

New silicoflagellates and a silicoflagellate zonation in north European Palaeocene and Eocene diatomites

KATHARINA PERCH-NIELSEN



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The following new silicoflagellates are described from the Palaeocene and Early Eocene diatomite at Fur, Denmark, and the Late Eocene diatomite on Voering Plateau, Norwegian Sea: *Corbisema ovalis*, *Distephanus norvegiensis*, *D. rosae*, *Mesocena concava*, *Naviculopsis danica*, *N. punctilia* and *N. vemae*. Species of *Naviculopsis*, *Corbisema* and *Dictyochoa* serve to define seven local silicoflagellate subzones: The *N. constricta*, *N. danica*, *D. elongata*, *C. naviculoidea* and the *N. aspera* subzones in the Palaeocene and early Eocene of Denmark and the *N. vemae* and *N. punctilia* subzones in the Late Eocene of the Norwegian Sea.

Katharina Perch-Nielsen, Institut for historisk Geologi og Palæontologi, Østervoldgade 10, DK-1350 København K, Denmark, and Geologisches Institut ETH, Sonneggstr. 5, CH-8006 Zürich, Switzerland. September 26th, 1975.

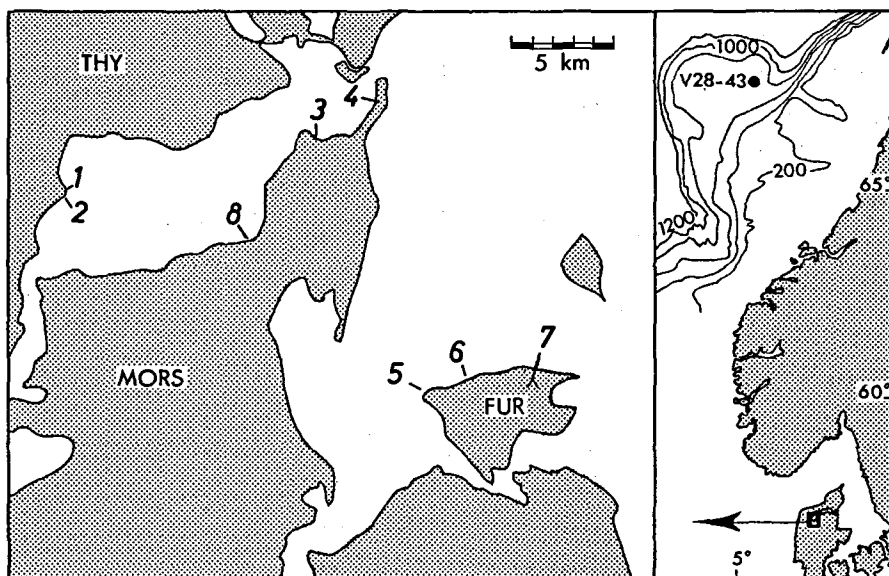
Silicoflagellates – microscopic siliceous skeletons produced by unicellular marine algae – have been recorded repeatedly from the diatomites at Fur Island and at Mors in Denmark. Lemmermann (1901), Schulz (1928), Gemeinhardt (1930), Hovasse (1932), Deflandre (1932, 1933, 1934, 1938, 1950, 1951), Deflandre & Deflandre-Rigaud (1970) and Frenguelli (1940) have described silicoflagellates and/or other siliceous microfossils as ebridians, archaeomonads and endoskeletal dinoflagellates from Fur as well as from Mors (see map). None of them mentioned the exact locality where their samples were taken at Fur and Mors or gave the details about the position of their samples in the sequence of over 200 numbered ash layers (A) that are interbedded with the up to 60 m thick diatomites of the Mo-clay formation (Andersen 1937, 1938; Bøggild 1918). An attempt is made herein to determine the stratigraphic position of these samples as part of a revision of the whole siliceous microfossil assemblage other than the dominating diatoms and the rare radiolarians. A new silicoflagellate species found during this investigation (*Naviculopsis danica*) is described below, together with a documentation of the stratigraphic results obtained so far. It was found that the assemblages described by the authors mentioned above must belong to layers above ca. A -17, because the assemblages below this level contain species that are not rare, but that have

not yet been cited from Danish localities: *Naviculopsis danica*, a new species, and *Dictyochoa elongata*, a species described from Siberia by Glezer (1964). On the other hand, some samples include species that do not occur below A -17, such as *Corbisema naviculoidea*. Five silicoflagellate subzones that seem useful for local correlations in high northern latitudes of the Atlantic area were recognised at several Danish localities and are described here.

Samples from another, shorter sequence of Eocene diatomites in northern Europe were made available by the Lamont-Doherty Geological Observatory, New York, from core VEMA 28/43, which was taken on a diapiric structure on the Voering Plateau in the Norwegian Sea (67°12' N, 06°10' E, see map). Below 170 cm of Neogene sediments, it penetrated some 400 cm of Upper Eocene diatomaceous clay (Bjørklund & Kellogg 1972). Several new species of silicoflagellates were found in this material, and two silicoflagellate subzones could be distinguished.

Method of study

From non-calcareous, unprocessed samples, smear slides were prepared on glass slides, covered with canada balsam and a coverslip, and studied with the light microscope at a magnification of $\times 500$. Calcareous samples



were treated with dilute hydrochloric acid and washed before smear slides were prepared. Another set of slides was made, using the residue on a 28 micron sieve through which the fluid sample was sieved. This residue was also used to prepare samples for scanning electron microscope observations.

Silicoflagellate zonation and age of samples

Five silicoflagellate subzones are proposed for the latest Palaeocene and earliest Eocene and two for the Late Eocene (tables 1 & 2). The five lower zones are found in Denmark, where the whole diatomaceous sequence can be assigned to the lower part of Bukry & Foster's (1974) *Naviculopsis constricta* Zone of Early to Middle Eocene age. Bukry (personal communication 1975) has since on the Falkland Plateau (Deep Sea Drilling Site 327A) found silicoflagellates of the *N. constricta* Zone accompanied by Late Palaeocene coccolith assemblages. The *N. constricta* Zone is thus in part of Late Palaeocene age. Coccoliths from sediments of the red "Plastic Clay" (Røsnæs Clay) overlying the diatomaceous deposits in Denmark at Knuden (Bonde 1974), belong to the *Discoaster binodosus* Zone, which was previously only known in Denmark from the bore-

hole at Viborg (Perch-Nielsen 1971) and which is of early Early Eocene age (NP 11 of Martini 1971). The Mo-clay formation, itself, is barren of coccoliths and was previously assigned a Late Palaeocene or Early Eocene age (Sorgenfrei 1956). The diatomaceous silty mudstones that form the cap rock to the Palaeocene reservoir sands in the Forties field on the western flank of the North Sea Tertiary basin are overlain by a mudstone unit dated as Late Palaeocene by a foraminiferal assemblage dominated by *Globigerina cf. triloculinoides* (Thomas et al. 1974).

