.

Material: Paratypes – five partly abraded and strongly silicified fragmentary corallia, a few centimetres in size (UAMIG.Tc-C.Lin. I/1/4, 23, 61, 68, 125). 18 transverse thin sections.

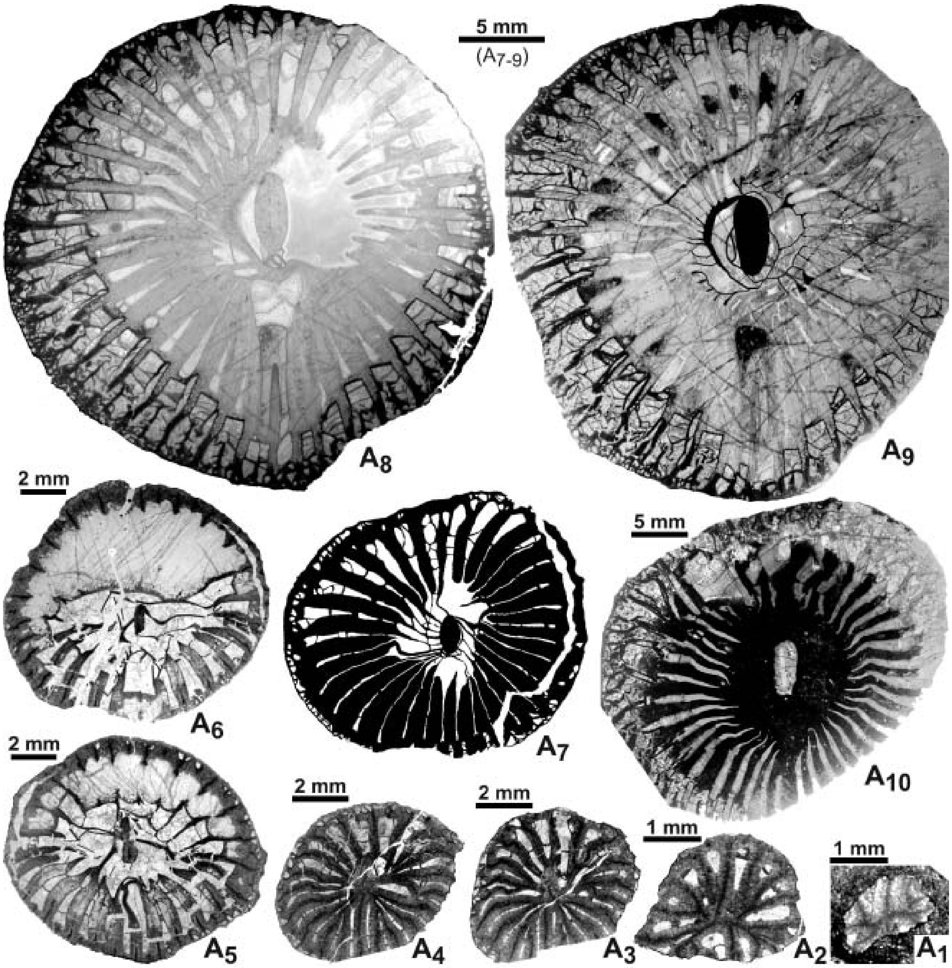


Fig. 55. A. *Barentsburgia crinisphyllia* gen. et sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation. Holotype, UAMIG.Tc-C.Lin. I/1/126, A_{1-4} – transverse thin sections from immature growth stage, A_{5-10} – transverse thin sections from mature growth stage.

Description: Corallites strongly corniculate, with longer curvature of 50.0 mm and shorter one 30.0 mm, calice 10.0 mm deep, more than 30.0 mm in diameter at rim. In the earliest growth stage available, n/d equals 9/1.0x1.5 (Fig. 55A_1); protosepta and alar septa joined at corallite axis; remaining major septa of varying length, not reaching corallite axis. In section made 2.0 mm higher (Fig. 55A_2), septal index = 14/2.5; major septa of varying length, with the longest (including protosepta) fused at corallite axis. In next sections (Fig. 55$A_{3,4}$) made 4.0 and 6.0 mm above previous one, septal indices attain 20/6 and 20/7, respectively; major septa long, with the longest reaching corallite

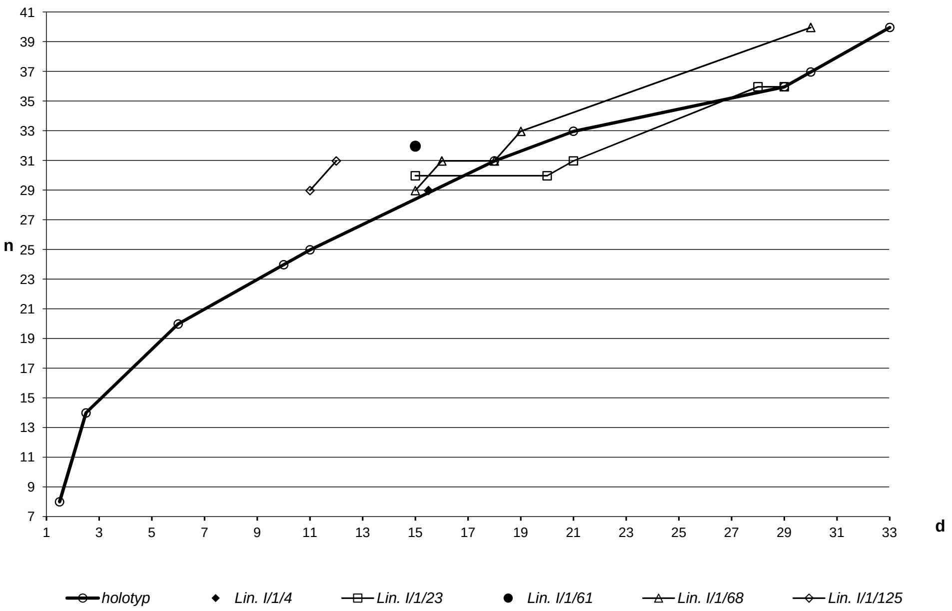


Fig. 56. Plot of the number of major septa (n) *vs.* diameters (d) of *Barentsburgia crinisphyllia* gen. et sp. nov. Symbols joined by lines represent values taken from individual specimens.

axis (as in previous sections, thickened in all quadrants); protosepta joined at corallite axis; dissepiments few; minor septa very short. In section made 3.0 mm higher (Fig. $55A_5$), septal index equals 24/10; major septa shortened to three-fourths corallite radius; cardinal protoseptum equal in length to remaining major septa, in open, tabular fossula, bordered by one pair of adjacent septa; counter protoseptum elongated and joined with pseudocolumella; one-row dissepimentarium built of oblique dissepiments; minor septa 0.5 mm long, slightly penetrating into tabularium. Partial silicification of counter quadrants and periaxial fragment of corallite blurs the image of major septa of those quadrants and axial tabellae. Advanced silicification makes major septa of counter quadrants poorly recognizable in next section (Fig. $55A_6$), made 3.0 mm above previous one, with septal index of 25/11. It seems that the broken link of the counter protoseptum with the pseudocolumella is not a result of diagenetic changes, because traces of tabulae visible in this place are not altered. This fact and the absence of relics of inner ends of major septa in the periaxial part of the corallite are indicative of major septa shortening to at least two-thirds to three-fourths of corallite radius. In turn, the substantial shortening of the cardinal protoseptum is only apparent. Its inner part, poorly visible because of re-crystallisation, in fact reaches the end of the cardinal fossula, which is equal in length to the remaining major septa of cardinal quadrants.

Almost total re-crystallisation of the upper part of corallite makes skeletal structures recognizable only on polished surfaces. From one of such surfaces a drawing was made (Fig. 55A_7). In this section the n/d index attains 31/18; counter protoseptum and some major septa link with oval axial structure by means of thin inner ends; cardinal protoseptum slightly shortened, longer than adjacent pair of major septa; dissepimentarium 1.0 mm wide, of 2-3 rows, built of fine oblique dissepiments; minor septa restricted to dissepimentarium zone; external wall ca. 0.5 mm thick. In section made right below calice bottom (Fig. 55A_8), ca. 10 mm above previous one, inner part of corallite re-crystallised. Septal n/d index equals 36/29. In this slightly oblique section major septa attain from ca. two-thirds to ca. four-fifths corallite radius in length. Counter protoseptum long, but not joining pseudocolumella. Cardinal protoseptum shortened to ca. one-half corallite radius, in narrow fossula bordered by successively shortening major septa of cardinal quadrants. Cardinal fossula slightly widens towards corallite axis. Dissepimentarium occupies ca. one-third corallite radius, built mainly of herringbone and very fine pseudo-herringbone dissepiments. Length of minor septa does not exceed two-thirds of dissepimentarium width.

Next section, coming from calice bottom (Fig. 55A_9), slightly less re-crystallised than previous one, with septal index of 37/30, shows long major septa attaining three-fourths corallite radius. Counter protoseptum reaches oval pseudocolumella, accompanied in this section by few axial tabellae. Cardinal protoseptum shortened to ca. one-half corallite radius.

At mid-depth, calice septal n/d index attains 40/33 (Fig. 55A_{10}); length of major septa from one-half to two-thirds corallite radius; dissepimentarium occupies no more than one-fourth corallite radius. Elliptic pseudocolumella visible in this section, 5 mm x 2.5 mm in size, can still be found at calice rim (no illustration).

Intraspecific variability: Not established. The five paratypes are distinguished from the holotype by slightly different diameters at comparable numbers of septa (Fig. 56). However, because of strong silicification of the paratypes, they are not illustrated.

Occurrence: Spitsbergen: Linnédalen (Wordiekammen Formation) – Sakmarian.

Family: incertae sedis

Genus: *Linnephyllum* gen. nov

Derivation of name: Name coined from the Linné valley of Spitsbergen and the suffix *-phyllum*.

Type species: *Linnephyllum spitsbergensis* gen. et sp. nov.

Diagnosis: Solitary corals with complex axial structure consisting of median lamella, septal lamellae, some extra septal lamellae and numerous small tabellae; major septa long; cardinal protoseptum amplexoid; cardinal fossula tabular, open; counter protoseptum may be longer than other major septa; minor septa may penetrate into outer tabularium; tabularium "biformly reduced"; dissepiments very fine, mostly pseudo-herringbone.

Remarks: The set of such features as: (1) sharply bounded axial structure with septal lamellae and median lamella, (2) usually shortened cardinal protoseptum, (3) elongated counter protoseptum, (4) wide tabularium, and (5) narrow dissepimentarium, resembles the family Aulophyllidae. However, the unique combination of those features found in a few Linnédalen specimens does not repeat in any of the genera of this family known so far. In the absence of the aulophyllids in the higher part of the Upper Carboniferous, the similarity of the specimens in question (coming from the Lower Permian) to Aulophyllidae may result from homeomorphy. In its axial structure, *Linnephyllum* gen. nov. is the closest to *Nervophyllum* Vasilyuk, 1959. However, the latter, known e.g. from the Lower Carboniferous of Donbas and Poland, has a wide dissepimentarium, a longer cardinal protoseptum which usually merges with the axial structure, longer major septa, and a less distinct axial structure.

The species of *Linnephyllum* gen. nov. described below are similar in size, length of major septa, and narrow dissepimentaria to *Fedorowskiphyllum* Kossovaya, 1997 (known from the Sakmarian of Timan), that also has an axial structure. However, the *Linnephyllum* gen. nov. species differ from *Fedorowskiphyllum* in having a shorter counter protoseptum, which does not meet the axial structure, and a more compact axial structure consisting of a median lamella as well as numerous septal lamellae and axial tabellae.

Linnephyllum spitsbergensis gen. et sp. nov.
Figs 57, 58A

Holotype: UAMIG.Tc-C.Lin. I/1/100 (Fig. 57). Two peels and six transverse thin sections.

Type locality: Linnédalen (N 78° 03.697′; E 13° 48.437′), central Spitsbergen (Figs 2C, 6).

Type horizon: Wordiekammen Formation, Sakmarian.

Derivation of name: *spitsbergensis* – described from Spitsbergen.

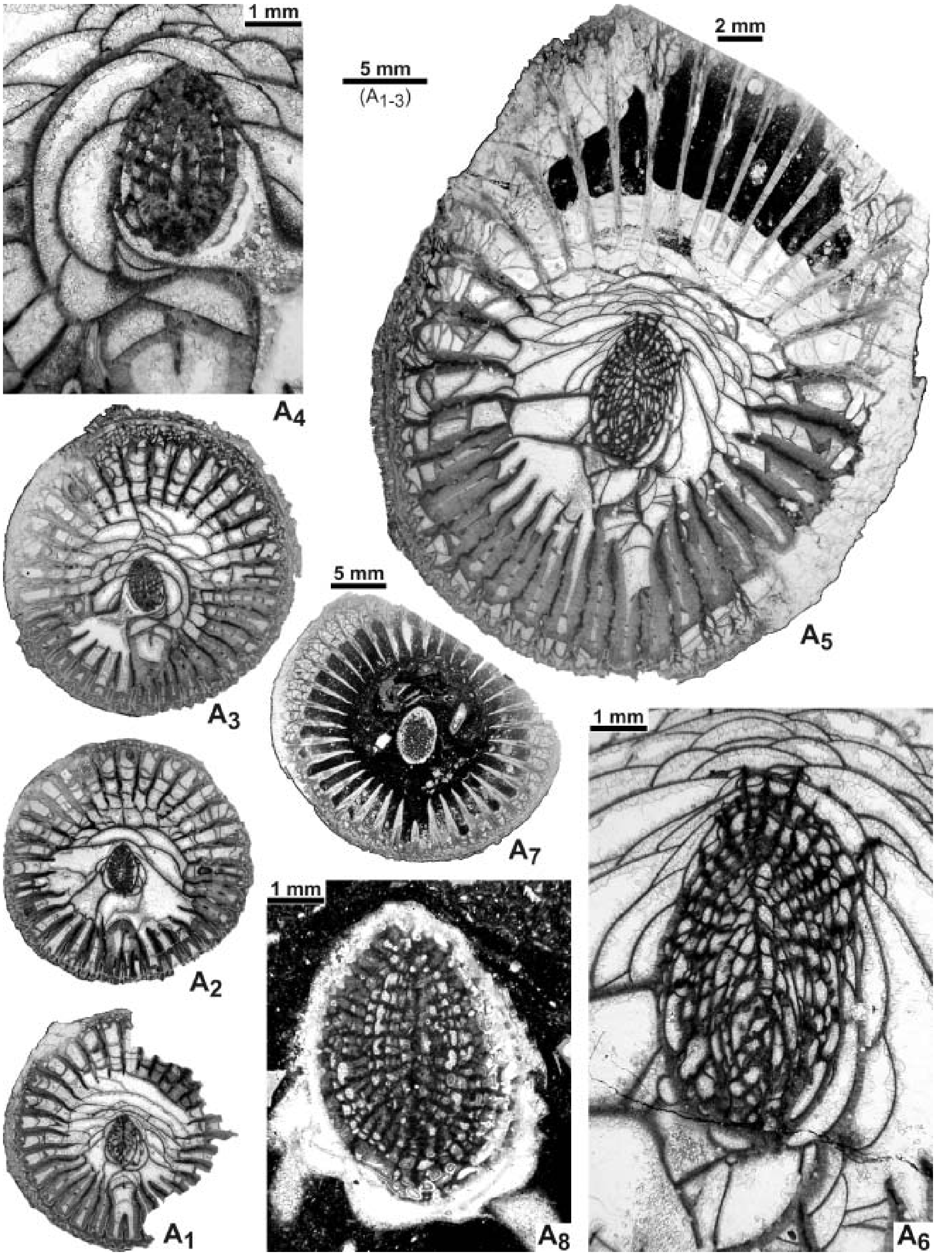


Fig. 57. A. *Linnephyllum spitsbergensis* gen. et sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.Lin. I/1/100; $A_{1\text{-}3,5,7}$ – transverse thin sections from mature growth stage; $A_{4,6,8}$ – enlarged axial structures from sections $A_{3,5}$ and slightly below section A_7, respectively.

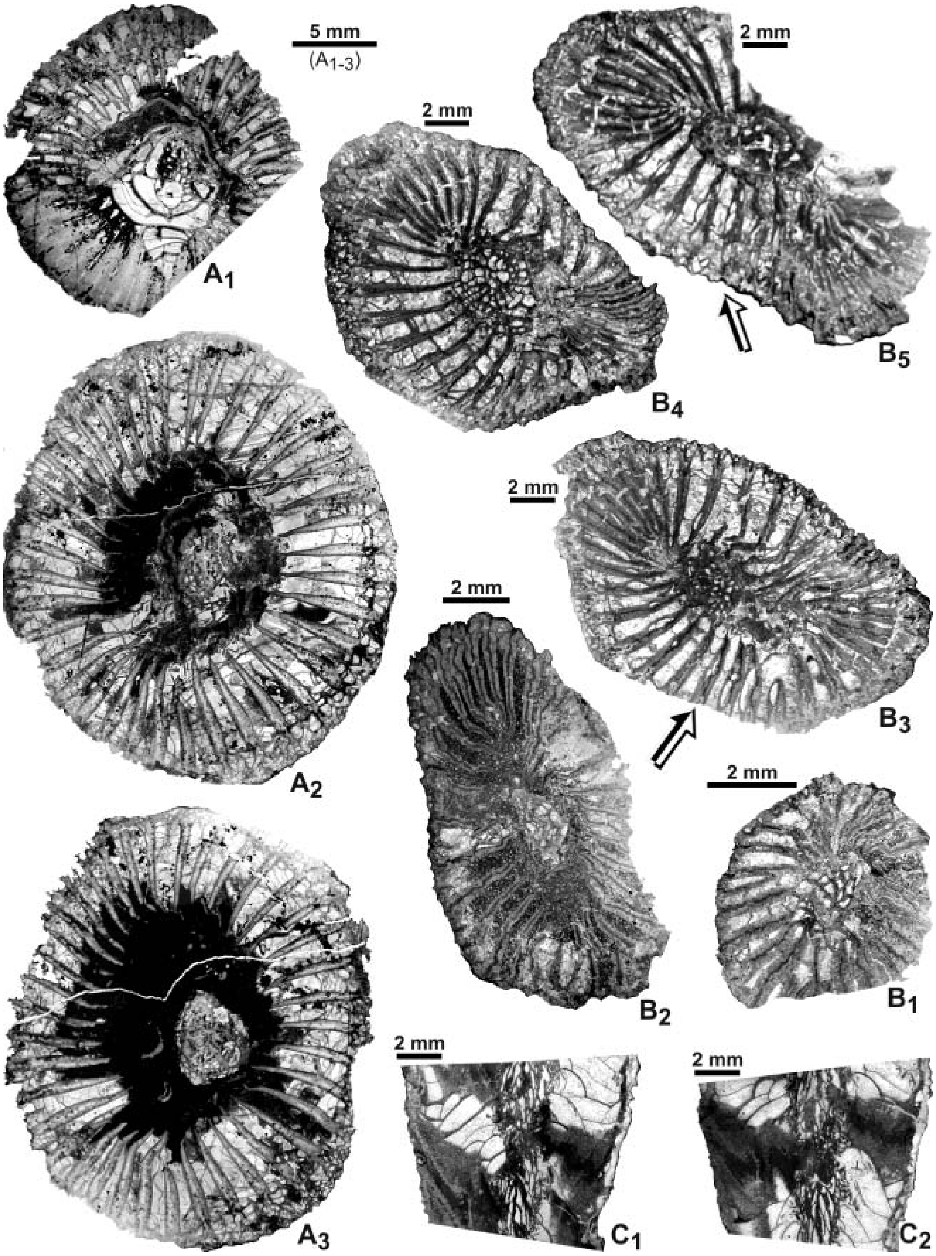


Fig. 58. A. *Linnephyllum spitsbergensis* gen. et sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation. B, C. *Linnephyllum longiseptatum* gen. et sp. nov.

A – UAMIG.Tc-C.Lin. I/1/28; $A_{1\text{-}3}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Lin. I/1/111; B_1 – transverse thin section from immature growth stage, $B_{2\text{-}5}$ – transverse thin sections from mature growth stage, arrows in B_3 and B_5 show anastomozing major septa.
C – UAMIG.Tc-C.Lin. I/1/12; $C_{1,2}$ – longitudinal thin sections.

Diagnosis: *Linnephyllum* with septal n/d indices from 31/15 to 35-38/18-29; major septa from one-half to two-thirds corallite radius in length, not extending to axial structure; counter protoseptum may be elongated; minor septa penetrating into tabularium; dissepimentarium occupying ca. one-third length of major septa.

Material: Paratype – one largely silicified fragment of calice with sub-calicular part (UAMIG.Tc-C.Lin. I/1/28; Fig. 58A). Eight transverse thin sections.

Description: The septal n/d index of the earliest growth stage available is 31/15 (Fig. 57A_1). Major septa attain two-thirds corallite radius, being slightly thicker in cardinal than in counter quadrants. An amplexoid cardinal protoseptum attains ca. one-half length of major septa. Cardinal fossula tabular, open, reaching axial structure. Counter protoseptum does not differ from remaining major septa of cardinal quadrants. Axial structure lenticular (4.0 mm x 3.0 mm), built of thick median lamella, a few septal lamellae and thickened axial tabellae. Minor septa penetrating into tabularium, one-fourth major septa in length. Sections through tabulae at minor septa indicative of "biformly reduced" tabularium. Dissepimentarium built of very fine interseptal dissepiments, occupies ca. one-fifth length major septa.

In section made 3 mm above the first one (Fig. 57A_2), n/d index equals 34/15. Major septa attain one-half corallite radius in length. Cardinal protoseptum as long as remaining major septa of cardinal quadrants. Cardinal fossula attains one-half corallite radius, bordered by two pairs of major septa. Counter protoseptum markedly longer than adjacent pair of major septa. Axial structure built of median lamella, septal lamellae (corresponding to most major septa) and closely adhering axial tabellae, which gives the impression of there being a compact columella. Tabularium "biformly reduced".

In sections from later growth stages (Figs 57A_3, 58A_1) septal indices attain 35-36/18.0-18.5. Major septa in cardinal quadrants distinctly thicker than in counter quadrants. Cardinal protoseptum shortened to ca. one-half to two-thirds length of major septa, in elongated fossula reaching axial structure. Counter protoseptum elongated, but not meeting axial structure (Fig. 57A_3), or not differing in length from remaining major septa (Fig. 58A_1). Axial structure built of median lamella, septal lamellae corresponding to major septa, and thickened axial tabellae (Fig. 57A_4).

In slightly oblique section through calice bottom and sub-calicular part (Fig. 57A_5), septal index is 35/25. Major septa of similar length, clearly thicker in cardinal than in counter quadrants. Cardinal protoseptum shortened to ca. two-thirds length of major septa; counter protoseptum not differing from remaining septa of counter quadrants. Openwork axial structure 7.5 x 4.0 mm in size, built of median lamella, thin septal lamellae converging on it, and axial tabellae (Fig. $57A_6$). In sections made slightly below calice bottom (Fig. $58A_{2,3}$), septal indices equal 38/23x27. Major septa of similar length and thickness. Minor septa short, restricted to narrow dissepimentarium zone, built of straight and pseudo-herringbone dissepiments. In the middle of calice depth (Fig. $57A_7$), n/d index = 35/26.5, cardinal protoseptum shortened, remaining major septa of equal length (ca. one-half corallite radius) and thickness. Dissepimentarium of variable width. In counter quadrants its width is ca. one-half length of major septa; towards cardinal protoseptum it narrows to ca. one-fourth length of major septa. Minor septa do not cross dissepimentarium zone. Axial structure oval (4.0 x 6.0 mm), compact, built of median lamella, thickened axial tabellae, and septal lamellae corresponding to all major septa and some minor septa (Fig. $57A_8$).

Remarks: The unique features of the species described above have not counterparts among the known solitary corals. They only show some similarity to corallites from phaceloid colonies of *Heritschioides columbicum* (see Fedorowski et al. 2007: pl. 9, figs 1-4). However, the morphological structure of the specimens described above is not indicative of their colonial nature: serial sections show them to have a corniculate shape characteristic of solitary forms. It also seems that the number of "specimens" would be greater if they came from fragmented phaceloid or dendroid colonies. But in a collection of more than 100 examined specimens from layers denoted as "Lin. I" (Fig. 7B, Table 1A, B), only two have features of the new species described above.

Occurrence: Spitsbergen: Linnédalen (Wordiekammen Formation) – Sakmarian.

Linnephyllum longiseptatum gen. et sp. nov.
Figs 58B, C, 59

Holotype: UAMIG.Tc-C.Lin. I/1/12 (Fig. $58C_{1,2}$, 59A1-12). 14 transverse thin sections and two longitudinal sections.

Type locality: Linnédalen (N 78° 03.697'; E 13° 48.437'), central Spitsbergen (Figs 2C, 6).

Type horizon: Wordiekammen Formation – Sakmarian.

Derivation of name: *longiseptatum* – having long major septa.

Diagnosis: *Linnephyllum* with septal n/d indices from 33/~12 to 35/~20; major septa long, usually connected with septal lamellae of axial structure; cardinal protoseptum in early growth stages reaching axial structure, in later ones shortened to ca. one-third corallite radius; length of minor septa attains one-fifth corallite radius, they can penetrate into tabularium; dissepimentarium

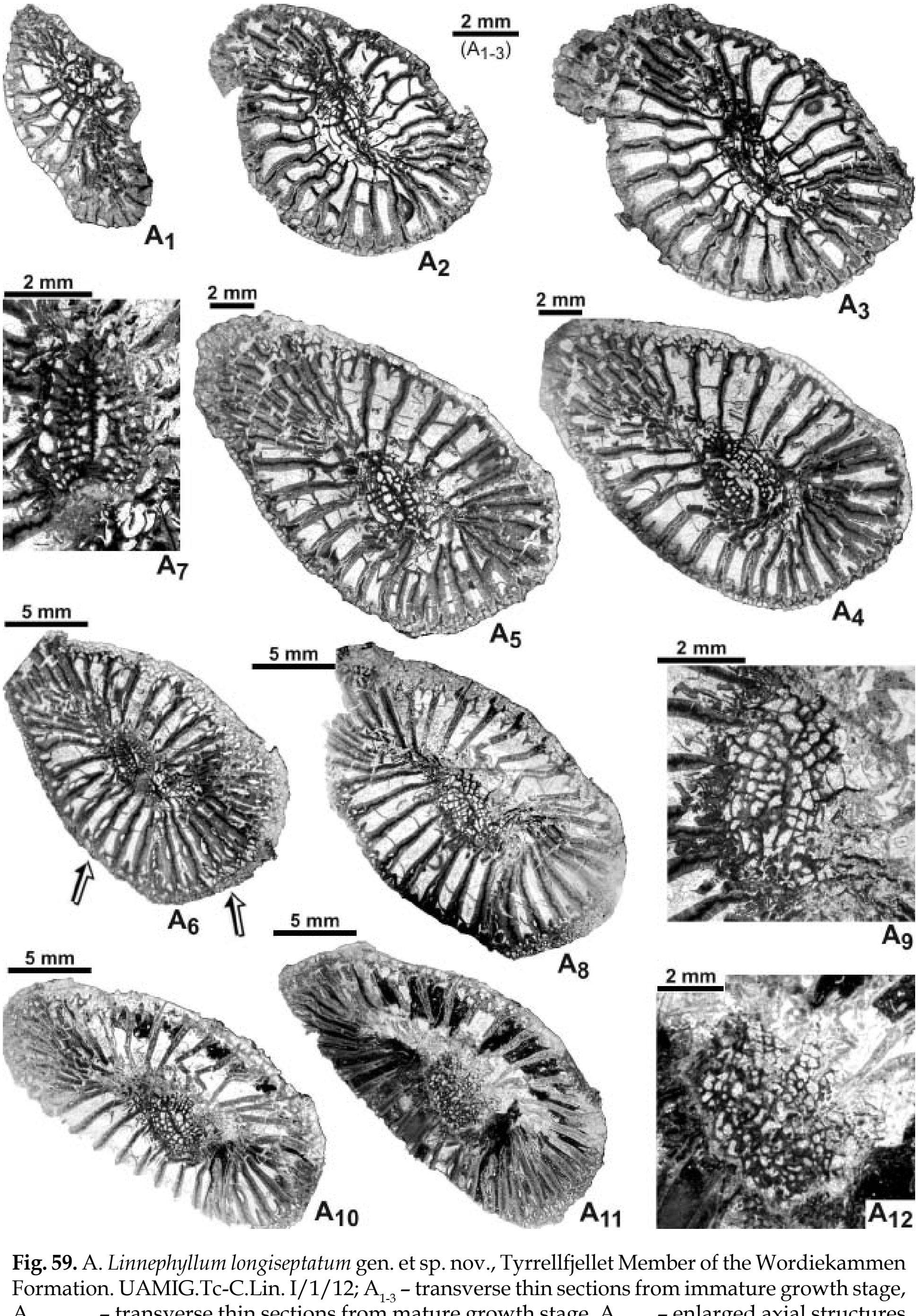


Fig. 59. A. *Linnephyllum longiseptatum* gen. et sp. nov., Tyrrellfjellet Member of the Wordiekammen Formation. UAMIG.Tc-C.Lin. I/1/12; $A_{1\text{-}3}$ – transverse thin sections from immature growth stage, $A_{4\text{-}6,\,8,\,10,\,11}$ – transverse thin sections from mature growth stage, $A_{7,\,9,\,12}$ – enlarged axial structures from sections A_6, A_8 and A_{11}, respectively; arrows in A_6 show anastomozing major septa.

occupies up to one-fifth corallite radius and is built of very fine interseptal dissepiments.

Material: Paratype (UAMIG.Tc-C.Lin. I/1/111) – small, slightly crushed fragment of calice with sub-calicular part (Fig. $58B_{1\text{-}5}$). Seven transverse thin sections.

Description of holotype: Because of damage caused by crushing, septal indices from all sections are estimates. In section from the earliest growth stage available (Fig. $59A_1$), the index is ~20/4x7. Major septa extend to poorly developed axial structure. Minor septa short, restricted to narrow (1-row) dissepimentarium.

In section made 3 mm above preceding one, septal index is ~28/~7 (Fig. $59A_2$). Major septa thickened, reaching axial structure; protosepta fused at the corallite axis *via* median lamella. Axial structure consists of median lamella, axial tabellae and several septal lamellae corresponding to major septa.

In successive sections (Fig. $59A_{3\text{-}10}$), the last of which comes from calice bottom, as corallite grows in size, its axial structure, composed of median lamella, numerous septal lamellae, axial tabellae and a few extra-septal lamellae, becomes more complicated (Fig. $59A_{7,\ 9}$). Septal indices range from 28/8.5 through 33/13 to 34/~16 (Fig. $59A_{3\text{-}8}$). Major septa thin in dissepimentarium, thickened in tabularium, locally anastomozing (Fig. $59A_6$, see arrows), with thin inner ends passing into septal lamellae. Cardinal protoseptum remains long after losing contact with axial structure (Fig. $59A_3$); it shortens to ca. one-third corallite radius in successive sections from later growth stage. Dissepimentarium, composed from one row to several rows, of very fine dissepiments, occupies a mere 1.5 mm in the widest place. Minor septa in dissepimentarium thin, in tabularium, into which they penetrate to ca. 0.5 mm, thickened.

In calice (Fig. $59A_{11}$) septal index attains ca. 35/~17; in axial structure median lamella becomes invisible (Fig. $59A_{12}$), while the remaining elements of its structure (septal lamellae, sections through axial tabellae) observed in sections from earlier growth stages are preserved. Despite partial re-crystallisation and deformation caused by crushing, major septa still seem to extend to openwork axial structure.

In longitudinal section (Fig. $58C_{1,\ 2}$), tabellae vesicular or flat, steeply upturned at axial structure and gently rising or declining at external wall; in axial structure numerous "linked axial tabellae" (*sensu* Fedorowski et al. 2007).

Intraspecific variability: As follows from the series of transverse sections obtained (Fig. $58B_{1\text{-}5}$), the paratype differs from the holotype only in having a bit shorter minor septa that do not penetrate into the tabularium. The remaining features, including the axial structure, septal indices (34-35/~13-15), the length and thickness of major septa, and an anastomozing nature of some of them (Fig. $58B_{3, 5}$, see arrows), as well as the form of the dissepimentarium, do not depart from those found in the holotype.

Because of a less deformed immature growth stage preserved in the paratype than in the holotype, it was possible to calculate its n/d index with a greater accuracy. Estimated at ~20/4.0x7.0 in the holotype, in the paratype major septa number 26 at a corallite diameter of 5.5 mm (Fig. $58B_1$). The axial structure, also better preserved in the paratype than in a similar growth stage of the holotype, reveals a median lamella, a few septal lamellae and a few axial tabellae, the outer ones thickened. It was also noted that the axial structure could be stereoplasmatically thickened irrespective of the growth stage. The thickening appears irregularly and at both, very early (Fig. $58B_1$) and late growth stages of the specimen (Fig. $58B_5$), obscuring details of its morphological structure.

The axial structure isolation from major septa observed in the early growth stage (Fig. $58A_2$) is an effect of mechanical damage (indicated by a deposit between skeletal structures), and not a feature from within an intraspecific variability.

Remarks: In comparison with *L. spitsbergensis* gen. et sp. nov., the specimens placed in *L. longiseptatum* gen. et sp. nov. have smaller corallite diameters at similar numbers of septa (35/17 *vs*. 35/18-27) and longer major septa, which reach the axial structure and can be anastomozing in the tabularium.

Occurrence: Spitsbergen: Linnédalen (Wordiekammen Formation) – Sakmarian.

Suborder: Plerophyllina Sokolov, 1960
Family: Polycoeliidae de Fromentel, 1861
Genus: *Calophyllum* Dana, 1846

Type species: *Turbinolia donatiana* King, 1849.

Emended diagnosis: See Fedorowski and Bamber (2001), p. 53.

Calophyllum columnare (Schlotheim, 1813)
Figs 61, 62

2001. *Calophyllum columnare* (Schlotheim, 1813); Fedorowski and Bamber: pp. 53-54 (cum synon.).
2007. *Calophyllum columnare* (Schlotheim, 1813); Chwieduk: pp. 299-300, pl. 6, figs 1-2; pl. 7, figs 1-2, pl. 8, fig. 2, pl. 9, figs 6-9.

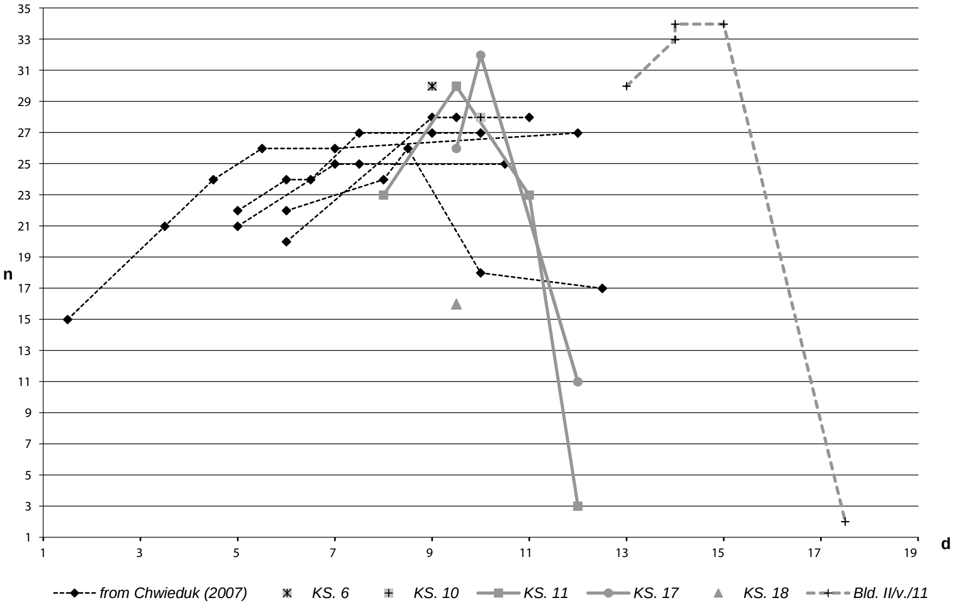


Fig. 60. Plot of the number of major septa (n) *vs*. diameters (d) of *Calophyllum columnare*. Symbols joined by lines represent values taken from individual specimens.

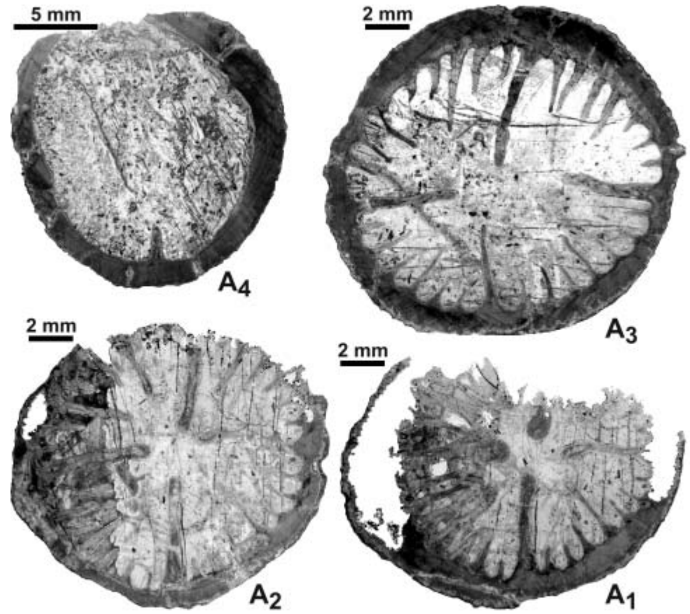


Fig. 61. A. *Calophyllum columnare* (Schlotheim, 1813), Hovtinden Member of the Kapp Starostin Formation. UAMIG.Tc-C.Bld. II/v./11; $A_{1\text{-}4}$ – transverse thin sections from mature growth stage.

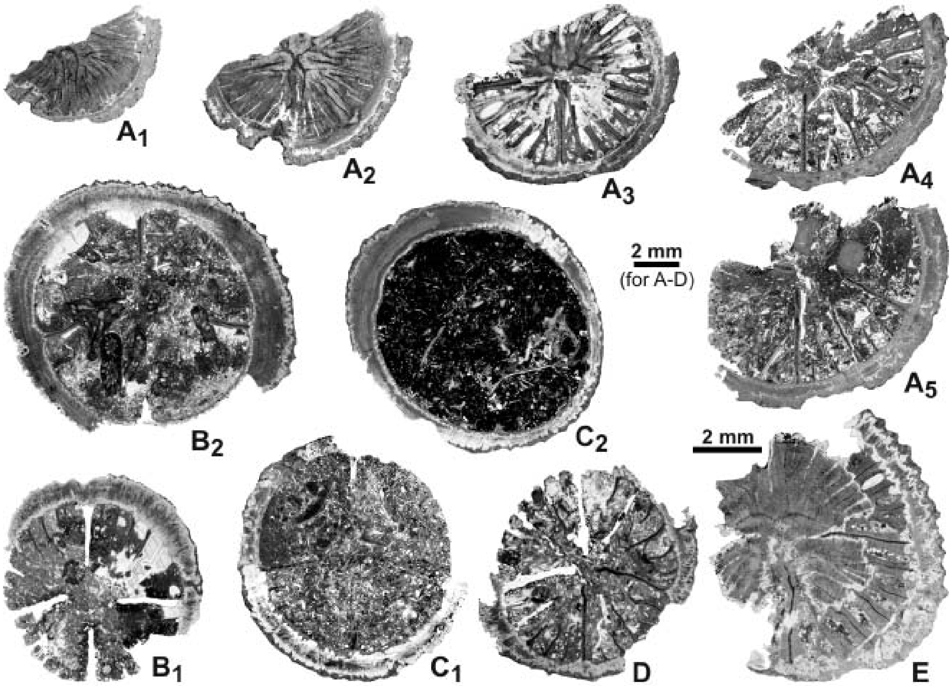


Fig. 62. A-E. *Calophyllum columnare* (Schlotheim, 1813).

A – UAMIG.Tc-C.Bld. III/1, Hovtinden Member of the Kapp Starostin Formation; $A_{1,2}$ – transverse thin sections from immature growth stage, $A_{3\text{-}5}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.KS. IB/17, Svenskeegga Member of the Kapp Starostin Formation; $B_{1,2}$ – transverse thin sections from mature growth stage.
C – UAMIG.Tc-C.KS. IA/11, Svenskeegga Member of the Kapp Starostin Formation; $C_{1,2}$ – transverse thin sections from mature growth stage.
D – UAMIG.Tc-C.KS. IA/10, Svenskeegga Member of the Kapp Starostin Formation; transverse thin section from mature growth stage.
E – UAMIG.Tc-C.KS. IA/6, Svenskeegga Member of the Kapp Starostin Formation; transverse thin section from immature growth stage.

Diagnosis: See Fedorowski and Bamber (2001), p. 54.

Material: Seven specimens (UAMIG.Tc-C.KS. IA/6, 10, 11; KS. IB/17, 18; UAMIG.Tc-C.Bld. III/1, II/v./11); all considerably corroded and re-crystallised. 31 transverse thin sections.

Description: Variations in size and n/d values are shown in Fig. 60. Major septa of varying length, the longest being protosepta and alar septa, in early growth stages fusing at the corallite axis. Thickness of major septa at maturity ranges from 0.1 to 0.7 mm (Figs $61A_{1\text{-}4}$, $62A_{3\text{-}5}$, $B_{1,2}$, $C_{1,2}$, D); in early growth stages thick, filling entire corallite lumen (Fig. $62A_{1\text{-}2}$, E). Minor septa absent and not recognizable in wall structure. External wall 1.3 mm – 2.0 mm thick; smooth or with septal furrows.

Remarks: A detailed analysis of the morphological structure of this species, its taxonomic affinity and a broad discussion of this topic can be found in Fedorowski (1982b). He also emphasised several fundamental characteristics of the genus. Later additions were made by Fedorowski and Bamber (2001) and Chwieduk (2007). The remarks discussed earlier, in the absence of new ones, will not therefore be repeated in this study.

Occurrence: Central European Basin – Wordian or Lower Capitanian; East European Platform – Lower Kazanian, Roadian; East Greenland: Kapp Stosch and Jameson Land (Foldvik Creek Group, Wegener Halvo Formation) – Wordian or Lower Capitanian; Sverdrup Basin (Degerbols and Trold Fiord Formations) – Wordian; Spitsbergen: Treskelen, Blendadalen, Kapp Starostin (Kapp Starostin Formation) – Wordian and/or Capitanian.

Genus: *Sochkineophyllum* Grabau, 1928

Type species: *Pleurophyllum artiense* Soshkina, 1925.

Diagnosis: See Fedorowski and Bamber (2001), p. 59.

Sochkineophyllum turgidiseptatum (Tidten, 1972)
Fig. 64A, B, D

1972. *Sassendalia turgidiseptata* sp. n.; Tidten: p. 30, pl. 4, figs 1-7, pl. 10, fig. 8, pl. 11, figs 11-14, pl. 12, figs 1-2, pl. 15, figs 11-12.
1974. *Sochkineophyllum* sp.; Bamber [in Thorsteinsson]: p. 70.
1992. *Sassendalia turgidiseptata* Tidten; Ezaki and Kawamura: pl. 5, figs 1-2.
1997. *Sassendalia turgidiseptata* Tidten; Ezaki: pl. 1, fig. 6
2001. *Soshkineophyllum turgidiseptatum* (Tidten, 1972); Fedorowski and Bamber: pp. 61-65, text-fig. 13, pl. 3, figs 7-8, pl. 4, figs 1-2, pl. 7, figs 1-2.

Diagnosis: See Fedorowski and Bamber (2001), p. 62.

Material: Four specimens (UAMIG.Tc-C.Bld. I/4, II/1, 2; II/v./3). 15 transverse thin sections.

Description: Variations in size and n/d values are shown in Fig. 63. Major septa, in early growth stages strongly thickened, fill entire corallite lumen (Fig. 64A_1); in later growth stages (Fig. 64A_2), inner part of major septa strongly thickened, touching laterally, most of them reaching corallite axis; below calice bottom and in calice (Fig. 64B, $D_{1,2}$), major septa of varying length, with rhopaloid ones longer and thicker than remaining majors, none of them reaching corallite axis. External wall from 1.5 mm to 2.0 mm thick. Minor septa poorly developed, recognizable in wall structure only in calice (Fig. 64$D_{1,2}$).

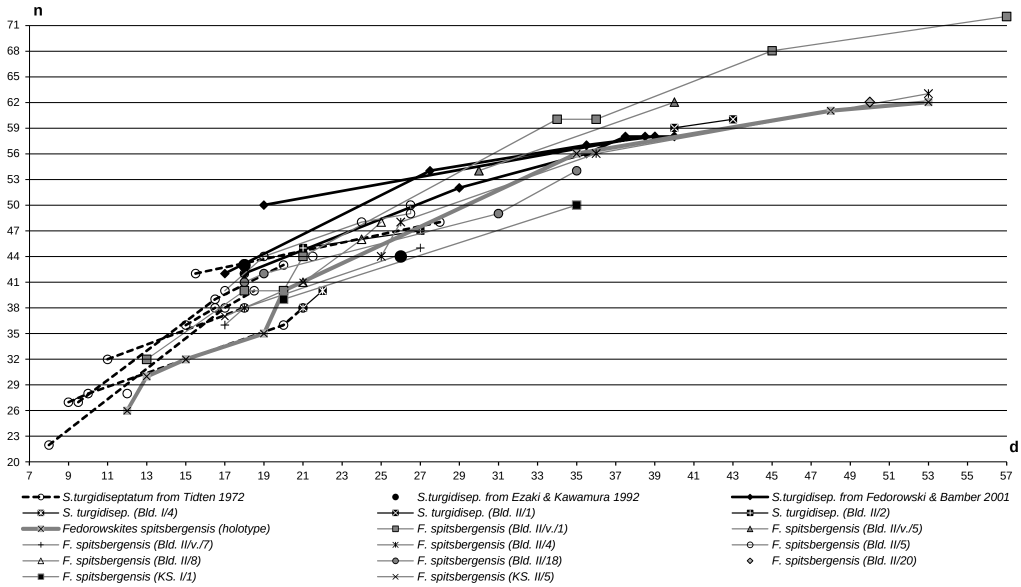


Fig. 63. Plot of the number of major septa (n) *vs*. diameters (d) of *Sochkineophyllum turgidiseptatum* and *Fedorowskites spitsbergensis* gen. et sp. nov. Symbols joined by lines represent values taken from individual specimens.

Remarks: Although Kossovaya (2009a) objects to synonymising *Sassendalia turgidiseptata* with *Sochkineophyllum turgidiseptatum*, justifying her standpoint only by the statement that "This species [i.e. *Sassendalia turgidiseptata*] was assigned to *Sochkineophyllum* (Fedorowski and Bamber 2001), but because of essential morphological differences the genus name *Sassendalia* is retained in this article [i.e. Kossovaya 2009a]", I decided to rely on the justification for synonymising *Sassendalia turgidiseptata* with *Sochkineophyllum turgidiseptatum* given by Fedorowski and Bamber (2001), much more comprehensive and supported by arguments, and retain *Sochkineophyllum turgidiseptatum*.

Although the available specimens from Blendadalen are poorly preserved and incomplete, their main morphological characteristics, especially the arrangement and length of major septa, were easily recognizable and closely similar to those of other specimens known from the Canadian Arctic Archipelago, described by Fedorowski and Bamber (2001), and from Spitsbergen (Sassendalen, Festningen), described by Ezaki (1997) and Ezaki and Kawamura (1992). Also septal indices of the specimens in question are within the range of those given in the literature for this species (Fig. 63; Fedorowski and Bamber 2001: fig. 12).

Occurrence: Canadian Arctic Archipelago: Ellesmere Island, Melville Island (Trold Fiord and Degerböls Formations) – Wordian; Spitsbergen: Sassendalen

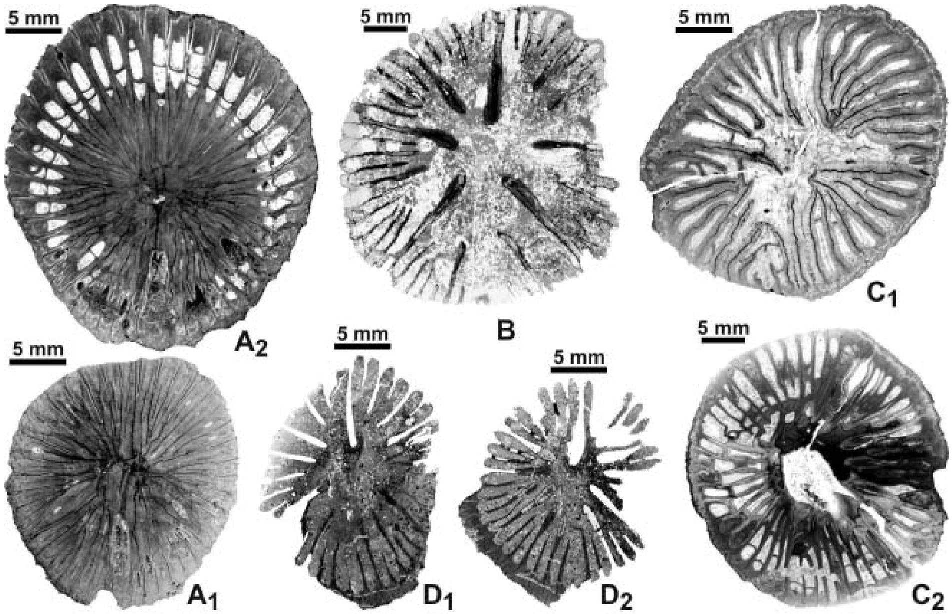


Fig. 64. A, B, D. *Sochkineophyllum turgidiseptatum* (Tidten, 1972).

