

First Oligocene Silicoflagellates from N. Europe (Silstrup, Denmark)

By

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With 3 Text-figures and 2 Tables

ABSTRACT

A Late Oligocene silicoflagellate assemblage from Denmark is described and illustrated for the first time. The silicoflagellates are found in a thin diatomite band overlying the Upper Paleocene/Lower Eocene Fur Formation at the base of the Upper Oligocene Vejle Fjord Formation. The absence of *Naviculopsis lata* and the presence of *Distephanus speculum hemisphaericus* assign this assemblage, which is dominated by

Distephanus crux s. ampl., to the *D. speculum baliomma* Subzone, which has been correlated to the Late Oligocene *Sphenolithus ciperoensis* Zone (NP 25) and the basal part of the Early Miocene *Triquetrorhabdulus carinatus* Zone (NN 1) of calcareous nannofossils.

The age of the Fur Formation at Silstrup is younger than 54 Ma and the sediments correlatable to the middle part of NP 10.

KURZFASSTUNG

Eine spätoligozäne Silicoflagellaten-Vergesellschaftung aus der Vejle Fjord-Formation von Dänemark wird erstmals beschrieben und illustriert. Die Silicoflagellaten finden sich in einem ca. 50 cm mächtigen Diatomit, der die bereits bekannten spätpaläozänen bis früheozänen Diatomite und Aschenlagen der Fur-Formation im nördlichen Jütland überlagert. Die Vergesellschaftung wird dominiert von *Distephanus crux* s. ampl. und enthält *Distephanus speculum hemisphaericus*, aber keine

Naviculopsis lata. Damit gehört sie in die spätoligozäne *D. speculum baliomma*-Subzone, die mit der spätoligozänen *Sphenolithus ciperoensis*-Zone (NP 25) und dem basalen Teil der frühmiozänen *Triquetrorhabdulus carinatus*-Zone (NN 1) der kalkigen Nannofossilien korreliert werden kann.

Das Alter der Fur-Formation in Silstrup ist jünger als 54 Ma und die Sedimente können zur mittleren NP 10 korreliert werden.

1. INTRODUCTION

So far, only Late Paleocene and Eocene silicoflagellates were described from the Paleogene of Denmark, Northern Germany, the North Sea area and the Norwegian Sea (MARTINI 1972, 1974, 1981, 1986, PERCH-NIELSEN 1976, MARTINI & MÜLLER 1976 and LOCKER & MARTINI 1986, 1987, 1989). In the present paper, a Late Oligocene assemblage is illustrated and discussed for the first time.

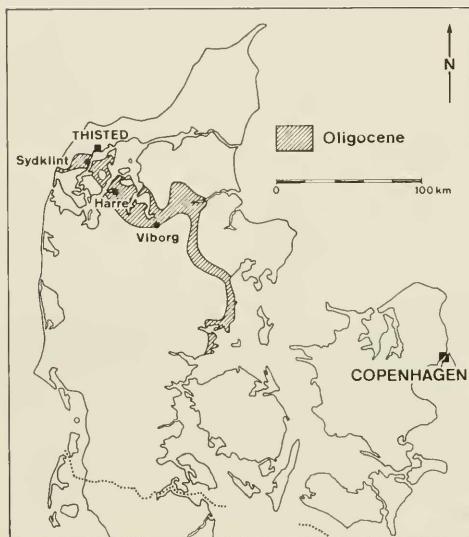
Recently, BERGGREN et al. (1992) reported laser fusion dates from ash layers of the silicoflagellate-bearing Fur Formation. KNOX (1989) showed the correlation of these ash layers to the calcareous nannofossil zonation. These informations allow for a better stratigraphic assignment of the sediments underlying the Late Oligocene layers than previously possible.

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LOCALITY AND MATERIAL



Text-fig. 1: Distribution of Oligocene sediments below the Quaternary in Denmark and localities.