The following dinoflagellates were determined by Dr. G. L. Eaton, Aberdeen, from scanning electron microscope pictures from samples KPN 539-20 and 514-1 from the Mo-clay formation and constitute an assemblage of Late Palaeocene to Early Eocene age:

- Cordosphaeridium* sp.
- Cyclonephelium ordinatum*
- Hystrichosphaeridium tubiferum*
- Operculodinium* sp.
- Spiriferites cornutus*
- S. pseudofurcatus*
- S. ramosus* var. *multibrevis*
- ? *Wetzeliella homomorpha*
- Wetzeliella* sp.

The two upper subzones are found in the core from the Voering Plateau, where the se-

AGE	SILICOFLAGELLATE ZONES & INDICATORS Bukry & Foster 1974	SILICOFLAGELLATE SUBZONES Denmark & Norwegian Sea Perch-Nielsen, this paper	SUBZONAL INDICATOR	SILICOFLAGELLATE ZONES & INDICATORS Martini 1974
OLIGOCENE	D.hexacantha +			N.lata * N.biapiculata
LATE EOCENE	D.hexacantha	N.punctilia	N.punctilia +	M.apiculata * D.bimucronata D.spinosa +
		N.vemae	N.vemae +	
MIDDLE EOCENE	D.hexacantha *		N.vemae *	N.foliacea D.bimucronata * N.minor
EARLY EOCENE	N.constricta		N.aspera +	D.transitoria + D.transitoria D.transitoria *
		N.aspera	C.naviculoidea +	D.naviculoidea
		C.naviculoidea	C.naviculoidea *	D.inaviculoidea *
		D.elongata	D.elongata *	D.deflandrei
		N.danica	N.danica *	
PALAEOCENE	N.constricta *	N.constricta	N.constricta *	D.deflandrei *

Table 1. Correlation of silicoflagellate zones and indicators of Martini (1974), Bukry & Foster (1974) and this paper. * = first, + = last occurrence of species.

SILICOFLAGELLATE ZONES SUBZONES												AGE		
D. hexa- cantha	N. punctilia	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆	samples A=ash layer VEMA 28/43, 177 cm VEMA 28/43, 220 cm VEMA 28/43, 330 cm VEMA 28/43, 520 cm	LATE EOCENE
	N. vemae	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆		
N. constricta	N. aspera	☆	☆										Fur. above ca. A+19 Mors, Thy	EARLY EOCENE & LATE PALAEO-CENE
	C. naviculoidea	☆	☆	☆		☆							Fur. ca. A+19 to -17 Mors, Thy	
	D. elongata	☆	☆	☆	☆	☆							Fur. ca. A-17 to 19A	
	N. danica	☆	☆	☆	☆								Fur. ca. A-21A to -33	
	N. constricta	☆											Fur. below ca. A-33 Mors, below ca. A-34	

Table 2. Silicoflagellate zones, subzones and diagnostic species in diatomites from Denmark and the Norwegian Sea.

quence can be assigned to the *Dictyocha hexacantha* Zone of Bukry & Foster (1974), that is of Middle to Late Eocene age. A Late Eocene age was proposed for these samples on the basis of diatoms and silicoflagellates by Burckle in Bjørklund & Kellogg (1972).

Naviculopsis constricta Subzone

Boundaries: The *N. constricta* Subzone includes the interval from the first occurrence of *N. constricta* to the first occurrence of *N. danica*.

Assemblage: *Dictyocha deflandrei*, *D. fibula* s. ampl., *Corbisema apiculata*, *C. triacantha*, *N. constricta*.

Remarks: The assemblage of the *N. constricta* Subzone is usually dominated by species of *Dictyocha*; *Corbisema* is abundant and *Naviculopsis* are few. This subzone was only found in the lowermost part of the diatomaceous sequence in Denmark and its base is not exposed.

Samples: Mors, Denmark: Coast cliff N of Langsbjerg Høj 539–7 ca. 1 m below A -34. Fur, Denmark: Stolleklint 602–16 below A -33.

Naviculopsis danica Subzone

Boundaries: The *danica* Subzone includes the interval from the first occurrence of *N. danica* to the first occurrence of *Dictyocha elongata*.

Assemblage: *C. apiculata*, *C. hastata*, *D. deflandrei*, *D. fibula* s. ampl., *N. aspera*, *N. constricta*, *N. danica*, *N. minor*, *N. robusta*.

Remarks: The assemblage of the *N. danica* Subzone is dominated by species of *Corbisema* and *Dictyocha* and some more species of *Naviculopsis* appear here. *N. danica* is not rare. The silicoflagellate assemblages previously described from various outcrops from Fur and Mors, do not include *N. danica*.

Samples: Fur, Denmark: Knudeklint 514–1 around A -22; 539–6 above A -33; 602–10, 13 around A -21A. Stolleklint 539–9 around A -24 to -27; 602–14, 15, 22 near A -26, A -30 and below A -30.

Dictyocha elongata Subzone

Boundaries: The *D. elongata* Subzone includes the interval from the first occurrence of

D. elongata to the first occurrence of *Corbisema naviculoidea*.

Assemblage: The same as in the *N. danica* Subzone plus *D. elongata* and less *N. robusta*.
Remarks: The assemblage of the *D. elongata* Subzone is very similar to the assemblage of the *N. danica* Subzone. *D. elongata* is not rare.
Sample: Fur, Denmark: Knudeklint 514–4 around A -19; 602–9, 11, 12 around A -17, A -19A and below A -19A.

Corbisema naviculoidea Subzone

Boundaries: The *C. naviculoidea* Subzone includes the interval from the first to the last occurrence of *C. naviculoidea*.

