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Abstract

Microfossils and palynomorphs from the Freja Member were studied with the purpose to improve the understanding of the age and depositional setting of the unit. The fossil evidence shows that the Freja Member is of Chattian (Late Oligocene) age in Frida-1 and Chattian (Late Oligocene) to probably early Aquitanian (earliest Miocene) age in Francisca-1. It is suggested that the palaeoenvironment changed from upper bathyal and outer neritic in the lower part of the Freja Member to neritic in the upper part in Francisca-1 and that the significant influx of marginal marine and terrestrial palynomorphs and phytoclasts was caused by transportation from the neighbouring coastal areas.

Introduction

The objectives of the present study are to improve the understanding of the Oligocene to Miocene Freja Member with regard to biostratigraphy and depositional setting. Sand units of this age from the Danish North Sea area have been described from a sequence stratigraphic point of view (e.g. Michelsen, 1994; Danielsen *et al.*, 1997), but only a very limited amount of information is available in the literature with regard to their fossil faunas and floras. The present paper focus on the stratigraphical and palaeoecological significance of the microfaunas (especially foraminiferids and diatoms) and palynomorphs.

Geological setting

During the Cenozoic, the North Sea area constituted a large epicontinental sea flanked by continental areas towards the East and Northeast (Scandinavia) and the West (the British Isles and the Shetland Platform) (Nielsen *et al.*, 1986). The post-Danian succession in the North Sea is more than 3000 m thick in the central part of the basin (Sorgenfrei, 1969; Michelsen, 1996), and fine-grained siliciclastic sediments, especially clays, dominates the lithology. The development of the Danish sector of the North Sea Basin during the Cenozoic was influenced by both the former Palaeozoic and Mesozoic structural elements and Cenozoic subsidence (Ziegler, 1990). Major structural elements in the sector is the Ringkøbing-Fyn High, which divides the basin in the northern Norwegian-Danish Subbasin and the southern German Basin, and the Sorgenfrei-Tornquist Fault Zone that penetrates the north-eastern part of the area. The deepest parts of the Danish sector are in the Central Graben area to the west of the Francisca-1 and Frida-1 wells (Fig. 1). Halokinetic movements of Zechstein evaporites and the resulting salt induced faulting have produced significant features both to the south in the southern Salt Dome Province and the north in the Northern Salt Province of the Danish Central Trough. During the Cenozoic, the North Sea Basin was also influenced by inversion tectonics (Late Cretaceous to Palaeogene) and late Cenozoic uplift and erosion.

The Oligocene and Miocene sediments consist mainly of clays with an upward increasing amount of silt and mica, but more coarse grained sand bodies have previously been reported from the north-eastern part of the Danish Sector, east of the Central Graben (Michelsen, 1994).

In the North Sea, the Oligocene–Miocene deposits are characterised by an overall progradational seismic pattern, which are in contrast to the concordant patterns of the underlying Palaeogene units (Danielsen *et al.*, 1997). The architecture shows that the siliciclastic source area was towards the east and northeast of the Danish North Sea basin. This direction is in accordance with recent studies by Rasmussen *et al.* (2002), who showed that three progradational wedges occur within the Lower to lower Middle Miocene succession in Jutland coming from a mainly northern source area. The Late Oligocene and Early Miocene time interval was characterised by a basinward migration of nearshore and fluvial deposits, reflecting uplift, subsequent erosion and a gradual sediment infill of the basin (Michelsen, 1996; Rasmussen *et al.*, 2002).

Material and methods

Microfossils. The investigated core samples from Francisca-1 were prepared by wet-sieving of the 63-1000 μm sediment fraction followed by drying, splitting and picking. Five samples were prepared from the Francisca-1 well from the following depth levels: 1715.72 m, 1711.62 m, 1707.84 m, 1581.85 m and 1568.85 m. The five samples from Francisca-1 were studied both qualitatively and quantitatively and two full trays of each sample were picked and mounted on microfossil slides. In addition, thirteen available microfossil slides from Frida-1 were studied qualitatively. Calcareous benthic, calcareous planktic and agglutinated foraminiferids were counted together with diatoms and radiolarians. All the observed taxa from Francisca-1 are listed in Fig. 2, and some of the key species are displayed in Plate 1.

Palynology. The samples were digested in hydrochloric and hydrofluoric acid following standard palynological preparation procedures (cf. Batten, 1999); residues were sieved at 11 μm . A brief oxidation (2 min. in 36 % nitric acid) was carried out on all residues. The residues were heavy-liquid separated using ZnCl_2 and mounted in glycerine jelly on microscope slides.

All samples were studied qualitatively in order to determine their age. The dinoflagellate and acritarch taxa encountered during the study are listed in Fig. 3. Key taxa are illustrated in Plate 2. The LVR numbers referred to in the plate text are file numbers in the fossil image database of GEUS. That database contains all relevant curatorial details on each photographed specimen (well name and location, sample depth, slide number, slide co-ordinates etc). Dinoflagellate taxa mentioned in the text, figures and plate are referenced in Williams *et al.* (1998) or herein. Acritarch taxa are referenced in Fensome *et al.* (1990).

For all samples, two data sets were obtained from two sets of kerogen counts in order to assess the palynofacies. The first count included the following eight categories (Major Kerogen Groups): black phytoclasts, brown phytoclasts, leaf cuticles, resin, fungal hyphae, degraded phytoclasts, amorphous organic matter (AOM) and palynomorphs. Herein, the term black phytoclast encompasses all angular to subrounded kerogen that is entirely opaque up to the edge, with or without signs of plant anatomy. The term brown phytoclast encompasses herein particles with signs of plant anatomy

that appear orange to dark brown. Degraded phytoclasts are orange to dark brown granular particles without obvious sign of plant anatomy, but with residual trace of structure. Amorphous organic matter encompasses herein grey to brown structureless, microgranular masses, commonly with inclusions. It is considered to have a marine origin (Tyson, 1995). Zooclasts were extremely rare in the samples and were not counted.

The second count encompassed palynomorphs only (Palynomorph Group). The following eight groups were counted: dinoflagellates (total of determinable and indeterminate), other phytoplankton (mainly acritarchs and *Palambages*), foraminifera test linings, fungal spores, thick-walled trilete spores, other non-saccate sporomorphs, saccate pollen and a group of highly degraded palynomorphs of algal or sporomorph origin. Truly non-marine microplankton was not observed. It was the intention to count at least 100 palynomorphs in each slide, but this was not possible for the two uppermost samples due to the scarcity of palynomorphs in these samples. The results of the two kerogen counts are shown in Fig. 4. The palaeoenvironmental significance of the kerogen groups is as follows:

Phytoclasts. Charcoal particles, which probably constitute the major part of the black phytoclasts in the samples, are considered more buoyant and resistant than brown phytoclasts, and survive longer during transportation (Cope, 1981; Van der Zwan, 1990). Black phytoclasts therefore have an increased relative abundance in distal facies (Tyson, 1989; Gorin and Steffen, 1991; Steffen and Gorin, 1993). The relative abundance of brown phytoclasts decreases in an offshore direction (Tyson, 1987, 1995; Van der Zwan, 1990; Waterhouse, 1995; Tyson *et al.*, 1996). A shift towards relative abundance of brown phytoclasts and degraded land plant material is characteristic of marine regression and indicates fresh-water influx (e.g. Tyson, 1995; Li and Habib, 1996). The relative abundance of brown and black phytoclasts in the samples is shown in Fig. 6.

AOM. The relative abundance of AOM increases in a proximal to distal direction, and AOM is the dominant kerogen constituent in distal dysoxic to anoxic shelf environments (Tyson, 1995). In line with this, Habib and Miller (1989), and Li and Habib (1996) found that the abundance of AOM increases during transgression and early highstand. Palliani *et al.* (1998) found that AOM is the main component at maximum flooding. AOM also occurs with high percentages in dysoxic to anoxic

environments caused by upwelling or stratification of the watermasses (e.g. Powell *et al.*, 1990; Tyson, 1995). The percentage of AOM in the samples is shown in Fig. 4.