A – UAMIG.Tc-C.Bld. II/2, Hovtinden Member of the Kapp Starostin Formation; $A_{1,2}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Bld. II/1, Hovtinden Member of the Kapp Starostin Formation; transverse thin section from mature growth stage.
D – UAMIG.Tc-C.Bld. I/4, Svenskeegga Member of the Kapp Starostin Formation; $D_{1,2}$ – transverse thin sections from mature growth stage.
C. *Fedorowskites spitsbergensis* gen. et sp. nov. UAMIG.Tc-C.KS. IA/1, Svenskeegga Member of the Kapp Starostin Formation; C_1 – transverse thin section from immature growth stage, C_2 – transverse thin section from mature growth stage.

(possibly Kapp Starostin Formation) – ?Wordian or Capitanian; Festningen (Kapp Starostin Formation) – ?Wordian or Capitanian; Blendadalen (Kapp Starostin Formation) – Wordian and/or Capitanian.

Genus: *Fedorowskites* gen. nov.

Derivation of name: Named in honour of Professor Jerzy Fedorowski, an outstanding Polish palaeontologist.

Type species: *Fedorowskites spitsbergensis* gen. et sp. nov.

Diagnosis: Solitary, non-dissepimental Polycoeliidae; early ontogeny calophylloid; mature growth stage with cardinal protoseptum shortened, counter protoseptum and alar septa moderately elongated; all major septa not truly rhopaloid; cardinal fossula tabular, open; minor septa poorly visible in peripheral part of thick external wall; tabular floor convex, axially depressed, tabulae incomplete.

Remarks: The characteristics of the newly established genus include an absence of dissepiments, a permanently elongated counter protoseptum, as well as alar septa and the cardinal protoseptum elongated in early growth stages. Hence it belongs to Polycoeliidae. However, the absence of the rhopaloid thickening of septa, a cardinal protoseptum shortening late in ontogeny, minor septa restricted to the septotheca, metasepta that are uniform in shape and length in adult stages (at maturity attaining from one-half to two-thirds of corallite radius), and a tabularium concave at the corallite axis, are features that do not comply with the diagnoses of the known genera of Polycoeliidae. Because of a scanty definition of Polycoeliinae given by Hill (1981), the only subfamily of Polycoeliidae with dissepiment-free forms, today in need of revision, like some genera included within this subfamily (see Fedorowski 2009), the newly established genus was not classified into this subfamily.

In their general habit and morphological structure, especially in early growth stages, the corallites assigned to the new genus seem close to *Sochkineophyllum* Grabau, 1928 and *Pentamplexus* Schindewolf, 1940. However, the *Sochkineophyllum*, known among others from the Wordian of the Canadian Arctic Archipelago, the Wordian or Capitanian of Spitsbergen and the Lower Permian of the Urals, in mature growth stages has distinctly elongated and rhopaloid alar septa and counter protoseptum as well as a markedly shortened cardinal protoseptum. Besides, the feature given as characteristic of *Sochkineophyllum* is an uneven length of the remaining major septa, the longer of which also become rhopaloid at maturity. Moreover, taxonomic status of *Sochkineophyllum* is not quite clear. Many species with the above morphological features, in particular an elongated, rhopaloid counter protoseptum, can in fact belong to *Lophophyllidium* Grabau, 1928 or *Empodesma* Moore and Jeffords, 1945 (Fedorowski and Bamber 2001). However, assuming the length and shape of protosepta and alar septa in immature stages and the remaining metasepta in adult stages, as well as a convex tabularium, to be features diagnostic of *Sochkineophyllum*, the specimens described below, with those elements developed differently and a unique combination of the remaining features of the morphological structure, cannot belong to this genus.

Features linking the newly established genus with the other of the compared genera (its type species being *Pentamplexus simulator* Schindewolf, 1940 known from the Lower Permian of Bitauni, Timor Island) are the calophylloid nature of early ontogeny, an elongated counter protoseptum in all growth stages, a well-developed cardinal fossula, and a long cardinal protoseptum in immature and early-mature growth stages, longer than the adjacent major septa.

What differentiate it are a cardinal protoseptum shortening immediately below the calice bottom (in *Pentamplexus* the cardinal protoseptum is still as long as major septa also above the bottom), greater corallite diameters with a greater number of major septa, and the form of the tabularium, which is convex in *Pentamplexus*, with edges of tabulae declining abaxially. Considering the fact that *Pentamplexus* is only known from the Palaeotethys, the presence of many analogous (in the biological sense) features in the morphological structure of *Fedorowskites* can result from convergence.

Fedorowskites spitsbergensis gen. et sp. nov.
Figs 64C, 65, 66, 67

1975. Genus and species indet.; Fedorowski: p. 70, text-fig. 12, pl. 7, fig. 4.
1992. Polycoeliidae gen. et sp. indet.; Ezaki and Kawamura: pl. 5, figs 3-4.
1997. Polycoeliidae gen. et sp. indet.; Ezaki: pl. 1, figs 7-8.

Holotype: UAMIG.Tc-C.Bld. II/v./2 (Fig. 65A1-7), corallite ceratoid, 180 mm long, concave on the side of cardinal protoseptum. Eight transverse thin sections.

Type locality: Blendadalen (N 78°03.242'; E 13°56.460'; 114 m above sea-level), west of Grønfjorden (Fig. 6).

Type horizon: Kapp Starostin Formation, Wordian and/or Capitanian.

Derivation of name: *spitsbergensis* – after Spitsbergen island.

Diagnosis: *Fedorowskites* with n/d values of 40-70/20-57; major septa attain from two-thirds to three-fourths corallite radius; cardinal fossula of variable morphology; minor septa are observable only in the microstructure of corallite wall in mature growth stages; external wall up to 4.0 mm thick and septothecal; surface of tabularium sigmoid, with hollows in corallite axis and at external wall.

Material: Paratypes – 25 specimens (UAMIG.Tc-C.Bld. II/4, 5, 8-18, 20; II/v./1, 4, 5, 7; UAMIG.Tc-C. KS. IA/1, IA/1/3, KS. IC/4, KS. II/2, 5, KS. II/2/7, KS. III/2/1). 71 transverse and one longitudinal thin sections.

Description of holotype: Ontogenetically the earliest preserved growth stage has n/d index of 25/12 (Fig. $65A_1$) and shows typically sochkineophylloid septal arrangement with long protosepta and alar septa reaching corallite axis; all major septa strongly thickened but not truly rhopaloid; external wall ca. 1.0 mm thick. In slightly later growth stage (Fig. $65A_2$), septal index is 29/15; major septa thickened; protosepta and alar septa slightly retreating from corallite axis; external wall ca. 1.3 mm thick.

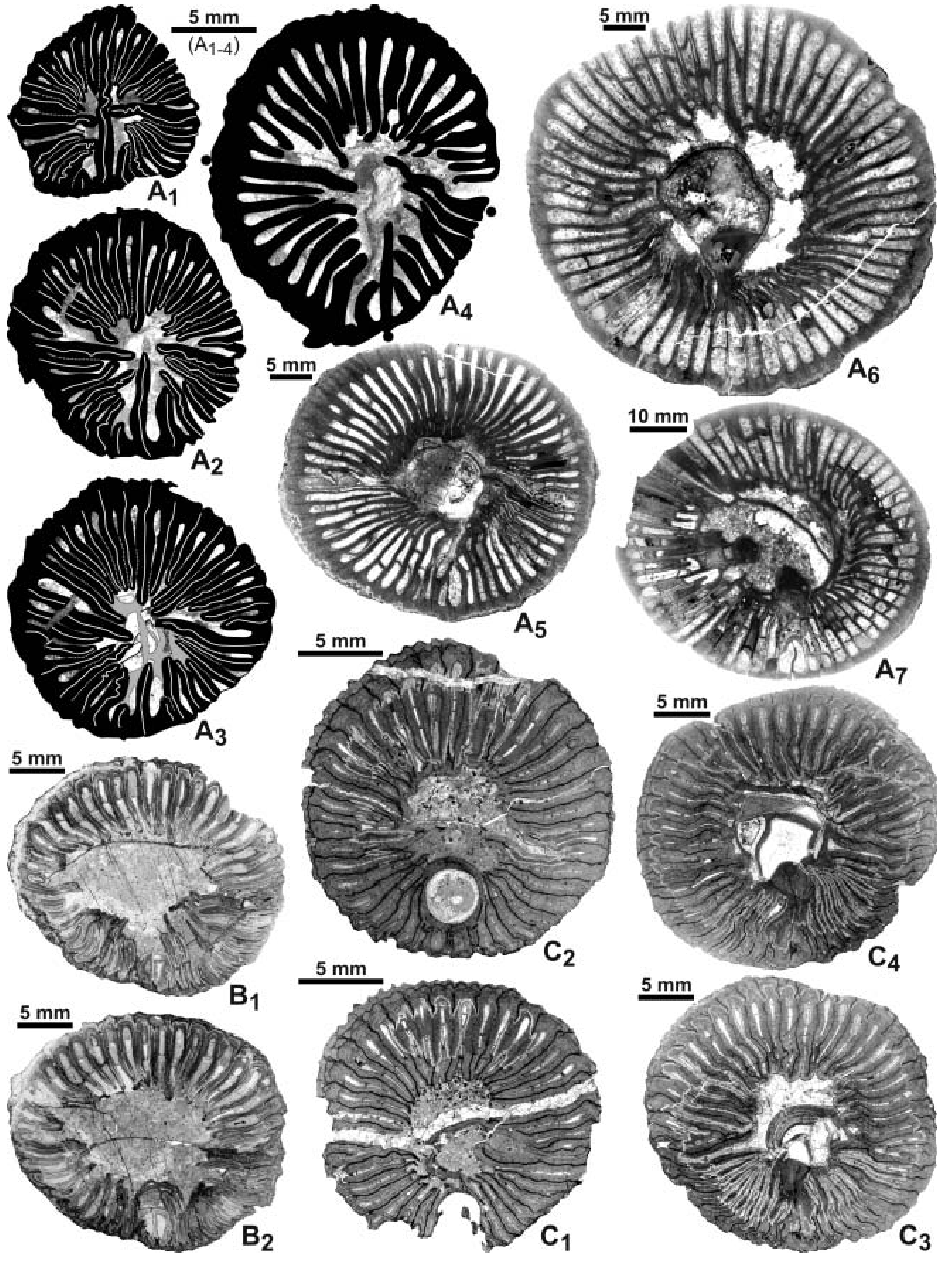


Fig. 65. A-C. *Fedorowskites spitsbergensis* gen. et sp. nov., Hovtinden Member of the Kapp Starostin Formation.

A – UAMIG.Tc-C.Bld. II/v./2; $A_{1\text{-}4}$ – transverse thin sections from immature growth stage, $A_{5\text{-}7}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Bld. II/8; $B_{1,2}$ – transverse thin sections from mature growth stage.
C – UAMIG.Tc-C.Bld. II/5; $C_{1\text{-}4}$ – transverse thin sections from mature growth stage.

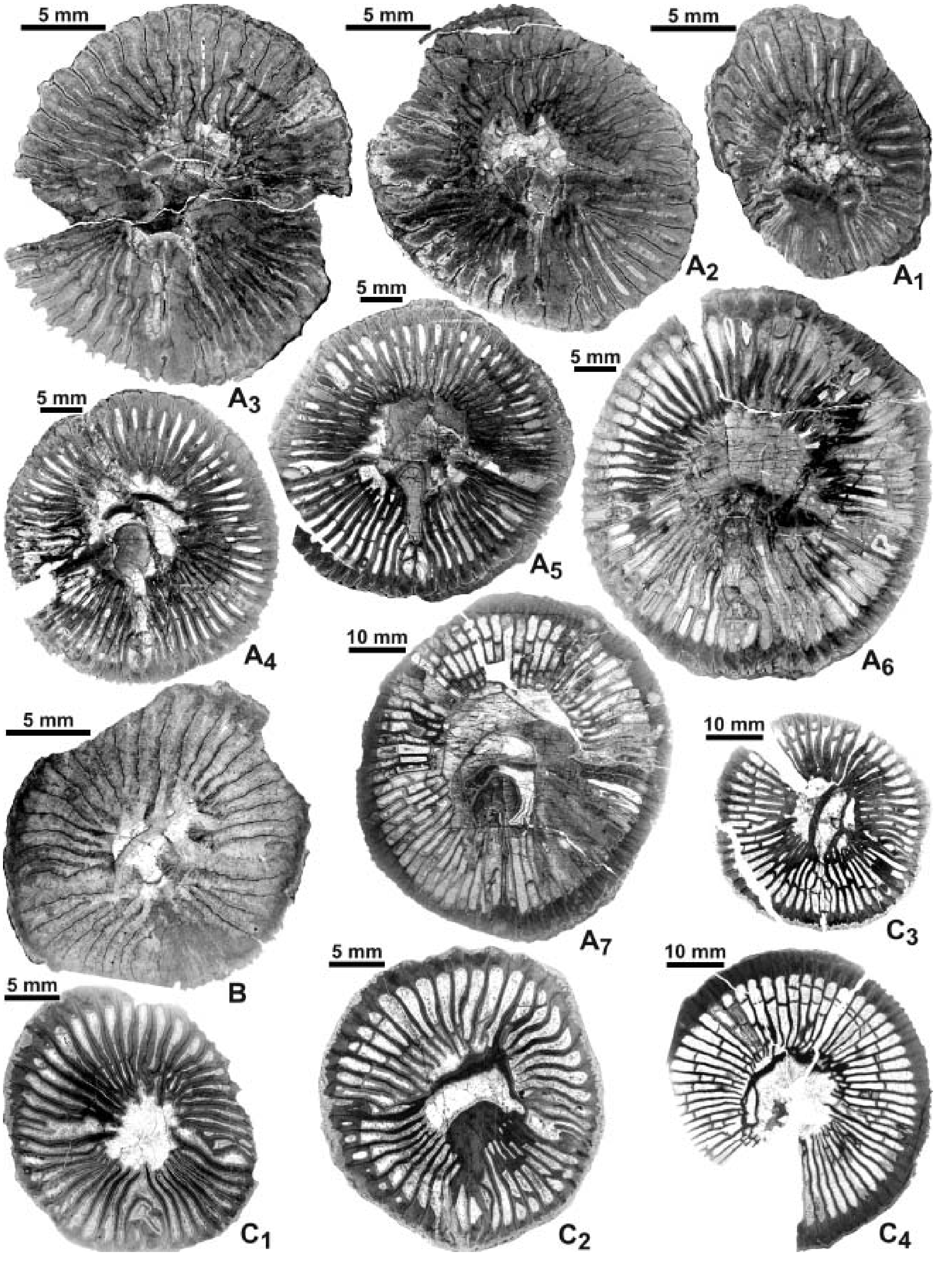


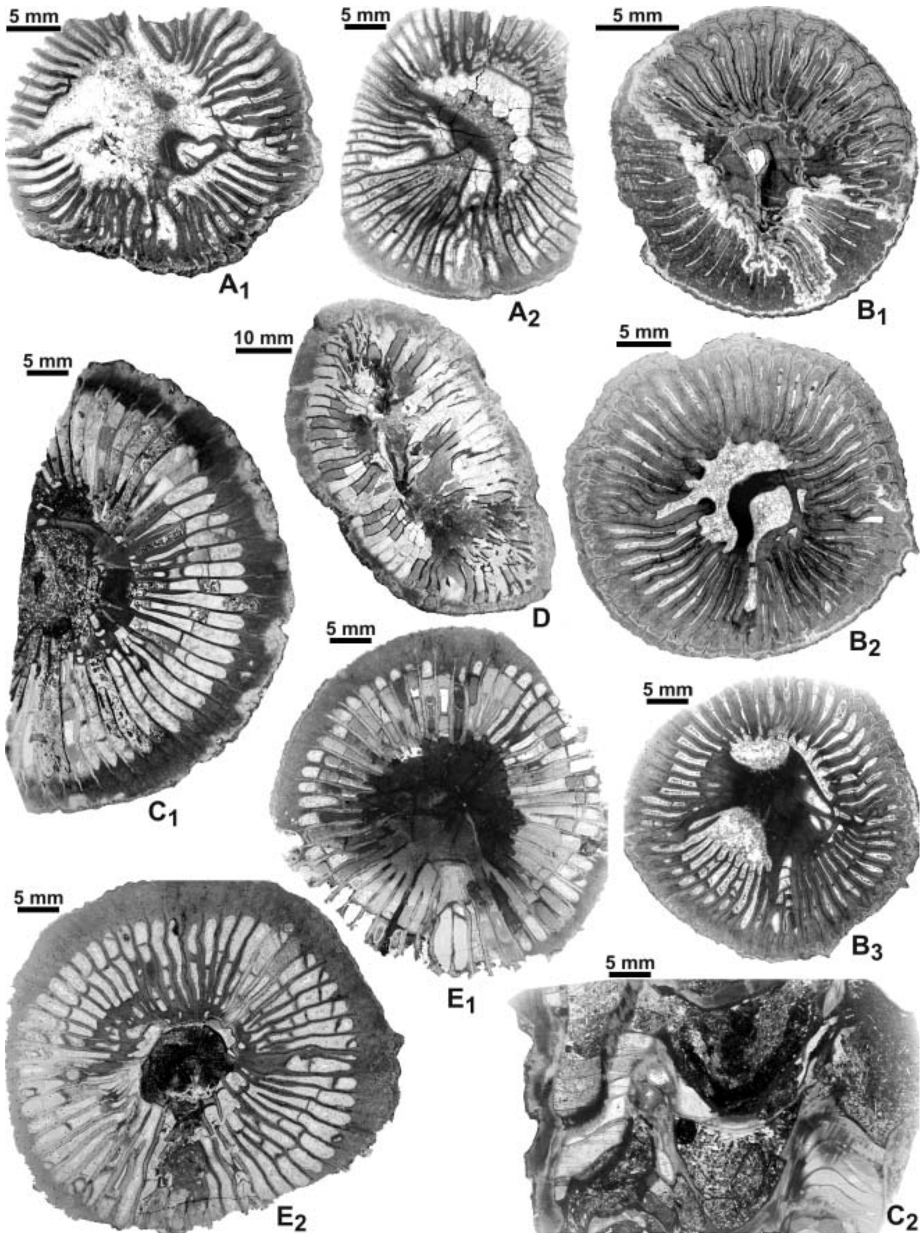
Fig. 66. A-C. *Fedorowskites spitsbergensis* gen. et sp. nov., Hovtinden Member of the Kapp Starostin Formation.

A – UAMIG.Tc-C.Bld. II/v./1; $A_{1,2}$ – transverse thin sections from immature growth stage, A_{3-7} – transverse thin sections from mature growth stage.

B – UAMIG.Tc-C.KS. II/5; transverse thin section from mature growth stage.

C – UAMIG.Tc-C.Bld. II/4; C_{1-4} – transverse thin sections from mature growth stage.

In early mature growth stage (Fig. $65A_{3,4}$), n/d indices are 31/19 and 36?/20; major septa shortened; axial zone free, oval, ca. 2 x 5 mm in diameter. Major septa thickened, of varying length, the longest being alar septa. Cardinal protoseptum as long as the longest major septa of cardinal quadrants; counter protoseptum equal in length to the longest major septa of counter quadrants.



Mature growth stage (Fig. 65$A_{5, 6}$) with septal indices attaining 56/35 and 61/48. Major septa 2-3 times thinner than in sections from earlier ontogenetic stages. Counter protoseptum and alar septa elongated; cardinal protoseptum shortened to three-fourths to one-half length of major septa; remaining major septa of nearly equal length, attaining two-thirds corallite radius; axial zone free from septa, occupying ca. one-third corallite diameter. Inner ends of major septa slightly thickened, but not rhopaloid. Cardinal fossula tabular, open, bordered by 2-3 pairs of successively shortening major septa. Minor septa very poorly visible in peripheral part of septothecal external wall, which attains 2.5 mm in thickness.

In the latest growth stage available (Fig. 65A_7), n/d index is 62/53. In this slightly oblique section, major septa above calice bottom (left side in Fig. 65A_7) are of different length, without rhopaloid inner ends, with long alar septum and short cardinal protoseptum. Major septa on the right side (below calice bottom, Fig. 65A_7) are of similar length, with counter protoseptum slightly longer than remaining major septa of counter quadrants. External wall ca. 2.5 mm thick.

Intraspecific variability: Corallites of the paratypes ceratoid, 40-80 mm long, mostly representing adult growth stages (Figs 64$C_{1, 2}$, 65B, C, 66A-C, 67A-E). In comparison with the holotype, they have: smaller numbers of major septa at similar corallite diameters in mature growth stages (Fig. 63); a greater diameter of the axial zone free from septa, which can occupy one-half corallite diameter (Figs 65$B_{1, 2}$, 67A_1); major septa withdrawn from corallite axis already at corallite diameter of ca. 14 mm (Fig. 66A_1); thickened major septa still at corallite diameter of 20-21 mm (Figs 66A_3, 67B_1); and greater differences in length of major septa in early-mature and adult growth stages (Figs 64C_1, 66A_{1-3}, C, 67$A_{1, 2}$, B_2). Also, a shortened cardinal protoseptum in mature growth stages may not exceed one-third length of major septa of cardinal quadrants, while a narrow, open cardinal fossula can extend beyond major septa of cardinal quadrants and widen towards corallite axis (Fig. 66A_{4-7}). Besides, in one case rhopaloid major septa were observed to occur in the calice (Fig. 64C_2). In turn, minor

Fig. 67. A-E. *Fedorowskites spitsbergensis* gen. et sp. nov.

A – UAMIG.Tc-C.Bld. II/v./5, Hovtinden Member of the Kapp Starostin Formation; $A_{1, 2}$ – transverse thin sections from mature growth stage.

B – UAMIG.Tc-C.Bld. II/18, Hovtinden Member of the Kapp Starostin Formation; B_1 – transverse thin section from immature growth stage, $B_{2, 3}$ – transverse thin sections from mature growth stage.

C – UAMIG.Tc-C.KS. III/2/1, Hovtinden Member of the Kapp Starostin Formation; C_1 – transverse thin section from mature growth stage, C_2 – longitudinal thin section.

D – UAMIG.Tc-C.KS. II/2, Hovtinden Member of the Kapp Starostin Formation; transverse thin section from mature growth stage.

E – UAMIG.Tc-C.KS. IC/4, Svenskeegga Member of the Kapp Starostin Formation; $E_{1, 2}$ – transverse thin sections from mature growth stage.

septa, as in the holotype, are very poorly visible (Fig. 65C_1); in most specimens they are not recognizable even in the septothecal structure of the external wall, the thickness of which can attain 6.0 mm (Figs 66A_7, 67C_1).

The examples given above show this species to display great intraspecific variability. Its identification on the basis of the morphological structure of a single specimen can therefore be difficult, and with only an early growth stage available, impossible. In turn, the occurrence of all specimens of this species in rocks of similar age and type (the Kapp Starostin Formation) indicates that the heterogeneity of the environment must have been greater than would follow from the lithological analysis of this formation, because genetic variability within a species usually increases with the heterogeneity of the environment.

In one of the sections of paratype UAMIG.Tc-C.KS. III/2/1 (Fig. 67C2), the surface of the tabularium, not observed in the holotype, is sigmoidally bent; axial tabellae are concave, peripheral ones are arched, with long, gently inclining outer edges and short, steeper inner ones.

Remarks: Placed in synonymy with this species are the specimen from Akseløya described as genus and species indet. (Fedorowski 1975), and those from Festningen, illustrated by Ezaki and Kawamura (1992) and Ezaki (1997), identified as gen. et sp. indet. The preserved adult growth stages of those corallites without doubt indicate *Fedorowskites spitsbergensis* gen. et sp. nov., since they have all the features of the morphological structure of the adult growth stage of the new species. The Akseløya specimen has also a tabularium developed nearly identically as *Fedorowskites spitsbergensis* gen. et sp. nov., (Fedorowski 1975: fig. 12d).

Occurrence: Spitsbergen: Akseløya, Festningen, Blendadalen, Kapp Starostin (Kapp Starostin Formation) – Wordian and/or Capitanian.

Suborder and family indet.
Gen. and sp. indet.
Fig. 68

Material: One almost completely preserved specimen (UAMIG.Tc-C.Krg. III/15). Four peels and 16 transverse thin sections.

Description: The specimen under study, with damaged proximal end but preserved early ontogenetic stages, is 7.5 cm long. Calice attains 2.5 cm in depth. N/d index in its bottom is 54/30 (Fig. 68A_{11}). Major septa of varying length, in counter quadrants arranged radially, in cardinal ones pinnately, gradually shortening towards cardinal protoseptum, which is ca. one-half corallite radius in length (Fig. 68A_{7-10}). Cardinal fossula deep, open, tabular, elliptic in

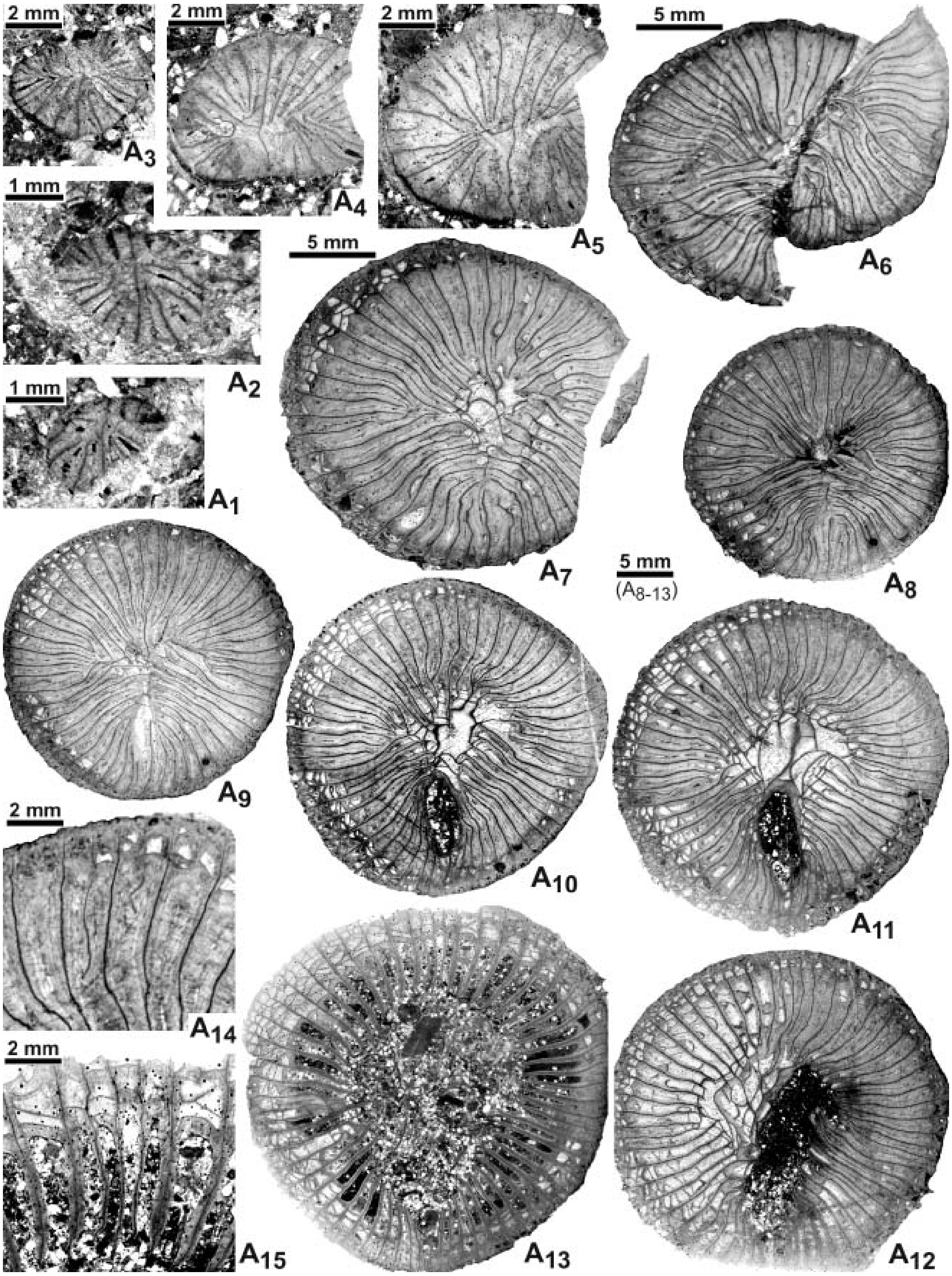


Fig. 68. A. Gen. and sp. indet. UAMIG.Tc-C.Krg. III/15, upper part of the Treskelodden Formation; $A_{1\text{-}5}$ – transverse thin sections from immature growth stage, $A_{6\text{-}13}$ – transverse thin sections from mature growth stage, $A_{14,\,15}$ showing elongated Km septa.

outline. Counter protoseptum the longest, reaching corallite axis. Alar septa equal in length to the longest major septa; alar fossulae distinct (Fig. $68A_{9-11}$). Minor septa, except Km, short, from 1 to 3 mm long. Km septa attain 6 and 7 mm in length, which is ca. two-thirds length of counter protoseptum (Fig. $68A_{11,\ 15}$). Dissepimentarium the widest in cardinal quadrants at alar septa, where it attains 5 mm in width, while narrowing to ca. 1 mm towards cardinal protoseptum. In counter quadrants, in the widest place (central part of quadrant), it attains 3 mm. Because of transverse sections being slightly oblique, dissepimentarium is clearly visible only on one side of them.

Ontogenesis: In the earliest growth stage available, the n/d index equals 9/1x2. Major septa of varying length and strongly thickened, filling almost entire corallite lumen (Fig. $68A_1$). Protosepta joined at corallite axis. Minor septa missing. External wall corroded.

In sections made 2 and 4 mm above previous one, n/d indices are 12/2.5x2 and 17/3, respectively (Fig. $68A_{2,\ 3}$). Skeletal elements developed similarly as in section described earlier. In next section made 3 mm above the previous, septal index is 21/7x5 (Fig. $68A_4$). Major septa arranged pinnately, of varying length, strongly thickened, filling almost entire corallite lumen. Protosepta fused at corallite axis. External wall, preserved at places, is 0.1 mm thick. In next section distanced at 2 mm (at n/d of 23/7) there appear the first minor septa, viz. Km septa, attaining 0.5 mm in length (Fig. $68A_5$).

Because of damage, next section (Fig. $68A_6$) was made ca. 20 mm above previous one. Septal index equals 38/18. Major septa strongly thickened, varying in length. Minor septa not exceeding 1 mm in length. Dissepimentarium irregular, built of 1-2 rows of dissepiments, visible only in counter quadrants. External wall attains 0.5 mm in thickness.

Next sections, made 5 and 10 mm above the one described previously (Fig. $68A_{7,\ 8}$) have septal indices of 44/20 and 46/22, respectively. Major septa of varying length, not reaching corallite axis, except counter protoseptum. Cardinal protoseptum shortened to ca. one-half corallite radius, in fossula bordered by successively shortening major septa, with inner ends bent towards cardinal protoseptum. Alar septa slightly shorter than adjacent major septa of cardinal quadrants. Minor septa do not exceed 1 mm in length. Km septa in section illustrated in Fig. $68A_7$ not differing from remaining minor septa; 5 mm higher (Fig. $68A_8$), one of Km septa attains 4 mm in length and is distinctly longer than the other one; remaining minor septa ca. 1 mm long. Dissepimentarium of variable width, attaining a maximum of 2 mm. Dissepiments herringbone and pseudo-herringbone. External wall 0.1 to 0.2 mm thick.

In section made 10 mm above previous one, n/d index is 50/25 (Fig. $68A_9$). Major septa of varying length, in counter quadrants arranged radially, in cardinal quadrants pinnately. Counter protoseptum reaching corallite axis, cardinal protoseptum shortened to one-half corallite radius. Cardinal fossula narrow, bordered by successively shortening major septa of cardinal quadrants. Alar septa slightly shorter than adjacent major septa, in distinct alar fossulae. Km septa 3 and 5 mm long, remaining minor septa of varying length, the longest attaining 1.5 mm. Dissepimentarium of variable width, being the widest in the central part of counter quadrant, at 3 mm. Dissepiments herringbone and pseudo-herringbone. External wall 0.3 mm thick.

Near calice bottom (Fig. $68A_{10}$), septal index equals 52/27. Major septa vary in length, but only counter protoseptum reaches corallite axis. Cardinal protoseptum attains three-fourths corallite radius. Cardinal fossula deep, elliptic, bordered by successively shortening major septa of cardinal quadrants. Km septa elongated to 4 and 6 mm, remaining minor septa short. Dissepimentarium in the widest part, in cardinal quadrant, attains 5 mm. Dissepiments herringbone and pseudo-herringbone. External wall 0.1 mm thick.

In calice bottom (Fig. $68A_{11,12}$) n/d indices are 54/29 and 54/30, respectively; remaining morphological features as in the description of the taxon. At ca. mid-depth of calice, n/d index equals 59/35 (Fig. $68A_{13}$). Major septa attain ca. one-half corallite radius. In cardinal quadrants they gradually shorten towards cardinal protoseptum, which attains one-fourth corallite radius in length. Counter protoseptum does not differ in length from remaining major septa; it is half their thickness, like Km septa, which are equal in length to major septa. Remaining minor septa ca. 2 mm long, which is one-half width of dissepimentarium. Dissepiments straight, herringbone and pseudo-herringbone. External wall ca. 0.1 mm thick.

Remarks: The occurrence in one specimen of such features as long Km septa, an elongated counter protoseptum, a cardinal protoseptum shortening only in the calice, a dissepimentarium of variable width, as well as short minor septa and major septa of variable length, are indicative not only of a new species or genus, but also of a new family. However, with only one specimen in the collection, despite its exceptionally good state of preservation, there are not enough grounds to create even a new species.

An extra complication in classifying the specimen in question is the presence of elongated Km septa. The known families embracing species of solitary corals with triads mostly include small, undissepimented forms (e.g. Cyathaxoniidae, Metriophyllidae, Laccophyllidae, Stereolasmatidae, Hapsiphyllidae, Pentaphyllidae). Ptenophyllidae is the only family with genera possessing larger corallites which, apart from a triad, also have dissepiments, e.g. the Lower Devonian *Dohmophyllum* or the Middle and Upper Devonian *Grypophyllum*. However, in the first case long major septa are twisted at the corallite axis, protosepta do not differ from the remaining major septa, and the dissepimentarium occupies nearly three-fourths of corallite radius; in the other case, major septa are thin, reaching corallite axis, the length of minor septa attains ca. one-third of corallite radius, protosepta do not differ from the remaining major septa, and a wide dissepimentarium occupies ca. one-half of corallite radius.

Out of the known families, none has the mosaic of features observed in the Kruseryggen specimen. In some of its characteristics (an elongated cardinal protoseptum in early growth stages, a pinnate arrangement of septa with respect to the fossula in cardinal quadrants, a radial arrangement of septa of counter quadrants, an elongated counter protoseptum) and in its stratigraphic range, the specimen is similar to the family Hapsiphyllidae from the Devonian to Permian. However, the genera in this family are mostly small, undissepimented forms.

It is possible that the elongation of Km septa in the specimen considered is an incidental or pathological change. If this feature is ignored, the specimen is closely similar to specimens UAMIG.Tc-C.Krg. III/16 and 17, illustrated in Figs 26 and 29A and identified as *Pseudotimania borealis* sp. nov., which differ from the specimen in question only in having a narrower dissepimentarium, apart from no elongated Km septa.

Thus, the determination of the systematic status of the specimen described above calls for an examination of a more abundant material. Till then, specimen UAMIG.Tc-C.Krg. III/15 is left as a genus and species indet. for which no higher-order taxonomic units could be established.

Occurrence: Spitsbergen: Kruseryggen (Treskelodden Formation) – Lower Sakmarian.

Suborder: Lithostrotionina Spasskiy and Kachanov, 1971
Family: Durhaminidae Minato and Kato, 1965
Genus: *Pararachnastraea* Stevens and Rycerski, 1989

Type species: *Pararachnastraea lewisi* Stevens and Rycerski, 1989.

Diagnosis: See Fedorowski et al. (2007), p. 65.

Pararachnastraea gracilis (Dobrolyubova, 1941)
Fig. 69

1941. *Wentzelella gracilis* Dobrolyubova; Soshkina et al.: p. 192, pl. 48, figs 1, 2, pl. 49, fig. 1.
2007. *Pararachnastraea gracilis* (Dobrolyubova, 1941); Fedorowski et al.: p. 66.

Diagnosis: See Fedorowski et al. (2007), p. 66.

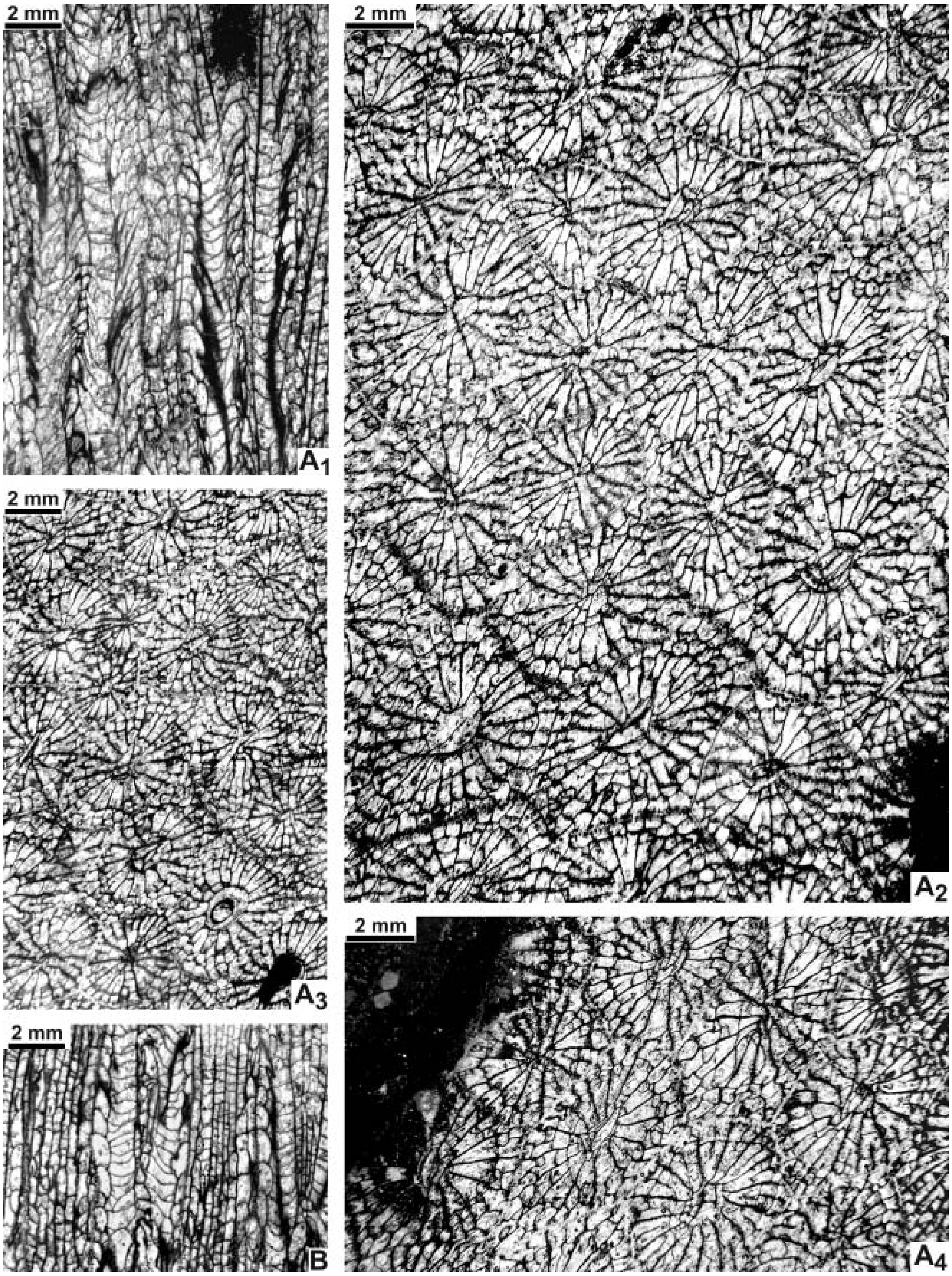


Fig. 69. A, B. *Pararachnastraea gracilis* (Dobrolyubova, 1941), upper part of the Treskelodden Formation.

A – UAMIG.Tc-C.Krg. Vx/2; A_1 – longitudinal thin section, A_{2-4} – transverse thin sections from mature growth stages.

B – UAMIG.Tc-C.Krg. Vx/3; longitudinal thin section.

Material: Two fragments of colony (UAMIG.Tc-C.Krg. Vx/2, 3). Four transverse and three longitudinal thin sections.

Description: Septal n/d index attains 15-16/3-5. Most major septa extend to outer tabellae bordering axial structure; few combine with median lamella by means of continuous or discontinuous inner ends (Fig. $69A_{2-4}$). Minor septa up to one-third to one-half length of majors, rarely interrupted by dissepiments, consistently penetrating tabularium to a depth of ca. 0.5 mm. Axial structure distinct, composed of continuous, irregular median lamella, few septal lamellae and many "linked axial tabellae" (*sensu* Fedorowski 2007). Dissepimentarium up to one-third corallite radius in width; composed of 2-3 rows of interseptal dissepiments, without lonsdaleoid ones. Tabularium bi-zonal (Fig. $69A_1$, B)."Linked axial tabellae" continuous; peripheral tabellae moderately to steeply elevated towards axial structure. Intercorallite wall 0.05 to 0.10 mm thick. Local discontinuities of intercorallite wall in Kruseryggen specimens was caused by growth of re-crystallised calcite, calcite veinlets, small breaks and others.

Remarks: The Kruseryggen specimens differ from the known representatives of this species in having smaller corallite diameters at a similar number of septa; for the holotype they equal 12/4 – 18/7-8. Their longer minor septa penetrate into the tabularium zone; in the holotype minor septa are restricted to the dissepimentarium.

Similar corallite diameters and minor septa penetrating into the tabularium can be observed in *P. amsburyi* known from northern Mexico. However, the specimens from Kruseryggen differ in having no lonsdaleoid dissepiments, a narrower dissepimentarium, and longer series of "linked axial tabellae". Besides, the number of major septa at similar corallite diameters is greater in the Kruseryggen specimens than in *P. amsburyi*, usually at 15/3-4 (*vs*. 11/3.0).

Occurrence: South Urals – Asselian-Lowermost Sakmarian (Lower Tastubian); Canadian Arctic: Devon Island – Middle Sakmarian (Upper Tastubian or Lower Sterlitamakian), Ellesmere Island – Upper Asselian; Spitsbergen: Kruseryggen – Lower Sakmarian.

Family: Kleopatrinidae Fedorowski et al., 2007

Type genus: *Kleopatrina* McCutcheon and Wilson, 1963.

Diagnosis: See Fedorowski et al. (2007), p. 79.

Genus: *Fomichevella* Fedorowski, 1975

Type species: *Campophyllum hoeli* Holtedahl, 1913.

Diagnosis: See Fedorowski et al. (2007), p. 79.

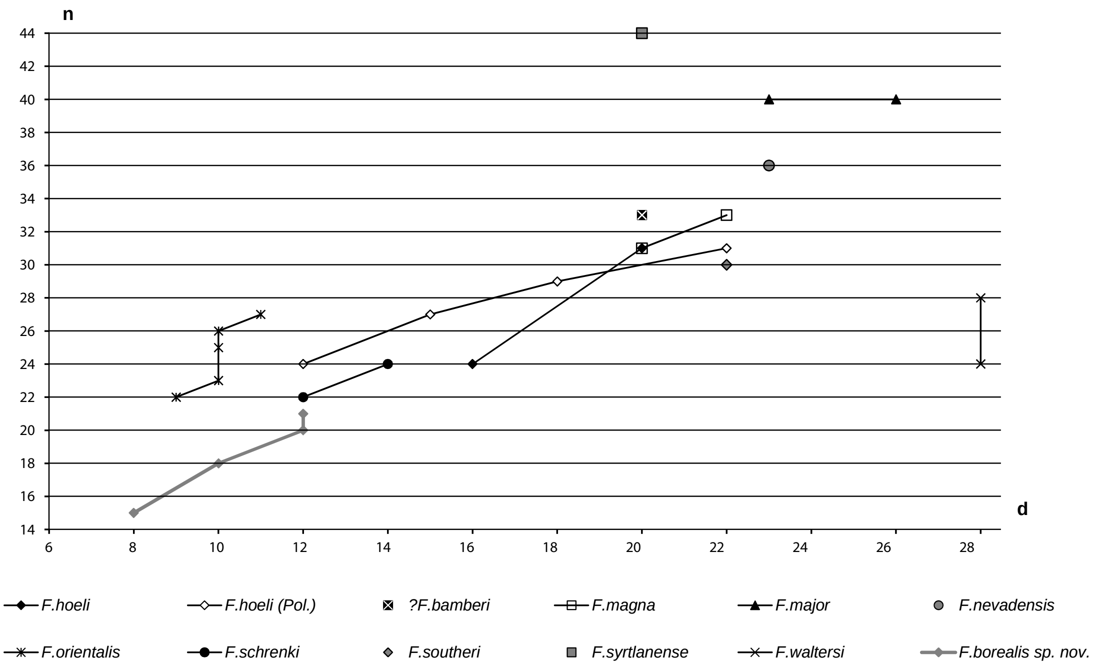


Fig. 70. Plot of the number of major septa (n) *vs*. diameters (d) of *Fomichevella* species. Symbols joined by lines represent values taken from individual specimens.

Fomichevella hoeli (Holtedahl, 1913)
Fig. 71

2007. *Fomichevella hoeli* (Holtedahl, 1913); Fedorowski et al.: p. 84 (cum synon.).

Diagnosis: See Fedorowski et al. (2007), p. 85.

Material: Small fragments of four dolomitised colonies (UAMIG.Tc-C.Pol. II/2, 3, 4, 5). 14 peels and five transverse thin sections as well as three peels and four longitudinal thin sections.

Description: Corallites with circular transverse sections. Septal indices in adult growth stages are 29-31/18-22 (Fig. 70). Major septa attain one-third to two-thirds corallite radius (Fig. 71A_{1-3}, $B_{1,2}$, C, $D_{1,2}$, $E_{1,2}$). Cardinal protoseptum distinctly shorter than remaining major septa. Cardinal fossula open, equal in length to adjacent major septa (Fig. 71A_1, D_1, E_1). Minor septa of varying length, but they do not cross dissepimentarium zone, which occupies ca. one-fourth corallite radius (Fig. 71A_{1-3}, $E_{1,2}$). Interseptal dissepiments mostly herringbone and pseudo-herringbone. Tabularium wide, tabulae usually flat, less commonly slightly convex or concave, usually complete, numbering 12/10 mm; in part of outer tabularium, additional vesicular tabellae (Fig. 71$D_{2,3}$, E_3).

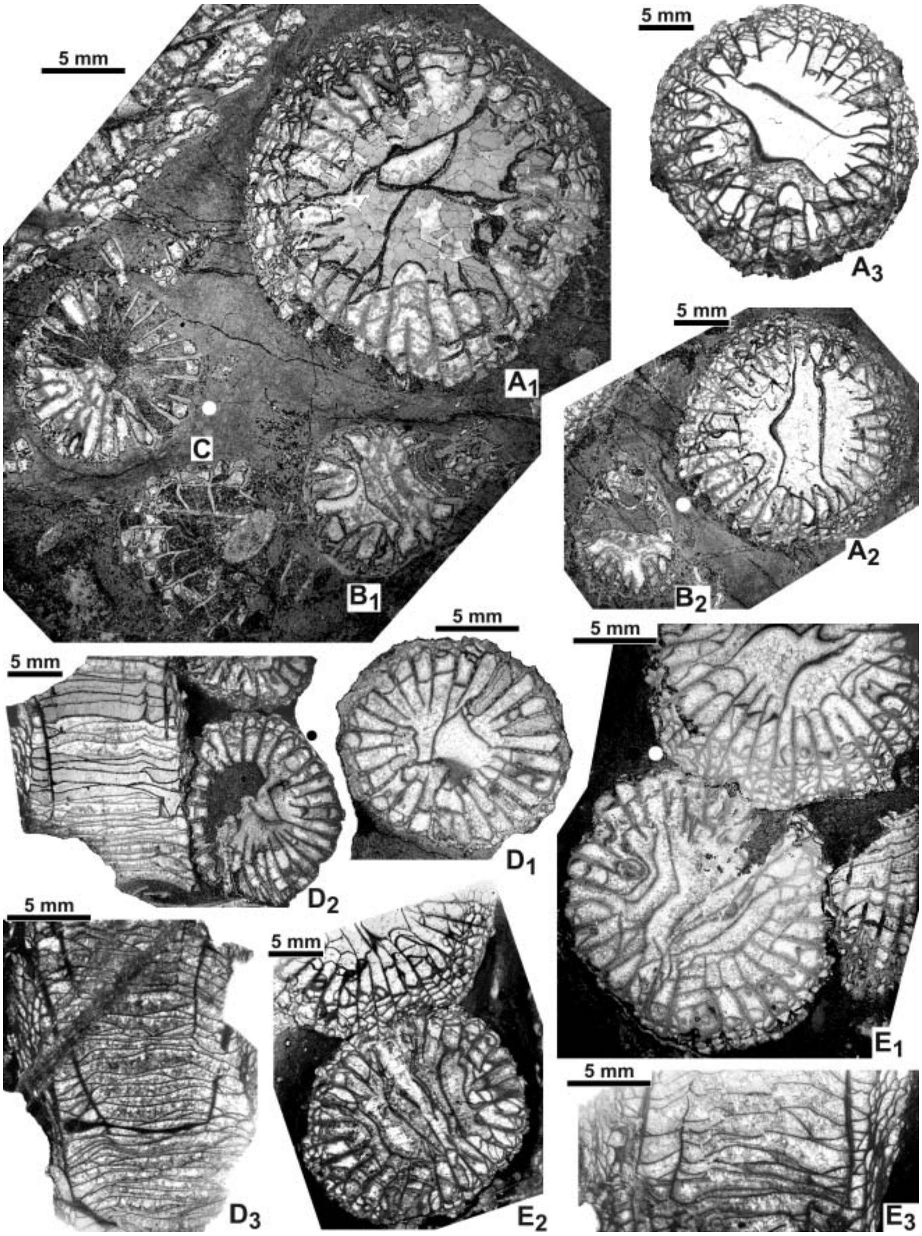


Fig. 71. A-E. *Fomichevella hoeli* (Holtedahl, 1913), lower part of the Treskelodden Formation.