Assemblage: The same as in the *D. elongata* Subzone, less *N. danica* and *D. elongata* but including *C. naviculoidea* and *N. minor*.

Remarks: The assemblage of the *C. naviculoidea* Subzone is usually dominated by species of *Corbisema* and *Naviculopsis*, while *Dictyocha* is less common. *C. naviculoidea* is common in some samples, while it is rare in those with poorly preserved silicoflagellates. *C. naviculoidea* was found in some of the samples studied by Deflandre (see below).

Samples: Fur, Denmark: Knudeklint 514–3 around A -11; 602–4 to 8 from A +1 to above A -17. Stolleklint 539–17 2 m below A -13. Holmens grav 539–18 above A -10; 539–1, 14, 20 around A +15. Mors, Denmark: Hanklint 600–11 to 18 from A +19 to below A -14. Thy, Denmark: Firkanten 601–13 to 18 from A +16 to below A -13.

Naviculopsis aspera Subzone

Boundaries: The *N. aspera* Subzone includes the interval from the last occurrence of *C. naviculoidea* to the last occurrence of *N. aspera*.

Assemblage: *C. apiculata*, *C. hastata*, *D. deflandrei*, *D. fibula* s. ampl., *N. aspera*, *N. constricta*.

Remarks: The assemblage of the *N. aspera* Subzone is usually dominated by species of *Corbisema* and *Naviculopsis*. *Dictyocha* is not rare, but usually less common than in the lower subzones. Still no representatives were found of the genus *Distephanus*, which is common in the Late Eocene.

Probably some of the samples previously

studied by Lemmermann (1901), Schulz (1928) Hovasse (1932), Deflandre (1932–1951) and Deflandre & Deflandre-Rigaud (1970) derived from localities representing this zone. During a visit to the "Laboratoire de Micropaléontologie" in Paris, I had the opportunity to study several of the slides with Danish material from which the late Prof. Deflandre described siliceous microfossils (X6, X5, A22, all from Fur; X57, X58, Cryptogamie 29, BA 29, all from Mors, and Skive 872, a sample of unknown origin, since there are no diatomite outcrops known from the vicinity of Skive). Most of these samples belong to the *N. aspera* Subzone while some, and certainly X6, belong to the *C. naviculoidea* Subzone.

Samples: Fur, Denmark: Knudeklint 514–5 around A +19; 514–6 around A +30; 514–7 around A +100; 602–3 above A +130. Færkør 539–12 around A +31. Holmens grav 539–19 around A +31. Mors, Denmark: Skarrehage 515–2 above A +21. N of Salgjer Høj 539–8 between A +25 and +28. Feggeklint 539–3 around A +101. Hanklint 600–1 to 10 from above A +130 to above +22. Thy, Denmark: Firkanten 516–3 above A +20; 601–4 to 12 from A +118 to A +19. Sydklint 539–2 above A +130; 601–1 to 3 from A +140 to A +129.

Naviculopsis vemae Subzone

Boundaries: The *N. vemae* Subzone includes the interval from the first to the last occurrence of *N. vemae*.

Assemblage: *Corbisema apiculata*, *C. hastata*, *C. ovalis*, *C. spinosa*, *C. triacantha*, *Dictyochoa deflandrei*, *D. mesophtalmus*, *D. norvegiensis*, *D. rosae*, *Mesocena concava*, *Naviculopsis constricta*, *N. longispina*, *N. vemae*, *Septame-socena apiculata*.

Remarks: The assemblage of the *N. vemae* Subzone is dominated by small forms of *Corbisema* and by *C. triacantha* s. ampl. *N. vemae* is not rare.

Sample: Voering Plateau, Norwegian Sea VEMA 28/43, 520 cm.

Naviculopsis punctilia Subzone

Boundaries: The *N. punctilia* Subzone includes the interval from the last occurrence of *N.*

vemae to the last occurrence of *N. punctilia* Assemblage: the same as in the *N. vemae* Subzone, less *D. mesophtalmus*, *D. norvegiensis*, and *N. vemae*, but plus *Cannopilus hemisphaericus*, *Corbisema lamellifera lamellifera* and *Naviculopsis foliacea*. *D. rosae* occurs only in the lowermost sample belonging to this subzone (330 cm).

Remarks: The assemblage of the *N. punctilia* Subzone is dominated by *C. spinosa*, *C. triacantha* s. ampl. and small forms of *Corbisema*. *N. punctilia* is rare.

Samples: Voering Plateau, Norwegian Sea VEMA 28/43, 330 cm, 220 cm & 177 cm.

Discussion

Bukry & Foster (1974) and Martini (1974) have also proposed silicoflagellate zonations for the Eocene. In table 1 these zonations are correlated, where possible, with the zonation presented here. Bukry & Foster (1974) distinguished only two zones in the Eocene and my subzones refine parts of their subdivision. The Danish samples (table 3) all lie within their *N. constricta* Zone. The VEMA samples all contain *C. spinosa*, a species Bukry & Foster seem to include in *Dictyochoa hexacantha*, and thus in their *D. hexacantha* Zone.

Martini (1974) distinguished 6 zones in the Eocene. His lowermost zone, the *Dictyochoa deflandrei* Zone has its reference localities in Denmark and could be subdivided into three subzones, each comprising about 8 m or more of sediment. While Martini (1974) found *D. naviculoidea* to be present also around A +69, I did not find this species in the many samples studied from the interval above A +19. According to Martini (oral communication 1974), the *D. naviculoidea* reported from near A +69 were not complete specimens and could well be parts of the large *Corbisema apiculata*. In the Late Eocene, Martini (1974) proposed the *N. biapiculata* Zone, with a reference locality at DSDP site 65 in the Equatorial Pacific, to contain the interval from the last occurrence of *D. spinosa* to the first occurrence of *Mesocena apiculata*. Since, in all VEMA samples, these two species occur together, a correlation of the two zonations is not possib-

le in the Late Eocene. The two species also occur together in the Late Oligocene at DSDP site 278 south of New Zealand (Perch-Nielsen 1975). This again underlines the usually only rather local correlative value of silicoflagellate zones.