Palynomorphs. This group includes both continental and marine elements and is therefore further subdivided herein: Abundance of dinoflagellates, acritarchs and other marine algae generally indicate a neritic marine environment with limited continental influence (e.g. Muller, 1959; Davey and Rogers, 1975; Morzadec-Kerfourn, 1977; Habib *et al.*, 1994; Tyson, 1995; Below and Kirsch, 1997). However, in distal shelf areas with stable stratified watermasses with low microplankton cyst production, their relative abundance may decline (Tyson, 1995). Organic foraminifera test linings are probably derived from benthic foraminifera and their presence is assumed to indicate marine salinity (Tyson, 1995). Their abundance shows a general decrease in an offshore direction (Tyson, 1993, 1995). Dinoflagellates, acritarchs, other marine algae and foraminifera have been grouped together and are shown as marine palynomorphs in Fig. 4, 5.

Fungal spores, thick-walled spores, other non-saccate sporomorphs and saccate pollen are terrestrially derived; their combined relative abundance generally decreases in an offshore direction across the shelf (cf. Davey and Rogers, 1975). However, in settings with low microplankton cyst production (see above), sporomorphs (especially saccate pollen and small sphaeromorph pollen) may swamp the assemblage even though their absolute abundance is low (cf. Tyson, 1995). The relative abundance of the terrestrial palynomorphs is complementary to the percentage of marine palynomorphs and is shown in 5.

Biostratigraphy

The palynostratigraphy of the Late Oligocene to Middle Miocene interval of the Frida-1 well was described by Dybkjær (2003), but except from this study, only very limited information on biostratigraphy is available in the literature. Based on dinocyst-events, Dybkjær (2003) assigned the Freja Member of Frida-1 to the Chattian (Late Oligocene).

Microfossils

The standard Cenozoic biostratigraphic schemes were based on planktic foraminifera from subtropical and tropical areas (e.g. Blow 1979, Berggren & Miller 1988, Berggren

et al. 1995). Many of the key fossils are missing in sediments of the temperate seas at higher latitudes, and precise correlations between the North Sea faunal successions and the standard zonations is often difficult to achieve. As a consequence, regional North Sea zonation schemes were established for microfossils during the 1980's (King 1983, 1989). A major advantage in using these schemes for the North Sea wells is that the zones to a great extent are based on first downhole occurrences (FDO), which is useful because the vast majority of the available offshore samples are ditch cutting samples. Separate schemes were established for agglutinated benthic, calcareous benthic and planktic foraminiferids and King (1989) named the three zonation schemes NSA, NSB and NSP, respectively. The NSP zones were based not solely on planktic foraminiferids but also on *Bolboforma*, diatoms and radiolarians. An alternative Cenozoic North Sea zonation scheme was introduced by Gradstein *et al.* (1994) based on appearance datums of all the main groups of foraminiferids and subsequent calculations based on quantitative, stratigraphic methods. Their work resulted in twelve RASC (ranking and scaling) interval zones through the Cenozoic succession of the North Sea. The latest Oligocene to Pleistocene succession of the Norwegian Ekofisk and Sleipner fields was dated biostratigraphically by Eidvin *et al.* (1999), who established a new zonation scheme mainly based on foraminifera. The present study has adapted the benthic foraminiferid zonation (NSB) of King (1983, 1989).

The dinoflagellate cyst stratigraphy is based on the zonation schemes of Köthe (1990) and Schiøler (in prep, see report 2003/73 this volume).

Zone NSB9 (*Plectofrondicularia seminuda* Zone)

Definition.- Interval from FDO of *Plectofrondicularia seminuda* to FDO of *Brizalina antiqua*.

Remarks.- The two uppermost samples in Francisca-1 (1581.85 m and 1568.85 m) and the interval from above 1300 m in Frida-1 (the upper boundary was not reached in the present study) correlates with the *P. seminuda* Zone (Fig. 7). In these wells the *P. seminuda* Zone is characterised by a diverse benthic foraminiferid fauna (Fig. 2) associated with rare to common planktic elements. Agglutinated foraminifera including *Haplophragmoides walteri* and *Ammodiscus cretaceous* dominate some levels, while

calcareous benthics, e.g. *Bulimina elongata*, *Globocassidulina subglobosa*, *Glabratella?* sp. A King, *Cibicidoides?* cf. *pygmeus*, *Plectofrondicularia seminuda*, *Cibicidoides pachyderma*, *C. peelensis* and *Siphonodosaria* spp. dominate other levels.

The benthic microfauna of this zone indicates a probable Early Miocene (Aquitainian) age according to King (1989), and this is in agreement with the co-occurrence of the planktic foraminiferids *Zeaglobigerina woodi* and *Globigerina ciperoensis*, and the lack of the diatom *Aulacodiscus insignis quadrata* (small morphotype) within the NSB9 Zone.

Zone NSB8 (*Brizalina antiqua* Zone)

Definition. - Interval from FDO of *B. antiqua* to FDO of *Rotaliatina bulimoides*.

Remarks.- Only the upper one of the three subzones, NSB8c, is represented with certainty in Francisca-1 (1715.72 m) and Frida-1 (the interval from about 1710 m to 1300 m) (Fig. 7). It was noted by King (1983) that the NSB8a Subzone (subzone with abundant *Asterigerina guerichi*) only may be readily differentiated in the inner sublittoral facies, and because the early Late Oligocene successions of the Francisca-1 and Frida-1 wells were probably deposited in an upper bathyal or outer neritic palaeoenvironment, the palaeoenvironment was probably too deep to contain microfossils typical of the NSB8a Subzone.

Subzone NSB8c (*Fursenkoina schriebersiana* Subzone)

Definition.- Interval from FDO of *Brizalina antiqua* to FDO of common *Elphidium subnodosum*.

Remarks.- The zone is characterised by a rich mixture of calcareous benthic, planktic and agglutinated foraminifera in Francisca-1 (1715.72 m) and Frida-1 (1710 m – 1300 m). Pyritised diatoms are abundant in some levels. Small specimens of *Cibicidoides mundulus* are very common but also *Paragloborotalia nana*, *Globigerina praebulloides*, *Spirosigmoilinella compressa*, *Cyclammina* spp. and *Glabratella?* sp. A King characterises the lower part of the zone. *Brizalina antiqua* was recorded from the upper

part, and *Pararotalia canui* from the lower part of the NSB8c Subzone in Frida-1 (Fig. 7).

The occurrence of e.g. *Aulacodiscus insignis quadrata* (small morphotype), *Paragloborotalia nana*, *Paragloborotalia opima*, *Brizalina antiqua*, *Pararotalia canui* and *Nonion* sp. A King indicates a Late Oligocene (Chattian) age for the lower part of the NSB8c Zone, and this is in accordance with the correlation by King (1989). The occurrence of a single specimen of the Early Oligocene (or older) marker fossil *Chiloguembelina cubensis* from the upper part of the Freja Member in Frida-1, is probably due to reworking.

Zone NSB7 (Rotaliatina bulimoides Zone)

Definition.- Interval from FDO of *Rotaliatina bulimoides* to FDO of *Uvigerina germanica*.

Remarks.- Only the upper one of the two subzones, NSB7b, has been investigated in the present work. See below further details.

Zone NSB7b (Rotaliatina bulimoides Subzone)

Definition.- Interval from FDO of *Rotaliatina bulimoides* to FDO of *Cassidulina carapitana*.

Remarks.- The sample from 1710 m in Frida-1 correlates with the *R. bulimoides* Zone (Fig. 7). The sample is dominated by diverse agglutinated foraminifera, e.g. *Haplophragmoides* spp. including *H. walteri*, *Recurvoides* spp. and *Rhabdammina discreta*. Calcareous benthics include among others *Cibicidoides* spp. and *R. bulimoides*. One badly preserved specimen of *Cassidulina* may possibly be classified as *C. carapitana*. If this is the case, and the specimen is *in situ*, the sample belongs to the Early Oligocene NSB7a Subzone, and a hiatus covering NSB7b occurs. Because of the bad state of preservation, however, we tentatively interpret the specimen as reworked and correlate the sample with NSB7b.

Palynomorphs

The dinoflagellate assemblage from the samples can be roughly divided into two different groups: a lower group encompassing the three lowermost samples (1715.72; 1711.62 and 1707.84 m) and an upper group encompassing the two upper samples studied (1581.85 m and 1568.85 m). The assemblages from the two groups treated as two composite samples below.

Zone D15 (Köthe, 1990) and zone O11 (Schiøler, in prep.)