A-C – UAMIG.Tc-C.Pol. II/3; $A_{1\text{-}3}$ – transverse acetate peels from mature growth stage, $B_{1,2}$ – oblique transverse acetate peels from immature growth stage, C – transverse acetate peels from mature growth stage.

D – UAMIG.Tc-C.Pol. II/2; D_1 – transverse acetate peel from mature growth stage, D_2 – transverse mature and longitudinal acetate peel, D_3 – longitudinal thin section.

E – UAMIG.Tc-C.Pol. II/5; $E_{1,2}$ – transverse thin sections from mature growth stages, E_3 – longitudinal thin section.

Remarks: The specimens under study have the following features in common with *F. hoeli* known from literature: similar n/d indices, the length of major septa, a narrow dissepimentarium, a distinct cardinal fossula with a shortened cardinal protoseptum, and usually complete tabulae. There are slight differences in the structure of the dissepimentarium and the length of minor septa: the specimens in question have no lonsdaleoid dissepiments (locally occurring in other corallites of this species), and their minor septa rarely cross the entire dissepimentarium. It was also observed that in zones with very short minor septa one could find herringbone dissepiments. It seems, however, that those features fall within the range of intraspecific variability.

Occurrence: Russia: Upper Carboniferous (recently considered by Russian geologists to be rather Lower Permian); Canadian Arctic: Ellesmere Island – Asselian to Middle Sakmarian (Upper Tastubian or Lower Sterlitamakian); Svalbard: Bjørnøya – Gzhelian, Skansen – Gzhelian-?Sakmarian, Polakkfjellet – Gzhelian.

Fomichevella borealis sp. nov.
Fig. 72

Holotype: UAMIG.Tc-C.Pol BVII/2 (Fig. 72A). Two peels and one transverse thin section as well as two longitudinal and oblique thin sections.

Type locality: Polakkfjellet (77°13.498′ N, 16°01.933′ E, 434 m above sea-level), central Spitsbergen (Fig. 2D).

Type horizon: Treskelodden Formation, Gzhelian.

Derivation of name: *borealis* – named for its occurrence in the far north.

Diagnosis: *Fomichevella* with n/d ratio from 15/8 to 21/12; major septa slightly dilated in tabularium, up to three-fourths corallite radius; cardinal protoseptum shortened in open, tabular fossula; minor septa enter tabularium; dissepimentarium occupies ca. one-fourth corallite radius; dissepiments regular and pseudo-herringbone; tabulae incomplete, vesicular.

Material: Paratypes – two fragments of colony (UAMIG.Tc-C.Pol. BVII/3, 10). Three peels and three transverse thin sections as well as three longitudinal thin sections.

Description: Septal indices range from 15-18/8-10 to 20-21/12 (Fig. 70). Major septa, except cardinal protoseptum, of equal length in all quadrants, more than three-fourths corallite radius (Fig. 72A_1, B_1, $C_{1,2}$). Cardinal protoseptum shortened to ca. one-half corallite radius, in open fossula (Fig. 72A_1, B_1; white dots). Minor septa straight, attaining ca. one-fourth length of major septa;

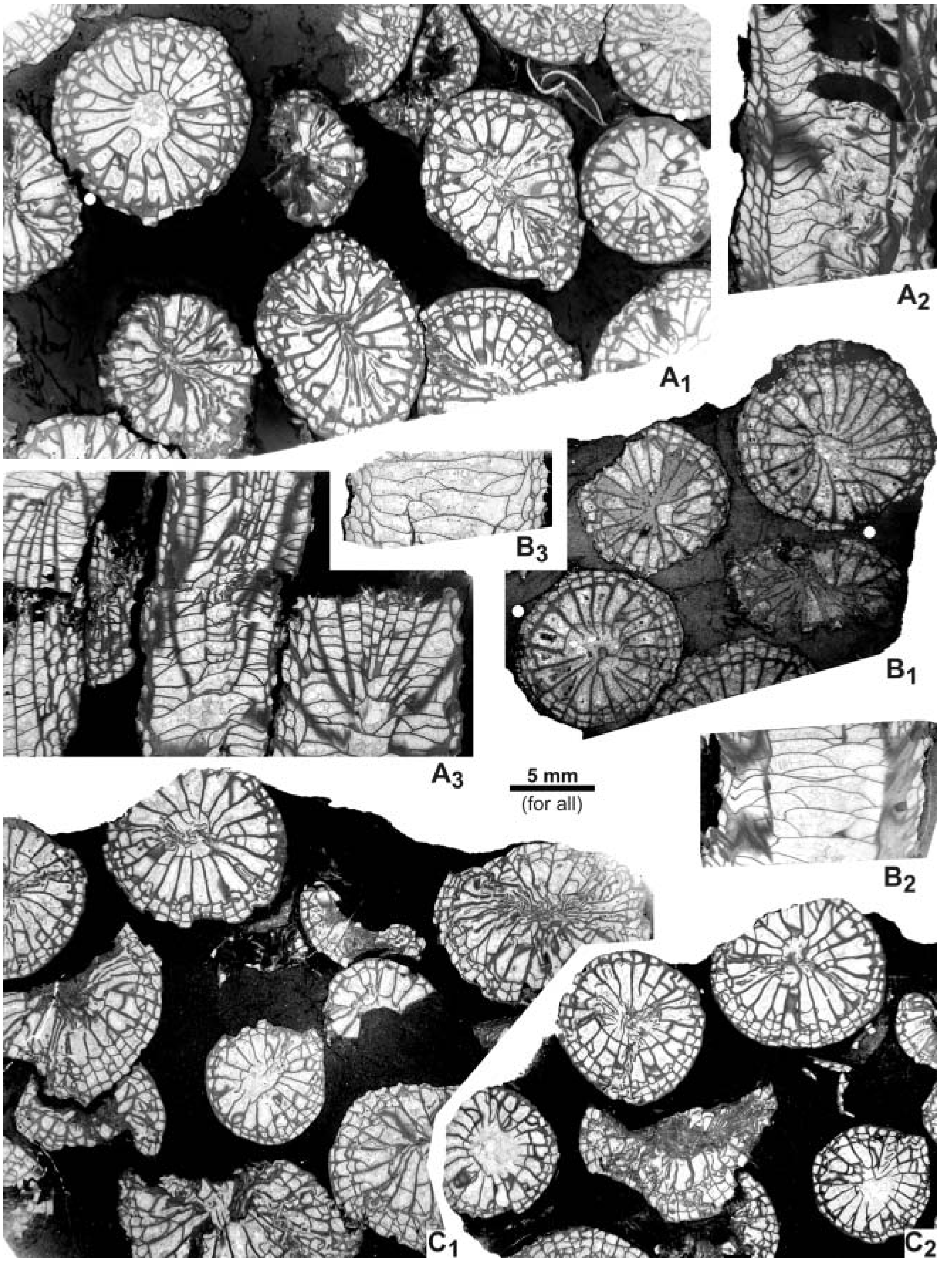


Fig. 72. A-C. *Fomichevella borealis* sp. nov., lower part of the Treskelodden Formation.

A – UAMIG.Tc-C.Pol. BVII/2; A_1 – transverse thin section from mature growth stages, $A_{2,3}$ – longitudinal and oblique longitudinal thin sections.

B – UAMIG.Tc-C.Pol. BVII/3; B_1 – transverse thin section from mature growth stages, $B_{2,3}$ – longitudinal thin sections; cardinal quadrants on the left of illustration.

C – UAMIG.Tc-C.Pol. BVII/10; $C_{1,2}$ – transverse thin sections from mature growth stages.

penetrating ca. 1 mm into tabularium zone. Dissepimentarium built of 2-3 rows of straight and pseudo-herringbone interseptal dissepiments, occupying ca. one-fourth corallite radius. Tabulae incomplete, vesicular, in corallite axis numbering 5-7/5 mm; on the side of cardinal protoseptum, at the border with dissepimentarium, concave (Fig. 72 $A_{2, 3}$; cardinal quadrants on left side of illustrations).

Remarks: Most elements of the morphological structure of *Fomichevella borealis* sp. nov. can be found in the known species of this genus (Table 4). In their septal indices at maturity the examined specimens are similar to *F. schrenki* (Fig. 70). A distinct cardinal fossula, a shortened cardinal protoseptum and long major septa make the newly erected species similar to *F. southeri*, while a shortened cardinal protoseptum and long minor septa can also be found in *F. magna*. However, *Fomichevella borealis* sp. nov. does not fully resemble any of the compared species in the rest of its morphological features. What differentiate it from *F. schrenki* are a distinct cardinal fossula with a shortened cardinal protoseptum, longer major and minor septa, and a wider dissepimentarium. From *F. southeri*, it differs in smaller sizes of corallites with a smaller number of major septa, longer minor septa, and an absence of herringbone dissepiments. Besides, *Fomichevella borealis* sp. nov. differs from all species of this genus in having incomplete, widely spaced, vesicular tabellae. In this it shows some similarity to *F. orientalis*, known from the Ambigua limestones of Bjørnøya and dated to Gzhelian (Fedorowski 1997). However, unlike in *Fomichevella borealis* sp. nov., in the Bjørnøya specimens one can find, apart from tabellae, vesicular at the corallite axis and flat at the border with the dissepimentarium, also convex, almost semicircular tabulae (Fedorowski 1975). Besides, *F. orientalis* also differs in having short major septa attaining ca. one-half corallite radius, a greater number of major septa at similar corallite diameters, short minor septa not reaching the tabularium, as well as straight dissepiments between major and minor septa and herringbone dissepiments above minor septa.

The features observed in the Polakkfjellet specimens described above do not occur in such a combination in any of the known *Fomichevella* species. And while the morphological structure of their early growth stages is not known, that of late stages is so unique that I decided to create a new species.

Occurrence: Spitsbergen: Polakkfjellet – Gzhelian.

Genus: *Heintzella* Fedorowski, 1967

Type species: *Heintzella multiseptata* Fedorowski, 1967.

Diagnosis: See Fedorowski et al. (2007), p. 89.

Table 4. Morphological differentiation of species of *Fomichevella* Fedorowski, 1975.

disting. characters \ species		*F. hoeli*	*F. magna*	*F. orientalis*	*F. schrenki*	*F. southeri*	*F. borealis* sp. nov.
n/d		24-31/16-20	31-33/20-22	22-27/8.7-11	22-24/12-14	up to 30/22	15-21/8-12
cardinal protoseptum		slightly shortened	shortened	differ length	slightly shortened	shortened	shortened
cardinal fossula		indistinct	indistinct	indistinct	indistinct or absent	distinct	distinct
septa	major	thin, 2/3 corallite radius	thin, 2/3 corallite radius	1/2 corallite radius	equally thin, 1/2 corallite radius	dilated, 2/3-3/4 corallite radius	dilated, 3/4 corallite radius
	minor	almost cross dissepimentarium	enter tabularium	very short	very short	very short	enter tabularium
dissepimentarium	width	up to 1/4 corallite radius	up to 1/4 corallite radius	up to 1/4 corallite radius	1/10-1/7 corallite radius	1/5-1/4 corallite radius	up to 1/4 corallite radius
	type	regular, lonsdaleoid small, rare	regular	rectangular, herringbone	regular	herringbone	regular and pseudo-herringbone
tabularium		complete, depressed adaxially	mostly complete, depressed	mostly incomplete, vesicular in corallite axis, flat by the dissepimentarium	mostly complete, subhorizontal to concave adaxially	mostly complete, closely spaced, axially depressed	incomplete, dissepiments-like

Heintzella borealis Fedorowski et al., 2007
Fig. 73

part 1965. *Tschussovskenia kiaeri* (Holtedahl); Fedorowski: p. 63, pl. 4, fig. 5, pl. 5, fig. 1, text-figs 17a-c [non pl. 4, fig. 4, text-figs 17d-e (= *Tschussovskenia dilata*).

2007. *Heintzella borealis* sp. nov.; Fedorowski et al.: p. 93, pl. 6, figs 6-7, pl. 7, figs 1-10.

Diagnosis: See Fedorowski et al. (2007), p. 92.

Material: Thirteen fragments of dolomitised or silicified colonies (UAMIG. Tc-C.Lin. I/1/35, 49, 72, 74, 76, 84, 114, 115, 122, 123, 131; II/1/59; III/3). 29 transverse and two longitudinal thin sections.

Description: Corallites circular in transverse sections. Septal n/d indices reach 23-26/11-11.5 (Fig. 74). Major septa attain one-half to two-thirds corallite radius (Fig. $73A_{1,2}$, B, $C_{1,2}$, $D_{1,2}$, E). Cardinal protoseptum variably shortened, situated in open fossula (Fig. $73A_2$, $C_{1,2}$, $D_{1,2}$, E); below calice its length attains one-half to three-fourths that of major septa; in calice, two-thirds. Counter protoseptum can be slightly longer than remaining major septa (Fig. $73A_2$, C_1). Minor septa thin, reaching one-third (sporadically one-half) length of major ones; most penetrate into tabularium. Dissepimentarium up to one-fifth coral-

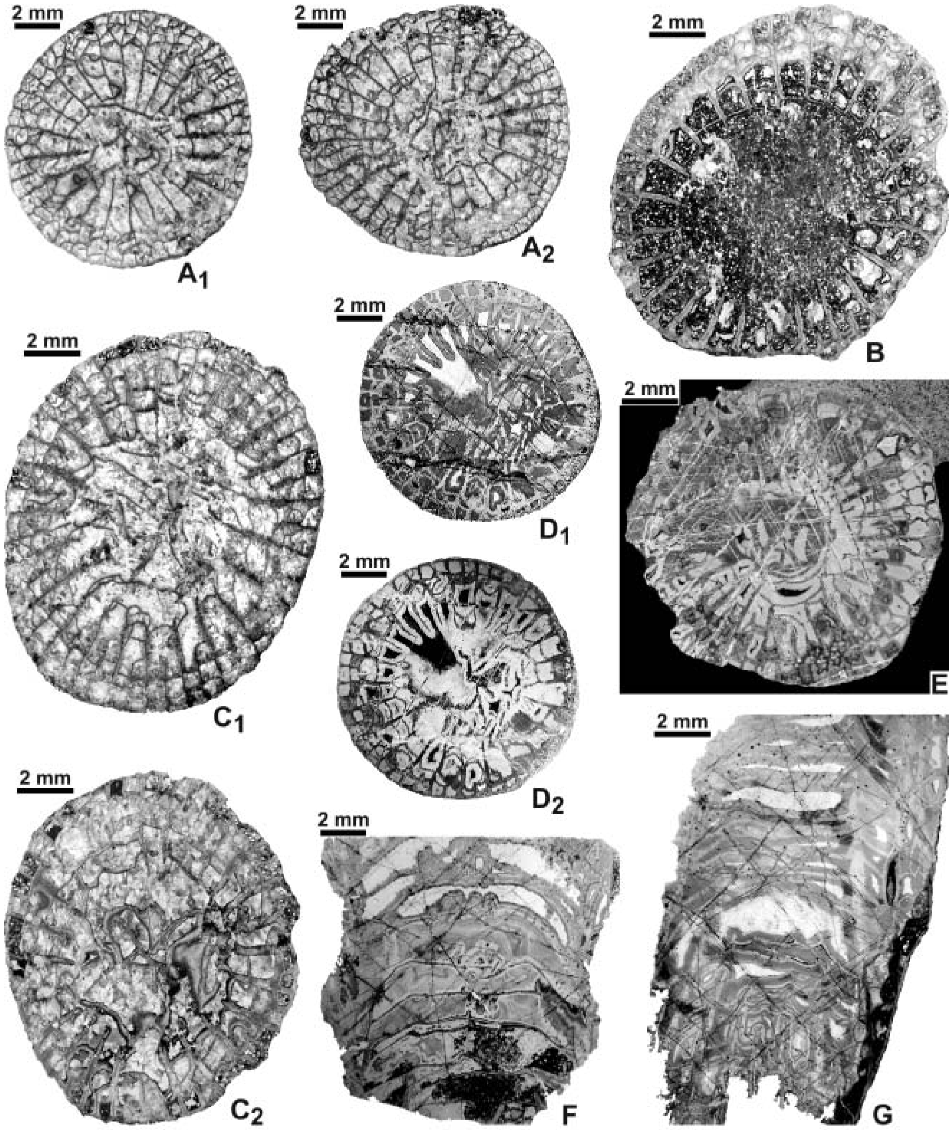


Fig. 73. A-G. *Heintzella borealis* Fedorowski et al., 2007, Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.Lin. I/1/72; $A_{1,2}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Lin. I/1/122; transverse thin section from mature growth stage.
C – UAMIG.Tc-C.Lin. I/1/123; $C_{1,2}$ – transverse thin sections from mature growth stage.
D – UAMIG.Tc-C.Lin. I/1/115; $D_{1,2}$ – transverse thin sections from mature growth stage.
E – UAMIG.Tc-C.Lin. I/1/84; transverse thin section from immature growth stage.
F – UAMIG.Tc-C.Lin. I/1/131; longitudinal thin section.
G – UAMIG.Tc-C.Lin. I/1/76; longitudinal thin section.

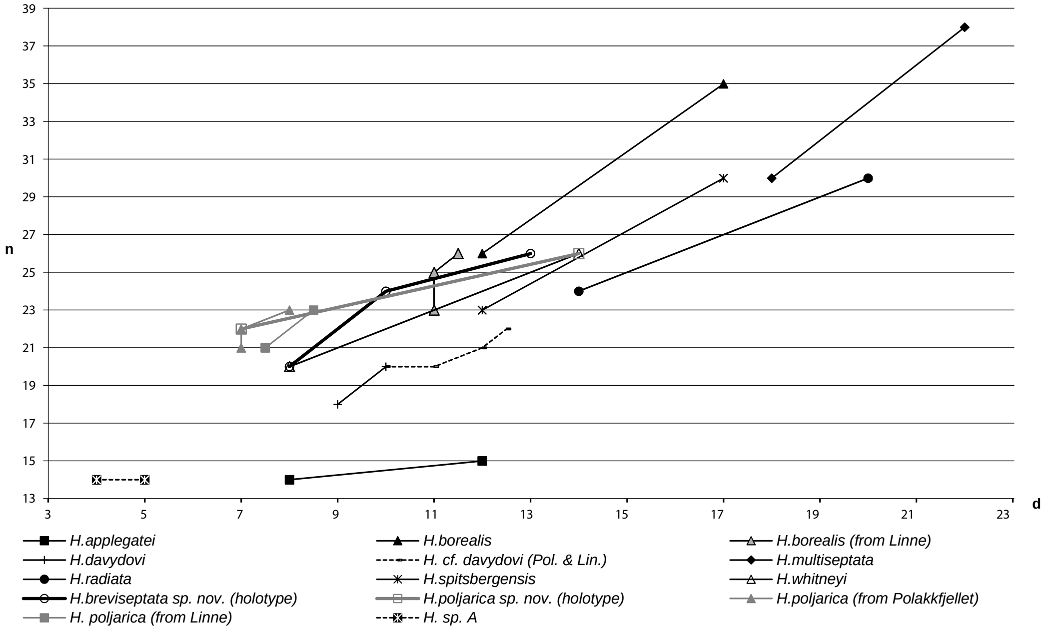


Fig. 74. Plot of the number of major septa (n) *vs*. diameters (d) of *Heintzella* species. Symbols joined by lines represent values taken from individual specimens.

lite radius in width; consists of irregular interseptal dissepiments, with inner row locally slightly thickened. Tabularium occupies ca. two-thirds corallite diameter. Tabulae trapezoid with downturned edges, numbering 8-10/10 mm (Fig. 73F, G). Axial structure irregular and discontinuous, consisting of median lamella, few septal lamellae and irregular axial tabellae. External wall 0.1 to 0.2 mm thick.

Remarks: The specimens from Linnédalen have many features in common with *Heintzella borealis* known from Hyrnefjellet (the Hornsund region, Fedorowski 1965) and Ellesmere Island (the Canadian Arctic Archipelago, Fedorowski et al. 2007). The similarity shown in poorly developed axial structure, a usually shortened cardinal protoseptum, a narrow dissepimentarium, the form of the tabularium, and minor septa locally penetrating into the tabularium.

Smaller sizes of the Linnédalen specimens (Fig. 74) and their slightly longer major septa (two-thirds *vs*. up to one-half corallite radius) are the only features differing them from those known from the literature. It seems, however, that those differences are due to the fact that the material here considered represents earlier growth stages of this species. This can be corroborated by the occurrence of long major septa, up to two-thirds corallite radius, in a few corallites of smaller diameters in the compared specimens from Hyrnefjellet and Ellesmere Island.

Occurrence: Canadian Arctic: Ellesmere Island – Middle Sakmarian, Upper Tastubian-Lower Sterlitamakian; Spitsbergen: Hyrnefjellet, Treskelen, Linnédalen – Sakmarian, probably Tastubian.

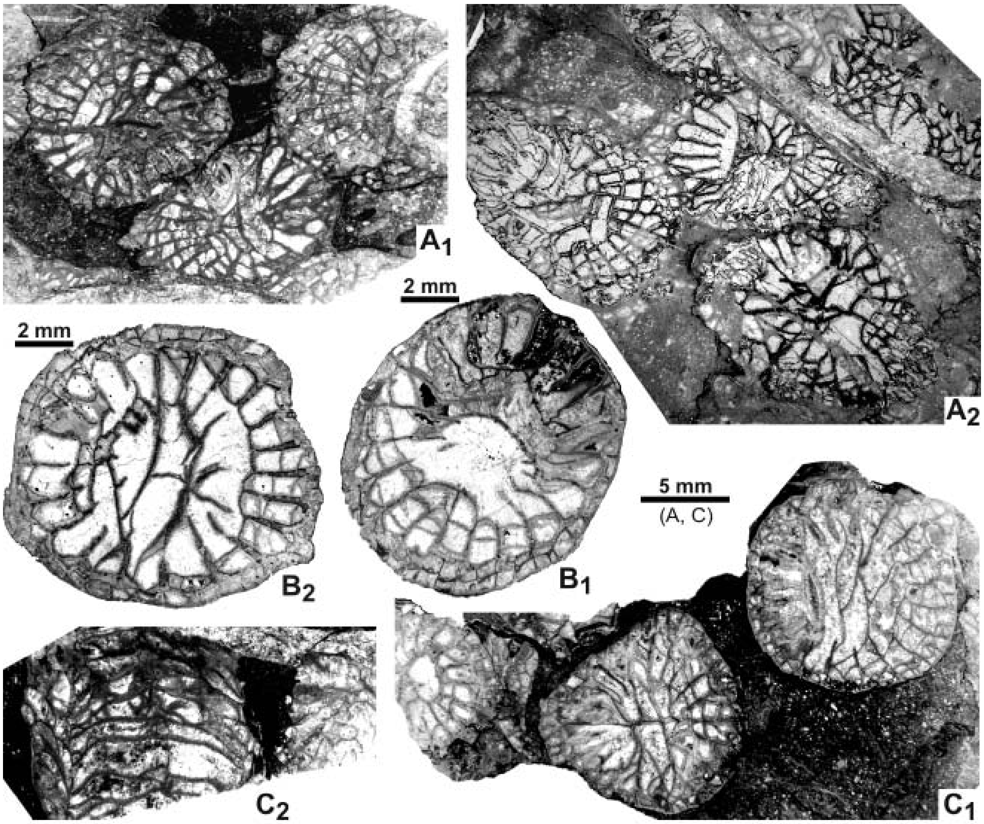


Fig. 75. A-C. *Heintzella* cf. *davydovi* Stevens, 2008.

A – UAMIG.Tc-C.Pol. BIII/1, lower part of the Treskelodden Formation; $A_{1,2}$ – transverse thin sections from mature growth stage.
B – UAMIG.Tc-C.Lin. I/1/8, Tyrrellfjellet Member of the Wordiekammen Formation; $B_{1,2}$ – transverse thin sections from mature growth stage.
C – UAMIG.Tc-C.Pol. BIII/3, lower part of the Treskelodden Formation; C_1 – transverse thin section from mature growth stage, C_2 – longitudinal thin section.

Heintzella cf. *davydovi* Stevens 2008
Fig. 75

Material: Four fragments of colony, including three heavily dolomitised (UAMIG.Tc-C.Lin. I/1/8; UAMIG.Tc-C.Pol. BIII/1-3). Five peels and six transverse thin sections and one longitudinal thin section.

Description: Major septa in all quadrants up to one-half corallite radius in length; in tabularium can be slightly thickened. Septal n/d indices of 20-22/10.0-12.5 (Fig. 74). Cardinal protoseptum slightly shortened (Fig. 75$B_{1, 2}$), or indistinguishable from other major septa (Fig. 75$A_{1, 2}$, C_1). Cardinal fossula indistinct. Counter protoseptum elongated in some sections (Fig. 75A_2), at the corallite axis can connect with a few longest major septa (Fig. 75A_2, C_1 – middle corallite), or indistinguishable from other major septa (Fig. 75B_1, C_1 – right corallite). Axial structure discontinuous, but visible in many transverse sections. Minor septa about 1 mm in length, crossing entire dissepimentarium, but not entering tabularium. Dissepimentarium of 2-3 rows, one-sixth corallite radius in width, consisting of slightly irregular interseptal dissepiments. In longitudinal section (Fig. 75C_2) dissepiments small, globose. Tabulae usually complete, flat or slightly convex in corallite axis, with downturned edges. External wall 0.15-0.20 mm thick, smooth in outline.

Remarks: The specimens described above have many features in common with the *Heintzella davydovi* known from the Asselian of northeast Nevada. The similarity shows in short major septa, very short minor septa, a variable axial structure absent from some corallites, and convex tabulae. What make them different from *H. davydovi*, except one corallite, are a greater number of septa and larger corallite diameters. Those features could be considered part of the intraspecific variability of *Heintzella davydovi*. However, since this species has not been documented in the area between Nevada and Spitsbergen, it seems that the similarity of the Spitsbergen specimens to *Heintzella davydovi* is rather due to convergence. A rather scanty and not well-preserved material from Linnédalen and Polakkfjellet does not allow creating a new species.

Occurrence: *Heintzella davydovi* – cratonal west-central USA: Nevada – Asselian; *Heintzella* cf. *davydovi* – Spitsbergen: Polakkfjellet – Gzhelian, Linnédalen – Sakmarian.

Heintzella breviseptata sp. nov.
Fig. 76B, C

Holotype: UAMIG.Tc-C.Lin. II/1/5 (Fig. 76C_{1-3}). Four transverse and two longitudinal thin sections.

Type locality: Linnédalen (N 78° 03.865′; E 13° 48.144′), central Spitsbergen (Figs 2C, 6).

Type horizon: Wordiekammen Formation, Upper Carboniferous-Lower Permian.

Derivation of name: *breviseptata* – named for its short major septa.

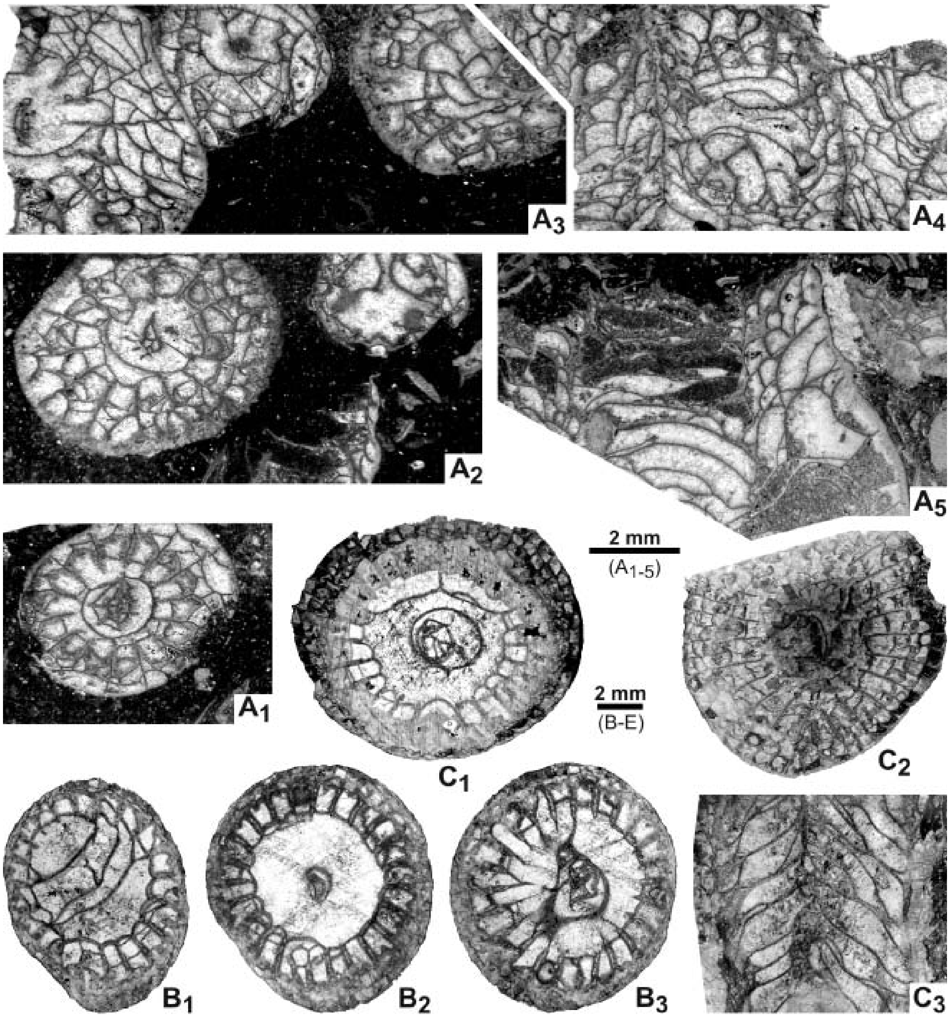


Fig. 76. A. *Heintzella* sp. A, Tyrrellfjellet Member of the Wordiekammen Formation. B, C. *Heintzella breviseptata* sp. nov.

A – UAMIG.Tc-C.Lin. III/1/8; $A_{1\text{-}3}$ – transverse thin sections from mature growth stage, A_4 – oblique section, 1e – longitudinal thin section.
B – UAMIG.Tc-C.Lin. I/1/54; $B_{1\text{-}3}$ – transverse thin sections from mature growth stage.
C – UAMIG.Tc-C.Lin. II/1/5; $C_{1,2}$ – transverse thin sections from mature growth stage, C_3 – longitudinal thin section.

Diagnosis: *Heintzella* with n/d ratios from 20/8 to 26/13; major septa commonly up to one-half corallite radius; axial structure irregular, with median lamella, few septal lamellae and axial tabellae; cardinal protoseptum shortened in open fossula; minor septa penetrate tabularium; dissepimentarium up to one-fifth corallite radius in width, dissepiments interseptal; tabulae numbering

8/10 mm, oblique to growth line, with upturned inner edges and downturned outer ones; few "linked axial tabellae".

Material: Paratype – one small fragment of colony (UAMIG.Tc-C.Lin. I/1/54; Fig. 76B_{1-3}). Four transverse thin sections.

Description: In transverse section corallites almost circular. Length of major septa attains one-third to one-half corallite radius (Fig. 76B_{1-3}, C_1), rarely longer (Fig. 76C_2). Septal index is usually 24/10. Cardinal protoseptum slightly shorter than remaining majors, in open fossula, equal in length to adjacent major septa. Minor septa of varying length, most penetrating into tabularium. Narrow dissepimentarium built of 1-3 rows of regular dissepiments. Most tabulae complete, sigmoid, with downturned edges; in corallite axis enriched with "linked axial tabellae". Axial structure of variable morphology, from simple, formed by median lamella (Fig. 76B_1, C_2) to complicated, built of median lamella, short series of "linked axial tabellae" and a few short septal lamellae (Fig. 76$B_{2,3}$, C_1).

Remarks: When compared with other *Heintzella* species, the Linnédalen specimens show some similarity to *H. whitneyi* and *H. borealis*. It includes, e.g. their septal indices, which can even be identical in all those species in some sections (Fig. 74). In the case of *H. whitneyi* they equal 20-26/8-14, and in *H. borealis*, 26-35/12-17 (*vs*. 20-26/8-13 in *Heintzella breviseptata* sp. nov.). A common feature of the new species and *H. whitneyi* is also a similarly built axial structure. However, *H. whitneyi* differs from *Heintzella breviseptata* sp. nov. in having longer major septa, attaining two-thirds corallite radius, a less distinct cardinal fossula, shorter and discontinuous minor septa, and a wider dissepimentarium (up to one-third corallite radius) with lonsdaleoid dissepiments.

In turn, in comparison with *H. borealis*, *Heintzella breviseptata* sp. nov. is generally smaller and has fewer major septa. Besides, the newly described species has sigmoid tabulae and a narrow dissepimentarium lacking lonsdaleoid dissepiments, which are features not found in *H. borealis*.

Occurrence: Spitsbergen: Linnédalen (Wordiekammen Formation) – Sakmarian.

Heintzella poljarica sp. nov.
Fig. 77

Holotype: UAMIG.Tc-C.Pol. BVII/5 (Fig. 77A1-5). Two peels and one transverse thin section and one longitudinal thin section.

Type locality: Polakkfjellet (N 77° 13.498′; E 16° 01.933′), central Spitsbergen (Fig. 2D).

Type horizon: Lower part of Treskelodden Formation, Gzhelian.

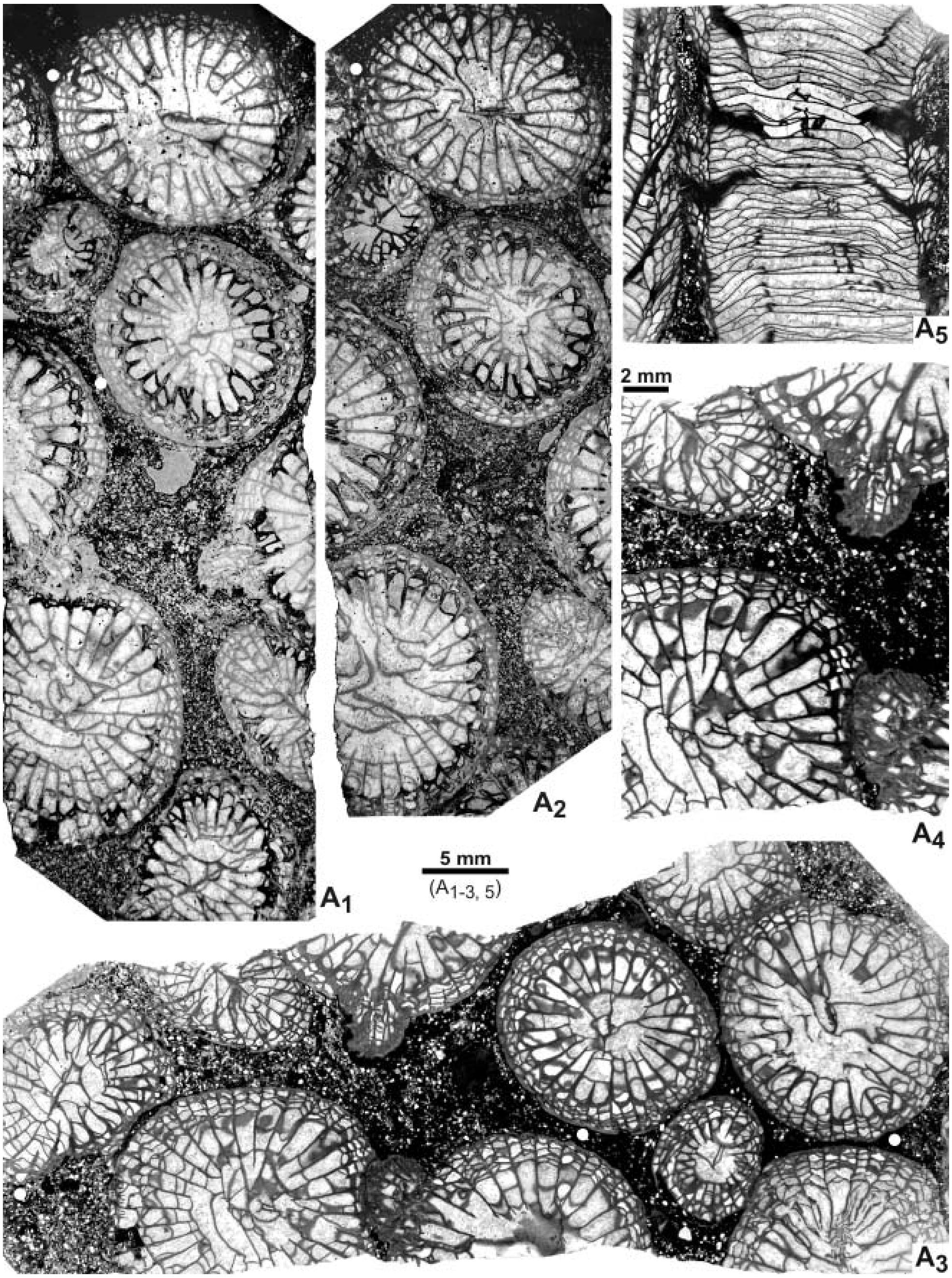


Fig. 77. A. *Heintzella poljarica* sp. nov. UAMIG.Tc-C.Pol. BVII/5, lower part of the Treskelodden Formation; $A_{1, 2}$ – transverse acetate peels from different growth stages, $A_{3, 4}$ – transverse thin sections from different growth stages, A_5 – longitudinal acetate peel.

Derivation of name: *poljaricum* – named for its occurrence in the polar region.

Diagnosis: *Heintzella* with n/d ratios from 22/7 to 26/14; major septa attain three-fourths corallite radius; cardinal protoseptum shortened in open fossula; counter protoseptum elongated; minor septa restricted to dissepimentarium zone, which is one-quarter corallite radius in width; dissepiments interseptal, regular and herringbone; tabulae mostly incomplete, subhorizontal, commonly slightly convex axially; axial structure discontinuous, comprising inner end of counter protoseptum, few septal lamellae and axial tabellae.

Material: Paratype – small fragment of colony (UAMIG.Tc-C.Pol. BVII/6). Two peels and two transverse thin sections and one peel from a longitudinal section.

Description: Corallites circular in transverse section. Septal indices in adult growth stages from 25/12 to 26/14. Major septa long, some of them reaching axial structure, remaining ones attaining one-half to three-fourths corallite radius; within dissepimentarium thin. Counter protoseptum often linked with thickened pseudocolumella (Fig. 77$A_{1,3}$). Cardinal protoseptum commonly shortened in very distinct, open cardinal fossula bordered by one pair of major septa (Fig. 77$A_{1,3}$, white dots). Minor septa thin, one-fifth to one-third major septa in length, equal in number to the majors, not piercing the interior wall. Axial structure consisting of thickened pseudocolumella lying usually on extension of counter protoseptum and often linked with it, few septal lamellae and few sections of tabulae (Fig. 77$A_{1\text{-}4}$); in some sections axial structure missing. Dissepimentarium of 3-4 rows, occupying one-fifth to one-fourth corallite radius; dissepiments small, interseptal, regular, herringbone and pseudo-herringbone. Tabularium occupies over three-fourths corallite diameter. Tabulae complete and incomplete, flat or slightly convex, closely spaced, 20 per 10 mm corallite length; peripheral edges of longer tabellae downturned; at border with dissepimentarium additional, globose tabellae can occur (Fig. 77A_5). Rudimentary axial structure occurs only in short fragments of longitudinal section.

Remarks: The fragment of a colony from Polakkfjellet described above resembles *H. radiata* in the general morphological structure of corallites. It differs from this species in having much smaller corallite diameters at a similar number of septa (Fig. 74). In *H. radiata* the septal index is usually 24/14 (*vs.* 21-23/7-8 in *Heintzella poljarica* sp. nov.). Besides, at maturity the corallite diameters of *Heintzella poljarica* sp. nov. do not exceed 14 mm (n/d = 26/14), while in *H. radiata* in this growth stage the septal index attains 30/20. This means that *Heintzella poljarica* sp. nov. is equal in size to *H. spitsbergensis* and *H. whitneyi* in adult growth stages. However, the former species has minor septa penetrating into the tabularium, which is built differently (in the *H. spitsbergensis* holotype tabellae are upturned towards the pseudocolumella and widely spaced, ca. 10/10 mm); in turn, the other species has a wide dissepimentarium with lonsdaleoid dissepiments. Besides, both *H. spitsbergensis* and *H. whitneyi* have a poorly developed cardinal fossula and an only slightly shortened cardinal protoseptum.

Occurrence: Spitsbergen: Polakkfjellet – Gzhelian.

Heintzella sp. A
Fig. 76A

Material: Five small fragments of colony (UAMIG.Tc-C.Lin. I/1/37, 102, 104; UAMIG.Tc-C.Lin. III/1/8; UAMIG.Tc-C.CrL. I/6/4). 11 transverse and four longitudinal thin sections.

Description: Very small corallites with septal indices of 14/4x5 to 14/5x6 (Fig. 74). Length of major septa attains two-thirds corallite radius (Fig. $76A_{1\text{-}3}$). Protosepta not different from remaining major septa. Minor septa very short, attaining at most one-fourth length of major septa. Dissepimentarium occupies up to one-third corallite radius; built mainly of herringbone dissepiments, less frequently of regular and lonsdaleoid ones (Fig. $76A_{1\text{-}4}$). Tabulae usually complete, numbering 6-8/3 mm (Fig. $76A_{4,5}$), in corallite axis convex; at border with dissepimentarium, additional, vesicular tabellae. Axial structure built of median lamella, few septal lamellae and few axial tabellae. External wall 0.1 to 0.25 mm thick.

Remarks: Although the corallites in question are small, the advanced features of their morphological structure (an extensive axial structure, a wide dissepimentarium) can indicate an advanced growth stage. The absence of descriptions of such fine corallites in *Heintzella* colonies in the literature suggests that we deal here with a new species. The smallest specimens found so far, with an n/d index of 14-15/8-12, were those of *H. applegatei* coming from the Lowest Permian (Asselian) of California (Wilson 1994, Fedorowski et al. 2007). However, at the same number of septa as in the specimen described above, their diameters are almost twice as large (Fig. 74).

Because the author had only two small fragments of a colony at his disposal, no new species was distinguished. Until a richer material has been found, those specimens will remain in the open nomenclature.

Occurrence: Spitsbergen: Linnédalen (Wordiekammen Formation.) – Sakmarian.

Genus: *Paraheritschioides* Sando, 1985

Type species: *Paraheritschioides grandis* Sando, 1985.

Diagnosis: See Fedorowski et al. (2007), p. 95.

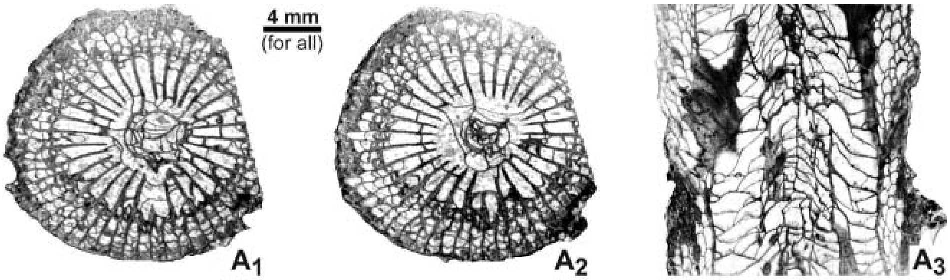


Fig. 78. A. *Paraheritschioides*? *californiense* (Meek, 1864). UAMIG.Tc-C.Krg. IVx/12, lower part of the Treskelodden Formation; $A_{1,2}$ – transverse thin sections from mature growth stage, A_3 – longitudinal thin section.

Paraheritschioides? californiense (Meek, 1864)
Fig. 78

2007. *Paraheritschioides? californiense* (Meek, 1864); Fedorowski et al.: p. 97, pl. 8, figs 1-2 (cum synon.).

Diagnosis: See Fedorowski et al. (2007), p. 97.

Material: One corallite fragment (UAMIG.Tc-C.Krg. IVx/12). Two transverse and two longitudinal thin sections.

Description: Corallite circular in transverse section. Septal n/d index reaches 31/20. Major septa attain up to three-fourths corallite radius; wedge-shaped in tabularium, thin in dissepimentarium. Counter protoseptum slightly longer than remaining majors and connected with axial structure (Fig. 78$A_{1,2}$). Cardinal protoseptum shortened to one-third corallite radius, in open fossula. Axial structure consisting of median lamella, few septal lamellae and irregular axial tabellae. Minor septa thin, reaching one-half major ones in length, locally penetrating into tabularium. Dissepimentarium one-fourth to one-third corallite radius in width, consisting of regular and pseudo-herringbone dissepiments, with inner row locally slightly thickened. In longitudinal section (Fig. 78A_3), dissepiments small, globose, arranged in four or five rows. Tabularium occupying about two-thirds corallite diameter; tabulae incomplete with additional tabellae "biformly reduced" when minor septa long; in axial area tabellae strongly upturned, at periphery slightly concave. External wall 0.10-0.15 mm thick.

Remarks: The single specimen from Kruseryggen is preserved in a small fragment. However, its main morphological characteristics, especially the n/d index, length of major septa, arrangement of the axial structure and the tabularium, were easily recognisable and closely similar to *Paraheritschioides? californiense*, the hypotype of which, GSC 124099, was described and illustrated by Fedorowski et al. (2007: 97, pl. 8, figs 1-2). The Kruseryggen specimen differs from the hypotype in two features, viz. a more distinct cardinal fossula and a narrower dissepimentarium. Those features, it seems, fall within the intraspecific variability of the species. Other features occurring in the remaining species of this genus are discussed in Fedorowski et al. (2007: 97); being irrelevant for the correct identification of the Kruseryggen specimen, they are not considered here.
Occurrence: Alaska: Wrangell terrane; British Columbia: Stikine terrane – Asselian or Lower Sakmarian; cratonal western Canada – Lower Sakmarian, Tastubian; California: Eastern Klamath terrane – possibly Uppermost Asselian or Lowermost Sakmarian; cratonal west-central USA: Utah – Lower Sakmarian, Tastubian; Nevada – Lower Sakmarian; Texas – Asselian or Lower Sakmarian; Spitsbergen: Kruseryggen – Lower Sakmarian, Tastubian.

Genus: *Kleopatrina* McCutcheon and Wilson, 1963

Type species: *Ptolemaia ftatateeta* McCutcheon and Wilson, 1963.
Diagnosis: See Fedorowski et al. (2007), p. 120.

Kleopatrina arcturusensis Stevens, 1967
Fig. 79

1967. *Kleopatrina (Porfirievella) arcturusensis* sp. nov.; Stevens: p. 427, pl. 54, fig. 1.
2007. *Kleopatrina arcturusensis* Stevens, 1967; Fedorowski et al.: p. 122.

Diagnosis: See Fedorowski et al. (2007), p. 122.

Material: One, locally silicified, specimen (UAMIG.Tc-C.CrL. I/7/11). Two transverse thin sections.

