Lower Pliocene dinoflagellate cysts from cored Utsira Formation in the Viking Graben, northern North Sea

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND MINISTRY OF ENVIRONMENT AND ENERGY

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Stefan Piasecki, Ulrik Gregersen & Peter N. Johannessen

Geological Survey of Denmark and Greenland (GEUS) Thoravej 8, DK-2400 Copenhagen NV, Denmark E-mail: sp@geus.dk., ug@geus.dk & pjo@geus.dk

Abstract

The Utsira Formation covers an area of at least 75 x 450 km with its main, sandy depocentre in the southern Norwegian Viking Graben. Here in the Sleipner area, the formation is *c*. 300 m thick and pinches out to the west and east. It consists of unconsolidated, very fine- to medium-grained sand mainly composed of quartz with small amounts of glaucony, shell fragments and lignite, probably deposited by turbidite flows. Earlier biostratigraphical studies of the Utsira Formation have been based on cuttings and the age has been considered to be mainly Late Miocene potentially including latest Middle Miocene and earliest Pliocene. In the present study, core samples from the well 15/9-A23 situated in the Sleipner area have been studied.

Dinoflagellate cysts were prepared from seven samples of very fine- to fine-grained sand taken from a core in the interval of 1080.0 - 1084.99 metres. The content of organic matter was low in all samples but yielded a diverse assemblage of Middle to Upper Miocene dinoflagellate cysts and acritarchs. A mixture of Middle and Upper Miocene stratigraphic marker-species indicate significant reworking of older species into younger strata in accordance with the interpretation of the depositional environment mentioned above. The main stratigraphical problem is therefore to distinguish reworked species from the in situ flora. The presumed in situ dinoflagellate flora comprises overall Upper Miocene to Pliocene species with relatively few species of precise and clear stratigraphical significance. The presence of Palaeocystodinium spp., Systematophora placacanta and Labyrinthodinium truncatum could indicate an early Late Miocene age. However these species may also have originated among the persistently reworked species from the Middle Miocene. Alternatively, a single record of Selenopemphix armageddonensis in the lowest sample may represent the stratigraphical highest occurrence of this species, approximately at the Mio-Pliocene transition, followed by the appearance of Bitectatodinium tepikiense higher in the core. This interpretation is supported by the presence of species such as Hystrichokolpoma rigaudiae and Reticulosphaera actinocoronata which are reported to range into the Lower Pliocene in the northern North Atlantic region. Several dinoflagellate cysts in the assemblage are well known from the Pliocene or even the Pleistocene of the North Atlantic region. Some acritarchs are particularly characteristic of the Pliocene of the northern North Atlantic region. The youngest possible age of these samples based on the content of dinoflagellate cysts is strongly dependent on the interpretation of which species that are considered reworked. However Amiculosphaera umbracula, Invertocysta lacrymosa and Ataxiodinium zevenboomii are generally reported to reach stratigraphically not much higher than mid-Pliocene.

The age of the cored interval of the Utsira Formation is therefore considered to be Early Pliocene, in accordance with unpublished foraminifer data from just below the succession studied here. This makes a significant part of the formation younger than indicated by previously published biostratigraphic data.

Keywords: Dinoflagellate cysts, Lower Pliocene, Utsira Formation, Sleipner Field, North Sea

1. Introduction

Miocene-Pliocene dinoflagellate cyst stratigraphy has evolved over the last 30 years. The pioneer time when every new paper gave significant progress with new useful data that improved the details of the stratigraphy and the precision in the age dating lasted into the early 1980'es e.g. (Manum 1976; Piasecki 1980; Edwards 1984). Data from the North Sea were systematised and a standard dinoflagellate cyst stratigraphy was formalised (Costa & Manum 1988; Powell 1992). The last part of the periode was characterised of increasing amounts of detailed studies especially from offshore regions e.g. (Head et al. 1989a; Head et al. 1989b; Manum et al. 1989; de Verteuil & Norris 1996; Poulsen et al. 1996) and studies of the type-sections (Zevenboom 1995) which lead to new conclusive charts of Miocene dinoflagellate stratigraphy e.g. (Hardenbol et al. 1998). These later studies clearly show abundance of species not recognised and described earlier. Previously stratigraphic significant species were claimed to have much wider ranges than realised earlier, and especially the last occurrences of many species were extended into the Plio-Pleistocene. However, in many cases reworking of these species may be the main cause for the extension of the stratigraphic ranges but this is not yet possible to confirm. Consequently, the stratigraphic value of many species decreased and stratigraphic precision diminished significantly. Many of the new species are now considered stratigraphically significant and precise but these species are not always common in the North-West European region and therefore difficult to find and to use with confidence when present.