The three lower samples from Francisca-1 (1715.72; 1711.62 and 1707.84 m) contain a diverse dinoflagellate and acritarch assemblage (32-39 taxa) indicating a mid-Chattian age (Fig. 8). This age assessment is based on the joint presence of *Distatodinium biffi*, *Membranophoridium aspinatum*, *Artemisiocysta cladodichotoma*, *Pentadinium imaginatum* and *Pentadinium lophophorum*. *Distatodinium biffi* has highest occurrence (HO) in the uppermost Chattian (Hardenbol *et al.*, 1998) whereas *M. aspinatum* ranges to the Oligocene-Miocene boundary, being very rare in the uppermost Oligocene (Powell, 1992). *Artemisiocysta cladodichotoma*, *P. imaginatum* and *P. lophophorum* are exclusively Chattian taxa with HO well below the Oligocene-Miocene boundary (Powell, 1992). The two former taxa have LO well above the Rupelian/Chattian boundary (Powell, 1992). This age assignment is supported by the absence of representatives for the otherwise common genus *Wetziella* spp. which have HO in the lowermost Chattian and the absence of *Ectosphaeropsis burdigalense* and other exclusively Miocene taxa. The assemblage belongs to the broadly Chattian D15 Zone of Costa & Manum (1988) as modified by Köthe (1990) based on the absence of both *Rhombodinium draco* and *Tuberculodinium vancampoae*. The samples belong to the intra-Chattian informal O11 zone of Schiøler (in prep, see report 2003/73 this volume), based on the joint presence of *Pentadinium laticinctum granulatum*, *Leptodinium italicum*, *Spiniferites ramosus* ssp. 3 and *Heterosphaeridium* sp. 1, both the latter of Schiøler (in prep., see report 2003/73 this volume).

Zone D15 (Köthe, 1990) and zone O11–M2 (Schiøler, in prep.)

The two upper samples from the Freja Member in Francisca-1 at 1581.85 m and 1568.85 m contain a very sparse dinoflagellate assemblage of only 4 and 8 taxa,

respectively. The poor assemblage and the lack of good marker taxa hamper unambiguous age assessment. The joint presence of *Caligodinium amiculum* and *Deflandrea phosphoritica* indicates an age not younger than earliest Aquitanian (Powell, 1992; de Verteuil & Norris, 1996). The samples lack all taxa restricted to the Oligocene (or older strata) otherwise encountered in the sample suite below, and therefore an early Aquitanian age is inferred for the samples. However, it is possible that the absence of Oligocene markers may also be an artefact caused by the general scarcity of dinoflagellates and acritarchs. The samples may be placed in the interval O11-M2 of the informal zonation of Schiøler (in prep, see report 2003/73 this volume).

The age of the Freja member, summary

Lower part. The benthic foraminiferid *Pararotalia canui* appears in the Freja Member of both Francisca-1 and Frida-1, and indicates a Late Oligocene (Chattian) age for the main part of the unit (King 1989). This is further supported by the occurrence of the planktic foraminiferids *Paragloborotalia opima* and *P. nana* in the middle claystone-dominated part of the Freja Member in Francisca-1, which indicates a mid or early Chattian (Zone P21b of Berggren *et al.* 1995) age for this part of member (1715.72 m) (Fig 8).

The palynomorph assemblages from the three lower samples (1715.72; 1711.62 and 1707.84 m) include *Distatodinium biffi*, *Membranophoridium aspinatum*, *Artemisiocysta cladodichotoma*, *Pentadinium imaginatum* and *Pentadinium lophophorum*, which support a middle Chattian age for the middle part of the Freja Member in Francisca-1.

Dybkjær (2003) dated the Freja Member of Frida-1 as Chattian based on dinoflagellate cysts.

Upper part. The uppermost part of the Freja Member in Francisca-1 contained *Zeoglobigerina woodi* in a core sample (1568.85 m), which supports an Early Miocene or latest Oligocene age (Chaproniere 1988). To judge from the FDO of the zonal species *Brizalina antiqua* (Zone NSB8) in the two wells, the top of Freja Member in Francisca-1 may correlate with a level in the claystones almost 200 m above the top of the Freja

Member in Frida-1. Accordingly, the deposition of sand seems to have persisted for a longer period in the Francisca-1 area than around Frida-1.

The palynomorph assemblage from 1581.85 m and 1568.85 m in the uppermost part of the Freja Member is poor, but the co-occurrence of *Caligodinium amiculum* and *Deflandrea phosphoritica* together with lack of taxa restricted to the Oligocene (or older strata) indicate a possible early Aquitanian age for the upper part of the unit in Francisca-1.

Palaeoenvironmental interpretation

The depocenter during the Late Oligocene and Early Miocene was situated in the area close to the Francisca-1 and Frida-1 wells just north of the Ringkøbing-Fyn High and east of the Danish Central Graben (Michelsen, 1996, fig. 3; Danielsen *et al.*, 1997). The sediments of the Freja Member are dominated by quartzitic sandstones with many mudstone stringers in the lowermost unit and the lower half of the middle unit, while the upper unit is characterised by relatively pure quartzitic sandstones (Schiøler *et al.*, see report 2003/71 in this volume). The nearest shoreline during the Late Oligocene and Early Miocene followed a line from Fyn and Ringkøbing across the Danish North Sea in a WNW direction (Rasmussen *et al.*, 2002).

Microfossil assemblages

The main part of the Freja Member is dominated by agglutinated foraminiferids, in particular epifaunal suspension feeders (*Rhabdammina* spp.) and shallow infaunal and surface detritivores (e.g. *Haplophragmoides* spp. and *Recurvoides* spp.). Calcareous benthic and planktic foraminifera were common to very common in some time intervals, the benthics especially in the upper part of the Freja Member in Francisca-1. Typical aerobic benthic foraminiferids (flat, spiral morphotypes *sensu* Kaiho, 1991) are as a rule more common than typical dysaerobic taxa (torpedo-shaped), and this relationship together with the relatively common diatom flora indicate well-aerated water-masses during most of the period. The relatively common occurrence of e.g. *Cibicidoides mundulus*, *Siphonodosaria* spp. and *Pullenia* spp. together with the very sparse occurrences of *Asterigerina* spp. may indicate a bathyal, probably upper bathyal to lower

neritic palaeoenvironment in most of the period when the Freja Member was deposited in both the investigated wells (van Morkhoven *et al.* 1986). The upper, more fine-grained, part of the Freja Member in Francisca-1 is dominated by a calcareous benthic foraminiferid fauna, which includes e.g. *Bulimina elongata*, indicating a more nearshore, neritic palaeoenvironment. Planktic foraminiferids constitute 29 % of the total foraminiferid fauna in sample 1715.72 m in Francisca-1 giving a P/B (planktic/benthic) ratio of nearly 1/3, while the ratio is only about 1/20 in the two samples from the upper part of the Freja Member. The material at hand is very sparse, but also the difference in the P/B ratios may indicate more nearshore conditions (Murray, 1976) – or a more pronounced influx from nearshore areas – in the period when the upper part of the Freja Member in Francisca-1 was deposited than in the lower part of the member. The Francisca-1 well displays more significant differences in the foraminiferal assemblages from the lower to the upper part of the Freja Member than was observed in Frida-1. With a few exceptions in the upper part of the member, the latter well is by far dominated by agglutinated assemblages throughout the sandstone member.

Palynofacies

The three lower samples have a palynofacies distinctively different from that of the two upper samples, and the two groups of samples are treated individually below.

Samples 1715.72 m; 1711.62 m and 1707.84 m

The three samples have very similar kerogen assemblages characterised by abundant palynomorphs and brown phytoclasts with common amorphous organic matter (AOM). Black phytoclasts are rare (Fig. 4, 6). The palynomorph assemblage is strongly dominated by marine palynomorphs, which ranges between 79 and 91 % (Fig. 4, 5). The abundance of brown phytoclasts, and their total dominance over black phytoclasts, together with the dominance of marine palynomorph in the palynomorph group point to deposition in an open marine mid- to inner shelf environment with considerable input from a nearby terrestrial source area. The relatively high abundance of AOM indicates deposition under dysoxic bottom conditions. As the bottom dysoxia is not a result of a

distal setting, judged by the low abundance of black phytoclasts, it may instead have been the result of high production rates in the overlying water masses, as also indicated by the abundance of marine plankton.

Samples 1581.85 m and 1568.85 m

The two samples have similar kerogen assemblages. The assemblages are totally dominated by brown phytoclasts (94–95 % of the kerogen); black phytoclasts and AOM are very rare or absent (Fig. 4, 6). Palynomorphs occur only with low percentages, and are dominated by terrestrial sporomorphs. The total dominance of brown phytoclasts together with low percentages of black phytoclasts and marine palynomorphs indicate a marginal marine inner shelf depositional environment dominated by influx from terrestrial source areas. The very low relative abundance of AOM indicates deposition under oxic bottom conditions.

