

Early Campanian silicoflagellates from the Ural Federal District, Russia: a taxonomic and biostratigraphic reexamination of the A. P. Jousé sample suite

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ABSTRACT: Nine samples of broad Late Cretaceous age, previously studied by the respected Russian diatomist A.P. Jousé, were reexamined in order to document the taxonomic composition of silicoflagellates at several localities within the Ural Federal District of Russia. New observations are provided on the range of morphological variability in several important taxa, and a new morphological term, “segment”, is presented for the basal skeletal components of *Cornua*. An attempt is also made to refine the age determinations for these samples using a recently established silicoflagellate biostratigraphic zonation for the Canadian margin. Our general conclusion is that the zonation developed based on the Canadian sections can be successfully used to provide age control for sections exposed in the northern part of Eurasia. The samples studied here are probably correlative to the lower Campanian *Cornua trifurcata* Partial Range Zone and the lowermost Campanian *Schulzyocha ruppelii* Range Zone of northern Canada. However, the recognition of the *Schulzyocha ruppelii* Zone is based on the presence of a secondary zonal marker (*Gleserocha tapiæ*), due to the absence of *Schulzyocha*. This may indicate that only the *Cornua trifurcata* Zone has interregional applicability, while the *Schulzyocha ruppelii* Zone may be restricted to the Canadian successions due to the endemism of *Schulzyocha*. Further studies on Late Cretaceous silicoflagellate paleobiogeography are required to resolve these issues.

Keywords: silicoflagellates, Campanian, Late Cretaceous, Urals, Jousé

INTRODUCTION

Silicoflagellates are cosmopolitan marine planktonic protists characterized by siliceous skeletons composed of tubular elements. They have a ~115 million year (myr) fossil record (Albian–Recent) and a variety of geological applications that include biostratigraphy and paleoceanography. Recent work on northern Canadian Santonian through Campanian (Upper Cretaceous) sections resulted in an improved understanding of the sequence of evolutionary events (McCartney et al. 2010b) for this microfossil group, including the timing of the basal ring development in *Corbisema* derived from ancestral *Cornua*, and the first appearance of *Lyrarmula*. However, in practical terms, the most important outcome of these studies is a considerably improved silicoflagellate-based biostratigraphic zonation for the Santonian through Maastrichtian (McCartney et al. 2011b; 2011c).

Sediment samples collected and studied by Anastasia Pantelimonovna Jousé (1905–1981) have recently been relocated by the Geographical Faculty, Moscow State University. Jousé was one of the most respected Soviet diatomists of the former century. She authored more than 100 publications that described about 350 new diatom species (Burckle et al. 2006); however, only two of these papers (Jousé 1949; 1951) dealt with Late Cretaceous siliceous microfossils. These two papers include descriptions of important diatom and silicoflagellate taxa but were published long before the advent of scanning electron micros-

copy and the development of modern taxonomic conventions. The illustrations generally consist of few simple line drawings with little information provided on the morphological variability of the species, stratigraphic distribution or evolutionary relationships. For these reasons, the samples relocated in the Moscow State University collections provide an excellent opportunity to reexamine the Late Cretaceous siliceous microfossil assemblages studied by A. P. Jousé.

The purpose of this study is to document the skeletal morphology and morphological variation in multiple poorly understood silicoflagellate taxa from a number of localities of broadly comparable Late Cretaceous age. The samples of the Jousé suite were collected from several localities. No precise sampling protocols were preserved in the Moscow State University collections, thus a strictly stratigraphic study is not currently possible. However, observations on the well-preserved silicoflagellate assemblages from an extensive area of Eurasia can be used to test whether the silicoflagellate-based biostratigraphic zonation proposed in the recent studies of Santonian through Campanian sediments from Canada can be applied to sediments from Russian sections.

MATERIAL AND METHODS

Small subsamples of dried, chemically treated residues from the A.P. Jousé collection curated at the Moscow State University were made available to the Palaeoceanology Unit, Faculty of



TEXT-FIGURE 1
Map showing distribution of samples used in this study.

Geosciences, University of Szczecin, Poland. The samples were accompanied by catalogue cards with brief locality information and a list of diatom taxa present in each sample. However, no detailed stratigraphic information was available for the samples. The diatoms and silicoflagellates preserved in at least part of these samples are, however, consistent with the illustrations provided by Jousé (1949; 1951).

The following samples were used in this study (for reference, Institute of Marine Sciences, University of Szczecin collection [SZCZ] numbers are indicated in brackets):

- Sample 21 (SZCZ #15270). According to the label, this sample was collected at Bolshoi Aktay River, in Sverdlovsk district. Consult Witkowski et al. (2012) for a discussion on the age and origin of the sample. Sample 21 was probably one of the samples examined for the Jousé (1949) study.

- Sample 45 (SZCZ #15273). The sampling locality given by the label is: Belaya Rechka village, Poludennyi Aktay River, Sverdlovsk district. The age assignment given by the label is Senonian, i.e., middle through late Cretaceous. This sample was considered by Witkowski et al. (2012) to have been included in the Jousé (1951) study.

- Sample 46 (SZCZ #19994). According to the label, the sample was collected at Pokrovskaya, Bolshoy Aktay River, in

Sverdlovsk district. Its age is estimated as Senonian, Late Cretaceous.

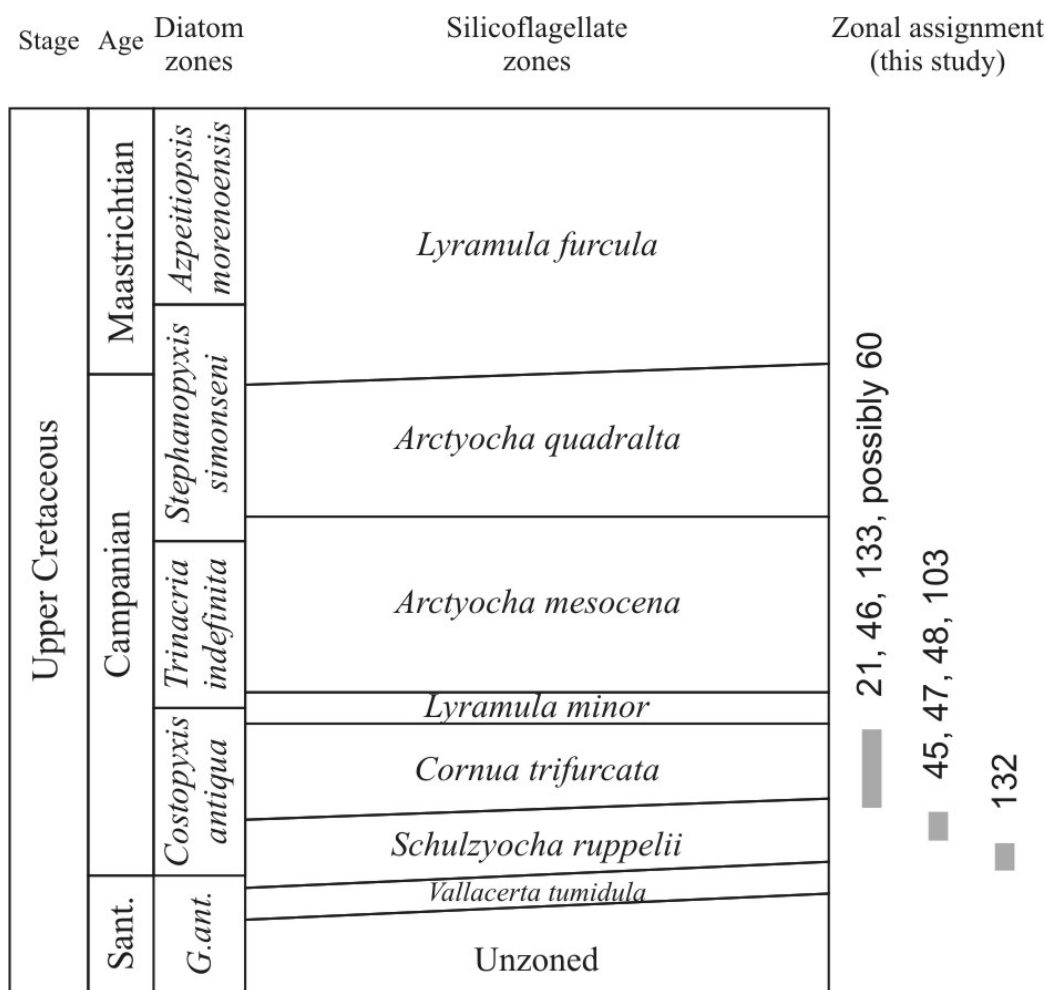
- Sample 47 (SZCZ #15274). According to the label, the sample was collected at Belaya Rechka village, Poludennyi Aktay River, Sverdlovsk district. The age indicated by the label is Senonian, Late Cretaceous.