2. SILICOFLAGELLATE ASSEMBLAGES AND THEIR AGE

2.1 SAMPLE 1

m	Lithology	Sample	Silicoflagellates	Fm	Age
7	d.brown, micaceous clay	5	barren	Vejle Fjord	L. Oligocene
6	d.brown clay	4	common		
5	brownish clay/diatomite glauconitic sand, bioturbated	3 A	common barren		
4		2	rare		
3	d.brown, sandy layer; ash + 140°				
2	Mo Clay (w. diatomites)				
1	ash + 138	1	common	Fur	Early Eocene

Tab. 1: Lithology, samples and silicoflagellate content of the sediments at Silstrup Sydklint. After notes by C. HEILMANN-CLAUSEN and the author.

Of the samples studied (Tab. 1), only two, 1 and 4, include rich silicoflagellate assemblages. Besides the common diatoms, also common archaeomonads and rare ebridians and endoskeletal dinoflagellates are present.

Silstrup Sydklint lies in Thy on the northwestern shore of Limfjorden, Jutland in western Denmark (text-fig. 1; 2 in fig. 1 in PERCH-NIELSEN 1976, where the legend is missing). A thin diatomite layer of Oligocene age was discovered at this locality by HEILMANN-CLAUSEN (1982: 58). The Oligocene layers of the Vejle Fjord Formation, from which the samples were taken, consist mainly of micaceous clays and, at their base, include some 50 cm of diatomites with silicoflagellates (tab. 1). Underlying these diatomites are the diatomites in the Mo Clay of the Fur Formation which spans the Paleocene/Eocene boundary.

The contact between the Lower Eocene Fur Formation and the Upper Oligocene Vejle Fjord Formation is not the result of Quaternary glacial disturbances as suggested by BOGGILD (1918) and ROSENKRANTZ (1945). Glauconite-filled burrows penetrate from the Vejle Fjord Formation down into the Fur Formation, showing that the contact, where a hiatus probably spanning over 30 million years is indicated, is not disturbed (GRY 1979).

2.2 SILICOFLAGELLATE CORRELATIONS AROUND THE PALEOCENE/EOCENE BOUNDARY

The Paleocene/Eocene diatomites of the Fur Formation in Denmark have been known since the last century. They crop out in western Denmark and contain the ash layers numbered from -39 to +140 by BOGGILD (1918). While most of the partly laminated Fur Formation is free of CaCO_3 , occasional layers of "cementstone" are calcareous and often include especially well preserved siliceous assemblages, but no calcareous nannofossils. Recently, KNOX (1989) correlated two prominent

AGE	SILICOFLAGELLATE ZONATION			locality	DENMARK	recognised
	Zone	Subzone	ZONAL MARKERS		FUR Fm : No of Ash layers	
PALEOEC.	N. lata		N. lata*	Sydklint		
		D.s. <i>haliomma</i>	Ds.s. <i>haliomma</i> * Ds.s. <i>hemisphaericus</i> *			
	N. biapiculata		C. <i>apiculata</i> + C. <i>chastata</i> + N. <i>biapiculata</i> +			
			D. <i>hexacantha</i> +			
	C. <i>apiculata</i>		N. <i>punctilia</i> +			
		D. <i>hexacantha</i>	N. <i>vemae</i> +			
	D. <i>hexacantha</i>	N. <i>vemae</i>	N. <i>vemae</i> *			
			D. <i>hexacantha</i> *			
	N. <i>foliacea</i>	D. <i>spinosa</i>	D. <i>spinosa</i> *			
		N. <i>robusta</i>	N. <i>foliacea</i> * N. <i>aspera</i> +			
EOCENE	N. <i>constricta</i>	N. <i>aspera</i>	C. <i>naviculoidae</i> +	above + 19 + 19 to -17 -17 to -19A -30 to -21A -33	Vejle Fjord	21 19/20 18
		C. <i>naviculoidae</i>	C. <i>naviculoidae</i> *		Søvind Marl	17
		D. <i>elongata</i>	D. <i>elongata</i> *		Lillebelt Clay	16
		N. <i>danica</i>	N. <i>danica</i> *		Røsnæs Clay	15
		N. <i>constricta</i>	N. <i>constricta</i> *			14
						12
						11

