

The Molo Formation, deposited by coastal progradation on the inner Mid-Norwegian continental shelf, coeval with the Kai Formation to the west and the Utsira Formation in the North Sea

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The Molo Formation represents a characteristic depositional unit on the inner Mid-Norwegian continental shelf and extends along the coast for about 500 km from Møre to Lofoten. It was deposited by coastal progradation in a wave-dominated environment with extensive long-shore drift. The age and stratigraphic relationships have been heavily debated since it was discovered and first described nearly forty years ago. Based on new age information from exploration wells in the Draugen Field on the Trøndelag Platform, the Molo Formation is now determined to be of Late Miocene to Early Pliocene age. It is interpreted to be the proximal equivalent to the deeper marine Kai Formation in the Norwegian Sea and a lateral equivalent to the Utsira Formation in the North Sea. These formations were all deposited as a result of the compression and uplift of mainland Norway in mid Miocene time. In this paper we describe and document the datings and formally define the Molo Formation as a new stratigraphic unit.

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Introduction

The Molo Formation (Figs. 1 and 2) corresponds to the characteristic seismic unit which was informally called the "Delta" by Bugge et al. (1976), IKU Bedrock Unit IX by Bugge et al. (1984) and Rokoengen et al. (1988, 1995) and the "Frøyrygg formation" by Askvik & Rokoengen (1985). The age assignment of the unit has varied from Eocene/Oligocene to Pliocene, thus being a time equivalent to the Brygge, Kai or Naust formations. The formation is nearly exposed on the seabed and forms an approximately 500 km long ridge on the inner shelf from Møre to Lofoten (Fig. 1). Since the unit forms a potential wave breaker and is related to the Naust, Kai or Brygge formations, Gustavson & Bugge (1995) proposed the name "Molo" (Jetty) formation.

In this paper we discuss its stratigraphic relationships and propose a Late Miocene to Early Pliocene age, coeval with most of the Kai Formation in the Norwegian Sea and most of the Utsira Formation in the North Sea. It has long been noted that it has high erosional resistance and therefore is most probably sand dominated. Bugge et al. (1976) proposed that it was deposited as a result of mainland uplift and erosion, and Rokoengen et al. (1995) classified the sediments as delta-like coastal deposits, probably formed in a wave-dominated environment with extensive long-shore drift. Our investigation of exploration wells shows that the proximal part of the unit consists mainly of quartzose and glauconitic sand. The distal part to the west consists mainly of glauconitic sand, silt and clay.

The unit was first described by Eldholm & Nysæther (1969) and Nysæther et al. (1969), and later by Bugge et al. (1976), Skarbø et al. (1983), Bugge et al. (1984), Askvik & Rokoengen (1985), Rokoengen et al. (1988), Sigmond (1992), Poole & Vorren (1993), Eidvin et al. (1995), Gustavson & Bugge (1995), Rokoengen et al. (1995), Henriksen & Vorren (1996), Henriksen & Weimer (1996), Eidvin et al. (1998 and 2000), Brekke (2000) and Bullimore et al. (2005). However, the age of the unit is still disputed. A reason for this is that few wells and boreholes have sampled the sediments with high quality conventional cores or sidewall cores. Another reason is that samples from wells and boreholes from the proximal part of the unit seem to be barren of *in situ* fossils and only contain assemblages which we now interpret to represent caved and reworked material. We therefore made a new effort concentrating on identifying wells that penetrate the outer, more distal and potentially more fine-grained part, although the entire Molo Formation is a proximal deposit. Many of the wells in the Draugen Field on the Trøndelag Platform (Fig. 1) seemed to have optimal locations, and wells 6407/9-1, 6407/9-2 and 6407/9-5 were re-analysed.

The obtained Late Miocene to Early Pliocene age contradicts ages previously given by the biostratigraphic consultants as well as our previous datings of wells and boreholes from proximal parts of the formation. Our new study is based on investigation of ditch cutting samples from wells 6407/9-1, 6407/9-2 and 6407/9-5 by means of foraminiferal, dinoflagellate and strontium isotope

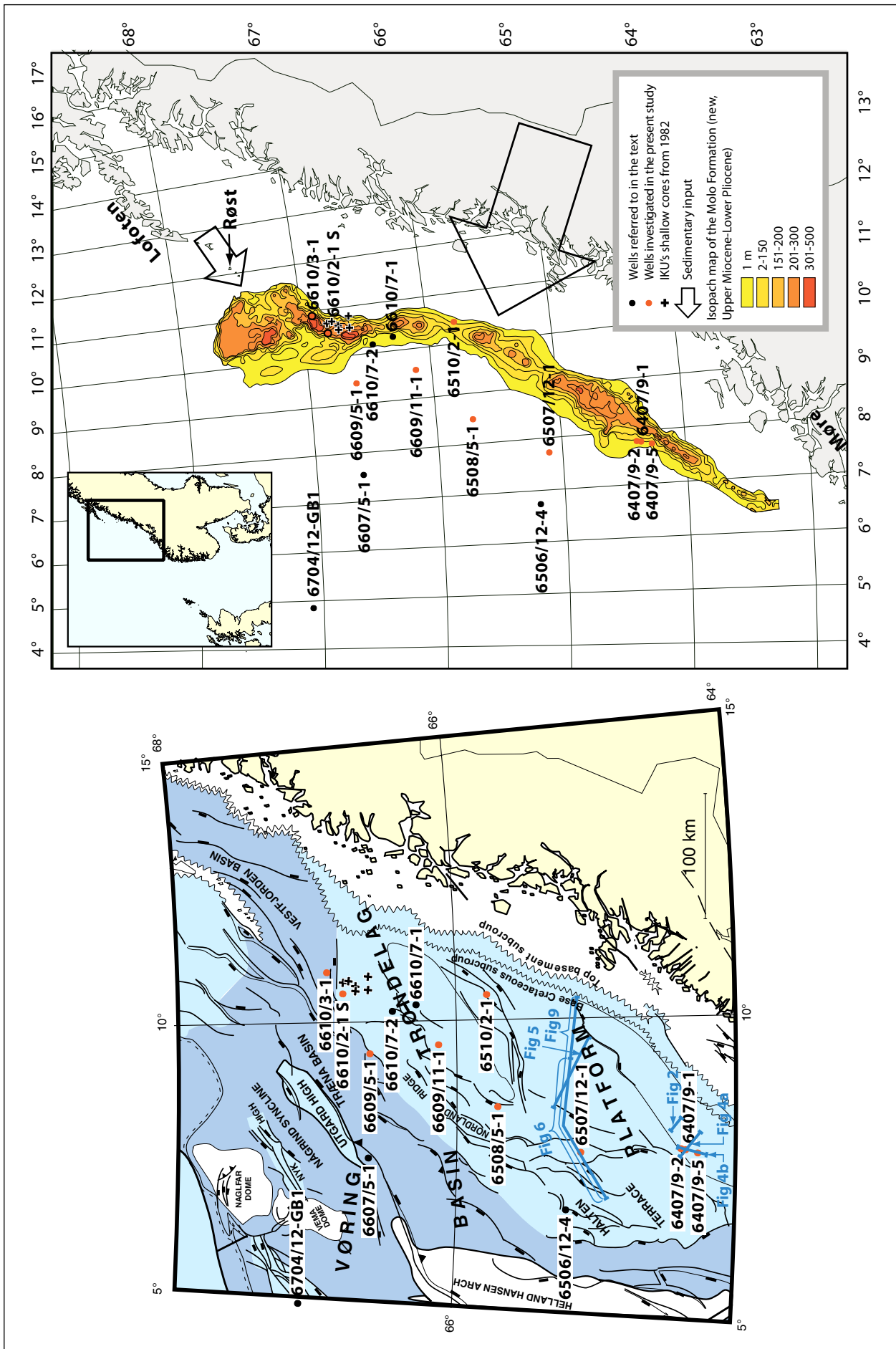


Fig. 1. The Molo Formation was deposited by coastal progradation in the Late Miocene to Early Pliocene. It is situated on the inner part of the continental shelf and extends for 500 km from More to Lofoten. The isopach map is from Bullimore et al. (2005), and the map showing structural elements and seismic lines is from Brekke (2000).

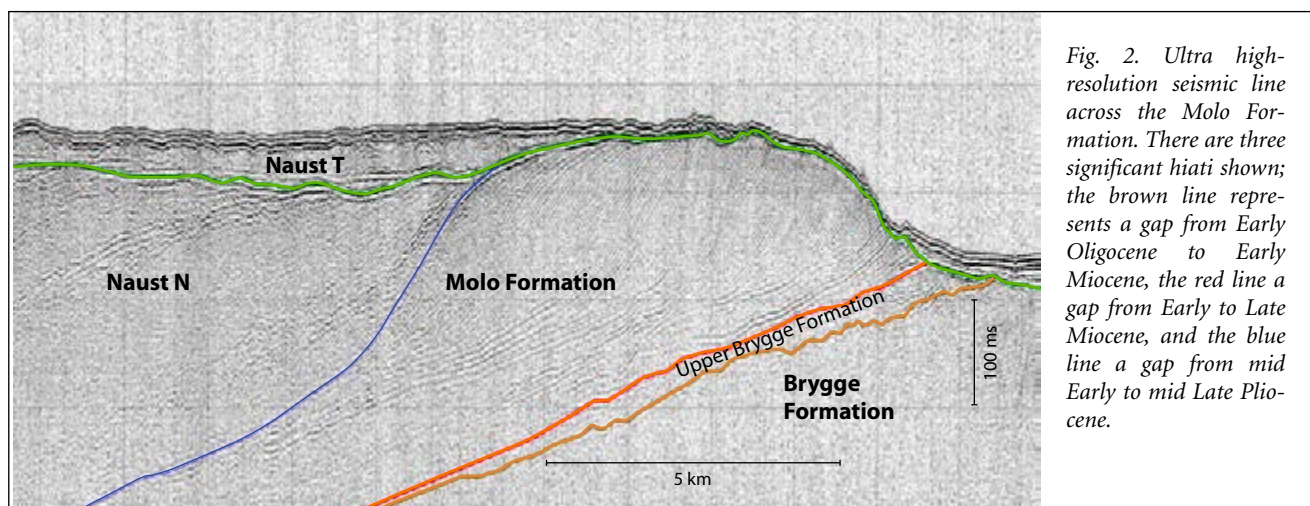


Fig. 2. Ultra high-resolution seismic line across the Molo Formation. There are three significant hiati shown; the brown line represents a gap from Early Oligocene to Early Miocene, the red line a gap from Early to Late Miocene, and the blue line a gap from mid Early to mid Late Pliocene.

analyses. Unfortunately, there are no other wells where we have succeeded in identifying what we believe represent *in situ* fossil assemblages, but in Appendix 1 we have presented results from our new investigations of wells from proximal parts of the Molo Formation including wells 6510/2-1 (Vega High), 6610/3-1 (Nordland Ridge) and 6610/2-1S (Nordland Ridge). In Appendix 1 we have also presented and discussed previous datings from other boreholes which have sampled the Molo Formation.

The stratigraphic and depositional relationship between the Molo Formation and the Brygge, Kai and Naust formations have long been debated, consequently we have also put emphasis on their stratigraphic relationships. The Brygge to Naust succession has been re-analysed or re-evaluated in most of the relevant wells in the Norwegian Sea, and in Appendix 1 we have also presented new investigations of wells 6508/5-1 and 6609/5-1 on the Nordland Ridge and wells 6507/12-1 and 6609/11-1 on the Trøndelag Platform. These wells have been tied to seismic data and incorporated in a seismic stratigraphic framework. This is discussed below, together with a correlation with the coeval Utsira Formation in the North Sea. We consider the revised stratigraphy and depositional history to be important for maturation, migration and entrapment of petroleum in the area.

In the main part of this paper we concentrate on the stratigraphic and depositional implications for the Molo Formation, but without going in depth we also include the same topics for the Brygge, Kai and Naust formations. Valuable studies of this succession were carried out in the Seabed Project of the Norwegian Deep Water Programme (Norwegian Deepwater Programme 2004). Much of this work and a synthesis of the present study were summed up in a presentation by Bugge et al. (2004).

All well analyses and interpretations are documented in Appendix 1. In Appendix 2 we present a formal definition of the new Molo Formation. If not stated otherwise, all absolute ages in the present study, are based on Berggren et al. (1995), and all depths in the wells are expressed as meters below the rig floor (mRKB).

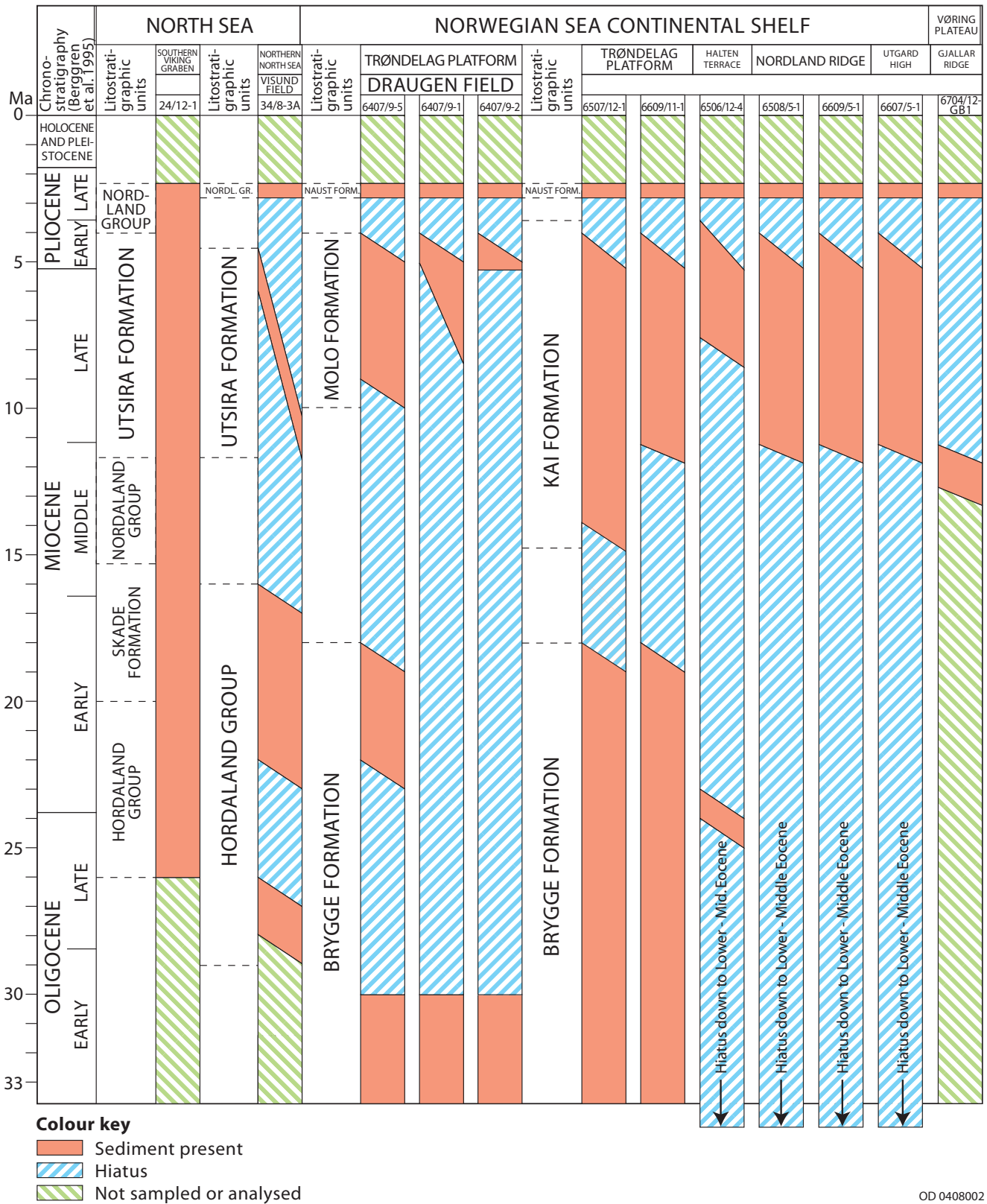
Previous age assessment of the Molo Formation

The Molo Formation was first sampled in 1982 by the Continental Shelf Institute (IKU, later Sintef Petroleum Research) in connection with their regional programme of mapping of outcropping Cainozoic and Mesozoic rocks on the Mid-Norwegian continental shelf. Their defined seismic unit IX, corresponding to the delta-like Molo Formation, was sampled in the Nordland Ridge area with vibro corer, piston corer and grab at localities with very sparse Pleistocene – Holocene cover (Fig. 1). The vibro coring disturbed the sediments during sampling and made biostratigraphical analysing difficult. The samples contained a blend of Pleistocene and Holocene foraminifera and Oligocene and Eocene dinoflagellates. The Oligocene dinoflagellates were thought to be *in situ* fossils (Skarbø et al. 1983; Bugge et al. 1984).

Not far south of these boreholes the unit was sampled with ditch cuttings in the exploration well 6610/7-1 (Fig. 1). Poole & Vorren (1993) presented a dating of this well, and they recorded no *in situ* fossils in the sediments which correspond to the Molo Formation, but reported Middle Miocene foraminifera from the section immediately below. However, Eidvin et al. (1995, 1998) recorded exclusively Lower-Middle Eocene fossils immediately below the barren Molo Formation.

Further north, the exploration well 6610/3-1 (Fig. 1) sampled the Molo Formation with sidewall cores. A biostratigraphical investigation of five sidewall cores of high quality was presented by Eidvin et al. (1995, 1998). Based on analyses by means of foraminifera, dinoflagellates and strontium isotopes they arrived at an Early Oligocene age for the deposits. However, the palynological residues were recently re-analysed and Early Miocene dinoflagellates were now also recorded. These new investigations are presented in Appendix 1.

Henriksen & Vorren (1996) interpreted the Molo Formation to be Early Pliocene in age or alternatively Early



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Fig. 3. Chronogram with a selection of the studied wells. Vertical axis is in Ma. We note that the Molo and Kai formations in the Norwegian Sea and the Utsira Formation in the North Sea all belong to the time interval Middle Miocene to Early Pliocene, i.e., above the mid Miocene unconformity. The stratigraphy in well 24/12-1 is after Rundberg & Eidvin (2005) and Eidvin & Rundberg (in press). The stratigraphy in well 34/8-3A is modified after Eidvin & Rundberg (2001). The stratigraphy in well 6506/12-4 and 6607/5-1 is modified after Eidvin et al. (1998) and the stratigraphy in borehole 6704/12-GB1 is according to personal investigations of T. Eidvin and M. Smelror.