Some remarks might be added regarding the length of the subzones described herein from Denmark. Sharma (1969) found three reversely magnetised intervals in the series of ash layers and therefore suggested a sedimentation period of at least 3 million years for the Mo-clay. Bonde (1974), on the other hand, suggested that the Mo-clay is probably com-

posed of annual varves similar to those described from the Californian coastal basins (alternating light, diatom rich spring/summer layers and darker, clay rich winter layers in an oxygen poor basin) and thus arrived at a very short duration of about 60,000 years for the deposition of the entire Mo-clay. This would mean a duration of 10–15,000 years for each silicoflagellate subzone recognised here, which seems too short a time span. A duration of about 3 million years for the deposition of the Mo-clay would give a mean length of 600,000 years for a subzone; this figure seems more in the order of resolution of a silicoflagellate zo-

ASH LAYER +positive -negative	LOCALITIES						SILICO- FLAGEL- LATE SUB- ZONES
	KPN 600 HANKLINT		KPN 601 SYDKLINT FIRKANTEN		KPN 602 KNUDEN STOLLEKLINT		
	ASH	SAMPLE	ASH	SAMPLE	ASH	SAMPLE	
+130	o 130	1	o 140	1	o 130	3	<i>N. aspera</i>
	o 130	2	o 130	2			
+118	118	3	129	3			
+114		4	118	4			
+102	*	4	*	5			
+101		5	90	5			
+90	90	5	90	6			
+77	79	6	79	7			
+62	62	7	62	8			
+60	52	8	51	9			
+51	*	9	35	10			
				11			
+30	22	10					<i>C. naviculoidea</i>
+25			19	12	b 19		
+19	19	11	19	12			
+9	16	12	16	13			
+3	9	13	9	14			
+1	+1	14	+1	15	+1	4	
-11	*	15			-11	5	
-12	-13	16	-13	16	13	6	
-13			b 13	17			
	b 14	17	b 13	18			
	b 14	18			o 17	7	
					o 17	8	
					17	9	
-17							<i>D. elongata</i>
-18					19A	11	
					b 19A	12	
-19					21A	10	
						13	
							<i>N. danica</i>
					26	14	
-22					30	15	
-29					b 30	22	
-33					33	16	
-34							<i>N. constricta</i>
-35							
-39							

Table 3. Position of samples studied in relation to the numbered ash layers in a composite ideal profile of the diatomites in Denmark. Total thickness of the sequence is up to 60 m. * = limestone, lines of dots = subzone boundary, o = sample above an ash layer, b = sample below an ash layer.

nation than the 10–15,000 years suggested by the model of Bonde (1974).

Systematics

The descriptive terms proposed in Deflandre (1950) for the silicoflagellates are largely followed in the description of the new and old species. The preparations containing the holotypes are deposited in the Geological Museum in Copenhagen under the MGUH-numbers given in the text. The negatives of scanning electron microscope photographs are on file at the electron microscope lab of the Federal Technical Highschool in Zürich, Switzerland, where they were made. Identification of species listed in text, but not described below, is based on Perch-Nielsen (1975).

Corbisema naviculoidea (Frenguelli 1940) n. comb. Figs 7, 19, 22.

1932 *Dictyocha navicula* Ehrenberg 1839 in Deflandre, fig. 13

1940 *Corbisema apiculata* f. *naviculoidea* Frenguelli, fig. 12h

1950 *Corbisema apiculata inermis* Lemmermann 1901 in Deflandre, fig. 88

1974 *Dictyocha naviculoidea* (Frenguelli 1940) in Martini, p. 528

Remarks: Dumitrica (1973) has recently described the subspecies *Corbisema inermis dissymmetrica* from the Middle Palaeocene of the Pacific Ocean. This form is very similar to *C. naviculoidea*, but relatively shorter and usually covered by a coarser ornamentation than the slender ridges connecting small knobs on the apical and abapical side of *C. naviculoidea* (table 4).

Table 4

	Length: width		
<i>C. inermis</i>			
<i>dissymmetrica</i>	1.1 to 1.7	mean 1.2	13 measurements
<i>C. naviculoidea</i>	1.8 to 2.3	mean 2.0	11 measurements

Dumitrica (1973) has shown the evolution from the triangular forms of *Corbisema inermis* to the bipolar form *C. inermis dissymmetrica* during the Early to the early Middle Palaeocene. Such a transition from a triangular to the bipolar form cannot be observed in the sequence of diatomites in Denmark. It might be

concluded that *C. naviculoidea*, which appears in Denmark in the late Palaeocene to early Early Eocene, is a successor of *C. inermis dissymmetrica* that found its way to the North Sea at that time.

C. naviculoidea is quite common in some samples between A -17 to A +19, but was not found higher up in the sequence in this study.

Corbisema ovalis n.sp.

Figs. 12, 13, 23

Holotype: fig. 12 (KPN Z2–9), MGUH 13889

Description: *Corbisema* with nearly oval basal windows and short radial horns pointing towards the basal window or oriented vertically to the plane of the basal ring. The apical bar is broad and the basal ring is strongly constricted, where it meets the apical bar. A very fine ornamentation in form of small knobs covers the apical side of the skeleton.

Remarks: *C. ovalis* differs from other species of *Corbisema* through the common occurrence of a strong constriction at the meeting point of basal ring and apical bar and short radial horns which are not oriented in the plane of the body ring.

Corbisema archangelskiana (Schulz) Frenguelli of various authors seems close to the new species. In his description of *Dictyocha triacantha* var. *archangelskiana*, Schultz specially mentioned the lack of radial horns, and only one of his figures shows a form with small radial horns. It is suggested here that *C. archangelskiana* be used only for the forms lacking radial horns.

Occurrence: *C. ovalis* is not rare in the siliceous samples studied from VEMA 28/43. The holotype is from VEMA 28/43, 330 cm (Voering Plateau, Norwegian Sea), a sample of Late Eocene age.

Corbisema spinosa Deflandre 1950
Fig. 25

1950 *Corbisema spinosa* Deflandre, p. 193, figs 178–182

Remarks: *C. spinosa* shows a round to triangular basal ring and usually quite long radial horns. The apical apparatus consists of more or less vertically oriented lateral bars

that support three long spines meeting in the centre of the apical apparatus. The ornamentation is developed mainly on the apical side of the skeleton and consists of a combination of small knobs and ridges. *C. spinosa*, which was described from the Upper Eocene of Barbados, is present in all siliceous VEMA samples studied and was found to be dominating the assemblage in VEMA 28/43, 330.