Palaeoenvironmental interpretation of the Freja Member, summary

Both microfaunas and palynofloras of the Francisca-1 well indicate a relatively more nearshore or shallow depositional setting in the upper part of the Freja Member than in the lower part of the unit. The phytoclasts show a substantial terrestrial influx in the upper two investigated samples and calcareous benthic foraminiferids dominate the uppermost sample. The lower part of the Freja Member in Francisca-1 and probably most of the member in Frida-1, except a small interval in the upper part of the unit, were likely deposited in an upper bathyal to lower neritic palaeoenvironment judging from the microfauna. Palynomorphs and phytoclasts indicate a slightly more nearshore conditions in a neritic palaeoenvironment. The geological setting during the mid Chattian, when the lower part of the Freja Member was deposited, was probably upper bathyal to outer neritic with a significant influx of more nearshore (neritic) environmental indicators derived from the adjacent coastal region north and northeast of Francisca-1.

During the late Chattian, the upper part of the Freja Member was deposited in a more nearshore, neritic (probably middle to outer neritic) palaeoenvironment. The microfossil assemblages were dominated by calcareous benthic microfossils together

with marginal marine and terrestrial phytoclasts derived from the neighbouring coastal areas.

Conclusion

The microfossil and palynomorph evidence show that the Freja Member is restricted to the Chattian (Upper Oligocene) in Frida-1, whereas it is Chattian to probably lowermost Aquitanian (Upper Oligocene to lowermost Miocene) in Francisca-1.

The microfossil assemblages indicate that the Freja Member was deposited in an upper bathyal to outer neritic palaeoenvironment during deposition of the lower part of the unit and a probably middle to outer neritic (shelf) environment during deposition of the upper part. The palynomorph assemblage indicates a similar general shallowing-upward pattern through the Freja Member, but in this case the palaeoenvironmental indices change from typically middle to inner neritic in the lower part to marginal marine in the upper part.

It is tentatively suggested, that the palaeoenvironment changed from upper bathyal or outer neritic in the lower part to neritic in the upper part of the Freja Member, and that the significant influx of marginal marine and terrestrial palynomorphs and phytoclasts were caused by transportation from the neighbouring coastal areas north and northeast of the study area.

References

- Batten, D.J., 1999. Small palynomorphs. In: Jones, T.P., Rowe, N.P. (Eds), *Fossil plants and spores: modern techniques*. Geological Society, London, pp. 15–19.
- Berggren, W.A & Miller, K.G. (1988). Paleogene tropical planktonic foraminiferal biostratigraphy and magnetobiochronology. *Micropaleontology*, 34, 362–380.
- Berggren, W.A., Kent, D.V., Swisher, C.C., & Aubry, M.-P. (1995). A revised Cenozoic geochronology and chronostratigraphy. In: W.A. Berggren, D.V. Kent, M.-P. Aubry, & J. Hardenbol, *Geochronology, time scales and global stratigraphic correlation*, Society for Sedimentary Geology Special Publication, 54, 129–212.
- Below, R., Kirsch, K.-H., 1997. Die kerogen-facies der tonstein-blättertonstein rhythmite des Ober-Barrême/Unter-Apt im Niedersächsischen Becken (Norddeutschland) am beispiel der bohrung Hoheneggelsen KB 50. *Palaeontographica*, Abt. B 242, 1–90.
- Blow, W.H. (1979). *The Cainozoic Globigerinida* (p. 1413). Leiden, The Netherlands: E.J. Brill, p. 1423.
- Chaproniere, G.C.H., 1988. *Globigerina woodi* from the late Oligocene and early Miocene of southeastern Australia. *Journal of Foraminiferal Research* 18, 124–129.
- Cope, M.J., 1981. Products of natural burning as a component of dispersed organic matter in sedimentary rocks. In: Brooks, J. (Ed.), *Organic maturation studies and fossil fuel exploration*. Academic Press, London, pp. 89–110.
- Danielsen, M., Michelsen, O. & Clausen, O.R. 1997. Oligocene sequence stratigraphy and basin development in the Danish North Sea sector based on log interpretations. *Marine and Petroleum Geology* 14, 931–950.

Davey, R.J., Rogers, J., 1975. Palynomorph distribution in recent offshore sediments along two traverses off South West Africa. *Marine Geology* 18, 213–225.

De Verteuil, L., Norris, G., 1996a. Part I, Dinoflagellate cyst zonation and allostratigraphy of the Chesapeake Group. *Micropaleontology* 42 supplement, 1–82.

Dybkjær, K. 2003. Palynostratigraphy of the Upper Oligocene – Middle Miocene succession in the Frida-1 well. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2003/28, 28 pp. (enclosed in this volume).

Eidvin, T.R., Riis, F & Rundberg, Y. 1999. Upper Cainozoic stratigraphy in the central North Sea (Ekofisk and Sleipner fields). *Norsk Geologisk Tidsskrift* 79, 97-128.

Fensome, R.A., Williams, G.L., Barss, M., Freeman, J.M., Hill, J.M., 1990. Acritarchs and fossil prasinophytes: an index to genera, species and infraspecific taxa. American Association of Stratigraphic Palynologists Foundation, Contribution Series 25, 771 pp.

Gorin, G.E., Steffen, D., 1991. Organic facies as a tool for recording eustatic variations in marine fine-grained carbonates - example of the Berriasian stratotype at Berrias (Ardèche, SE France). *Palaeogeography, Palaeoclimatology, Palaeoecology* 85, 303–320.

Gradstein, F.M., Kaminski, M.A., Berggren, W.A., Kristiansen, I.L. & D'Iorio, M.A. (1994). Cenozoic biostratigraphy of the North Sea and Labrador Shelf. *Micropaleontology* 40, supplement for 1994, 1–152.

Habib, D., Miller, J.A., 1989. Dinoflagellate species and organic facies evidence of marine transgression and regression in the Atlantic Coastal Plain. *Palaeogeography, Palaeoclimatology, Palaeoecology* 74, 23–47.

- Habib, D., Eshet, Y., Van Pelt, R., 1994. Palynology of sedimentary cycles. In: Traverse, A. (Ed.), *Sedimentation of organic particles*. Cambridge University Press, Cambridge, pp. 311–335.
- Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., de Graciansky, P.-C., Vail, P.R., 1998. Mesozoic and Cenozoic sequence chronostratigraphic chart. In: de Graciansky, P.-C., Hardenbol, J., Jacquin, T., Vail, P.R., Farley, M.B (Eds.), *Mesozoic and Cenozoic sequence stratigraphy of European Basins*. SEPM Special Publication 60, 3–13.
- Kaiho, K., 1991. Global changes of Paleogene aerobic / anaerobic benthic foraminifera and deep sea circulation. *Palaeogeography, Palaeoclimatology, Palaeoecology* 83, 65–85.
- King, C. 1983. Cainozoic micropaleontological biostratigraphy of the North Sea. *Institute of Geological Sciences Report 82-7*, 1–40.
- King, C. 1989. Cenozoic of the North Sea. In: Jenkins, D.G. and Murray, J.W. (eds), *Stratigraphical atlas of fossil foraminifera*. Ellis Horwood, 418–489.
- Köhte, A., 1990. Paleogene dinoflagellates from Northwest Germany-biostratigraphy and paleoenvironment. *Geol. Jb. A* 118, 111 pp.
- Li, H., Habib, D., 1996. Dinoflagellate stratigraphy and its response to sea level change in Cenomanian–Turonian sections of the Western Interior of the United States. *Palaios* 11, 15–30.
- Michelsen, O. 1994. Stratigraphic correlation of the Danish onshore and offshore Tertiary successions based on sequence stratigraphy. *Bulletin of the Geological Society of Denmark* 41, 145–161.
- Michelsen, O. 1996. Late Cenozoic basin development of the eastern North Sea Basin. *Bulletin of the Geological Society of Denmark* 43, 9–21.

van Morkhoven, Berggren, W.A. & Edwards, A.S., 1986. Cenozoic cosmopolitan deep-water benthic foraminifera. *Bulletin des Centres de Recherches Exploration-Production, Elf-Aquitaine, Memoire 11*. 422 pp., Pau.