Description: Corallites polygonal, with maximum diameter of about 12 mm. Septal indices commonly equal to 17-18/9.0-10.0. Major septa usually attain two-thirds corallite radius in length, the longest can reach outer tabellae bordering axial structure; straight to slightly sinuous; thin in dissepimentarium, dilated in tabularium. Cardinal protoseptum slightly shortened (Fig. 79, white dot). Minor septa irregularly developed, locally interrupted, restricted to dissepimentarium, commonly represented as septal spines on lonsdaleoid dissepiments. Dissepimentarium up to one-third corallite radius in width;

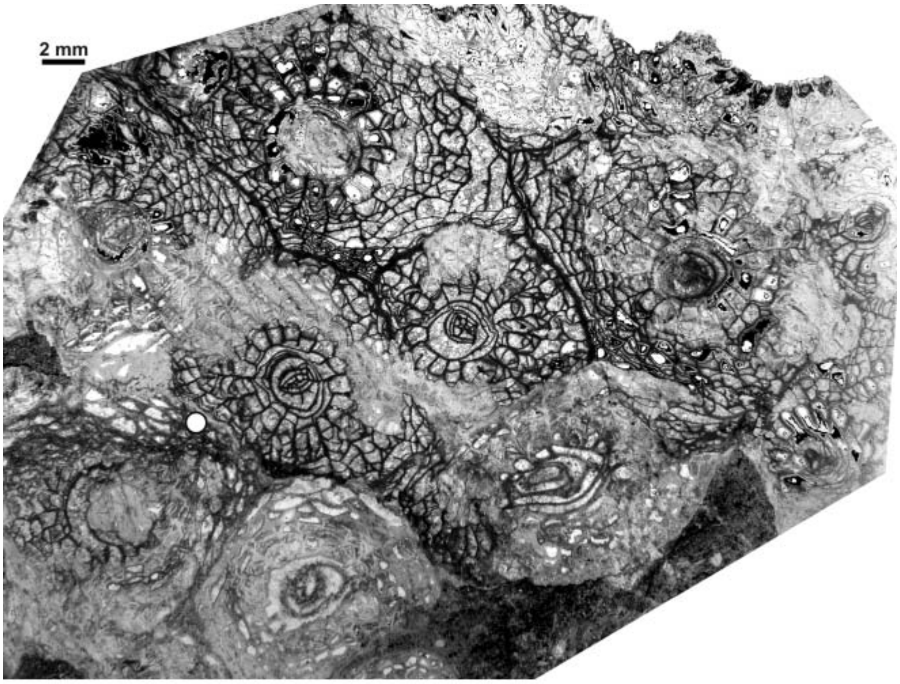


Fig. 79. *Kleopatrina arcturusensis* Stevens, 1967. UAMIG.Tc-C.CrL. I/7/11, Tyrrellfjellet Member of the Wordiekammen Formation; transverse thin section from mature growth stages.

lonsdaleoid dissepiments variably developed, crossing a maximum of four major septa. Axial structure having straight, thickened median lamella, radiating septal lamellae commonly represented by spines on axial tabellae; width of axial structure, one-fifth to one-six corallite diameter.

Remarks: The Spitsbergen specimen is distinguished from the *K. arcturusensis* from Nevada by its slightly shorter major and minor septa as well as a narrower dissepimentarium with fewer lonsdaleoid dissepiments. The remaining morphological features, including the septal index and the arrangement of the axial structure, are closely similar to those observed in the Nevada specimens. Thus, the differences were considered to be part of intraspecific variability and the Spitsbergen specimen was classified as *K. arcturusensis*.

Occurrence: Cratonal west-central USA: Nevada – Lower Artinskian; Spitsbergen: Linnédalen – Sakmarian.

Kleopatrina ftatateeta (McCutcheon and Wilson, 1961)

Fig. 81

2007. *Kleopatrina ftatateeta* (McCutcheon and Wilson, 1961); Fedorowski et al.: p. 122 (cum synon.).

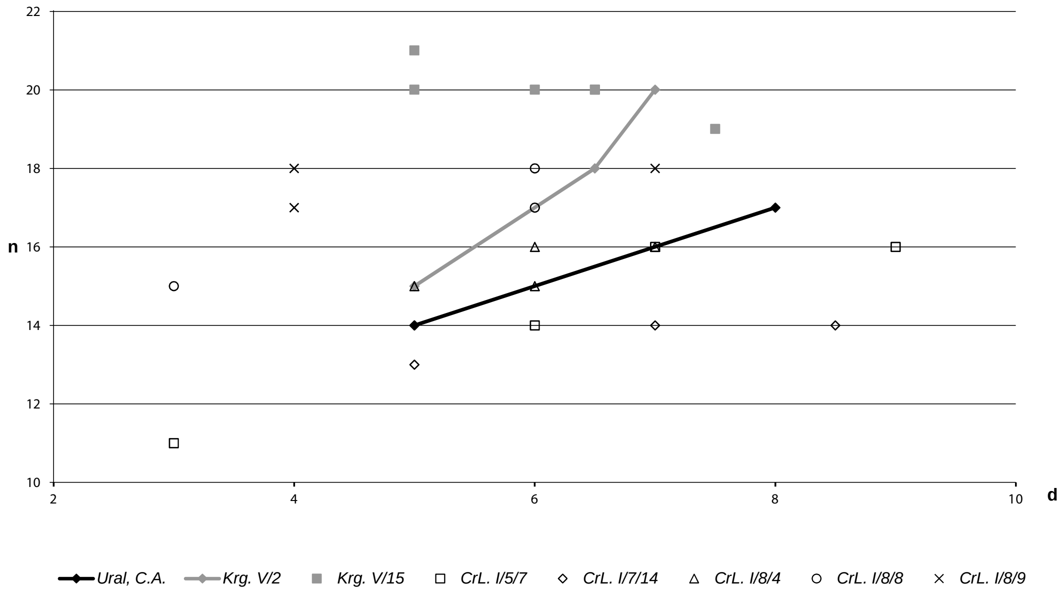


Fig. 80. Plot of the number of major septa (n) *vs*. diameters (d) of *Kleopatrina ftatateeta*. Symbols joined by lines represent values taken from individual specimens.

Diagnosis: See Fedorowski et al. (2007), p. 122.

Material: 13 fragments of cerioid colony (UAMIG.Tc-C.Krg. Vy/2; Krg. Vz/15; Krg. Vv/1; UAMIG.Tc-C.CrL. I/6/5; UAMIG.Tc-C.CrL. I/7/14, 15, 17; UAMIG. Tc-C.CrL. I/8/2, 4, 5, 8, 9, 10). 28 transverse and seven longitudinal thin sections.

Description: Septal indices from 11-15/3 to 21/5 and 16/9 (Fig. 80). Major septa reaching of two-thirds to three-fourths corallite radius in length (Fig. 81$A_{1,2}$, B, C_1, D); the longest joining outer axial tabellae. Protosepta, or counter protoseptum alone, can unite with median lamella (Fig. 81$A_{1,2}$, C_1). Minor septa entering outermost tabularium. Axial structure usually present in all transverse sections of corallites; formed by median lamella, inner margins of several major septa and few axial tabellae. Dissepimentarium commonly one-fourth to one-third corallite radius in width, occasionally exceeding one-half corallite radius; dissepiments mainly interseptal, comprising up to three rows of usually small, distinctly globose dissepiments, declined adaxially (Fig. 81A_3, C_2). Lonsdaleoid dissepiments rare (Fig. 81B, C_1, D). Tabularium broad, tabulae commonly incomplete, moderately to steeply elevated adaxially, locally concave or slightly convex, numbering 16-18 per 10 mm corallite length (Fig. 81A_3, C_2).

Remarks: The specimens described above display a wide range of septal indices (Fig. 80). Worth noting is a slightly greater number of septa in the

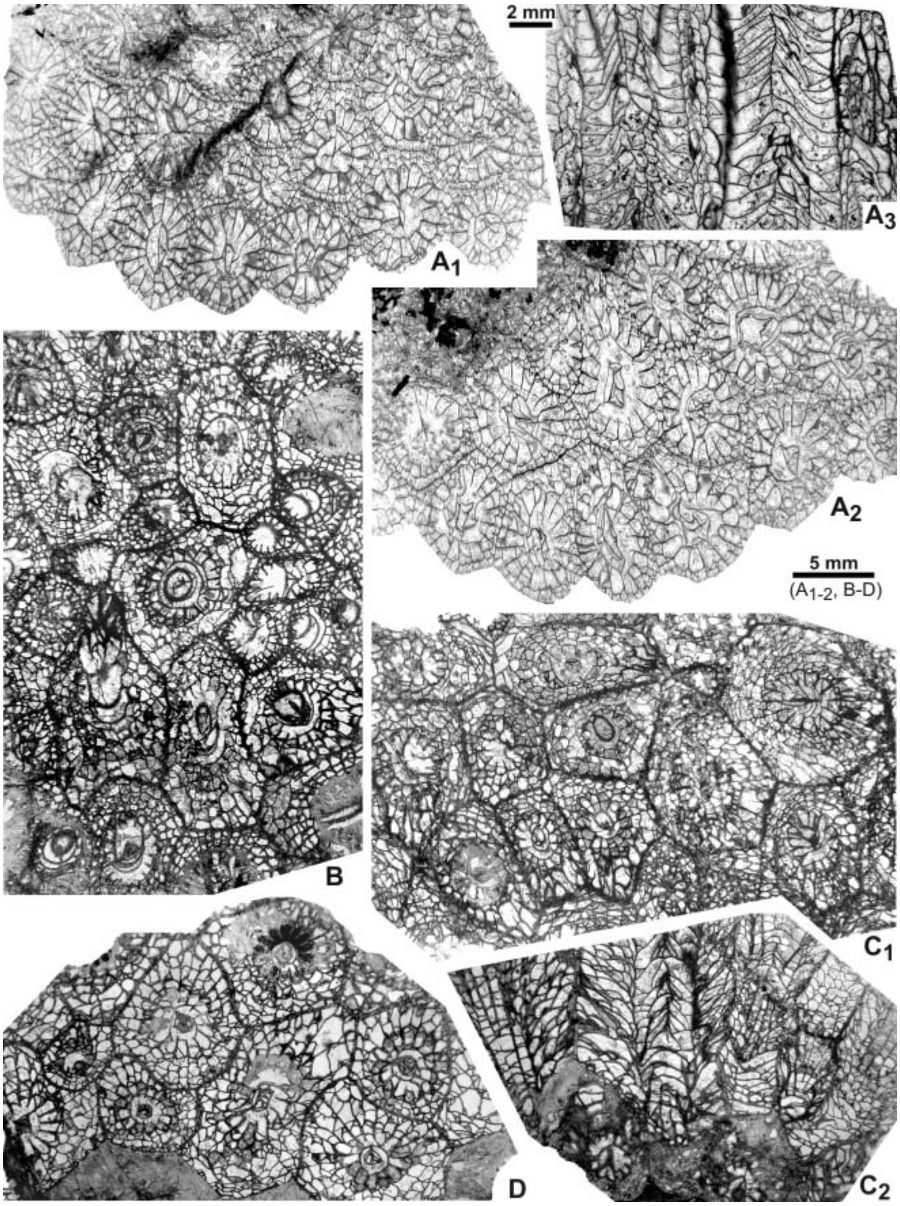


Fig. 81. A-D. *Kleopatrina ftatateeta* (McCutcheon and Wilson, 1961).

A – UAMIG.Tc-C.Krg. Vy/2, upper part of the Treskelodden Formation; $A_{1,2}$ – transverse thin sections from mature growth stages, A_3 – longitudinal thin section.

B – UAMIG.Tc-C.CrL. I/8/8, Tyrrellfjellet Member of the Wordiekammen Formation; transverse thin section from different growth stages.

C – UAMIG.Tc-C.CrL. I/7/14, Tyrrellfjellet Member of the Wordiekammen Formation; C_1 – transverse thin section from mature growth stages, C_2 – oblique longitudinal thin section.

D – UAMIG.Tc-C.CrL. I/7/15, Tyrrellfjellet Member of the Wordiekammen Formation; transverse thin section from mature growth stages.

specimens from Kruseryggen than in those from Linnédalen as well as those known from the Urals and Arctic Canada. It was also observed that the slightly shortened cardinal protoseptum in the *K. ftatateeta* known from the literature, in the Kruseryggen specimens could be of variable length, and in some sections could join an elongated counter protoseptum at the corallite axis (Fig. 81A_1, left). Also the dissepimentarium of the Kruseryggen specimens can depart slightly from the one in the typical *K. ftatateeta*. Both its width and the arrangement of dissepiments can be variable. Two or three rows of vesicular dissepiments with very rarely occurring lonsdaleoid dissepiments are present at a dissepimentarium width of one-fourth corallite radius (Fig. 81A_{1-3}). In typical representatives of this species at similar growth stages, the dissepimentarium occupies ca. one-third corallite radius, and lonsdaleoid dissepiments are much more numerous. Thus, the specimens from Linnédalen that possess those features (Fig. 81B, $C_{1, 2}$, D) seem to be closer to the typical *K. ftatateeta* than those from Kruseryggen. It is possible that the variously developed cardinal protoseptum and dissepimentarium express the ecological variability of this species.

Occurrence: South Urals – probably Asselian-Sakmarian; Canadian Arctic: Ellesmere Island – Sakmarian, Upper Tastubian-Lower Sterlitamakian; cratonal west-central USA: Nevada – Lower Sakmarian; Spitsbergen: Kruseryggen, Linnédalen – Sakmarian.

Kleopatrina grinnellensis Fedorowski et al., 2007
Fig. 82

?1936a. *Lithostrotionella* sp.; Dobrolyubova: p. 29, pl. 13, figs 36-37.
1960. *Lithostrotion kunthi* (Stuckenberg); Harker: p. 46, pl. 13, figs 5-6.
2007. *Kleopatrina grinnellensis* sp. nov.; Fedorowski et al.: pp.123-124, pl. 13, figs 1-7.

Diagnosis: See Fedorowski et al. (2007), p. 124.

Material: One, locally silicified, fragment of colony (UAMIG.Tc-C.CrL. I/6/18). Four transverse thin sections.

Description: Septal indices of 12-14/3.0-6.0. Average length of major septa is two-thirds to three-fourths corallite radius, the longest joining axial structure. In dissepimentarium major septa slightly thinner than in tabularium, in a few places interrupted by lonsdaleoid dissepiments (Fig. 82). Protosepta commonly united with median lamella. Minor septa one-half to four-fifths length of majors, consistently penetrating into tabularium. Axial structure of variable morphology; in immature growth stages formed by median lamella united with protosepta, axial tabellae and few septal lamellae; at maturity consisting of median lamella irregularly developed, locally well expressed, several

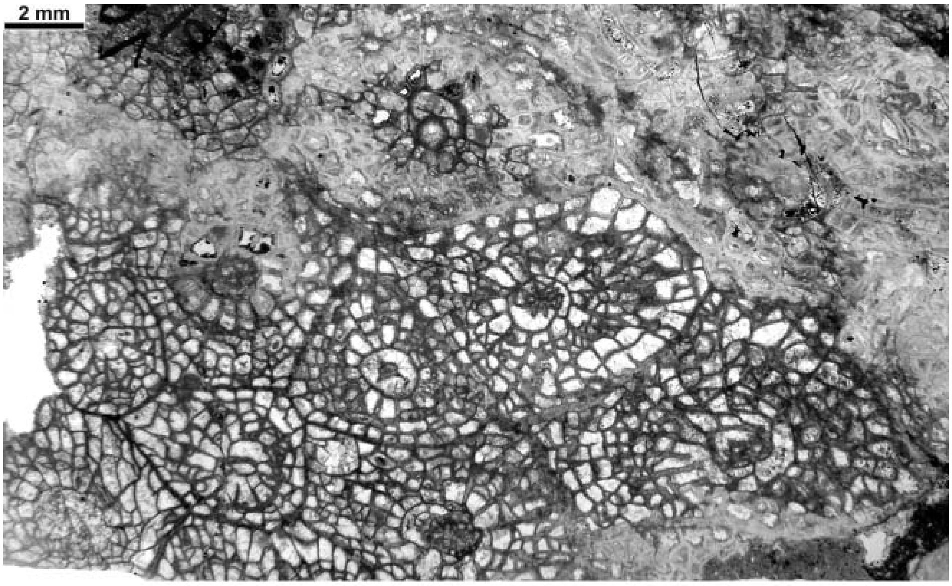


Fig. 82. *Kleopatrina grinnellensis* Fedorowski et al., 2007. UAMIG.Tc-C.CrL. I/6/18, Tyrrellfjellet Member of the Wordiekammen Formation; transverse thin section from different growth stages.

septal lamellae and axial tabellae; in all growth stages major septa commonly withdraw from axis to leave narrow, open axial area. Dissepimentarium commonly up to one-half corallite radius in width, mainly interseptal, comprising 3-4 rows of small, globose dissepiments; lonsdaleoid dissepiments rare. Tabularium occupying about one-half corallite diameter; "biformly reduced" morphology well expressed. Intercorallite wall continuous, 0.1 mm thick, locally weakly sinuous.

Remarks: The specimen described above differs from the type specimens and all other *K. grinnellensis* specimens described so far in its weakly sinuous corallite walls and a more variable length of minor septa. In the corallites of this species known from the Urals and Arctic Canada, inter-corallite walls are strongly sinusoid, while the length of minor septa usually reaches three-fourths length of major septa. The remaining features observed in the Spitsbergen specimens, including septal indices and the axial structure, are closely similar to those found in the representatives of this species known from the literature.

Occurrence: Central Urals – Asselian-Lower Artinskian undivided, age indefinite; Canadian Arctic: Devon and Ellesmere Islands – Lower Artinskian; Spitsbergen: Linnédalen – Sakmarian.

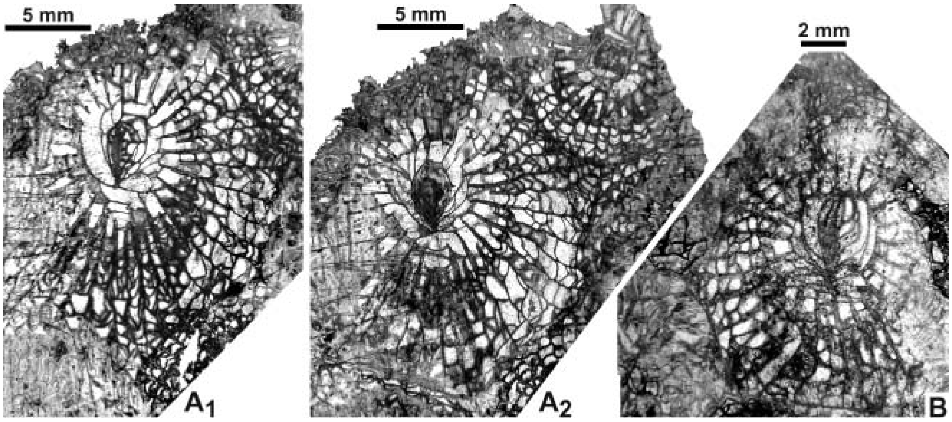


Fig. 83. A, B. *Kleopatrina rozkowskae* Fedorowski, 1967, Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.Lin. I/1/51; $A_{1,2}$ – transverse thin section from mature growth stages.
B – UAMIG.Tc-C.Lin. I/1/65; transverse thin section from mature growth stages.

Kleopatrina rozkowskae Fedorowski, 1967
Fig. 83

1967. *Kleopatrina (Kleopatrina) rozkowskae* sp. nov.; Fedorowski: p. 27, pl. 4, figs 4-5, text-figs 12-13.
1972. *Kleopatrina (Kleopatrina) magnifica* (Porfiryev); Fedorowski [in Birkenmajer et al.]: p. 161, pl. 1, figs 3a-b.
2007. *Kleopatrina rozkowskae* Fedorowski, 1967; Fedorowski et al.: pp. 125-126.

Diagnosis: See Fedorowski et al. (2007), p. 126.

Material: Three fragments of colony (UAMIG.Tc-C.Lin. I/1/51, 65, 75). Four transverse thin sections.

Description: Septal indices equal to 25/17-20. Major septa long, straight, attaining three-fourths corallite radius, commonly withdrawn from axial structure (Fig. 83$A_{1,2}$, B). Cardinal protoseptum shortened; as long as minor septa. Counter protoseptum joining continuous median lamella. Minor septa penetrate into tabularium, rarely interrupted by dissepiments; in tabularium attaining one-third to one-half length of major septa. Axial structure oval (4 x 2 mm), continuous, containing slightly thickened median lamella, few short septal lamellae and few "linked axial tabellae". Dissepimentarium up to one-half corallite radius in width; lonsdaleoid dissepiments locally developed. Tabularium "biformly reduced". Intercorallite wall about 0.1 mm thick.

Remarks: The corallites described above are highly incomplete and recrystallized, but their main morphological characteristics match those of *Kleopatrina rozkowskae* noted from Treskelen (the Hornsund area) and Torell Land (south Spitsbergen). The similarity shows in their septal indices (23-26/15.0-20.5 for the Treskelen specimens *vs*. 24/19 for those from Torell Land), axial structure and dissepimentarium, and in the arrangement of major septa. The Linnédalen corallites differ from those known from the literature only in having longer minor septa penetrating ca. 1.0 mm into the tabularium zone. In the specimens of this species described earlier, minor septa are usually restricted to the dissepimentarium area, and only some approach the tabularium.

Long minor septa penetrating into the tabularium can be observed in *K. uralensis*. However, corallites in those colonies have smaller diameters and smaller numbers of septa (19-21/10-16), while their cardinal protoseptum is as long as the remaining major septa. Out of the remaining *Kleopatrina* species with a shortened cardinal protoseptum and minor septa locally penetrating into the tabularium (*K. ftatateeta, K. arcturusensis, K. prismatica*), all have corallite diameters not exceeding 15.0 mm and smaller numbers of major septa (see Fedorowski et al. 2007: table 22).

Occurrence: South Urals – Artinskian; Spitsbergen: Treskelen, Torell Land – probably Lower Sakmarian; Linnédalen – Sakmarian.

Kleopatrina uralensis (McCutcheon and Wilson, 1961)
Fig. 84

2007. *Kleopatrina uralensis* (McCutcheon and Wilson, 1961); Fedorowski et al.: pp. 126-127 (cum synon.).

Diagnosis: See Fedorowski et al. (2007), p. 127.

Material: Four fragments of colony (UAMIG.Tc-C.Krg. IVy/1, 11; Krg. Vy/7; UAMIG.Tc-C.Lin. I/1/113). Four transverse and one longitudinal thin sections.

Description: Septal indices range from 16/5.0 to 21/14.0. Major septa long, wavy, attaining two-thirds corallite radius; some of them approaching axial structure (Fig. 84$A_{1,2}$, B_1, C). Protosepta may join continuous median lamella. Minor septa attain one-half to two-thirds length of major septa, commonly penetrating outer tabularium; rarely interrupted by lonsdaleoid dissepiments. Axial structure continuous, containing continuous, slightly thickened median lamella, very few, short septal lamellae and few "linked axial tabellae". Dissepimentarium up to one-half corallite radius in width; lonsdaleoid dissepiments locally developed. Tabularium "biformly reduced", tabulae complete as well, arched; at axial structure slightly raised (Fig. 84A_2). Intercorallite wall about 0.1 mm thick.

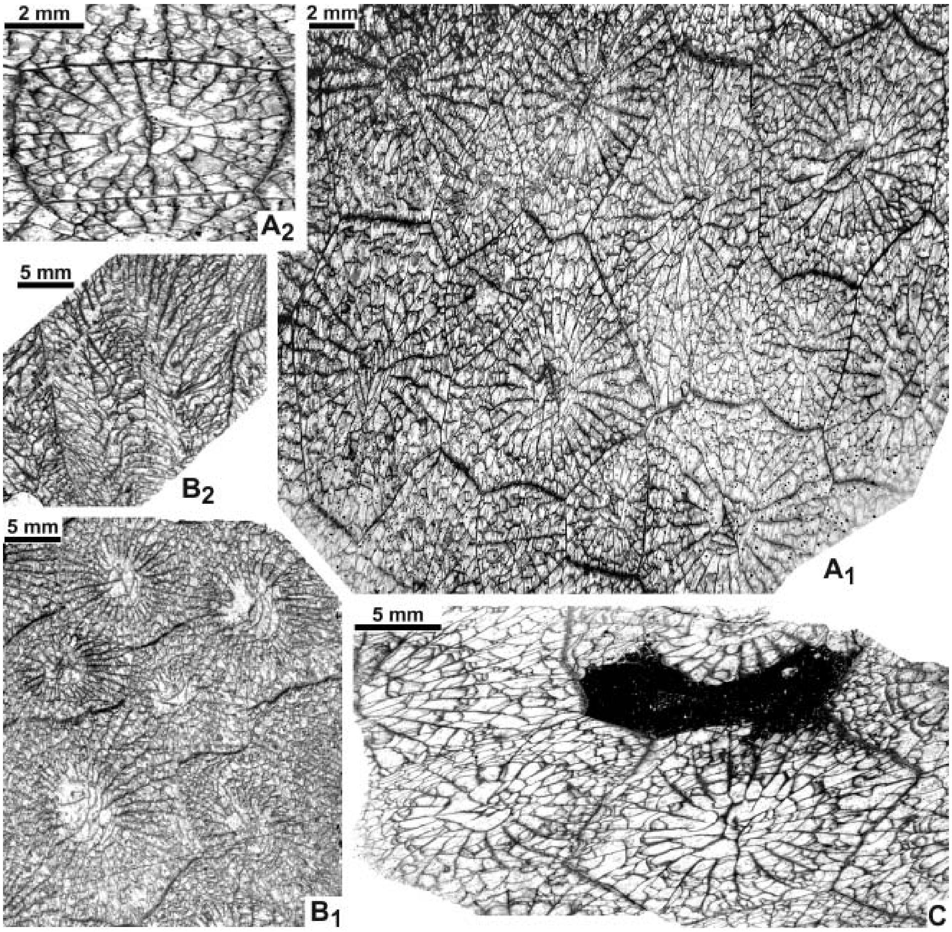


Fig. 84. A-C. *Kleopatrina uralensis* (McCutcheon and Wilson, 1961), upper part of the Treskelodden Formation.

A – UAMIG.Tc-C.Krg. IVy/11; A_1 – transverse thin section from different growth stages, A_2 – enlarged corallite from A_1.

B – UAMIG.Tc-C.Krg. IVy/1; B_1 – transverse thin section from mature growth stages, B_2 – slightly oblique longitudinal thin section.

C – UAMIG.Tc-C.Krg. Vy/7; transverse thin section from mature growth stages.

Remarks: In comparison with the holotype, the corallites described above differ only in having a few longer major septa which can combine with the axial structure. In this feature the Kruseryggen specimens are similar to *K. atava*, in which major septa commonly reach the axial structure. However, unlike *K. uralensis*, *K. atava* has a more extensive axial structure and incomplete tabulae, which are flat or concave in the periaxial area, and often rising toward the axis. Moreover, in the axial area *K. atava* has numerous very steep, tent-shaped, sometimes vesicular tabellae which, together with the columella and axial ends of major septa, form a complicated axial structure. The mentioned fusion of some major septa with the axial structure observed in the material under study can therefore be treated as a new feature of *K. uralensis* expanding the range of the genetic variability of this species.

Occurrence: South and North Urals and Timan – Tastubian; Canadian Arctic: Ellesmere and Devon Islands – Sakmarian, Upper? Tastubian-Sterlitamakian; California: Eastern Klamath terrane – probably Lower Sakmarian; Spitsbergen: Hyrnefjellet, Kruseryggen – Lower Sakmarian, Tastubian; Linnédalen – Sakmarian.

Genus: *Protowentzelella* Porfiryev, 1941 (in: Soshkina et al. 1941)

Type species: *Petalaxis kunthi* Stuckenberg, 1895.

Diagnosis: See Fedorowski et al. (2007), p. 106.

Protowentzelella columellata Fedorowski et al., 2007
Fig. 85

2007. *Protowentzelella columellata* sp. nov.; Fedorowski et al.: p. 111 (cum synon.).

Diagnosis: See Fedorowski et al. (2007), pp. 111-112.

Material: Two fragments of colony (UAMIG.Tc-C.Krg. Vy/8, 10). Three transverse and two longitudinal thin sections.

Description: Septal n/d indices of 18-23/7-14. Major septa commonly up to three-fourths corallite radius in length, the length varying; almost straight, slightly thickened in tabularium; some of them may join axial structure. Protosepta may join axial structure (Fig. $85A_{1,2}$). Minor septa short, may approach tabularium. Axial structure formed by straight, thin median lamella (sometimes linked with two opposite major septa), 2 or 3 short septal lamellae, and few “linked axial tabellae”. Tabularium occupies about one-half corallite diameter. Tabulae commonly incomplete, moderately to steeply elevated adaxially, generally sub-planar, locally globose (Fig. $85A_3$). Dissepimentarium occupies one-third to one-half corallite radius. Dissepiments varying in size and shape; lonsdaleoid dissepiments rare. Intercorallite wall 0.1-0.2 mm thick.

Remarks: The septal indices of the specimens under study depart slightly from those given in the literature for this species. Corallites from colonies coming from Kruseryggen usually have a slightly greater number of septa at smaller corallite diameters (18-20/7-10 *vs.* 16-18/9-11 in the holotype). However, con-

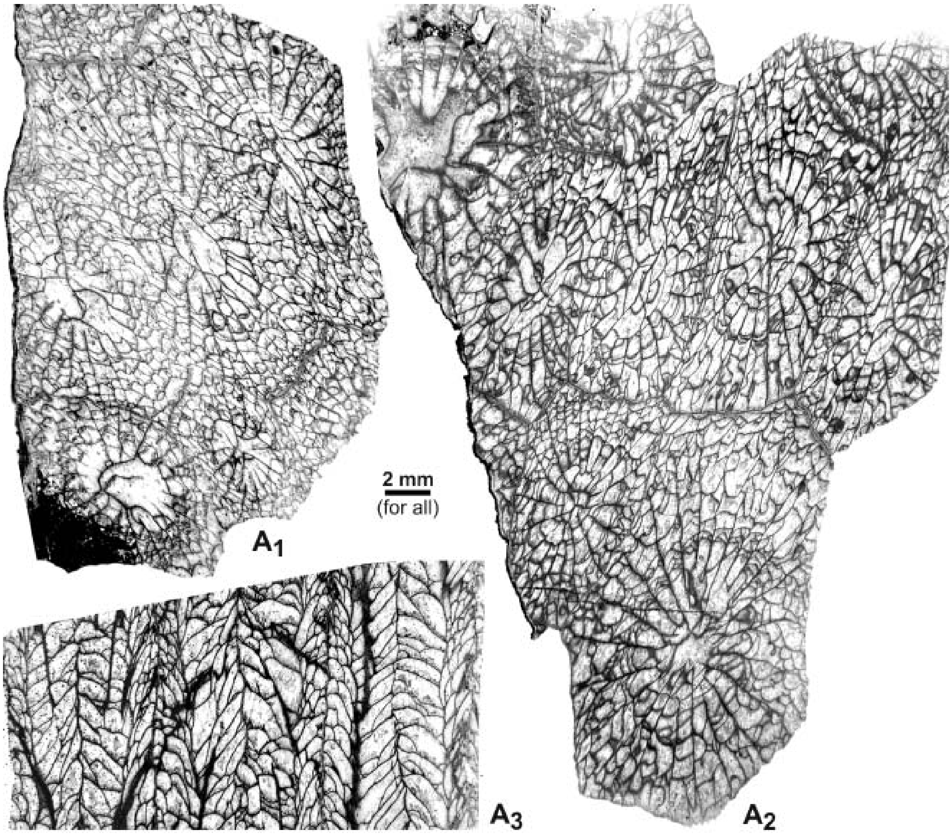


Fig. 85. A. *Protowentzelella columellata* Fedorowski et al., 2007. UAMIG.Tc-C.Krg. Vy/8, upper part of the Treskelodden Formation; $A_{1,2}$ – transverse thin section from mature growth stages, A_3 – longitudinal thin section.

sidering the remaining morphological features, including the formation of the tabularium, almost identical with that observed in the holotype, it was decided to treat the slight differences in the septal indices as a genetically variable feature of this species.

Occurrence: Central Urals – Asselian-Lower Artinskian; Canadian Arctic: Devon and ?Ellesmere Islands – Sakmarian, Tastubian-Lower Sterlitamakian; Spitsbergen: Treskelen, Triasnuten, Kruseryggen – Lower Sakmarian, Tastubian.

Protowentzelella hyporiphaea (Porfiryev, 1941)
Fig. 86

2007. *Protowentzelella hyporiphaea* (Porfiryev, 1941); Fedorowski et al.: p. 114 (cum synon.).

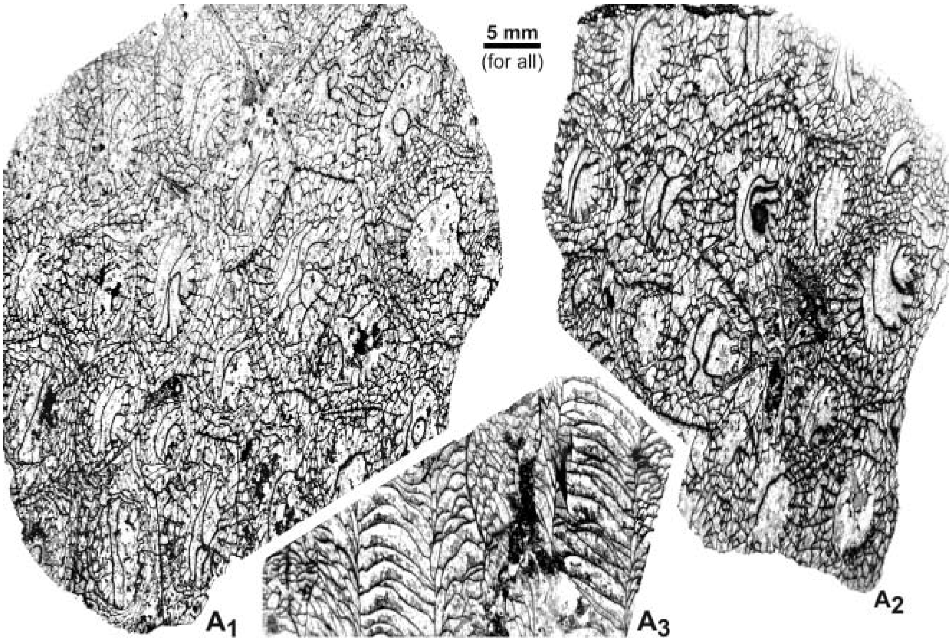


Fig. 86. A. *Protowentzelella hyporiphaea* (Porfiryev, 1941). UAMIG.Tc-C.Krg. Vz/2, upper part of the Treskelodden Formation; $A_{1,2}$ – transverse thin section from different growth stages, A_3 – longitudinal thin section.

Diagnosis: See Fedorowski et al. (2007), p. 114.

Material: Two fragments of colony (UAMIG.Tc-C.Krg. Vz/2, 3). Four transverse and two longitudinal thin sections.

Description: Septal n/d indices of 18-25/6-11. Major septa short, up to one-half corallite radius in length, penetrating about 1 mm into tabularium (Fig. 86$A_{1,2}$); in dissepimentarium discontinuous. Minor septa not developed in full number, discontinuous, restricted to outer 1-3 rows of dissepiments. Dissepimentarium occupying one-third to ca. one-half corallite radius. Dissepiments mostly regular, at places lonsdaleoid. Axial structure absent, and in corallite axis there can be sections through tabulae. Tabularium occupying ca. one-half corallite diameter. Tabulae usually complete, from nearly flat to distinctly convex or asymmetrically elevated adaxially (Fig. 86A_3); spaced 8-11 per 10 mm of corallite length. Intercorallite wall 0.1 mm thick.

Remarks: Most corallites from the described colony differ from typical representatives of this species in having a greater number of septa at similar corallite diameters (25/11 *vs.*18/10). They have eighteen major septa at a corallite diameter of 6.0 mm. Those fairly big differences notwithstanding, the fragments were placed in *P. hyporiphaea* because they have the remaining features of the species (short major septa, poorly developed, disrupted minor septa, no axial structure). It was also noted that the septal n/d indices of corallites in colonies illustrated by Fedorowski (1965: text-fig. 25) showed wider differences than would follow from the description. Apart from the most common ones given in the diagnosis of the species (18-23/10-16), there are also some I found in the examined material, e.g. 18/6.0 and 21/10.5-11.0. In turn, I did not find corallites with the number of major septa attaining 25. Still, it seems that the great variety of septal indices in this species can be its genetically variable feature.

When comparing the specimens from Kruseryggen with the remaining *Protowentzelella* species, their n/d indices are the closest to *P. variabilis*, in which it is usually 16-20/7-10. However, *P. variabilis* corallites have a discontinuous axial structure built of a sigmoid median lamella and variously developed septal lamellae. Neither this type, nor any other type of axial structure was found in sections from the colonies under study.

Convex, usually complete tabulae make the examined corallites similar to those from *P. kunthi* colonies. This species, however, has much smaller corallites with a smaller number of major septa (its n/d equals 14-17/5-8) and a median lamella.

Occurrence: South Urals – possibly Sakmarian; Spitsbergen: Treskelen, Triasnuten, Kruseryggen – Lower Sakmarian, Tastubian.

Protowentzelella kunthi (Stuckenberg, 1895)
Fig. 87

2007. *Protowentzelella kunthi* (Stuckenberg, 1895); Fedorowski et al.: p. 109 (cum synon.).

Diagnosis: See Fedorowski et al. (2007), p. 109.

Material: Five fragments of colony (UAMIG.Tc-C.Krg. Vx/1; UAMIG.Tc-C.CrL. I/6/10, 13; UAMIG.Tc-C.CrL. I/7/3; UAMIG.Tc-C.CrL. I/8/14). 13 transverse and four longitudinal thin sections.

Description: Septal n/d ratios of 13-18/5.0-7.0. Major septa commonly continuous, slightly wavy, attaining one-half to two-thirds corallite radius in length; some interrupted by lonsdaleoid dissepiments (Fig. 87$A_{1,2}$, B, C). Minor septa very short, restricted to peripheral part of dissepimentarium, commonly terminating at first, rarely second, ring of dissepiments; absent from some loculi. Axial structure inconsistently developed, visible in few transverse sections of corallites, built of median lamella and few thin septal lamellae. Tabulae mostly complete with additional tabellae; axially convex, spaced at varying intervals, usually (in axial part) 16-18 per 10 mm (Fig. 87$A_{3,4}$). Peripheral tabellae few, of variable morphology, from convex to concave; "linked axial tabellae" absent.

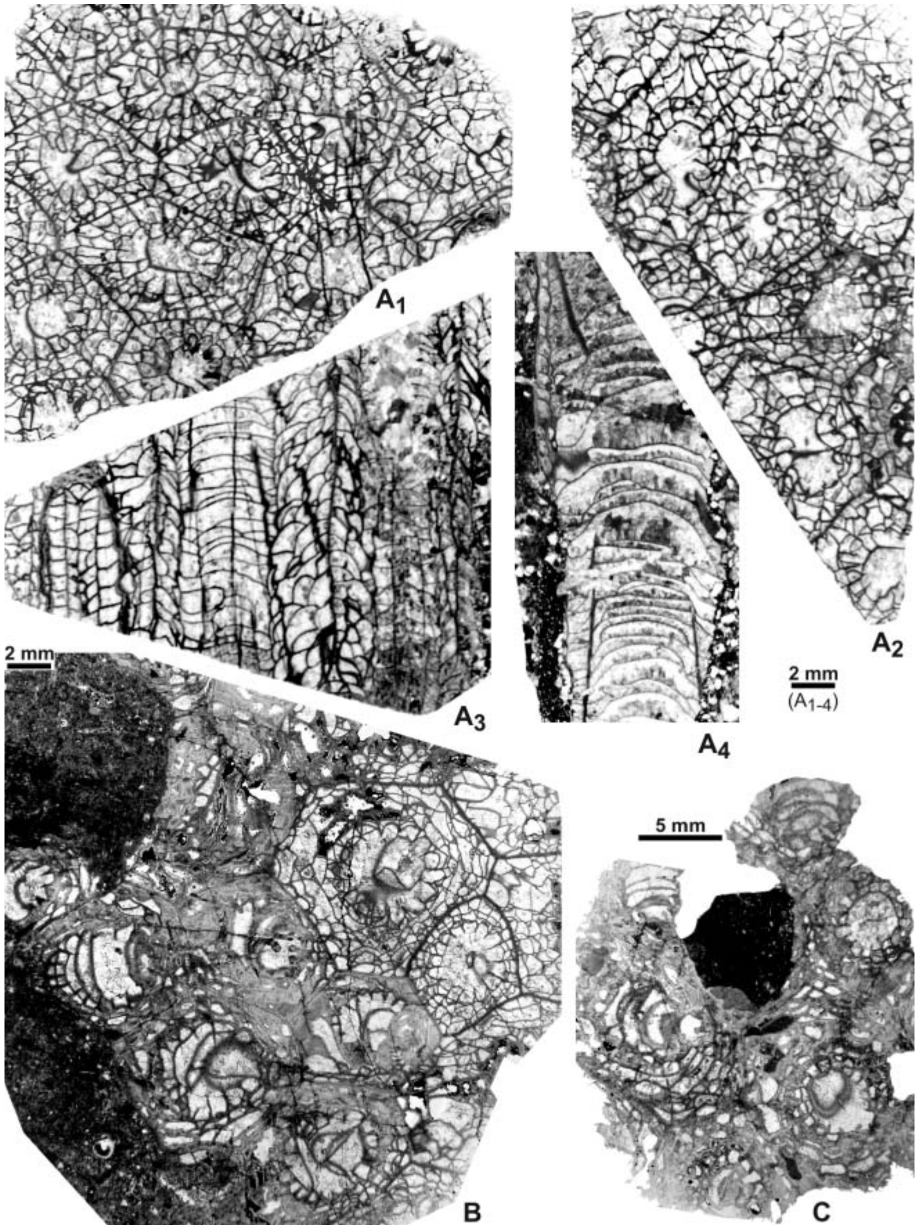


Fig. 87. A-C. *Protowentzelella kunthi* (Stuckenberg, 1895).

A – UAMIG.Tc-C.Krg. Vx/1, upper part of the Treskelodden Formation; $A_{1,2}$ – transverse thin sections from mature growth stages, $A_{3,4}$ – longitudinal thin sections.

B – UAMIG.Tc-C.CrL. I/6/10, Tyrrellfjellet Member of the Wordiekammen Formation; transverse thin section from different growth stages.

C – UAMIG.Tc-C.CrL. I/7/3, Tyrrellfjellet Member of the Wordiekammen Formation; transverse thin section from mature growth stages.

Dissepimentarium with lonsdaleoid dissepiments, up to one-third (in corners one-half) corallite radius in width. Intercorallite wall 0.10-0.15 mm thick.

Remarks: As Fedorowski et al. (2007) demonstrated, *P. kunthi* shows wide intraspecific variability. The fragments of a Spitsbergen colony of this species fit within the range of this variability. Only the specimens from Linnédalen (Fig. 87B, C) differ slightly from those known so far in having a greater number of lonsdaleoid dissepiments. This is a feature making them similar to *P. cystosa*, known from the Urals through Spitsbergen and Arctic Canada to Texas. However, since the Linnédalen specimens have half the corallite diameter of *P. cystosa* at the same number of septa (18/7 *vs*. 18/14) as well as longer minor septa locally reaching one-half length of major septa, they cannot belong to *P. cystosa*. It seems more probable that the numerous lonsdaleoid dissepiments found in the Linnédalen specimens expand the already wide range of genetically variable features of *P. kunthi*.

The specimen from Kruseryggen, in turn, is closely similar to the south-Ural lectotype of *P. kunthi* (see Ivanovsky 1987: pl. 17, figs 3a-b and Fedorowski et al. 2007: pl. 11, fig. 8). In both, corallites have similar septal indices, an uncomplicated axial structure, and major septa of similar length. In turn, convex tabulae with additional tabellae in the Kruseryggen specimen make it similar to colonies from the southern Urals described and illustrated by Soshkina et al. (1941: 180, pl. 41, fig. 1).

Occurrence: South Urals – Lower Sakmarian, Lower Tastubian; Canadian Arctic: Ellesmere Island – Sakmarian, Upper Tastubian; cratonic western Canada – Upper Asselian-Lower Sakmarian; cratonic west-central USA: Nevada – Lower Sakmarian, California – Lower Artinskian, Texas – probably Lower Sakmarian; Spitsbergen: Kruseryggen – Lower Sakmarian (Tastubian), Linnédalen – Sakmarian.

Protowentzelella longiseptata Fedorowski, 1980
Fig. 88A

1980. *Protowentzelella longiseptata* n. sp.; Fedorowski [in Birkenmajer and Fedorowski]: p. 18, pl. 3, figs 3-5.
2007. *Protowentzelella longiseptata* Fedorowski, 1980; Fedorowski et al.: p. 114.

Diagnosis: See Fedorowski et al. (2007), p. 114.

Material: One fragment of colony (UAMIG.Tc-C.CrL. I/8/11), partly silicified, at places crushed. Two transverse and one longitudinal thin sections.

Description: Septal indices are 8-19/9.0-12.0. Major septa commonly up to four-fifths corallite radius in length, few longer ones fuse with axial structure.

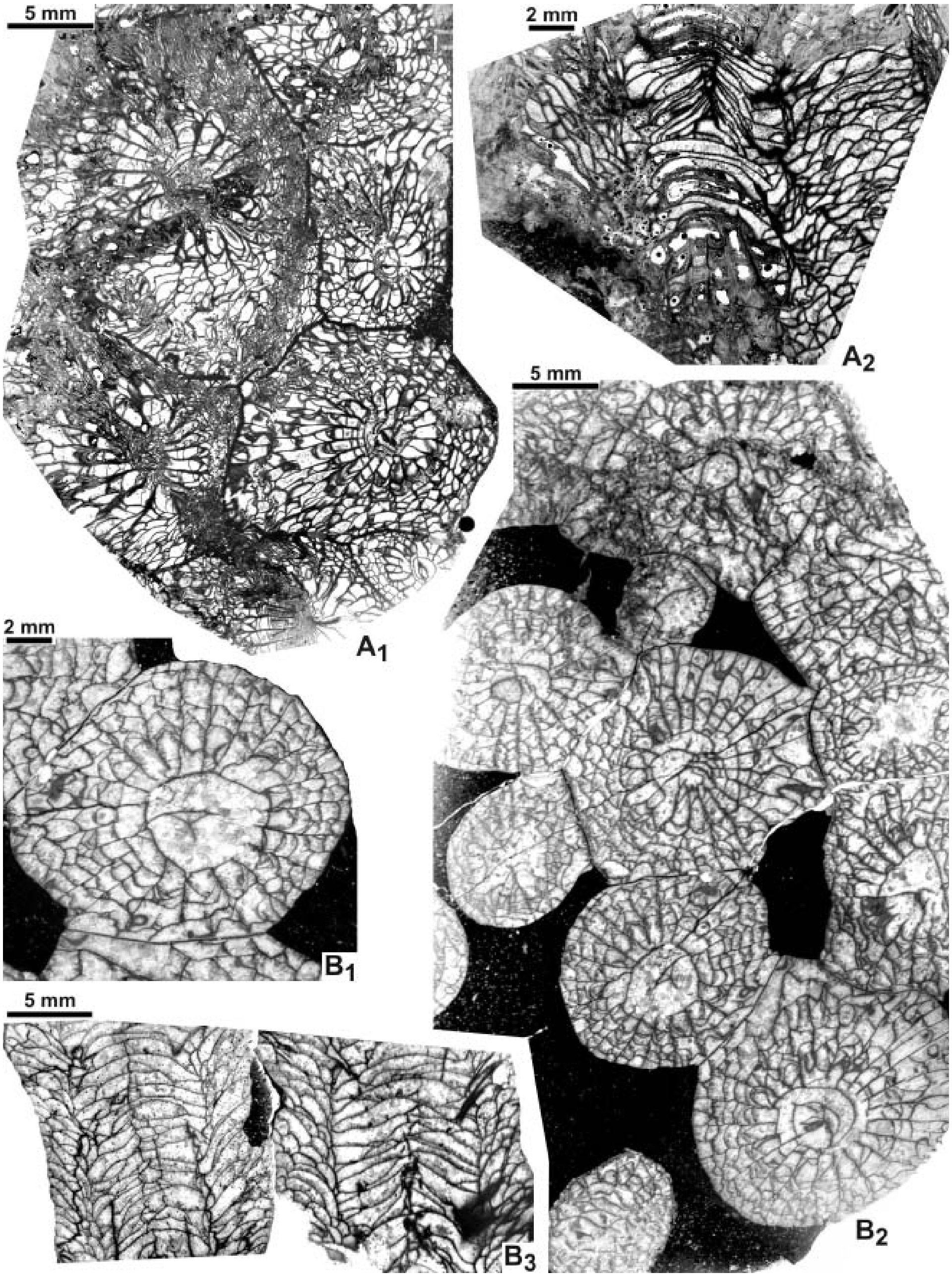


Fig. 88. A. *Protowentzelella longiseptata* Fedorowski, 1980. UAMIG.Tc-C.CrL. I/8/11, Tyrrellfjellet Member of the Wordiekammen Formation; A_1 – transverse thin section from different growth stages, A_2 – oblique longitudinal thin sections. B. *Protowentzelella variabilis* Fedorowski, 1965. UAMIG.Tc-C.Krg. Vy/6, upper part of the Treskelodden Formation; $B_{1,2}$ – transverse thin sections from different growth stages, B_3 – longitudinal thin section.

Cardinal protoseptum can be shortened (Fig. 88A$_1$, black dot). Minor septa commonly attain one-fourth length of major septa; locally longer, crossing entire dissepimentarium, or interrupted or completely reduced in some septal loculi. Axial structure discontinuous (Fig. 88A$_2$), having short median lamella and few axial tabellae. Dissepimentarium up to one-half corallite radius in width. Dissepiments regular, at periphery small, lonsdaleoid; herringbone dissepiments develop only occasionally. In longitudinal section (Fig. 88A$_2$), dissepiments are of different sizes, from very small to horizontally elongated, making the number of rows hard to estimate. Tabulae usually complete, slightly convex; upturned and sigmoid near irregular pseudocolumella.

Remarks: *P. longiseptata* is known from the Lower Permian of Triasnuten (south Spitsbergen), from layers considered to be the Lower Sakmarian (Birkenmajer and Fedorowski 1980). The Linnédalen specimen described by the present author is closely similar to specimen no. A37094 described by Fedorowski (1980, in Birkenmajer and Fedorowski 1980). The similarity shows in a slightly thickened median lamella, which may be free or attached to one or two major septa, long minor septa that may reach the inner row of dissepiments, the morphology of a wide dissepimentarium with lonsdaleoid dissepiments, and the morphology of a tabularium with complete, domed and upturned tabulae.