- Sample no. 48 (SZCZ #15275). The sampling site according to the label is Poludennaya village, Poludennyi Aktay River, Sverdlovsk district. The sample is dated as Senonian (Late Cretaceous). Most of the diatoms listed on the label were dealt with in Jousé (1949).

- Sample no. 60 (SZCZ #15276). The sample was collected at River Sin'ya, Prepolarskaya, and dated as Late Cretaceous. Strelnikova (1974) considered the diatom-bearing Late Cretaceous sediments outcropping in Til'tim on the river Sin'ya as early Campanian in age.

- Sample 103 (SZCZ #15277). The label lists this sample as being from the Upper Cretaceous of the northern bank of the Nyais River.

- Sample no. 132 (SZCZ #15278). The sampling spot given by the label is the upper reaches of the river Leplya, Prepolarskaya. The age assignment is Late Cretaceous.



TEXT-FIGURE 2

Silicoflagellate and diatom zones for the Upper Cretaceous with interpreted zonal assignments of samples examined in this study. Tentative zonal boundaries are sloped. For formal description of diatom zones see Tapia and Harwood (2002), for silicoflagellate zones see McCartney et al. (2011a; 2011b). Abbreviations: Sant. – Santonian; G. ant. – *Gladius antiquus*.

- Sample 133 (SZCZ #15279). The sampling locality according to the label is Leplya River, Berezovsk region, Prepolars Urals. The sample is dated as Late Cretaceous.

Permanent slides for light microscopy (LM) were mounted using Naphrax diatom mountant and 18 × 18 mm cover slips. LM examination was performed with a Leica DMLB microscope. Multiple slides of each sample were examined. All identifiable fragments of silicoflagellate skeletons were counted in order to document the taxonomic composition of the silicoflagellate assemblages. Specimen counts were made using ×20 magnification. A ×50 objective was used for digital photography by means of a Nikon DS-1 camera. In order to avoid presenting multiple focal depths for each of the specimens depicted on plates, multiple light microphotographs were spliced using the freeware software CombineZM. Scanning electron microscope (SEM) examination was performed using a Hitachi S-4500 microscope in J. W. Göthe-Universität, Frankfurt am Main, Germany. Specimens for SEM examination were selected using a mechanical micromanipulator, following the procedure proposed by Nikolaev (1982).

RESULTS

A total of 20 silicoflagellate species are identified in this study (Table 1). The preservation is generally good with complete specimens of relatively fragile skeletons such as *Gleserocha wisei* and *G. tapiae* observed. As is commonly found in Campanian and Maastrichtian silicoflagellate assemblages, skeletons of *Lynamula* are the most abundant, but species of *Corbisema*, *Cornua* and *Vallacerta* also occur frequently.

A remarkable finding of this study are five double skeletons of *Vallacerta hortonii* and one of *V. simplex* that were observed in Samples 60, 103 and 133. The matrix occasionally found stuck to the siliceous microfossils has prevented the separation of the sibling skeletons in the sample preparation process. All specimens are in the Star-of-David configuration (McCartney et al. 2010a), with the basal spines of each skeleton being positioned approximately midway between the corners of the sibling skeleton. Double skeletons of this configuration have also been observed in Cretaceous *Corbisema* (McCartney et al. 2010a; 2015) and *Schulzyocha* (McCartney et al. 2011b).

SYSTEMATIC PALEONTOLOGY

Synonymy information listed here is in addition to that provided by McCartney et al. (2011b).

Genus *Corbisema* Hanna 1928

Type species: Corbisema geometrica Hanna 1928

Corbisema apiculata (Lemmermann) Hanna 1931

Corbisema apiculata (Lemmermann) - McCARTNEY, WITKOWSKI and HARWOOD 2011c, pl. 5, fig. 7.

Remarks: Specimens are generally fragmentary and identified by the possession of sharp corners and small corner spines. There is a small pike on the abapical side of the basal ring beneath the strut attachment. This morphology is distinctly different from the basal rings of *C. lateradiata*, which has more rounded corners and longer basal spines.

Corbisema archangelskiana (Schulz) Frenguelli 1940

Plate 1, figures 2, 5-6; Plate 2, figures 1-5

Remarks: Large skeleton with a generally fragile appearance and tightly rounded or squared corners and linear sides that are not scalloped at the strut attachments. Pikes, if present, tend to be small. Small spines at the corners may also occur. A fragmentary specimen with two corners, one with and one without a small spine, was observed.

McCartney et al. (2011b) illustrated several specimens that had a more robust basal ring and prominent, usually linear pikes. A few specimens of this type were observed in the present study, but were not counted separately (see Pl. 2, figs. 4-5, for examples with more curved pikes). One specimen had slightly expanded strut attachments similar to *C. archangelskiana*, although not as exaggerated as specimens illustrated by McCartney et al. (2011b, Pl. 2, figs. 7, 9-11). *Corbisema archangelskiana* is generally identified by the triangular shape of the basal ring with straight sides and rounded corners, but it may be that there are several species with this general basal morphology that are differentiated by the pikes or other more subtle features. A more detailed study of these large silicoflagellates is needed.

A few specimens with flattened and squared corners similar to *C. furcata* were observed (e.g., in Sample 133). While these specimens lack the small spines typical of *C. furcata*, they were counted as *C. furcata* and suggest that there is a close relationship between these morphologies.