Morzadec-Kerfourn, M.-T., 1977. Les kystes de dinoflagellés dans les sédiments récents le long des côtes Bretonnes. *Revue de Micropaléontologie* 20, 157–166.

Müller, J., 1959. Palynology of recent Orinoco delta and shelf sediments: reports of the Orinoco Shelf Expedition; Volume 5. *Micropaleontology* 5, 1–32.

Murray, J.W. 1976. Comparative studies of living and dead benthic foraminiferal distributions. In Hedley, R.H. and Adams, C.G. (Eds), *Foraminifera*, vol. 2, pp. 45–109. Academic Press, London.

Nielsen, O.B., Sørensen, S., Thiede, J. & Skarabø, O. 1986: Cenozoic Differential Subsidence of North Sea. *The American Association of Petroleum Geologists Bulletin* 70, 276–298.

Palliani, R.B., Cirilli, S., Mattioli, E., 1998. Phytoplankton response and geochemical evidence of the lower Toarcian relative sea level rise in the Umbria-Marche Basin (central Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology* 142, 33–50.

Powell, A. J., 1992. Dinoflagellate cysts of the Tertiary System. In: Powell, A.J. (Ed.), *A Stratigraphic Index of Dinoflagellate Cysts*. Chapman and Hall, London, pp. 155–251.

Powell, A.J., Dodge, J.D., Lewis, J., 1990. Late Neogene to Pleistocene palynological facies of the Peruvian continental Margin upwelling, Leg 112. In: Suess, E., Von Huene, R., *Proceedings of the Ocean Drilling Project, Scientific Results 112*, College Station, pp. 297–321.

Rasmussen, E.S., Dybkjær, K. & Piasecki, S. 2002: Miocene depositional systems of the eastern North Sea Basin, Denmark. Development of sedimentological and stratigraphical principals in modern sedimentology. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2002/89.

Schiøler, P., Palynology of the Rupelian to Burdigalian (Oligocene to Lower Miocene) interval of the Alma-1X well, Danish North Sea. Manuscript submitted to Review of Palaeobotany and Palynology (enclosed as GEUS Report 2003/73, this volume).

Schiøler, P., Andsbjerg, J., Clausen, O.R., Dam, G., Dybkjær, K., Hamberg, L., Heilmann-Clausen, C., Kristensen, L.E., Prince, I. & Rasmussen, J.A. 2003. Lithostratigraphy of the Palaeogene siliciclastic sediments in the Danish North Sea sector. Danmarks og Grønlands Geologiske Undersøgelse Rapport 2003/71 (enclosed in this volume).

Sorgenfrei, T. 1969. Geological perspectives in the North Sea area. Bulletin of the Geological Society of Denmark 19, 160–196.

Steffen, D., Gorin, G.E., 1993. Sedimentology of organic matter in Upper Tithonian–Berriasian deep-sea carbonates of southeast France: evidence of eustatic control. In: Katz, B., Pratt, L. (Eds.), Source rocks in a sequence stratigraphic framework. AAPG Studies in Geology 37, 49–65.

Tyson, R.V., 1987. The genesis and palynofacies characteristics of marine petroleum source rocks. In: Brooks, J., Fleet, A.J. (Eds.), Marine petroleum source rocks. Geological Society (London) Special Publication 26, 47–67.

Tyson, R.V., 1989. Late Jurassic palynofacies trends, Piper and Kimmeridge Clay Formations, UK onshore and northern North Sea. In: Batten, D.J., Keen, M.C. (Eds.), Northwest European micropalaeontology and palynology. Ellis Horwood Publishers, Chichester, pp. 135–172.

Tyson, R.V., 1993. Palynofacies analysis. In: Jenkins, D.J. (Ed.), Applied micropalaeontology, Kluwer, Dordrecht, pp. 153–91.

Tyson, R.V., 1995. Sedimentary organic matter. Organic facies and palynofacies. Chapman and Hall, London.

Tyson, R.V., Piper, A.T., Vincent, A.J., 1996. Middle Jurassic palynofacies patterns from the onshore UK: Yorkshire and Inner Hebrides. 9th International Palynological Congress, American Association of Stratigraphic Palynologists Foundation, Dallas, p. 163.

Van der Zwan, C.J., 1990. Palynostratigraphy and palynofacies reconstruction of the Upper Jurassic to lowermost Cretaceous of the Draugen Field, offshore Mid Norway. *Review of Palaeobotany and Palynology* 62, 157–186.

Waterhouse, H., 1995. High-resolution palynofacies investigation of Kimmeridgian sedimentary cycles. In: House, M.R., Gale, A.S. (Eds.), *Orbital forcing timescales and cyclostratigraphy*. Geological Society (London) Special Publication 85, 75–114.

Williams, G.L., Lentin, J.K., Fensome, R.A., 1998. The Lentin & Williams index of fossil dinoflagellates, 1998 edition. American Association of Stratigraphic Palynologists Contribution Series 34, 817 pp.

Ziegler, P.A., 1990. *Geological Atlas of Western and Central Europe*. Elsevier, Amsterdam, 239 pp.

Figure captions

Fig. 1. Map of the Danish North Sea sector showing the location of the Francisca-1 and Frida-1 wells.

Fig. 2. Distribution of foraminiferids in the studied samples from Francisca-1. The abundance in each sample is marked with a number and biostratigraphic ranges with a yellow line.

Fig. 3. Distribution of dinoflagellates and acritarchs in the studied samples from Francisca-1. Actual occurrences are marked with a black dot and biostratigraphic ranges with a yellow line.

Fig. 4. Kerogen and palynomorph counts of five studied samples from the Freja Member of the Francisca-1 well.

Fig 5. Palynomorph groups of the five studied samples from the Freja Member of the Francisca-1 well.

Green (1): Terrestrial palynomorphs, Blue (2): Marine palynomorphs.

Fig. 6. Kerogen groups of the five studied samples from the Freja Member of the Francisca-1 well. Black (1): Black phytoclasts; Dark brown (2): Brown phytoclasts including degraded phytoclasts, leaf cuticles, resin and fungal hyphae; Grey (3): Amorphous organic material; Orange (4): Palynomorphs.

Fig. 7. Benthic foraminiferid biostratigraphy of the Freja Member in the the Francisca-1 and Frida-1 wells.

Fig. 8. Microfossil and palynomorph biostratigraphy of the Freja Member in the the Francisca-1 well.

Plate 1. Foraminiferids from the Freja Member of the Francisca-1 well, Sample 1568.85 m.

See the inserted bar for scale.

1–2, 5: *Glabratella* sp. A King, 1989.

3–4: *Siphonodosaria* spp.

6–9: *Cibicidoides?* cf. *pygmeus* (Hantken)

10: *Globocassidulina subglobosa* (Brady)

11: *Glomospira gordialis* (Jones & Parker)

12: Agglutinated foraminiferid, Gen et sp. indet.

13–15: *Zeaglobigerina woodi* (Jenkins)

Plate 2. Palynomorphs from the Freja Member of the Francisca-1 well.

Figures are to the same scale. Scale bar in Fig. 1=20 μ m.

1: *Distatodinium biffi*. LVR No. 26283. Sectional focus.

2: *Pentadinium laticinctum granulatum*. LVR No. 26284. Sectional focus.

3: *Deflandrea phosphoritica*. LVR No. 26292. Sectional focus.

4: *Membranophoridium aspinatum*. LVR No. 26285. Sectional focus.

5: *Caligodinium amiculum*. LVR No. 26289. Sectional focus.

6: *Spiniferites ramosus* ssp. 3. LVR No. 26290. Sectional focus.

7: *Heterosphaeridium* sp. 1. LVR No. 26279. Sectional focus, ventral surface up.

8: *Heterosphaeridium* sp. 1. LVR No. 26291. Axial view, archeopyle in high focus.

9: *Selenopemphix nephroides*. LVR No. 226287. Sectional focus.

10: *Artemisiocysta cladodichotoma*. LVR No. 26288. Sectional focus.