Dictyocha elongata Glezer 1960

Fig. 2

1960 *Dictyocha elongata* Glezer, p. 131, 132, table 1, pl. 2, figs 16–20

1966 *Dictyocha elongata* Glezer in Glezer, p. 236, 237, pl. 11, figs 1–7

Remarks: *D. elongata* has so far been found only in the USSR in the Early Eocene and ?Middle Eocene (Glezer 1966). It is surprising that it was not previously reported from Denmark, where it is not rare in samples from below A -17 and above A -21. Where present only the strongly triangular form illustrated in fig. 2 has been found. None of the more elongate forms with a reduced third radial horn, as observed by Glezer, occur in Denmark.

Distephanus norvegiensis n.sp.

Figs. 15, 16, 20

Holotype: fig. 16 (KPN Z2–26), MGUH 13890

Description: *Distephanus* with a zig-zag outline, five short radial horns, long lateral bars, a small apical ring. The long sustaining spines are attached slightly beside the point where the lateral bars join the basal ring. Five-sided forms are dominant, but four-sided forms also occur. The apical side of the skeleton is covered by an ornamentation consisting of small knobs connected by ridges.

Remarks: *D. norvegiensis* differs from the younger *D. speculum* s. ampl. and other species of *Distephanus* by the strongly zig-zag outline of the former and the small apical ring. In *D. norvegiensis*, the apical apparatus is high, while it is low in *D. speculum regularis contracta* Schulz from the Mioocene of Japan, another form with a basal ring somewhat constricted at the meeting point of basal ring and

lateral bars. The five-sided form *D. quin-quangellus* Bukry & Foster 1973 has straight sides, its sustaining spines are attached about midway between the corner and the lateral bar, and the radial horns are long.

D. norvegiensis differs from the similar *D. rosae* by the maximum frequency of number of radial horns at five in *D. norvegiensis* and the place of attachment of the sustaining spines. *D. rosae* has consistently more corners and the shorter sustaining spines are attached at the meeting point of the lateral bars with the basal ring.

Occurrence: *D. norvegiensis* is not rare in the Late Eocene diatomite in core VEMA 28/43, 520 cm (Voering Plateau, Norwegian Sea), which is the source of the holotype specimen.

Distephanus rosae n.sp.

Figs. 14, 17

Holotype: fig. 14 (KPN Z2–23), MGUH 13891

Description: *Distephanus* with a zig-zag outline, six or more radial horns, short sustaining spines attached at the meeting point of lateral bars and basal ring and a relatively small apical ring. The apical apparatus is high. The ornamentation consists of slender ridges.

Remarks: 6 to 13 radial spines were found in *D. rosae*, thus consistently more than in the probably related species *D. norvegiensis*. The distribution of forms was found as shown in table 5.

Table 5

VEMA 28/43 sample	<i>D. norvegiensis</i> sides:		<i>D. rosae</i>					cannopiloid forms	total counts			
	4	5	6	7	8	9	10	11	12	13		
177 cm											+++	
220 cm											++	
330 cm			?	10	7	5	15				+	20
520 cm			+ 80	8	5	3	+ 33	+ +			+	62

+ = present, but not in the counts.

Although *D. rosae* shows no predominance in the number of sides at 520 cm, the 8-sided forms clearly dominate at 330 cm and the forms have disappeared higher up, where an increasing number of cannopiloid specimens with slightly zig-zag outline was found. *D. rosae* is distinguished from *Distephanus polyactis*

(Ehrenberg) and *D. octonarius* (Ehrenberg) by its zig-zag outline.

Occurrence: see above. The holotype, an 11-sided specimen of the species, is from the Late Eocene diatomite in core VEMA 28/43 520 cm (Voering Plateau, Norwegian Sea).

Mesocena concava n.sp.

Figs. 11, 24

Holotype: fig. 11 (KPN Z2-16), MGUH 13892

Description: *Mesocena* without radial spines, without septa, with rounded corners and strongly concave sides. The ornamentation consists of ridges parallelling the outline of the silicoflagellate.

Remarks: *M. concava* is similar to *M. muticata* Glezer from the ?Early Eocene of the USSR. The latter, however, has less concave sides and truncated rather than 'rounded corners' as *M. concava*.

Occurrence: *M. concava* occurs, rare to few, in all of the siliceous samples studied from the VEMA core. The holotype is from the Late Eocene diatomite in core VEMA 28/43, 520 cm, where the species is most common.

Naviculopsis aspera (Schulz) n.comb.

Figs. 8, 9, 31, 34, 35

1928 *Dictyocha navicula* Ehrenberg var. *aspera* Schulz p. 245, figs 20a, b

Remarks: *N. aspera* has been reported from the diatomites of Denmark mainly as *Dictyochla navicula* var. *biapiculata* Lemmermann, *Naviculopsis biapiculata* and probably also *N. constricta*. The skeleton of *N. aspera*, however, is considerably different from these species. The flat basal ring is modified to a quite high siliceous wall topped by an apical bar. A quite coarse ornamentation which consists of individual knobs as well as knobs aligned perpendicular to the basal ring, covers most of the skeleton. A large knob tops the apical bar in some specimens. In Denmark, typical *N. aspera* is restricted to the interval from A -21 and upward. In younger specimens the wall tends to be less high and the ornamentation finer. Below A -21, *N. aspera* shows more constriction where the apical bar, plate-like at this level, meets the wall, and there is no large knob on the apical structure.

Naviculopsis constricta (Schulz 1928)

Frenguelli 1940

Figs. 29, 30

1928 *Dictyocha navicula* Ehrenberg var. *constricta* Schulz, p. 245, fig. 21

1940 *Naviculopsis constricta* (Schulz) Frenguelli, p. 61

Remarks: The specimens found in the Danish diatomites of this species show only a slight constriction of the basal ring where it meets with the apical bar. The latter is formed of a plate with slightly thickened borders. The ornamentation consists of small knobs and is finer than on *N. aspera* but coarser than on *N. minor*. *N. constricta* is usually rare in samples from Fur and Mors.

Naviculopsis danica n.sp.

Figs. 5, 6, 21

Holotype: fig. 6 (KPN Z2-33), MGUH 13893

Description: *Naviculopsis* with long radial horns, a round to elliptical basal ring and three lateral rods forming the apical apparatus. The length of the basal ring is shorter than the length of a radial horn.