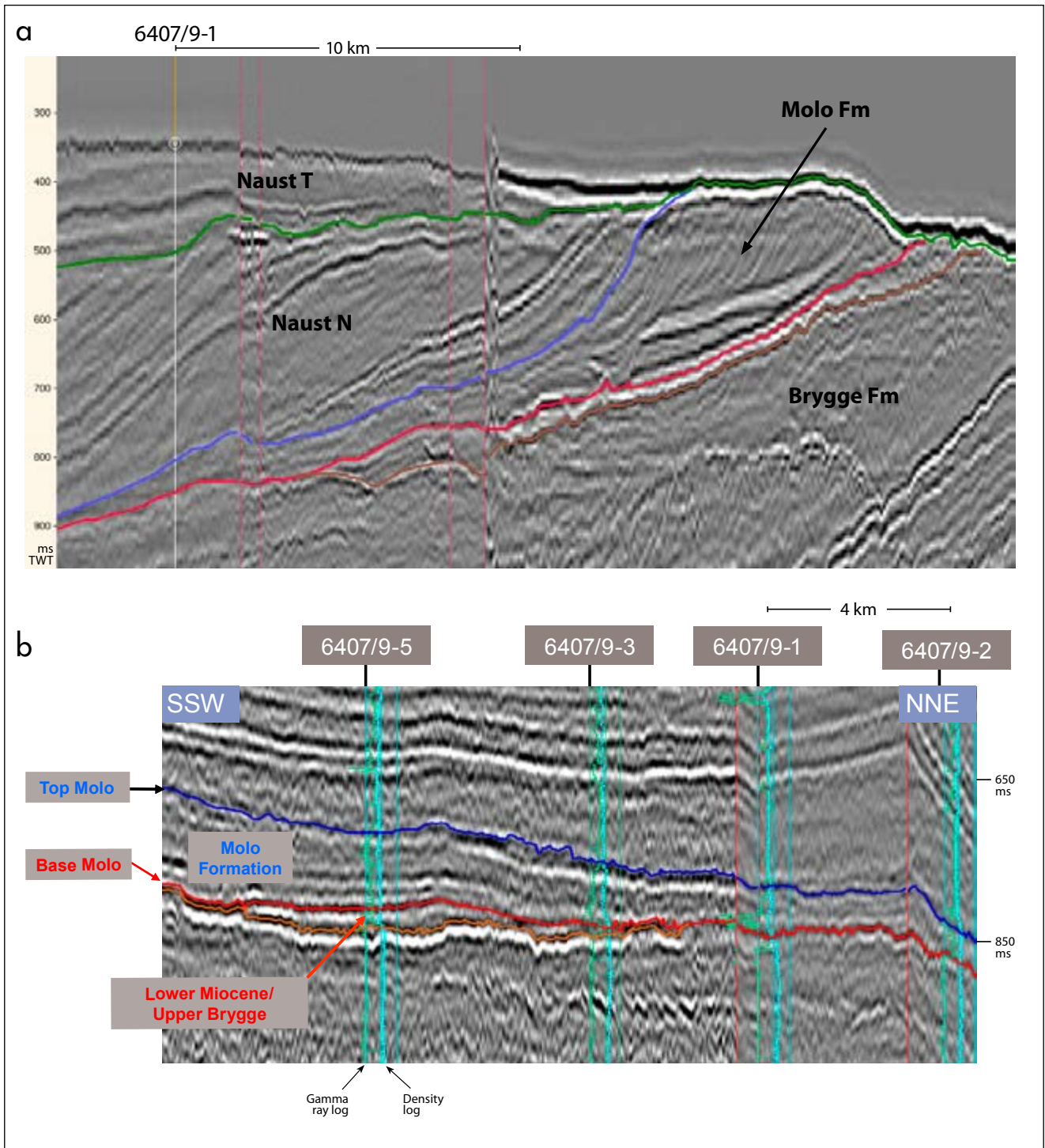


Fig. 4. The Molo Formation in the Draugen Field. Note the Upper Brygge Formation wedge of Early Miocene age between the brown and red line. It rests on a clear erosional surface with the mid Miocene unconformity (red) on top. Fig. 4a is a dip line and 4b is a strike line.

Oligocene. The Early Pliocene age was based on regional stratigraphic considerations and a possible correlation with the global sea-level curve of Haq (1991). The Early Oligocene age was based on the datings of Skarbø et al. (1983) and Eidvin et al. (1995). Henriksen & Weimer (1996) held on to the Early Pliocene age.

The exploration well 6610/2-1S was drilled on the Nordland Ridge just to the southwest of well 6610/3-1 (Fig. 1). In this

well the sediments immediately below the Molo Formation were sampled with ditch cuttings. The deposits have been given an Early Oligocene age based on foraminiferal, dinoflagellate and strontium isotope analyses (Appendix 1).

In the exploration well 6510/2-1 on the Vega High to the south (Fig. 1) the Molo Formation was sampled with sidewall cores. Unfortunately, the cores were not of very high quality and the *in situ* sampled material was mixed

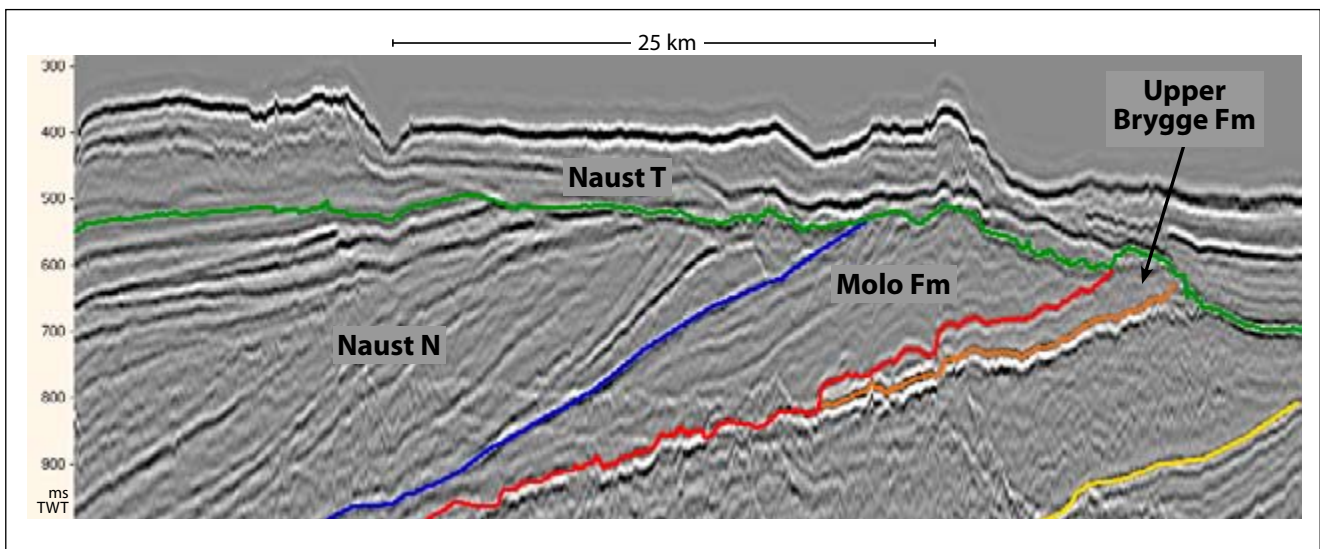


Fig. 5. The Molo Formation 50 km north of Draugen. Although not dated the unit between the brown and red lines is probably equivalent to the upper Brygge Formation unit at Draugen.

with caved sediments. The cores were investigated by means of foraminifera, dinoflagellate and strontium isotope analyses and the deposits assigned an Early Miocene age in Appendix 1.

This was the status when we started re-analysing the Draugen field wells.

Regional framework

In order to embrace the Molo Formation both in space and stratigraphically, we here discuss the entire period from the opening of the Norwegian Sea in earliest Eocene to the Present day, keeping focus on the Molo Formation. This period spans deposition of the Brygge Formation sediments (Hordaland Group) from Early Eocene to Early Miocene, the Kai/Molo formations from Middle Miocene to Early Pliocene (approximately 14-4 Ma) and the Naust Formation from the Late Pliocene to the Present (<2.8 Ma). The Kai/Molo and Naust formations belong to the Nordland Group (Fig. 3).

After regional uplift during the Palaeocene with shallow marine conditions and subaerial exposure of large areas, the entire margin subsided and the sea transgressed the margin and part of the mainland. The Brygge Formation was deposited in this period and is clay-dominated on the present day shelf and ooze-dominated in the distal, deeper marine Møre and Vøring basins. Deposition was concentrated in the Møre Basin and the outer part of the Vøring Basin, with thicknesses of 600-1000 m and 500-700 m, respectively (Norwegian Deepwater Programme 2004). The ooze sediments are characterised by small-scale polygonal faulting, interpreted to be caused by compaction and water escape. The Brygge Formation

sediments have in some places been remobilised by different processes. Sliding is observed occasionally on the shelf and palaeoslope, while mounding and diapirism are more frequent in the basins, for instance around the Vema Dome/Nyk High. Liquefaction and vertical squeezing has been observed in crater-like forms within the Storegga Slide area, west of the Haltenbanken (Vigrid) area and in the Vema Dome area (Riis et al. 2005). All reactivation seems to have occurred during or after deposition of the glacially influenced Naust Formation sediments.

During the Oligocene there seems to have been tectonic activity resulting in compression and uplift of basin flanks and the landward part of the margin. It culminated in a regional uplift in the mid Miocene (e.g. Brekke 2000; Løseth & Henriksen 2005), corresponding to the “mid Miocene unconformity”. The exact age of this phase has been widely discussed, but it has now been accurately dated to the Early-Middle Miocene transition in several wells, with almost complete sediment columns, from the southern Viking Graben (Rundberg & Eidvin 2005; Eidvin & Rundberg in press). There is a significant hiatus in most wells on the middle and inner margins (Fig. 3). The missing section frequently spans from Lower/Middle Eocene to Middle Miocene. The Molo and Kai formations rest on top of the Middle Miocene unconformity.

In wells 6407/9-3 and -5 there is an up to 22 m thick section of Lower Miocene sediments. It is wedge-shaped and overlies a clear erosional unconformity (Fig. 4). The stratigraphic gap in well 6407/9-5 ranges from Lower Oligocene to Lower Miocene. A fine grained Lower Miocene unit in the northern North Sea is bounded below and above by similar unconformities (Eidvin & Rundberg 2001; Rundberg & Eidvin 2005). About 50 km northeast of the Draugen Field another wedge with the same stratigraphic position and appearance has been observed (Fig. 5). It has not

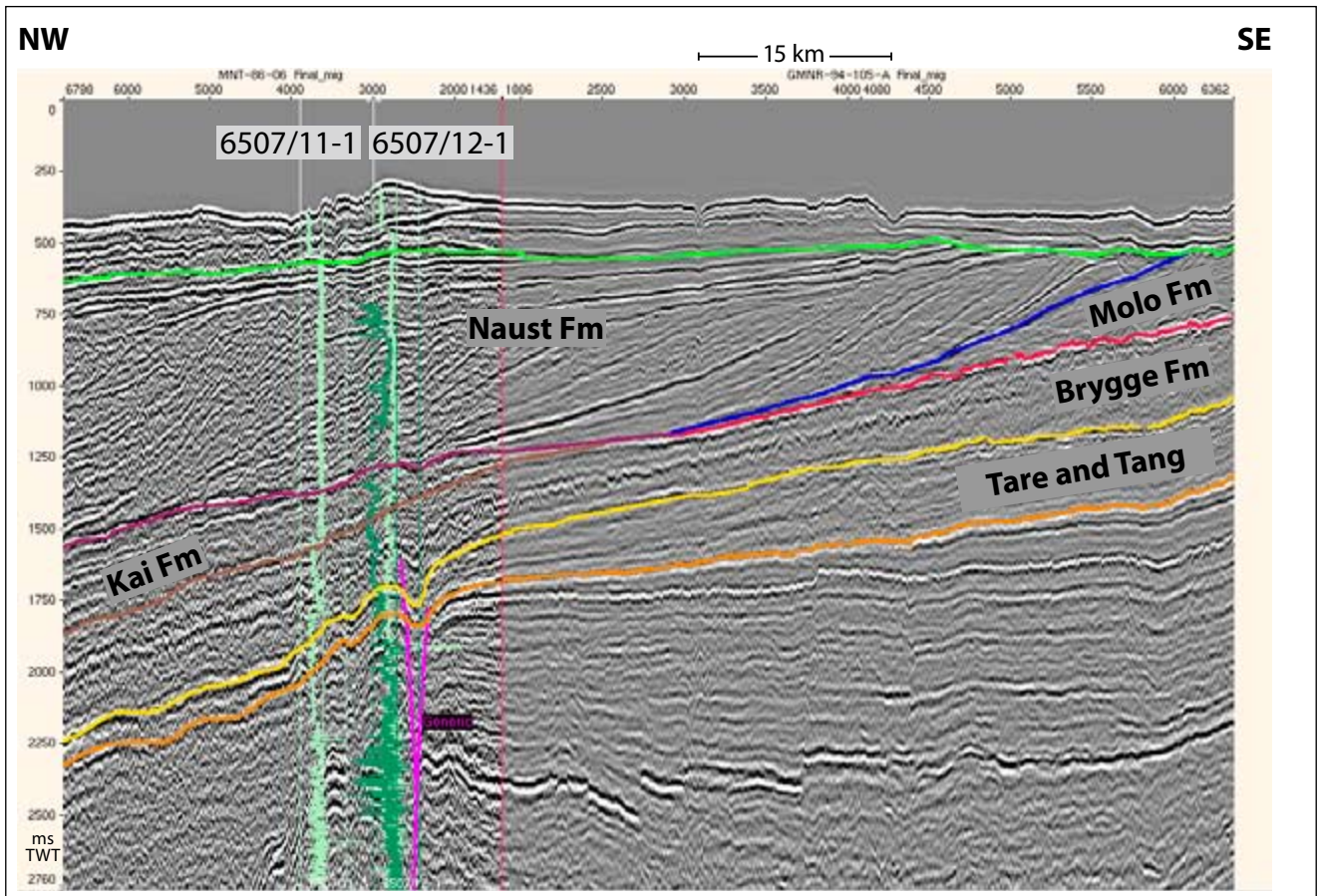


Fig. 6. NW-SE line on northern Haltenbanken showing the stratigraphic relationships of the Brygge, Kai and Molo formations. The Molo Formation is the proximal time equivalent to the Kai Formation. Well correlation and dating of the formations are essential to obtain the correct definition.

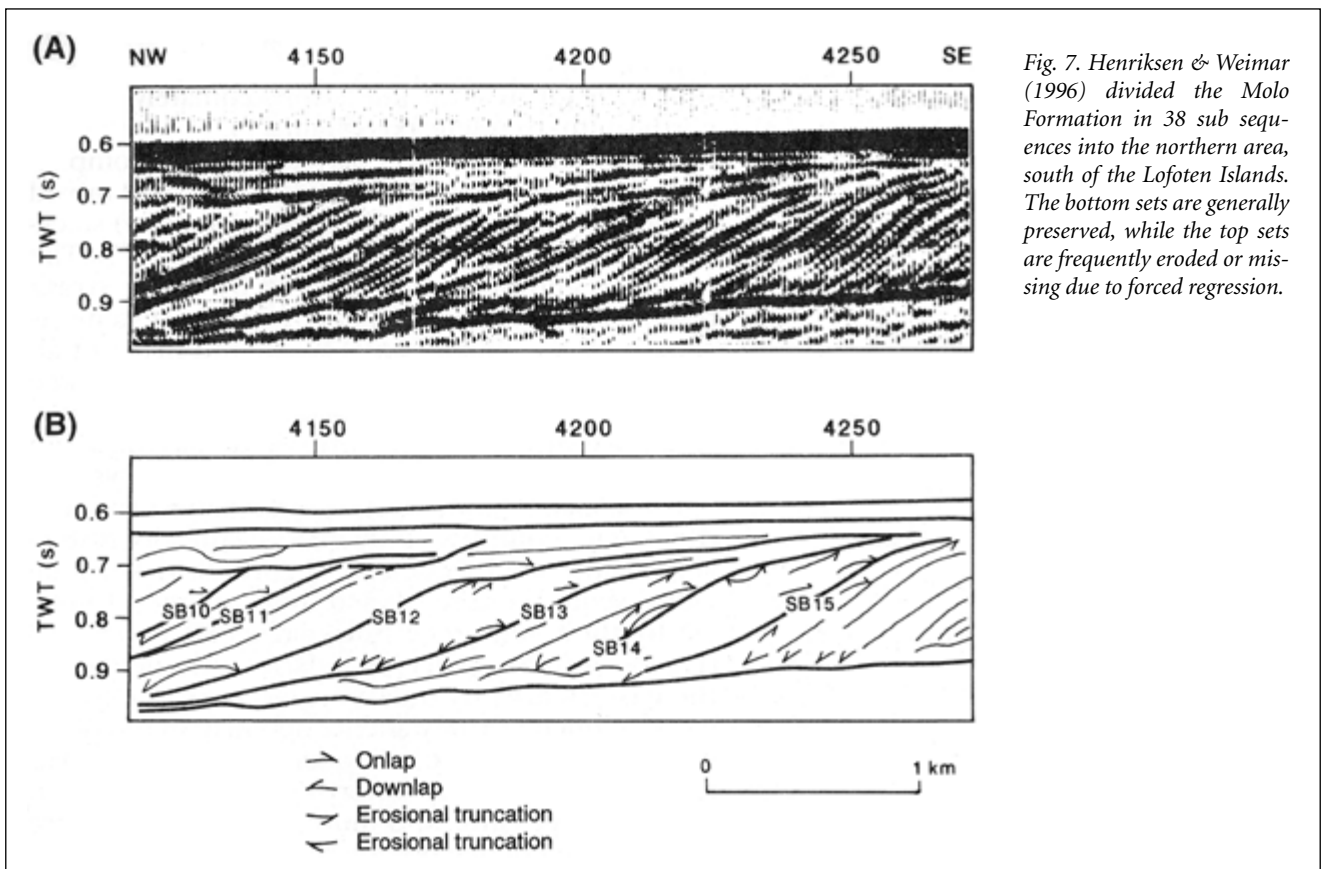


Fig. 7. Henriksen & Weimar (1996) divided the Molo Formation in 38 sub sequences into the northern area, south of the Lofoten Islands. The bottom sets are generally preserved, while the top sets are frequently eroded or missing due to forced regression.

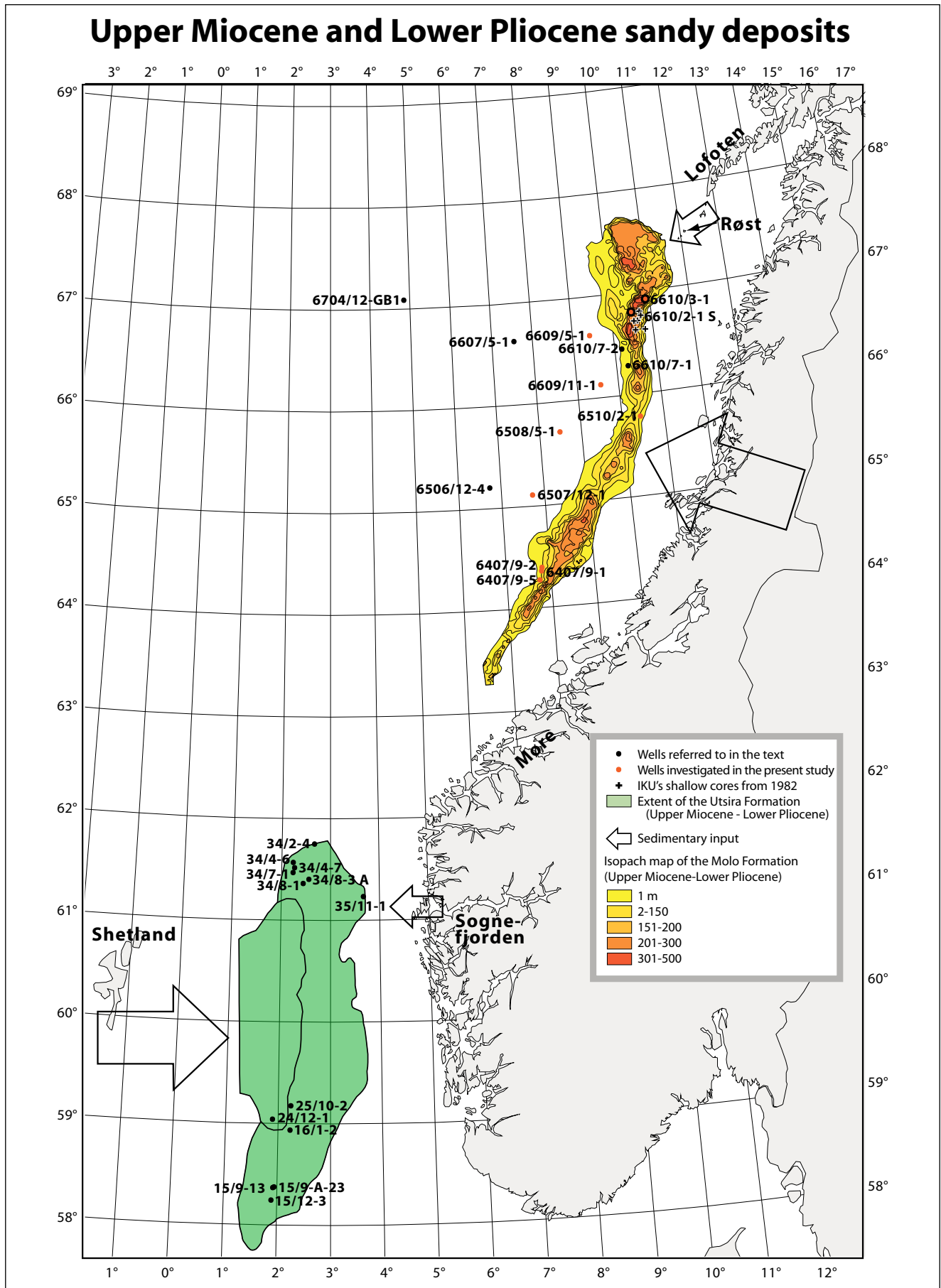


Fig. 8. The Molo Formation is the time equivalent to the Utsira Formation in the North Sea. The Molo Formation was deposited from the east, while the Utsira Formation was deposited both from the Shetland Platform in the west and the Sognefjorden area in the east. The extent of the Utsira Formation is according to Rundberg & Eidvin (2005), and the isopach map of the Molo Formation is according to Bullimore et al. (2005).