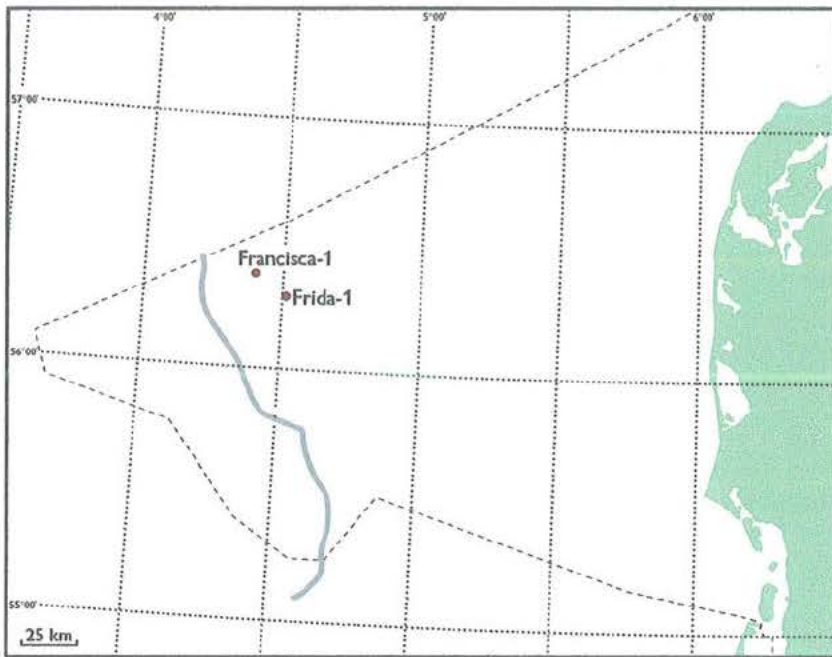


Fig.1

	1707,84	1715,72	1711,62	1581,85	1568,85
	barren		barren		
<i>Alabamina tangentialis</i>					1
<i>Brizalina antiqua</i>		2			
<i>Bulimina elongata</i>				8	6
<i>Cancris</i> sp. indet.		1			
<i>Cibicidoides mundulus</i>		28			
<i>Cibicidoides pachyderma</i>					2
<i>Cibicidoides peelensis</i>					4
<i>Cibicidoides?</i> cf. <i>pygmaeus</i>					9
<i>Cibicidoides</i> sp. indet.				1	
<i>Glabratella?</i> sp. A King 1989		9		8	7
<i>Globocassidulina subglubosa</i>					16
<i>Grigelis pyrula</i> (d'Orbigny)					4
<i>Gyroidina soldanii soldanii</i>					1
<i>Lagena elongata</i> (D-80)		1			6
<i>Lagena</i> spp.		2			4
<i>Lenticulina</i> sp.					1
<i>Melonis barleeaanum</i>		7		1	5
" <i>Nodosaria</i> " <i>emaciata</i>		1			
<i>Nodosaria</i> sp. indet.		1			
<i>Nonion</i> sp. A King 1989		8			
<i>Nonion</i> sp. indet.					1
<i>Nonionella</i> sp.		1			
<i>Oridorsalis umbonatus</i>		6			
<i>Plectofrondicularia seminuda</i>		1			7
<i>Pullenia bulloides</i>		1			
<i>Pyrgo bulloides</i>					1
<i>Quinqueloculina</i> spp.		1			1
<i>Siphonodosaria</i> spp.					7
<i>Sphaeroidina bulloides</i>		1		1	1
<i>Trifarina</i> sp. indet.				1	
<i>Turrilina alsatica</i>					1
Calc. benthic indet.		1			5
<i>Ammodiscus cretaceus</i>		4		13	
<i>Ammodiscus tenuis</i>		3			
<i>Annectina biadai</i>		2			
<i>Cyclammina acutidorsata</i>		2			
<i>Cyclammina placenta</i>		2			
<i>Cyclammina rotundidorsata</i>		7			
<i>Cyclammina</i> sp.				2	
<i>Karrerella siphonella</i>					2
<i>Glomospira gordialis</i>		1		3	6
<i>Haplophragmoides kirki</i>				5	
<i>Haplophragmoides walteri</i>		7		17	10
<i>Haplophragmoides</i> sp. indet.					1
<i>Rhabdammina discreta</i>		3			1
<i>Saccamina</i> sp.		1			1
<i>Spirosigmolinella compressa</i>		14			
<i>Trochammina</i> sp. indet.		1			2
<i>Usbekistania charoides</i>		2			
Agglut. indet.				3	2
<i>Globigerina angustiumblicata?</i>					1
<i>Globigerina ciperoensis</i>		1			1
<i>Globigerina praebulloides</i>		17		1	
<i>Globigerina?</i> <i>venezuelana</i>		1			
<i>Zeaglobigerina woodi</i>					2
<i>Paragloborotalia nana</i>		19			
<i>Paragloborotalia opima</i>		11			
Planctic indet. sp. A (4 ch., twisted, small last ch.)				4	
Planctic indet.		1			1
<i>Fenestrella</i> cf. <i>antiqua</i>		3			
<i>Aulacodiscus insignis quadrata</i> (small)		4			
<i>Coscinodiscus</i> sp. A		35		9	7
<i>Coscinodiscus</i> sp. B		17		3	1
<i>Coscinodiscus</i> sp. C				1	
<i>Coscinodiscus</i> sp. D		14			
<i>Cenodiscus</i> sp.		1			
Fish teeth		3		3	
sponge spicules				24	
Indet. tubes					4
Pyritic, ovate "spherules"		1		9	

Fig. 2

	1715,72	1711,62	1707,84	1581,85	1568,85
<i>Achomosphaera ramulifera</i>	●		●		
<i>Adnatosphaeridium robustum</i>			●		
<i>Apteodinium australiense</i>			●		●
<i>Artemisiocysta cladodichotoma</i>	●	●			
<i>Batiacasphaera hirsuta</i>	●				
<i>Caligodinium amiculum</i>	●	●	●		●
<i>Charlesdowniea clathrata</i>	R				
<i>Chiropteridium galea</i>	●	●	●		
<i>Chiropteridium lobospinosum</i>			●		
<i>Chiropteridium</i> sp. 1			●		
<i>Cordosphaeridium minimum</i>	●	●	●		
<i>Cribopteridium guiseppi</i>	●	●	●		
<i>Cyclopsiella</i> sp. 1	●				
<i>Dapsilidium pseudocolligerum</i>	●	●			
<i>Deflandrea phosphorica</i>			●	●	●
<i>Distatodinium biffi</i>	●	●	●		
<i>Distatodinium paradoxum</i>	●	●	●		
<i>Exochosphaeridium insigne</i>					●
<i>Filisphaera filifera</i>	●				
<i>Fromea chytra</i>			●		
<i>Fromea</i> sp. 1		●	●		
<i>Gerlachidium aechmophorum</i>			●		
<i>Glaphyrocysta?</i> vicina	●				
<i>Heteraulacacysta campanula</i>		●			
<i>Heterosphaeridium</i> sp. 1	●		●		
<i>Heterosphaeridium</i> sp. 2			●		
<i>Homotryblium</i> cf. oceanicum		●			
<i>Homotryblium floripes</i>	●	●			
<i>Homotryblium plectilum</i>	●	●			
<i>Homotryblium tenuispinosum</i>	●				
<i>Hystrichokolpoma cinctum</i>	●	●	●		
<i>Hystrichokolpoma rigaudiae</i>	●	●	●		
<i>Impagidinium velorum</i>			●		
<i>Lejeunecysta cinctoria</i>	●				
<i>Lejeunecysta fallax</i>	●	●			
<i>Lejeunecysta hyalina</i>	●				
<i>Leptodinium italicum</i>		●			
<i>Lingulodinium macherophorum</i>	●	●	●		
<i>Melitasphaeridium choanophorum reductum</i>					●
<i>Membranophoridium aspinatum</i>	●	●			
<i>Operculodinium centrocarpum</i>				●	
<i>Operculodinium</i> sp. 3 of de Verteuil & Norris, 1996			●		
<i>Operculodinium</i> sp. 7		●			
<i>Palaeocystodinium golzowense</i>	●		●		
<i>Palaeocystodinium</i> sp. 1 of Manum et al., 1989	●	●			
<i>Pentadinium imaginalum</i>	●		●		
<i>Pentadinium laticinctum granulatum</i>	●	●	●		
<i>Pentadinium laticinctum laticinctum</i>		●			
<i>Pentadinium lophophorum</i>	●				
<i>Reticulatosphaera actinocoronata</i>	●	●			
"round brown" spp.	●		●		
<i>Selenopemphix nephroides</i>	●	●	●		
<i>Spiniferites pseudofurcatus pseudofurcatus</i>	●		●		
<i>Spiniferites ramosus ramosus</i>	●	●	●	●	●
<i>Spiniferites ramosus</i> ssp. 3	●	●			
<i>Systematophora ancyrea</i>				●	
<i>Systematophora placacantha</i>	●	●	●		
<i>Tectatodinium pellitum</i>	●				
<i>Thalassiphora</i> cf. patula		●	●		
<i>Thalassiphora pelagica</i>					●
<i>Tityrosphaeridium cantharellus</i>	●	●	●	●	●