Remarks: Deflandre (1950, fig. 92) has illustrated a similar form to *N. danica* as an abnormal form of *N. constricta*. Typical specimens of *N. constricta* show a normal, simple apical plate, the basal ring is considerably longer than a radial horn and the total length is around 100 μm . *N. danica* measures between 38 and 70 μm with a mean length of 52 μm (from 27 measurements). The ornamentation consists of small knobs.

Occurrence: *N. danica* occurs as rare to few in samples from Knudeklint and Stolleklint on Fur between A -17 and A -33. The holotype is from the Early Eocene diatomite at Stolleklint, Fur (KPN 539-9).

Naviculopsis cf. *N. foliacea* Deflandre 1950

Figs. 10, 28, 33

cf 1950 *Naviculopsis foliacea* Deflandre, p. 204, figs 235-240

Remarks: *N.* cf. *N. foliacea* is rare to common in the Late Eocene diatomites in core VEMA 28/43. The length of the apical plate varies but is usually longer than the length of the

basal windows in the specimens from this locality. In *N. foliacea* as illustrated and described by Deflandre from the Late Eocene of Barbados and California, the apical plate is slightly shorter or of equal length to the basal windows. He also described small laminated surfaces situated in the two internal extremities of the basal ring that were not recognised in the specimens studied here.

Naviculopsis minor (Schulz 1928)

Frenguelli 1940

Figs. 26, 27

1928 *Dictyocha navicula* Ehrenberg var. *minor* Schulz, p. 246, fig. 22

1940 *Naviculopsis minor* (Schulz) Frenguelli, p. 61

Remarks: The presence of *N. minor* in the diatomites from Denmark has been reported previously by Glezer (1966). The outline of these specimens is more elliptical than in the type which Schulz described as more rectangular. The apical bar is developed as a plate. The ornamentation seems to be only patchy, leaving most of the skeleton with a quite smooth surface. *N. minor* occurs with varying frequency in samples from Fur and Mors, Denmark.

Naviculopsis punctilia n.sp.

Figs. 1, 32

Holotype: fig. 1 (KPN Z2-10), MGUH 13894

Description: Large species of *Naviculopsis* with relatively short radial horns, an elliptical basal ring and an apical bar supported by four lateral bars. The very fine ornamentation consists of very small knobs.

Remarks: *N. punctilia* differs from other species of *Naviculopsis* by the four lateral bars supporting the apical bar which lies more or less parallel to the small axes of the elliptical basal ring. The latter is longer than a radial horn. The total length of *N. punctilia* varies from 122 μm to 165 μm , with a mean length of 142 μm (from 8 measurements). Deflandre (1950) has shown a series of forms lying between a typical *Dictyocha* and a typical *Naviculopsis* for *D. mutabilis* from the Miocene of California. In the material studied here, no such intermediate forms have so far been found.

Occurrence: *N. punctilia* is rare in the Late Eocene diatomites in core VEMA 28/43, 177 to 330 cm. The holotype is from 330 cm.

Naviculopsis vema n.sp.

Figs. 3, 4, 18

Holotype: fig. 4 (KPN Z2-13), MGUH 13895

Description: *Naviculopsis* with radial horns of more or less equal length, a slim elliptical to slightly rhombohedral basal ring and an elevated short apical bar oriented more or less parallel to the long axes of the basal ring, supported by four lateral bars. The ornamentation is usually only barely visible and consists of small knobs connected by ridges.

Remarks: *N. vema* differs from other species of *Naviculopsis* by the special form of the apical apparatus with its longitudinally oriented apical bar. *N. vema* is considerably smaller than *N. punctilia*. The total length of *N. vema* varies from 70 to 105 μm with a mean length of 81 μm (from 10 measurements).

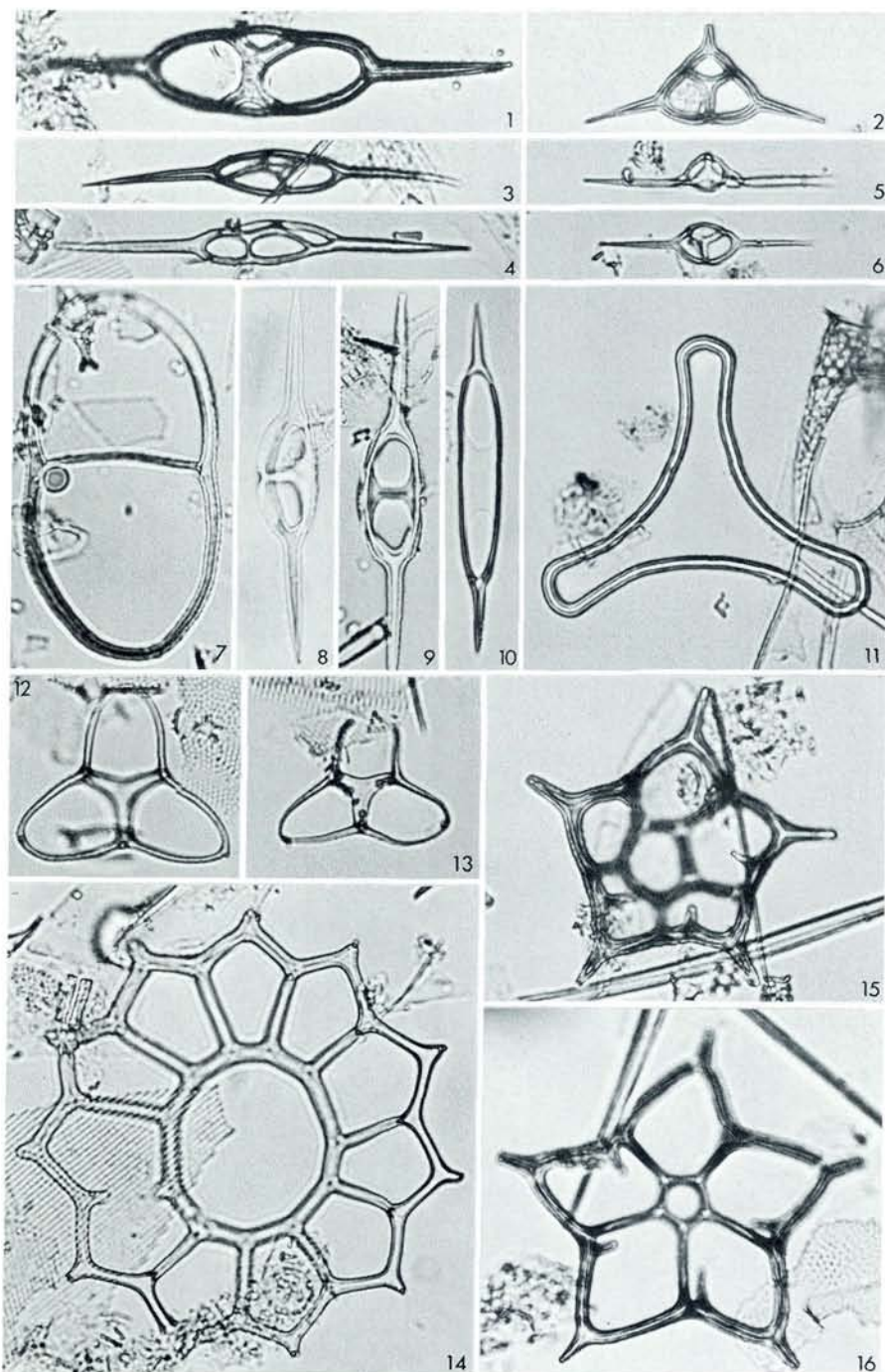
Occurrence: *N. vema* is not rare in the Late Eocene diatomite in core VEMA 28/43, 520 cm, the only sample in which it has been found.