Occurrence: Spitsbergen: Triasnuten – probably Lower Sakmarian (Tastubian), Linnédalen – Sakmarian.

Protowentzelella variabilis Fedorowski, 1965
Figs 88B, 89

2007. *Protowentzelella variabilis* Fedorowski, 1965; Fedorowski et al.: p. 117 (cum synon.).

Diagnosis: See Fedorowski et al. (2007), p. 117.

Material: Four fragments of colony (UAMIG.Tc-C.Krg. IVz/1, Krg. Vx/8, Krg. Vy/6, Krg. Vz/1). Five transverse and three longitudinal thin sections.

Description: Septal n/d indices reach 16-23/6.0-13.0. Major septa generally thin, up to one-half (rarely three-fourths) corallite radius, continuous, locally separated from epitheca by marginal dissepiments (Figs 88B$_{1,2}$, 89A$_{1,2}$). Axial structure very poorly developed, discontinuous, irregular, built of short median lamella, 2-3 septal lamellae and few sections through axial tabulae. It is only visible in some transverse sections. Out of the three longitudinal sections, only one (Fig. 88B$_3$) clearly shows vertical elements of the axial structure. In the remaining two, only in one (Fig. 89A$_4$ – extreme left corallite) it is possible to discern a small fragment of the axial structure, while the other (Fig. 89A$_3$) shows no elements indicative of its presence whatsoever. Minor septa rarely in full number, very

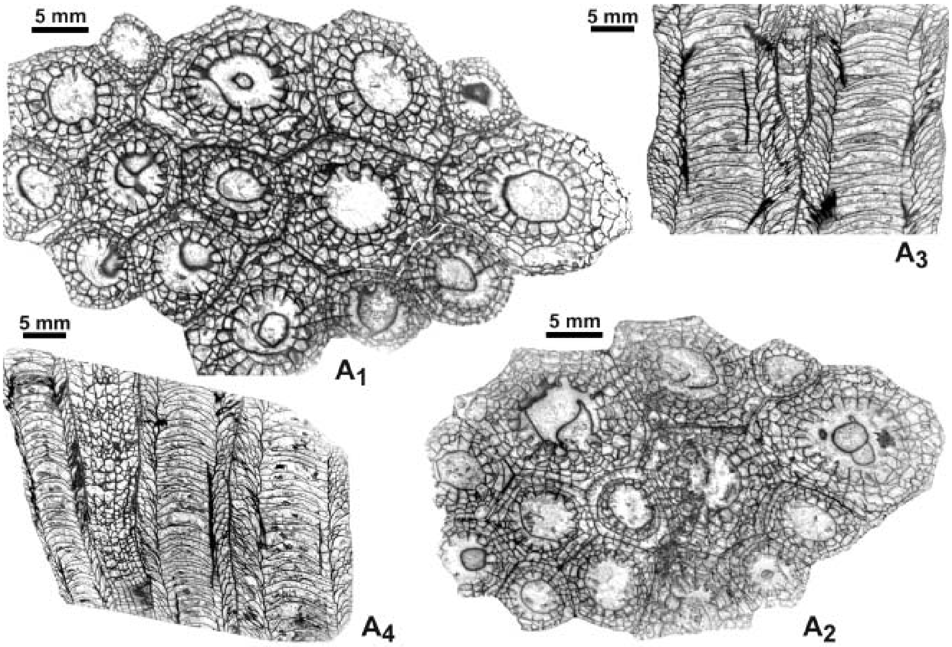


Fig. 89. A. *Protowentzelella variabilis* Fedorowski, 1965. UAMIG.Tc-C.Krg. Vz/1, upper part of the Treskelodden Formation; $A_{1,2}$ – transverse thin section from different growth stages, $A_{3,4}$ – longitudinal thin sections.

short, reaching at most inner series of dissepiments; rarely attaining one-half length of major septa (Fig. 88B_1); locally reduced to short septal segments on dissepiments. Dissepimentarium occupies one-third to one-half corallite radius; built of straight and herringbone interseptal dissepiments as well as lonsdaleoid dissepiments, which sporadically cross up to four major septa (Fig. 89$A_{1,2}$). In longitudinal sections dissepiments of different sizes, not forming distinct rows. Tabularium occupies up to one-half corallite diameter. Where axial structure is absent, tabulae usually complete, slightly arched, with rare tabellae. In those corallite sections where axial structure is present (Fig. 88B_3), tabulae incomplete, gently elevated adaxially. Intercorallite wall about 0.1 mm thick.

Remarks: The Kruseryggen specimens differ from the known representatives of this species in slightly greater sizes of corallites in adult growth stages. While in early ontogeny the septal indices of the specimens from Kruseryggen and other places of the world are comparable (16/6 in the Kruseryggen specimens *vs*. 16/7 in other ones), in later growth stages the Kruseryggen corallites attain 23/13, while in typical representatives the ratio is 20/10. The remaining morphological features of the specimens in question do not depart from the diagnostic ones of the species.

The only notable fact is the occurrence of an extensive and more continuous axial structure in corallites located on the margins of the colony (Fig. 88B_{1-3}) than in those placed inside it, where it is very rarely observed, built at most of a short median lamella (Figs 88A_2, 89A_2, upper and middle corallites). It was also observed that in the inner corallites the short-lived appearance of an axial structure throughout ontogeny was usually preceded by long periods of its absence (Fig. 89A_4). This observation seems significant for two reasons. First, in the case of an insufficient number of sections, the presence of an axial structure could have been overlooked, and this in consequence could lead to a wrong identification of the species. An example of one built similarly, without an axial structure, is *P. hyporiphaea*. Secondly, it seems that in colonies of this species the axial structure may have performed the role of an additional construction element rather than have anything to do with physiological functions; in this way corallites of the outer part of the colony, more exposed to mechanical damage, gained an additional reinforcement. Perhaps it appeared in corallites inside the colony, too, only when the dynamics of the environment increased.

Occurrence: South Urals – Upper Asselian; Canadian Arctic: Devon and Ellesmere Islands – Sakmarian, Tastubian; cratonal western Canada – probably Lower Sakmarian; Eastern Klamath terrane – Lower Sakmarian; cratonal west-central USA: Nevada, California – Lower Sakmarian; Spitsbergen: Treskelen, Kruseryggen – Lower Sakmarian, Tastubian.

Family: Lithostrotionidae d'Orbigny, 1851
Subfamily: Diphyphyllinae Dybowski, 1873

Type genus: *Diphyphyllum* Lonsdale, 1845.

Diagnosis: See Fedorowski et al. (2007), p. 143.

Genus: ***Tschussovskenia*** **Dobrolyubova, 1936a**

Type species: *Tschussovskenia captiosa* Dobrolyubova, 1936a.

Diagnosis: See Fedorowski et al. (2007), p. 145.

Tschussovskenia captiosa Dobrolyubova, 1936a
Fig. 90

2007. *Tschussovskenia captiosa* Dobrolyubova, 1936a; Fedorowski et al.: p. 146 (cum synon.).

Diagnosis: See Fedorowski et al. (2007), p.146.

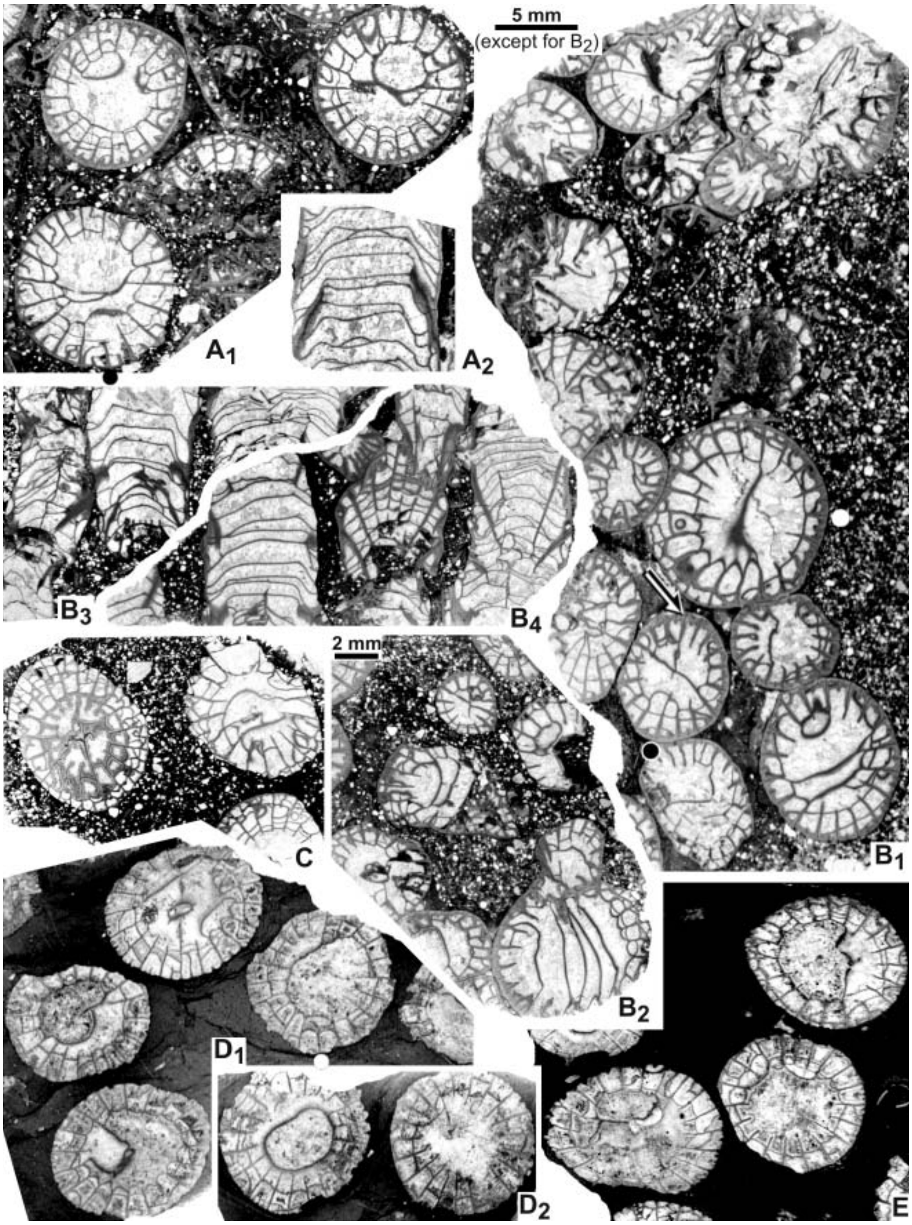


Fig. 90. A-E. *Tschussovskenia captiosa* Dobrolyubova, 1936*a*, upper part of the Treskelodden Formation.

A – UAMIG.Tc-C.Krg. IVx/26; A_1 – transverse thin section from mature growth stages, A_2 – longitudinal thin section.

B – UAMIG.Tc-C.Krg. IVx/4; $B_{1,2}$ – transverse thin sections from different growth stages, $B_{3,4}$ – longitudinal and oblique longitudinal thin sections, arrow in B_1 shows counter protoseptum.

C – UAMIG.Tc-C.Krg. IVx/25; transverse thin section from mature growth stages.

D – UAMIG.Tc-C.Krg. IVz/13; $D_{1,2}$ – transverse thin sections from mature growth stages.

E – UAMIG.Tc-C.Krg. IVz/12; transverse thin section from mature growth stages.

Material: Eleven fragments of colony, at places abraded, with partly re-crystallised axial zones of corallites (UAMIG.Tc-C.Krg. IVx/1-4, 25-27; Krg. IVz/12, 13; Krg. Vy/20, 21). Two peels and 17 transverse thin sections as well as nine longitudinal thin sections.

Description: Corallites cylindrical. Septal indices equal to 14-23/4.0-10.5. Length of major septa attains one-third to one-half, sporadically two-thirds to three-fourths, corallite radius (Fig. 90A_1, $B_{1,2}$, C, $D_{1,2}$, E), with single septa extending to corallite axis (Fig. 90C, left specimen). Minor septa mostly very short, sporadically attaining one-third length of major septa. Cardinal protoseptum of variable length, from shortened (Fig. 90A_1 – black dot, B_1, D_1 – white dots), through non-distinct in length (Fig. 90A_1 – upper corallites, B_1 – lower corallites, E), to elongated (Fig. 90B_1 – black dot). Counter protoseptum can be elongated (Fig. 90B_1 – arrow, D_1 – upper corallite, D_2 – right corallite). Poorly developed, irregular axial structure present only in some transverse sections. Dissepimentarium discontinuous, narrow, consisting of 1-3 rows of regular dissepiments. Tabularium wide, tabulae trapezoid, complete (Fig. 90A_2, $B_{3,4}$), numbering ca. 10/10 mm of corallite height. External wall 0.2 to 0.4 mm thick.

Remarks: When compared with the *T. captiosa* known from Urnetoppen (Fedorowski 1965) and Treskelen (Fedorowski 1967), with septal indices of 21-22/7.5-9.5 and 17-27/4.0-16.0, respectively, the specimens described above are closer to those from Urnetoppen (the Hornsund region). Apart from similar septal indices, they have a similarly developed tabularium, major and minor septa, and dissepimentarium. What differentiates them from both Urnetoppen and Treskelen specimens is a less extensive axial structure. This feature makes them similar to specimens from the central Urals described by Dobrolyubova (1936a), from which they only differ in smaller sizes. The largest Kruseryggen specimens attain at most an average size of the Ural ones, in which the n/d indices range from 17/4-6 to 27/16.

Occurrence: South and Central Urals, Timan – Upper Asselian-Lower Sakmarian; Spitsbergen: Treskelen, Urnetoppen, Kruseryggen – Lower Sakmarian, Tastubian.

Tschussovskenia dilata Fedorowski et al. 2007
Fig. 91

part 1965. *Tschussovskenia kiaeri* (Holtedahl); Fedorowski: p. 63; pl. 4, fig. 4, text-fig. 17d-e [non pl. 4 fig. 5, pl. 5, fig. 1, text-fig. 17a-c (= *Heintzella borealis*)].
2007. *Tschussovskenia dilata* Fedorowski et al.; Fedorowski et al.: p. 147, pl. 14, fig. 6, pl. 15, figs 1-2.

Diagnosis: See Fedorowski et al. (2007), pl. 147.

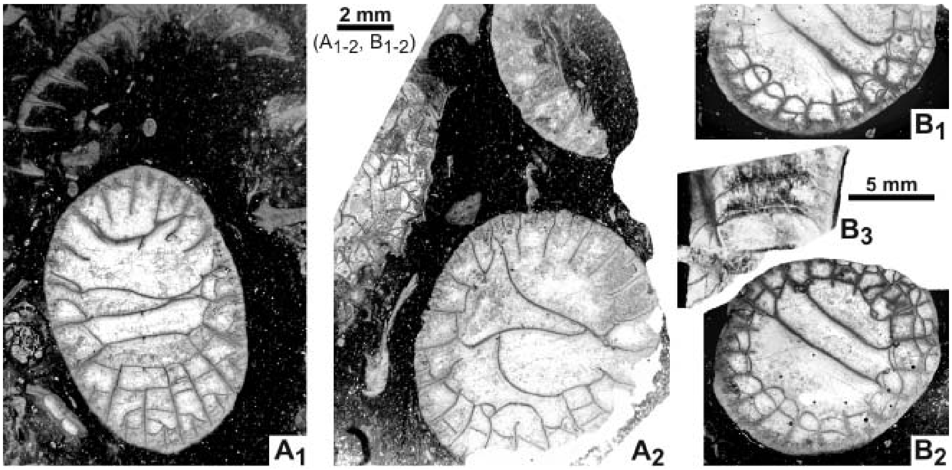


Fig. 91. A, B. *Tschussovskenia dilata* Fedorowski et al. 2007, Tyrrellfjellet Member of the Wordiekammen Formation.

A – UAMIG.Tc-C.Lin. III/1/9; $A_{1, 2}$ – transverse thin section from mature growth stage.
B – UAMIG.Tc-C.Lin. III/1/18; $B_{1, 2}$ – transverse thin section from mature growth stages, B_3 – longitudinal thin sections.

Material: Two fragments of colony (UAMIG.Tc-C.Lin. III/1/9, 18). Five transverse thin sections.

Description: Septal indices range from 18/7 to 21/8. Major septa thin, attaining one-fourth to one-third corallite radius in length (Fig. 91$A_{1, 2}$, $B_{1, 2}$). Counter protoseptum no different from remaining major septa. Cardinal protoseptum can be slightly shortened (Fig. 91$A_{1, 2}$). Cardinal fossula shallow, tabular, bordered by one pair of straight major septa. Minor septa extend to inner edge of dissepimentarium, attaining one-fourth length of major septa. Dissepimentarium 0.8 mm wide, consisting of 1 or 2 series of interseptal dissepiments. Axial structure indiscernible in the material described. Tabulae trapezoid, widely spaced, ca. 3/5 mm of corallite height (Fig. 91B_3). External wall 0.15 to 0.20 mm thick.

Remarks: The specimens from Linnédalen of central Spitsbergen, although small in diameter, appear to belong to *T. dilata*. They show an especially close similarity to specimens from the Treskelen Peninsula of the Hornsund area described by Fedorowski (1965) and Fedorowski et al. (2007). Both have similar major and minor septa, dissepimentaria and tabularia. The smaller corallite diameters and number of major septa in the Linnédalen corallites (21/8 *vs*. 26/11) may indicate immature growth stages of this species. Those features can therefore be seen as part of the intraspecific variability of *T. dilata*. It also seems that a shallow cardinal fossula in early growth stages can be an individually variable feature not found in mature growth stages. In turn, the absence of an axial structure in the examined specimens is probably due to the fact that the material included only small fragments of a colony, and since the axial structure occurs in this species only sporadically, it could have been missed.

Among the remaining *Tschussovskenia* species, also *T. minor* corallites are small in size. However, the specimens in question differ from this species first of all in having a greater number of septa at similar corallite diameters (20-21/8 *vs*. 17/8) and shorter major septa, which in *T. minor* attain more than one-half corallite radius.

Occurrence: Cratonal west-central USA: Nevada – Lower Sakmarian; Guatemala – Cisuralian; Spitsbergen: Treskelen, Linnédalen – Lower Sakmarian, Tastubian.

Tschussovskenia borealis sp. nov.
Fig. 92

Holotype: UAMIG.Tc-C.Pol VI/18 (Fig. 92$B_{1\text{-}5}$). Seven transverse and one longitudinal thin sections.

Type locality: Polakkfjellet (N 77° 13.498′; E 16° 01.933′), central Spitsbergen (Fig. 2D).

Type horizon: Lower part of Treskelodden Formation, Gzhelian.

Derivation of name: *borealis* – named for its occurrence in the far north.

Diagnosis: *Tschussovskenia* with n/d ratios from 21/7 to 24/12; major septa up to two-thirds corallite radius; cardinal protoseptum commonly shortened; minor septa locally penetrate tabularium; axial structure with median lamella, septal lamellae and axial tabellae; dissepimentarium with 1-3 rows of dissepiments, up to one-fifth corallite radius in width; tabularium commonly incomplete, tabulae and tabellae convex, locally subhorizontal.

Material: Paratypes – small fragments of two heavily dolomitized colonies with partly crushed corallites (UAMIG.Tc-C.Pol. VI/1, 4). Six thin sections from transverse sections and two from longitudinal ones were made.

Description: Corallites circular in transverse section. Septal indices in adult growth stages attain 20-24/8-12. Major septa in early growth stages of varying length, with the longest reaching corallite axis (Fig. 92$A_{1,3}$ – lower specimen, A_4 – upper and lower specimens); in later growth stages attaining one-half to three-fourths corallite radius (Fig. 92$A_{2,3}$ – right specimen, $A_{2,4}$ – right specimen, B5, $C_{1,2}$). At places advanced recrystallization of corallite inner morphological

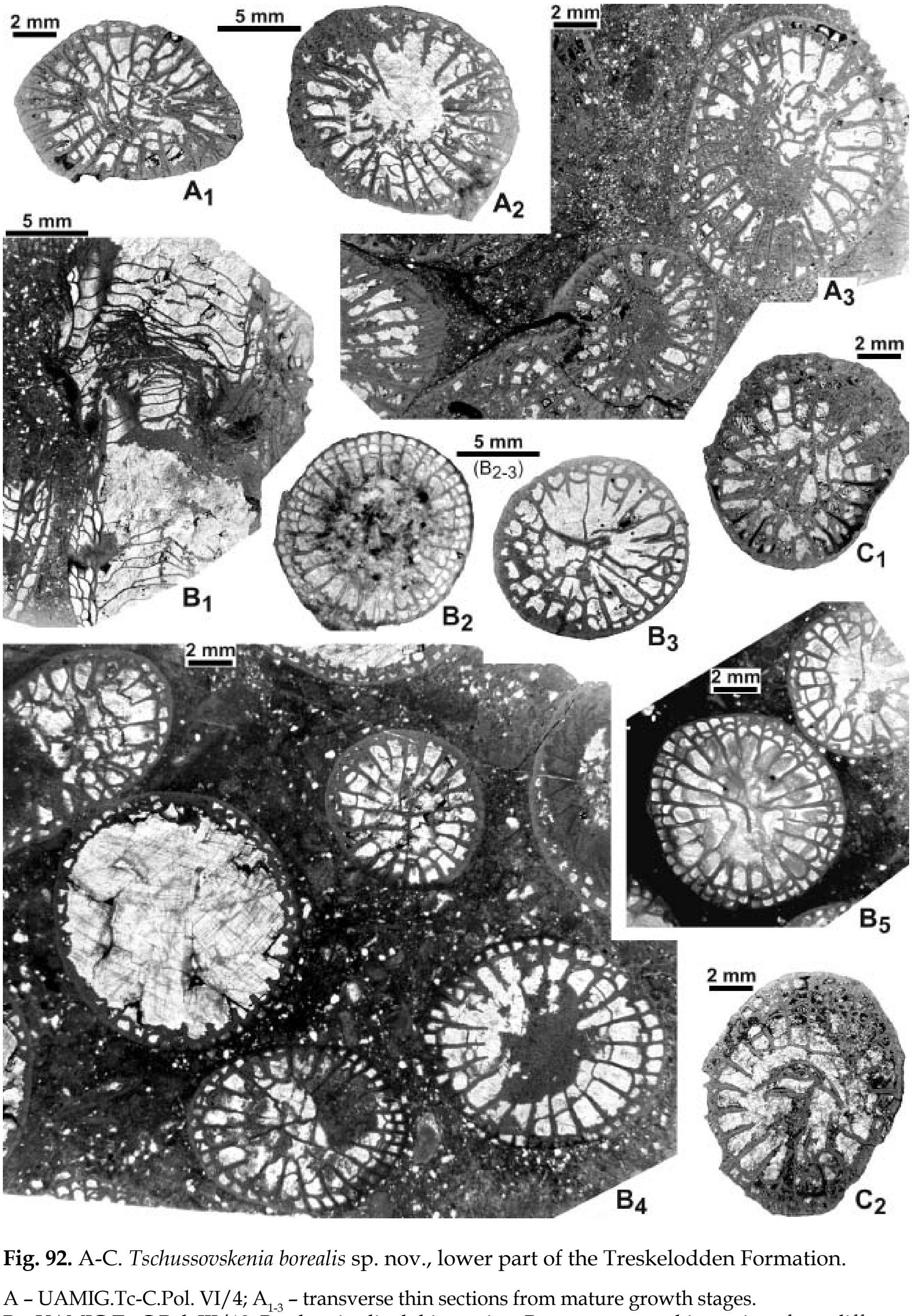


Fig. 92. A-C. *Tschussovskenia borealis* sp. nov., lower part of the Treskelodden Formation.

A – UAMIG.Tc-C.Pol. VI/4; $A_{1\text{-}3}$ – transverse thin sections from mature growth stages.
B – UAMIG.Tc-C.Pol. III/18; B_1 – longitudinal thin section, $B_{2\text{-}5}$ – transverse thin sections from different growth stages.
C – UAMIG.Tc-C.Pol. VI/1; $C_{1,2}$ – transverse thin sections from mature growth stage.

structure. For this reason some, or all (Fig. $92A_4$ – left specimen), major septa are strongly "shortened". For the same reason, in longitudinal sections it is hard to establish the number of tabulae per millimeter (Fig. $92B_1$). Cardinal protoseptum in early growth stages merging at the corallite axis with counter protoseptum (Fig. $92B_{3,4}$); in mature growth stages shortened (Fig. $92A_2$, A_2, C_1). Minor septa variable in length, sporadically penetrating into tabularium (Fig. 92A1, $A_{2,4}$); in ontogeny appear before dissepiments (Fig. $92A_4$ – upper corallite). Axial structure built of median lamella, few septal lamellae and few sections through tabulae, upturned in corallite axis. Tabularium built mainly of incomplete tabulae (Fig. $92B_1$). Surface of tabularium from slightly convex through flat to slightly concave; marginal tabellae concave. Dissepimentarium attains one-fifth corallite radius, built of a maximum of three rows of interseptal dissepiments.

Remarks: The corallites from the described fragments of a colony are similar in size to *T. captiosa*, especially to those from Kruseryggen, with n/d indices of 23/10.5. However, such features as a usually shortened cardinal protoseptum, major septa longer than one-half corallite radius, a dissepimentarium built of more than one row of dissepiments, and an absence of trapezoid tabulae, precludes their assignment to this species.

A shortened cardinal protoseptum and a 3-row dissepimentarium can be found in *T. connorsensis* and *T. minor*. However, the former species has major septa shorter than one-half corallite radius and no septal lamellae and sections through tabulae in corallite axis. In turn, *T. minor* representatives stand out primarily for their small size, short major septa and, in most specimens, an absence of median lamella and septal lamellae.

Occurrence: Spitsbergen, Polakkfjellet (Treskelodden Formation) – Gzhelian.

?*Tschussovskenia columellata* sp. nov.
Fig. 93

Holotype: UAMIG.Tc-C.Krg. Vx/20 (Fig. 93B). Four transverse and two longitudinal thin sections.

Type locality: Kruseryggen (N 77° 03.498′; E 16° 04.933′), central Spitsbergen (Fig. 2E).

Type horizon: Upper part of Treskelodden Formation, Lower Sakmarian.

Derivation of name: *collumelata* – named for its continuous axial structure.

Diagnosis: *Tschussovskenia* with n/d ratios from 15/3.0 to 17/6.0; major septa up to two-thirds corallite radius; minor septa up to one-fourth length of

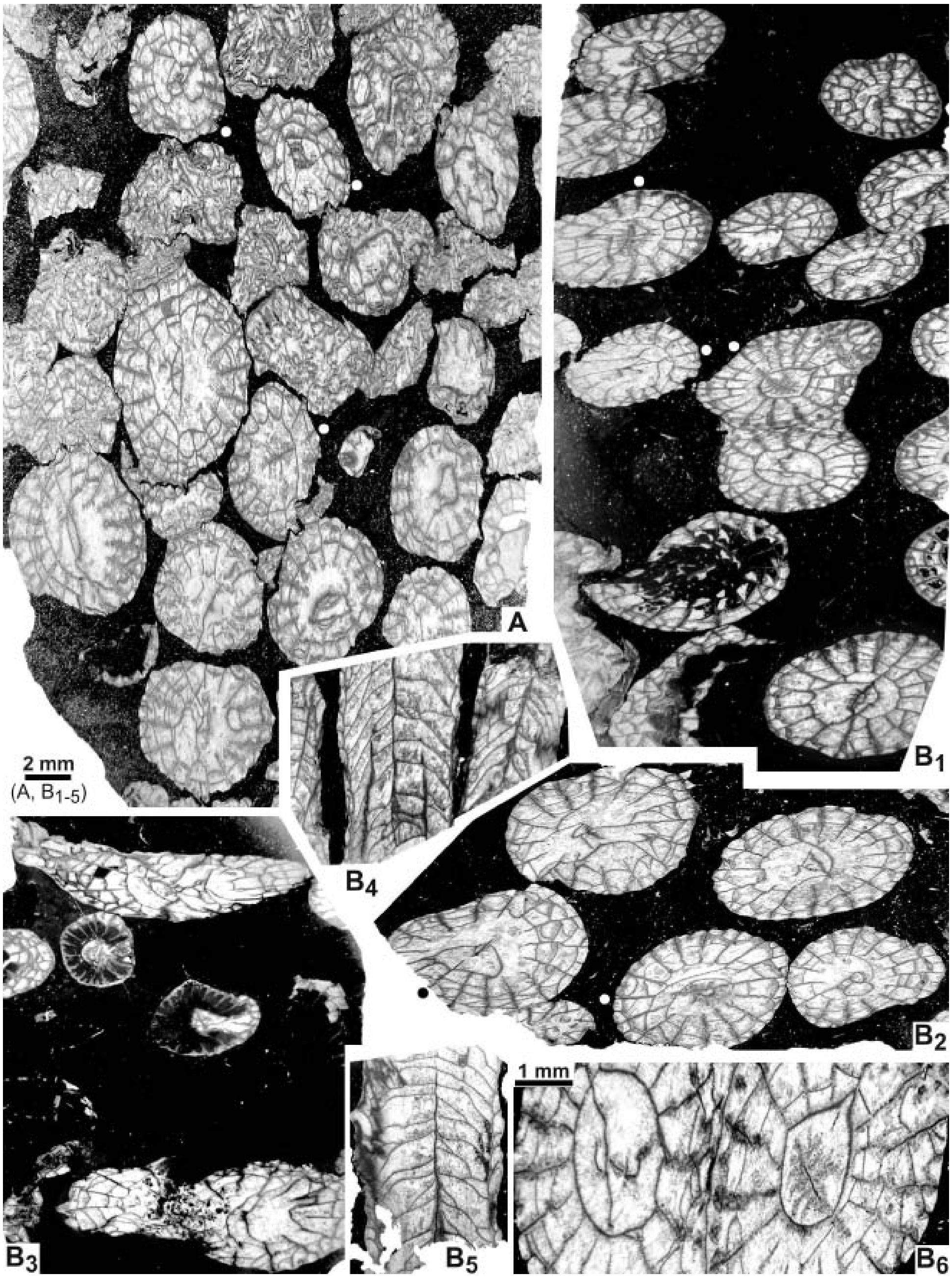


Fig. 93. A, B. *Tschussovskenia? columellata* sp. nov., upper part of the Treskelodden Formation.

A – UAMIG.Tc-C.Krg. Vx/25; transverse thin section from different growth stages.
B – UAMIG.Tc-C.Krg. Vx/20; B_{1-3} – transverse thin sections from different growth stages, $B_{4,5}$ – longitudinal thin sections, B_6 – enlarged central corallites from B_1.

major septa; cardinal protoseptum of variable length, commonly shortened; dissepimentarium with one row of globose dissepiments; axial structure composed of continuous median lamella, septal lamellae and axial tabellae; tabulae commonly incomplete, elevated adaxially, "linked axial tabellae" occurring locally.

Material: Paratypes – small fragments of two colonies with partly abraded and crushed corallites (UAMIG.Tc-C.Krg. Vx/13, 25). Three transverse and two longitudinal thin sections.

Description of holotype: Corallite diameters of 6.0 mm at maturity. Major septa numbering 16-17, usually attaining one-half, sporadically two-thirds, corallite radius (Fig. $93B_{1, 2, 6}$). Protosepta can connect with median lamella (Fig. $93B_1$ – lower corallite); cardinal protoseptum can be slightly shortened (Fig. $93B_{1, 2}$ – white dots); counter protoseptum can be slightly elongated (Fig. $93A_2$ – black dot). Axial structure on surface of tabulae very extensive, formed by median lamella and septal lamellae corresponding to all major septa (Fig. $93A_6$); above tabulae, number of septal lamellae smaller; instead, there appear sections through tabulae because here they are upturned towards corallite axis, and locally there are also "linked axial tabellae" (Fig. $93A_{4, 5}$). Axial structure, observed in calice, is built of median lamella, few septal lamellae and sections through tabulae (Fig. $93B_3$). Minor septa 0.2 to 0.5 mm in length, the longer ones being one-fourth length of major septa; they do not penetrate into tabularium. One-row dissepimentarium (Fig. $93A_{4, 5}$), built of vesicular interseptal dissepiments. External wall 0.1 mm thick.

Description of paratype: Because of damage (corrosion of outer surface of corallites, crushing), elements of the morphological structure are not recognisable in all specimens in the paratype (Fig. 93A). The diagnostic features of the new species are clearly visible in the illustrated fragment of a colony. The only difference discerned between the holotype and the paratype is the occurrence of 18 major septa at ~6.0 mm corallite diameter (Fig. 93A – extreme left corallite). In the holotype, at 6.0 mm corallite diameter this number amounted to a maximum of 17.

Remarks: With its small corallite size, a one-row dissepimentarium, and major septa exceeding one-half corallite radius, *T. columellata* sp. nov. is similar to *T. minor* Fedorowski, 1965. Fundamental differences, however, consist in the examined specimens having a continuous, more extensive axial structure and tabulae upturned towards the corallite axis, while representatives of *T. minor* have a poorly developed, irregular and discontinuous axial structure and trapezoid tabulae. Besides, it seems that also the difference in corallite diameters, while slight – *T. columellata* sp. nov. have diameters only 2.0-2.5 mm smaller than *T. minor* (15/3.0-17/6.0 *vs*. 15/5.5-17/8.0) – is significant. Given the small sizes of corallites of the compared species, this means that the specimens of *T. columellata* sp. nov. are as much as ca. 30% smaller than those of *T. minor*. What differentiate *T. columellata* sp. nov. from the remaining species of this genus, apart from much smaller corallite diameters, are longer major septa and an absence of domed and/or trapezoid tabulae.

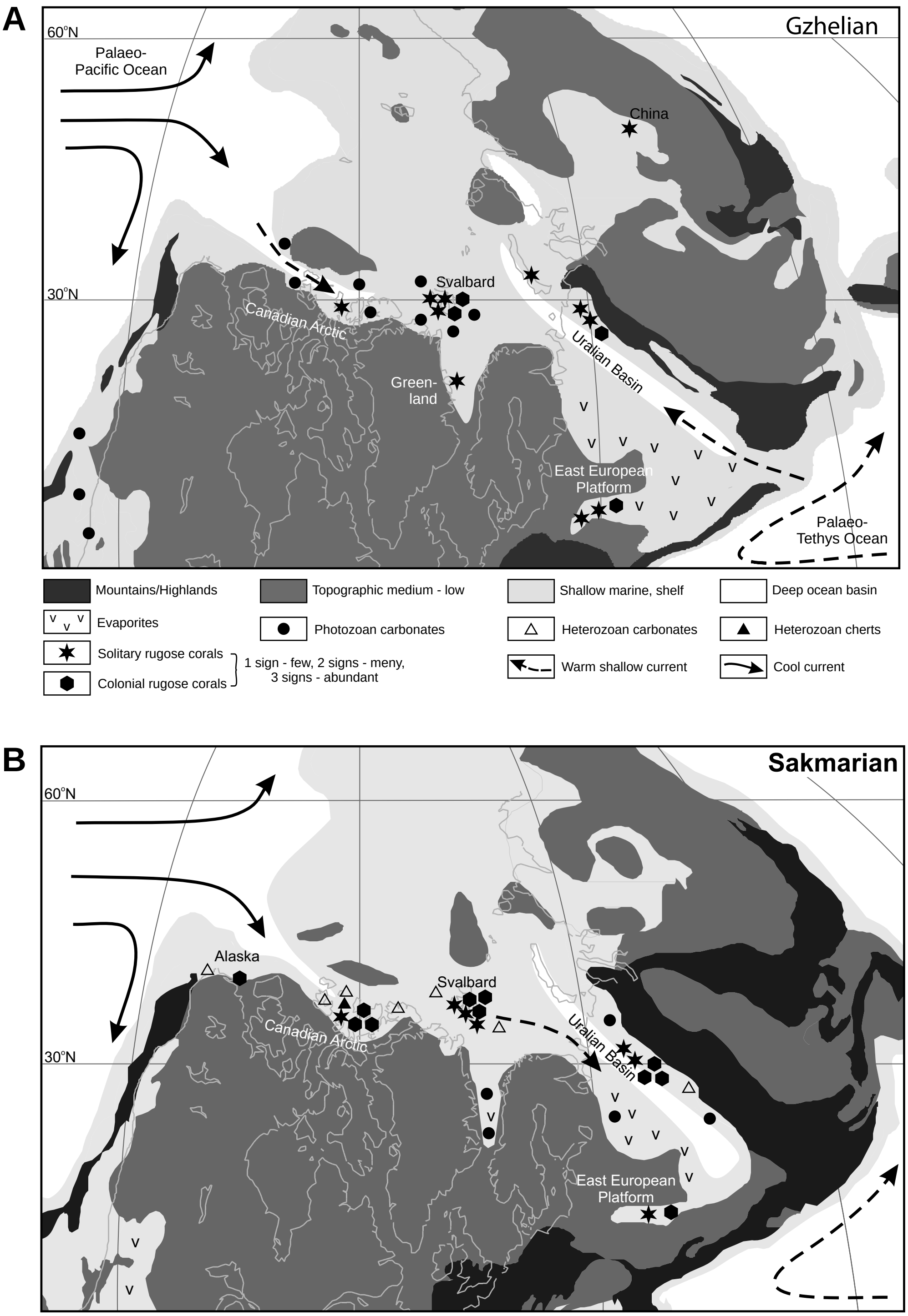
Occurrence: Spitsbergen, Kruseryggen – Lower Sakmarian, Tastubian.

5 ANALYSIS OF THE CORAL FAUNA

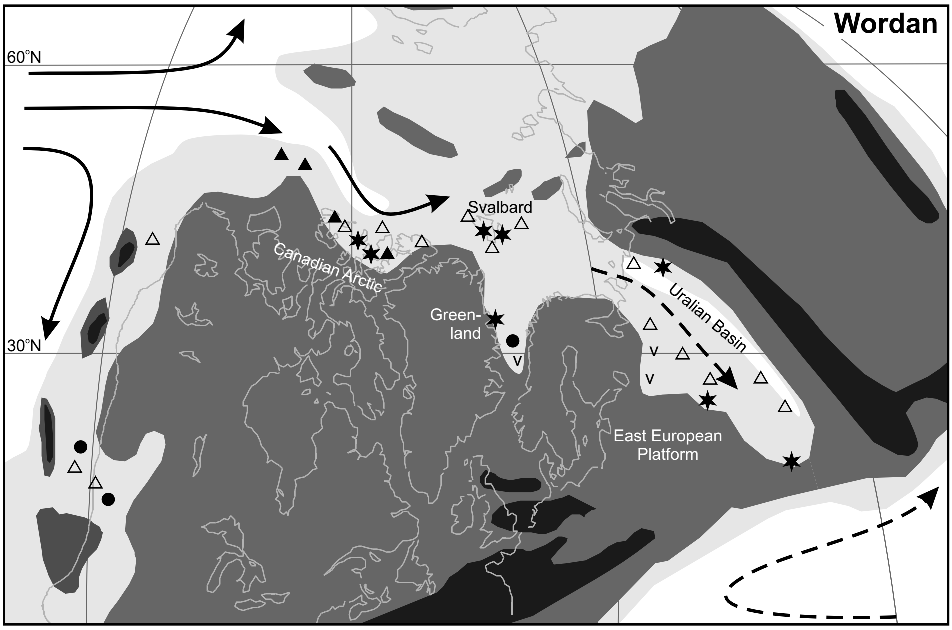
The collection of the Permian-Carboniferous Rugosa corals that served to form stratigraphic, palaeogeographical and ecological conclusions consists in 79% (339 specimens) of solitary forms and in 21% (90 specimens) of colonial ones (Table 1A, B). Among the solitary forms, the most numerous in the material under study are new species of *Pseudotimania*. They make up 29.5% of this group of specimens (or 23.3% of the entire collection, i.e. of solitary and colonial forms taken together). The less abundantly represented genera are: *Yakovleviella* – 10.9% (8.6%), *Arctophyllum* – 10.0% (7.9%), *Siedleckia* – 8.3% (6.5%), *Fedorowskites* gen. nov. – 7.7% (6.1%), *Gronfjordphyllum* gen. nov. – 5.3% (4.2%), and *Krusenella* gen. nov. – 4.1% (3.3%). Specimens of the remaining genera account for less than 3.0% of all solitary forms.

Among the colonial forms (Table 1B), more than one-fourth of specimens represent the genus *Heintzella*. They make up 5.8% of the entire collection. A bit less numerous are *Kleopatrina*, which account for 24.4% of the colonial forms (or 5.1% of the entire collection). Out of the remaining genera, *Tschussovskenia* make up 21.1% (4.4% of the total), *Protowentzelella* – 15.6% (3.3%), and *Fomichevella* – 7.8% (1.6%). *Paraheritschioides*? and *Pararachnastraea* are represented by single species: *P.? californiense* and *P. gracilis*.

In sum, this paper describes 62 taxa from Spitsbergen's Permian-Carboniferous exposures, of which as many as 17 are new species (Table 1A, B) established on the basis of 222 specimens making up 51.6% of the collection. Such a large number of specimens belonging to new species may be indicative of environmental conditions on Spitsbergen being perhaps more favourable for this, perhaps endemic, fauna than in the remaining areas of the northern shelf of Pangea (Figs 94A-C, 96A-D). Apart from the newly described species, also notable are those known from other parts of the Arctic, but found on Spitsbergen for the first time: *Yakovleviella tschernyschewi*, *"Alekseeviella"*, *Lytvolasma asymetrica, Kleopatrina arcturusensis, K. ftatateeta, K. grinnellensis, Paraheritschioides? californiense, Pararachnastraea gracilis,* and *Protowentzelella kunthi*.


A
Gzhelian
60°N
30°N
Palaeo-
Pacific Ocean
China
Svalbard
Canadian Arctic
Green-
land
Uralian Basin
East European
Platform
Palaeo-
Tethys Ocean
Mountains/Highlands
Topographic medium - low
Shallow marine, shelf
Deep ocean basin
Evaporites
Photozoan carbonates
Heterozoan carbonates
Heterozoan cherts
Solitary rugose corals
Colonial rugose corals
1 sign - few, 2 signs - meny,
3 signs - abundant
Warm shallow current
Cool current
B
Sakmarian
60°N
30°N
Alaska
Svalbard
Canadian Arctic
Uralian Basin
East European
Platform

C



D

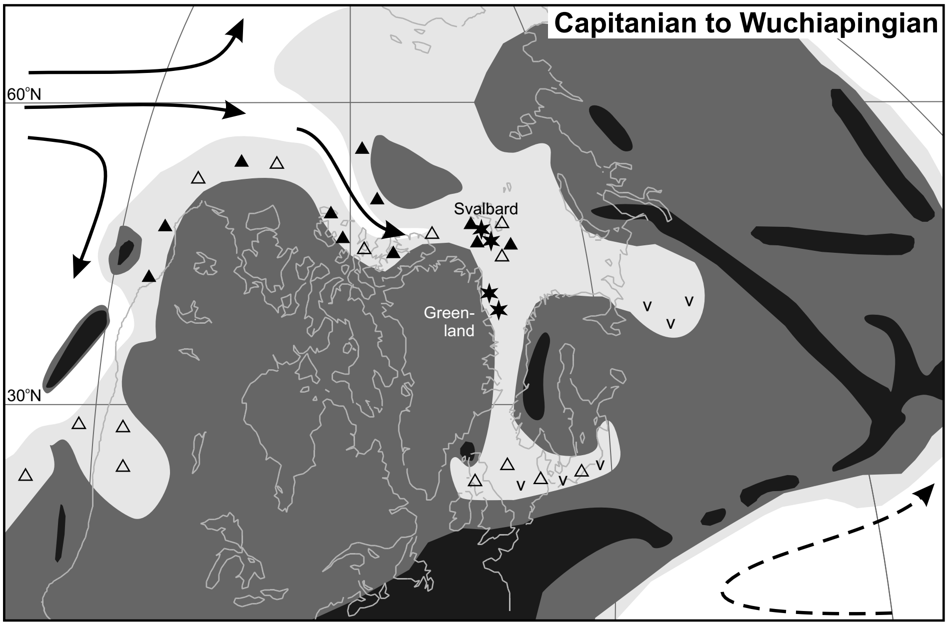
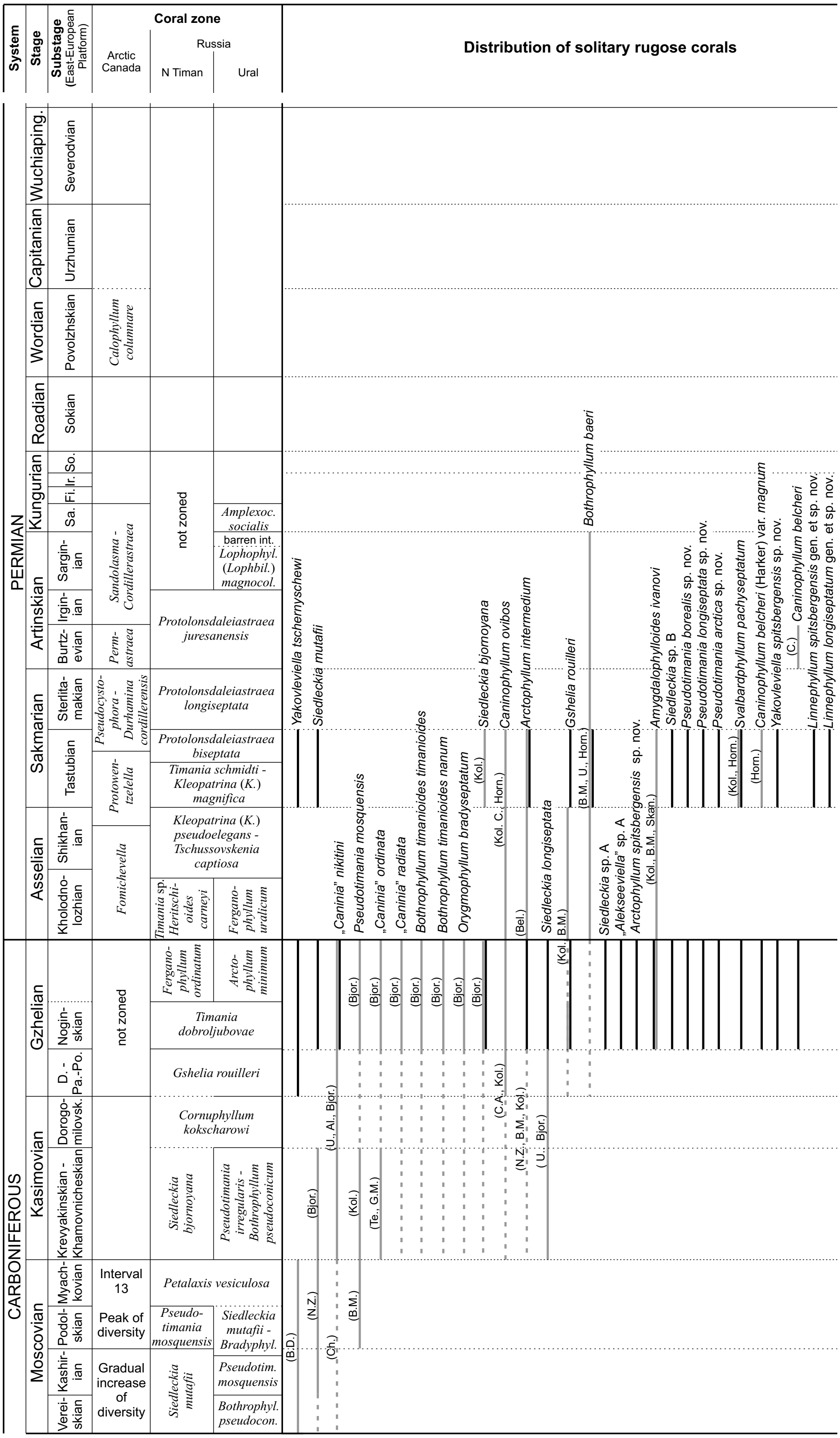


Fig. 94A-D. Carbonate environment reconstruction and coral localities. Base map modified from Golonka and Ford 2000, Reid et al. 2007. The terms photozoan and heterozoan, after James (1997), with colonial and solitary corals distinguished separately.