Comprehensive and conclusive stratigraphic work is published recently and summarises many of these problems in the resulting stratigraphy (Zevenboom 1995; de Verteuil & Norris 1996; Poulsen *et al.* 1996; Hardenbol *et al.* 1998). The Upper Miocene – Pliocene part of this dinoflagellate cyst stratigraphy is dominantly based on the last occurrence of species, and several of these species are not abundant or geographically widespread in the North Atlantic dinoflagellate cyst flora of this time. So, the Miocene–Pliocene transition in the northern North Atlantic region is not biostratigraphically pin-pointed by dinoflagellate cysts. The present study of core material with a well-preserved and abundant flora close to the Miocene–Pliocene boundary may be a small contribution to the solution of this problem.

2. Geology

The northern North Sea was an epicontinental subsiding basin during the Late Cenozoic time (Fig. 1). The basin was confined by the Scandinavian and British land and shelf areas, that were affected by episodic uplift, locally more than 600 m (Jordt *et al.* 1985; Rundberg 1989; Ghazi 1992; Galloway *et al.* 1993; Hansen 1996).

The Utsira Formation was deposited along the Viking Graben area, extending approximately 450 x 75 km, with a major southern- and a minor northern depocenter (Fig. 2) (Gregersen *et al.* 1997). The sands of the Utsira Formation are located centrally in the basin and are stacked into minor mounds, giving blocky gamma log responses which probably indicate a turbiditic origin (Fig. 3) (Gregersen *et al.* 1997; Gregersen *et al.* 2000). The sand was probably temporarily deposited on shallow marine shelf areas, prior to subsequent redeposition in deeper basinal areas probably by means of turbidite flows. The analysed core is from the Sleipner West hydrocarbon field (well 15/9-A23) in the southern depocenter of the Utsira Formation (Figs 1–3). The core was taken as part of the SACS Project (Saline Aquifer CO₂ Storage). The formation consists of mainly fine- to mediumgrained unconsolidated quartz sand, locally with glaucony, fragments of shells and lignite. The formation is located stratigraphically within shales of the Neogene Hordaland- and Nordland Groups (Isaksen & Tonstad 1989) and is succeeded by Pliocene and Quarternary depositions with a thickness up to 900 metres.

The age of the Utsira Formation has earlier been determined Middle Miocene to Late Miocene (Isaksen & Tonstad 1989) but has more recently been revised to latest Middle Miocene to Early Pliocene based on foraminifers (Eidvin *et al.* 1999).

4. Stratigraphy

4.1 Description of the assemblages

Operculodinium spp., Spiniferites/Achomosphaera spp. and Barssidinium graminosum dominate the composite dinoflagellate cyst flora. The dinoflagellate flora in the two upper samples is further characterised by abundance of acritarchs (*Michrystridium* spp. and *Cymatiosphaera* spp.) and *Bitectatodinium tepikiense*. Most other species recorded occur relatively rare in each sample and remarkable many species are represented by only one or two specimen in a sample. This may reflect the low content of organic matter in the samples or that the species are reworked.

The dinoflagellate cysts in the lower 5 samples and the upper two samples respectively may then be considered as two separate assemblages. However, as described below, there are distinct differences and variations in the samples of each assemblage (Figs 4–5). The composition of the assemblages is very typical for Upper Miocene – Pliocene dinoflagellate assemblages in general, except for the abundance of *Barssidinium graminosum* in Pliocene, which is not recorded commonly. However, *Barssidinium* spp. dominated assemblages are reported from the Pliocene e.g. *Barssidinium pliocenium* in United Kingdom (Head 1997). Most other reports of *Barssidinium* spp. in the North Atlantic region is from the Miocene (Piasecki 1980; Lentin *et al.* 1994; Hardenbol *et al.* 1998; Louwye 1999).

4.1.1. Lower assemblage

<u>Sample 1084,99 m</u>: The organic content of the lowermost sample differs from the higher samples in the same assemblage. The organic matter comprises unstructured organic matter (amorphous kerogen) after brief oxidation and several chorate cysts are smothered with amorphous matter between the processes. The remaining organic matter is similar in composition to the other samples except for a much lower proportion of rounded, coaly grains.