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Dansk sammendrag

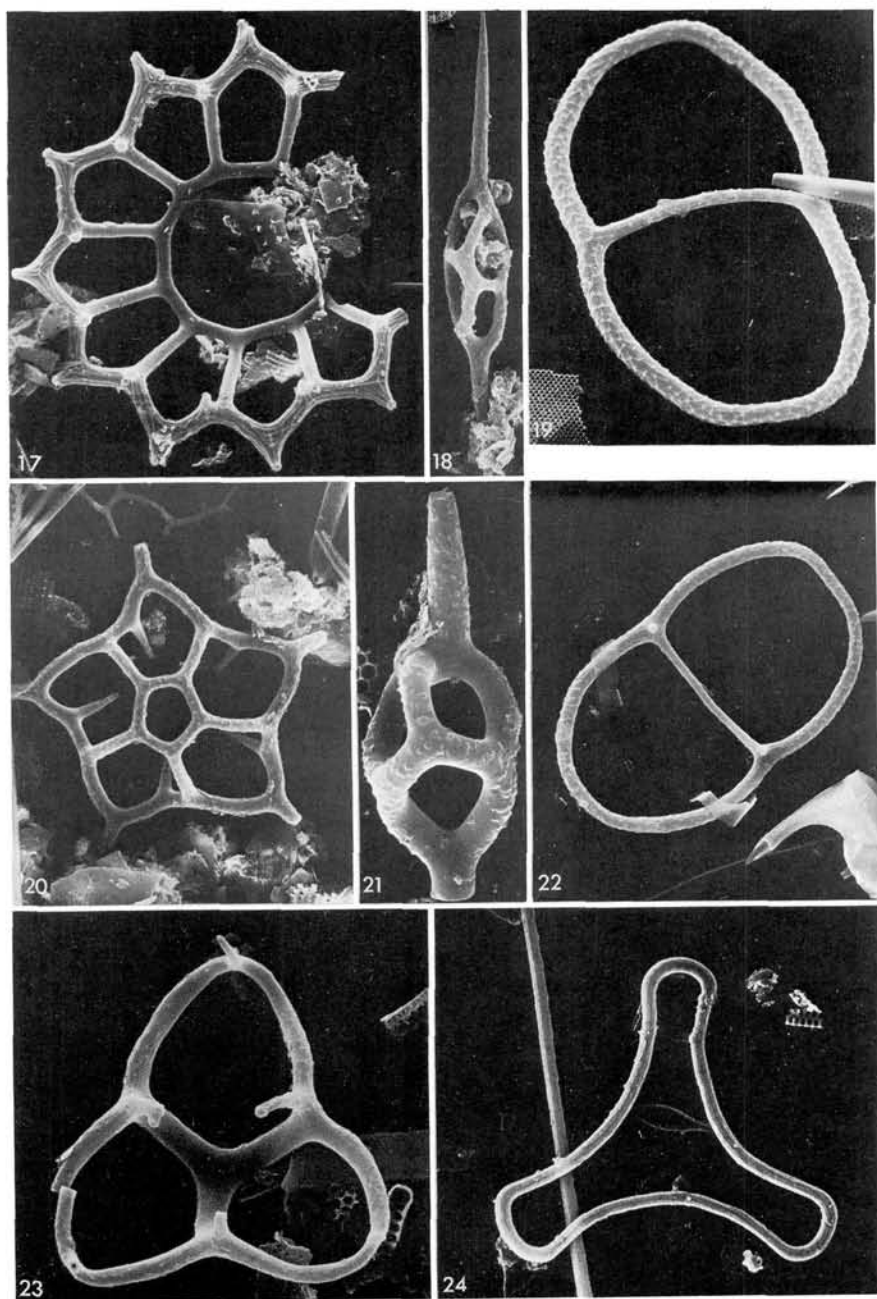
Der beskrives følgende nye silicoflagellater – mikroskopiske kiselskeletter, som er dannet af encellede, marine alger – fra de øvre palæocæne til nedre eocæne diatomiter på Fur, Danmark, og øvre eocæne diatomiter på Voering Plateauet i Norske Havet: *Corbisema ovalis*, *Distephanus norvegiensis*, *D. rosae*, *Mesocena concava*, *Naviculopsis danica*, *N. punctilia* og *N. vema*.

Den op til 60 m mægtige diatomit lagserie (moleret) i Danmark kan inddeles i fem subzoner på ca. 8 eller mere meter ved hjælp af silicoflagellater. Det kortere profil i Norske Havet kan inddeles i to subzoner ved hjælp af de nye silicoflagellat arter.