A single teratoid four-sided specimen of this taxon was observed in Sample 60. A similar specimen identified as “*Corbisema* sp. cf. *C. archangelskiana*” (Oligocene in age) was photographed by Bukry (1975, Pl. 1, figs. 2-3).

Corbisema furcata Jousé 1949

Plate 1, figures 3-4

Remarks: Single specimens of this species were illustrated by Jousé (1949) and McCartney et al. (2011b). In this study, *C. furcata* was generally fragmentary, but its abundance was high in Sample 60. This sample also included specimens of *C. archangelskiana* with squared corners and the two taxa are believed to be closely related. This taxon appears to be most abundant in samples that have common *Lyracula minor*.

Corbisema hanna McCartney, Witkowski and Harwood 2011b
Plate 1, figure 1

Remarks: Specimens encountered in this study were generally similar to those illustrated by McCartney et al. (2011b). However, a few specimens with slightly less rounded corners, and with a small corner spine are here included in this taxon. The apical structures consist of delicate struts that are often broken. This species generally lacks pikes, but small pikes were observed on a specimen in Sample 47. Although Gleser (1966) reported pikes measuring up to 10µm, pikes are also generally absent in *C. geometrica*, which has a basal ring similar to *C. hanna*, but differs in the presence of an expanded apical plate in *C. geometrica*. Furthermore, *C. geometrica* occurs in a later time interval, i.e., late Campanian to Maastrichtian (McCartney et al. 2011b).

Corbisema lateradiata (Schulz) Perch-Nielsen 1975

Plate 1, figure 7; Plate 2, figures 6-7

Remarks: Skeletons of this species usually have rounded corners and small pikes on the basal ring beneath the strut attachment, where the sides are indented. All specimens examined in this study had an apical plate, with the central area slightly depressed in larger specimens. Furthermore, several specimens displayed apical rings and a single skeleton of this morphology was illustrated by Jousé (1949). Size from corner to opposite side is generally 40 to 55µm.

Genus *Cornua* Schulz 1928

Type species: Cornua trifurcata Schulz 1928

Remarks: The descriptive terminology used for this genus is amended here. Silicoflagellate skeletons consist of a framework of linear to curved rod-shaped members that are referred to as “elements,” “spines” and “pikes”. The term element was at one time applied to all skeletal components but has more recently been used for rods that connect to other skeletal members at both ends, while spines and pikes connect to elements at one end but terminate distally (McCartney et al. 2015). Spines may occur on the basal or apical structures and point away from the middle of the cell while pikes are exclusively basal. In *Cornua*, the struts attach to basal skeletal components that are distally terminated but are not aligned as typical spines. McCartney et al. (2011b; 2011c) referred to these as elements since that is what they become evolutionarily with the formation of corbisemid basal rings. In this paper, we use the term “segment” for basal skeletal members that are pointed distally but are attached to the apical structure, following McCartney et al. (2015).

Cornua poretzkajae Gleser 1959

Plate 2, figure 8

Cornua poretzkajae Gleser – McCARTNEY, WITKOWSKI and HARWOOD 2010b, fig. 5k. – McCARTNEY, WITKOWSKI and HARWOOD 2011c, pl. 1, figs. 9, 11, 12, pl. 5, fig. 11, pl. 3, figs. 3, 6.

Remarks: Only four specimens were observed, all generally resembling the specimen illustrated by Gleser (1959).

Cornua trifurcata Schulz 1928

Plate 1, figures 10-12; Plate 2, figures 9-10

Remarks: Skeletons of this species were typically small, with struts measuring about 10µm, but fragments with struts up to 30µm long were observed. The general range of variation was

TABLE 1

Abundance of silicoflagellate species in selected samples from Urals Federal District. Samples are not listed in stratigraphic order. Species (in alphabetical order) are recorded as total number of specimens observed in the counted slides. Abbreviations: f = fragment.

Locality	Jouse Collection sample number	SZCZ sample number	Number of slides counted	<i>Corbisema apiculata</i>	<i>C. archangeliskiana</i>	<i>C. furcata</i>	<i>C. hannai</i>	<i>C. latiradiata</i>	with apical ring	<i>Cornua poretzkajae</i>	<i>C. trifurcata</i>	<i>Gleserocha harrisonii</i>	<i>G. tapiae</i>	<i>G. wisei</i>	<i>Lynamula arctica</i>	<i>L. deflandrei</i>	<i>L. furcula</i>	<i>L. furcula</i> (long-spined)	<i>L. furcula</i> (near-circular)	<i>L. minor</i>	<i>L. simplex</i> var. <i>simplex</i>	<i>L. simplex</i> var. <i>inflata</i>	<i>L. simplex</i> var. <i>spinosa</i>	<i>Vallacerta hortonii</i>	4-sided	6-sided	<i>V. siderea</i>	<i>V. simplex</i>	<i>V. tumidula</i>	<i>Variramus aculeifera</i>	Total silicoflagellates	
<i>Cornua trifurcata</i> Partial Range Zone																																
Bolshoi Aktay River	21	15270	3	4	1	1	19			15		4	2	1	16	31	2	19	3	2	1	59	1		7	29	10	2	229			
Pokrovskaya	46	19994	2	10			22	2		16		1	3		31	80	6	137	12	5		57	1		12	6	2	1?	403			
Leplya River	133	15279	2	6	2		4	1		10			2	7	42	15	8	33	10	3		40			7	10	6			206		
tentatively correlated to <i>Cornua trifurcata</i> Partial Range Zone																																
River Sin'ya	60	15276	2	13	8		16	2		9		5	8	2		39	36	28	154	32	8		45			8	20	7		440		
<i>upper Schulzyocha ruppelii</i> Range Zone																																
Belaya Rechka	45	15273	3	f?	7		8	6		63	9	6	11	4		25	75	2	9	14	24		19	1		8	2	23	3	319		
Belaya Rechka	47	15274	2	f?	6		1	1		41	2	8	4		2	17	42	5	26	5	2		28			2	4	11		207		
Poludennaya	48	15275	2	2	1		2			9		1	6	1		18	41	2	21	3		8		2	5	6	9	1	138			
Nyais River	103	15277	2		15		2	21		33		1	3	2		83	11	15	68	33	4		124		4	10	24	26		479		
<i>lower Schulzyocha ruppelii</i> Range Zone																																
Leplya River	132	15278	3				2	1		3	40	1	3	1?	1		16		15	1		5								88		

consistent with that reported by McCartney et al. (2011b). The segments are generally linear but may be distally curved in the general direction of the next adjacent segment of the next strut.

Genus *Gleserocha* McCartney, Witkowski and Harwood 2014
Type species: *Gleserocha wisei* (McCartney, Witkowski and Harwood) McCartney, Witkowski and Harwood 2014

Gleserocha harrisonii McCartney, Witkowski and Harwood 2014
Plate 2, figure 13

Gleserocha harrisonii McCARTNEY, WITKOWSKI and HARWOOD 2014, pl. 3, figs. 13-15, pl. 5, figs. 1-5.