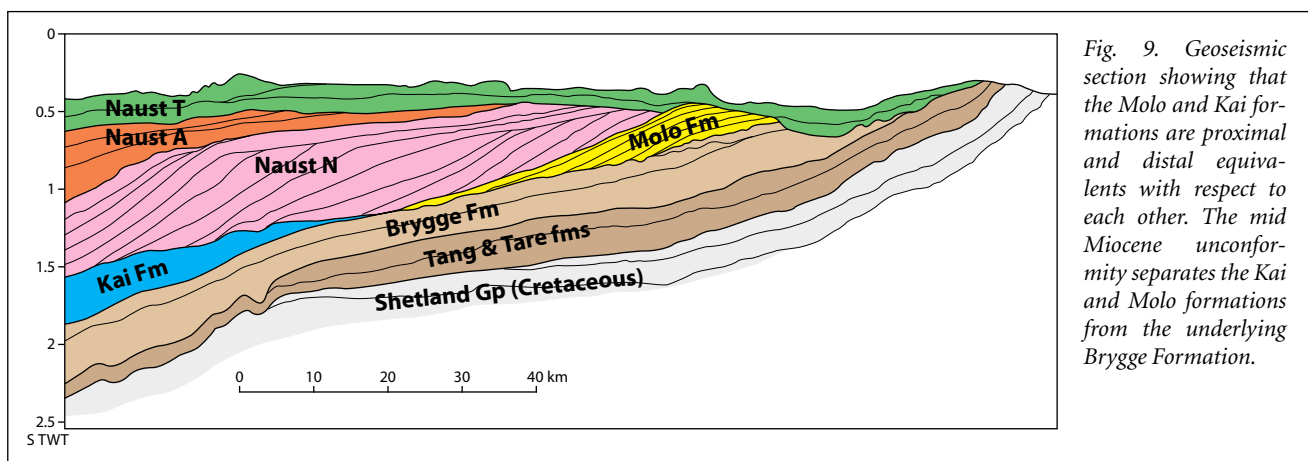


Fig. 9. Geoseismic section showing that the Molo and Kai formations are proximal and distal equivalents with respect to each other. The mid Miocene unconformity separates the Kai and Molo formations from the underlying Brygge Formation.

been dated, but from comparisons it might be similar to the one at the Draugen Field. Stratigraphically and age-wise, the wedge belongs to the Brygge Formation. The unconformity below the wedge seems to represent more active erosion than the Mid Miocene unconformity on top. There are few signs of erosional products related to any of the two hiatus, which indicates that the Mid Miocene Unconformity is more one of non-deposition rather than indicative of a major erosional episode.

After the Mid Miocene uplift, sedimentation resumed on the outer and middle part of the margin. Clay-dominated sediments belonging to the Kai Formation are dated as late Middle Miocene and younger. On the middle/inner part of the shelf, we have dated the sand-dominated Molo Formation as Late Miocene and Early Pliocene. This implies that the Molo Formation is of the same age as the Kai Formation, but may lack the oldest (Middle to early Late Miocene) part (Fig. 3). Based on dating and seismic correlation we interpret the Molo Formation to be the proximal equivalent to the more distally deposited Kai Formation (Fig. 6). A more thorough description of the Molo Formation is given below.

On the shelf and slope down to the deeper Møre and Vøring basins the Kai Formation is overall clayey with ooze in the basinal part. It has a similar polygonal fault pattern as the Brygge Formation, although in detail there are differences in seismic facies between the two units. After deposition of the Kai and Molo formations, the climate cooled, glaciers started to grow and the glaciations in Scandinavia were introduced. Based on the amount of ice-rafted debris in deep-sea cores (Fronval & Jansen 1996), it is common to interpret the first glacial advances to the Norwegian coast to be Late Pliocene, approximately 2.8 million years ago. Until approximately 1.5 Ma, the glaciers were probably restricted to the mainland and did not extend on to the shelf (Bugge et al. 2004, Rise et al. 2005). Up to approximately 0.5 Ma glaciers periodically advanced on to the shelf, and after 0.5 Ma massive glaciers covered the entire shelf during three glacial periods.

The thick Naust Formation was deposited during a com-

paratively short time and contains few significant biostratigraphical events. Fossil analyses of ditch cuttings are not sufficient to obtain a detailed stratigraphy in this formation. Only paleomagnetic investigations of cored sections can give satisfactory results, but such evidence is scarce. However, our investigation indicates that there is generally a hiatus below the Naust Formation. Sediments representing late Early to early Late Pliocene are identified with certainty, only on the Vøring Plateau where these deposits are cored in ODP/DSDP-drillings.

Characteristics of the Molo Formation

The Molo Formation has a unique seismic character, particularly on high-resolution seismic data. The Continental Shelf Institute (IKU, later Sintef Petroleum Research) mapped it in detail by acquiring a regular grid of single channel sparker data on the Mid-Norwegian continental shelf (Rokoengen et al. 1988). The seismic facies is not always easy to recognise on conventional multichannel 2D data and correct correlation and mapping of the outcrop position often benefits from correlation with the map published by Rokoengen et al. (1988).

The Molo Formation was deposited from the coast off Møre (63°15'N) to the Lofoten Islands (67°50'N), i.e., over a distance of about 500 km (Fig. 1). It represents a prograding system comprising fairly steep clinoforms (5-15 degrees). In the inner part top set beds are normally missing and we interpret this to be the result of later erosion. The outer part normally includes the top sets. The bottom sets are preserved all through. Henriksen & Weimer (1996) mapped the northern part of the Molo Formation in detail and subdivided it in up to 38 sub sequences (Fig. 7). There is clear evidences for forced regression during the time of deposition, thus demonstrating relative lowering of sea level. This could be due to uplift rather than to lowering of the eustatic sea level. We prefer uplift for several reasons. The coincidence with the mid Miocene compression and uplift event seems to explain why such a significant volume of sediment was eroded and re-deposited during a rea-

Trøndelag Platform

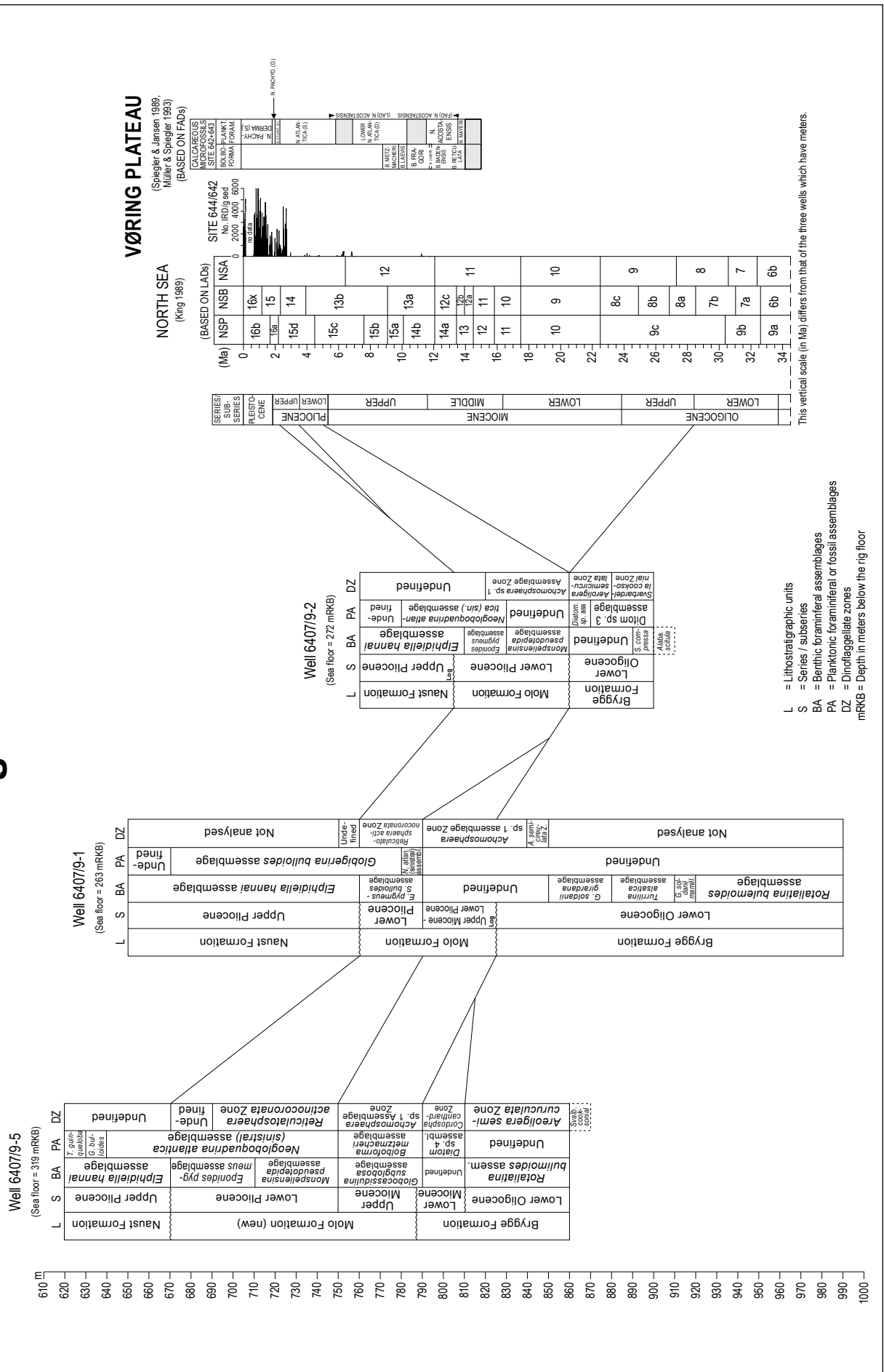


Fig. 10. Correlation of fossil assemblages and zones between wells 6407/9-5, 6407/9-1, 6407/9-2 as well as from these wells to King's (1989) North Sea fossil zonation and to the fossil zonation of the ODP sites 642 and 643 on the Vøring Plateau. (Spiegler & Jansen 1989, Müller & Spiegler 1993). The IRD curve is after Jansen & Sjøholm (1991) and Fronval & Jansen (1996).

Norwegian Sea continental shelf

North Sea

Southern Viking Graben

Well 25/10-2
(Sea floor = 111.6 mRKB)

440 m L S PA
460 m L S PA
480 m L S PA
500 m L S PA
520 m L S PA
540 m L S PA
560 m L S PA
580 m L S PA
600 m L S PA
620 m L S PA
640 m L S PA
660 m L S PA
680 m L S PA
700 m L S PA
720 m L S PA
740 m L S PA
760 m L S PA
780 m L S PA
800 m L S PA
820 m L S PA
840 m L S PA
860 m L S PA

Trøndelag Platform

Well 6407/9-5
(Sea floor = 319 mRKB)

620 m L S PA
640 m L S PA
660 m L S PA
680 m L S PA
700 m L S PA
720 m L S PA
740 m L S PA
760 m L S PA
780 m L S PA
800 m L S PA
820 m L S PA
840 m L S PA
860 m L S PA

Trøndelag Platform

Well 6507/12-1
(Sea floor = 250 mRKB)

1300 m L S PA
1320 m L S PA
1340 m L S PA
1360 m L S PA
1380 m L S PA
1400 m L S PA
1420 m L S PA
1440 m L S PA
1460 m L S PA
1480 m L S PA
1500 m L S PA
1520 m L S PA
1540 m L S PA
1560 m L S PA
1580 m L S PA
1600 m L S PA

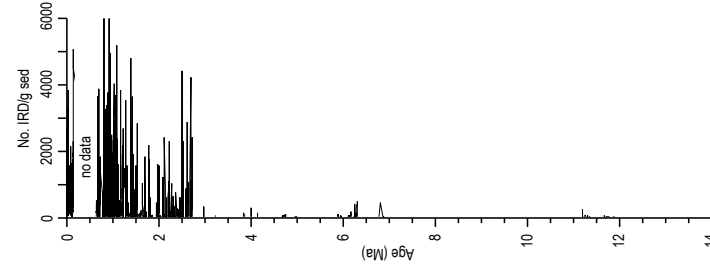
Nordland Ridge

Well 6508/5-1
(Sea floor = 435 mRKB)

1120 m L S PA
1140 m L S PA
1160 m L S PA
1180 m L S PA
1200 m L S PA
1220 m L S PA
1240 m L S PA
1260 m L S PA
1280 m L S PA
1300 m L S PA
1320 m L S PA
1340 m L S PA
1360 m L S PA
1380 m L S PA
1400 m L S PA

VØRING PLATEAU

ODP SITE 644/642



CALCAREOUS MICROFOSSILS ODP SITE 642-643	BOLBO-FORMA	PLANKTIC FORAMS	N. PACHYDERMA (S.)	N. ATLAN-TICA (S.)	LOWER N. ATLAN-TICA (D)	B. METZ-MACHERI	B. LAEVIS	B. FRA-GORI	B. COMPR-	N. ACOSTA-ENSIS	B. RETICU-LATA	N. MAYERI
			N. PACY-DERMA (S.)									

THIS VERTICAL SCALE (in Ma) DIFFERS FROM THAT OF THE FOUR WELLS (DEPT IN mRKB)

L = Lithostratigraphic units
S = Series / subseries
PA = Planktonic foraminiferal or fossil assemblages
mRKB = Depth in meters below the rig floor

Fig. 11. Correlation of planktonic fossil assemblages and zones between well 25/10-2 (southern Viking Graben, North Sea), 6407/9-5 (Trøndelag Platform, Norwegian Sea continental shelf), 6507/12-1 (Trøndelag Platform, Norwegian Sea continental shelf) as well as from these wells to the fossil zonation of the ODP sites 642 and 643 on the Vøring Plateau (Spiegler & Jansen 1989, Müller & Spiegler 1993). The correlation lines for the Bolboforma metzmacheri assemblage are shown in yellow. The IRD curve is after Jansen & Sjøholm (1991) and Fronval & Jansen (1996).

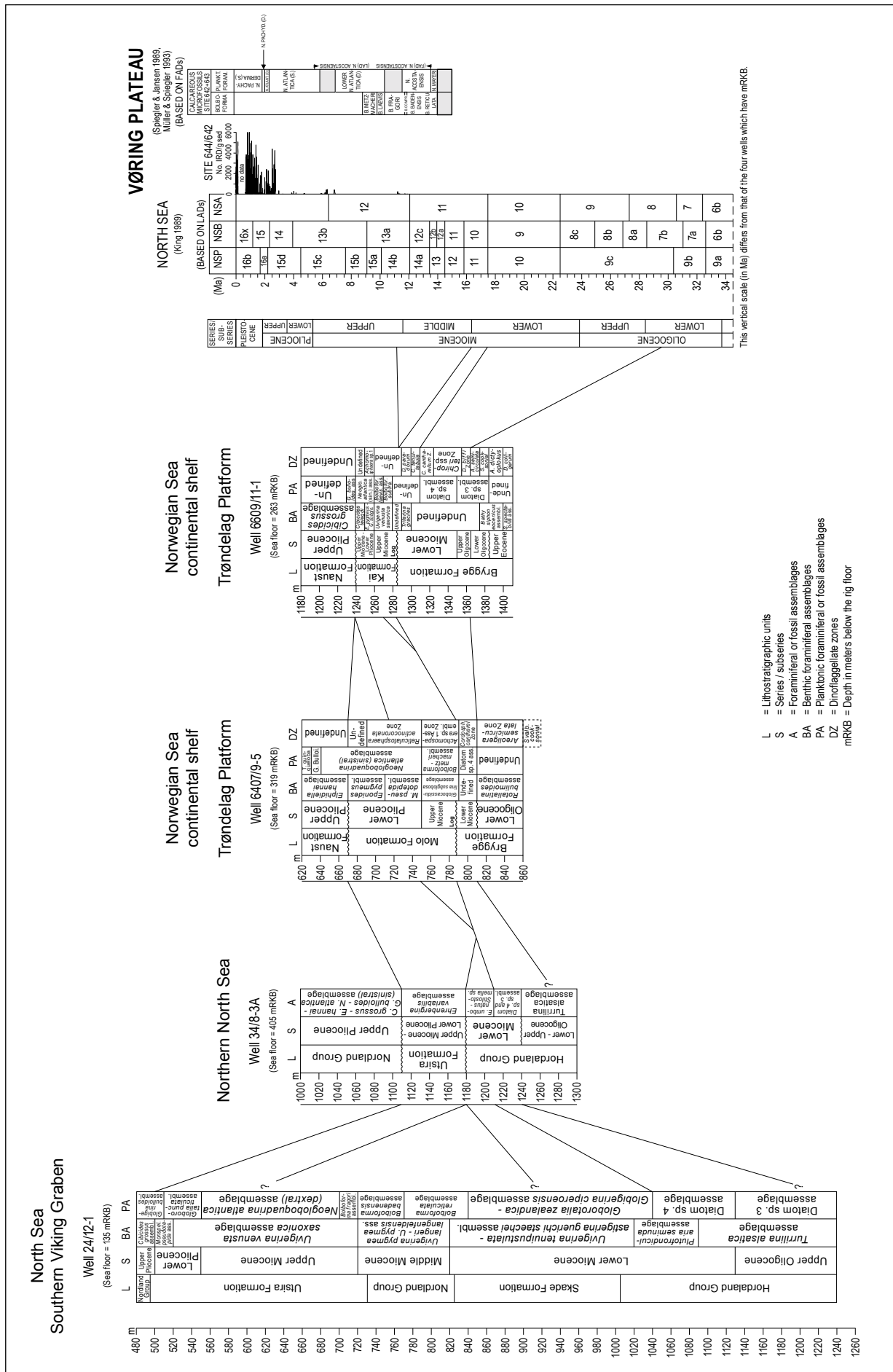


Fig. 12. Correlation of the fossil assemblages and zones between well 24/12-1 (southern Viking Graben, North Sea), 34/8-3A (northern North Sea), 6407/9-5 (Trøndelag Platform, Norwegian Sea continental shelf) and 6609/11-1 (Trøndelag Platform, Norwegian Sea continental shelf) as well as from these wells to King's (1989) North Sea fossil zonation and to the fossil zonation of the ODP sites 642 and 643 on the Vøring Plateau (Spiegler & Jansen 1989, Müller & Spiegler 1993). The IRD curve is after Jansen & Sjøholm (1991) and Fronval & Jansen (1996).

sonably short period. The *in situ* fossil assemblages in the Draugen Field area indicate a shallow shelfal environment, and the assemblages in the proximal wells are reworked. The prograding clinoforms suggest a fairly high-energy coastal environment. The sandy lithology also supports such an interpretation. Some of the wells in proximal parts and some of the vibro cores acquired by IKU contain deep red to yellow oxidized sand similar to the deposits cored from the Palaeocene Tare Formation outcropping 10-15 km to the east of the Molo Formation (Bugge et al. 1984), and similar to the sediment recorded in the Tare Formation in well 6510/2-1 (Vega High, Appendix 1). Erosion and recycling of these sediments are better explained by uplift to the east than by eustatic lowering of sea level.