The dinoflagellate cyst assemblage contains a suite of stratigraphical significant species which must be considered reworked from Lower – Middle Miocene strata due to their inconceivable common occurrence (Figs 4–5). Preservation and colour of the clearly reworked specimens do not deviate from the *in situ* specimens, so they can only be discriminated and excluded from the stratigraphical discussion on the basis of subjective criteria as their previously known stratigraphical occurrence. Most of these species occur in one or more higher samples as well. The Upper Miocene *Selenopemphix armageddonensis* and *Selenopemphix brevispinosum* are limited to the lowermost sample and this occurrence may either be the stratigraphic highest occurrence of these species in top Miocene strata, or they may be reworked together with the older species. In either case, these occurrences indicate strata of the Miocene–Pliocene transition or younger because the species are reported to disappear close to the boundary. *Selenopemphix armageddonensis* appears in nannoplankton zone NN 11 and is stratigraphically restricted to uppermost Miocene (Head et al. 1989b; de Verteuil & Norris 1996). Ataxaiodinium zevenboomii and Cyst type 1 (de Vernal & Mudie 1989) occur in this and several higher samples; both these species are mainly characteristic for Pliocene assemblages (de Vernal & Mudie 1989; Head & Norris 1999).

<u>Samples 1084,73–13 m</u> contain no unstructured organic matter after oxidation and the remaining organic matter is composed of palynomorphs and rounded to slightly angular, black grains. Dinoflagellate cysts prevail together with organic innerlinings of foraminifers; spores and pollen occur frequent in all samples.

New dinoflagellate cyst species appear especially in the middle sample (1084,33 m) and the upper sample (1084,13 m), both samples with more diverse assemblages than in the two other samples. The stratigraphically important species *Bitectatodinium serratum*, *Invertocysta lacrymosa* and *Amiculasphaera umbracula* appear in sample 1084,33 m. *Bitectatodinium tepikiense* and *Geonettia* spp. are the only stratigraphically important species out of seven species that occurs only in the uppermost sample (1084,13 m). The other species are long-ranging and probably present in this sample because the highest diversity of the assemblage is found here in.

4.1.2. Upper assemblage

<u>Samples 1080 and 1080,80 m</u>: Both samples in the upper assemblage are characterised by abundance of unstructured organic matter after oxidation and rounded, coaly grains are equally abundant. Therefore the relative content of marine palynomorphs, dinoflagellate cysts and foraminifer innerlinings are low compared to the samples below, and this is accentuated by an increased content of spores and pollen compared to the lower samples. The diversity of the dinoflagellate cyst assemblage is lower than below but acritarchs becomes more abundant and slightly more diverse because *Pterospermella* spp. and *Micrystridium* spp. appears. Several stratigraphic important species from the assemblage below are not present here (e.g. Cyst Type 1 (de Vernal & Mudie 1989), *Reticulosphaera actinocoronata* and *Nematosphaeropsis lemniscata*) and new species of *Impagidinium* spp. appear. The stratigraphical significance of these changes are difficult to interprete.

4.2. Stratigraphical discussion

A high number of the recorded species has to be reworked because the presence of these species conflicts with the presence of other younger species. These are Apteodinium australiense, Apteodinium spiridoides, Apteodinium tectatum, Cerebrocysta poulsenii, Cribroperidinium tenuitabulatum, Distatodinium paradoxum, Cousteaudinium aubryae and Unipontidinium aequaeducta. Highest occurrence of these species in respectively Lower, Middle and lowermost Upper Miocene of the North Atlantic region is well established for these species (Zevenboom 1995; de Verteuil & Norris 1996; Poulsen et al. 1996). The reworked status of the species above suggests that another suite of recorded species with an established, stratigraphically significant, last occurrence in the Upper Miocene or lowermost Pliocene may also be reworked into the studied succession from the lower part of

their ranges in association with the Lower – Middle Miocene species mentioned above (e.g. Labyrinthodinium truncatum, Palaeocystodinium spp., Systematophora placacantha, Selenopenphix armageddonensis, Selenopenphix brevispinosum and Reticulosphaera actinocoronata). Approximately 20–50% of the recorded species may consequently be considered reworked from older strata (Figs 4–5) and this is in accordance with figures reported by Smelror (1999; pers. comm. 2000) from Neogene deposits on the Norwegian shelf and western Svalbard margin.