Tab. 2: North European Silicoflagellate zonation and the stratigraphic occurrence of silicoflagellate-bearing sediments correlated to the lithologic formations and their calcareous nannofossil zonal assignment. After MINKELSEN (1975), PERCH-NIELSEN (1971, 1976, 1979) and THIEDE et al. (1980). * = First occurrence, + = last occurrence. The ash layers in the Fur Formation are numbered from bottom to top from -34 to +140. Silicoflagellates were only found from -34 to +130.

and chemically distinct ash layers, -17 and +19, with two ash layers in a borehole in N. Germany and with DSDP Site 550. The latter lies some 600 km to the W of the westernmost tip of Great Britain, thus about 1850 km from the Danish occurrences. At Site 550, the two ash layers occur in the lower part of the unusually thick (about 50 m) calcareous nannofossil zone NP 10 of MARTINI (1971) which lies in Polarity Chron 24R.

BERGGREN et al. (1992) reported new laser fusion dates from ashes -17 (54.5 Ma) and +19 (54 Ma) in the Fur Formation of Denmark and the correlation of these ashes to the base of the London Clay Formation (Hales and Harwich Member, respectively). According to KNOX (1984, 1989) the entire series of ashes is contained within NP 10 at Site 550 and the uppermost ashes occur around the middle of NP 10.

No decision as to the exact position of the GSSP (global stratotype section and point) for the Paleocene/Eocene boundary has yet been taken. The current usage, however, puts the boundary within NP 9, at the NP 9/10 boundary, or at the base of the London Clay. All of these positions are below ash layer +19. Thus the layers outcropping at Silstrup Sydklint and containing ash-layers 118 and higher, are younger than 54 Ma and of early Eocene age.

2.3 SAMPLE 4

The silicoflagellate assemblage of sample 4 is totally different from the one in sample 1. It includes the species illustrated on Figures 2 and 3 and discussed below. *Distephanus crux s. ampl.* dominates, while all other species together make up less than 10%. The assemblage can be assigned to the *Naviculopsis biapiculata* Zone of BURRY (1974, 1978). This zone is defined from the last occurrence of *Corbisema apiculata* or *C. hastata* or the first occurrence of *Naviculopsis biapiculata* to the first occurrence of *N. lata*. The presence of *Distephanus speculum hemisphaericus* assigns the assemblage at Silstrup to the *D.*

speculum haliomma Subzone of BURRY (1981), which is defined from the first occurrence of *D. speculum haliomma* and the first occurrence of *D. speculum hemisphaericus* to the first occurrence of *N. lata*. This subzone has been correlated by BURRY (1981) to the Late Oligocene calcareous nannofossil zone of *Sphenolithus ciperoensis* and the basal Miocene zone of *Triquetrorhabdulus carmatus* (NP 25 and NN 1, respectively of MARTINI 1971).

Similar assemblages were found by BURRY (1976b) and MARTINI & MULLER (1976) at DSDP Site 338 on the Voering Plateau in the Norwegian Sea, where they were accompanied by a Late Oligocene calcareous nannofossil assemblage including *Dicyococcites bisectus* and *Cyclicargolithus abiseptus* (MULLER 1976). The diatomite samples from Silstrup are non-calcareous and thus barren of calcareous nannofossils. Also, they do not include any reworked silicoflagellates from the underlying diatomites of the Lower Eocene part of the Fur Formation.

No corresponding siliceous interval was found in the Harre boring which was cored only some 30 km to the SSE of Silstrup (Fig. 1; BJØRSLEV NIELSEN et al., in prep.; VON SALIS in prep.) and penetrated Miocene through Danian sediments. In the Oligocene interval of the Viborg boring, cored some 70 km to the SSE of Silstrup (Fig. 1), very rare diatoms but no silicoflagellates have been observed (THIEDE et al. 1980).