Remarks: This is an unusual skeletal morphology. Each strut attaches to two segments that may or may not be similar in shape or length. The pair of segments associated with one strut generally lie along a curved surface that is rotated away from the basal plane defined by the three strut attachments. The rotations of the three segment pairs are such that they appear to generally curve around a spherical surface. One or more of the segments may be more linear or otherwise deviate from the apparent spherical surface formed by the other segments. There are no pikes at the strut attachment or elsewhere.

Gleserocha tapiae (McCartney, Witkowski and Harwood) McCartney, Witkowski and Harwood 2014
Plate 1, figures 8-9

Cornua tapiae McCARTNEY, WITKOWSKI and HARWOOD 2011c, pl. 2, figs. 1-5, pl. 6, figs. 7-12.

Gleserocha tapiae (McCartney, Witkowski and Harwood) – McCARTNEY, WITKOWSKI and HARWOOD 2014, pl. 2, figs. 13-14, pl. 3, figs. 1-4, pl. 5, figs. 6-9.

Remarks: Skeletons of this species were uncommon in this study. The species was not observed in the *Cornua trifurcata* Zone by McCartney et al. (2011b) in the Horton River section, nor by McCartney et al. (2011c) in the Devon Island succession. Furthermore, it was absent from Samples 21, 46 and 133

of this study, which are interpreted to fall within the *Cornua trifurcata* Zone (see discussion below).

Gleserocha wisei (McCartney, Witkowski and Harwood) McCartney, Witkowski and Harwood 2014

Plate 3, figure 6-8

Variramus wisei McCARTNEY, WITKOWSKI and HARWOOD 2011c, pl. 3, figs. 1-9, pl. 9, figs. 4-6.

Gleserocha wisei (McCartney, Witkowski and Harwood) – McCARTNEY, WITKOWSKI and HARWOOD 2014, pl. 2, figs. 7-8, 10-12, pl. 3, figs. 1-4, pl. 5, figs. 6-9.

Remarks: This species was present in all samples of this study if a questionable specimen is included from Sample 132. *Gleserocha wisei* ranges from the Albion of Ocean Drilling Program Site 693 in the Weddell Sea to the early Campanian, where it has been observed in the *Cornua trifurcata* Zone in the Horton River, Hoodoo Dome and Devon Island sections (McCartney et al. 2011b; 2011c) in the Canadian Arctic.

Genus *Lynamula* Hanna 1928

Type species: *Lynamula furcula* Hanna 1928

Lynamula arctica Bukry 1985

Plate 4, figure 6

Remarks: This taxon has a Y-shaped skeleton with equant limbs separated by an angle larger than 80°. The size of the skeletons is generally in the lower range of size variation for *Lynamula furcula*, about 40-65µm. Specimens of *Lynamula minor* with widely separated limbs were also observed but counted within the range of variation of that species.

Lynamula deflandrei Perch-Nielsen and Edwards 1975

Plate 4, figure 7

Remarks: McCartney et al. (2011b) observed this taxon in a single sample in the middle Campanian, which is presumably younger than the age of the sediments examined here. High abundance of *L. deflandrei* was reported from the CESAR-6

core in the Arctic Ocean (Ling et al. 1973) and from Deep Sea Drilling Project (DSDP) Site 275 (Perch-Nielsen 1975), both of which are also of younger age.

Lynamula furcula Hanna 1928

Plate 3, figure 1; Plate 4, figures 1-5

Remarks: This taxon generally shows considerable variability in size and shape of the limbs. Two skeletal morphologies of *L. furcula* were consistently present in some or all of the examined samples but are not formally described in this study, in part because of the uncertain stratigraphic relationships of the localities, and also because the group deserves a more thorough morphological and statistical analysis than can be provided here. There is a considerable intergradation among the *Lynamula* skeletal morphologies that have a spine at the point where the two limbs meet at an angle, which includes *L. furcula*, *L. minor* and *L. arctica*.

One variation of *L. furcula* that was widely observed in this study has a spine that is longer than typical, with a length often more than 30% of the limbs (Pl. 4, figs. 4-5; see also Pl. 6, fig. 4 in Jousé 1951). Skeletons of this variety are generally of a smaller size within the wider range of *L. furcula*, with a common specimen having a limb of 52µm, measured along the axis of the spine, and a spine 22µm long (spine length = 42% of limb). Spines can reach lengths of nearly half the limb. Specimens of *Lynamula* of this general appearance were observed in all the samples of this study, except Sample 132. Specimens of this morphology are listed as “long-spined” in Table 1.

A second group (Pl. 4, figs. 1-3), listed as “near-circular” in Table 1, has two limbs that together describe at least half a circular morphology. The length and width of the skeleton are nearly equal, with length measured from the point where the spine meets the two intersecting limbs to the end of the longest limb,

in the direction of the spine, and width being the maximum distance from the outside edge of one limb to the other. Large specimens (Pl. 4, fig. 2) have lengths and widths greater than 100µm, while small specimens have measurements of about 30µm. This general morphology was observed in all the samples of this study except 132, and was especially abundant in Samples 60 and 103. Specimens of *L. minor* that have this general shape were observed but counted separately.

Two specimens of the near circular morphology were observed in close proximity to one another and in similar orientation (Pl. 3, fig. 1). There is a slight difference in size between the two specimens and this occurrence does not qualify as strong evidence that these skeletons are members of a double skeleton pair. However, these two specimens were observed in a slide from Sample 60 that also contained double skeletons of *Vallacerta hortonii* and *V. simplex* and are included here as a possible disarticulated double skeleton. McCartney et al. (2010b, p. 97) have speculated on possible double skeleton configurations for *Lynamula*.