It has not been possible to identify any particular entry points for sediments being fed into the Molo Formation. This may be explained by a regional uplift of the mainland and eastern basin margin exposing the entire coastline to erosion. Long-shore currents probably redeposited and redistributed the sediments. All the way up towards Lofoten, the Molo Formation seems to have been deposited from the east. An exception is the northern part where the strike turns to a more westerly direction, indicating that the Røstbanken/Røst High area off Lofoten was a source area. This represents the northern termination of the Molo Formation.

Dating of the Molo Formation and correlation between the Molo, Kai and Utsira formations

Re-analysis of the Molo Formation in the Draugen Field wells 6407/9-1, 6407/9-2 and 6407/9-5 shows the occurrence of *in situ* Late Miocene and Early Pliocene *Bolboforma*, planktonic and benthic foraminifera and dinoflagellate cysts. Datings by means of strontium isotope stratigraphy support the ages given by biostratigraphic correlations. Upper Miocene sediments are only recorded in well 6407/9-5. Sediments giving a general Late Miocene to Early Pliocene age are observed in well 6407/9-1. Lower Pliocene deposits are recorded in all the wells (Figs. 10 and A1-A6).

In the present study we have investigated the Kai Formation in well 6507/12-1, 6508/5-1, 6609/5-1 and 6609/11-1 (Figs. A12-A16). In previous studies we have investigated the Kai Formation in well 6506/12-4 on the Halten Terrace (Eidvin et al. 1998), well 6607/5-1 on the Utgard High (Eidvin et al. 1998) and in cored sections of borehole 6704/12-GB1 at the Gjallar Ridge (T. Eidvin personal investigation, Fig. 1). The Utsira Formation has been investigated in wells 15/12-3, 15/9-A-23, 16/1-2, 24/12-1 and 25/10-2 in the southern Viking Graben (North Sea, Rundberg & Eidvin 2005 and in press) and in wells 34/8-1, 34/8-3A, 34/7-1, 34/4-7, 34/4-6, 34/2-4 and 35/11-1 in the

northern North Sea (Eidvin & Rundberg 2001, Fig. 8).

In the lower part of all formations, except in most wells from the northern North Sea Quadrant 34, we were able to recognise planktonic fossil assemblages which include the important index fossil of the genus *Bolboforma*. These can be correlated with the *Bolboforma* zonation of Spiegler & Müller (1992) and Müller & Spiegler (1993), established through the ODP/DSDP drillings in the North Atlantic and the Norwegian Sea. Correlation with these zones may yield quite accurate ages, since the zones are of short duration and are calibrated using nannoplankton and paleomagnetic data. The *Bolboforma metzmacheri* assemblage recorded in the lower part of the Utsira Formation in well 25/10-2 (Eidvin & Rundberg in press), in the lower to middle part of the Kai Formation in wells 6508/5-1, 6609/5-1 and 6607/5-1 (Eidvin et al. 1998) and in the lower part of the Molo Formation in well 6407/9-5 can be correlated with the *B. metzmacheri* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993, Figs. 11, A1, A14 and A15). This zone is described from sediments with an age of approximately 10.0-8.7 My in the North Atlantic and the Norwegian Sea.

The *Bolboforma fragori* assemblage in the base of the Utsira Formation in wells 24/12-1 and 25/10-2 (Eidvin & Rundberg in press), the *Bolboforma subfragori* assemblage in the base of the Kai Formation in well 6609/11-1 and the *B. subfragori* - *B. fragori* assemblage in wells 6507/12-1, 6508/5-1 and 6609/5-1 can be correlated with the *B. fragori/B. subfragori* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993, Figs. 11, 12, A12, A14, A15 and A16). This zone is known from deposits with an age of approximately 11.9-10.3 My in the North Atlantic and the Norwegian Sea. Immediately below the Utsira Formation (lower part of the Nordland Group) in well 24/12-1 and 25/10-2 (Eidvin & Rundberg in press) we recorded the *Bolboforma badenensis* and *Bolboforma reticulata* assemblages. These can be correlated with the *B. badenensis/B. reticulata* Zone of Müller & Spiegler (1993) which they recognised in deposits with an age slightly older than 14.0 to 11.9 My in the North Atlantic and the Norwegian Sea. This unit is also present in the base of the Kai Formation, immediately above the mid Miocene seismic reflector in well 6507/12-1 (Trøndelag Platform), and the upper part of the unit is recorded in the Kai Formation in borehole 6704/12-GB1 (Gjallar Ridge, T. Eidvin personal investigation, Figs. 8, 11 and 12).

In the lower and middle part of the Utsira Formation in wells 24/12-1 and 25/10-2, we recorded the calcareous benthic *U. venusta saxonica* assemblage. This assemblage is also present in the lower to middle part of the Kai Formation in wells 6609/11-1, 6508/5-1, 6507/12-1 and 6609/5-1 (Figs. 11, 12, A12, A14, A15 and A16). According to King (1989) *Uvigerina venusta saxonica* is known from Upper Miocene to Lower Pliocene deposits in the North Sea area. This unit is not present in the Molo Formation in well 6407/9-5. This may be because there is a hiatus within the unit, but it is most likely due to depositional water depth or other environmental factors. Uppermost in the Utsira For-

Table 1. Strontium isotope data from investigated wells						
Well 6407/9-5						
Litho. Unit	Sample (DC)	Measured ^{87/86} Sr	2S error	Corrected ^{87/86} Sr	Dating (H&McA)	Comments
Molo Fm	710-730 m	0.709124	0.000010	0.709010	5.69 Ma	
Molo Fm	740 m	0.709090	0.000012	0.709006	5.75 Ma	
Molo Fm	750-760 m	0.709144	0.000026	0.709030	5.18 Ma	
Molo Fm	770-780 m	0.709087	0.000007	0.709003	5.79 Ma	
Hordaland Gr	810-830 m	0.708049	0.000010	0.707972	30.30 Ma	
Well 6407/9-1						
Molo Fm	790 m	0.708953	0.000023	0.708989	6.0 Ma	
Hordaland Gr	900 m	0.707848	0.000014	0.707884	32.4 Ma	
Well 6510/2-1 (according to Nødtvedt, 1999)						
Molo Fm	480 m			0.708680	17.06 Ma	Reworked
Well 6610/3-1 (according to Eidvin et al., 1998a)						
Molo Fm	525 m (SWC)				33.6 Ma	Reworked
Molo Fm	555 m (SWC)				36.9 Ma	Reworked
Well 6610/3-1						
Molo Fm	555 m (SWC)	0.707776	0.000014	0.707745	37.53 Ma	Reworked
Well 6610/2-1S (according to Nødtvedt, 1999)						
Hordaland Gr	990-1010 m		0.000015	0.707894	32.22 Ma	
Well 6609/11-1						
Kai Fm	1260 m	0.708983	0.000013	0.708968	6.32 Ma	
Well 6508/5-1						
Kai Fm	1260 m	0.709015	0.000008	0.798991	5.95 Ma	
Kai Fm	1260 m	0.708989	0.000012	0.708965	6.42 Ma	
Well 6609/5-1						
Kai Fm	1650-1660 m	0.708911	0.000016	0.708900	9.55 Ma	
Well 6507/12-1						
Kai Fm	1430-1450 m	0.708937	0.000008	0.708897	9.67 Ma	
Kai Fm	1460 m	0.708971	0.000029	0.708931	7.95 Ma	
Kai Fm	1470 m	0.708904	0.000009	0.708865	10.86 Ma	
Well 6607/5-1 (according to Nødtvedt, 1999)						
Kai Fm	2322-2301 m		0.000010	0.709021	5.22 Ma	
Kai Fm	2331-2322 m		0.000010	0.709027	5.07 Ma	
Kai Fm	2331-2322 m		0.000008	0.708967	6.24 Ma	
Kai Fm	2361-2337 m		0.000008	0.708947	6.89 Ma	
Kai Fm	2361 m		0.000009	0.708993	5.74 Ma	
Kai Fm	2361-2337 m		0.000011	0.708992	5.92 Ma	Plankt. foram.
Kai Fm	2391 m		0.000009	0.708859	11.01 Ma	<i>Bolboforma</i>
Well 6506/12-4						
Kai Fm	1820-1800 m		0.000023	0.709025	5.32 Ma	
Kai Fm	1880-1840 m		0.000026	0.709026	5.30 Ma	

Table 1. Strontium isotope data from investigated wells. If not stated otherwise the samples are based on analyses of tests of calcareous benthic foraminifera. All Sr ratios were corrected to NIST 987 = 0.710248. Numerical ages were derived from the SIS Look-up Table Version 3:10/99 of Howard & McArthur (1997). SWC = sample from sidewall core. DC = sample from ditch cuttings. NIST = National Institute for Standard and Technology.

mation in well 24/12-1 we recorded the calcareous benthic *Monspeliensina pseudotepida* assemblage. This unit is also recognised in the upper part of the Molo Formation in well 6407/9-5 and in the lower part of this formation in well 6407/9-2 where a smaller section of this assemblage is present (Figs. 10 and 12). According to King (1989) *M. pseudotepida* is known from the uppermost Upper Miocene to the lowermost Upper Pliocene in the North Sea area. *M. pseudotepida* is not recorded in any well where we have investigated the Kai Formation. This is probably due to the fact that *M. pseudotepida* was a shallow water dweller (Skarbø & Verdenius 1986). The upper parts of the Utsira and Molo formations were probably deposited on the inner shelf unlike the Kai Formation, which was probably deposited on the middle and outer shelf.

Uppermost in the Molo Formation we recorded a calcareous benthic *Eponides pygmeus* assemblage or *E. pygmeus* – *Sphaeroidina bulloides* assemblage. An *E. pygmeus* assemblage is also recognised in the upper part of the Kai Formation in wells 6507/12-1 and 6508/5-1 (Figs. 10, A14 and A16). An *E. pygmeus* – *Globocassidulina subglobosa* assemblage is seen in the upper part of the Kai Formation in well 6607/11-1, and a *Cibicides telegdi* – *E. pygmeus* assemblage was recorded in the upper part of the Kai Formation in wells 6607/5-1 (Utgard High) and 6506/12-4 (Halten Terrace, Eidvin et al. 1998). *E. pygmeus* is also known from the upper part of the Utsira Formation in wells 24/12-1 and 25/10-2 (Eidvin & Rundberg in press) and 34/8-3A (Eidvin & Rundberg 2001, Fig. 8) and in several other wells where the Utsira Formation has been investigated.

Strontium isotope stratigraphy, based on analyses of calcareous index fossils, can also be used for correlation between the formations. The four intervals analysed for strontium isotopes in the Molo Formation in well 6407/9-5 gave ages varying from approximately 5.8 to 5.2 My (Table 1, Fig. A1). Such ages fit quite well with the ages suggested by biostratigraphic correlation for the upper part of the unit. However, it is somewhat younger than the age suggested by correlation of the occurrence of *B. metzmacheri*, in the lower part of the unit, to the deep sea record (approximately 10.0–8.7 My). One sample taken from the upper part of the Molo Formation in well 6407/9-1 gave an age of approximately 6.0 My (Table 1, Fig. A3). It should be noted that all the studied Draugen wells (6407/9-1, /9-2 and /9-5) are distally located in the Molo Formation and do not penetrate the oldest parts of the formation (Fig. 4a). The Molo Formation could thus comprise somewhat older sediments than the ones dated.

One sample taken from the middle part of the Kai Formation in well 6609/11-1 gave an age of approximately 6.3 My (Table 1, Fig. A12). Two samples taken from one interval in the middle part of the Kai Formation in well 6508/5-1 gave ages of approximately 6.4 and 6.0 My (Table 1, Fig. A14). Two samples taken from an interval in the lower half of the Kai Formation in well 6506/12-4

(Halten Terrace, Table 1, Fig. 1) gave both ages of approximately 5.3 My. Several samples taken from the lower half of the Kai Formation in well 6607/5-1 (Utgard High, Table 1, Fig. 1) gave ages varying from 6.9 to 5.1 My. The oldest age is recorded from the lowermost of these samples occurring in a *B. metzmacheri* assemblage. One sample close to the base of the Kai Formation in the same well gave an age of approximately 11.0 My. This sample occurs in a *B. subfragori/B. fragori* assemblage (Eidvin et al. 1998, Nødtvedt 1999). Two samples close to the base of the Kai Formation in well 6507/12-1 (Trøndelag Platform), which also occur in a *B. subfragori/B. fragori* assemblage, gave approximately 8.0 and 10.9 My (Table 1, Fig. A16). One sample taken from the lower half of the Kai Formation in well 6609/5-1 gave an age of approximately 9.6 My (Table 1, Fig. A15). This sample occurs in a *Bolboforma laevis* assemblage, which is known from deposits with an age of approximately 10.3–10.0 My in the Norwegian Sea and in the North Atlantic (Spiegler & Müller 1992, Müller & Spiegler 1993).

Several samples taken from the thin unit of glauconitic sand, which represents the Utsira Formation in well 34/8-1, 34/4-6 and 34/4-7 (northern North Sea, Fig. 8), gave ages varying from 5.6 to 5.0 My (Eidvin & Rundberg 2001).

A large number of strontium isotope ages were obtained from the Utsira Formation in the wells 15/12-3, 15/9-A-23, 16/1-2, 24/12-1 and 25/10-2 from the southern Viking Graben. In these wells mainly mollusc fragments were used for the analyses since the deposits are very rich on molluscs, but not so rich in foraminiferal index fossils. We were not able to identify the mollusc fragments and consequently could not exclude caved or reworked shells. The analyses gave some variation in age, and it was obvious that some caved and reworked shells were analysed. However, most samples in the upper parts, i.e. parts which, according to the biostratigraphic correlation are of Early Pliocene age, gave ages varying from approximately 5 to 4 My. Most samples from the lower parts, i.e. parts which according to biostratigraphic correlation are of Late Miocene age, gave ages varying from approximately 12 to 5 My (Eidvin & Rundberg in press).

Lithologically, there are also large similarities between the Molo Formation in wells from the Draugen Field (Trøndelag Platform) and the Utsira Formation in wells from the Snorre and Visund fields in the northern North Sea (Fig. 8). The Utsira Formation in these wells consists mainly of very dark glauconitic sand (Eidvin & Rundberg 2001). The same kind of sand is also present in the Molo Formation in the Draugen Field, but these deposits also contain some clay and silt. East of the Snorre and Visund fields in the northern North Sea the glauconitic beds probably drape over the main Utsira sand (Eidvin & Rundberg 2001). The main Utsira sand was investigated in well 35/11-1, and the sediments here consist of white, coarse, well sorted quartzose sand which probably originates from the Sognefjord area. The deposits are nearly

barren of micro fossils, but the few recorded forms point to a Late Miocene age (Eidvin & Rundberg 2001). The Utsira Formation, in wells from the southern Viking Graben, also contains mainly quartzose sands with some thin glauconite beds. These sands are also mainly whitish, but in some sections the grains are slightly rust-tinted due to oxidation of the glauconite. The quartzose sands from the North Sea are, however, quite different from the quartzose sands recorded in wells and boreholes from the proximal part of the Molo Formation in the Nordland Ridge area. The deposits here consist of red to dark yellow, probably lateritic sand, with well rounded, tinted pebbles. These differences indicate that the sandy sediments on the Nordland Ridge were originally deposited during a period with a much warmer climate and were later redeposited and incorporated into the Molo Formation.

In Eidvin et al. (1998, 2000) the *Cibicides telegdi-Eponides pygmeus-Neogloboquadrina atlantica* (dextral) zone in the upper part of the Kai Formation in well 6607/5-1 (Utgard High) and the *Nonion affine – Neogloboquadrina atlantica* (dextral) zone and the *Cibicides telegdi-Eponides pygmeus-Neogloboquadrina atlantica* (dextral) zone in the upper part of the Kai Formation in well 6506/12-4 (Halten Terrace, Fig. 1) were given a Late Miocene age based on the occurrence of *N. atlantica* (dextral). However, *N. atlantica* (dextral) is known to occur in both uppermost Upper Pliocene and Upper Miocene on the Vøring Plateau (Spiegler & Jansen 1992, Müller & Spiegler 1993). These stratigraphical units most likely correlate with the foraminiferal assemblages in the upper part of the Kai Formation in wells 6609/11-1 and 6507/12-1 (Trøndelag Platform) and the upper part of the Molo Formation in wells 6407/9-1, /9-2 and /9-5 (Trøndelag Platform) and are most likely of Early Pliocene age (Fig. 1). The occurrence of *N. atlantica* (dextral) is probably caved from Upper Pliocene deposits or reworked from Upper Miocene deposits. A Late Miocene age for the lower part of the Kai Formation in wells 6607/5-1 and 6506/12-4 was verified by strontium isotope analyses (Table 1).

In addition to regional uplift the deposits of the Molo, Kai and Utsira formations are probably also a response to the Neogene climatic evolution of regions surrounding the North Atlantic and the Norwegian-Greenland Sea. The first signs of Northern Hemisphere glaciation, recorded in ODP sites on the Vøring Plateau probably originated in Greenland and date to ~12.6 Ma (latest Middle Miocene, Fronval & Jansen 1996). This event is associated with a global reorganisation of ocean circulation which occurred at the same time (Wright & Miller 1993), and marks the onset of continuous northern component deep water and the subsequent increased water mass exchange between the sub-Arctic and the world ocean. Although the onset of a more erosive regime on the Norwegian mainland appears to be related to climatic development in the Miocene, there is so far no evidence for the existence of glaciers on the eastern seaboard of the Norwegian-Greenland Sea during this period. There was a significant increase in the supply of ice-rafted debris

to the deep ocean, associated with climatic cooling in the latest Miocene (Messinian event, Jansen & Sjøholm 1991, Fronval & Jansen 1996). To date, however, firm evidence for the existence of glaciers has been documented only from Greenland (Larsen et al. 1994, Jansen, Raymo & Blum et al. 1996), but small ice caps may also have been present in the highest areas of Fennoscandia.

Conclusions

During the Oligocene there seems to have been tectonic activity resulting in compression and uplift of basin flanks on the landward parts of the margin. It culminated in a regional uplift in the mid Miocene. There is a significant hiatus in most wells on the middle and inner margins (Fig. 3). The missing section spans from Lower/Middle Eocene to Middle Miocene. The Molo Formation was deposited by coastal progradation as a result of this uplift. The sediments are sandy, shallow marine with a typical clinofold geometry. Distally to this the Kai Formation was deposited in a generally deeper marine setting. There was often a bypass zone between the Molo and the Kai formations. (Fig. 9).