BACHMANN (1970) described and illustrated a silicoflagellate assemblage from Austria with a very similar assemblage as the one found at Silstrup. He assigned the austrian assemblage to the Late Oligocene. Since it includes *Naviculopsis lata*, the form marking the base of the zone of that name which presently is correlated to the Lower Miocene calcareous nannofossil zones NN 1 and NN 2 of MARTINI (1971), an Early Miocene age is indicated. The fact that *N. lata* was not found in the assemblage from Silstrup suggests a Late Oligocene to possibly earliest Miocene age for it. BURRY (1985), who studied the silicoflagellates from Rockall Plateau west of Scotland which is on a similar latitude as Silstrup found *N. cf. N. lata* in

DSDP Hole 406. He assigned these samples an ?Early Miocene age. The underlying Late Oligocene assemblage differs from the one treated here by including common specimens of *Naviculopsis biapiculata* and, in its lower part, of the diatom *Rocella gelida*. Both species were not found at Silstrup. The

assemblage at Site 406 also includes *Distephanus speculum baliomma*, the presence of which defines the uppermost Oligocene subzone of this name. The presence of this subzone at Silstrup is indicated by the presence of *D. speculum hemisphaericus*.

3. SYSTEMATIC PALAEOENTOLOGY

Silicoflagellates are marine, unicellular algae with flagellae. They produce microscopic (30–100 µ), tubular skeletons of opal and thus are mainly preserved in diatomites underlying modern or ancient ocean upwelling areas or in diatomites preserved due to nearby volcanism. The classification follows KRISTIANSEN (1990), the terminology of the silicoflagellates is the one of PERCH-NIELSEN (1985).

Phylum Chrysophyta

Class Dictyochophyceae (silicoflagellates)
Order Dictyochales
Family Dictyochaceae LEMMERMANN, 1901

Bachmannocena apiculata subsp. *glabra* (SCHULZ, 1928)
BUKRY, 1987
Text-Fig. 2, fig. 1, 2

1928 *Mesocena polymorpha* var. *triangula* fa. *glabra* SCHULZ: 237, fig. 3b, 3c.

1978 *Mesocena apiculata glabra* (SCHULZ) BUKRY: 562, pl. 2, fig. 14, 15.

1987 *Bachmannocena apiculata glabra* (SCHULZ) BUKRY: 404.

Remarks: *M. apiculata* has short spines and straight to slightly concave sides.

Corbisema triacantha (EHRENBURG, 1845) HANNA, 1928
Text-Fig. 3, fig. 15, 16

1845 *Dictyocha triacantha* EHRENBURG, 1844: 80.

1931 *Corbisema triacantha* (EHRENBURG) HANNA: 198, pl. D, fig. 1.

1974 *Corbisema triacantha* (EHRENBURG) LOCKER: 634, pl. 1, fig. 10 (= holotype).

Remarks: The holotype of this species is a specimen from the Miocene with short spines and strongly convex sides of the basal ring. The very rare specimens at Silstrup have longer spines and less convex sides than in the holotype.

Dictyocha aspera (LEMMERMANN, 1901) BUKRY & FOSTER, 1973
Text-Fig. 2, fig. 5, 6

1901 *Dictyocha fibula* var. *aspera* LEMMERMANN: 260, pl. 10, fig. 27, 28.

1973 *Dictyocha aspera* (LEMMERMANN) BUKRY & FOSTER: 815–871.

Remarks: The spines are of medium length and the sides of the basal ring only slightly convex and nearly equal in length. A

short basal pike is attached about halfway between the strut and the corner of the basal ring in each side. The central bar is less than a third of the length of the diagonal and runs slightly oblique to it. The form is similar to *D. aspera clinata* where, however, the central bar measures about half the length of the diagonal and the basal pikes, where present, are attached at or near the base of the struts.

Dictyocha medusa HAECKEL, 1887

Text-Fig. 2, fig. 3, 4?

1887 *Dictyocha medusa* HAECKEL: 1560, pl. 101, figs. 13, 14.