Distribution of solitary rugose corals
System
Stage
Substage (East-European Platform)
Coral zone
Arctic Canada
Russia
N Timan
Ural
CARBONIFEROUS
PERMIAN
Moscovian
Kasimovian
Gzhelian
Asselian
Sakmarian
Artinskian
Kungurian
Roadian
Wordian
Capitanian
Wuchiaping.
Verei-skian
Kashir-ian
Podol-skian
Myach-kovian
Krevyakinskian - Khamovnicheskian
Dorogo-milovsk.
D. - Pa.-Po.
Nogin-skian
Kholodno-lozhian
Shikhan-ian
Tastubian
Sterlita-makian
Burtz-evian
Irgin-ian
Sargin-ian
Sa.
Fi.
Ir.
So.
Sokian
Povolzhskian
Urzhumian
Severodvian
Gradual increase of diversity
Peak of diversity
Interval 13
not zoned
Fomichevella
Protowentzelella
Pseudocystophora - Durhamina cordillerensis
Permastraea
Sandolasma - Cordillerastraea
Calophyllum columnare
Siedleckia mutafii
Pseudotimania mosquensis
Petalaxis vesiculosa
Siedleckia bjornoyana
Cornuphyllum kokscharowi
Gshelia rouilleri
Timania dobroljubovae
Ferganophyllum ordinatum
Timania sp. Heritschioides carneyi
Kleopatrina (K.) pseudoelegans - Tschussovskenia captiosa
Timania schmidti - Kleopatrina (K.) magnifica
Protolonsdaleiastraea biseptata
Protolonsdaleiastraea longiseptata
Protolonsdaleiastraea juresanensis
Bothrophyl. pseudocon.
Pseudotim. mosquensis
Siedleckia mutafii - Bradyphyl.
Pseudotimania irregularis - Bothrophyllum pseudoconicum
Arctophyllum minimum
Ferganophyllum uralicum
Lophophyl. (Lophbil.) magnocol.
barren int.
Amplexoc. socialis
Yakovleviella tschernyschewi
Siedleckia mutafii
„Caninia" nikitini
Pseudotimania mosquensis
„Caninia" ordinata
„Caninia" radiata
Bothrophyllum timanioides timanioides
Bothrophyllum timanioides nanum
Orygmophyllum bradyseptatum
Siedleckia bjornoyana
Caninophyllum ovibos
Arctophyllum intermedium
Siedleckia longiseptata
Gshelia rouilleri
Bothrophyllum baeri
Siedleckia sp. A
„Alekseeviella" sp. A
Arctophyllum spitsbergensis sp. nov.
Amygdalophylloides ivanovi
Siedleckia sp. B
Pseudotimania borealis sp. nov.
Pseudotimania longiseptata sp. nov.
Pseudotimania arctica sp. nov.
Svalbardphyllum pachyseptatum
Caninophyllum belcheri (Harker) var. magnum
Yakovleviella spitsbergensis sp. nov.
Caninophyllum belcheri
Linnephyllum spitsbergensis gen. et sp. nov.
Linnephyllum longiseptatum gen. et sp. nov.
(B.D.)
(N.Z.)
(Ch.)
(B.M.)
(Bjor.)
(U., Al., Bjor.)
(Kol.)
(Te., G.M.)
(C.A., Kol.)
(N.Z., B.M., Kol.)
(U., Bjor.)
(Kol. C., Horn.)
(Bel.)
(Kol. B.M.)
(B.M., U., Horn.)
(Kol., B.M., Skan.)
(Kol., Horn.)
(Horn.)
(C.)

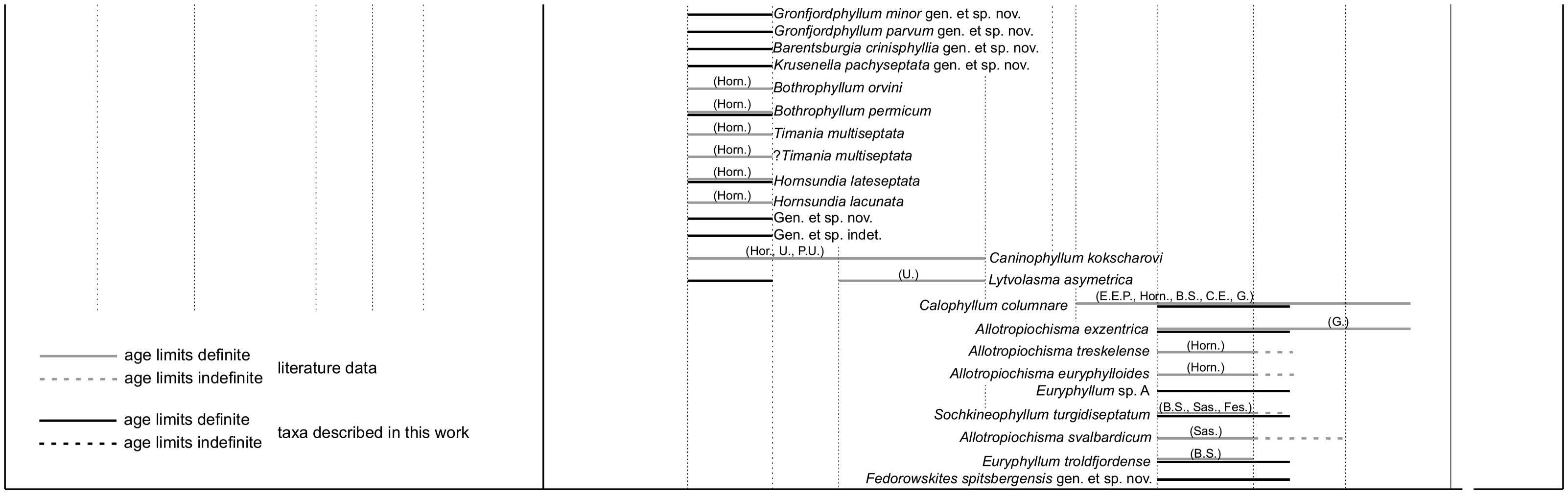
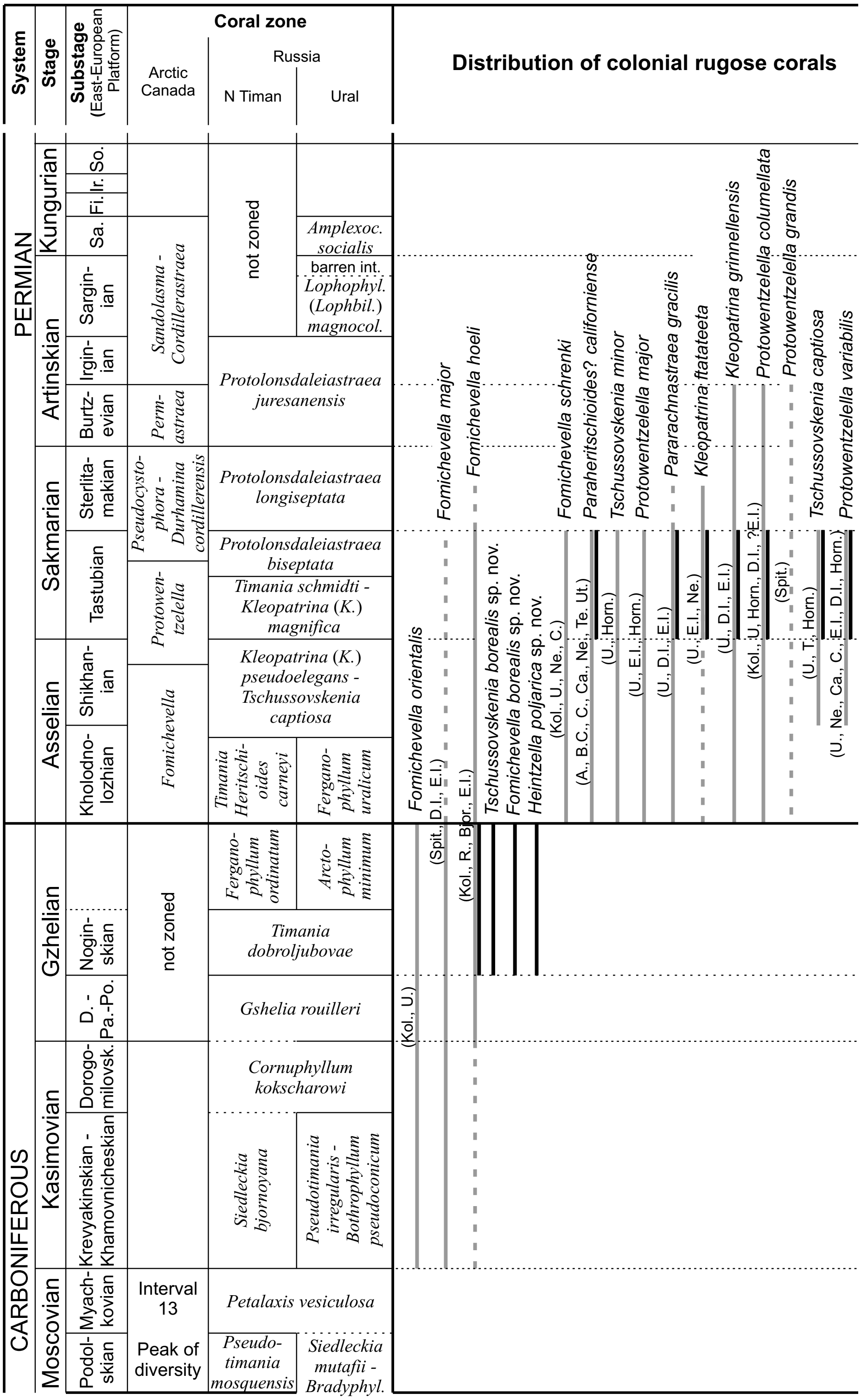


Fig. 95A. Distribution and zonation of Upper Carboniferous and Lower Permian solitary rugose corals known from Svalbard. Stratigraphic abbrev.: D. – Pa.-Po. = Dobryatinskian – Pavlovo-Posadskian zones; Sa. – Saranian; Fi. – Filippovskian; Ir. – Irenian; So. – Solikamskian (after Sando 1989; Kossovaya 1996; Goreva and Kossovaya 1997; Kossovaya 1997b; Kossovaya et al. 2001; Kossovaya 2009a; Fedorowski et al. 2007). Geographic abbrev.: A. – Alaska, Al. – Alps, B.C. – British Columbia, B.D. – Donetsk Basin, Bel. – Bellsund, Bjor. – Bjørnøya, B.M. – Moscow Basin, B.S. – Sverdrup Basin, C – cratonal Canada, C.A. – central Asia, Ca. – California, C.E. – Central European Basin, Ch. – China, D.I. – Devon Island, E.E.P. – East European Platform, E.I. – Ellesmere Island, Fes. – Festningen, G. – Greenland, G.M. – Glass Mts., Gu. – Guatemala, H.I. – Helen Island, Horn. – Hornsund (south Spitsbergen), Id. – Idaho, Kol. – Kolosseum (central Spitsbergen), Ne. – Nevada, N.Z. – Novaya Zemlya, R. – Russia (age and/or places not specified), Sas. – Sassendalen (central Spitsbergen), Skan. – Skansen (central Spitsbergen), Spit. – Spitsbergen (age and/or places not specified), T. – Timan, Te. – Texas, U – Urals, Ut. – Utah.



System
Stage
Substage (East-European Platform)
Coral zone
Arctic Canada
Russia
N Timan
Ural
Distribution of colonial rugose corals
CARBONIFEROUS
PERMIAN
Moscovian
Kasimovian
Gzhelian
Asselian
Sakmarian
Artinskian
Kungurian
Podol-skian
Myach-kovian
Krevyakinskian - Khamovnicheskian
Dorogo-milovsk.
D. - Pa.-Po.
Nogin-skian
Kholodno-lozhian
Shikhan-ian
Tastubian
Sterlita-makian
Burtz-evian
Irgin-ian
Sargin-ian
Sa.
Fi.
Ir.
So.
Peak of diversity
Interval 13
not zoned
Fomichevella
Protowen-tzelella
Pseudocysto-phora - Durhamina cordillerensis
Perm-astraea
Sandolasma - Cordillerastraea
Pseudo-timania mosquensis
Siedleckia mutafii - Bradyphyl.
Petalaxis vesiculosa
Siedleckia bjornoyana
Pseudotimania irregularis - Bothrophyllum pseudoconicum
Cornuphyllum kokscharowi
Gshelia rouilleri
Timania dobroljubovae
Fergano-phyllum ordinatum
Arcto-phyllum minimum
Timania Heritschi-oides carneyi
Fergano-phyllum uralicum
Kleopatrina (K.) pseudoelegans - Tschussovskenia captiosa
Timania schmidti - Kleopatrina (K.) magnifica
Protolonsdaleiastraea biseptata
Protolonsdaleiastraea longiseptata
Protolonsdaleiastraea juresanensis
Lophophyl. (Lophbil.) magnocol.
barren int.
Amplexoc. socialis
Fomichevella orientalis
(Kol., U.)
Fomichevella major
(Spit., D.I., E.I.)
Fomichevella hoeli
(Kol., R., Bjor., E.I.)
Tschussovskenia borealis sp. nov.
Fomichevella borealis sp. nov.
Heintzella poljarica sp. nov.
(Kol., U., Ne., C.)
Fomichevella schrenki
(A., B.C., C., Ca., Ne., Te. Ut.)
Paraheritschioides? californiense
(U., Horn.)
Tschussovskenia minor
(U., E.I., Horn.)
Protowentzelella major
(U., D.I., E.I.)
Pararachnastraea gracilis
(U., E.I., Ne.)
Kleopatrina ftatateeta
(U., D.I., E.I.)
Kleopatrina grinnellensis
(Kol., U, Horn., D.I., ?E.I.)
Protowentzelella columellata
(Spit.)
Protowentzelella grandis
(U., T., Horn.)
Tschussovskenia captiosa
(U., Ne., Ca., C., E.I., D.I., Horn.)
Protowentzelella variabilis

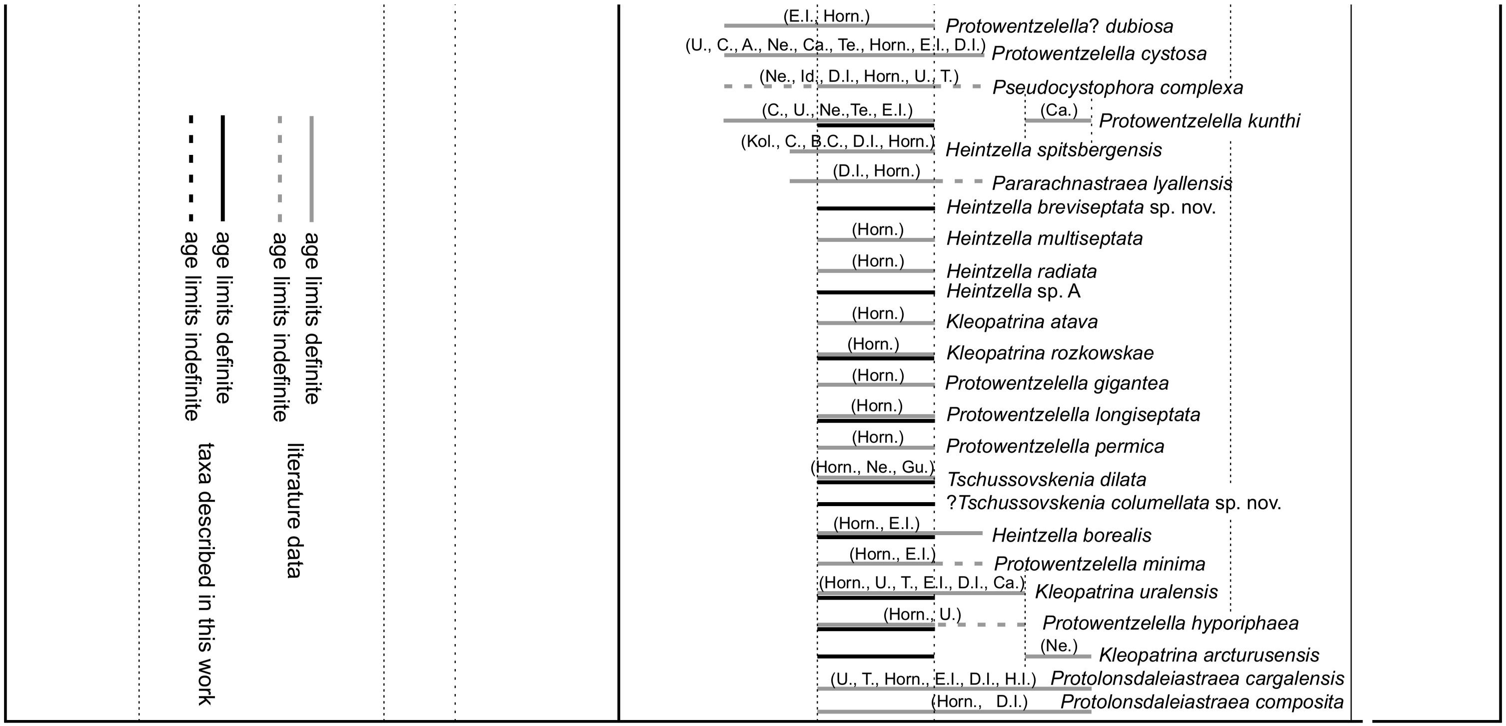


Fig. 95B. Distribution and zonation of Upper Carboniferous and Lower Permian colonial rugose corals known from Svalbard. For explanations see Fig. 95A.

Together with the taxa known from the literature, so far there have been 44 solitary coral species of 23 genera and 40 colonial coral species of 9 genera described from Svalbard (Fig. 95A, B). The taxonomic analysis of those animals has shown the principal characteristics of the collection described here to conform to the general rule of the occurrence of Rugosa in the Late Carboniferous and Early Permian as well as in the Middle Permian, at the end of Rugosa development. Predominant at the Permian and Carboniferous boundary are solitary dissepimental forms (Fig. 95A, an exception being *Krusenella pachyseptata* sp. nov.). Colonial forms, little diversified and less numerous in the Upper Carboniferous, attain the peak of their differentiation in the Early Permian (Figs 95B, 96A, B, D). In the Middle Permian (Figs 95A, B; 96C, D) there are no colonial forms, and solitary forms are dominated by non-dissepimental species of long-lived genera. This regularity, emphasised by Fedorowski (1982a) and observed earlier by Flügel (1973), with the only exception mentioned above, is not questioned in this dissertation, either.

Among the areas under study, the one best known in terms of coral associations is the Hornsund region with exposures on Treskelen, Kruseryggen and Triasnuten (Fedorowski 1964, 1965, 1967, 1975, 1982a, 1997; Birkenmajer 1964; Birkenmajer and Fedorowski 1980; Fedorowski et al. 1999; Fedorowski et al. 2007; Chwieduk 2007, 2009a). While the corals from Kruseryggen (Fig. 2E) were provisionally identified already in 1982 (Fedorowski 1982a) and first described in palaeontological terms (only solitary forms) in 2009 (Chwieduk 2009a), it is only this monograph that shows all the wealth of this group of animals in this region. The coral associations found there (Fig. 4, Tables 5, 6) demonstrate that they have much in common with the coral horizons distinguished by Birkenmajer (1964) on Treskelen, on Triasnuten (Birkenmajer and Fedorowski 1980), and to a lesser extent also with the slightly less well-studied corals from Lorchbreen, Urnetoppen and Hyrnefjellet (the Hornsund area, Fedorowski 1965). An analysis of the 32 fragments of the Kruseryggen colony (Table 1B) showed them to belong to three families: Durhaminidae Minato and Kato, 1965, Kleopatrinidae Fedorowski et al., 2007, and Lithostrotionidae D'Orbigny, 1851, in which four genera were identified with ten species, including one new, *Tschussovskenia columellata* sp. nov.

The most important element of this monograph, which is also most interesting from the cognitive point of view, is the palaeontological characterisation of Rugosa corals so far completely unknown from the Polakkfjellet, Linnédalen and Blendadalen regions (Figs 2C-D, 5-8). They vary greatly in qualitative and quantitative in terms, which shows this group of animals to have contributed a substantial share to the faunas of the Upper Carboniferous as well as the Lower and Middle Permian on Svalbard. The Polakkfjellet collection (Figs 2D, 5) contains solitary and colonial forms of five families (Bothrophyllidae

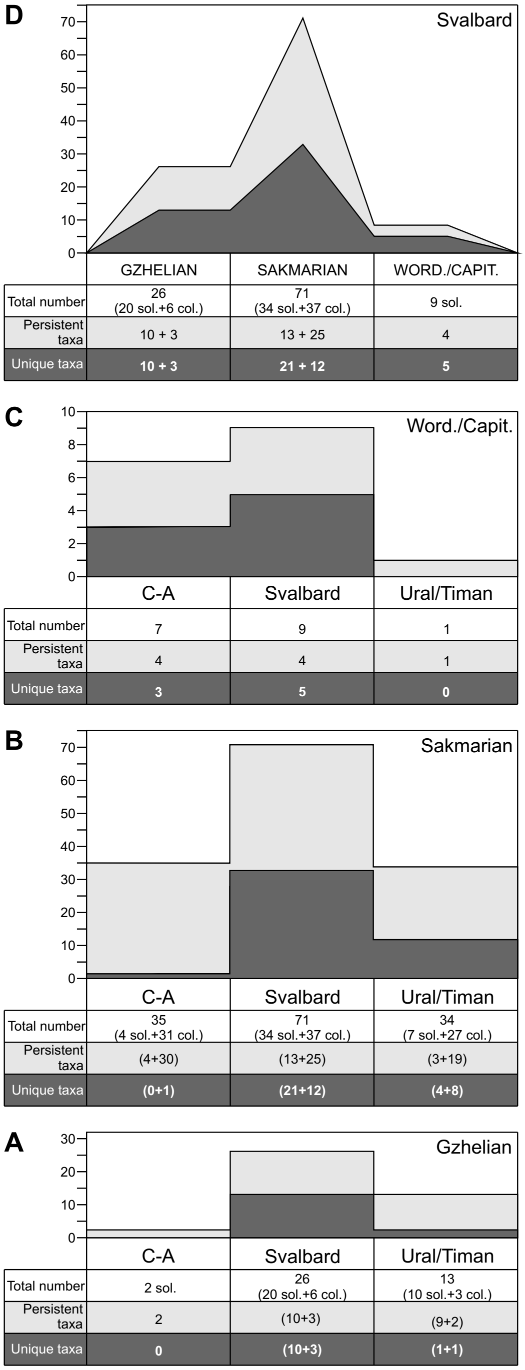


Fig. 96A-D. Dynamics of Rugosa in northern Pangea in the Gzhelian-Wordian/Capitanian. C-A – Arctic Canada; sol. – solitary rugose corals, col. – colonial rugose corals

Table 5. Distribution of solitary Rugosa in the Treskelen, Kruseryggen and Triasnuten areas, south Spitsbergen.

		Treskelen – Creek IV (Fedorowski, 1965)	**Kruseryggen** (Chwieduk 2009*a* and this work)	**Triasnuten** (Birkenmajer and Fedorowski, 1980)
Coral horizons	V	*Bothrophyllum permicum* Fedorowski, 1965; *Caninophyllum belcheri* var. *magnum* Fedorowski, 1965; *Caninophyllum ovibos* (Salter); *Caninophyllum* sp.; *Timania multiseptata* Fedorowski, 1965	*Bothrophyllum baeri* Stuckenberg, 1895; *Bothrophyllum* cf. *orvini*; *Caninophyllum belcheri* var. *magnum* Fedorowski, 1965; *Hornsundia lateseptata* Fedorowski, 1965; *Krusenella pachyseptata* gen. et sp. nov.; *Pseudotimania borealis* sp. nov.; *Pseudotimania longiseptata* sp. nov.; *Timania multiseptata* Fedorowski, 1965; ?*Timania multiseptata* Fedorowski, 1965	?*Hornsundia* sp. *Pseudotimania* sp.
	IV	*Bothrophyllum permicum* Fedorowski, 1965; *Caninophyllum kokscharowi* (Stuckenberg, 1895); *Svalbardphyllum pachyseptatum* Fedorowski, 1965	*Bothrophyllum baeri* Stuckenberg, 1895; ?*Timania multiseptata* Fedorowski, 1965	
	III	*Caninophyllum kokscharowi* (Stuckenberg, 1895); *Svalbardphyllum* sp.	*Hornsundia lateseptata* Fedorowski, 1965; *Pseudotimania borealis* sp. nov.; *Pseudotimania longiseptata* sp. nov.; ?*Timania multiseptata* Fedorowski, 1965; *Svalbardphyllum pachyseptatum* Fedorowski, 1965	*Pseudotimania* sp., *Svalbardphyllum pachyseptatum* Fedorowski, 1965
	II	*Caninophyllum* sp.; *Svalbardphyllum pachyseptatum* Fedorowski, 1965		
	I	*Bothrophyllum orvini* Fedorowski, 1967		

Fomitchev, 1953, Cyathopsidae Dybowski, 1873, Geyerophyllidae Minato, 1955, Kleopatrinidae Fedorowski et al. 2007, and Lithostrotionidae D'Orbigny, 1851), in which 13 genera were identified with 17 species (7 of them new) and one subspecies; three taxa were left in the open nomenclature (Table 1A, B). All the taxa come from the lower part of the Treskelodden Formation dated to the Gzhelian (Fig. 5).

From the Linnédalen area, 267 specimens were used for palaeontological studies, including 43 fragments of a colony (Table 1A, B). The rugosans of this area belong to six families: Antiphyllidae Ilina, 1970, Aulophyllidae Dybowski, 1873, Bothrophyllidae Fomitchev, 1953, Cyathopsidae Dybowski, 1873, Kleopatrinidae Fedorowski et al. 2007, and Lithostrotionidae D'Orbigny, 1851. For taxonomic reasons, three new genera (*Linnephyllum, Gronfjordphyllum* and *Barentsburgia*), represented by 28 specimens, were not assigned to any of the known families; for the time being they were left in the family *incertae sedis*. The Linnédalen corals come from two formations, Wordiekammen (Figs 3, 7, the Linnédalen area) and Kapp Starostin (Figs 3, 8, the Blendadalen and Kapp Starostin profiles).

Table 6. Distribution of colonial Rugosa from the Treskelen to Triasnuten areas, south Spitsbergen.

Coral horizons	Treskelen – Creek IV (Fedorowski, 1965)	Hyrnefjellet (Fedorowski 1965)	Urnetoppen (Fedorowski 1965)	Kruseryggen (this work)	Triasnuten (Birkenmajer and Fedorowski 1980; Fedorowski et al. 2007)
V	*Protowentzelella cystosa* (Dobrolyubova, 1936*a*); *P. hyporiphaea* (Porfiriev, 1941); *P. variabilis* Fedorowski, 1965; *P. minima* (Fedorowski, 1967); *P. gigantea* (Fedorowski, 1965)	*Kleopatrina magnifica* (Porfiriev, 1941); *Protowentzelella permica* (Fedorowski, 1965)	*Protowentzelella permica* (Fedorowski, 1965)	*Kleopatrina ftatateeta* (McCutcheon and Wilson, 1961); *K. uralensis* (McCutcheon and Wilson, 1961); *Pararachnastraea gracilis* (Dobrolyubova, 1941); *Protowentzelella columellata* Fedorowski et al., 2007; *P. hyporiphaea* (Porfiriev, 1941); *P. kunthi* (Stuckenberg, 1895); *P. variabilis* Fedorowski, 1965; *Tschussovskenia captiosa* Dobrolyubova, 1936*a*; ?*Tschussovskenia columellata* sp. nov.	*Pararachnastraea atava* (Fedorowski, 1965); *Protowentzelella columellata* Fedorowski et al., 2007; *P. cystosa* (Dobrolyubova, 1936*a*); *P. hyporiphaea* (zPorfiriev, 1941); *P. longiseptata* Fedorowski, 1980; *P. variabilis* Fedorowski, 1965; *P.* sp.; *Tschussovskenia minor* Fedorowski, 1965
IV	*Heintzella radiata* (Fedorowski, 1965); *Protowentzelella minima* (Fedorowski, 1967); *Tschussovskenia captiosa* Dobrolyubova, 1936*a*	*Kleopatrina atava* (Fedorowski, 1965), *Pararachnastraea lyallensis* Fedorowski et al., 2007	*Tschussovskenia captiosa* Dobrolyubova, 1936*a*	*Paraheritschioides*? *californiense* (Meek, 1864); *Kleopatrina uralensis* (McCutcheon and Wilson, 1961); *Protowentzelella variabilis* Fedorowski, 1965; *Tschussovskenia captiosa* Dobrolyubova, 1936*a*	
III	*Heintzella multiseptata* Fedorowski, 1967				
II	*Heintzella borealis* Fedorowski et al., 2007, *H. densiseptata* Fedorowski, 1967; *H. multiseptata* Fedorowski, 1967; *H. spitsbergensis* Fedorowski, 1965); *Kleopatrina magnifica* (Porfiriev, 1941); *K. rozkowskae* Fedorowski, 1967; *Permastraea biseptata* (Dobrolyubova, 1936*a*); *Protolonsdaleiastraea composita* Fedorowski, 1967; *Protowentzelella cystosa* (Dobrolyubova, 1936*a*); *P. hyporiphaea* (Porfiriev, 1941); *P. variabilis* Fedorowski, 1965; *P. permica* (Fedorowski, 1965); *P. minima* (Fedorowski, 1967); *P*?. *dubiosa* (Fedorowski, 1967); *Tschussovskenia kiaeri* Fedorowski, 1965; *T. dilata* Fedorowski et al., 2007				
I	*Heintzella spitsbergensis* (Fedorowski, 1965)	*Kleopatrina atava* (Fedorowski, 1965)			

It seems that the rugosans presented in this monograph are the largest collection in the world of corals described from Spitsbergen. With the foraminifer dating obtained on Polakkfjellet and the earlier studies of corals (Fedorowski, 1965, 1967, 1982a; Birkenmajer and Fedorowski, 1980; Somerville 1997; Fedorowski et al. 2007), they provided a basis for a reconstruction of the sedimentary environments, palaeogeography, and a more consistent stratigraphy of the Upper Carboniferous and Lower Permian on Spitsbergen. Those generalisations, and especially the correlation of the sedimentary formations of the central and southern parts of the island, have so far rested on suppositions rather than facts.

5.1. Stratigraphic significance of the Spitsbergen rugosans

On Spitsbergen, biostratigraphic studies are closely connected with lithostratigraphic ones. The history of the latter starts in the early 20th century. Among the first notes on the Late Palaeozoic stratigraphy of Spitsbergen (the Billefjorden and Tempelfjorden areas) were those published by Nathorst (1910). The layers with *Cyathophyllum* that he described were then assigned to the Gipshuken and Wordiekammen Formations (Gee et al. 1953). Later those separations were revised by Forbes et al. (1958) as well as Cutbill and Challinor (1965). The latter authors put the informal lithostratigraphic units into order and proposed three age groups for them: an Early Carboniferous one, included within the lithostratigraphic Billefjorden Group, a Late Carboniferous-Early Permian one, called the Gipsdalen Group, and a Late Permian one, assigned to the Tempelfjorden Group. The revision of the Late Carboniferous and Permian stratigraphy outlined by Dallmann et al. (1996 *fide* Harland 1997) and Pickard et al. (1996), and complemented by Harland (1997) to include the next formations and lower-order units, brought the inclusion of all those separations into a higher-order unit that covers the rock succession from the entire Svalbard area. This is the so-called Bünsow Land Supergroup (Fig. 3). And while the upper boundary of the Kapp Starostin Formation has not been determined with any accuracy, this division is generally accepted by both, geologists (e.g. Dallmann 1999) and palaeontologists, e.g. Somerville (1997), Fedorowski (1997), and Fedorowski et al. (2007).

In spite of the growing number of biostratigraphic data of the Late Palaeozoic succession based on fusulinids, conodonts and corals (Nilsson 1988 and 1993 *fide* Samuelsberg and Pickard 1999; Nakrem et al. 1992; Fedorowski 1965, 1967, 1982a; Birkenmajer and Fedorowski 1980; Somerville 1997), stratigraphy of this region is still neither complete, nor unequivocal. This may be due to the complicated geological structure of Svalbard. The Spitsbergen Basin is tectonically complex and dissected by several faults, mainly N-S and NNW-SSE oriented, among which the Kongsbreen-Hansbreen Fault, separating western and central Spitsbergen, and the Billefjorden Fault, separating central Spitsbergen from its eastern part (Fig. 2B), were active nearly throughout the Carboniferous (Harland 1997). Two chief blocks (Nordfjorden and Ny Friesland) were active north of Isfjorden, and one (Sørkapp-Hornsund) in the south of Spitsbergen. From the Bashkirian on, those blocks were positive landforms. Directly adjacent to the Spitsbergen Basin, they greatly affected the character of sedimentation in it as well as the distribution and taxonomic diversity of its Carboniferous and Permian rugosans.

The Rugosa corals known from the Spitsbergen Basin are a substantial element of the Carboniferous and Permian fauna. Their stratigraphic value, while not great, lies in the possibility of complementing, or making more precise, the existing stratigraphic data, especially those obtained on the basis of lithostratigraphic research. Regrettably, not all Rugosa corals found on Spitsbergen are of acceptable taxonomic and stratigraphic worth. The first Spitsbergen collections of rugosans were often described and illustrated in an unsatisfactory way, sometimes only in the form of lists (as in Forbes et al. 1958, for example). Such lists cannot provide a basis for any detailed studies also because of the current state of systematics, which still leaves much room for a subjective interpretation of individual taxa. Besides, sampling sites were not always marked correctly. This is the case with the collections examined by Heritsch (1939). The sites where they were sampled are indicated in highly general terms (e.g. Cyathophyllum Limestone, Coral Limestone or Dickson Bay), and their age has partly been established only after repeated determinations of those collections. They indicate, for example, that *Caninia hoeli*, today *"Caninia" hoeli*, probably comes from the Uppermost Moscovian (Forbes et al. 1958), *Cystophora svalbardica*, included within *Permastraea* (Fedorowski et al. 2007), from the Sakmarian-Lower Artinskian, while the age of three species of *"Petalaxis"* and two of *"Orionastraea"*, classed by Fedorowski et al. (2007) as *Protowentzelella*, is Asselian-Lower Artinskian. In the opinion of the last authors, in terms of age they can correspond to specimens described by Somerville (1997) as *Stylastraea*, which he collected from the so-called Limestone B dated to the Sakmarian. In turn, species included by Heritsch (1939) within *Lithostrotion* and *Lithostrotionella*, today placed in *Petalaxis*, were probably collected from equivalents of upper layers of the Moscovian, because representatives of this genus are not known from the Spitsbergen Permian (Fedorowski et al. 2007).

One of the regions with a well-studied coral fauna is certainly the eastern part of Isfjorden (James 1 and Bünsow Lands – the Kolosseum, Coraholmen and Skansen areas; Somerville 1997). This author reports numerous occurrences of cerioid colonies of *Petalaxis* as well as phaceloid colonies of

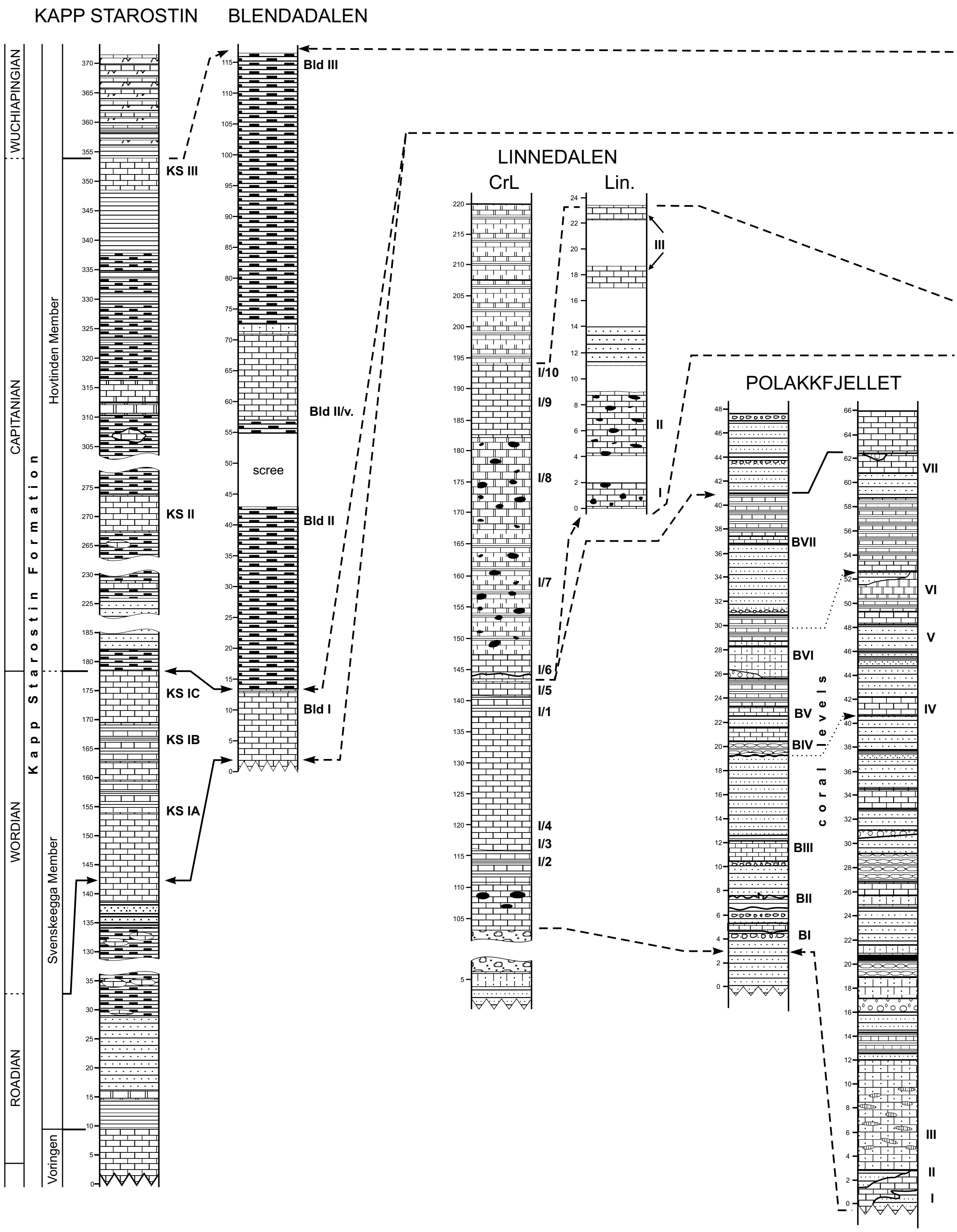
?Tschussovskenia, ?Profischerina and *Fomichevella* in the lower part of the Wordiekammen Formation (Kapitol Member, Upper Moscovian). Solitary Rugosa corals (*Amygdalophylloides ivanovi, Arctophyllum intermedium, "Caninia", "Caninophyllum" ovibos, Carinthiaphyllum sp., Cornuphyllum nikitini, Gshelia rouilleri*), according to him, predominate in the upper part of the Kapitol and Cadellfjellet Members, dated here to the Kasimovian and Gzhelian, where they co-occur with colonial Tabulata, algal bioherms, and a few *Fomichevella*. In the Lower Asselian, Somerville (1997) finds *Amygdalophylloides ivanovi, Bothrophyllum timanioides, Carinthiaphyllum* sp., *Gshelia rouilleri*, *Fomichevella, Heintzella spitsbergensis* and *Tschussovskenia*. In turn, near the top of the Tyrrellfjellet Member (the so-called Limestone B), dated to the Sakmarian, he observes colonial rugosans *[Kleopatrina (Kleopatrina) magnifica*, *"Stylastraea"* sp. and *"Thysanophyllum" dubiosum*, today all included within *Protowentzelella* (Fedorowski et al. 2007)] co-occurring with solitary ones: *Bothrophyllum* sp., *Gshelia* sp., *Timania* sp., *Pseudotimania latifossulata*, *Svalbardphyllum pachyseptatum* and *Siedleckia bjornoyana*. This information is significant because of the occurrence in the eastern part of Isfjorden of the species important for the analysis of the corals I collected in the western part of Isfjorden, in the Linnédalen area. It turns out that the corals found in the Linnédalen area in the Upper Carboniferous (Wordiekammen Formation, Fig. 7) have no counterparts in the fauna presented by Somerville (1997) as characteristic of eastern Isfjorden. Out of the Rugosa identified in Linnédalen, in the lower part of the Tyrrellfjellet Member, *Siedleckia longiseptata, S. mutafii, "Caninia" nikitini, Arctophyllum spitsbergensis* sp. nov. and *Yakovleviella tschernyschevi*, dominant in the Carboniferous, are indicative of the Gzhelian. However, none of those species are on Somerville's (1997) list of the Upper Carboniferous corals from the eastern part of Isfjorden. Also representatives of *Caninophyllum, Cornuphyllum, Amygdalophylloides, Carinthiaphyllum* or *Fomichevella*, documented in the Gzhelian of east Isfjorden are absent from the Gzhelian of Linnédalen. In turn, *Gshelia rouilleri*, known in eastern Isfjorden from the Gzhelian throughout the Asselian to the Sakmarian, in the Linnédalen area only appears in the Sakmarian.

Species of colonial *Kleopatrina, Heintzella* and *Protowentzelella*, solitary *Hornsundia lateseptata* and *Bothrophyllum permicum* as well as those of newly established genera *Krusenella, Linnephyllum, Barentsburgia* and *Gronfjordphyllum* that were dominant in the Tastubian, indicate the upper layers of Tyrrellfjellet to be of Permian age. In Linnédalen they co-occur with *Gshelia, Pseudotimania* and *Siedleckia* (Fig. 7), known also from the east of Isfjorden where there are also numerous *Protowentzelella*. By combining those biostratigraphic data with the stratigraphic relations established, the upper boundary of the Wordiekammen Formation in the Linnédalen area can be placed in the higher part of the

Sakmarian. The absence from my study area of representatives of colonial *Fomichevella* and *Tschussovskenia* as well as solitary *Amygdalophylloides ivanovi, Bothrophyllum timanioides* and *Carinthiaphyllum*, documented by Somerville (1997) in the Asselian of eastern Isfjorden, can suggest non-deposition or erosion in the western part of Isfjorden at that time. The Gzhelian/Sakmarian boundary in this area would run roughly in mid-thickness of the Wordiekammen Formation, in the erosional surface (Fig. 7).

The research I conducted in the Linnédalen area also made it possible to refer to the youngest part of the Permian-Carboniferous succession, viz. the Kapp Starostin Formation (Fig. 8), with stratigraphically the youngest autochthonous Svalbard rugosans. Corals are scarce in this formation and still hardly known. They may include the two species described by Heritsch (1939), who, however, did not determine their stratigraphic position. One can presume (by analogy) that they come from the Kapp Starostin Formation. One species was described by Tidten (1972); another, left in the open nomenclature, by Fedorowski (1975); a few specimens, assigned to three species and two left in the open nomenclature, were illustrated (without a description) by Ezaki and Kawamura (1992). Thus, the Rugosa collection from the Kapp Starostin Formation I present in this work is the largest one so far. Not counting the specimens from Treskelen described earlier (Chwieduk 2007), it consists of 49 corallites (Table 1A) documenting the presence of the Svenskeegga and Hovtinden Members on Kapp Starostin and in Blendadalen (Fig. 6). In terms of age, therefore, it matches the Wordian and Capitanian (Fig. 8). Considering the lithological characteristics of this formation and the fact that the Vøringen and Svenskeegga Members pinch out towards the south of Spitsbergen, on Treskelen we should have the Hovtinden Member. It seems, therefore, that on Treskelen the age of the Kapp Starostin Formation, initially determined as the Wordian (Chwieduk 2007), can in fact extend to the Capitanian (Figs 8, 97).

In the Hornsund area (the Treskelen Peninsula), apart from the Middle Permian (the Kapp Starostin Formation), also equivocal are stratigraphic results of studies of the Carboniferous and Permian boundary. The Hyrnefjellet and Treskelodden Formations characteristic of this region changed their stratigraphic positions many times. Birkenmajer and Czarniecki (1960) assigned the Hyrnefjellet "member" to the Bashkirian and Moscovian Stages, the Treskelodden "member" to the Gzhelian, and brachiopod limestones with cherts (today the Kapp Starostin Formation) to the Kungurian. Having no unequivocal foraminifer data (Liszka 1964), Birkenmajer (1964) considered the Treskelodden "member" to be Upper Carboniferous (Gzhelian) – Lower Permian (Sakmarian). In his 1963 research on corals (published in 1965), Fedorowski gave the preliminary age of the upper Treskelodden layers as the Artinskian. Czarniecki (1969), on the basis of brachiopods, again as-



KAPP STAROSTIN
BLENDADALEN
LINNEDALEN
CrL
Lin.
POLAKKFJELLET
WUCHIAPINGIAN
CAPITANIAN
WORDIAN
ROADIAN
Kapp Starostin Formation
Hovtinden Member
Svenskeegga Member
Voringen
KS III
KS II
KS IC
KS IB
KS IA
Bld III
Bld II/v.
scree
Bld II
Bld I
I/10
I/9
I/8
I/7
I/6
I/5
I/1
I/4
I/3
I/2
III
II
I
BVII
BVI
BV
BIV
BIII
BII
BI
coral levels
VII
VI
V
IV
III
II
I

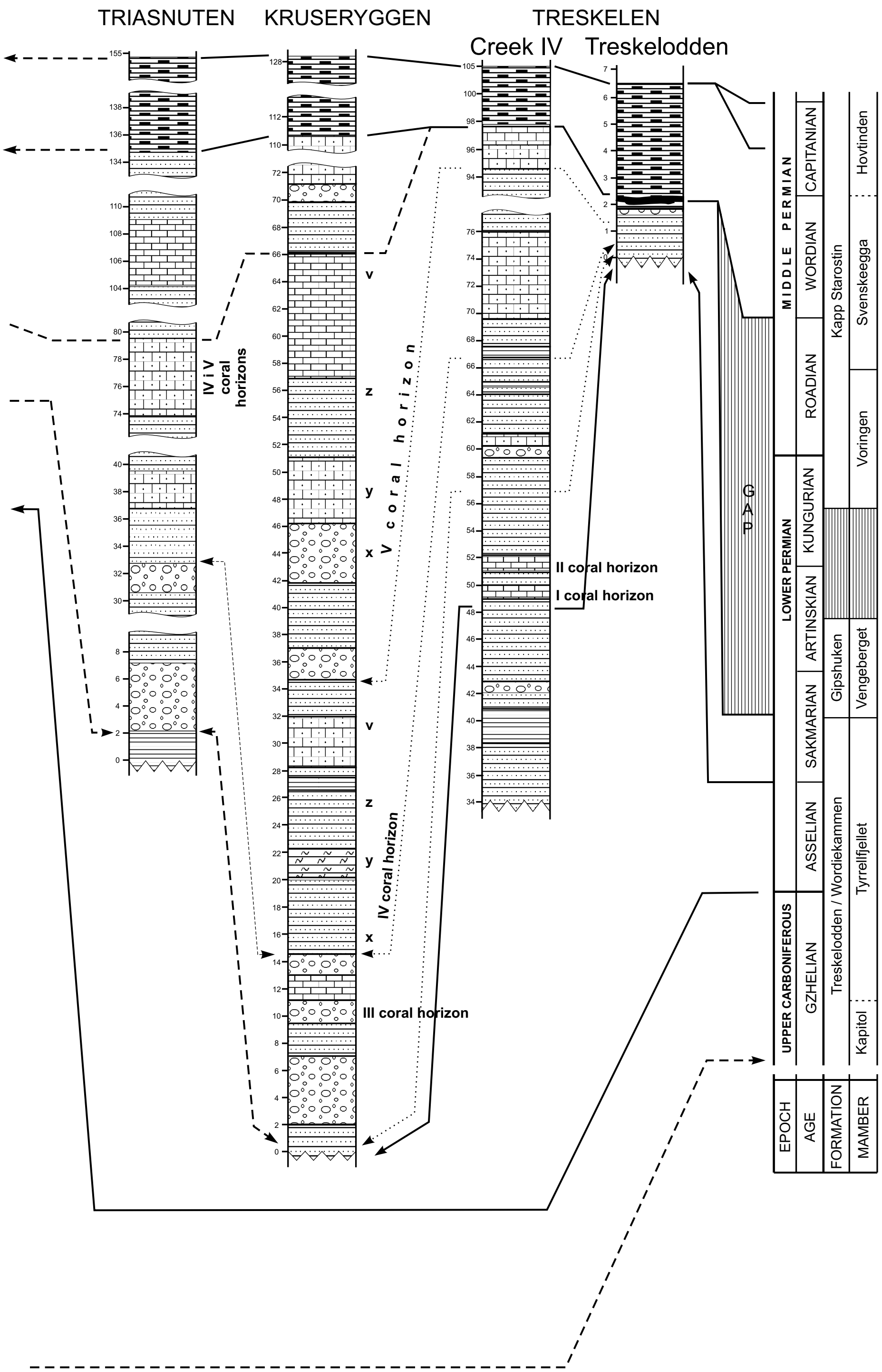


Fig. 97. Biostratigraphic correlation of the Gzhelian-Capitanian in the west of Spitsbergen (the Hornsundu area, Polakkfjellet hill and Linnédalen area).

signed the entire Treskelodden "member" to the Upper Carboniferous. His opinion was corrected by Waterhouse (1976), who, on the basis of the same fauna, decided the Treskelodden "member" to be Lower Permian. In turn, Keilen (1992) as well as Stemmerik and Worsley (1989, 1995) considered the age of this formation to be Late Carboniferous-Early Asselian. This, however, was opposed by Fedorowski et al. (1999), Fedorowski and Bamber (2001), and Fedorowski et al. (2007), who claimed the controversial age of the upper part of the Treskelodden Formation to correspond probably to the Late Asselian and Early Sakmarian. They came to this conclusion on the basis of an analysis of the fauna of the C-A-U Realm. This means they did not accept the extension of the age range of the Treskelodden Formation to the Lower Artinskian, as proposed by Dallmann (1999).