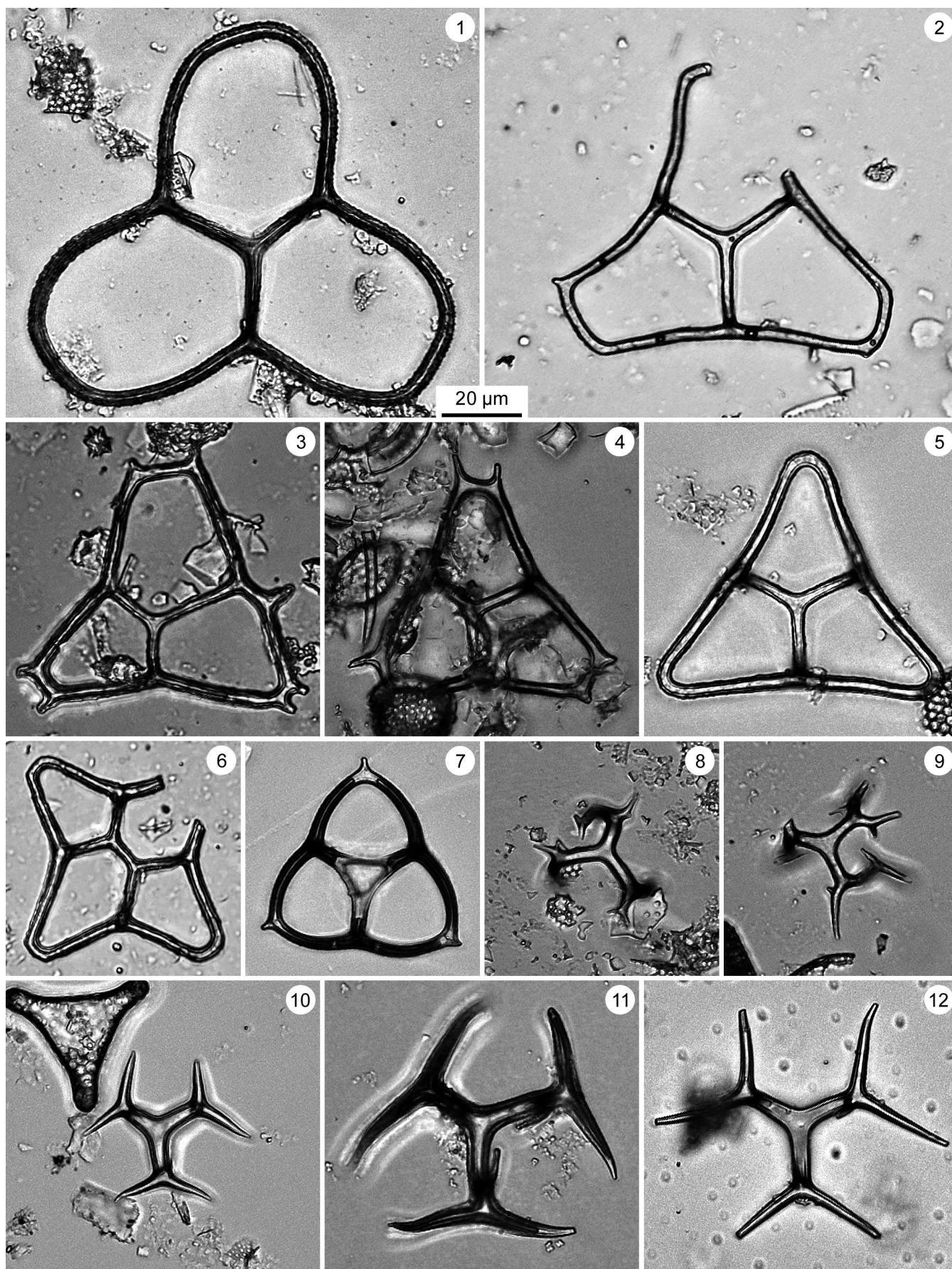
Lynamula minor (Deflandre) Deflandre 1950

Plate 4, figures 8-9

Remarks: Skeletons are of small size, usually 20-30µm long. Specimens as large as 45µm, however, were counted and included in this species if they appeared more similar to *L. minor* and less similar to co-occurring *L. furcula*. Specimens of *L. minor* generally have limbs that are more widely bowed and are generally less heavily silicified than *L. furcula*. Specimens of this taxon appear more likely to have distorted limbs, including limbs that are twisted away from the plane of the spine and other limb. There is some overlap in the size range of *L. minor* and *L. furcula*, but in general these appear distinct enough to warrant separation.

PLATE 1

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| <p>1 <i>Corbisema hanna</i> McCartney, Witkowski and Harwood; Sample 47.</p> <p>2,5-6 <i>Corbisema archangelskiana</i> (Schulz) Frenguelli; 2, sample 60; 4, Sample 21; 5, Sample 60.</p> <p>3-4 <i>Corbisema furcata</i> Jousé; 3, sample 60; 4, Sample 133.</p> | <p>7 <i>Corbisema lateradiata</i> (Schulz) Perch-Nielsen; Sample 21.</p> <p>8-9 <i>Gleserocha tapiae</i> McCartney, Witkowski and Harwood; 8, Sample 47, apical view; 9, Sample 60, abapical view.</p> <p>10-12 <i>Cornua trifurcata</i> Schulz; 10, sample 21; 11-12, sample 132.</p> |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|



Lynamula simplex* var. *simplex Hanna 1928

Lynamula simplex var. *simplex* Hanna – McCARTNEY, HARWOOD and WITKOWSKI 2011a, pl. 1, figs. 1-5.

Remarks: Specimens were observed over a wide range of size, from about 40 to 100µm.

Lynamula simplex* var. *inflata McCartney, Harwood and Witkowski 2011a

Plate 4, figure 10

Lynamula simplex var. *inflata* McCARTNEY, HARWOOD and WITKOWSKI 2011a, pl. 1, figs. 13, 15-19.

Remarks: Most of the specimens were only slightly inflated and are consistent with the single *Lynamula simplex* illustrated by Jousé (1951); a specimen of this morphology is also illustrated by McCartney et al. (2011a, Pl. 1, fig. 4). This variety makes up about half of the observed specimens of *L. simplex* in Sample 45, which includes some specimens that show larger inflations more typical of those illustrated by McCartney et al. (2011a).

Lynamula simplex* var. *spinosa McCartney et al. 2011a

Lynamula simplex var. *spinosa* McCARTNEY, HARWOOD and WITKOWSKI 2011a, pl. 1, figs. 6-9, 11.

Remarks: Only a single specimen of this variety was observed, in Sample 21.

Genus *Vallacerta* HANNA 1928

Type species: *Vallacerta hortonii* Hanna 1928

Vallacerta hortonii Hanna 1928

Plate 2, figures 15-16; Plate 3, figures 3-4

Remarks: McCartney et al. (2011b) reported that skeletons of *Vallacerta hortonii* and *V. siderea* often grade into one another, which makes the separation between these species difficult and inconsistent. In this study, and especially in Sample 21, these

taxa are distinctly different. Skeletons of *V. hortonii* are small, with more linear sides. The domal surface has a mottled texture when observed from apical view. The size is typically 25µm from corner to opposite side, but can be significantly larger. Spine length can vary considerably. Specimens in Sample 21 often had one spine longer than the others.

Rare double skeletons were observed in Samples 60 (one specimen), 103 (two specimens) and 133 (two specimens). All double skeletons were of the “Star-of-David” configuration (see McCartney et al. 2010a). A possibly disaggregated double skeleton of the variant morphology that had one spine longer than the others was also observed (Pl. 3, fig. 3).