Consequently, the main problem in this stratigraphical interpretation is to decide which species can be considered *in situ* with confidence. *Selenopenphix armageddonensis* and *Selenopenphix brevispinosum* in the lowermost sample are among the critical species because their last occurrences are generally reported in the uppermost or top Miocene (de Verteuil & Norris 1996; Poulsen *et al.* 1996; Hardenbol *et al.* 1998; Louwye & Laga 1998; Smelror 1999). If these records were the actual last occurrences of these two species, the basal sample could be Miocene and the Miocene–Pliocene boundary could be located lowermost in the core. But the limited occurrence and abundance of these two species rather indicate that they are reworked into Pliocene strata so that the entire core are deposited above the Miocene–Pliocene boundary.

The remaining *in situ* dinoflagellate cyst and acritarch assemblage is mainly restricted to species rarely reported and not formally described. The stratigraphical significance of these species is consequently restricted. However, the *in situ* assemblage do provide sufficiently stratigraphic information for a precise age determination of these strata. *Ataxiodinium zevenboomei* is reported from the Miocene? – Pliocene Haps Formation of the Netherlands (Zevenboom 1995) but otherwise only from the Lower Pliocene (Head 1997). Cyst Type 1 (de Vernal & Mudie 1989) is reported to occur only in the middle Lower Pliocene in the North Atlantic (de Vernal & Mudie 1989; Head & Norris 1999). Both species are represented in most samples of the core and indicate an Early Pliocene age. *Bitectatodinium tepikiense* is not recorded in the two lowest samples of the core but becomes abundant upwards. (Hardenbol *et al.* 1998) reports the first occurrence of *Bitectatodinium tepikiense* at the disappearance of *S. armageddonensis* in the mid-Tortonian (Upper Miocene) of NW-Europe. More locally for the studied material, the first occurrence of *Bitectatodinium tepikiense* is recorded in the uppermost Miocene of the Møre Basin (Mangerud & Charnock 1999).

The assemblage of dinoflagellate cysts are also stratigraphically limited upwards to Lower Pliocene by the presence of a number of species as far as they are considered *in situ; Amiculosphaera umbracula, Invertocysta lacrymosa, Hystrichokolpoma rigaudiae, Melitasphaeridium choanophorum* and others. However, reports of their last occurrence vary. The occurrence of *Reticulatosphaera actinocoronata* in the lower part of the core may be *in situ* (see above) and the last occurrence of this species is reported from the uppermost Miocene in NW-Europe to the Lower Pliocene in the North Atlantic (Powell 1992; Louwye & Laga 1998; Head & Norris 1999).

4.3. Age

Based on the stratigraphical discussion above the age of the sediments of the Utsira Formation in the studied core are considered Zanclean, Early Pliocene. Most of the *in situ* species have an stratigraphical overlap in the Lower Pliocene close to the Miocene/Pliocene boundary. No species in the recorded assemblage contradict this age assignment.

This age is in accordance with biostratigraphic data based on foraminifers in cutting samples that indicate the upper part of the Utsira Formation in the Sleipner area to be younger, Early Pliocene, than in the type well (Eidvin *et al.* 1999). Foraminifers from the same core as studied here but from a lower level (1085–1086 meters; MD) indicate a latest Miocene – earliest Pliocene age (Wilkinson 1999).

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5. Depositional environment

The organic content is highly marine in composition in all samples. Low organic content dominated of rounded black coaly grains and diverse assemblages of marine fossils (dino-flagellate cysts and foraminifer innerlinings) may indicate deposition on the outer shelf. The rounded coaly grains reflects distal depositional facies after extensive transportation and oxidation of the organic matter (eventually recycling). This process could be enhanced by increased flow-regime during deposition of the sand but the general absence of e.g. woody and other coarse terrestrial organic matter supports the interpretation of an outer shelf deposition. This is in accordance with a fauna rich in planktonic foraminifers and very few shallow water indicators (Eidvin *et al.* 1999; Wilkinson 1999). The combination of unstructured organic matter in the lowest sample, little direct influx of terrestrial organic matter in general and a good marine dinoflagellate flora could indicate deposition during transgression.

The high (potentially very high) frequence of reworked species indicates that at least parts of the sediments are sourced from reactivation of older deposits and redeposited in form of storm sands or turbidites derived from the shelf areas.