Fig. 3

Depth	Kerogen groups										Palynomorphs													
	Black phytoclasts	Brown phytoclasts	Leaf cuticles	Resin	Fungal hyphae	Degraded phytoclasts	AOM	Palynomorphs	SUM	% Black phytoclasts	% Brown phytoclasts	% AOM	% Palynomorphs	Dinoflagellates	Other marine algae	Foraminifera test linings	Fungal spores	Degraded palynomorphs	Thick-walled spores	Other non-saccate sporomorphs	saccate pollen	SUM	% Marine palynomorphs	% non-marine palynomorphs
1568,9	0	51	0	0	0	241	5	14	311	0,0	93,9	1,6	4,5	2	0	1	0	0	0	7	4	14	21,4	78,6
1581,9	3	69	0	0	0	227	0	11	310	1,0	95,5	0,0	3,5	1	0	0	0	0	0	5	5	11	9,1	90,9
1707,8	12	42	0	2	0	53	68	126	303	4,0	32,0	22,4	41,6	112	0	3	0	0	0	6	5	126	91,3	8,7
1711,6	12	41	1	0	1	97	29	126	307	3,9	45,6	9,4	41,0	99	0	0	0	0	0	15	12	126	78,6	21,4
1715,7	14	48	0	0	1	70	48	122	303	4,6	39,3	15,8	40,3	97	0	1	0	0	0	15	9	122	80,3	19,7