Vallacerta siderea (Schulz) Bukry 1981

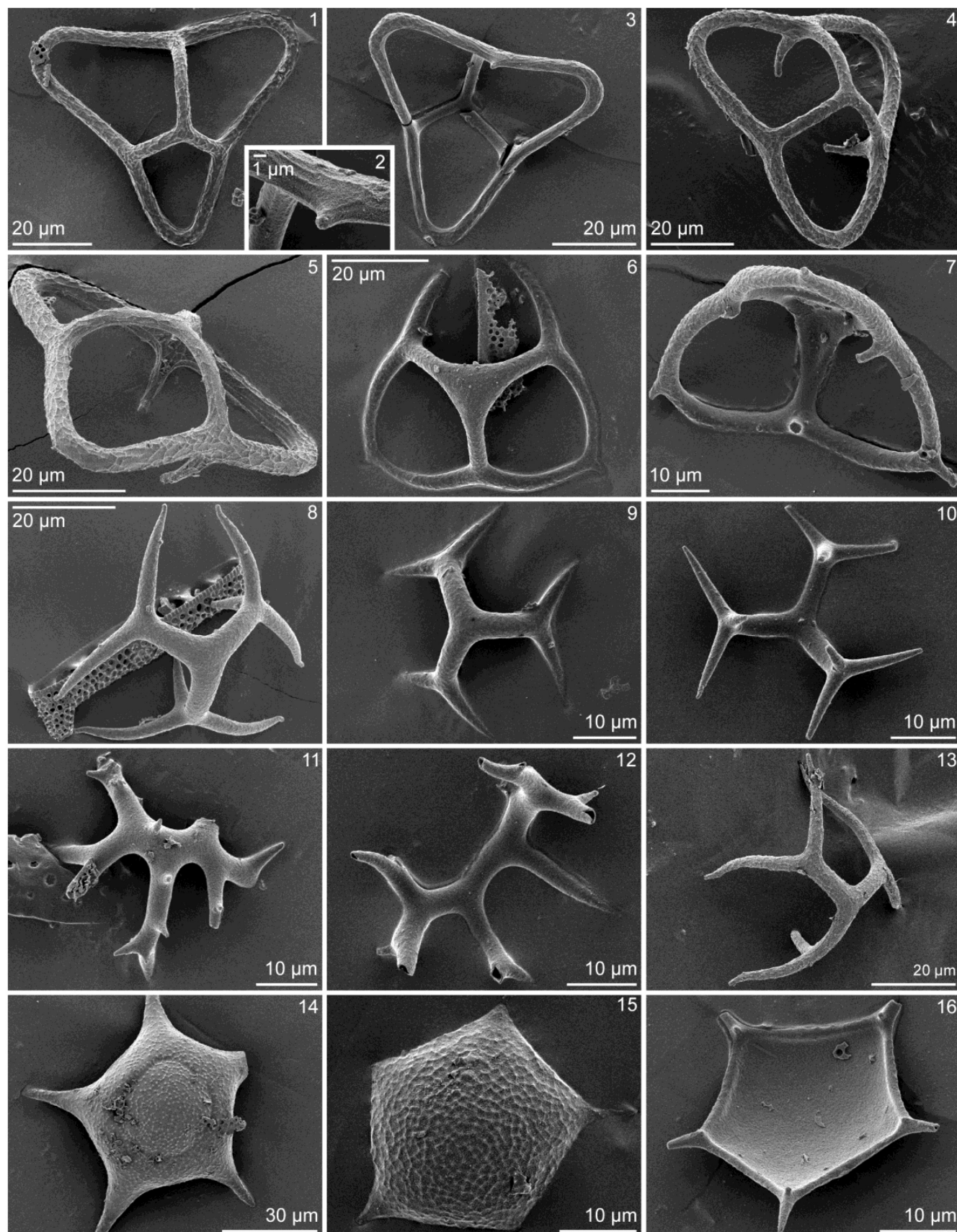
Remarks: Skeletons are usually larger, measuring 25-50µm, than those of the co-occurring *Vallacerta hortonii*. The sides have a smooth curve rather than being linear in at least the middle portion of each side. Whereas McCartney et al. (2011b) observed that *V. siderea* appeared to intergrade with *V. hortonii*, in this study *V. siderea* appears to be more closely related to *V. tumidula*. *Vallacerta siderea* and *V. tumidula* are often of similar size and can only be distinguished by the presence of a circular cupola in the latter. A circular pattern on the domal surface of *V. siderea* can be present and can be more obvious in tilted specimens, which makes identification more subjective. Some intergradation between *V. siderea* and *V. hortonii* is also observed.

Vallacerta simplex Jousé 1949

Remarks: McCartney et al. (2011b) found this taxon difficult to distinguish from *V. hortonii* specimens with basal spines broken off. Fractured five-sided specimens were counted as *V. simplex* if there were no spines, although these may have been *V. hortonii* with the spines removed through breakage. Skeletons

PLATE 2

- | | |
|------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| 1-3 <i>Corbisema archangelskiana</i> (Schulz) Frenguelli; Sample 21; 1, apical view; 3, abapical view. | 9-10 <i>Cornua trifurcata</i> Schulz; Sample 21; 9, apical view; 10, abapical view. |
| 4-5 <i>Corbisema</i> sp. cf. <i>archangelskiana</i> (Schulz) Frenguelli; Sample 45; 4, oblique apical view; 5, lateral view. | 11-12 <i>Variramus aculeifera</i> McCartney, Wise, Harwood and Gersonde; 11, Sample 45; 12, Sample 21. |
| 6-7 <i>Corbisema lateradiata</i> (Schulz) Perch-Nielsen; Sample 21; 6, apical view; 7, oblique abapical view. | 13 <i>Gleserocha harrisonii</i> ; Sample 45, apical view. |
| 8 <i>Cornua poretzkajae</i> Gleser; Sample 45, oblique apical view. | 14 <i>Vallacerta tumidula</i> Gleser; Sample 21, apical view. |
| | 15-16 <i>Vallacerta hortonii</i> Hanna; Sample 21; 15, apical view; 16, abapical view. |



of *V. simplex* and *V. hortonii* are of about the same size. Jousé (1949) illustrated three specimens of *V. simplex*, one of which (Pl. 2, fig. 8 of that study) would probably have been identified as *V. hortonii* in this study.

An incomplete double skeleton of this taxon was observed in Sample 60. Sibling skeletons are in the Star-of-David configuration.

Vallacerta tumidula Gleser 1959

Plate 3, figure 2

Remarks: The illustrated specimen is unusually large for this species.

Genus ***Variramus*** MCCARTNEY, WISE, HARWOOD AND GERSONDE 1990

Type species: *Variramus aculeifera* (Deflandre) McCartney, Wise, Harwood and Gersonde 1990

Variramus aculeifera (Deflandre) McCartney, Wise, Harwood and Gersonde 1990

Plate 2, figure 11-12; Plate 3, figure 9

Variramus aculeifera (Deflandre) - MCCARTNEY, WITKOWSKI and HARWOOD 2011c, pl. 3, figs. 10-15. – MCCARTNEY, WITKOWSKI and HARWOOD 2014, pl. 3, figs. 5-12, pl. 6, figs. 10-12.

Remarks: This taxon occurred rarely in this study.

DISCUSSION

Zonal interpretation

In a recent report on Campanian diatoms and silicoflagellates from the Saratov region, Oreshkina et al. (2013) demonstrated that diatom and silicoflagellate zonations recently developed for the Canadian Margin (Tapia and Harwood 2002; McCartney et al. 2011b; 2011c) are well-suited for providing age control for mid-latitude Upper Cretaceous successions. Since our understanding of siliceous phytoplankton paleobiogeography is still insufficient for the Late Cretaceous, this study aims to test whether it is possible to apply these zonations to date the Upper

Cretaceous sediments exposed in Eurasian sections located further to the north.

Based on the occurrence of *Cornua trifurcata* in the absence of *Gleserocha. tapiae*, Samples 21, 46 and 133 fit the *Cornua trifurcata* Zone as described by McCartney et al. (2011b). Samples 21 and 133, however, also include *Corbisema furcata*, which was only observed in the lower Campanian *Lyrarmula minor* Zone by McCartney et al. (2011b). The presence of *C. furcata* is a possible indication of a younger age for these samples.