Regrettably, in the absence of index fossils, the problem of the age of this formation is still open. Thus, the stratigraphic position of the Treskelen corals is still uncertain, which complicates the correlation of this region with the Polakkfjellet area and central Spitsbergen. Filling the gaps in an earlier study of Kruseryggen corals (Chwieduk 2009a) also contributed little to the stratigraphy because they turned out to match the Treskelen stratigraphy proposed by Fedorowski et al. (1999, 2007). Out of the five coral horizons (*sensu* Birkenmajer 1964) documented in the area of their typical development, i.e. Treskelen, the higher three were identified on the Kruseryggen elevation (Figs 4, 97; Table 5, 6). The first and second, documented on Treskelen, were not found on Kruseryggen, even though the corresponding layers were identified at both sites. This would corroborate an earlier thesis (Fedorowski 1982a) derived from studies of the Triasnuten rugosans that the lower coral horizons do not occur in the northern part of Burgerbukta.

By reference to the stratigraphic ranges of corals identified on Treskelen and Triasnuten, the age of the Kruseryggen coral horizons was established to be Early Sakmarian (Tastubian; upper part of the Treskelodden Formation). This result, although initially obtained on the basis of solitary corals (Chwieduk 2009a), has been fully documented on examination of the colonial forms of Rugosa described in this monograph for the first time (Figs 4, 97).

With the above-mentioned works on the corals of central and southern Spitsbergen in mind, as well as studies by Nysaether (1977) and Hellem and Worsley (1978) of Torell and Sørkapp Lands presenting the equivalents of rocks of the Treskelodden Formation, I undertook to correlate the profiles I examined in the belt of Permian-Carboniferous outcrops extending from Treskelen to Linnédalen (Figs 2, 97). A good link between the Hornsund corals and those of the western part of the Isfjorden area is coral associations identified on Polakkfjellet. They consist of solitary dissepimental forms and phaceloid colonies (Table 1A, B; Fig. 5). Those Gzhelian-dated corals coming from the Treskelodden Formation are treated as an association characterising its lower part, so they are among the oldest ones in this part of Spitsbergen.

The species found in the southern part of the Polakkfjellet hill are few and represented by a small number of specimens, which makes them insufficient for stratigraphic considerations (Fig. 5A). Fortunately, the foraminifers found in the higher part of the profile made it possible to specify the age of those rocks as Late Gzhelian. In the northern part of the elevation corals are more numerous and more diversified in qualitative terms (Fig. 5B). The species identified in the coral levels distinguished there were both, those typical of the Upper Carboniferous and those known from the Lower Permian (compare Fig. 5 with Fig. 95A, B), which can be indicative of a transitional nature of coral associations representing the Gzhelian on Polakkfjellet.

This fact, therefore, supplies some information about the stratigraphic ranges of the species found there. *Siedleckia longiseptata, S. mutafii* and *S. bjornoyana*, so far known from the Moscovian and/or Kasimovian, extend their stratigraphic ranges to younger stages. In turn, the species and one subspecies so far known from the Lower Permian (*Svalbardphyllum pachyseptatum, Caninophyllum belcheri* and *C. belcheri* (Harker) var. *magnum*) enlarge their stratigraphic ranges to the Gzhelian. Similarly *Heintzella* (*Heintzella* cf. *davydovi*), so far never documented outside the Permian anywhere in the world, seems to have expanded its range to the Gzhelian stage. Among the new species of solitary rugosans, *Arctophyllum spitsbergensis* sp. nov can be of some significance for stratigraphy in the future because its Gzhelian age is corroborated by the occurrence of those corals in the Linnédalen area in rocks of similar age (Fig. 7). What can also indirectly point to the Gzhelian is the similarity of *Arctophyllum spitsbergensis* sp. nov to the Early Gzhelian *A. lugankaensis* known from the Donets Basin. The remaining new species of solitary corals (*Pseudotimania arctica* sp. nov., *P. borealis* sp. nov. and *P. longiseptata* sp. nov.), also found in the Linnédalen area (Gzhelian-?Asselian-Sakmarian), with two of them (*P. longiseptata* sp. nov. and *P. borealis* sp. nov.) also on Kruseryggen in Lower Sakmarian rocks (Table 1A), can thus be taken to have a wider stratigraphic range.

Colonial forms, although of greater stratigraphic significance than solitary forms, on Polakkfjellet contribute nothing to the stratigraphy adopted. *Fomichevella hoeli*, known from Bjørnøya, Russia and Ellesmere Island (?Kasimovian-Late Sakmarian), is of little use because of its wide stratigraphic distribution. *F. borealis* sp. nov., *Heintzella poljarica* sp. nov. and *Tschussovskenia borealis* sp. nov., as only known from Polakkfjellet, cannot be used in stratigraphy today. Even so, it is worth of notion that the last two species belonging to genera considered typically Permian, on Polakkfjellet were found in Gzhelian rocks. *Tschussovskenia*, apart from a single occurrence in the Uppermost Carboniferous of the cratonal western part of the USA, has practically been known so far exclusively from the Permian. Carboniferous *?Tschussovskenia* on Spitsbergen were mentioned by Somerville (1997), but Fedorowski et al. (2007) suggested that this taxon could belong to another genus. In the light of the new data, it is not impossible that Somerville's *?Tschussovskenia* could actually belong to *Tschussovskenia*. With the presence of this genus revealed on Polakkfjellet, it stops being unique to the Carboniferous of Spitsbergen. Unfortunately, a single illustration presenting *?Tschussovskenia*, without any description of this taxon, despite its general similarity to *T. borealis* sp. nov. does not allow its unambiguous classification.

When comparing rugosans from the Hornsund succession and Polakkfjellet with species found in the Isfjorden area, it was noted that the Upper-Carboniferous corals of Polakkfjellet had common features with the fauna of both, James 1 Land and Linnédalen, but species linking Polakkfjellet with the eastern part of Isfjorden were not identical with those that connect Polakkfjellet with Linnédalen (i.e. with the western part of the Isfjorden area). On Polakkfjellet and James 1 Land there was an abundance of *Gshelia rouilleri, Arctophyllum intermedium, Amygdalophylloides ivanovi*, and representatives of colonial *Fomichevella*, while the species found in the Linnédalen area and also occurring on Polakkfjellet were *Pseudotimania arctica* sp. nov., *Siedleckia mutafii, Arctophyllum spitsbergensis* sp. nov., *"Caninia" nikitini, Siedleckia longiseptata*, and an unspecified *Bothrophyllum* (Figs 5, 7A). *Gshelia rouilleri*, found in the Gzhelian on Polakkfjellet and James 1 Land, in the Linnédalen area appears in the Sakmarian.

In turn, when comparing Lower-Permian rugosans from coral horizons found in the Hornsund area (Fig. 4; Table 5, 6) with the species of the Lower Sakmarian of Linnédalen (Fig. 7; Table 1A, B) and James 1 Land examined by Somerville (1997), Hornsund turns out to share much more species with Linnédalen. What connect the eastern part of Isfjorden and the Hornsund area are exclusively representatives of unspecified species of *Bothrophyllum, Timania, Pseudotimania, Protowentzelella* and *Svalbardphyllum pachyseptatum*. The species that the Hornsund area has in common with the western part of Isfjorden include colonial *Heintzella borealis, Kleopatrina ftatateeta, K. rozkowskae, K. uralensis, Protowentzelella kunthi, P. longiseptata*, and *Tschussovskenia dilata*, as well as solitary *Bothrophyllum baeri, B. permicum, Hornsundia lateseptata, Krusenella pachyseptata* sp. nov., *Pseudotimania borealis* sp. nov., and *P. longiseptata* sp. nov. The upper part of the Tyrrellfjellet Member of the Wordiekammen Formation in the western part of Isfjorden is therefore comparable with the upper part of the Treskelodden Formation from the Hornsund area. Assuming, after Kossovaya (1996, 1997a), who correlated Tastubian ranges of *Timania schmidti-Kleopatrina (K.) magnifica* and *Protolonsdaleiastraea biseptata* with the coral associations of the Treskelodden Formation, and after Fedorowski et al.

(2007), who thought that all colonial corals in the Hornsund area belonged to the upper part of the Treskelodden Formation dated to the Sakmarian (probably the Tastubian), the same age can also be assigned to the upper layers of the Wordiekammen Formation in the Linnédalen area.

The above comparisons show that while there is nothing peculiar about solitary corals at the Carboniferous-Permian boundary (passing to the Permian are large species of the genera *Bothrophyllum, Gshelia, Siedleckia, Amygdalophylloides* and *Pseudotimania*), in the stratigraphic distribution of colonial rugosans one can note a deviation from a set rule (Fig. 95A, B). With the exception of *Fomichevella*, still documented in the Carboniferous in the Urals (from the Bashkirian to the Asselian; on Svalbard in the Kasimovian and Gzhelian, until the ?Sakmarian), in Spitsbergen's Carboniferous *Tschussovskenia* and *Heintzella* are documented for the first time. This means that, given the present status of stratigraphic ranges of the typically Permian lithological units identified on Spitsbergen, colonial Rugosa are taken to include *Kleopatrina, Paraheritschioides, Pararachnastraea, Protolonsdaleiastraea,* and *Protowentzelella*.

5.2. Ecological aspect of the corals under study

In the Carboniferous and Permian of today's Spitsbergen, the marine fauna developed in warm and shallow waters, in environments controlled by sea-level changes. In rock sequences they are marked by short – and long-term cyclic sedimentation. For long-term cycles, either large-scale tectonic or eustatic mechanisms are proposed (Goldhammer et al. 1991, 1994; Heckel 1994; Samuelsberg and Pickard 1999). In the case of the Carboniferous-Permian boundary, a superior role in controlling a long-term cycle was played by the eustatic mechanism connected with glaciations in the south of Gondwana (Hambrey and Harland 1981; Veevers and Powell 1987; Visser 1993) and eastern Siberia (Epshteyn 1981). In turn, short-term cycles were determined by regional subsidence (Samuelsberg and Pickard 1999) and local tectonics (Birkenmajer 1964, 1975, 1981; Fedorowski 1982a).

Greatly simplifying, long-term sedimentary cycles of the Late Palaeozoic on Spitsbergen can be grouped into five periods: (1) the Late Famennian, Tournaisian, Viséan and Serpukhovian (Billefjorden Group), with deposition dominated by terrestrial deposits with sequences containing coal beds (Harland 1997); (2) the Bashkirian, Moscovian and Early Kasimovian, with characteristic red layers of terrestrial deposits and coastal-marine facies built of evaporites and carbonates (Ludwig 1989); (3) the Gzhelian, Asselian and Early Sakmarian, with deposition dominated by carbonates from a warm and shallow sea as well as deltaic facies; (4) the Late Sakmarian and Early

Artinskian, with platform-derived carbonates and evaporite episodes; and (5) the Kungurian until Wuchiapingian, with the entire deposition consisting of shallow-sea clastics and carbonates.

Thus, in the Early Carboniferous, Svalbard featured extensive marshes and wetlands of both, fluvial and lacustrine derivation, because it was drifting from a desert climate that obtained there in the Devonian to a humid, tropical climate favourable to an environment with lakes, lagoons and tidal flats.

In the Late Carboniferous, the deposition on Svalbard varied between that on land and in shallow seas. In this period the climate became dry. The typical rocks are breccias, limestones and dolomitic limestones as well as beds of gypsum and/or anhydrite. The most abundant in the limestones and dolomites are gastropods, bivalves, brachiopods and corals (Fig. 94A).

The Svalbard of the Early Permian was primarily subtropical shallow seas. Deposits were similar to those from the Late Carboniferous since they had accumulated in similar environments, mainly shallow waters. This was also the time (Asselian, Sakmarian, Artinskian) of the most intensive development of the fauna in the entire C-A-U Realm (Fig. 94B). On the Svalbard Platform, Rugosa corals had the best conditions for development in the Early Sakmarian (Fedorowski 1964, 1965, 1967, 1975, 1982a, 1997; Fedorowski et al. 1999; Fedorowski and Bamber 2001; Fedorowski et al. 2007; Birkenmajer and Fedorowski 1980; Chwieduk 2009a).

Intensive evaporation during dry periods when the Sakmarian was turning into the Artinskian led to the formation of gypsums, anhydrides and dolomites. Coastal carbonates, evaporites and, more rarely, sandstones are typical of this time interval on Spitsbergen and North-Eastern Land. On the basis of his observations from central Spitsbergen, Lauritzen (1981) suggests that the environment favourable to the formation of this type of rock could be a sebkha. This, in turn, indicates regression of an already shallow sea that earlier provided a sedimentation environment for the underlying layers of the Wordiekammen Formation (Steel and Worsley 1984).

The development of sedimentation in the Middle and Late Permian (the Kapp Starostin Formation) indicates a transition from shallow-sea conditions (the Vøringen Member) to deeper ones created by the subsidence-related lowering of the shelf. The resultant environments, characterised by low energy and good oxidation (the Svenskeegga and Hovtinden Members; Steel and Worsley 1984), were favourable to the development of the organic world. Those rocks contain numerous fossils of gastropods, bivalves, brachiopods, siliceous sponges, bryozoans and, to a lesser extent, corals (Fig. 94C, D). Towards the end of the Permian, the general uplift of Svalbard produces a regional stratigraphic gap.

The long-term sequences presented above are certainly of stratigraphic significance and can be used in correlations. But the information they convey about ecological environments is highly general, and the information about the organic world usually matches the general pattern of fauna occurring in this type of environments. Instead, information about habitats of organisms is provided by small-scale cycles producing short-term local units, rather impossible to trace in extensive geographical areas. Such cycles, connected with local tectonics, are best documented in the Inner Hornsund area. What turned out to be significant when tracing environmental changes in this area was the full identification of Rugosa corals from Kruseryggen. This elevation lies in the northern part of Inner Hornsund, and because of its location between the exposures on the Treskelen Peninsula and Triasnuten (Fig. 2E), it complements the lateral extent of the coral horizons (*sensu* Birkenmajer 1964) in this area and supplies new data about the local tectonics.

On the basis of the identified Rugosa and the lithological characteristics, it was shown that there were three higher coral horizons on Kruseryggen. After Birkenmajer (1964), they were numbered III, IV and V. In addition, because of lithological differences and a somewhat different faunal composition, in the two highest horizons four sub-horizons were distinguished denoted as x, y, z, and v (Fig. 4). So far the absence of the lower horizons (I and II) was explained either by eustatic sea-level changes or the activation of a fault zone located SW of Hornsund, leading to an uplift of the Hornsund Fault, which since the Carboniferous was supposed to be the source area of the clastic material deposited here (Birkenmajer 1964, Czarniecki 1969, Birkenmajer and Fedorowski 1980, Fedorowski 1982a, Harland 1997). As follows from my observations, the fauna-documented bathymetric changes recorded in the characteristics of facies along the Treskelodden-Kruseryggen section rather indicate relative sea-level changes. The differences in the thickness of both, clastic horizons without a coral fauna and carbonate ones with a Rugosa-dominated fauna, as well as the falling number of coral horizons when passing from Treskelen across Kruseryggen towards Triasnuten (Figs 2E, 97), can be associated with synsedimentary block movements in the north of Inner Hornsund. Those movements would be responsible for the pinch-out of coral horizons I and II towards the north caused by the shallowing of this area, as can be judged from the fact that on Treskelen the rugosans of horizons I and II occur in bioclasts which, in the opinion of Birkenmajer (1979) and Fedorowski (1982a), were transported to the shallow water from a variety of environments. Thus, the local extent of changes in the fauna and the movement of corals within those horizons would be due to transport forced, possibly, by increased dynamics of the shallowing water body.

At the time of sedimentation corresponding to coral horizons I and II on Treskelen, the Triasnuten and Kruseryggen areas could be even shallower, and the Kruseryggen area could even be a land, as indicated by red-coloured sandstones and conglomerates. Then came a short period of ingression (coral horizon III, known from the entire area) resulting in erosion and the redeposition of fauna to horizon III from layers earlier exposed to the action of the atmosphere or fresh water (well-rounded, variegated corals), but it was only in the Triasnuten area that the shallow-water conditions which developed then lasted until coral horizon V had formed, even leading to stratigraphic condensation. The co-occurrence on Triasnuten of corals of horizons IV and V in a sandy limestone package about 5-metre thick was noted by Birkenmajer and Fedorowski (1980). In turn, the Kruseryggen area (lying some 2 km south of Triasnuten) at that time probably kept subsiding under the greater thickness of its coral horizons IV and V, clearly separated by clastic horizons of sandstones and conglomerates of considerable thickness. It seems, therefore, that there would have to be at least one synsedimentary fault somewhere between Kruseryggen and Triasnuten, and because the combined thickness of coral horizons III-V and clastic horizons is greater on Kruseryggen than on Treskelen, it is highly probable that also between those areas there could be a synsedimentary fault responsible for the difference in their subsidence.

It is highly probable that there were local areas of shallowing also north of Triasnuten. On Polakkfjellet, some 16 km from Triasnuten, there is a large accumulation of Rugosa corals in the lower layers of the Treskelodden Formation (Table 1A, B; Fig. 5). The appearance of this group of animals in the Hornsund area only in the upper layers of this formation (Figs 4, 97) indicates a marine transgression from the north towards the south of Spitsbergen. The absence of corals in the upper part of the Treskelodden Formation on Polakkfjellet may suggest that there were local shallowing episodes in the long-term cycle lasting at least from the Gzhelian to the Sakmarian. While the lithological and biotic components of the limestones and dolomites of the lowest part of the Treskelodden Formation suggest that during the deposition of those rocks there was an open but shallow sea here (Nysaether 1977), the higher part of this formation, but still belonging to the Gzhelian, was probably deposited nearer the coast in restricted lagoon environments. What indicates shallow-sea to coastal environmental conditions is the porosity of the rocks (Cutler 1981 *fide* Dallmann et al. 1992). On Polakkfjellet the shallowing is marked by empty spaces in carbonate rocks left by dissolved sulphates, and by intercalations of clastics (Fig. 5). The steady shrinkage of the sea in the Polakkfjellet area after the deposition of the Treskelodden Formation ended in the accumulation of relatively pure carbonates and anhydrites (the Gipshuken Formation). The abundance of intercalated dolomite and anhydrite in the lower part of the Gipshuken Formation suggests the predominance of a lagoon and/or an intertidal environment.

The abundance of corals in rocks of the Uppermost Carboniferous indicates exceptionally favourable conditions for the development those animals. They occur here in both, carbonate and clastic rocks (from claystones to conglomerates), often intercalated with sandstones. Although the fossils have clear traces of an earlier transport, it does not seem they came from previously consolidated rocks. None of the specimens described here was a pebble with a fragment of another rock; what is more, in conglomerate pebbles no macrofossils were found. The state of preservation of corals in conglomerates varies greatly. Broken specimens and their fragments are common. Calices and the earliest parts of corallites, least resistant to mechanical damage, have not been preserved at all. And the sharp edges of all fragments of corals suggest that their transport was fast and along a short distance. What seems significant, however, is that profiles A and B differ in their lithological characteristics and in the qualitative and quantitative characteristics of corals accumulated in them (Table 1A, B, Fig. 5). It is not known whether the limited distribution of the deposit was caused by the topography of the basin floor or by block tectonics and erosion. It seems that, as in the Hornsund area, the cyclicity of sedimentation on Polakkfjellet marked by coral levels was largely controlled by small-scale tectonic events. However, one cannot preclude that there were many factors contributing to sea-level changes in this region, and that apart from the advancing marine transgression, also synsedimentary block tectonics, subsidence, and the accumulation of deposit had their part.

When moving farther north to the Linnédalen area (Figs 2C, 6), the exposures examined there show that in the Late Carboniferous and Early Permian it was covered by a deeper sea than in the Polakkfjellet and Hornsund areas. Uniform sedimentation was dominated by carbonate rocks. Even if deposition in this area occurred near the coastline, in the Linnédalen area we do not see any impact of terrigenous material. The process of marine transgression probably started there in the Moscovian. The Tarnkanten Formation, which Gobbett (1963) and Cutbill and Challinor (1965) include into this stage, represents the environment of a delta fan near the south-western coast of the St. Jonsfjorden Trough, with transport coming from the north-east (Steel and Worsley 1984). The overlying Wordiekammen Formation is probably already connected with the process(es) that caused eustatic sea-level changes, producing a transgressive sequence in this area (Steel and Worsley 1984). The regional appearance of evaporites in the stratigraphic time interval corresponding to the Wordiekammen Formation suggests an influence of the climatic factor.

The stratigraphic position of Carboniferous and Permian rocks in the Linnédalen area was established on the basis of the stratigraphic ranges of the known Rugosa species (Figs 7, 8, 95A, B) and a comparison of corals of this area with those found in the eastern Isfjorden, Polakkfjellet and Hornsund.

In the Gzhelian of Linnédalen, a surprising was the occurrence of corals not documented by Somerville (1997) in coeval rocks in the eastern part of Isfjorden. The faint similarity of the Linnédalen corals to those from areas east of Isfjorden may be indicative of barriers existing between those areas at that time. Perhaps such a barrier in the Uppermost Carboniferous was a shallowing caused by the activation of the Nordfjorden block along the Billefjorden and Kongresbreen-Hansbreen Faults (Figs 2B). Nilsson (1988 and 1993, *fide* Samuelsberg and Pickard 1999) believes that this block dropped below sea-level in the Late Moscovian. Samuelsberg and Pickard (1999) claim that the subsidence stopped in the Middle Gzhelian when the borderline fault had been covered by rocks with a predominant share of carbonates (the Tyrrellfjellet Member of the Wordiekammen Formation). The presence in the eastern and western areas of Isfjorden of different coral associations suggests that the tectonically controlled relative change in sea-level in the Nordfjorden block area could still effectively limit the migration of those animals even in the Uppermost Carboniferous and Lower Permian. As a result, the deeper-sea carbonate deposits accumulating at that time inside the Billefjorden Trough (Pickard et al. 1996) and in the Linnédalen area contain unique coral associations.

The similar coral fauna found in the Gzhelian of Linnédalen and Polakkfjellet (Figs 5, 7) indicates, in turn, that in the Uppermost Carboniferous it reached at least the area of the recent Polakkfjellet with the marine transgression from central Spitsbergen. The similar thicknesses of coeval rocks in the compared areas suggest similar rates of sedimentation and subsidence. Their varying lithology reflects the diversified morphology of basin floors. Besides, with its larger proportion of clastic rocks, the Polakkfjellet area could have been closer to the coastline.

As it has been mentioned above, in the Early Permian the transgressing sea reached Treskelen. In the middle part of the Lower Permian, when a succession of carbonates and coarse evaporites kept accumulating in entire central Spitsbergen (McCann and Dallmann 1996), a regressive cycle appeared that was recorded in the rocks of the Gipshuken Formation. The higher part of the Permian, dominated by limestones with cherts (the Kapp Starostin Formation, Figs 3, 8), points to a return of an open-sea environment. Bioclastic rocks of the lower members of the Kapp Starostin Formation were still being deposited in a shallow, near-shore environment composed of limestones and rubble mixed with remains of organisms and terrigenous material from a nearby coast or river mouth. Towards the top of the profile, the thickening layers with cherts and quartzitic conglomerates can be interpreted as a beach deposit. Sparitic limestones, with a small amount of organic remains and quartz, probably developed in lagoon-related conditions or on a coast flooded during a tide. Deeper-sea conditions appeared with the start of the deposition of the

Svenskeegga Member. The abundance of organic remains with only slight or no traces of transport with numerous *Zoophycos* indicate a relatively quiet water far from the coast, with a slow sedimentation rate. Rugosa corals appeared first in deposits of the Hovtinden Member. They represent exclusively non-dissepimental solitary forms commonly thought to be psychrophilic. A similar taxonomic collection in the central (Linnédalen) and southern (Hornsund) parts of Spitsbergen suggests that at the time of deposition of the earliest part of the Kapp Starostin Formation environmental conditions were the same throughout the study area, and the impoverishment of coral associations should be put down to a cooling of the climate.

5.3. Palaeogeographical significance of Spitsbergen corals

In the Late Carboniferous and Early Permian (Moscovian – Middle Sakmarian) the latitude of the Spitsbergen was ~30° north (Reid et al. 2007). It was one of a series of connected basins which produced an extensive mosaic of deposits in the northern part of Pangea (Stemmerik and Worsley 1989, 1995; Gudlaugsson et al. 1998; Grogan et al. 1999). The Pangea land developing at that time separated the fauna of the eastern shelf from that of the western and northern shelves. Rugosa corals formed vast zoogeographical provinces termed the Palaeo-Tethys Realm and the C-A-U Realm, respectively (Fedorowski 1989, 1997, Fedorowski et al. 1999). In the C-A-U Realm they contributed a significant percentage of the marine fauna (Fig. 94A-D). Those from the Canadian Arctic Archipelago (Fedorowski and Bamber 2001, Fedorowski et al. 2007), Greenland (Flügel 1973, Fedorowski 1982b), and the Urals (Stuckenberg 1895, Dobrolyubova 1936a, b; Gorsky 1978; Kossovaya 1996, 1997a, 2009a, b; Fedorowski et al. 1999, 2007) are well-studied. The richest associations have been identified on Spitsbergen (see the chapter *Previous taxonomic studies of Svalbard Rugosa*). They belong to the Palaeozoic province of Durhaminidae, which developed after the Carboniferous (Viséan/Serpukhovian boundary) closure of the sea route joining the western and northern Pangea coasts with Palaeo-Tethys (Fedorowski 1989; Fedorowski et al. 1999, 2007). According to those authors, also the inflow of warm waters from Palaeo-Tethys was cut off, but there were still currents running along the western coast of Pangea and keeping up constant communication of the thermophilic fauna with the psychrophilic, boreal one from its northern coasts, which is corroborated by the presence of non-tropical genera in the intertropical fauna of western Pangea. Shi and Grunt (2000) are of a similar opinion. They think that the factor responsible for the mixing of faunas with different thermal requirements was probably western sea currents. However, they do not preclude the migration of some brachiopods to the C-A-U Realm from Palaeo-Tethys (Fig. 94A), the connection supposedly being the Ural sea route with its system of islands still linking the two realms in the Asselian. Reid et al. (2007) suggest that the east-west circulation of water on the northern shelf of Pangea could have occurred even in the Early Sakmarian.

However, this solution is in conflict with the occurrence on the northern shelf of Pangea in the Gzhelian and Sakmarian of corals known only from the C-A-U Realm. Free communication between Palaeo-Tethys, the Ural Ocean and the eastern Palaeo-Pacific, existing at least from the Bashkirian to the Kasimovian and making possible an exchange of corals between the C-A-U and Palaeo-Tethys Realms, certainly existed no longer in the Gzhelian and throughout the Permian. The earlier links of rugosans of the two realms are indicated by common Carboniferous roots of a considerable number of Permian corals, as demonstrated by the *Petalaxis* and *Cystolonsdaleia* species (Bamber and Fedorowski 1998). To some extent, such taxa blur the separateness of corals coming from the different realms (Fedorowski 1997). Still, in the Upper Carboniferous there were already two groups of Rugosa corals characteristic of the C-A-U Realm (Durhaminidae-Kleopatrinidae) and the Palaeo-Tethys Realm (Kepingophyllidae-Waagenophyllidae). Since then the C-A-U Realm developed a character of its own, the result being its unique zoogeographical provinces (Fedorowski and Bamber 2001, Fedorowski et al. 2007) in which no contact with the fauna of the Palaeo-Tethys Realm has been found. Accepting the thesis of Reid et al. (2007), one should then find a mechanism of a selective migration of the fauna. A possible explanation could be lack of resistance of coral larvae to elevated salinity levels obtaining in the southern part of the Ural Basin in the Uppermost Carboniferous and Early Permian, since those were areas where evaporites were the predominant rocks (Fig. 94A). However, the occurrence of corals on the East-European Platform (Fig. 94A, B), taxonomically similar to those from the Urals and Spitsbergen, seems to contradict this thesis.

In the Permian, Durhaminidae and Kleopatrinidae as well as Kepingophyllidae and Waagenophyllidae became the most readily distinguishable components of the two realms (Fedorowski 1997, Fedorowski et al. 2007). At the global scale, those corals were less diversified that the older ones, and were clearly non-tropical in nature. On the northern shelves of Pangea they were represented by thermophilic and psychrophilic associations, while the fauna of the eastern coasts (Palaeo-Tethys) was generally tropical at that time (Waterhouse and Bonham-Carter 1975, Fedorowski et al. 2007). They constituted a small proportion of the marine benthos only in the Upper Permian (Fig. 94C, D). On Spitsbergen they are an important component of this benthos, because they are the closing link connecting coeval Rugosa coral associations of the Sverdrup Basin in the Canadian Arctic Archipelago with

Zechstein ones, corals of the Central European Basin much poorer in qualitative and quantitative terms, and the relatively rich coral associations of a short-lived marine lagoon extending in the Kazanian (~Roadian-Wordian) from the Pechora to the Volga catchment area (Nechajev 1894; Soshkina 1925, 1928, 1932; Soshkina et al. 1941).

Thus, the changes in the coral associations on Svalbard were largely due to the formation of a land barrier south of the Ural Basin (Figs 1, 94A-C) and the drift of the archipelago from sub-Arctic to temperate conditions. The dynamics of the development of rugosans on the northern shelf of Pangea from the Gzhelian to the Wordian-?Capitanian is presented in Figs 94A-D, 96A-D. All the Rugosa taxa I identified belong to the C-A-U Realm. A considerable proportion of them have readily visible coelenterate equivalents in the neighbouring regions of the Arctic (Fig. 95A, B). Thus, the explosive growth of the Carboniferous and Permian rugosans on Spitsbergen was correlated with the development of the fauna in the Canadian Arctic, on Alaska, Greenland, Novaya Zemlya, the Timan, and the Urals. In the Gzhelian, the species documented in the various parts of the Arctic include, among others, the solitary *Amygdalophylloides ivanovi, Arctophyllum intermedium, Bothrophyllum baeri, "Caninia" nikitini, Gshelia rouilleri, Pseudotimania mosquensis, Siedleckia longiseptata, S. mutafii,* and *Yakovleviella tschernyschevi* (Fig. 95A) as well as the colonial *Fomichevella hoeli, F. major,* and *F. orientalis* (Fig. 95B). Among them are also species common to such widely distant regions as the Moscow Basin, the Donets Basin, China, and Texas (Fig. 95A, B). Those data suggest that the Late-Carboniferous seas were relatively good communication routes for the fauna migrating over great distances: there were connections with the Ural Mountains, with epicontinental seas in Russia, and with the north-western and western shelves of Pangea.

Most of the coral associations of the Lower Permian of Spitsbergen, richer in qualitative and quantitative terms, also show features of fast-dispersing organisms. They include solitary species known from other areas of the C-A-U Realm (Fig. 95A, B): *Amygdalophylloides ivanovi, Arctophyllum intermedium, Bothrophyllum baeri, Caninophyllum kokscharowi, C. ovibos, Gshelia rouilleri, Lytvolasma asymetrica,* and *Yakovleviella tschernyschewi*, as well as numerous colonial species of *Fomichevella, Heintzella, Kleopatrina, Paraheritschioides?, Pararachnastraea, Protolonsdaleiastraea, Protowentzelella*, and *Tschussovskenia*. Thus, the Spitsbergen rugosans of the Late Carboniferous and Early Permian are the link connecting the coeval fauna of the C-A-U Realm. There is nothing peculiar about this because at that time Spitsbergen was a nodal point (Fig. 1) between the Timan and the Urals (in the east), eastern Greenland and the Central European Basin (in the south), and Alaska and the Sverdrup Basin (in the west). However, this simple picture of the dispersal of corals in the Arctic is somewhat spoilt by the presence of unique species on Svalbard (Figs 95A, B; 96A-D). Among a very large number of species identified on Svalbard (which is a result of a taxonomic study of corals rather than of their exceptional accumulation there), there are many that have not been found in the other areas of the Arctic. In the Gzhelian they include the solitary *Bothrophyllum timanioides timanioides, B. t. nanum, Caninophyllum belcheri* var. *magnum, Siedleckia bjornoyana, Svalbardphyllum pachyseptatum*, and the newly described *Arctophyllum spitsbergensis, Pseudotimania arctica, P. borealis,* and *P. longiseptata*. The Gzhelian colonial forms known only from Svalbard are represented by *Fomichevella borealis* sp. nov., *Heintzella poljarica* sp. nov., and *Tschussovskenia borealis* sp. nov. In turn, the Lower Permian of Spitsbergen is represented by numerous specimens of newly described species (Fig. 95A, B) as well as by, among others, *Bothrophyllum permicum, Hornsundia lateseptata, Siedleckia bjornoyana,* and *Timania multiseptata*.

To a lesser extent, also the Urals show unique species of Gzhelian age, e.g. *Bothrophyllum samaraense* and *Fomichevella volgense*. In the Lower Permian, there developed species not known from anywhere else: *Permastraea columellaris, P. major, Protowentzelella aseptata, Pseudocystophora delicata,* and *P. dobrolyubovae*. There were also unique Lower-Permian species in the Timan Ridge (*Pararachnastraea? integrata, Pseudocystophora sakmarensis, Heritschioides densicolumella*) and on Alaska (*Durhamina alaskense*).

Because of the wide dispersal of many of the remaining species, the mechanism responsible for restricting the occurrence of the above species to some areas cannot be limited communication possibilities of the Arctic fauna. The local occurrence of taxa in the C-A-U Realm (Figs 95, 96) in the time interval under study is rather indicative of special environmental conditions that determined such a taxonomic composition, or of our still incomplete palaeontological knowledge of those areas. Also for this reason the new taxa are consciously not called endemites.

The development dynamics of the Late Carboniferous and Early Permian rugosans in the C-A-U Realm (Fig. 96) shows that although the directions of their dispersal varied, it is possible to distinguish a main one: from the east (Novaya Zemlya, the Timan, the Urals, the Moscow and Donets Basins), to Spitsbergen and then to the Canadian Arctic Archipelago [*Arctophyllum intermedium* – Novaya Zemlya, Moscow Basin (Kasimovian, Gzhelian), Spitsbergen (Middle Kasimovian-Sakmarian); *Pseudotimania mosquensis* – Moscow Basin (Moscovian), Svalbard (Kasimovian, Gzhelian); *Siedleckia longiseptata* – Urals (Kasimovian-Gzhelian), Svalbard (Gzhelian); *Siedleckia mutafii* – Novaya Zemlya (Moscovian), Svalbard (Gzhelian, Sakmarian); *Yakovleviella tschernyschewi* – Donets Basin (Moscovian), Spitsbergen (Gzhelian, Sakmarian); *Fomichevella hoeli* – Russia (Upper Carboniferous), Svalbard (Gzhelian-Sakmarian), Ellesmere

Island (Asselian-Middle Sakmarian); *Fomichevella orientalis* – Urals (Lower Carboniferous), Spitsbergen (Kasimovian-Gzhelian); *Kleopatrina ftatateeta* – Urals (Asselian-Sakmarian), Spitsbergen (Tastubian), Ellesmere Island (Upper Tastubian or Lower Sterlitamakian), Nevada (Sakmarian); *Kleopatrina grinnellensis* – Urals (Asselian-Lower Artinskian), Spitsbergen (Tastubian), Devon and Ellesmere Islands (Lower Artinskian); *Kleopatrina uralensis* – Urals and Timan (Tastubian), Spitsbergen (Tastubian), Ellesmere and Devon Islands (Upper Tastubian-Sterlitamakian); *Protolonsdaleiastraea cargalensis* – Timan (Lower Sakmarian), Urals (Sakmarian), Spitsbergen (Tastubian), Ellesmere and Devon Islands (Upper Sakmarian, Lower Artinskian), Helena Island (Lower Artinskian); *Protowentzelella columellata* – Urals (Asselian-Lower Artinskian), Spitsbergen (Tastubian), Devon Island (Tastubian-Lower Sterlitamakian); *Protowentzelella major* – Urals (Lower Asselian-Lower Sakmarian), Spitsbergen (Lower Sakmarian), Ellesmere Island (Sakmarian, ?Upper Tastubian); *Protowentzelella variabilis* – Urals (Upper Asselian), Spitsbergen (Tastubian), Canadian Arctic (Sakmarian); *Tschussovskenia minor* – Urals (Lower Asselian), Spitsbergen (Lower Sakmarian); and *Tschussovskenia captiosa* – Urals (Upper Asselian-Lower Sakmarian), Spitsbergen (Tastubian)].

The dispersal of corals from the western regions of the C-A-U Realm towards the east is less distinct. This direction is documented by: *"Caninia" ordinata* [Texas, Glass Mts (Kasimovian), Svalbard (Gzhelian)]; *Paraheritschioides? californiense* [Texas (Asselian or Lower Sakmarian), British Columbia (Asselian or Lower Sakmarian), California (Upper Asselian or Lower Sakmarian), Alaska (?Sakmarian), cratonal western Canada (Lower Sakmarian), Spitsbergen (Sakmarian)]; *Protowentzelella? dubiosa* [Ellesmere Island (Upper Asselian or Lower Sakmarian), Spitsbergen (Lower Sakmarian)]; and *Protowentzelella kunthi* [cratonal western Canada (Upper Asselian-Lower Sakmarian), Spitsbergen (Lower Sakmarian), the Urals (Lower Sakmarian)].

On the basis of the current knowledge of the Permian-Carboniferous coral species in the C-A-U Realm, also Spitsbergen can be regarded as a source area of some species. Among those found here are some documented earlier deposits in the remaining regions of the C-A-U Realm. Thus, their appearance on Spitsbergen would have been evolutionary in nature as against ecological in the remaining areas. They include: *Amygdalophylloides ivanovi* [Spitsbergen (Gzhelian-Lower Permian), Moscow Basin (recently considered by Russian geologists to be rather Lower Permian)], *Gshelia rouilleri* [Spitsbergen (Gzhelian, Lower Permian), Moscow Basin (?Lower Permian)], *Lytvolasma asymetrica* [Spitsbergen (Sakmarian), Urals (Artinskian)], *Fomichevella major* [Spitsbergen (Upper Carboniferous or Asselian), Devon Island (Sakmarian, ?Tastubian), Ellesmere Island (probably Middle or Upper Asselian)], *Heintzella borealis* [Spitsbergen (Lower Sakmarian), Ellesmere Island (Middle

Sakmarian, Upper Tastubian-Lower Sterlitamakian)], *Kleopatrina arcturusensis* [Spitsbergen (Tastubian), Nevada (Lower Artinskian)], *Protolonsdaleiastraea composita* [Spitsbergen (Tastubian), Devon Island (Lower Artinskian)], and *Protowentzelella minima* [Spitsbergen (Lower Sakmarian), Ellesmere Island (Middle Sakmarian, Upper Tastubian-Lower Sterlitamakian)].

Stratigraphically the youngest autochthonous Spitsbergen corals come from the Middle Permian, from the Kapp Starostin Formation. According to Beauchamp's (1994) hypothesis, the northern shelves of the north-drifting Pangea attain at that time a boreal, or even a sub-Arctic location. Because of a change in climatic conditions, predominant in the entire area of the northern shelf of Pangea is a psychrophilic fauna dominated by brachiopods, bryozoans and sponges. Solitary non-dissepimental Rugosa corals are little differentiated in qualitative terms, and contribute a minor proportion to the fauna of this age.

The coral component of the Middle-Permian fauna of the northern hemisphere includes mainly polyprovincial *Allotropiochisma, Calophyllum, Sochkineophyllum, Tachylasma*, and *Ufimia*. There is a complete absence not only of colonial forms of Rugosa, but of all photozoa (Fig. 94C, D) and the large, dissepimental solitary forms occurring in great numbers in the underlying formations (Wordiekammen and Treskelodden), considered to be indicative of tropical and/or subtropical conditions. The species commonest in the Middle Permian are *Calophyllum columnare* and *Tachylasma variabilis*. On the East European Platform they are dated to the Roadian. On Spitsbergen and in the Sverdrup Basin, *C. columnare* appears in the Wordian. Most of the remaining species (Fig. 95A) are dated to the Wordian and/or Capitanian. They are best documented on Spitsbergen and in the Sverdrup Basin, where they occur in large accumulations and show a great taxonomic similarity. Still, apart from the polyprovincial species, both areas also have unique ones. In the Sverdrup Basin those are *Euryphyllum boreale* and *Lytvolasma canadensis*, and on Spitsbergen, *Allotropiochisma euryphylloides, A. svalbardicum, A. treskelense*, and the newly described *Fedorowskites spitsbergensis*. The Urals and the East European Platform are practically monospecific at that time with *C. columnare* and a secondary contribution of *Tachylasma* and *Ufimia*. In those areas the development and differentiation of corals was certainly not facilitated by the shallowing of the sea on the East European Platform and the narrowing of the Ural Basin. As in Alaska and Arctic Canada, they survived until the Wordian and then retreated/became extinct, possibly for ecological reasons. On Spitsbergen corals survived slightly longer, probably until the Capitanian. They still had the best conditions for development on today's Greenland. As the conodont data show (Mei and Henderson 2002), the Foldvik Creek Formation, from which derive, e.g., *C. columnare, Tachylasma variabilis, T. rhizoides, Allotropiochisma birkenmajeri*, as well as *A. exzentrica* and *A. (A.) longiseptata*, is of Wuchiapingian age.

BIBLIOGRAPHY

Baker, B.H., Forbes, C.L. and Holland, M.F.W. 1952. Fossiliferous strata at Kapp Scania, Daudmannsøyra, Vestspitsbergen. *Geological Magazine* **89**(4), 303-304.

Bamber, E.W. and Fedorowski, J. 1998. Biostratigraphy and systematics of Upper Carboniferous cerioid rugose corals, Ellesmere Island, Arctic Canada. *Geological Survey of Canada Bulletin* **511**, 127 pp.

Bates, D.E. and Schwarzacher, W. 1958. The geology of the lad between Ekmanfjorden and Dicksonfjordenin central Vestspitsbergen. *Geological Magazine* **95**, 219-233.

Beauchamp, B. 1994. Permian climatic cooling in the Canadian Arctic. *In*: G.D. Klein (ed.) Pangea: Paleoclimate, tectonics, and sedimentation during accretion, zenith and breakup of a supercontinent. *Geological Society of America Special Paper* **288**, 229-246.

Beauchamp, B. and Desrochers, A. 1997. Permian warm – to very cold-water carbonates and chert in the Sverdrup Basin-Barents Sea area, northwestern Pangea. *In*: N.P. James and J.A.D. Clarke (eds) Cool-water Carbonates. *Society of Economic Paleontologists and Mineralogists Special Publication*, **56**, 349–364.

Beauchamp, B. and Baud, A. 2003. Growth and demise of Permian biogenic chert along the northwest Pangea: evidence for end-Permian collapse of thermohaline circulation. *Palaeogeography, Palaeoclimatology, Palaeoecology* **184**, 37–63.

Bergh, S.G. and Grogan, P. 2003. Tertiary structure of the Sørkapp-Hornsund Region, South Spitsbergen, and implications for the offshore southern extension of the fold-thrust Belt. *Norwegian Journal of Geology* **83**, 43-60.

Biernat, G. and Birkenmajer, K. 1981. Permian brachiopods from the base of the Kapp Starostin Formation at Polakkfjellet, Spitsbergen. *In*: K. Birkenmajer (ed.) Geological Results of the Polish Spitsbergen expeditions. *Studia Geologica Polonica* **73**, 7–24.

Birkenmajer, K. 1959. Report on the geological investigations of the Hornsund area, Vestspitsbergen, in 1958. Pt. 2: Post-Caledonian succession. *Bulletin of the Polish Academy of Sciences, Earth Sciences* **7**(2), 191-196.

Birkenmajer, K. 1964. Devonian, Carboniferous and Permian formations of Hornsund, Vestspitsbergen. *Studia Geologica Polonica* **11**, 47-123.

Birkenmajer, K. 1972. Tertiary history of Spitsbergen and continental drift. *Acta Geologica Polonica* **22**, 193-218.

Birkenmajer, K. 1975. Caledonian of Svalbard and plate tectonics. *Bulletin of the Geological Society of Denmark* **24**, 1-19.

Birkenmajer, K. 1979. Channeling and orientation of Rugose corals in shallow-marine Lower Permian of south Spitsbergen. *In*: K. Birkenmajer (ed.) Geological Results of the Polish Spitsbergen expeditions. *Studia Geologica Polonica* **60**, 45–56.

Birkenmajer, K. 1981. The geology of Svalbard, the western part of the Barents Sea, and the continental margin of Scandinavia. *In*: A.E.M. Nairn, M. Churkin and F.G. Stehli (eds.) The ocean basins and margins. *The Arctic Ocean* **5**, 265-329. Plenum Press, New York/London.

Birkenmajer, K. 1984*a*. Cyclic sedimentation in mixed alluvial to marginal-marine conditions: the Treskelodden Formation (?Upper Carboniferous to Lower Permian) at Hornsund, south Spitsbergen. *Studia Geologica Polonica* **80**, 25-46.

Birkenmajer, K. 1984*b*. Mid-Carboniferous red beds at Hornsund, south Spitsbergen: their sedimentary environment and source area. *Studia Geologica Polonica* **80**, 7-23.

Birkenmajer, K. 1990. *Geological map of the Hornsund area, Spitsbergen. Explanations to the map 1:75 000*. 42 pp. Katowice.

Birkenmajer, K. and Czarniecki, S. 1960. Stratigraphy of Marine Carboniferous and Permian Deposits in Hornsund (Vestspitsbergen), Based on Brachiopods. *Bulletin de l'Academie Polonaise des Sciences, Serie des sci. geol. et geogr* **8**, 203-209.

Birkenmajer, K. and Turnau, E. 1962. Lower Carboniferous age of the so-called Wijde Bay Series in Hornsund, Vestspitsbergen. *Norsk Polarinstitutt*, *Arbok 1961*, 41-61.

Birkenmajer, K. and Logan, A. 1969. On the fauna and age of the Cancrinella Limestone (Permian) at Kopernikusfjellet, Vestspitsbergen. *Norsk Polarinstitutt Arbok 1967*, 28-45.

Birkenmajer, K. and Fedorowski, J. 1980. Corals of the Treskelodden Formation (Lower Permian) at Triasnuten, Hornsund, South Spitsbergen. *Studia Geologica Polonica* **66**, 7-27.

Birkenmajer, K., Fedorowski, J. and Smulikowski, W. 1972. Igneous and fossiliferous sedimentary drift pebbles in marine Tertiary of Torell Land, Spitsbergen. *Norsk polarinstitut – Arbok 1970*, pp. 146-164.

Błażejowski, B., Hołda-Michalska, A. and Michalski, K. 2006. *Schellwienia arctica* (Fusulinidae) from the Carboniferous-?Permian strata of the Treskelodden Formation, south Spitsbergen. *Polish Polar Research* **27**(1), 91-103.

Burov, Yu. P., Klubov, B.A., Pavlov, A.V., Gavrilov, B.P. and Ustritskiy, V.I. 1965. New data on the Permian rocks of Spitsbergen. *In*: V.N. Sokolov (ed.) Conference on the Geology of Spitsbergen, Leningrad 1964, 6-8.

Carruthers, R.G. 1908. A revision of some Carboniferous corals. *Geological Magazine* **5**, 63-74, 158-171.

Chwieduk, E. 2007. Middle Permian rugose corals from the Kapp Starostin Formation, South Spitsbergen (Treskelen Peninsula). *Acta Geologica Polonica* **57**, 281-304.

Chwieduk, E. 2009*a*. Early Permian solitary rugose corals from Kruseryggen (Treskelodden Fm., Hornsund area, southern Spitsbergen). *Geologos* **15**(1), 57–75.

Chwieduk, E. 2009*b*. Polish palaeontological research in the Arctic. *Geologos* **15**(2), 133–143.

Cutbill, J.L. 1968. Carboniferous and Permian stratigraphy of Ny Friesland, Spitsbergen. *Norsk Polarinstitutt Arbok 1966*, 12-24.

Cutbill, J.L. and Challinor, A. 1965. Revision of the stratigraphical scheme for the Carboniferous and Permian rocks of Spitsbergen and Bjørnøya. *Geological Magazine* **102**, 418-439.

Czarniecki, S. 1964. Occurrence of genus Archimedes (Hall) in Hornsund, Vestspitsbergen. *Studia Geologica Polonica*, 11: 147-153.

Czarniecki, S. 1969. Sedimentary environment and stratigraphical position of the Treskelodden beds. *Prace Muzeum Ziemi* **16**, 201-336.

Dallmann, W.K. 1992. Multiphase tectonic evolution of the Sørkapp-Hornsund mobile zone (Devonian, Carboniferous, Tertiary), Svalbard. *Norsk Geologisk Tidsskrift* **72**, 49-66.

Dallmann, W.K. (ed.) 1999. Lith*ostratigraphic Lexicon of Svalbard*. 318 pp. Norsk Polarinstitutt, Oslo.

Dallmann, W.K., Hjelle A., Andresen A., Ohta Y. and Salvigsen O. 1992. *Geological map of Svalbard 1:100,000. Sheet B9G Isfjorden*. 52 pp. Norsk Polarinstitutt Temakart 16. Oslo.

Dallmann, W.K., Birkenmajer, K., Hjelle, A., Mørk, A., Ohta, Y., Salvigsen, O. and Winsnes, T.S. 1993. *Geological map of Svalbard 1:100,000, Sheet C13G Sørkapp*. 73 pp. Norsk Polarinstitutt Temakart 17. Oslo.

Dana, J.D. 1846. Genera of fossil corals of the family Cyathophyllidae. *American Journal of Sciences and Arts* (*series 2*) **1**, 178-189.

Dineley, D.L. 1958. A review of the Carboniferous and Permian rocks of the west coast of Vestspitsbergen. *Norsk geologisk Tidsskrift* **38**(2), 197-217.

Dobrolyubova, T.A. 1936*a*. Corals of the Upper Carboniferous of the western slope of the central Urals and their stratigraphic significance. *Trudy Vsesoyuznogo Nauchno-Issledovatelskogo Instituta, Mineralnogo Syriya* **103**, 1-68 [In Russian, English summary].