In wells 6407/9-3 and /9-5 there is a section about 20 m thick of Lower Miocene sediments. It is wedge-shaped and overlies a clear erosional unconformity (Fig. 4). The stratigraphic gap ranges from Lower Oligocene to Lower Miocene. Stratigraphically and age-wise, the wedge belongs to the Brygge Formation. The unconformity below the wedge seems to represent more active erosion than the Mid Miocene unconformity on top. There are few signs of erosional products related to any of the two hiatus, which indicates that the Mid Miocene Unconformity is more related to non-deposition rather than marking a major erosional episode. After the Mid Miocene uplift clay-dominated sediments belonging to the Kai Formation were deposited on the outer and middle parts of the margin. On the middle/inner part of the shelf sand-dominated sediments of the Molo Formation were laid down.

The Molo Formation was deposited from the coast off Møre (63°15'N) to the Lofoten Islands (67°50'N), i.e., over a distance of about 500 km (Fig. 1). It represents a prograding system comprising fairly steep clinofolds (5-15 degrees). In the inner part top set beds are normally missing and we interpret this to be the result of later erosion. The outer part somewhere includes top sets, but forced regression frequently prevented these from being deposited. The bottom sets are preserved throughout.

A re-dating of the Molo Formation in the distal Draugen Field wells 6407/9-1, 6407/9-2 and 6407/9-5, based on analyses of planktonic and benthic foraminifera, dinoflagellate cysts and strontium isotopes, gave the unit a Late Miocene to Early Pliocene age. This age contradicts the ages previously given to this unit by biostratigraphic consultants. It also contradicts an Early Oligocene age which

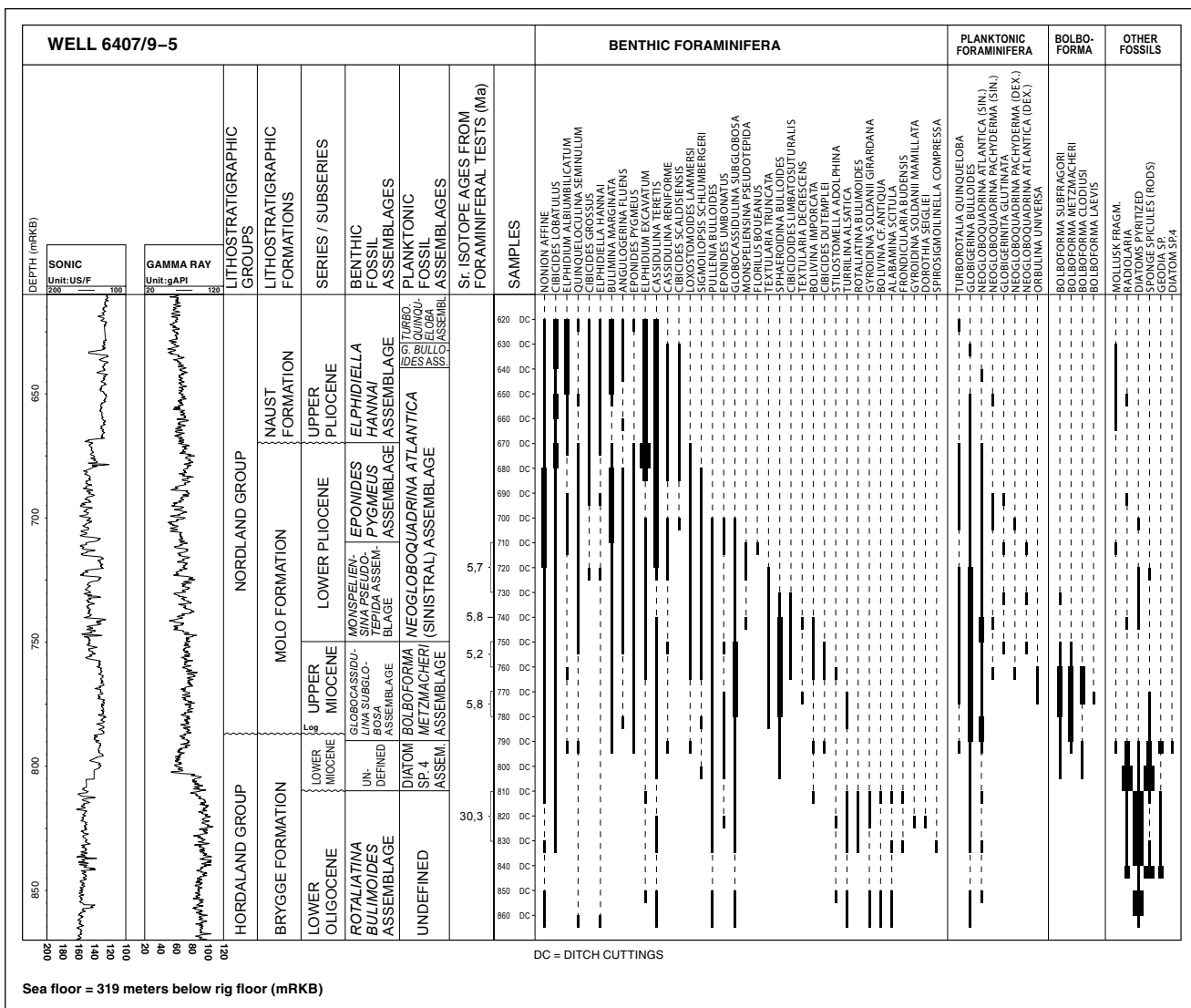


Fig. A1. Range chart of the most important benthic and planktonic foraminifera, *Bolboforma* and other planktonic index fossils in the investigated interval of well 6407/9-5. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units, $\mu\text{s/f}$ = microseconds per foot.

was obtained by our previous investigation of wells and boreholes from the proximal parts of the formation.

We are able to correlate the Molo Formation with the Kai Formation to the west and the Utsira Formation in the North Sea by means of the benthic and planktonic fossil and strontium isotope data. The most complete section of the Molo Formation was found in well 6407/9-5, and especially noteworthy is the recording of the planktonic *B. metzmacheri* assemblage in the lower part of the unit in this well. Correlation of shelfal fossil assemblages with the deep ocean *Bolboforma* zones may yield quite accurate ages, since the zones are of short duration and are calibrated using nannoplankton and paleomagnetic data. Spiegler & Müller (1992) and Müller & Spiegler (1993) were able to give their *B. metzmacheri* Zone an accurate age of 10.0-8.7 My. In addition to well 6407/9-5, we have recorded a *B. metzmacheri* assemblage in the lower part of the Utsira Formation in well 25/10-2 (Eidvin & Rundberg in press) and in the

lower to middle part of the Kai Formation in wells 6508/5-1, 6609/5-1 and 6607/5-1 (Figs. 11, A14 and A15).

At the base of the Utsira Formation in well 25/10-2 and near the base in well 24/12-1 and at the base or near the base of the Kai Formation in wells 6609/11-1, 6508/5-1, 6609/5-1 and 6507/12-1 we were able to record a *B. fragori* assemblage which correlates with the *B. fragori/B. subfragori* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993, 11.9-10.3 Ma). In the base of the Kai Formation in well 6507/12-1 we were also able to record a *B. badenensis/B. reticulata* assemblage which correlates with the *B. badenensis/B. reticulata* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993). This zone is the oldest of the *Bolboforma* zones in the North Atlantic and the Norwegian Sea and gives an age slightly older than 14 to 11.9 My. In the southern Viking Graben, North Sea, the *B. badenensis/B. reticulata* assemblage is recorded in a number of wells in the fine grained deposits at the base of the

Nordland Group, just below the Utsira Formation. However, in wells 24/12-1 and 15/12-3 the uppermost part of the *B. badenensis*/*B. reticulata* assemblage is within the lowermost part of the Utsira Formation (Eidvin & Rundberg in press). This implies that the oldest part of both the Utsira Formation and the Kai Formation is older than the oldest sediment we were able to record from the Molo Formation in the Draugen Field wells (the oldest parts were not penetrated). It also indicates that the oldest part of the Kai Formation is slightly older than the oldest part of the Utsira Formation (Fig. 3), although it should be noted that none of the wells penetrated the oldest parts.

Appendix 1

Investigation of the Molo Formation

Stratigraphy and lithology of wells 6407/9-1, 6407/9-2 and 6407/9-5 in the Draugen Field on the Trøndelag Platform

Well locations, material and methods

Wells 6407/9-1 (64°21'56.14"N, 07°47'20.86"E), 6407/9-2 (64°24'1.31"N, 07°48'11.26"E) and 6407/9-5 (64°16'42.35"N, 07°44'14.66"E) were drilled in the southern distal part of the Molo Formation in the Draugen Field (Trøndelag Platform, Fig. 1). A number of 30 ditch cutting samples from well 6407/9-1, 15 ditch cutting samples from well 6407/9-2 and 25 ditch cutting samples from well 6407/9-5 were used for the study. All the samples were analysed for foraminifera and *Bolboforma* and in some sections also for pyritized diatoms. Nine samples were analysed for dinoflagellates in well 6407/9-1, 14 samples in well 6407/9-2 and 25 samples in well 6407/9-5. For analyses of foraminifera, *Bolboforma* and diatoms 50-100 g of material were used. The micropalaeontological identification was carried out in the 106- to 500- μ m fraction. The fractions <106 μ m and >500- μ m were also inspected. Approximately 300 individuals were picked from each sample. In order to optimise identification of the assemblages, a number of samples rich in terrigenous grains were gravity-separated in heavy liquid. In such cases, 1000-1500 individuals were analysed in fossil-rich samples. Palynomorphs were extracted from 20-30 g material, using conventional preparation methods involving removal of carbonates and silica by HCL and HF, respectively. The organic residues were subsequently oxidised with nitric acid to remove pyrite and some of the amorphous organic matter.

Micropalaeontological assemblages

The Upper Miocene and Pliocene sections contain rich to moderately rich faunas of mainly calcareous benthic and planktonic foraminifera. In addition, the Upper Miocene (well 6407/9-5) contains a moderately rich assemblage of *Bolboforma*. The fossil assemblages in the Oligocene and

Lower Miocene (well 6407/9-5) sections are dominated by radiolaria, pyritized diatoms and sponge spicules, but contain also sparse faunas of calcareous benthic foraminifera and some agglutinated foraminifera. It is supposed that the faunal turnover at the mid-Miocene unconformity reflects a change in depositional conditions from shallow water (above) to deeper water (below).

Well 6407/9-5

Benthic foraminiferal assemblages

ELPHIDIELLA HANNAI ASSEMBLAGE

Definition: The top of the assemblage extends to the uppermost investigated sample (620 m). The base is marked by the highest/youngest consistent occurrence of *E. pygmeus*.

Depth range: 620-670 m.

Material: Five ditch cutting samples.

Age: Late Pliocene.

Lithostratigraphic unit: Naust Formation.

Correlation: Zone NSB 15 of King (1989), *Cibicides grossa* zone of Stratlab (1988) and Zone NSR 12 B of Gradstein & Bäckström (1996).

Description: This interval contains a rich benthic fauna of mainly calcareous foraminifera. *Elphidium excavatum* and *Cassidulina teretis* occur most frequently. *Cibicides lobatulus*, *Elphidium albumbilicatum* and *Bulimimina marginata* are also common. Other important species include *Elphidiella hannai*, *Cibicides grossus*, *Nonion affine*, *Cassidulina reniforme* and *Cibicides scaldisiensis* (Fig. A1).

Remarks: With the exception of *E. hannai* and *C. grossus* all the *in situ* benthic foraminifera are extant species. According to King (1989) *E. hannai* and *C. grossus* are found in the northern North Sea in Upper Pliocene to lower Pleistocene deposits. According to King (1989) the first appearance datums (FADs) of these species are considerably higher than the Lower/Upper Pliocene boundary (3.56 Ma). *C. grossus* is, however, recorded in deposits as old as the late Middle Miocene on the Vøring Plateau (T. Eidvin, unpublished data) and as old as the Late Miocene in the Netherlands. However, *E. hannai* is known from Upper Pliocene deposits in the latter area (Doppert 1980).

EPONIDES PYGMEUS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest consistent occurrence of *E. pygmeus*. The base is marked by the highest/youngest occurrence of *M. pseudotepida*.

Depth range: 670-710 m.

Material: Four ditch cutting samples.

Age: Early Pliocene.

Lithostratigraphic unit: Molo Formation.

Correlation: Probably *Cibicides telegdi* – *Eponides pygmeus* – *Neoglobobadrina atlantica* (dextral) zone of Eidvin et al. (1998) and probably lower part of *Melonis* – *Trifarina* zone of Stratlab (1988).

Description: This assemblage contains a rich benthic fauna of mainly calcareous foraminifera. *N. affine* and *C. teretis* occur most frequently. Other important taxa

includes *E. pygmeus*, *Loxostomoides lammersi*, *Sigmilopsis schlumbergeri* (agglutinated), *Quinqueloculina seminulum*, *B. marginata*, *C. lobatulus*, *Angulogerina fluens* and *G. subglobosa* (lowermost sample, Fig. A1).

Remarks: Most of the recorded benthic specimens are known from sediments from almost the entire Neogene. However, *E. pygmeus* is described from the Oligocene in Denmark and Germany (Grossheide & Trunko 1965, Hausmann 1964, Kummerle 1963, Ulleberg 1974). This species is recorded in deposits from the Oligocene to the Lower Pliocene in the North Sea and on the Norwegian Sea continental shelf (Stratlab 1988, Eidvin et al. 1998, Eidvin & Rundberg 2001 and Eidvin & Rundberg in press). In the North Sea, a few tests of *E. pygmeus* are also recorded in basal Upper Pliocene deposits (Eidvin & Rundberg 2001, Eidvin & Rundberg in press). However, *E. pygmeus* have very small tests are easily transported and the occurrence in Upper Pliocene deposits is probably due to reworking. Since taxa no older than earliest Late Miocene are recorded in the immediately underlying assemblage, this assemblage is most likely of Early Pliocene age.

MONSPELIENSINA PSEUDOTEPIDA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *M. pseudotepida*. The base is marked by the highest/youngest common occurrence of *G. subglobosa*.

Depth range: 710-750 m.

Material: Four ditch cutting samples.

Age: Early Pliocene.

Lithostratigraphic unit: Molo Formation.

Correlation: Subzone NSB 14a of King (1989), Zone NSR 12A of Gradstein & Bäckström (1996).

Description: This interval contains a moderately rich benthic fauna of mainly calcareous foraminifera. There are fewer specimens than in the immediately overlying unit. No species are common, but important taxa include *M. pseudotepida*, *G. subglobosa*, *L. lammersi*, *Textularia truncate* (agglutinated), *S. bulloides* (lower part), *Cibicidoides limbatusuturalis* (lower part), *S. schlumbergeri* (agglutinated), *Pullenia bulloides*, *C. tertis*, *E. pygmeus*, *N. affine*, *C. lobatulus* and *Florilus boueanus* (uppermost sample, Fig. A1).

Remarks: According to King (1989), in the North Sea area, *M. pseudotepida*, *C. limbatusuturalis* and *T. truncata* are known from the uppermost Upper Miocene to the lowermost Upper Pliocene and *F. boueanus* is described from the Upper Oligocene to the Lower Pliocene. *G. subglobosa* is recorded from the Oligocene to the Lower Pliocene in the North Sea (Eidvin & Rundberg 2001 and Eidvin & Rundberg in press).

GLOBOCASSIDULINA SUBGLOBOSA ASSEMBLAGE

Definition: The top and base of the assemblage are taken at the highest/youngest and lowest/oldest common occurrence of *G. subglobosa*.

Depth range: 750-790 m.

Material: Four ditch cutting samples.

Age: Late Miocene (partly based on planktonic fossil evidence).

Lithostratigraphic units: Molo Formation.

Correlation: Probably Zone NSB 12c and 13a of King (1989) and probably *G. subglobosa* – *Ehrenbergina variabilis* zone of Stratlab (1988).

Description: This assemblage contains a moderately rich benthic fauna of mainly calcareous foraminifera. *G. subglobosa* and *S. bulloides* are both common. Other characteristic species include *Bolivina imporcata*, *Cibicides dutemplei*, *N. affine*, *C. lobatulus*, *C. teretis*, *P. bulloides*, *Eponides umbonatus*, *T. truncata* (agglutinated) and *E. pygmeus* (Fig. A1).

Remarks: *B. imporcata* is described from the Middle to Upper Miocene in the Netherlands (Doppert 1980). *C. dutemplei* is known from the Upper Oligocene to the Lower Pliocene in the same area (Doppert 1980) and from the Upper Oligocene to the Upper Miocene on the Norwegian continental shelf (Skarbø & Verdenius 1986). A few specimens of *Turrilina alsatica*, which are reworked from Oligocene deposits, are recorded in some samples.

UNDEFINED INTERVAL

Depth range: 790-810 m.

Material: Two ditch cutting samples.

Age: Early Miocene (based on planktonic fossil evidence).

Lithostratigraphic unit: Brygge Formation.

Description: This interval contains a sparse benthic fauna of mainly calcareous foraminifera including *N. affine*, *C. lobatulus*, *C. teretis*, *P. bulloides*, *E. umbonatus*, *G. subglobosa* and *S. bulloides* (Fig. A1). However, all or most of these forms are probably caved.

ROTALIATINA BULIMOIDES ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *R. bulimoides*. The base of the assemblage is undefined.

Depth range: 810-860 m (lowermost investigated sample).

Material: Six ditch cutting samples.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSB 7 of King (1989), *Rotaliatina bulimoides* zone of Stratlab (1988) and probably Zone NSR 7A and lower part of Zone NSR 7B of Gradstein & Bäckström (1996).

Description: This unit contains a sparse benthic fauna of mainly calcareous foraminifera. Characteristic taxa include *R. bulimoides*, *T. alsatica*, *Gyroidina soldanii girardana*, *Gyroidina soldanii mamillata* (upper part), *Alabama scitula*, *P. bulloides*, *G. subglobosa*, *Frondicularia budensis*, *Dorothia seigliei* (agglutinated, upper part, Fig. A1).

Remarks: *G. soldanii mamillata* and *R. bulimoides* are known from the Lower Oligocene to the lowermost Upper Oligocene in the North Sea area according to King (1989). According to Gradstein & Bäckström (1996) these species are known from Eocene to Lower Oligocene deposits in the same area. They have also recorded *R. bulimoides* from such sediments in the Haltenbanken area. *T. alsatica* and *G. soldanii girardana* are known from the Lower Oligocene to the lowermost Lower Miocene succession in the North Sea (King 1989). According to Gradstein & Bäckström (1996) are *T. alsatica* recorded from Lower

Oligocene to lowermost Upper Oligocene sediments in the North Sea and the Haltenbanken area. They describe *G. soldanii girardana* from the Upper Eocene to the lowermost Lower Miocene in the North Sea area.

A. scitula is recorded from Lower Oligocene to Lower Miocene sediments in the North Sea and the Haltenbanken area (Gradstein & Bäckström 1996). *D. seigliei* is recorded from Eocene to Lower Oligocene deposits in the North Sea and from Upper Palaeocene to Upper Eocene deposits in the Haltenbanken area (Gradstein & Bäckström 1996). *F. budensis* is known from the Lower Oligocene in the North Sea (King 1989).

Planktonic fossil assemblages

TURBOROTALIA QUINQUELOBA ASSEMBLAGE

Definition: The top of the assemblage extends to the uppermost investigated sample (620 m). The base is marked by the highest/youngest occurrence of *Globigerina bulloides*.

Depth range: 620-630 m.

Material: One ditch cutting sample.

Age: Late Pliocene.