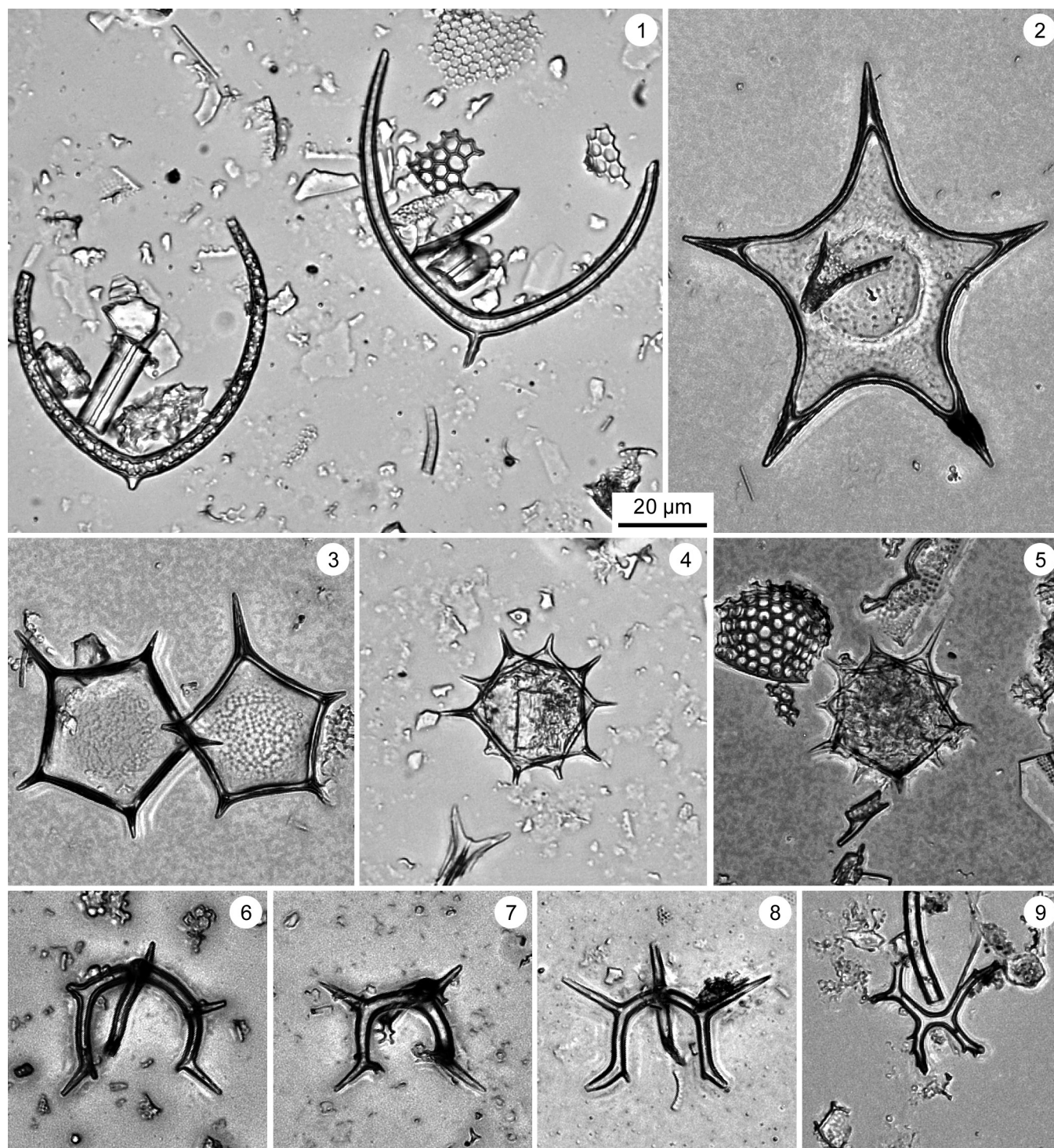
The correlation of Sample 60 is more challenging. This sample includes *C. furcata* and *C. lateradiata*, which are indicative of the *Cornua trifurcata* Zone, and *G. tapiae*, which may be indicative of the *Schulzyocha ruppelii* Zone. However, based on the high abundance of *C. furcata* in Sample 60, we tentatively place this sample within the *Cornua trifurcata* Zone, alongside Samples 21 and 133, which also include this rare corbisemid species. In such case, the presence of *G. tapiae* in Sample 60 might suggest its placement lower within the *Cornua trifurcata* Zone.

There are a number of differences between the *Cornua trifurcata* Zone assemblage described from the Horton River section of Canada and the samples examined in this study that are placed within the same zone. This study shows the occurrence of *Vallacerta siderea* and *V. simplex*, which were not observed in the *Cornua trifurcata* Zone at Horton, and the often common occurrence of *V. hortonii*, which was sparse in the Horton River section. *Corbisema apiculata*, which was abundant in this zone at the Horton River section, is rare in samples from the Ural district, while *C. lateradiata* is generally present in this study, but occurs in a later time interval in the Horton River section. These differences may suggest contrasting environmental conditions between the Canadian and Eurasian localities.

Samples 45, 47, 48 and 103 may range below the bottom of the *Cornua trifurcata* Zone, as suggested by the presence of *G. tapiae*. The base of the *Cornua trifurcata* Zone is defined as the last occurrence of *Schulzyocha ruppelii*, which is also the zonal marker for the next lower unit, the *Schulzyocha ruppelii* Range

PLATE 3

- 1 *Lyrarmula furcula* Hanna (near-circular); Sample 60.
- 2 *Vallacerta tumidula* Gleser; Sample 21.
- 3 *Vallacerta hortonii* Hanna; Sample 21.
- 4-5 *Vallacerta hortonii* Hanna (double skeleton); 4, Sample 103; 5, Sample 60.
- 6-8 *Gleserocha wisei* (McCartney, Witkowski and Harwood); 6, Sample 47; 7, Sample 60; 8, Sample 45.
- 9 *Variramus aculeifera* (Deflandre) McCartney, Wise, Harwood and Gersonde; Sample 21.



Zone. However, none of the five *Schulzyocha* species determined by McCartney et al. (2011b) to be restricted to the *Schulzyocha ruppelii* Zone were observed in the Jousé sample suite. Therefore, *G. tapiae*, recorded in the *Schulzyocha ruppelii* Zone in the Canadian sections, is used as an auxiliary zonal marker in this study. The upper part of the *Schulzyocha ruppelii* Zone in the McCartney et al. (2011c) study, includes *C. archangelskiana* and other taxa that occur in the Ural district. McCartney et al. (2011c) reported *C. trifurcata*, *L. furcula* and *V. tumidula* from the upper part of the *Schulzyocha ruppelii* Zone in relative numbers similar to Samples number 45, 47 and 103, in which *G. tapiae* is also present. Sample 48 also appears to fall within the *Schulzyocha ruppelii* Zone, but has relatively lower abundances of *C. trifurcata* and *V. tumidula*. This sample, however, includes abundant *V. hortonii* which was not observed in the upper part of the *Schulzyocha ruppelii* Zone in Canada. Overall, these differences suggest that key taxa observed in the *Schulzyocha ruppelii* Zone of northern Canada may be endemic to that region. Further study on Late Cretaceous silicoflagellate paleobiogeography is required to elucidate the applicability of the lower part of the northern Canadian biostratigraphic scheme to northern Eurasian sections.