Figs 1-16. Magnification ca. $\times 530$. Fig. 1. *Naviculopsis punctilia* n.sp., VEMA 28/43, 330 cm. Fig. 2. *Dictyocha elongata* Glezer, Knudeklint, Fur, KPN 514-4. Figs 3, 4. *Naviculopsis vemae* n.sp., VEMA 28/43, 520 cm. Holotype fig. 4. Figs 5, 6. *Naviculopsis danica* n.sp., Stolleklint, Fur, KPN 539-9. Holotype fig. 6. Fig. 7. *Corbisema naviculoidea* (Frenguelli) n.comb., Holmens grav, Fur, KPN 539-20. Figs 8, 9. *Naviculopsis aspera* (Schulz) n.comb., Holmens grav, Fur, KPN 539-

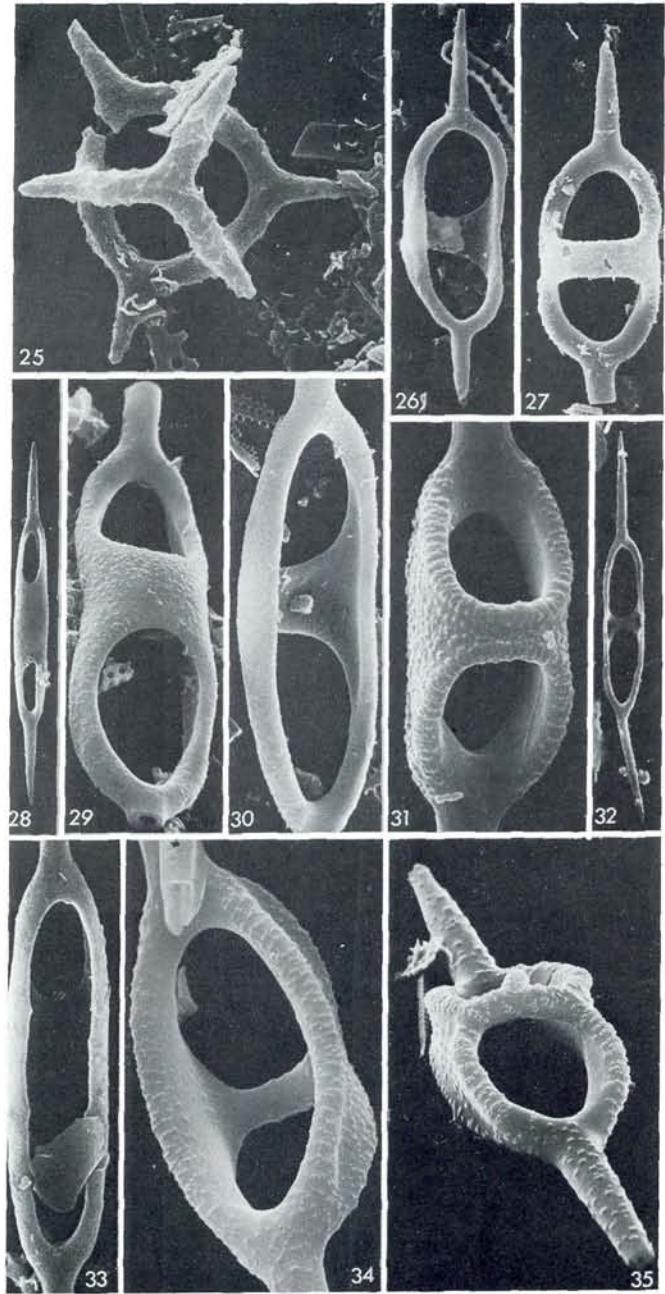
14, 539-1. Fig. 10. *Naviculopsis* cf. *N. foliacea* Deslandre, VEMA 28/43, 330 cm. Fig. 11. *Mesocena concava* n.sp., VEMA 28/43, 520 cm. Holotype. Figs 12, 13. *Corbisema ovalis* n.sp., VEMA 28/43, 330 cm, 520 cm. Holotype fig. 12. Fig. 14. *Distephanus rosae* n.sp., VEMA 28/43, 520 cm. Holotype. Figs 15, 16. *Distephanus norvegiensis* n.sp., VEMA 28/43, 520 cm. Holotype fig. 16.



Figs 17-24. Fig. 17. *Distephanus rosae* n.sp., abapical view; VEMA 28/43, 520 cm; $\times 660$. Fig. 18. *Naviculopsis vemae* n.sp., apical view; VEMA 28/43, 520 cm; $\times 800$. Figs 19, 22. *Corbisema naviculoidea* (Frenguelli) n.comb., apical and abapical views showing the ornamentation and small diameter of the apical bar and the small sustaining spines; Holmens grav, Fur,

KPN 539-20; $\times 860$, $\times 500$. Fig. 20. *Distephanus norvegiensis* n.sp., apical view; VEMA 28/43, 520 cm; $\times 660$. Fig. 21. *Naviculopsis danica* n.sp., apical view; Knudeklint, Fur, KPN 514-1; $\times 1600$. Fig. 23. *Corbisema ovalis* n.sp., abapical view; VEMA 28/43, 520 cm; $\times 1200$. Fig. 24. *Mesocena concava* n.sp., VEMA 28/43, 520 cm; $\times 660$.

Figs 25–35. Fig. 25. *Corbisema spinosa* Deflandre, apical view; VEMA 28/43, 330 cm; $\times 2130$. Figs 26, 27. *Naviculopsis minor* (Schulz) Frenguelli, abapical and apical views showing the apical bar to consist of a plate and the basal ring to be slightly thinning where it meets the apical bar; Stolleklint, Fur, KPN 539-9; $\times 1330$. Figs 28, 33. *Naviculopsis* cf. *N. foliacea* Deflandre, apical and abapical views; VEMA 28/43, 330 cm and 220 cm; $\times 500$, $\times 1330$. Figs 29, 30. *Naviculopsis constricta* (Schulz) Frenguelli, apical views and an abapical view; Stolleklint, Fur, KPN 539-9; $\times 930$ and $\times 2200$. Figs 31, 34, 35. *Naviculopsis aspera* (Schulz) n.comb., apical views (figs 31, 35) and abapical view; Silstrup Sydkiint, KPN 539-2 (fig. 31), Holmens grav, Fur, KPN 539-1 (fig. 34), 539-20 (fig. 35); $\times 1330$, $\times 1600$, $\times 2000$. Fig. 32. *Naviculopsis punctilia* n.sp., abapical view; VEMA 28/43, 330 cm; $\times 330$.



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