Lithostratigraphic unit: Naust Formation.

Correlation: Probably *Neogloboquadrina atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).

Description: Just a few specimens of *T. quinqueloba* are recorded in the sole sample from this interval (Fig. A1).

Remarks: *T. quinqueloba* is known from deposits from almost the entire Neogene on the Norwegian continental shelf (T. Eidvin personal observation).

GLOBIGERINA BULLOIDES ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *G. bulloides*. The base is marked by the highest/youngest occurrence of *Neogloboquadrina atlantica* (sinistral).

Depth range: 630-640 m.

Material: One ditch cutting sample.

Age: Late Pliocene.

Lithostratigraphic unit: Naust Formation.

Correlation: *Globigerina bulloides* Zone of Weaver & Clement (1986).

Description: Just a few specimens of *G. bulloides* are recorded in the sole sample which constitutes this interval (Fig. A1).

Remarks: Weaver & Clement (1986) describe a *G. bulloides* Zone from the North Atlantic (DSDP Leg 94) in Late Pliocene sediments as young as 2.2 Ma. On the Vøring Plateau *G. bulloides* is common in Late Miocene to Late Pliocene deposits older than 2.4 Ma (Spiegler & Jansen, 1989). *G. bulloides* is also common in the warmest interglacials of the last 0.5 My in the North Atlantic (Kellogg 1977).

NEOGLOBOQUADRINA ATLANTICA (SINISTRAL) ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *N. atlantica* (sinistral). The base is marked by the highest/youngest occurrence of *B.*

metzmacheri.

Depth range: 640-750 m

Material: Eleven ditch cutting samples.

Age: Early to Late Pliocene.

Lithostratigraphic units: Molo and Naust formations.

Correlation: *N. atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).

Description: This unit is characterized by a moderately rich (lower part) to sparse (upper part) fauna of planktonic foraminifera. *G. bulloides* and *N. atlantica* (sinistral) occur most frequently. *T. quinqueloba* is also recorded in most parts of the unit. A few specimens of *Neogloboquadrina pachyderma* (dextral), *Neogloboquadrina pachyderma* (sinistral), *Globigerinita glutinata* and *Neogloboquadrina atlantica* (dextral) are also recorded in some samples (Fig. A1).

Remarks: *N. atlantica* (sinistral) is known from the North Atlantic and on the Vøring Plateau in Late Miocene to Late Pliocene sediments. The last appearance datum (LAD) of this species is in both areas approximately 2.4 Ma (Weaver & Clement 1986, Spiegler & Jansen 1989). On the Vøring Plateau there is a marked dominance of this species together with *G. bulloides* in Pliocene deposits older than this (Spiegler and Jansen 1989).

BOLBOFORMA METZMACHERI ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. metzmacheri*. The base is marked by the highest/youngest occurrence of Diatom sp. 4 (King 1983).

Depth range: 750-790 m.

Material: Four ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Molo Formation.

Correlation: *Bolboforma metzmacheri* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993), *Bolboforma metzmacheri* zone of Stratlab (1988), Zone NSR 10 of Gradstein & Bäckström (1996) and Subzone NSP 14b of King (1983).

Description: The unit contains a moderately rich fossil assemblage of *Bolboforma* and foraminifera. *B. subfragori* and *B. metzmacheri* are the most common *Bolboforma* species. *Bolboforma clodiusi* and *B. laevis* (few) are also recorded in some samples. *G. bulloides* and *N. atlantica* (sinistral) are the most important foraminifera. Other taxa include *N. atlantica* (dextral), *T. quinqueloba* and *Orbulina universa* (Fig. A1).

Remarks: A *B. fragori/B. subfragori* Zone is known from deposits with an age of approximately 11.7-10.3 My from the North Atlantic and the Vøring Plateau. *B. metzmacheri* is described from sediments with an age of approximately 10.0-8.7 My in the same areas (Spiegler & Müller 1992 and Müller & Spiegler 1993). Consequently, in contrast to well 6407/9-5, *B. metzmacheri* occurs in slightly younger sediments than *B. subfragori* in these areas. This can be due to the fact that the *Bolboforma* forms may have a slightly different range in the Draugen area on the inner continental shelf, than in the open ocean sites of the Norwegian Sea and the North Atlantic. It may also be due to the fact that the specimens of *B. subfragori* might be reworked. A

number of pictures taken of this species with the electron microscope, reveal that most of the tests show indications of wear. It is also possible that sediment corresponding to the uppermost part of the *B. metzmacheri* Zone in the Norwegian Sea and North Atlantic is missing in well 6407/9-5.

DIATOM SP. 4 ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of Diatom sp. 4. The base of the assemblage is undefined biostratigraphically, but is taken at the gamma log break at approximately 810 m.

Depth range: 790-810 m.

Material: Two ditch cutting samples.

Age: Early Miocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSP 10 of King (1983).

Description: This interval contains a rich planktonic fossil assemblage of pyritized diatoms (including Diatom sp. 4) and radiolaria. A few caved *Bolboforma* and planktonic foraminifera are also recorded (Fig. A1).

Remarks: Diatom sp. 4 is described from Lower Miocene deposits in the North Sea (King 1983).

UNDEFINED INTERVAL

Depth range: 810-860 m.

Material: Six ditch cutting samples.

Age: Early Oligocene (based on benthic foraminiferal and palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Description: Also this unit contain a rich planktonic fossil assemblage of pyritized diatoms and radiolaria (dominant), but no diatom index fossil is recorded (Fig. A1).

Well 6407/9-2

Benthic foraminiferal assemblages

ELPHIDIELLA HANNAI ASSEMBLAGE

Definition: The top of the assemblage extends to the uppermost investigated sample (760 m). The base is marked by the highest/youngest consistent occurrence of *E. pygmeus*.

Depth range: 760-810 m.

Material: Five ditch cutting samples.

Age: Late Pliocene.

Lithostratigraphic unit: Naust Formation.

Correlation: Zone NSB 15 of King (1989), *Cibicides grossa* zone of Stratlab (1988) and Zone NSR 12 B of Gradstein & Bäckström (1996).

Description: This unit contains a rich benthic fauna of calcareous foraminifera. *E. excavatum* occurs most frequently. Other important taxa include *C. grossus*, *N. affine*, *E. albiumbilicatum*, *C. reniforme*, *B. marginata*, *C.*

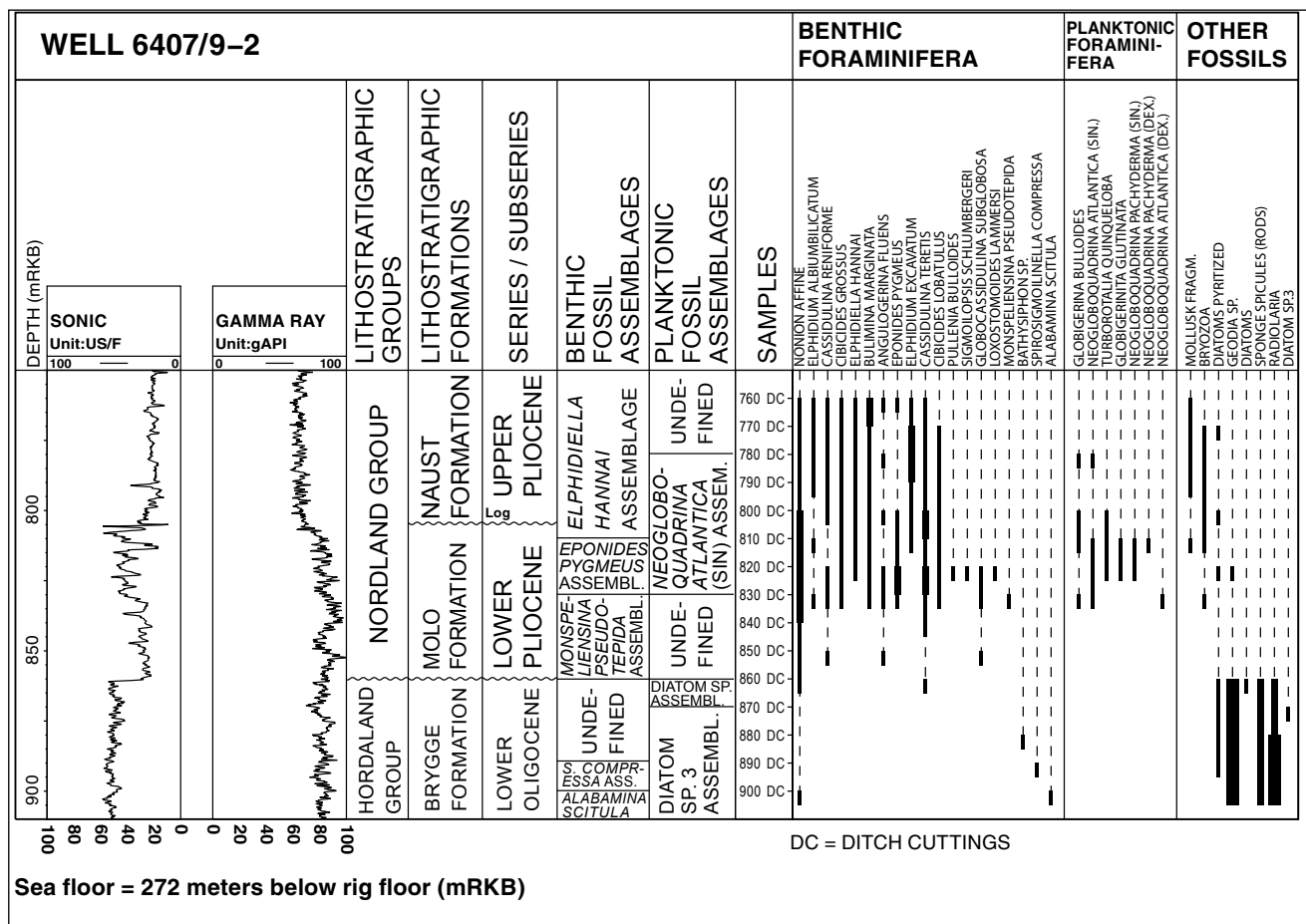


Fig. A2. Range chart of the most important benthic and planktonic foraminifera and other planktonic index fossils in the investigated interval of well 6407/9-2. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units, $\mu\text{s}/\text{f}$ = microseconds per foot.

teretis and *C. lobatulus* (Fig. A2).

Remarks: The occurrence of *E. hannai* and *C. grossus* shows that this unit is of Late Pliocene age (Doppert 1980, King 1989). One, probably reworked, specimen of *E. pygmeus* is recorded in the lowermost sample (Fig. A2).

EPONIDES PYGMEUS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest consistent occurrence of *E. pygmeus*. The base is marked by the highest/youngest occurrence of *M. pseudotepida*.

Depth range: 810-830 m.

Material: Two ditch cutting samples.

Age: Early Pliocene.

Lithostratigraphic unit: Molo Formation.

Correlation: Probably *Cibicides telegdi* – *Eponides pygmeus* – *Neogloboquadrina atlantica* (dextral) zone of Eidvin et al. (1998) and probably the lower part of the *Melonis* – *Trifarina* zone of Stratlab (1988).

Description: This assemblage contains a rich benthic fauna of mainly calcareous foraminifera. *E. pygmeus*, *N. affine* and *C. teretis* are all common. Other recorded species include *C. lobatulus*, *P. bulloides*, *S. schlumbergeri* (agglutinated), *G. subglobosa* and *L. lammersi* (Fig. A2).

Remarks: This unit is correlated with the *E. pygmeus* assemblage in well 6407/9-5. Since taxa no older than earliest Late Miocene are recorded in the immediately underlying assemblage, this assemblage is most likely of Early Pliocene age.

MONSPELIENSINA PSEUDOTEPIDA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *M. pseudotepida*. The base of the unit is undefined biostratigraphically, but is taken at the sonic log break at approximately 860 m.

Depth range: 830-860 m

Material: Three ditch cutting samples.

Age: Early Pliocene.

Lithostratigraphic unit: Molo Formation.

Correlation: Subzone NSB 14a of King (1989), Zone NSR 12A of Gradstein & Bäckström (1996).

Description: This unit contains a moderately rich (upper part) to sparse (lower part) benthic fauna of calcareous foraminifera. *N. affine* is common in the upper part of the unit. Other recorded taxa include *M. pseudotepida*, *G. subglobosa*, *C. teretis* and *E. pygmeus* (Fig. A2).

Remarks: *M. pseudotepida* is known from the uppermost Upper Miocene to the lowermost Upper Pliocene in the North Sea area (King 1989). This unit is correlated with the *M. pseudotepida* assemblage in well 6407/9-5.

UNDEFINED INTERVAL

Depth range: 860-890 m.

Material: Three ditch cutting samples.

Age: Early Oligocene (based on palynological evidence and seismic correlation).

Lithostratigraphic unit: Brygge Formation.

Description: This interval is nearly barren of benthic foraminifera and only a long range agglutinated form (*Bathysiphon* sp.) is recorded (Fig. A2).

SPIROSIGMOILINELLA COMPRESSA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *S. compressa*. The base is marked by the highest/youngest occurrence of *Alabamina scitula*.

Depth range: 890-900 m.

Material: One ditch cutting sample.

Age: Early Oligocene (partly based on palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Probably Zone NSR 7A or 7B of Gradstein & Bäckström (1996) and probably Zone NSA 7 or 8 of King (1989).

Description: Just a few specimens of *S. compressa* (agglutinated) are recorded in the sole sample of this unit (Fig. A2).

Remarks: *Spirosigmoilinella* sp. A (synonymous with *S. compressa*) is known from the Lower Oligocene to Lower Miocene succession in the North Sea (King, 1989). According to Gradstein & Bäckström (1996) this species is known from the Middle Eocene to the Upper Oligocene in the North Sea and from the Middle Eocene to the Lower Oligocene in the Haltenbanken area.

ALABAMINA SCITULA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *A. scitula*. The base of the assemblage is undefined.

Depth range: 900 m (one sample only).

Material: One ditch cutting sample.

Age: Early Oligocene (partly based on palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Probably Zone NSR 7A or 7B of Gradstein & Bäckström (1996).

Description: Just a few specimens of *A. scitula* are recorded in the sole sample of this unit (Fig. A2).

Remarks: According to Gradstein & Bäckström (1996) *A. scitula* is known from the Lower Oligocene to Lower Miocene in the North Sea and from the Lower Oligocene to the basal Middle Miocene in the Haltenbanken area.

Planktonic fossil assemblages

UNDEFINED INTERVAL

Depth range: 760-780 m.

Material: Two ditch cutting samples.

Age: Late Pliocene (based on benthic foraminiferal evidence).

Lithostratigraphic unit: Naust Formation.

Description: This unit is barren of planktonic foraminifera.

NEOGLOBOQUADRINA ATLANTICA (SINISTRAL) ASSEMBLAGE

Definition: The top and base of the assemblage are taken at the highest/youngest and lowest/oldest occurrence of *N. atlantica* (sinistral).

Depth range: 780-830 m.

Material: Six ditch cutting samples.

Age: Early to Late Pliocene.

Lithostratigraphic units: Molo Formation and Naust Formation.

Correlation: *N. atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).

Description: This unit is characterized by a sparse (upper part) to moderately rich (lower part) fauna of planktonic

foraminifera. *G. bulloides* and *N. atlantica* (sinistral) occur most frequently. Other recorded taxa include *T. quinqueloba*, *G. glutinata*, *N. pachyderma* (dextral) and *N. atlantica* (dextral, Fig. A2).

Remarks: *N. atlantica* (sinistral) is known from the North Atlantic and on the Vøring Plateau in Late Miocene to Late Pliocene sediments. The LAD of this species is in both areas, approximately 2.4 Ma (Weaver & Clement 1986, Spiegler & Jansen 1989). *N. atlantica* (dextral) is known to occur in the uppermost Upper Pliocene and in the Upper Miocene on the Vøring Plateau (Spiegler & Jansen 1992, Müller & Spiegler 1993). Consequently, the sole specimen recorded here is either caved or reworked from Upper Miocene deposits.

UNDEFINED INTERVAL

Depth range: 830-860 m

Material: Three ditch cutting samples.

Age: Early Pliocene (based on palynological evidence).

Lithostratigraphic unit: Molo Formation.

Description: This interval is barren of planktonic foraminifera.

DIATOM SP. ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest consistent occurrence of pyritized diatoms. The base is marked by the highest/youngest occurrence of Diatom sp. 3 (King, 1983).

Depth range: 860-870 m.

Material: One ditch cutting sample.

Age: Early Oligocene (based on palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Subzone NSP 9c of King (1989).

Description: This interval contains a moderately rich planktonic fossil assemblage of pyritized diatoms and radiolaria (Fig. A2).

Remarks: No planktonic index fossils are recorded.

DIATOM SP. 3 ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of Diatom sp. 3. The base of the assemblage is undefined.

Depth range: 870-900 m.

Material: Four ditch cutting samples.

Age: Early Oligocene (partly based on palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Subzone NSP 9c of King (1989).

Description: This unit contains a moderately rich planktonic fossil assemblage of pyritized diatoms and radiolaria. Diatom sp. 3 is recorded in the upper part of the unit (Fig. A2).

Remarks: Diatom sp. 3 is known from the upper part of the Lower Oligocene to the lower part of the Lower Miocene in the North Sea area (King 1989).

Well 6407/9-1

Benthic foraminiferal assemblages

ELPHIDIELLA HANNAI ASSEMBLAGE

Definition: The top of the assemblage extends to the

uppermost investigated sample (650 m). The base is marked by the highest/youngest occurrence of *S. bulloides* and the highest consistent occurrence of *E. pygmeus*.

Depth range: 650-760 m.

Material: Eleven ditch cutting samples.

Age: Late Pliocene.

Lithostratigraphic unit: Naust Formation.

Correlation: Zone NSB 15 of King (1989), *Cibicides grossa* zone of Stratlab (1988) and Zone NSR 12 B of Gradstein & Bäckström (1996).

Description: This assemblage contains a moderately rich fauna of mainly calcareous foraminifera. *E. excavatum* and *C. lobatulus* occur most frequently. Other characteristic taxa include *E. hannai*, *C. grossus*, *N. affine*, *E. albi-umbilicatum* and *B. marginata* (Fig. A3).

Remarks: The occurrence of *E. hannai* and *C. grossus* indicates a Late Pliocene age (Doppert 1980, King 1989).

EPONIDES PYGMEUS – SPHAEROIDINA BULLOIDES ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest *E. pygmeus*. The base is marked by the lowest/oldest consistent occurrence of *E. pygmeus* and *S. bulloides*.

Depth range: 760-790 m.

Material: Four ditch cutting samples.

Age: Early Pliocene.

Lithostratigraphic unit: Molo Formation.

Correlation: Probably *Cibicides telegdi* – *Eponides pygmeus* – *Neogloboquadrina atlantica* (dextral) zone of Eidvin et al. (1998) and probably lower part of *Melonis* – *Trifarina* zone of Stratlab (1988).

Description: This unit contains a rich fauna of mainly calcareous foraminifera. *N. affine* and *C. teretis* occur most frequently. Other characteristic taxa include *E. pygmeus*, *S. bulloides*, *A. fluens*, *L. lammersi* and *P. bulloides* (Fig. A3).

Remarks: This unit is correlated with the *E. pygmeus* assemblages in wells 6407/9-5 and 6407/9-1 and is most likely of Early Pliocene age.

UNDEFINED INTERVAL

Depth range: 790-850 m.

Material: Four ditch cutting samples.

Age: Early Oligocene (lower part) and Late Miocene to Early Pliocene (upper part, based on palynological evidence and log correlation).

Lithostratigraphic unit: Brygge Formation and Molo Formation.