Remarks: *D. medusa* includes forms with a simple central cross and without basal pikes. The form shown in Text-Fig. 1, fig. 4 seems to be a form between *Dictyocha medusa* and *Distephanus crux darwinii* BUKRY, 1976.

Distephanus boliviensis var. *major* (FRENGUELLI, 1951)

CIESIELSKI, 1975

Text-Fig. 3, fig. 22, 23

1940 *Dictyocha boliviensis* var. *major* FRENGUELLI: 44, fig. 4.

1975 *Distephanus boliviensis* var. *major* (FRENGUELLI) CIESIELSKI: 660, pl. 8, figs. 1–5.

Remarks: As pointed out by McCARTNEY & WISE (1990), six-sided *Distephanus* exhibit a considerable variability. The forms assigned to *D. boliviensis* differ from those commonly assigned to *D. speculum* by their more massive appearance. But „in many samples the two taxa are distinct and easily separated, but in other samples they appear to intergrade“. The variety *major* is characterised by more than one apical opening. The spines are unequal in length.

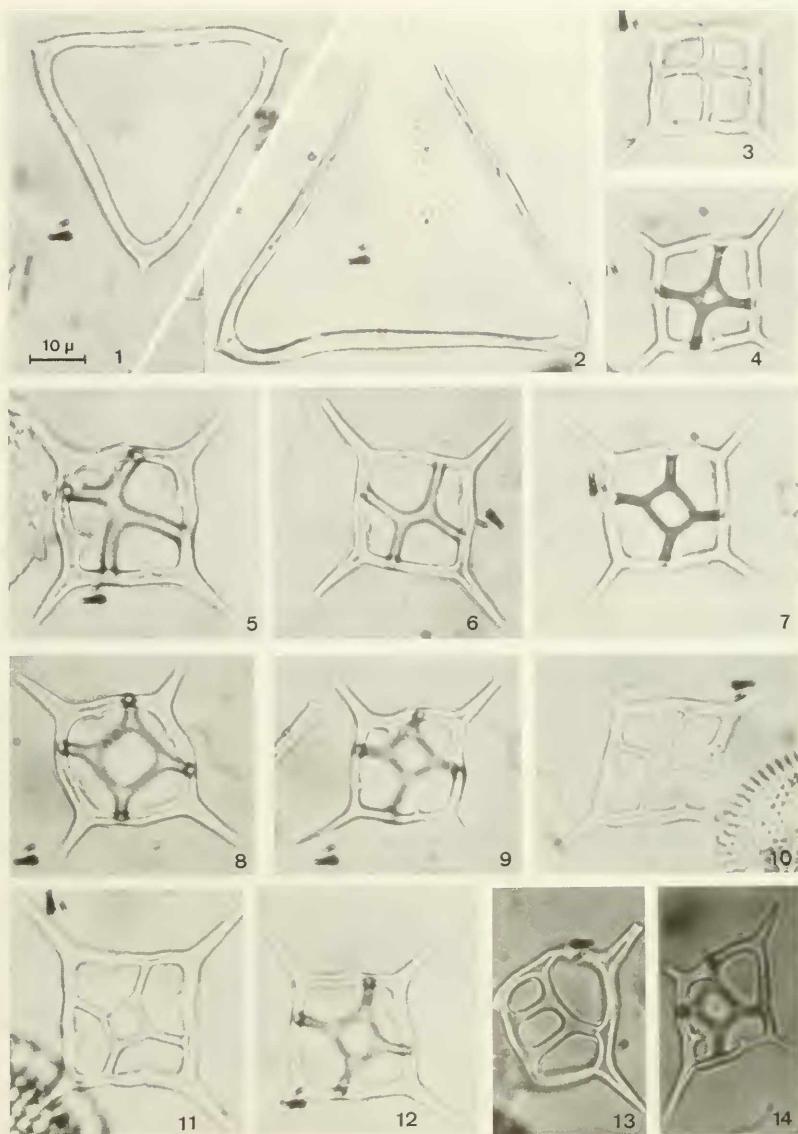
Distephanus crux (EHRENBURG, 1841) HAECKEL, 1887

Text-Fig. 2, fig. 7–9, 11, 12

1841 *Dictyocha crux* EHRENBURG, Ber. 1840: 207–208.