Sample 132 differs from other samples examined here by the presence of *C. poretzkajae*, and the absence of all *Vallacerta* species except *V. hortonii*. The silicoflagellate assemblage in this sample is similar to the one reported from Kologrivovka, in the Saratov region (Oreshkina et al. 2013). The bottom part of the *Schulzyocha ruppelii* Zone at Devon Island (McCartney et al. 2011c) includes *C. poretzkajae*, which suggests that Sample 132 may be of similar age. The absence in Sample 132 of the diverse and unusual taxa associated with the *Vallacerta tumidula* Partial Range Zone (McCartney et al. 2011c), suggests that the maximum age for this sample is younger than the base of the *Schulzyocha ruppelii* Zone. However, based on the available evidence, there can be no certainty that the lower part of the silicoflagellate zonation for the Canadian margin can be applied to the northern Eurasian sections.

Thus, on the basis of the silicoflagellate assemblages documented here, we believe that Samples 21, 46 and 133 are correlative to the *Cornua trifurcata* Zone of the Canadian Arctic, Samples 45, 47, 48 and 103 may correlate to the upper *Schulzyocha ruppelii* Zone, and Sample 132 likely is of an earlier age, with the best approximation based on the limited evidence being the lower *Schulzyocha ruppelii* Zone.

ACKNOWLEDGMENTS

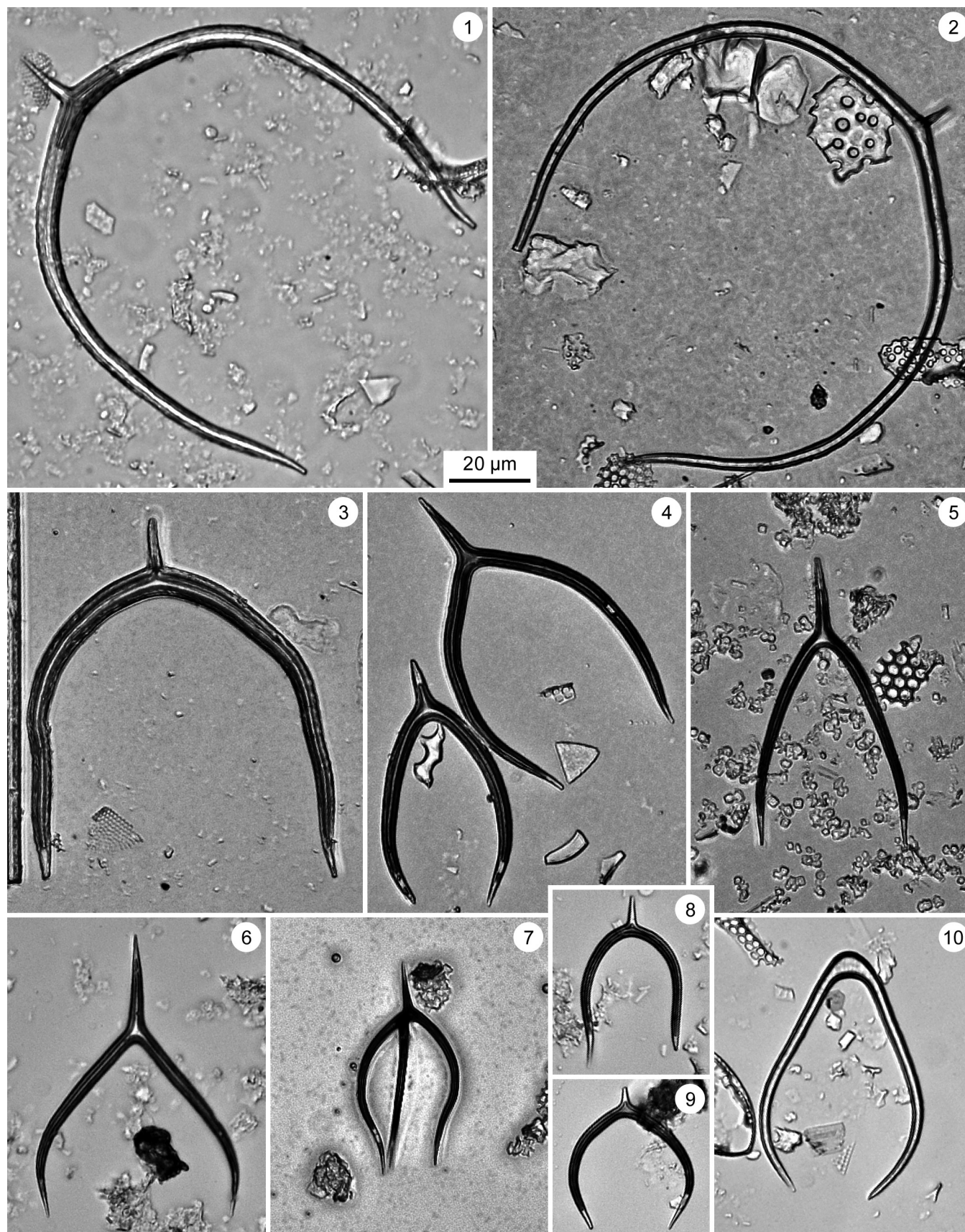
We thank Dr. Yelena Polyakova for making available the Jousé collection samples, and Dr. Tatyana Oreshkina for samples from Kologrivovka that were an aid in interpreting the material of this study. Manfred Ruppel operated the scanning electron microscope during examination of specimens for this study. Wulf Herwig lent his expertise in siliceous microfossil microphotography, including stacking photographs. Sherwood W. Wise, Jr. and Richard W. Jordan made constructive comments that improved the paper. We are grateful to the University of Maine at Presque Isle for a research sabbatical that provided time for the first author to do this study and Dr. Andrzej Witkowski for office space and equipment at the University of Szczecin, where most of this research was done. Financial support for Jakub Witkowski was provided by the Foundation for Polish Science ('Start' programme). An anonymous reviewer is thanked for constructive comments and suggestions.

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PLATE 4

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|----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| 1-3 <i>Lyamula furcula</i> Hanna (near-circular); Sample 60. | 7 <i>Lyamula deflandrei</i> Perch-Nielsen and Edwards; Sample 47. |
| 4-5 <i>Lyamula furcula</i> Hanna (long-spined); 4 (both specimens), Sample 21; 5, Sample 47. | 8-9 <i>Lyamula minor</i> (Deflandre) Deflandre; Sample 45. |
| 6 <i>Lyamula arctica</i> Bukry; Sample 45. | 10 <i>Lyamula furcula</i> var. <i>inflata</i> McCartney, Harwood and Witkowski; Sample 60. |



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