Description: This interval is nearly barren of benthic foraminifera and only a long range agglutinated form (*Bathysiphon* sp.) is recorded (Fig. A3).

GYROIDINA SOLDANII GIRARDANA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *G. soldanii girardana*. The base is marked by the highest/youngest occurrence of *T. alsatica*.

Depth range: 850-880 m.

Material: Three ditch cutting samples.

Age: Early Oligocene (partly based on palynological evidence).

Lithostratigraphic unit: Brygge Formation.

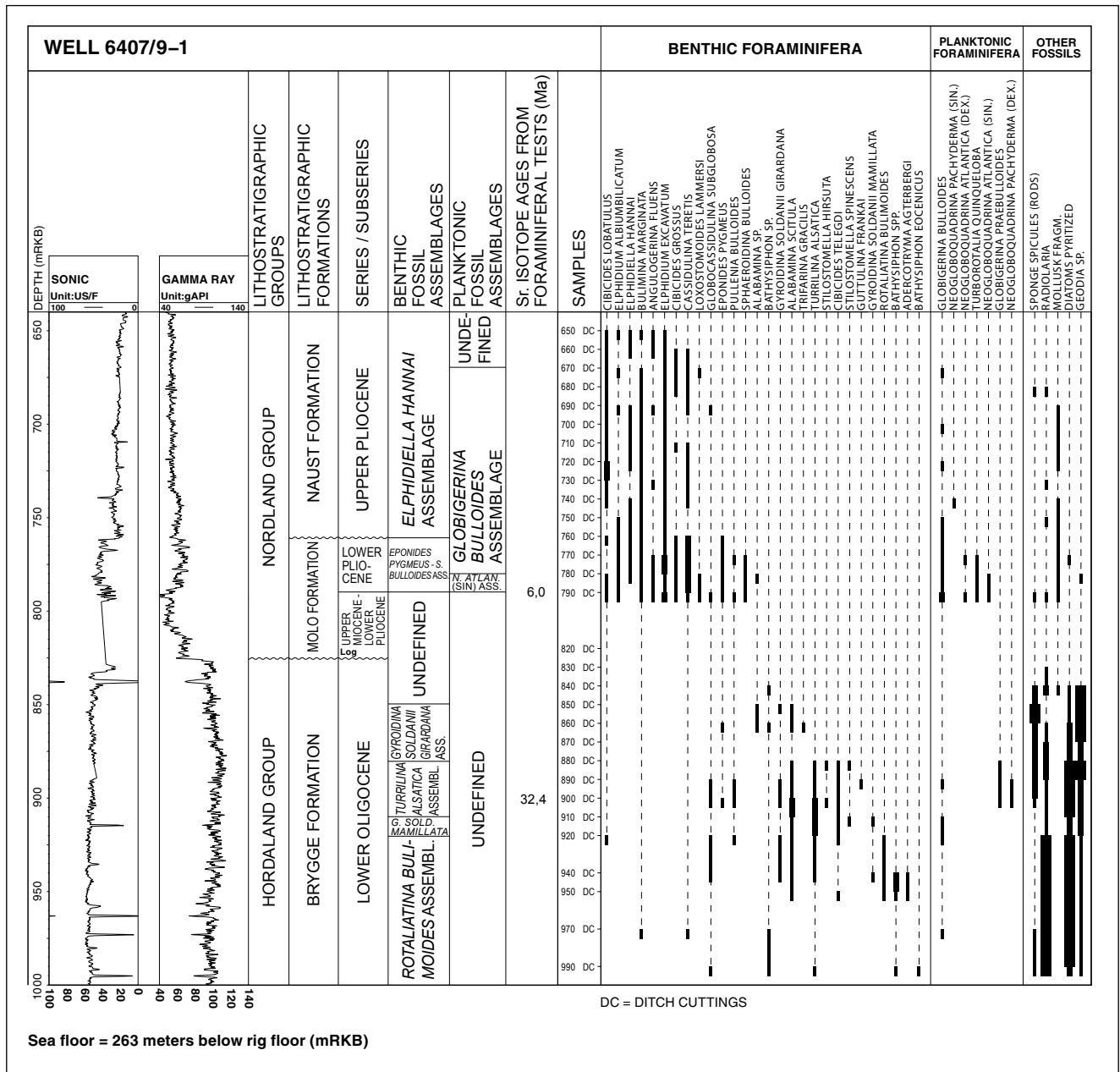


Fig. A3. Range chart of the most important benthic and planktonic foraminifera and other planktonic index fossils in the investigated interval of well 6407/9-1. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units, $\mu s/f$ = microseconds per foot.

Correlation: Zone NSB 7 of (King 1989) and probably Zone NSR 7A or 7B of Gradstein & Bäckström (1996).
Description: This interval contains a sparse benthic fauna of mainly calcareous foraminifera. Characteristic taxa include *G. soldanii girardana*, *E. pygmeus*, *A. scitula*, *Bathysiphon* sp. (agglutinated) and *Trifarina gracilis* (Fig. A3).
Remarks: *G. soldanii girardana* is known from the Lower Oligocene to the lowermost Lower Miocene succession in the North Sea according to (King, 1989), and from the Upper Eocene to the lowermost Lower Miocene in the same area according to Gradstein & Bäckström (1996). *T. gracilis* is described from Lower Oligocene to Lower Miocene deposits on the Norwegian continental shelf according to Skarbø & Verdenius (1986).

TURRILINA ALSATICA ASSEMBLAGE
Definition: The top of the assemblage is taken at the highest/youngest occurrence of *T. alsatica*. The base is marked by the highest/youngest occurrence of *G. soldanii mamillata*.
Depth range: 880-910 m
Material: Three ditch cutting samples.
Age: Early Oligocene (partly based on Sr. analyses).
Lithostratigraphic unit: Brygge Formation.
Correlation: Probably Zone NSB 7 of King (1989) and probably Zone NSR 7A or 7B of Gradstein & Bäckström (1996).
Description: This unit contains a moderately rich benthic fauna of mainly calcareous foraminifera. *T. alsatica* and *A. scitula* occur most frequently. Other characteristic species include *G. subglobosa*, *P. bulloides*, *E. pygmeus*, *C.*

telegdi, *G. soldanii girardana*, *Stilostomella hirsuta*, *Stilostomella spinescens* and *Guttulina frankei* (Fig. A3).

Remarks: According to Gradstein & Bäckström (1996) *A. scitula* is known from the Lower Oligocene to Lower Miocene in the North Sea and from the Lower Oligocene to the basal Middle Miocene in the Haltenbanken area. *T. alsatica* is described from the Lower Oligocene to lowermost Lower Miocene in the North Sea area according to King (1989), and from Lower Oligocene to lowermost Upper Oligocene sediments in the North Sea and Haltenbanken areas according to Gradstein & Bäckström (1996). *S. hirsuta*, *S. spinescens* and *G. frankei* are described from the upper part of the Lower Oligocene in Denmark (Ulleberg 1974).

GYROIDINA SOLDANII MAMILLATA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *G. soldanii mamillata*. The base is marked by the highest/youngest occurrence of *R. bulimoides*.

Depth range: 910-920 m.

Material: One ditch cutting sample.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSB 7 of King (1989) and Zone NSR 7A or 7B of Gradstein & Bäckström (1996).

Description: This assemblage contains a moderately rich fauna of mainly calcareous foraminifera. *T. alsatica* occurs most frequently. Other recorded taxa include *G. soldanii mamillata*, *A. scitula* and *C. telegdi* (Fig. A3).

Remarks: *G. soldanii mamillata* is known from the Lower Oligocene to the lowermost Upper Oligocene in the North Sea area according to King (1989). According to Gradstein & Bäckström (1996) this species is known from Eocene to Lower Oligocene deposits in the same area.

ROTALIATINA BULIMOIDES ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *R. bulimoides*. The base of the assemblage is undefined.

Depth range: 920-990 m (lowermost investigated sample).

Material: Five ditch cutting samples.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSB 7 of King (1989), *Rotaliatina bulimoides* zone of Stratlab (1988) and probably Zone NSR 7A or 7B of Gradstein & Bäckström (1996).

Description: This assemblage contains a moderately rich benthic fauna of calcareous and agglutinated foraminifera. Characteristic calcareous taxa include *R. bulimoides*, *T. alsatica*, *A. scitula* and *S. spinescens* and agglutinated forms include *Bathysiphon eocenicus*, *Bathysiphon* spp., *Adercotryma agterbergi* and *Glomospira* sp. (Fig. A3).

Remarks: *R. bulimoides* is recorded from the Lower Oligocene to the lowermost Upper Oligocene in the North Sea according to King (1989) and from the Eocene to the Lower Oligocene in the North Sea and Haltenbanken area according to Gradstein & Bäckström (1996). *A. agterbergi* is known from Eocene to Lower Oligocene deposits in the North Sea and Haltenbanken area according to Gradstein & Bäckström (1996).

Planktonic fossil assemblages

UNDEFINED INTERVAL

Depth range: 650-670 m.

Material: Two ditch cutting samples.

Age: Late Pliocene (based on benthic foraminiferal evidence).

Lithostratigraphic unit: Naust Formation.

Description: This unit is barren of planktonic foraminifera.

GLOBIGERINA BULLOIDES ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *G. bulloides*. The base is marked by the highest/youngest occurrence of *N. atlantica* (sinistral).

Depth range: 670-780 m.

Material: Eleven ditch cutting samples.

Age: Early to Late Pliocene.

Lithostratigraphic unit: Molo Formation and Naust Formation.

Correlation: *G. bulloides* Zone of Weaver & Clement (1986) and probably *N. atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).

Description: Planktonic foraminifera are quite sparse in this unit. *G. bulloides* is recorded throughout. *N. pachyderma* (sinistral) is recorded in one sample in the middle part of the unit and a few specimens of *T. quinqueloba* and *N. atlantica* (dextral, one specimen) are recorded in one sample in the lower part of the unit (Fig. A3).

Remarks: A *G. bulloides* Zone is described from the North Atlantic (DSDP Leg 94) in Pliocene sediments as young as 2.2 Ma (Weaver & Clement 1986). On the Vøring Plateau *G. bulloides* is common in Pliocene deposits older than 2.4 Ma (Spiegler & Jansen 1989). *G. bulloides* is also common in the warmest interglacials of the last 0.5 My in the North Atlantic (Kellogg 1977). *N. atlantica* (dextral) is known to occur in the uppermost Upper Pliocene and in the Upper Miocene on the Vøring Plateau (Spiegler & Jansen 1992, Müller & Spiegler 1993). Consequently, the sole specimen recorded here is either caved or reworked from Upper Miocene deposits.

NEOGLOBOQUADRINA ATLANTICA (SINISTRAL) ASSEMBLAGE

Definition: The top and base of the assemblage is taken at the highest/youngest and lowest/oldest occurrence of *N. atlantica* (sinistral).

Depth range: 780-790 m.

Material: Two ditch cutting samples.

Age: Early Pliocene.

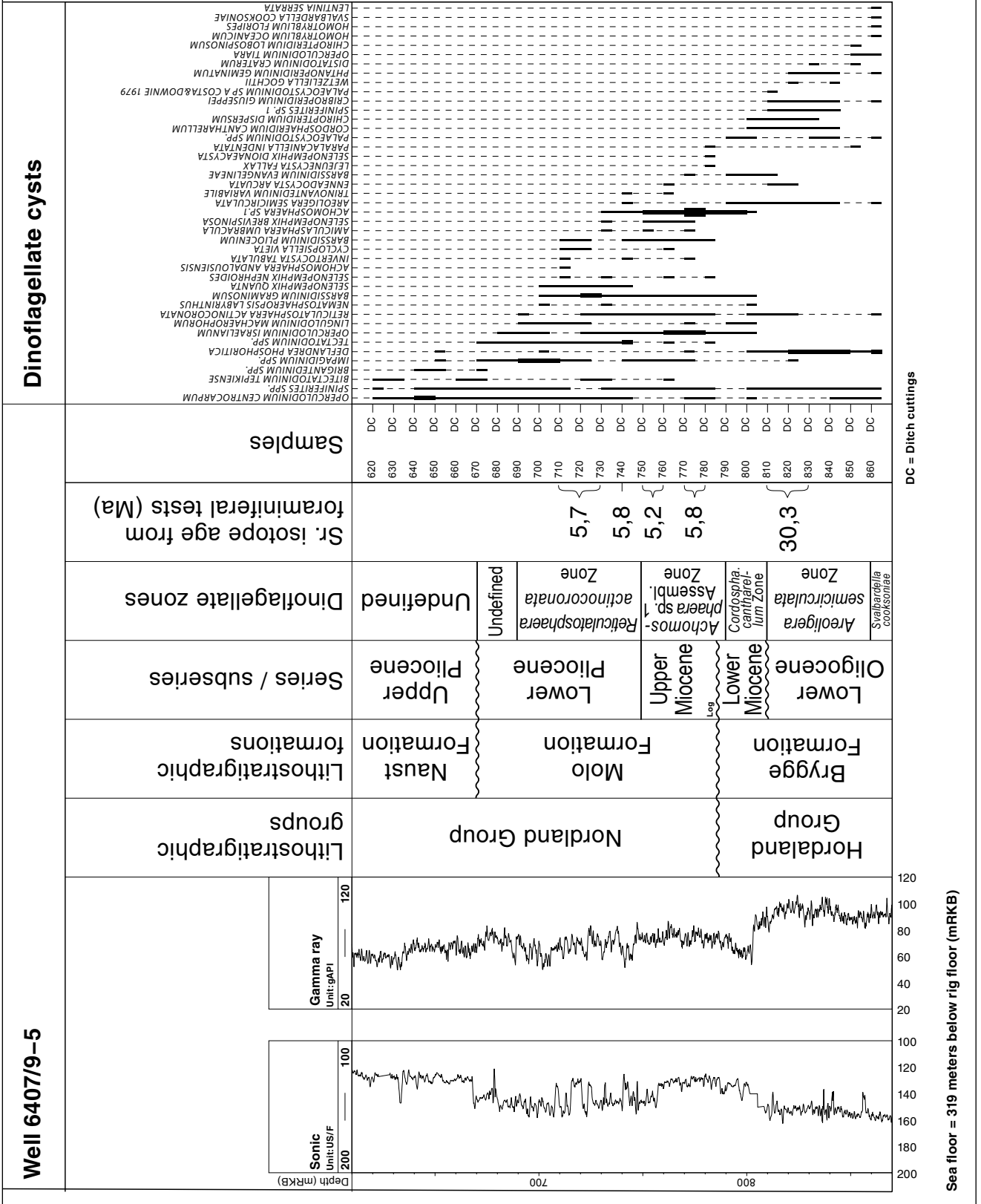
Lithostratigraphic unit: Molo Formation.

Correlation: *N. atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).

Description: This interval is characterized by a sparse fauna of planktonic foraminifera. Recorded taxa include *G. bulloides*, *N. atlantica* (sinistral), *T. quinqueloba* and *N. atlantica* (dextral, one specimen, Fig. A3).

Remarks: *N. atlantica* (sinistral) is known from the North Atlantic and on the Vøring Plateau in Late Miocene to Late Pliocene sediments. The sole specimen of *N. atlantica* (dextral) is either caved or reworked.

Fig. A4. Range chart of the most important dinoflagellate index fossils in the investigated interval of well 6407/9-5. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. MRKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units, μsif = microseonds per foot.



UNDEFINED INTERVAL

Depth range: 790-990 m.

Material: 15 ditch cutting samples.

Age: Early Oligocene in the lower part and Late Miocene to Early Pliocene in the upper part (based on benthic foraminiferal and palynological evidence and Sr. analyses).

Lithostratigraphic unit: Brygge Formation and Molo Formation.

Description: This interval contains a moderately rich planktonic fossil assemblage dominated by pyritized diatoms and radiolaria (Fig. A3), but no radiolaria or diatom index fossils are recorded. A few planktonic foraminifera are recorded in some samples including *G. bulloides*, *N. pachyderma* (dextral) and *Globigerina praebulloides*. The first two species are probably caved.

Remarks: *G. praebulloides* is known from Oligocene to lower Upper Miocene deposits in the North Atlantic (Poore 1979) and from Oligocene to lower Middle Miocene deposits in the North Sea (Gradstein & Bäckström 1996). Poore (1979) suggests that a clear separation of *G. praebulloides* and *G. bulloides* may be difficult in extra-tropical regions.

Dinoflagellate cyst zones

The investigated Upper Pliocene succession contains few *in situ* dinoflagellate cysts, but common to abundant reworked older Cenozoic and Mesozoic specimens. More rich and diverse marine microfloras are encountered in the Lower Pliocene strata, and the abundance and diversity increases further downward into Upper and Lower Miocene deposits. A relative rich and diverse dinoflagellate cyst assemblage is also recovered from the Lower Oligocene sequence in the wells. The poor recovery of *in situ* dinoflagellate cysts in the Upper Pliocene succession provides no mean for a palynostratigraphic zonation of these strata. The recovered marine micro flora allows, however, a good biostratigraphic breakdown of the Lower Pliocene to Lower Oligocene interval in the Draugen Field wells 6407/9-5, -/9-2 and -/9-1.

Well 6407/9-5

UNDEFINED INTERVAL

Depth range: 620-670 m.

Material: Seven ditch cutting samples.

Age: Late Pliocene (based on benthic and planktonic foraminiferal evidence).

Lithostratigraphic unit: Naust Formation.

Description: This interval contains only a few *in situ* dinoflagellate cysts, including *Brigantedinium* spp., *Bitectatodinium tepikiense*, *Operculodinium centrocarpum*, *Impagidinium* spp. and *Spiniferites* spp. (Fig. A4). The unit contains reworked Palaeogene, Cretaceous and Jurassic dinoflagellate cysts.

Remarks: There are no age-diagnostic dinoflagellate cyst species and the age of this interval is determined by the presence of the *Elphidella hannai* foraminiferal assemblage.

UNDEFINED INTERVAL

Depth range: 670-690 m.

Material: Three ditch cutting samples.

Age: Early Pliocene (partly based on benthic and planktonic foraminiferal evidence).

Lithostratigraphic unit: Molo Formation.

Description: This interval contains only a few *in situ* dinoflagellate cysts (typically with less than 5 species present), but common to abundant reworked older Cenozoic and Mesozoic specimens. The *in situ* marine microfloras include *Brigantedinium* spp., *Bitectatodinium tepikiense*, *Operculodinium centrocarpum*, *Operculodinium israelianum*, *Impagidinium* spp., *Tectatodinium* spp. and *Spiniferites* spp. (Fig. A4).

Remarks: There are no age-diagnostic dinoflagellate cyst species and the age of this interval is determined by the presence of the *Eponides pygmeus* foraminiferal assemblage. The recovery of the thermophilic dinoflagellate species *Operculodinium israelianum* at 680-690 m may, however, be taken as an indicator of somewhat warmer and thus Early-Mid Pliocene climatic conditions. This species is also consistently present in the underlying Lower Pliocene strata.

RETICULATOSPHAERA ACTINOCORONATA ZONE

Definition: The body of strata between the highest/youngest occurrence of *Reticulatosphaera actinocoronata* and the highest/youngest occurrence of *Achomosphaera* sp. 1.

Depth range: 690-750 m.

Material: Seven ditch cutting samples.

Age: Early Pliocene.

Lithostratigraphic unit: Molo Formation.

Description: This interval contains moderately rich and diverse assemblages of *in situ* dinoflagellate cysts. Reworked Paleogene, Cretaceous and Jurassic dinoflagellate cysts are relatively common. Characteristic *in situ* species include *Amiculosphaera umbracula*, *Barssidinium graminosum*, *Barssidinium pliogenicum*, *Impagidinium* spp., *Tectatodinium* spp., *Operculodinium israelianum*, *Lingulodinium machaerophorum*, *Reticulatosphaera actinocoronata*, *Selenopemphix* spp. and *Trinovantedinium variabile* (Fig. A4).