Palaeoclimatic interpretations based on dinoflagellate cysts are still disputable. But the appearance of *Bitectatodinium tepikiense* in the lower core and the significant increase in abundance in the upper core combined with a weak opposite trend for *Lingulodinium machaerophorum* may reflect climatic cooling during deposition (Dale 1996). Alternatively, it may reflect climatic conditions near the temperate-subarctic transition where *L. machaerophorum* disappears and *B. tepikiense* appears/increases in abundance towards the north (Dale 1996). The significant increase in content of acritarchs (especially *Cymatiosphaera* spp. and *Micrystridium* spp.) in the high core clearly reflects some environmental/depositional signal and is combined with abundant *Bitectatodinium tepikiense*. This may indicate a shift towards a more cool climate.

The presence of few *Impagidinium* spp. including the appearance of *Impagidinium paradoxum* and *Impagidinium velum* high in the core may reflect upwards increasing oceanity or may just signal some oceanic influence of the succession in general (Dale 1996).

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6. Conclusions

Well preserved and diverse dinoflagellate cyst assemblages may occur in- and be prepared from apparently clean quarts sand.

The *in situ* dinoflagellate cyst assemblage in the studied strata of the Utsira Formation indicate an Early Pliocene, Zanclean age of this succession. This implicate that a major part of the Utsira Formation is younger (Pliocene) than previously considered on the basis of calcareous micro-fauna from ditch-cutting samples.

The content of dinoflagellate cysts in the studied strata of the Utsira Formation comprises a high proportion of reworked species. Abundance of reworked dinoflagellate cysts strongly indicate that other fossil groups may have been equally subjected to reworking with corresponding stratigraphic problems. This also supports that the sand of the Utsira Formation is reactivated shelf deposits deposited in the deep basin e.g. by turbidite flows or as storm sands.

The stratigraphical first occurrence of dinoflagellate species in Upper Miocene – Pliocene sediments of the North Atlantic must be used for precise dating of the successions. Reports of the last occurrence of dinoflagellate species in this part of the sedimentary succession appear to be strongly influenced by extensive reworking and not very reliable for precise dating

Interpretation of the depositional environment can only be extracted from the dinoflagellate cyst assemblage with reluctance. The succession are distally deposited with some oceanic influence, possibly during a time of cooling climate and near the transition from temperate to sub-arctic climate.

The stratigraphical interpretation of the *in situ* dinoflagellate assemblage clearly show the stratigraphical potential of the dinoflagellate cysts. However, the assemblages near the Miocene – Pliocene transition need more studies to elucidate the clear palaeogeographical diachonism of the appearance and disappearance of specific species and to elaborate the full stratigraphical potential of dinoflagellate cysts close to this transition in the North Atlantic region.

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Appendix 1: Alphabetic list of species

The recorded taxa are listed alphabetically. The name of the species is followed by its stratigraphical range or the stratigraphical important first/last occurrence of the species, followed by the geographical region where the range is recorded. A bibliographic reference to the source of the stratigraphic data occurs last. Species not included into the range charts are marked with an asterisk.

Dinoflagellate cysts

Achomosphaera andalousiense subsp. andalousiense, upper Middle Miocene - Lower Pleistocene, North Atlantic region, (Head et al. 1989b). Achomosphaera andalousiense subsp. suttonensis, mid to Upper Pliocene, North-East Europe, (Head 1997) Achomosphaera sp. Head 1997, mid to Upper Pliocene, North-West Europe, (Head 1997) Amiculosphaera umbracula, uppermost Middle Miocene - Upper Pleiocene, North Atlantic region, (Hardenbol et al. 1998) Apteodinium australiense, reworked Apteodinium spiridoides, reworked Apteodinium tectatum, reworked Ataxiodinium zevenboomii, (Upper Miocene?) - Pliocene, (Head 1997) Batiacasphaera spherica, Lower Miocene - ?, North Atlantic, (Stover 1977) Barssidinium graminosum, Middle Miocene - ? Lower Pliocene, North Atlantic region, (Lentin et al. 1994) Bitectatodinium serratum, Upper Miocene, Labrador Sea, (Head et al. 1989b) Bitectatodinium tepikiensis, Upper Miocene - Recent, North Atlantic, (Hardenbol et al. 1998) Cribroperidinium tenuitabulatum, reworked Distatodinium paradoxum, top Middle Miocene, North Atlantic region, (Manum et al. 1989) Filisphaera filifera, Upper Oligocene – Lower Pleistocene, northern North Atlantic region. (Head 1997) Geonettia sp. Habibacysta tectata Homotryblium sp. Hystrichokolpoma rigaudiae, Lower Eocene - Pleistocene, North Atlantic region, (Head 1997) Hystrichosphaeropsis membraniphorum, top in lowermost Pliocene, North Atlantic, (Hardenbol et al. 1998) *Impagidinium sp., I. cf. paradoxum, *Impagidinium sp., I. cf. densiverricosum, Upper Miocene, Italy, (Zevenboom 1995) Invertocysta lacrymosa, Middle Miocene - lower Upper Pliocene, North Atlantic region, (Head 1997) Invertocysta sp.