Dobrolyubova, T.A. 1936*b*. Rugose corals of the Middle and Upper Carboniferous and Lower Permian of the northern Urals (map-sheet 123). *Trudy Polyarnoi Komissii, Akademiya Nauk SSSR* **28**, 77-158 [In Russian, English summary].

Dobrolyubova, T.A. 1937. Solitary corals of the Myachkovian and Podolskian horizons, Middle Carboniferous, Moscow Basin. *Trudy Paleontologicheskogo Instituta, Akademiya Nauk SSSR*, **6**(3): 5-92 [In Russian, English summary].

Dobrolyubova, T.A. 1940. Rugose corals of the Upper Carboniferous of the Moscow Basin. *Trudy Paleontologicheskogo Instituta Akademiya Nauk SSSR* **9**(3), 1-87 [In Russian].

Dobrolyubova, T.A. 1941. The Rugosa corals of the Upper Carboniferous of the Moscow Basin. *Trudy Paleontolgicheskogo Instituta, Akademiya Nauk SSSR* **9**(3), 1-88 [In Russian].

Dobrolyubova, T.A. and Kabakovitsch, N.V. 1948. Some Middle and Upper Carboniferous representatives of the Rugosa from the Moscow Basin. *Trudy Paleontolgicheskogo Instituta, Akademiya Nauk SSSR* **14**, 5-37 [In Russian].

Dybowski, W. 1873. Monographie der Zoantharia Sclerodermata Rugosa aus der Silurformation Estlands, Nord-Livlands und der Insel Gotland. *Archiv für Naturkunde des Livlands, Estlands und Kurlands* **1**, 415-532.

Easton, W.H. 1945. Corals from the Otter Formation (Mississippian) of Montana. *Journal of Paleontology* **19**(5), 522-528.

Ehrenberg, C.G. 1834. Beiträge zur physiologischen Kenntnis der Corallenthiere im allgemeinen, und besonders des Rothen Meeres, nebst einem Versuche zur physiologischen Systematik derselben. *Kaiserliche Akademie der Wissenschaften, physikalisch-mathematischen Abhandlungen*, 1832, 225-380.

Epshteyn, O.G. 1981. Late Permian ice-marine deposits of the Atkan Formation in the Kolyma river headwaters region, U.S.S.R. *In*: M.J. Hambrey and W.B. Harland (eds) Earth's pre-Pleistocene glacial record. *Cambridge University Press*, 270-273.

Ezaki, Y. 1997. Cold-water Permian Rugosa and their extinction in Spitsbergen. *Boletin de la Real Sociedad Española de Historia Natural (Seccion Geologia)* **92**(1-4), 381-388.

Ezaki, Y. and Kawamura, T. 1992. Carboniferous-Permian corals from Skansen and Festningen, Central Spitsbergen: their faunal characteristic. *In*: K. Nakamura (ed.) Investigations on the Upper Carboniferous-Upper Permian Successions of West-Spitsbergen by Japanese-Norwegian Research Group. *Hokkaido University*, 59-75. Sapporo.

Ezaki, Y., Kawamura, T. and Nakamura, K. 1994. Kapp Starostin Formation in Spitsbergen: a sedimentary and faunal record of Late Permian palaeoenvironments in an arctic region. *In*: A.F. Embry (ed.) Pangea: global environments and resources. *Canadian Society of Petroleum Geologists, Memoir* **17**, 647-665.

Fedorowski, J. 1964. On Late Palaeozoic Rugosa from Hornsund, Vestspitsbergen. *Studia Geologica Polonica* **11,** 139-146.

Fedorowski, J. 1965. Lower Permian Tetracoralla of Hornsund, Vestspitsbergen. *Studia Geologica Polonica* **17**, 1-173.

Fedorowski, J. 1967. The Lower Permian Tetracoralla and Tabulata from Treskelodden, Vestspitsbergen. *Norsk Polarinstitutt, Skrifter* **142**, 1-61.

Fedorowski, J. 1975. On some Upper Carboniferous Coelenterata from Bjornoya and Spitsbergen. *Acta Geologica Polonica* **25**(1), 27-78.

Fedorowski, J. 1980. Corals. *In*: K. Birkenmajer and J. Fedorowski, Corals of the Treskelodden Formation (Lower Permian) at Triasnuten, Hornsund, South Spitsbergen. *Studia Geologica Polonica* **66**, 8-27.

Fedorowski, J. 1982*a*. Coral thanatocoenoses and depositional environments in the upper Treskelodden beds of the Hornsund area, Spitsbergen. *Palaeontologia Polonica* **43**, 17-68.

Fedorowski, J. 1982*b*. Some rugose corals from the Upper Permian of East Greenland. *Rapport Gronlands geologiske Undersogelse* **108**, 71-91.

Fedorowski, J. 1986. The rugose coral faunas of the Carboniferous/Permian boundary interval. *Acta Palaeontologica Polonica* **31**, 47-70.

Fedorowski, J. 1987. Upper Palaeozoic rugose corals from southwestern Texas and adjacent areas: Gaptank Formation and Wolfcampian corals. Part I. *Palaeontologia Polonica* **48**, 271 pp.

Fedorowski, J. 1989. Extinction of Rugosa and Tabulata near the Permian/Triassic boundary. *Acta Palaeontologica Polonica* **34**, 47-70.

Fedorowski, J. 1991. Dividocorallia a new subclass of the Palaeozoic Anthozoa. *Bulletin de L'Institut Royal des Sciences Naturelles de Belgique* **61**, 21-105.

Fedorowski, J. 1997. Diachronism in the development and extinction of Permian Rugosa. *Geologos* **2**, 59-164.

Fedorowski, J. 2004. Considerations on most Rugosa and the Dividocorallia from de Groot's (1963) collection. *Scripta Geologica* **127**, 71-311.

Fedorowski, J. 2009. On *Pentamplexus* Schindewolf, 1940 (Anthozoa, Rugosa) and its possible relatives and analogues. *Palaeontology* **52**(2), 297-322.

Fedorowski, J. 2010. Does similarity in rugosan characters and their functions indicate taxonomic relationship? *Palaeoword* **19**(3-4), 374-381.

Fedorowski, J. and Gorianov V.B. 1973. Redescription of tetracorals described by E. Eichwald in "Palaeontology of Russia". *Acta Palaeontologica Polonica* **18**, 3-70.

Fedorowski, J., Bamber, W. and Stevens, C. 1999. Permian corals of the Cordilleran-Arctic-Uralian Realm. *Acta Geologica Polonica* **49**, 159-173.

Fedorowski, J. and Bamber, W. 2001. Guadalupian (Middle Permian) solitary rugose corals from the Degerbols and Trold Fiord formations, Ellesmere and Melville islands, Canadian Arctic Archipelago. *Acta Geologica Polonica* **51**(1), 31-79.

Fedorowski, J., Bamber, E.W. and Stevens, C.H. 2007. *Lower Permian colonial rugose corals, Western and Northwestern Pangea: Taxonomy and distribution.* XII + 231 pp. National Research Council of Canada. Monograph Publishing Program, Ottawa.

Fischer S. von Waldheim, 1830. *Oryctographie du Gouvernement de Moscou*. 1st ed. A. Semen, Moscow, 202 pp.

Flügel H.W. 1973. Rugose Korallen aus dem oberen Perm Ost-Grönland. *Verhandlungen der Geologischen Bundes Anstalt* **H.1**, 1-57.

Flügel H.W. 1993. *Bothrophyllum* Trautschold (Rugosa) aus dem Jungpaläozoikum von Nordiran und Bemerkungen zur Septenabspaltung bei Rugosa. *Geologisch Paläontologische Mitteilungen Innsbruck* **19**, 49-70.

Fomitchev, V.D. 1939. Coelenterata. *In*: I.I. Gorsky (ed.) Atlas of guide fossils in the fossil faunas of the USSR, Number 5, Middle and Upper divisions of the Carboniferous System. *Tsentralnyi Nauchno-Issledovatelskyi Geologo-razvedochnyi Institut, Leningrad, Moscow*. 50-64 pp., 166-168 pp., 6-11 pls. [In Russian].

Fomitchev, V.D. 1953. Rugose corals and stratigraphy of the Middle and Upper Carboniferous and Permian deposits of the Donetsk Basin. *Trudy Vsesoyuznyi Nauchno-Issledovatelskyi Geologicheskyi Institut (VSEGEI), Gosudarstvennoe Isdatelstvo Geologicheskoi Literatury*, 622 pp., 91 pp. and 44 pls under separate cover. [In Russian].

Forbes, C.L. 1960. Carboniferous and Permian fusulinidae from Spitsbergen. *Palaeontology* **2**(2), 210-225.

Forbes, C.L., Harland, W.B. and Huges, N.F. 1958. Palaeontological evidence for the age of the Carboniferous and Permian rocks of Central Vestspitsbergen. *Geological Magazine* **95**(6), 465-490.

Frebold, H. 1928. Das Festungsprofil auf Spitzbergen. Jura und Kreide. II: Die Stratigraphie. *Skrifter om Svalbard og Ishavet* **19**, 1-39.

Frebold, H. 1937. Das Festungsprofil auf Spitzbergen. IV: Die Brachiopoden – und Lamellibranchiatenfauna und die Stratigraphie des Oberkarbons und Unterperms. *Skrifter om Svalbard og Ishavet* **69**, 1-94.

Frebold, H. 1939. Das Festungsprofil auf Spitzbergen. V: Stratigraphie und Invertebratenfauna der älteren Eotrias. *Skrifter om Svalbard og Ishavet* **77**, 1-58.

Frebold, H. and Stoll, E. 1937. Das Festungsprofil auf Spitzbergen. III: Stratigraphie und Fauna des Jura und der Unterkreide. *Skrifter om Svalbard og Ishavet* **68**, 1-85.

Frey H. and Leuckart R. 1847. *Beiträge zur Kenntnis wirbelloser Tiere, mit besonderer Berücksichtigung der Fauna des Norddeutschen Meeres*. 170 pp. Braunschweig.

Fromentel, E. de, 1861. Introduction a l'étude des polypiers fossiles. *Mémoires de la Société d'Émulation du Doubs*, 357 pp.

Gee, D.G., Harland, W.B. and McWhae, J.R.H. 1953. Geology of central Vestspitsbergen. Part I: Review of the geology of Spitsbergen with special reference to central Vestspitsbergen. *Transactions Royal Society of Edinburgh* **52**(9), 299-356.

Gervais, P. 1840. Astrée, Astraea. *In*: Dictionnaire des Sciences Naturelles, Supplément **1**, 481-487.

Gjelberg, J.G. and Steel, R.J. 1981. An outline of Lower-Middle Carboniferous sedimentation on Svalbard: effects of climatic, tectonic and sea level changes in rift basinsequences. *In*: J.W. Kerr and A.J. Fergusson (eds) Geology of the North Atlantic Borderlands. *Canadian Society of Petroleum Geologists Memoir* **7**, 543-561.

Gobbett, D.J. 1963. Carboniferous and Permian brachiopods of Svalbard. *Norsk Polarinstitutt Skrifter* **127**, 1-201.

Goldhammer, R.K., Oswald, E.J. and Dunn P.A. 1991. Hierarchy of stratigraphic forcing; example from Middle Pennsylvanian shelf carbonates of the Paradox Basin. *In*: E.K. Franseen, W.L. Watney, C.G.S.C Kendall and W. Ross (eds) Sedimentary Modeling;

computer simulations and methods for improved parameter definition. *Kansas Geological Survey Bulletin* **233**, 361-413.

Goldhammer, R.K., Oswald, E.J. and Dunn P.A. 1994. High-frequency, glacio-eustatic cyclicity in the Middle Pennsylvanian of the Paradox Basin; an evolution of Milankovitch forcing. *In*: P.L. de Boer and D.G. Smith (eds) Orbital Forcing and Cyclic Sequences. *Special Publication of the International Association of Sedimentologists* **19**, 243-283.

Golonka, J. and Ford, D. 2000. Pangean (Late Carboniferous-Middle Jurassic) palaeoenvironments and lithofacies. *Palaeogeography, Palaeoclimatology and Palaeoecology* **161**, 1-34.

Goreva, N.V. and Kossovaya, O.L. 1997. Biostratigraphy of the Carboniferous deposits, the northern Timan. XIII International Congress on the Carboniferous and Permian. *Prace Państwowego Instytutu Geologicznego, Proceedings* **157**, 131-140.

Gorsky, I.I. 1938. Carboniferous corals of Novaya Zemlya. *Trudy Vsesoyuznyi Arkticheskogo Instituta* **93**, 1-221 [In Russian].

Gorsky, I.I. 1939. Atlas of guide fossils in the fossil faunas of the USSR. Vol. 5, Middle and Upper divisions of the Carboniferous System. *Tsentralnyi Nauchno-Issledovatelskyi Geologo-razvedochnyi Institut, Leningrad, Moscow*. [In Russian].

Gorsky, I.I. 1978. *Middle Carboniferous corals from the western slope of the Urals*. 223 pp. Nauka, Moscow [In Russian].

Grabau, A.W. 1928. Palaeozoic corals of China: Part 1, Tetraseptata II. *Palaeontologia Sinica* **B2**(2), 175 pp.

Grek, N. 1936. The representatives of the genus *Caninia* from the limestones of the Verkhnie Chussovskyie Gorodki, Colva-Vuschera rivers and Ufimskoe Plateau. *Transactions of the Oil Geological Institute* **B61**, 1-26 [In Russian].

Grogan, P., Østvedt-Ghazi, A.-M., Larssen, G.B., Fotland, B., Nyberg, K., Dahlgren, S. and Eidvin, T. 1999. Structural elements and petroleum geology of the Norwegian sector of the northern Barents Sea. *In*: A.J. Fleet and S.A.R Boldy (eds) Petroleum Geology of Northwest Europe. *Proceedings of the 5th Conference*, 247-259.

Gudlaugsson, S.T., Faleide, J.I., Johansen, S.E. and Breivik, A.J. 1998. Late Palaeozoic structural development of the South-Western Barents Sea. *Marine and Petroleum Geology* **15**, 73-102.

Hambrey, M.J. and Harland, W.B. 1981. *Earth's Pre-Pleistocene Glacial Record*. Cambridge University Press, Cambridge.

Harker, P. 1960. Corals, brachiopods, and molluscs of Grinnell Peninsula. *In*: P. Harker and R. Thorsteinsson (eds) Permian rocks and faunas of Grinnell Peninsula, Arctic Archipelago. *Geological Survey of Canada*, *Bulletin* **309**, 39-79.

Harland, W.B. 1997. *The Geology of Svalbard*. 521 pp. The Geological Society, Memoir 17, London.

Heckel, P.H. 1994. Glacial-eustatic base-level-climatic model for late Middle to Late Pennsylvanian coal-bed formation in the Appalachian Basin. Jour*nal of Sedimentary Research, Section B: Stratigraphy and Global Studies* **65**(3), 348-356.

Hellem, T. and Worsley, D. 1978. An outcrop of the Kapp Starostin Formation at Austjøkeltinden, Sørkapplandet. *Norsk Polarinstitutt Arbok 1977*, 340-343.

Heritsch, F. 1929. Eine Caninia dem Karbon des de Geer-Beiges im Eisfjordgebiet auf Spitzbergen. *Skrifter om Svalbard og Ishavet*, *24*.

Heritsch, F. 1939. Die Korallen des Jungpalaozoikums von Spitsbergen. *Arkiv für Zoologii* **31A**(16), 1-138.

Hill, D. 1938-1941. A monograph of the Carboniferous rugose corals of Scotland. *Monograph of the Palaeontographical Society*, 213 pp. London.

Hill, D. 1956. Rugosa. *In*: R.C. Moore (ed.) Treatise on Invertebrate Paleontology. Part F. Coelenterata. *Geological Society of America and University of Kansas Press*, Lawrence, Kansas.

Hill, D. 1981. Supplement 1, Rugosa and Tabulata. *In*: C. Teichert (ed.) Treatise on Invertebrate Paleontology, Part F. Coelenterata. *Geological Society of America and University of Kansas Press*, Boulder Colorado and Lawrence, Kansas.

Hjelle, A. 1993. *Geology of Svalbard*. 163 pp. Norsk Polarinstitut, Oslo,

Hjelle, A., Lauritzen, Ø., Salvigsen, O. and Winsnes, T.S. 1986. *Geological map Svalbard 1:100000, sheet B10 Van Mijenfjorden*. 37 pp. Norsk Polarinstitutt Temakart nr 2.

Hoel, A. 1925. The coal deposits and coal mining of Svalbard (Spitsbergen and Bear Island). *Resultater norske statsunderstøttede Spitsbergenekspedisjoner 6*.

Hoel, A. and Orvin, A.K. 1937. Das Festungsprofil auf Spitzbergen. Karbon-Kreide. I: Vermessungsresultate. *Skrifter om Svalbard og Ishavet* **18**, 1-59.

Holtedahl, O. 1913. Zur Kenntnis der Karbonablagerungen des westlichen Spitzbergens. II. Allgemeine stratigraphische und tektonische Beobachtungen. *Videnskapsselskapets Skrifter* **23**, 1-91.

Hudson, R.G.S. 1936. The development and septal notation of the Zoantharia Rugosa (Tetracoralla). *Proceedings of the Yorkshire Geological Society*, **23**(2), 68-78.

Horn, G. 1928. Beiträge zur Kenntnis der Kohle von Svalbard. *Skrifter om Svalbard og Ishavet* **17**, 1-60.

Ilina, T.G. 1970. Some new Permian Rugosa from the Southeastern Pamir. *In*: G.G. Astrova and I.I. Chudinova (eds) *New species of Palaeozoic bryozoa and corals*. Nauka, 146-151. Moscow. [In Russian].

Ivanovsky, A.B. 1987. Rugosa described by A. A. Stuckenberg (1888-1905). *Nauka*, Moscow. [In Russian].

James, N.P. 1997. The cool-water carbonate depositional realm. *In*: N.P. James, J.A.D. Clarke (eds) *Cool-water carbonates*. SEPM Special Publication **56**, 1-23.

Karczewski, L. 1982. Some gastropods and bivalves from the Treskelodden and Kapp Starostin Formations, Hornsund region, Spitsbergen. *Palaeontologia Polonica* **43**, 97-105.

Keilen, H.B. 1992. Lower Permian sedimentary sequences in Central Spitsbergen, Svalbard. *In*: K. Nakamura (ed.) *Investigations on the Upper Carboniferous-Upper Permian succession of West Spitsbergen 1989-1991*. Hokkaido University, Sapporo, 127-134.

Kellogg, H.E. 1975. Tertiary stratigraphy and tectonism in Svalbard and continental drift. *American Association of Petroleum Geologists Bulletin* **59**, 465-485.

King, W. 1849. On some Families and Genera of Corals. *Annals and Magazine of Natural History*, *Series 2* **3**, 388-390.

Kleinspehn, K.L., Steel, R.J., Johannessen, E. and Netland, A. 1984. Conglomeratic fan-delta sequences, Late Carboniferous-Early Permian, Western Spitsbergen. *In*: E.H. Koster and R.J. Steel (eds) Sedimentology of Gravels and Conglomerates. *Memoirs of the Canadian* Society *of Petroleum Geologists*, **10**, 279-294.

Kossovaya, O.L. 1992. Upper Carboniferous and Lower Permian rugose corals from the Karachatyr. *Izdatelstvo St.-Peterburgskogo Universiteta. Voprosy Paleontologii* **10**, 13-27 [In Russian].

Kossovaya, O.L. 1996. Correlation of Uppermost Carboniferous and Lower Permian rugose coral zones from the Urals to Western North America. *Palaios* **11**, 71-82.

Kossovaya, O.L. 1997*a*. Rugose corals from standard sections of the Gzhelian-Artinskian stages of northern Timan and the western slope of the Urals. *In*: G.A. Stukalina (ed.) Atlas of refernce complexes of Palaeozoic benthic fauna of north-eastern European Russia. Ostracods, brachiopods, rugosans. *Izdatelstvo Vserossiiskyi Nauchno-Issledovatelskyi Geologicheskii Institut im. A. P. Karpinskogo (VSEGEI)* **3**, 53-96 pp., 106-115 pp., 128-154 pp. St. Petersburg.

Kossovaya, O.L. 1997*b*. Middle and Upper Carboniferous composite zonal sequence based on Rugosa corals (western part of Russia). XIII International Congress on the Carboniferous and Permian. *Prace Państwowego Instytutu Geologicznego, Proceedings* **157**, 85-98.

Kossovaya, O.L. 2001. Rugosa. *In*: A.S. Alekseev and S.M. Shik (eds) Middle Carboniferous of the Moscow Basin (southern part), Part 2, Palaeontological Characteristics. *Russian Academy of Science, Geological Institute, Palaeontological Institute, Moscow* **11**, 152-171 [In Russian].

Kossovaya, O.L. 2009*a*. Artinskian–Wordian antitropical rugose coral associations: A palaeogeographical approach. *Elsevier, Palaeoworld* **18**, 136–151.

Kossovaya, O.L. 2009*b*. Some middle Carboniferous Rugosa from the Southern Urals. http://ig.ufaras.ru/File/PubTxt/CARBON_2009/01_07_09.pdf

Kossovaya, O.L., Guseva, E.A., Lukin, A.E. and Zhuravlev A.V. 2001. Middle Artinskian (Early Permian) ecological event: a case study of the Urals and northern Timan. *Institute of Geology, Proceedings of the Estonian Academy of Sciences,* **50**(2), 95-113.

Lauritzen, Ø. 1981. The development of the Gipshuken Formation (Lower Permian) at Trollfuglfjella in central Spitsbergen, Svalbard. *Norsk Polarinstitutt Skrifter* **176**, 1-22.

Lewis H.P. 1929. On the Avonian Coral *Caninophyllum,* gen. nov. and *C. archiaci* (Edwards and Haime). *Annals and Magazine of Natural History* **10**(3), 456—468.

Liszka, S. 1964. Occurrence of Lower Permian Foraminifera in the Treskelodden Beds of Hornsund, Vestspitsbergen. *Studia Geologica Polonica* **11**, 169-172.

Lonsdale, W. 1845. Description of some characteristic Palaeozoic corals of Russia. *In*: R.I. Murchison, E. De Verneuil and A. Keyserling von (eds) The geology of Russia in Europe and Ural Mountains **1**, 591-634, John Murray (London).

Lowell, J.D. 1972. Spitsbergen Tertiary orogenic belt and the Spitsbergen Fracture Zone. *Geological Society of America Bulletin* **83**, 3091-3102.

Ludwig, P. 1989. Depositional environment in the Middle Carboniferous of the Brøggerhalvøya (Svalbard) – facies and tectonic interpretation of sedimentary sequences. *Polarforschung* **59**, 79-99.

Maher, H.D., Ringset, N. and Dallmann, W.K. 1989. Tertiary structures in the platform cover strata of Nordenskiöld Land, Svalbard. *Polar Research* **7**, 83-93.

McCann, A.J. and Dallmann, W.K. 1996. Reactivation history of the long-lived Billefjorden Fault Zone in north central Spitsbergen, Svalbard. *Geological Magazine* **133**(1), 63-84.

McCutcheon, V.A. and Wilson, E.C. 1961. *Ptolemaia*, a new colonial rugose coral from the Lower Permian of eastern Nevada and western Russia. *Journal of Paleontology* **35**, 1020-1028.

McCutcheon, V.A. and Wilson, E.C. 1963. *Kleopatrina*, new name for *Ptolemaia* McCutcheon and Wilson. *Journal of Paleontology* **37**, 299 pp.

Meek, F.B. 1864. Description of the Carboniferous fossils. *In*: F.B. Meek and W.M. Gabb (eds) Palaeontology of California, Volume 1. *Geological Survey of California*, *Caxton Press, Philadelphia*, 3-9.

Mei, S., Henderson, C.M. and Wardlaw B.R. 2002. Evolution and distribution of the conodonts *Sweetognathus* and *Iranognathus* and related genera during the Permian, and their implications for climate change. *Palaeogeography, Palaeoclimatology, Palaeoecology* **180**, 57-91.

Milne Edwards, H. and Haime, J. 1850-1855. A monograph of the British fossil corals. *Palaeontographical Society*, London. 1850 (1-71 pp.), 1852 (147-210 pp.), 1853 (211-244 pp.), 1855 (245-299 pp.).

Minato, M. 1955. Japanese Carboniferous and Permian corals. Journal of the Faculty of Science, *Hokkaido University, Series 4, Geology and Mineralogy* **9**, I-IV pp., 1-202 pp.

Minato, M. and Kato, M. 1965. Durhaminidae (Tetracoral). *Journal of the Faculty of Science, Hokkaido University Series, 4, Geology and Mineralogy* **13**, 13-86.

Moore, R.C., and Jeffords, R.M. 1945. Description of Lower Pennsylvanian corals from Texas and adjacent states. *University of Texas, Publication* **4401**, 77-208.

Mørk, A., Knarud, R. and Worsley, D. 1982. Depositional and diagenetic environments of the Triassic and Lower Jurassic succession of Svalbard. *Canadian Society of Petroleum Geologists* **8**, 371-391.

Nakamura, K., Kimura, G. and Winsnes, T.S. 1987. Brachiopod zonation and age of the Permian Kapp Starostin Formation (Central Spitsbergen). *Polar Research* **5**, 207-219.

Nakrem, H.A., Nilsson, I. and Mangerud, G. 1992. Permian biostratigraphy of Svalbard (Arctic, Norway) – a review. *International Geology Review* **34**, 933-959.

Nathorst, A.G. 1910. Beiträge zur Geologie der Bäreninsel, Spitzbergens und des König-Karl-Landes. *Bulletin Geologiska Institutionen Universitetet Uppsala (1910-1911)* **10**, 261-416.

Nathorst, A.G. 1920. Zur Kulmflora Spitzbergens. Zur fossilen Flora der Polarländer. *Stockholm II*, 45 pp.

Nechajev, A. 1894. Fauna permskikh otlozhenyi vostochnoj polosy Evropeyskoj Rossii. *Trudy Obshchestva Estestvoispytatelei Rossii pri Kazanskom Institutie* **27**(4), 1-501.

Nowiński, A. 1982. Some new species of Tabulata from the Lower Permian of Hornsund, Spitsbergen. *Palaeontologia Polonica* **43**, 83-96.

Nowiński, A. 1991. Late Carboniferous to Early Permian Tabulata from Spitsbergen. *Palaeontologia Polonica* **51**, 3-74.

Nysaether, E. 1977. Investigations on the Carboniferous and Permian stratigraphy of the Torell Land area, Spitsbergen; *Norsk Polarinstitutt Arbok 1976*, 21-41.

Ogar, V.V. 2010. New data on the Carboniferous corals of the Donets Basin. *Elsevier*, *Palaeoworld* **19**, 284-293.

Ohta, Y., Bernard-Griffiths, J. and Peucat, J.J. 1992. Geochronological studies on the basement rocks of Svalbard. *In*: *Arctic Research Seminar Proceedings*, October 15-16, 1992.

Ohta, Y. and Dallmann W.K. 1999. *Geological map of Svalbard 1:100,000. Sheet B12G Torellbreen*. Norsk Polarinstitutt Temakart 29. Oslo.

Olivier, W.A. 1996. Origins and relationship of Paleozoic coral groups and the origin of the Scleractinia. *Paleontological Society Papers* **1**, 107-134.

Orbigny, A.C.V.D. d' 1851. *Cours élémentaire de paleontology et géologie stratigraphique*. 382 pp. V. Masson 2(1), Paris.

Orvin, A.K. 1940. Outline of the geological history of Spitsbergen. *Skrifter om Svalbard og Ishavet 78* (reprint 1969, 1-57).

Osmólska, H. 1968. The new trilobites from the Treskelodden beds of Hornsund. *Acta Palaeontologica Polonica* **13**, 605-613.

Padget, P. 1954. Notes on some corals from late Paleozoic rocks of inner Isfjorden, Spitsbergen. *Norsk Polarinstitutt. Skrifter* **100**, 1-10.

Pchelina, T.M. 1977. Permian and Triassic deposits of Edgeøya (Svalbard). *In*: V.N. Sokolov (ed.) Stratigraphy and Palaeontology of the Precambrian and Paleozoic of Northern Siberia. *A Collection of Scientific Papers, NIIGA*, 59-71 [In Russian].

Pickard, N.A.H., Eilertsen, F., Hanken, N.-M., Johansen, T.A., Lønøy, A., Nakrem, H.A., Nilsson, I., Samuelsberg, T.J. and Somerville, I.D. 1996. Stratigraphic framework of Upper Carboniferous (Moscovian-Kasimovian) strata in Bünsow Land, central Spitsbergen: palaeogeographic implications. *Norsk Geologisk Tidsskrift* **76**(3), 169-185.

Playford, G. 1962. Lower Carboniferous microfloras of Spitsbergen. Part I. *Palaeontology* **5**, 550-618.

Playford, G. 1963. Lower Carboniferous microfloras of Spitsbergen. Part II. *Palaeontology* **5**, 619-678.

Poty, E. 1981. Recherches sur les Tétracoralliaires et les Hétérocoralliaires du Viséen de la Belgique. *Mededelingen rijks geologische dienst* **35**(1), 161 pp.

Reid, C.M., James, N.P., Beauchamp, B. and Kyser, T.K. 2007. Faunal turnover and changing oceanography: Late Palaeozoic warm-to-cool water carbonates, Sverdrup Basin, Canadian Arctic Archipelago. *Palaeogeography, Palaeoclimatology, Palaeoecology* **249**, 128-159.

Ross, C.A. 1965. Fusulinids from the Cyathophyllum Limestones, Central Vestspitsbergen. *Contributions from the Cushman Foundation for Foraminiferal Research* **16**, 74-86.

Ross, C.A. and Ross, J.P. 1962. Pennsylvanian, Permian rugose corals, Glass Mountains, Texas. *Journal of Paleontology* **36**, 1163-1188.

Różycki, S.Z. 1959*a*. Geology of the north-western part of Torell Land, Vestspitsbergen. Part I. *Studia Geologica Polonica* **2**, 1-38 [In Polish].

Różycki, S.Z. 1959*b*. Geology of the north-western part of Torell Land, Vestspitsbergen. Part II. *Studia Geologica Polonica* **2**, 39-94.

Saleé, A. 1910. Contribution à l'étude des polypiers du Calcaire Carbonifère de la Belgique. Le genere *Caninia*. Société Belge de Géologie, Nouvelle Mémoire Série **4**(3), 1-62.

Salter, J.W. 1855. Account of the Arctic Carboniferous fossils, collected by the expedition under Sir E. Belcher, 1852-1854. *In*: E. Belcher (ed.) Last of the Arctic voyages; being a narrative of the expedition in H.M.S. Assistance, under the command of Captain Sir Edward C.B. Belcher, in search of Sir John Franklin during the years 1852-53-54 **2**, 377-391.

Samuelsberg, T.J. and Pickard, N.A.H. 1999. Upper Carboniferous to Lower Permian transgressive-regressive sequences of central Spitsbergen, Arctic Norway. *Geological Journal* **34**, 393-411.

Sando, W.J. 1985. *Paraheritschioides*, a new rugose coral genus from the Upper Pennsylvanian of Idaho. *Journal of Paleontology* **59**, 979-985.

Sando, W.J. 1989. Dynamics of Carboniferous coral distribution, western Interior USA. *Memoir of the Association of Australasian Palaeontologists* **8**, 251-265.

Schindewolf, O.H. 1940. „Konwergenzen" bei Korallen und bei Ammoneen. *Fortschrift für Geologie und Paläontologie*, **12**, 389-492.

Schlotheim, E.T. von. 1813. Beiträge zur Naturgeschichte der Versteinerungen in geognostischer Hinsicht. *Leonhard's Taschenbuch der Mineralogie* **7**, 1–134.

Scotese, C.R. 2000. Paleomap Project. *http://www.scotese.com/earth.htm*.

Scrutton, C.T. 1997. The Palaeozoic corals: origins and relationships. *Proceedings of the Yorkshire Geological Society* **51**(3), 177-208.

Semenoff-Tian-Chansky, P. 1974. Recherches sur les Tétracoralliares du Carbonifere du Sahara Occidental. *Centre De Recherches Sur Les Zones Arides*, *série Géologie* **21**, 316 pp.

Shi, G.R. and Grunt, T.A. 2000. Permian Gondwana-Boreal antitropicality with special reference to brachiopod faunas. *Palaeogeography, Palaeoclimatology, Palaeoecology* **155**, 239-263.
Siedlecki, S. 1964. Permian succession on Tokrossoya, Sorkapplandet, Vestspitsbergen. *In* Birkenmajer, K. (ed.), Geological Results of the Polish 1957-1958, 1959, 1960 Spitsbergen Expeditions, Part 3. *Studia Geologica Polonica* **11**, 155-167.
Siedlecki, S. and Turnau, E. 1964. Palynological investigations of Culm In the Area SW of Hornsund, Vestspitsbergen. *Studia Geologica Polonica* **11**(3), 125-138.
Skaug, M., Dons, C., Lauritzen, Ø. and Worsley, D. 1982. Lower Permian Palaeoaplysinid bioherms and associated sediments from central Spitsbergen. *Polar Research* **2**, 57-75.
Sokolov, B.S. 1960. Permian corals from the south-eastern part of the Omolon Massif (with general review of the plerophyllid Rugosa). *Trudy Vsesoyuznogo Nauchno-Issledovatelskogo Gornogo Instituta (VNIGRI)* **154**, 38-77. [In Russian].
Somerville, D.I. 1997. Biostratigraphy and biofacies of Upper Carboniferous-Lower Permian rugose coral assemblages from the Isfjorden area, central Spitsbergen. *Boletin de la Real Sociedad Española de Historia Natural (Seccion Geologia)* **92**(1-4), 363-378.
Sosipatrova, G.P. 1967. Upper Palaeozoic Foraminifera of Spitsbergen. *In*: V.N. Sokolov (ed.) *Stratigraphy of Spitsbergen*, 125-165. Institut Geologii Arktiki, Leningrad. [In Russian, English translation available from the Lending Division of the British Library Board, 1977].
Soshkina, E.D. 1925. Les coraux du Permien inférieur (étage d'Artinsk) du versant occidental de l'Oural. *Bulletin de la Société des Naturalistes de Moscou, Section Géologique,* **33**, 76-104. Moscow. [In French].
Soshkina, E.D. 1928. The Lower Permian (Artinskian) corals of northern Urals. *Bulletin of the Moscow Society for Natural Research, Geological Section* **6**, 337-393 [In Russian].
Soshkina, E.D. 1932. The Lower Permian (Artinskian) corals of Ufim area. *Bulletin of the Moscow Society for Natural Research, Geological Section* **10**, 251-267. [In Russian].
Soshkina, E.D., Dobrolyubova, T.A. and Porfiriev, G.S. 1941. Permian Rugosa of the European part of the USSR. *In*: B.K. Licharev (ed.) Paleontology of the USSR. *Akademiya Nauk SSSR, Paleontologicheskii Institut, Moscow/Leningrad* **5**(3), 304 pp. [In Russian].
Spasskiy, N.Ya. 1974. Dialectic conformity of spatial-temporal rules in evolution (example tetracorals). *Zapiski Leningradskogo Gornogo Instituta* **67**(2), 127-135. [In Russian].
Spasskiy, N.Ya. and Kachanov, E.I. 1971. New primitive corals found in the Lower Carboniferous of the Altai and the Urals. *Zapiski Leningradskogo Gornogo Instituta* **59**, 48-64. [In Russian].
Steel R.J. and Worsley D. 1984; Svalbard's post-Caledonian strata. An atlas of sedimentational patterns and palaeogeographic evolution. *In*: A.M. Spencer (ed.) Petroleum Geology of the North European Margin. *Norwegian Petroleum Society, Graham and Trotman Ltd.*, 109-135.
Steel, R.J., Gjelberg, J., Helland-Hansen, W., Kleinspehn, K., Nøttvedt, A. and Larsen, M.R. 1985. The Tertiary strike-slip basins and orogenic belt of Spitsbergen, *In*: K.T. Biddle and N. Cristie-Blick (eds) Strike-slip deformation, basin formation, and sedimentation. *Society of Economic Paleontologists and Mineralogists Special Publication* **37**, 339-359.
Stemmerik, L. 1988. Discussion. Brachiopod zonation and age of the Permian Kapp Starostin Formation. *Polar Research* **6**, 179-180.
Stemmerik, L. 1995. Permian history of the Norwegian-Greenland Sea area. *In*: P.A. Scholle, T.M. Peryt and D.S. Ulmer-Scholle (eds) The Permian of Northern Pangea. *Sedimentary Basin and economic Resources* **2**, 98-118.

Stemmerik, L. 1997. Permian (Artinskian–Kazanian) cool-water carbonates in North Greenland, Svalbard and the western Barents Sea. *In*: N P. James and J.A.D. Clarke (eds) Cool-water carbonates. *Society of Economic Paleontologists and Mineralogists Special Publication* **56**, 349–364.

Stemmerik, L. 2000. Late Palaeozoic evolution of the North Atlantic margin of Pangea. *Palaeogeography, Palaeoclimatology, Palaeoecology* **161**, 95-126.

Stemmerik, L. and Worsley, D. 1989. Late Palaeozoic sequence correlations, North Greenland, Svalbard and the Barents Shelf. *In*: J.D. Collinson (ed.) Correlation in Hydrocarbon Exploration. *Norwegian Petroleum Society, Graham & Trotman, London*, 99-111.

Stemmerik, L. and Worsley, D. 1995. Permian history of the Barents shelf area. *In*: P.A. Scholle, T.M. Peryt and D.S. Ulmer-Scholle (eds) The Permian of Northern Pangea. *Sedimentary Basin and economic Resources* **2**, 81-97.

Stemmerik, L. and Worsley, D. 2005. 30 years on – Arctic Upper Palaeozoic stratigraphy, depositional evolution and hydrocarbon prospectivity. *Norwegian Journal Geology* **85**, 151-168.

Stevens, C.H. 1967. Leonardian (Permian) compound corals of Nevada. *Journal of Paleontology* **41**, 423-431.

Stevens, C.H. 2008. Fasciculate rugose corals from Gzhelian and Lower *Permian* strata, Pequop Mountains, northeast Nevada. *Journal of Paleontology* **82**(6), 1190-1200.

Stevens, C.H. and Rycerski, B. 1989. Early Permian colonial rugose corals from the Stikine River Area, British Columbia, Canada. *Journal of Paleontology* **63**, 158-181.

Stuckenberg, A.A. 1888. Corals and bryozoans from the upper stage of the central Russian Carboniferous limestone. *Trudy Geologicheskago Komiteta* **5**, 1-54 [In Russian, German summary].

Stuckenberg, A.A. 1895. Corals and bryozoans from the Carboniferous deposits of the Urals and Timan. *Trudy Geologicheskago Komiteta* **10**, 1-244 [In Russian with German summary].

Stuckenberg, A.A. 1905. Fauna of the Upper Carboniferous strata of the Samarian bend. *Trudy Geologicheskago Komiteta, Novaya Seriya* **23**, 1-144 [In Russian with German summary].

Szaniawski, H. and Małkowski, K. 1979. Conodonts from the Kapp Starostin Formation (Permian) of Spitsbergen; *Acta Palaeontologica Polonica* **24**(2), 231-264.

Tangen, O. 1981. A sedimentological and environmental interpretation of the upper part of the Nordenskiöldbreen Formation and the Gipshuken Formation on Western Spitsbergen. *Candiatus realium thesis, University of Bergen*, 256 pp.

Thorsteinsson, R. 1974. Carboniferous and Permian stratigraphy of Axel Heiberg Island and western Ellesmere Island, Canadian Arctic Archipelago. *Geological Survey of Canada, Bulletin*, 224 pp.

Tidten, G. 1972. Morphogenetisch-ontogenetische Untersuchungen an Pterocorallia aus dem Permo-Karbon von Spitsbergen. *Palaeontographica, Abt. A* **139**(1-3), 1-63.

Toula, F. 1875. Eine Kohlenkalk-Fauna von den Barents-Inseln (Nowaja Semlja N.W.). *Sitzungsberichte der Akademieder Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Klasse*, **71**, 527-608.

Trautschold, H.A. von, 1879. Die Kalkbrüche von Mjatschkova: Eine Monographie des oberen Berkalks. *Nouveaux Mémoires de la Société Impériale des Naturalistes de Moscou, Mémoire* **14**, 1-82.

Ustritskiy, V.I. 1979. On the distribution of brachiopods in Upper Permian deposits of Spitsbergen. *In*: N.I. Shulgina (ed.) The Upper Palaeozoic and Mesozoic of the islands and coasts of the Arctic seas of the USSR, 126-133. Leningrad. [In Russian].

Veevers, J.J. and Powell, M. 1987. Late Paleozoic glacial episodes in Gondwanaland reflected in transgressive-regressive depositional sequences in Euramerica. *Geological Society of America Bulletin* **98**(4), 475-487.

Verrill, A.E. 1865. Classification of polyps (Extract condensed from a synopsis of the polypi of the North Pacific Exploring Expedition, under Captians Ringgold and Rodgers, U.S.N.). *Proceedings of the Essex Institute* **4**, 145-149.

Visser, J.N.J. 1993. Sea-level changes in a back-arc-foreland transition; the Late Carboniferous-Permian Karoo Basin of South Africa. *Sedimentary Geology* **83**(1-2), 115-131.

Wang, H.C. 1950. A revision of the Zoantharia Rugosa in the light of their minute skeletal structures. *Philosophical Transactions of the Royal Society of London, Series B. Biological Sciences* **611**, 175-264.

Waterhouse, J.B. 1976. World correlations for Permian marine faunas. *Papers of Department of Geology, University of Queensland* **7**(2), 1-232.

Waterhouse, J.B. and Bonham-Carter, G.F. 1975. Global distribution and character of Permian biomes based on brachiopod assemblages. *Canadian Journal of Earth Sciences* **12**, 1085-1146.

Weiss, L.E. 1958. The structure of the Trygghamna-Vermlandryggen area, Isfjorden. *Norsk geologisk Tidsskrift* **38**, 218-219.

Wilson, E.C. 1994. Early Permian corals from the Providence Mountains, San Bernardino County, California. *Journal of Paleontology* **68**, 938-951.

Winsnes, T.S. 1966. Observations on the Carboniferous and Permian rocks of Vestspitsbergen. *Norsk Polarinstitutt Arbok 1964*, 7-29.

Winsnes, T.S., Birkenmajer, K., Dallmann, W.K., Hjelle, A. and Salvigsen, O. 1993. *Geological map of Svalbard 1:100,000, Sheet C13G Sørkapp*. 73 pp. Norsk Polarinstitutt Temakart 17. Oslo.

*

Acknowledgements

I express my warmest thanks to Professor Jerzy Fedorowski (Institute of Geology, Adam Mickiewicz University) for his guidance, help and valuable discussions during the writing of the present paper. I am deeply grateful to Dr Piotr Głowacki (Institute of Geophysics, Polish Academy of Sciences in Warsaw) for his kind help in the organization of the expedition to Spitsbergen. This research was financed by the State Committee for Scientific Research (KBN), project No. 0421/PO4/2003/24.

PALEOGRAFICZNE I PALEOEKOLOGICZNE ZNACZENIE PERMO-KARBOŃSKICH KORALOWCÓW RUGOSA SPITSBERGENU

Streszczenie

Opracowane koralowce Rugosa pochodzą z gżelu, dolnego sakmaru (tastub) i wordu (gwadelup), z formacji Treskelodden, Wordiekammen i Kapp Starostin. Odsłaniają się one wzdłuż wychodni permo-karbonu, od półwyspu Treskelen, położonego w południowej części Spitsbergenu, poprzez Kruseryggen, Triasnuten, Polakkfjellet po Linnédalen znajdujący się na zachodzie centralnej części Spitsbergenu (pd.-zach. Isfjorden). Koralowce Rugosa, pochodzące ze wspomnianych formacji, reprezentują 52 gatunki i jeden podgatunek. Spośród nich, 30 gatunków i jeden podgatunek oraz osiem taksonów bliżej nieokreślonych gatunków, należy do 22 rodzajów (w tym pięciu nowych) reprezentujących formy osobnicze: "*Alekseeviella*" Kossovaya, 2001, *Allotropiochisma* Fedorowski, 1982, *Amygdalophylloides* Dobrolyubova i Kabakovitsch, 1948, *Arctophyllum* Fedorowski, 1975, *Bothrophyllum* Von Trautschold, 1879, *Calophyllum* Dana, 1846, *Caninia* Michelin in Gervais, 1840, *Caninophyllum* Lewis, 1929, *Euryphyllum* Hill, 1938, *Gshelia* Stuckenberg, 1888, *Hornsundia* Fedorowski, 1965, *Lytvolasma* Soshkina, 1925, *Pseudotimania* Dobrolyubova i Kabakovitsch, 1948, *Siedleckia* Fedorowski, 1975, *Sochkineophyllum* Grabau, 1928, *Svalbardphyllum* Fedorowski, 1965, *Timania* Stuckenberg, 1895, *Barentsburgia* gen. nov., *Fedorowskites* gen. nov., *Gronfjordphyllum* gen. nov., *Krusenella* gen. nov., *Linnephyllum* gen. nov. Pozostałe 22 gatunki, z siedmiu rodzajów: *Fomichevella* Fedorowski, 1975, *Heintzella* Fedorowski, 1967, *Kleopatrina* McCutcheon i Wilson, 1963, *Pararachnastraea* Stevens i Rycerski, 1989, *Protowentzelella* Porfiriev, 1941, *Tschussovskenia* Dobrolyubova, 1936*a*, *Paraheritschioides*? Sando, 1985, reprezentują formy kolonijne.

Dwanaście gatunków koralowców osobniczych: *Arctophyllum spitsbergensis* sp. nov., *Barentsburgia crinisphyllia* gen. et sp. nov., *Fedorowskites spitsbergensis* gen. et sp. nov., *Gronfjordphyllum minor* gen. et sp. nov., *Gronfjordphyllum parvum* gen. et sp. nov., *Krusenella pachyseptata* gen. et sp. nov., *Linnephyllum spitsbergensis* gen. et sp. nov., *Linnephyllum longiseptata* gen. et sp. nov., *Pseudotimania arctica* sp. nov., *Pseudotimania borealis* sp. nov., *Pseudotimania longiseptata* sp. nov., *Yakovleviella spitsbergensis* sp. nov. oraz pięć gatunków koralowców kolonijnych: *Fomichevella borealis* sp. nov., *Heintzella breviseptata* sp. nov., *Heintzella poljaricum* sp. nov., *Tschussovskenia borealis* sp. nov., *Tschussovskenia columellata* sp. nov., to nowe gatunki. Sześć nowych gatunków koralowców osobniczych reprezentuje wspomniane wyżej cztery nowe rodzaje, pozostałe, podobnie jak wszystkie nowe gatunki koralowców kolonijnych, należą do znanych rodzajów.

Ponadto dziewięć gatunków koralowców osobniczych: *Allotropiochisma exzentrica* (Flügel, 1973), *Caninophyllum belcheri* (Harker, 1960), *Euryphyllum troldfiordense* Fedorowski i Bamber,

2001, *Gshelia rouilleri* Stuckenberg, 1888, *Lytvolasma asymetrica* Soshkina, 1925, *Siedleckia bjornoyana* Fedorowski, 1975, *Siedleckia longiseptata* (Grek, 1936), *Siedleckia mutafii* (Gorsky, 1938), *Yakovleviella tschernyschevi* Fomitchev, 1953 i sześć gatunków kolonijnych koralowców: *Kleopatrina arcturusensis* Stevens, 1967, *Kleopatrina ftatateeta* (McCutcheon i Wilson, 1961), *Kleopatrina grinnellensis* Fedorowski et al., 2007, *Paraheritschioides*? *californiense* (Meek, 1864), *Pararachnastraea gracilis* (Dobrolyubova, 1941), *Protowentzelella kunthi* (Stuckenberg, 1895), zostało stwierdzonych na Spitsbergenie po raz pierwszy. Ze względu na słaby stan zachowania i/lub ubogi materiał, problematyczne okazy pozostawiono bądź w nomenklaturze otwartej znanych rodzajów (cztery taksony koralowców osobniczych i jeden takson formy kolonijnej), bądź jako Gen. et sp. nov. i Gen. et sp. indet.

Kompleksowa analiza materiału kopalnego, zebranego w mało poznanym i nowym terenie, pokazała, że koralowce te należą do zarówno znanych, jak i nowych gatunków. Ujawniają zatem, z jednej strony, powinowactwo Rugosa ze Spitsbergenu z koralowcami pozostałej części królestwa K-A-U, potwierdzając związki tych koralowców z fauną Alaski, Uralu, Basenu Centralnej Europy, Arktycznej Kanady (Basen Sverdrupa). Z drugiej jednak strony wskazują na ograniczone możliwości komunikacyjne, ewentualnie sygnalizują obecność na Spitsbergenie obszarów o warunkach środowiskowych determinujących taki skład taksonomiczny. Ponadto, zaobserwowane zmiany w strukturze gatunkowej tych zwierząt pozwoliły przybliżyć, wciąż niejasną i kontrowersyjną, stratygrafię i paleogeografię tej części Svalbardu w badanym przedziale czasowym.

Rozpoznane, osobnicze i kolonijne koralowce Rugosa wieku gżel-dolny sakmar (Tastubian substage), wskazują na ciepło-wodne warunki na Spitsbergenie w tym czasie. Natomiast osobnicze koralowce wieku ?road-word są interpretowane jako zimno-wodne.