1887 *Distephanus crux* (EHRENBURG) HAECKEL: 1563.

Remarks: LOCKER (1974) has indicated that a population of *D. crux* may include a variety of sizes of the apical ring. Basal pikes are either missing or relatively short. LOCKER (1974) suggested *Distephanus staurodon* to be a synonym of *D. crux*. The two species are distinguished here on the basis of the form of the basal ring: more or less quadratic in *D. crux* and rhomboedrical in *D. staurodon*.



Text-fig. 2 Light microscope micrographs from sample A, diatomite of the Vejle Fjord Formation, Silstrup. Scale bar = 10 μ .

Fig. 1, 2 *Bachmannocena apiculata* subsp. *glabra* (SCHULZ, 1928) BUKRY, 1987.

Fig. 3 *Dictyocha medusa* HAECKEL, 1887.

Fig. 4 Specimen between *Dictyocha medusa* HAECKEL, 1887 and *Distephanus crux* subsp. *darwini* (BUKRY, 1976). The latter is often found in the Oligocene *Naviculopsis biapiculata* Zone.

Fig. 5, 6 *Dictyocha aspera* (LEMERMANN, 1901) BUKRY & FOSTER, 1973.

Fig. 7-9, 11, 12 *Distephanus crux* (EHRENBURG, 1941) HAECKEL, 1887. - Forms without basal pikes, very small basal pikes and well developed basal pikes; forms with small and forms with wide apical opening, which is round, quadrat or rectangular

Fig. 10, 14 *Distephanus staurodon* (EHRENBURG, 1945) BUKRY, 1978.

Fig. 13 Abnormal specimen of *Distephanus crux* s. ampl.

Distephanus speculum (EHRENBURG, 1838) HAECKEL, 1887

s. ampl.

Text-Fig. 3, fig. 19

1838 *Dictyocha speculum* EHRENBURG: 132. Nomen nudum.1840 *Dictyocha speculum* EHRENBURG, 1838: 129, pl. 4, fig. X n.1887 *Distephanus speculum* (EHRENBURG) HAECKEL: 1565.

Remarks: *D. speculum* has six sides and spines of equal or unequal length according to LOCKER (1974) who studied the type material of this species. The specimen illustrated here is abnormal in that its apical ring is supported only by five struts.

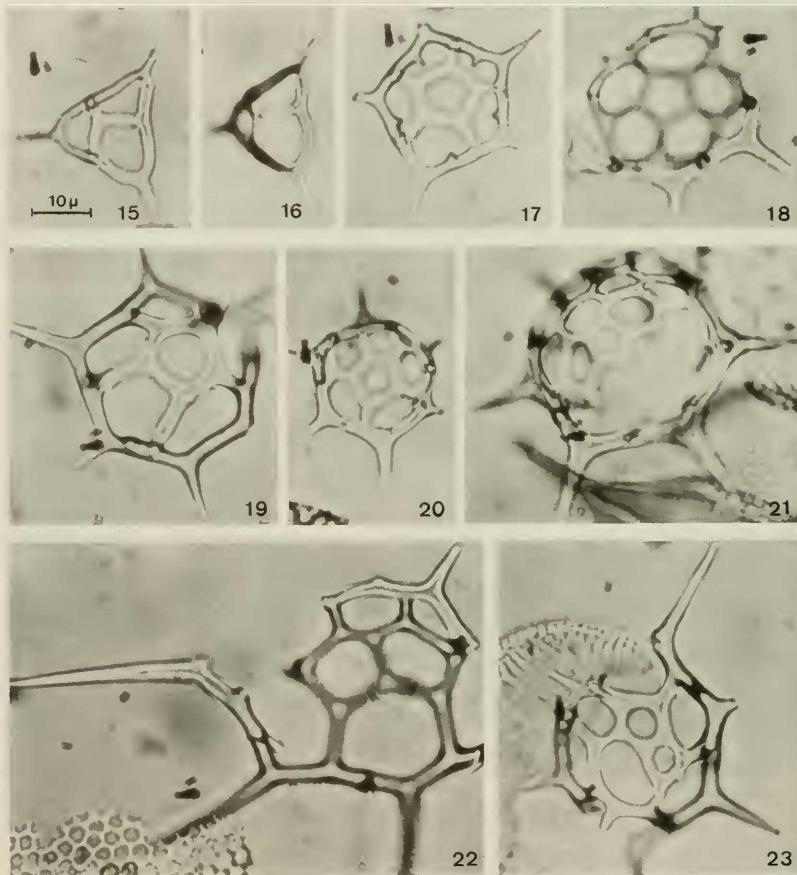
Distephanus speculum subsp. *hemisphaericus*