Labyrinthodinium truncatum var. truncatum, Middle Miocene, Middle – Upper Miocene, Eastern USA, (de Verteuil & Norris 1996)

Labyrinthodinium truncatum subsp. reductum, Middle – Upper Miocene, northern Germany, (Strauss & Lund 1992)

Lingulodinium machaerophorum, Upper Paleocene – Recent, (Head 1996) Lejeunecysta aff. fallax

Remarks: This species has an overall similarity with both *L. communis* and *L. fallax* but deviates in the absence of a well developed apical horn/extended epicyst. Most other characters of *L. fallax* are present but the wall is significantly more thin. *Lejeunecysta* spp. in pl. 3, fig, 13, 15, (Head *et al.* 1989b) from Miocene – Lower Pliocene, Labrador Sea, show more discrete longitudinal folds/thickenings and less pronounced thickening of the apex. The size of *Lejeunecysta* aff. *fallax* is in accordance with all these species.

The overall morphology is similar to Selenopemphix sp. in this study but Lejeunecysta aff. fallax has no spines on the cingular membranes.

Lejeunecysta sp. 2

Remarks: The species is characterised by a laevigate surface with "shaddows" of cingulum on the dorrsal side merging into heavy folds on the ventral side. The sulcal region is marked faintly by "shadows" (epicystal part) and micro granulae (hypocystal part). No apical horn but two antapical horns are indicated by sligthly conveks antapical region. Discrete wall thickening occurs at the apex and clear spines/granulae occur at the point of each antapical horn.

Melitasphaeridium choanophorum, Lower Oligocene - Pleistocene, (Head 1997)

Nematosphaeropsis lemniscata, Oligocene – Lower Pleistocene, North Atlantic, (Head et al. 1989b)

Operculodinium centrocarpum,

Opercuculodinium sp.

Operculodinium janduchenei, Upper Miocene – ?(Pliocene – Quarternary), North Atlantic region

Operculodinium sp. 1

Palaeocystodinium spp, Paleogene – mid Upper Miocene, North Atlantic region, (Head et al. 1989b)

*Pentadinium sp.

Polysphaeridium zoharyi, Miocene - Recent, North Atlantic region

Reticulosphaera actinocoronata, Miocene – ?Lower Pliocene, North Atlantic region, (Head et al. 1989b)

Selenopemphix armageddonensis, Upper Miocene, North Atlantic region, (de Verteuil & Norris 1996)

Selenopemphix brevispinosum, Middle – lower Upper Miocene, (Head et al. 1989a) Selenopemphix sp.

Remarks: No clear archaeopyle have been identified in Selenophemphix sp. in this material. A hemicystal archaeopyle is indicated by ruptures along the cinglar membranes. The overall morphology is similar to Halodinium minor (Bujak 1984) but without the central pylome of that genus. Furthermore, Selenophemphix sp. show an aequatorial invagination which may indicate the sulcal region and has an ellipsoidal shape in polar view.

Spiniferites pseudofurcata, Lower Paleogene – Miocene – (Plio-Pleistocene?), North Atlantic region, (Head et al. 1989b)

18

Spiniferites solidago, Upper Oligocene – Upper Miocene, Eastern USA, (de Verteuil & Norris 1996) Spiniferites cf. pseudofurcata Spiniferites sp. Cf. Systematophora spp., Palaeogene – Iower Upper Miocene, North Atlantic region, (Head et al. 1989b) Thalassiphora gonoperforata / Cousteaudinium aubryae, reworked Tectatodinium pellitum Upper Cretaceous – Recent Trinovantedinium sp. Tuberculodinium vancampoae., Upper Oligocene – Recent, (Head et al. 1989a)

Acritarchs

Cyclopsiella granulata, Miocene, (Head et al. 1992) Cymatiosphaera invaginata, Upper Miocene - Lower Pleistocene, Baffin Bay, (de Vernal & Mudie 1989; Head et al. 1989a) Michrystridium spp.