Fig. 4

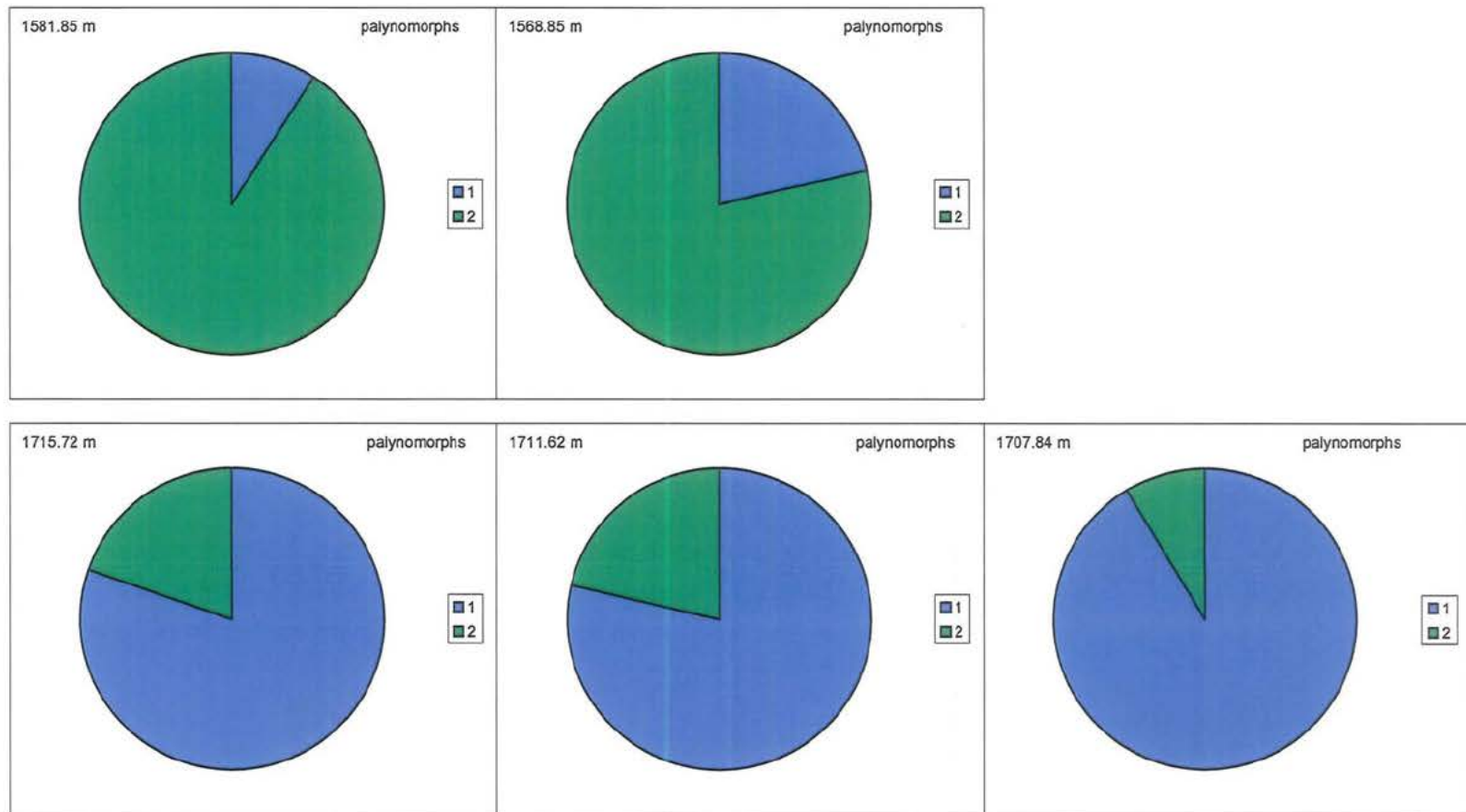


Fig. 5

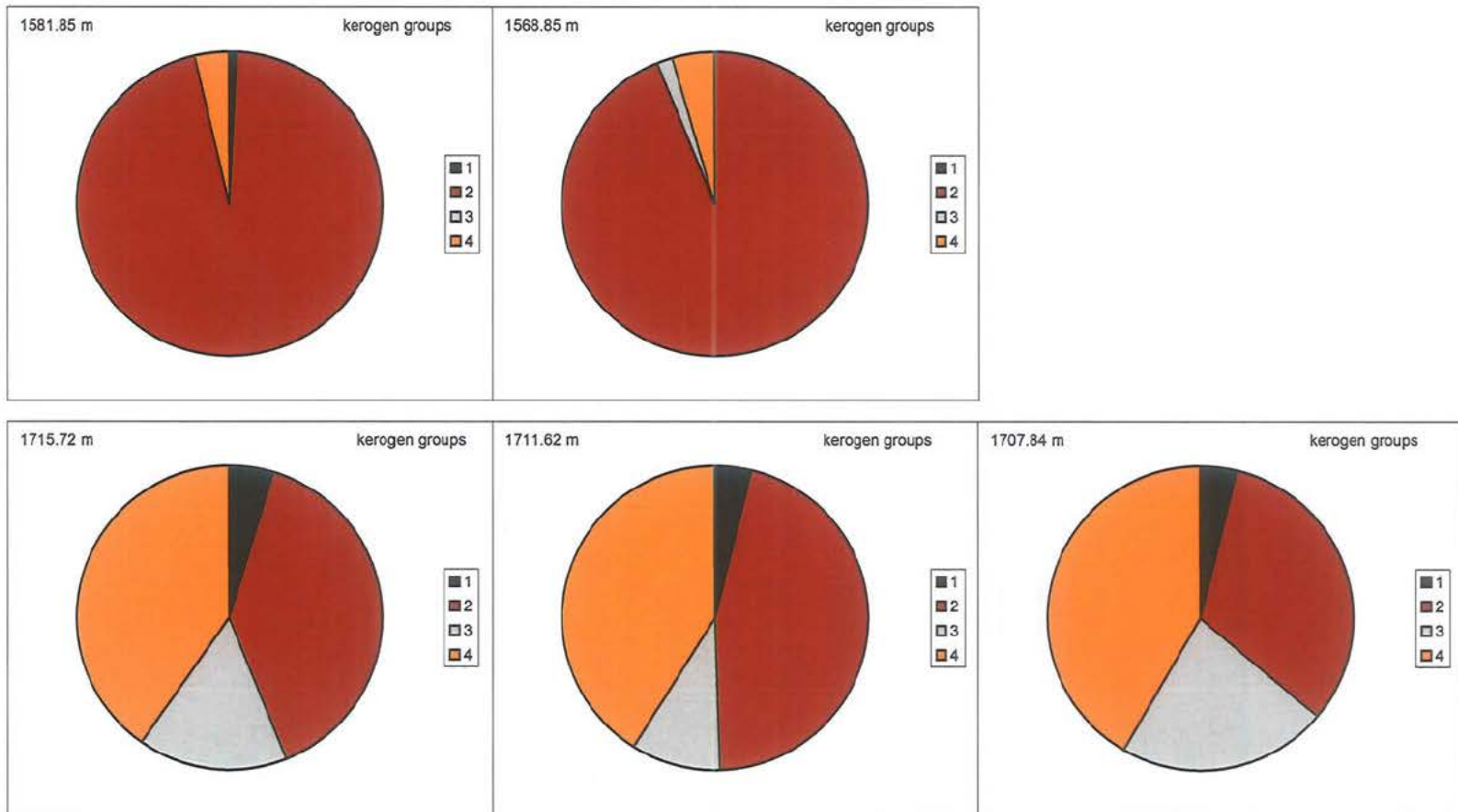


Fig. 6

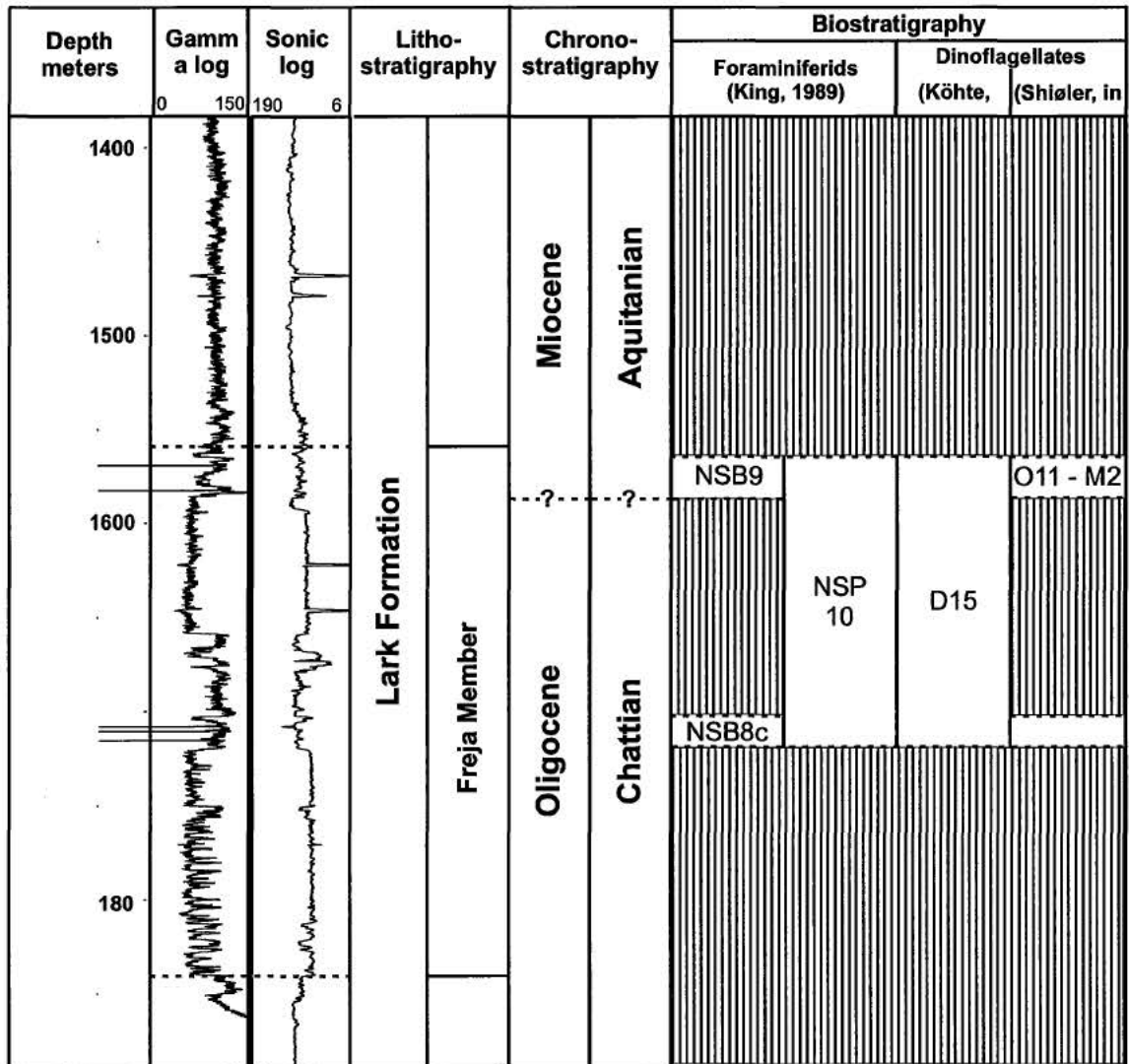


Fig. 8

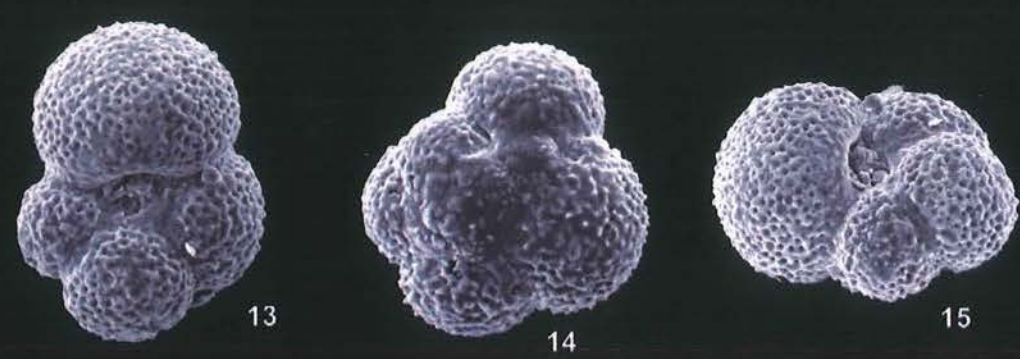


Plate 1

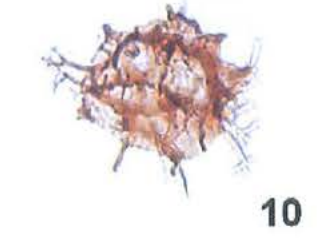
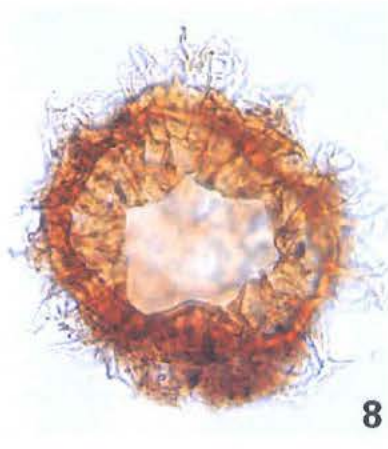
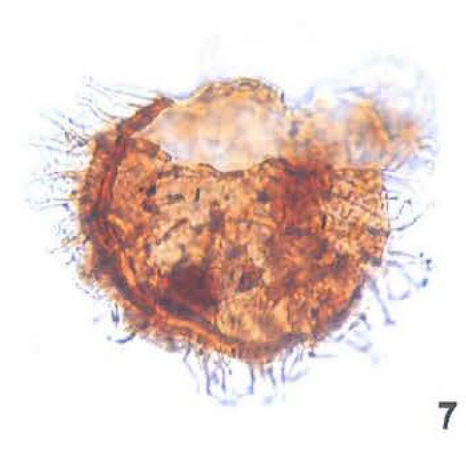
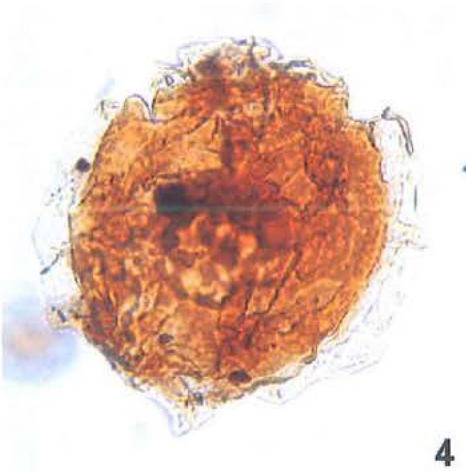


Plate 2