(EHRENBURG, 1845) BUKRY, 1978

Text-Fig. 3, fig. 18, 21

1845 *Dictyocha hemisphaerica* EHRENBURG, 1844: 266, 267.1978 *Distephanus speculum hemisphaericus* (EHRENBURG) BUKRY: 697.

Remarks: Not following LOCKER (1974) but rather BUKRY (1978), the forms described in the literature as *Distephanus speculum hemisphaericus* and *D. speculum triommata* are not included in *Cannopilus hemisphaericus* but treated as separate subspecies of *Distephanus speculum*.



Text-fig. 3 Light microscope micrographs from sample A, diatomite of the Vejle Fjord Formation, Silstrup. Scale bar = 10 μ .

Fig. 15, 16 *Corbisema triacantha* (EHRENBURG, 1845) HANNA, 1931.

Fig. 17 *Distephanus speculum* subsp. *pentagonus* LEMMERMANN, 1901.

Fig. 18, 21 *Distephanus speculum* subsp. *hemisphaericus* (EHRENBURG, 1845) BUKRY, 1978.

Fig. 19 *Distephanus speculum* (EHRENBURG, 1838) HAECKEL, 1887 s. ampl.

Fig. 20 *Distephanus speculum* subsp. *triommata* (EHRENBURG, 1846) BUKRY, 1976a.

Fig. 22, 23 *Distephanus boliviensis* var. *major* (FRENGUELLI, 1951) CIESIELSKI, 1975.

Distephanus speculum subsp. *pentagonus* LEMMERMANN, 1901
Text-Fig. 3, fig. 17

1901 *Distephanus speculum* subsp. *pentagonus* LEMMERMANN: 264, pl. 11, fig. 19.

Remarks: This form is very rare. The spines are of about equal length, the basal pikes are short and the struts nearly radial.

Distephanus speculum subsp. *triommata* (EHRENBURG, 1846)
BUKRY, 1976
Text-Fig. 3, fig. 20

1846 *Dictyocha triommata* EHRENBURG, 1845: 76

1974 *Dictyocha triommata* EHRENBURG LOCKER: 643, pl. 4, fig. 5 (holotype figured).

1976a *Distephanus speculum triommata* (EHRENBURG)
BUKRY: 896.

Remarks: *D. speculum triommata* is characterised by 3 apical windows. LOCKER pointed out that the population in the sample of the holotype of this subspecies includes forms with 2-5 windows.

Distephanus staurodon (EHRENBURG, 1845) BUKRY, 1978
Text-Fig. 2, fig. 10, 14

1845 *Dictyocha staurodon* EHRENBURG, Ber. 1844: 80.

1978 *Distephanus staurodon* (EHRENBURG) BUKRY: 697.

Remarks: The basal ring of *D. staurodon* is rhomboedric in shape, while the one of *D. crux* is more or less quadratic. The basal pikes are generally better developed in the former than in the latter. The spines are longer along the long axis of the form than along the short one.

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