Other Algae

Cyst type I de Vernal & Mudie 1989, Lower Pliocene, Labrador Sea, (de Vernal & Mudie 1989; Head & Norris 1999)

Tasmanites spp.





Figure 1: Geographical and structural map of the North Sea and the Viking Graben. The Sleipner Field with well 15/9-A23 is indicated in the southern Viking Graben.





Figure 2: Isopach map of the Utsira Formation (Gregersen, 1996) with the position of well 15/9-A23 marked in the depo-center of the southern part of the basin.

Figure 3.



Figure 3: Lithological interpretation of gamma ray (GR) and resistivity (RD) logs from well 15/9-A23 in the Utsira Formation. The core analysed for dinoflagellate cysts are marked together with the stratigraphical classification of the Utsira Formation in Miocene and Pliocene respectively.

ENCLOSUF	RE	SHEET: SCALE:	1	1 Groups: SPADE 1 Figure 4: Range-chart of the marine palynomorphs in the seven studied samp 1 ***** Complete spp. set														ed samples.	The samples are not	GEUS														
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Plate 1



25 µm

Plate 1: Dinoflagellate cysts from the Utsira Formation. The magnification is indicated by the 25 micron bar; the bar in Fig. 4 also represents 25 microns. Figs 1-2: *Selenophemphix armageddonensis*, sample 1084.99 metres, MI 10.605. Fig. 3: *Selenophemphix brevispinosum*, sample 1084.99 metres, MI 10.586. Fig 4: *Cymatiosphaera invaginata*, three levels of focus, sample 1080.00 metres, MI 11.375. Fig. 5: *Lejeunecysta* sp., sample 1084.13, MI 10.583. Fig. 6: *Barssidinium graminosum*, sample 1084,13, MI 11.374. Fig. 7: *Apteodinium australiense*, sample 1084.13 metres, MI 10611. Fig. 8: *Apteodinium spiridoides*, sample 1084.28, MI 10.613. Fig. 9: *Apteodinium tectatum*, sample 1084.13, MI 10.612.

Plate 2



 $25\ \mu m$

Plate 2: Dinoflagellate cysts from the Utsira Formation. The magnification is indicated by the 25 micron bar; the bars in Figs 9-11 also represents 25 microns. Figs 1-2: Cyst type 1 (de Vernal and Mudie, 1989), sample 1084.13, MI 10.578. Figs 3-4: Cyst type 1 (de Vernal and Mudie, 1989), sample 1084.33 metres, MI 10.579. Figs 5-6: Cyst type 1 (de Vernal and Mudie, 1989), sample 1084.99 metres, MI 10.560. Figs 7-8: *Habibacysta tectata*, sample 1084.13 metres, MI 10617. Figs 9-10: *Bitectatodinium tepikiense*, sample 1080.00 metres, MI 10.417. Fig. 11: *Cyclopsiella granosa*, sample 1080.00 metres, MI 10.396.

Plate 3



25 µm

Plate 3: Dinoflagellate cysts from the Utsira Formation. The magnification is indicated by the 25 micron bar. Figs 1-7 illustrate the morphological variation of *Ataxiodinium zevenboomii* with respect to the overall shape and the morphology of the outer wall layer. Figs 8-9: *Ataxiodinium* sp. Fig. 1: *A. zevenboomii*, sample 1084.99 metres, MI 10.559. Figs 2-3: *A. zevenboomii*, sample 1084.99 metres, MI 10.561. Figs 4-5: *A. zevenboomii*, sample 1084.13 meters, MI 10562. Fig. 5: *A. zevenboomii*, sample 1084.33 metres, MI 10.558. Figs 6-7: *A. zevenboomii*, sample 1084.13 metres, MI 10.564. Figs 8-9: *Ataxiodinium* sp., sample 1084.33 metres, MI 10.556, the folds of the outer wall-layer forms flat, distal platforms in contrast to other species of *Ataxiodinium*.