Remarks: Poulsen et al. (1996) used the last occurrence datum of *Reticulatosphaera actinocoronata* to define the upper boundary of their Pli1 Zone in ODP Holes 908 and 909. This zone was dated as Zanclean, i.e. time equivalent to calcareous nannoplankton zones NN12-14.

ACHOMOSPHAERA SP. 1 ASSEMBLAGE ZONE

Definition: The body of strata defined by the presence of *Achomosphaera* sp. 1.

Depth range: 750-790 m.

Material: Four ditch cutting samples.

Age: Late Miocene-Early Pliocene (partly based on benthic foraminiferal and planktonic fossil evidence).

Lithostratigraphic unit: Molo Formation.

Description: The ditch cutting samples from this zone contains moderate diversity of dinoflagellate cysts, including common to abundant *Achomosphaera* sp. 1, together

with *Amiculosphaera umbracula*, *Barssidinium graminosum*, *Barssidinium pliogenicum*, *Barssidinium evangelinae*, *Cyclopsiella vieta*, *Selenopemphix* spp. and common *Operculodinium israelianum* (Fig. A4).

Remarks: *Achomosphaera* sp. 1 has previously been consistently recorded in Upper Miocene-Lower Pliocene strata at ODP Sites 907, 908 and 909 in the Norwegian-Greenland Sea (Poulsen et al. 1996).

CORDOSPHAERIDIUM CANTHARELLUM ZONE

Definition: The body of strata between the highest/youngest occurrence of *Cordosphaeridium cantharellum* and the highest/youngest occurrence of *Caligodinium amiculum*.

Depth range: 790-810 m.

Material: Two ditch cutting samples.

Age: Mid Early Miocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a rather poor and low and diverse assemblage of *in situ* dinoflagellate cysts. The samples from this zone are otherwise obscured by reworked Palaeogene and caved Neogene dinoflagellate cysts. The recovered *in situ* key species include *Cordosphaeridium cantharellum*, *Palaeocystodinium* spp. and *Thalassiphora pelagica* (Fig. A4).

Remarks: Powell (1992) calibrated the LAD of *Cordosphaeridium cantharellum* to the lower NN 4 Zone in the British Tertiary, while de Verteuil & Norris (1996) placed the LAD in the upper NN 2 in their study on the Miocene of the U.S. Atlantic Margin. Williams and Manum (1999) gave an age of 17.95 Ma for the LAD of *C. cantharellum*, which is in agreement with a calibration to the lower NN 4 Zone.

AREOLIGERA SEMICIRCULATA ZONE

Definition: The body of strata between the highest/youngest occurrence of *Areoligera semicirculata* and the highest/youngest occurrence of *Svalbardella cooksoniae*.

Depth range: 810-860 m.

Material: One ditch cutting sample.

Age: Early Oligocene (partly based on benthic foraminiferal evidence and Sr. analyses).

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a moderately rich and diverse marine microflora. Characteristic for this zone in well 6407/9-5 is the acme of *Deflandrea phosphoritica*, and the presence of *Chiropteridium lobospinosum* and *Spiniferites* sp. 1 which are restricted to this zone in the well (Fig. A4).

Remarks: According to Powell (1992) the LAD of *A. semicirculata* lies within the lower NP25 calcareous nannoplankton biozone in Britain and in the North Sea area. Manum et al. (1989) found that the LAD of this species (named *Glaphyrocysta intricata* in their publication) corresponded to the upper boundary of their Early/Late Oligocene *Areosphaeridium? actinocoronatum* in ODP Hole 643 in the Norwegian Sea. The LAD of this species also defines the upper boundary of the Oli4 Zone of Poulsen et al. (1996) as defined in ODP Hole 908 on the Hovgaard Ridge between Svalbard and NE Greenland.

SVALBARDELLA COOKSONIAE ZONE

Definition: The body of strata between the highest/youngest occurrence of *Svalbardella cooksoniae* and the highest/youngest occurrence of *Areosphaeridium dictyoplokkus*.

Depth range: 860 m.

Material: One ditch cutting sample.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a fairly rich and diverse marine microflora, with *Svalbardella cooksoniae*, *Deflandrea phosphoritica*, *Lentinia serrata* and *Homotrybilum oceanicum* being characteristic species (Fig. A4).

Remarks: Manum et al. (1989) found that *Svalbardella cooksoniae* was restricted to their Early Oligocene *Chiropteridium lobospinosum* Zone in ODP Hole 643 in the Norwegian Sea.

Well 6407/9-2

UNDEFINED INTERVAL

Depth range: 760-820 m.

Material: Six ditch cutting samples.

Age: Early to Late Pliocene (partly based on benthic and planktonic foraminiferal evidence).

Lithostratigraphic unit: Upper part of Molo Formation and Naust Formation.

Description: This interval contains only a few *in situ* dinoflagellate cysts, but common to abundant reworked older Cenozoic and Mesozoic specimens. The *in situ* marine microfloras include *Achomosphaera andalousiensis*, *Bitectatodinium tepikiense*, *Operculodinium centrocarpum*, *Filisphaera filifera* spp., *Lingulodinium machaerophorum* and *Spiniferites* spp. (Fig. A5).

Remarks: The single record of *Filisphaera filifera* at 780 m suggests a correlation to the Upper Pliocene *Filisphaera filifera* Zone of Smelror et al. (in press.). Otherwise the age of this interval is determined by the presence of the *Elphidella hannai* foraminiferal assemblage.

ACHOMOSPHERA SP. 1 ASSEMBLAGE ZONE

Definition: The body of strata defined by the presence of *Achomosphaera* sp. 1.

Depth range: 820-860 m.

Material: Four ditch cutting samples.

Age: Early Pliocene (partly based on benthic foraminiferal evidence).

Lithostratigraphic unit: Molo Formation.

Description: The samples from this zone have a moderate diversity of dinoflagellate cysts, including common to abundant *Achomosphaera* sp. 1, together with *Amiculosphaera umbracula*, *Barssidinium graminosum*, *Cyclopsiella vieta*, *Impagidinium* spp., *Reticulosphaera actinocoronata*, *Operculodinium janduchenei* and common *Operculodinium israelianum* (Fig. A5). The zone also contains common reworked Early-Middle Miocene, Paleogene, Cretaceous and Jurassic dinoflagellate cysts.

Remarks: *Achomosphaera* sp. 1 has previously been consistently recorded in Upper Miocene-Lower Pliocene

strata at ODP Sites 907, 908 and 909 in the Norwegian-Greenland Sea (Poulsen et al. 1996).

AREOLIGERA SEMICIRCULATA ZONE

Definition: The body of strata between the highest/youngest occurrence of *Areoligera semicirculata* and the highest/youngest occurrence of *Svalbardella cooksoniae*.

Depth range: 860-880 m.

Material: Two ditch cutting samples.

Age: Early Oligocene (partly based on log correlation).

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a moderately rich and diverse marine microflora. An acme of *Deflandrea phosphoritica* and *Cordosphaeridium cantharellum* is found in the lower part of the zone. *Areoligera semicirculata* is common throughout the zone (Fig. A5). The sample at 860 m contains reworked Early Cretaceous dinoflagellate cysts.

Remarks: See remarks given under the *Areoligera semicirculata* Zone in well 6407/9-5.

SVALBARDELLA COOKSONIAE ZONE

Definition: The body of strata between the highest/youngest occurrence of *Svalbardella cooksoniae* and the highest/youngest occurrence of *Areosphaeridium dictyoplokkus*.

Depth range: 880-890 m.

Material: Two ditch cutting samples.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a fairly rich and diverse marine microflora, with *Svalbardella cooksoniae*, *Deflandrea phosphoritica* and *Glaphyrocysta semitecta* (Fig. A5). The lowermost sample at 890 m also contains reworked Middle-Late Jurassic dinoflagellate cysts.

Remarks: Manum et al. (1989) found that *Svalbardella cooksoniae* was restricted to their Early Oligocene *Chiropteridium lobospinosum* Zone in ODP Hole 643 in the Norwegian Sea.

Well 6407/9-1

UNDEFINED INTERVAL

Depth range: 750-760 m.

Material: Two ditch cutting samples.

Age: Late Pliocene (based on benthic and planktonic foraminiferal evidence).

Lithostratigraphic unit: Naust Formation.

Description: This interval contains only few *in situ* dinoflagellate cysts, but abundant reworked older Cenozoic and Mesozoic specimens. The *in situ* marine microfloras include *Bitectatodinium tepikiense*, *Operculodinium centrocarpum*, *Lingulodinium machaerophorum* and *Spiniferites* spp. (Fig. A6).

Remarks: There are no age-diagnostic dinoflagellate cyst species and the age of this interval is determined by the presence of the *Elphidella hannai* foraminiferal assemblage.

RETICULATOSPHAERA ACTINOCORONATA ZONE

Definition: The body of strata between the highest/youngest occurrence of *Reticulosphaera actinocoronata* and

the highest/youngest occurrence of *Achomosphaera* sp. 1.

Depth range: 760-790 m.

Material: Seven ditch cutting samples.

Age: Early Pliocene

Lithostratigraphic unit: Molo Formation.

Description: This interval contains moderately rich and diverse assemblages of *in situ* dinoflagellate cysts. Characteristic species include *Amiculospaera umbracula*, *Barssidinium graminosum*, *Operculodinium israelianum*, *Reticulosphaera actinocoronata*, and common *Impagidinium* sp. A (Fig. A6). Reworked Palaeogene, Cretaceous and Jurassic dinoflagellate cysts are also present.

Remarks: The foraminifera suggest that the sample at 760 m belongs to the Upper Pliocene interval. The presence of *Reticulosphaera actinocoronata*, together with the thermophilic species *Operculodinium israelianum*, suggests, however, an Early Pliocene age for this sample. Alternatively these taxa could be reworked.

ACHOMOSPHAERA SP. 1 ASSEMBLAGE ZONE

Definition: The body of strata defined by the presence of *Achomosphaera* sp. 1.

Depth range: 790-840 m.

Material: Three ditch cutting samples.

Age: Early Oligocene (lowermost part, based on log correlation) and Late Miocene-Early Pliocene.

Lithostratigraphic unit: Upper part of Brygge Formation and Molo Formation.

Description: The ditch cutting sample from this zone contains a moderate diversity of dinoflagellate cysts, including common *Achomosphaera* sp. 1, together with *Barssidinium graminosum* (Fig. A6). The zone also includes reworked Early-Middle Miocene, Palaeogene and Early Cretaceous dinoflagellate cysts.

Remarks: *Achomosphaera* sp. 1 has previously been consistently recorded in Lower Pliocene-Upper Miocene strata at ODP Sites 907, 908 and 909 in the Norwegian-Greenland Sea (Poulsen et al. 1996). The occurrence of *Achomosphaera* sp. 1 in Lower Oligocene deposits is probably caved.

AREOLIGERA SEMICIRCULATA ZONE

Definition: The body of strata between the highest/youngest occurrence of *Areoligera semicirculata* and the highest/youngest occurrence of *Svalbardella cooksoniae*.

Depth range: 840-850 m.

Material: Two ditch cutting samples.

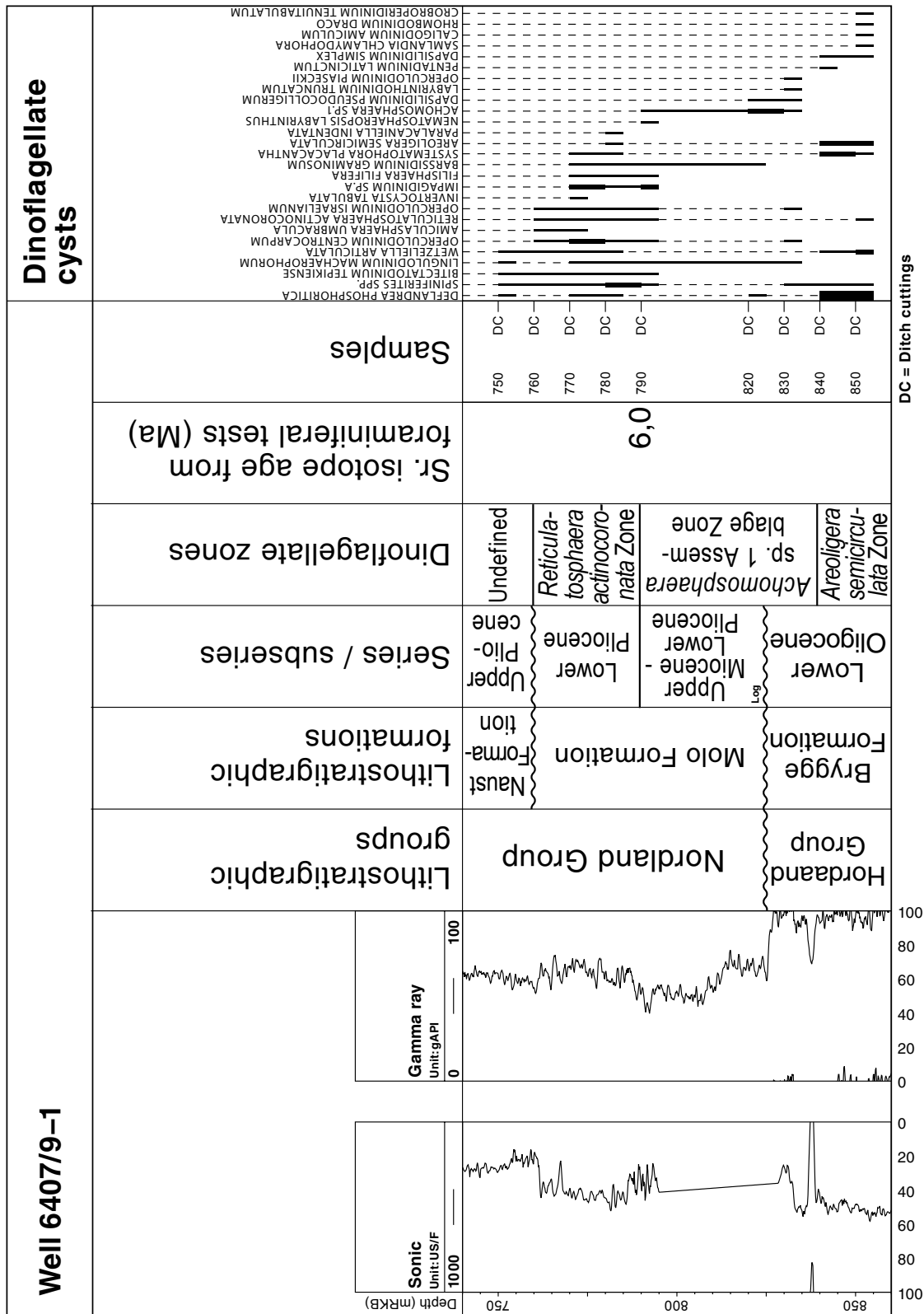
Age: Early-Late Oligocene (partly based on benthic foraminiferal evidence).

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a moderate rich and diverse marine microflora. Characteristic for this zone in well 6407/9-1 is the acme of *Deflandrea phosphoritica* and *Systematophora placacantha*, combined with common *Areoligera semicirculata*. Other characteristic species include *Dapsilidinium simplex*, common *Wetzeliella articulata*, *Rhombodinium draco* and *Samlandia chlamydophora* (Fig. A6).

Remarks: See remarks given under the *Areoligera semicirculata* Zone in well 6407/9-5.

Fig. A6. Range chart of the most important dinoflagellate index fossils in the investigated interval of well 6407/9-1. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. MRKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units, μsif = microseonds per foot.



Sea floor = 263 meters below rig floor (mRKB)

Well 6407/9-1

Dinoflagellate cysts

Samples

Sr. isotope age from foraminiferal tests (Ma)

Dinoflagellate zones

Series / subseries

Lithostratigraphic formations

Lithostratigraphic groups

Gamma ray
Unit: gAPI

Sonic
Unit: μsif

DC = Ditch cuttings

Sea floor = 263 meters below rig floor (mRKB)

Strontium isotope stratigraphy

Four intervals from well 6407/9-5 and two intervals from well 6407/9-1 were analysed for strontium isotopes. 16 to 60 tests of calcareous foraminifera were used for the analyses. A problem with obtaining strontium isotope ages from foraminifera is the common presence of impurities in the foraminiferal chambers. Careful cleaning is sometimes not able to remove these, and this can influence the strontium rates and consequently the datings (Eidvin et al. 1999). In this work, we have used the look-up table presented by Howard & McArthur (1997: version 3:10/99) for numerical age assignments, and all results are corrected to NIST (National Institute of Standards and Technology) 987 = 0.710248.

In well 6407/9-5 presumed *in situ* tests of *G. subglobosa*, *S. bulloides* and *M. pseudotepida* were picked from the interval 710-730 m. The sample gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.709010. On the seawater Sr isotope curve of Howarth & McArthur (1997) this $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio corresponds to an age of approximately 5.7 Ma. Tests of *G. subglobosa* and *S. bulloides* from the sample at 740 m gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.709006 corresponding to an age of approximately 5.8 Ma. Tests of the same foraminiferal species from the interval 750-760 m and 770-780 m gave corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratios of 0.709030 and 0.709003 corresponding to ages of approximately 5.8 and 5.2 Ma respectively. Tests of *G. soldanii girardana*, *T. alsatica*, *F. budensis*, *Bolivina cf. antique* and *A. scitula* from the interval 810-830 m gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.707972 corresponding to an age of approximately 30.3 Ma (Table 1, Fig. A1).

In well 6407/9-1 tests of *S. bulloides*, *E. pygmeus*, *Cerato-bulimina* sp. and *G. subglobosa* from the sample at 790 m gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.708981 corresponding to an age of approximately 6.0 Ma. Tests of *Bolivina cf. antique*, *T. alsatica*, *A. scitula* and *G. soldanii girardana* from the sample at 900 m gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.707876 corresponding to an age of approximately 32.4 Ma (Table 1, Fig. A3).

Lithology

Upper Pliocene (Naust Formation)

The ditch cutting samples from this unit contain a clay-rich diamicton which is rich in sand, silt and pebbles. The pebbles are mostly of crystalline lithology, but some of sedimentary rocks are also recorded. All these pebbles are interpreted as ice-rafted. Glacio-marine sediments of the Vøring Plateau have been the subject of studies by Jansen & Sjøholm (1991) and Fronval & Jansen (1996). These studies demonstrated the presence of ice-rafted material in sediments as old as 12.6 Ma. The frequency of ice-rafted material increases during the period between 7.2 and 6.0 Ma, but remains relatively low between 6.0 Ma and 2.78 Ma. A marked increase in the supply of such material after about 2.78 Ma reflects the expansion

of the northern European glaciers. The maximum age of the Naust Formation in the studied wells is therefore assigned to be 2.78 Ma.

Upper Miocene and Lower Pliocene (Molo Formation)

The ditch cutting samples from these units contain mainly glauconitic sand, silt and clay. Some pebbles are also recorded, but these are probably caved.

Oligocene and Lower Miocene (Brygge Formation)

These sections contain mostly fine grained material. Mostly clay is found in the samples, but small amounts of silt and glauconitic sand are also recorded. The latter may be caved from the immediately overlying Molo Formation.

Stratigraphical conclusion for wells 6407/9-5, 6407/9-2 and 6407/9-1

Upper Pliocene (Naust Formation)

The lower part of the Upper Pliocene is investigated in all wells and corresponds to the benthic foraminifera *E. hannai* assemblage (Fig. 10). In well 6407/9-5 these deposits correspond to planktonic foraminifera *T. quinqueloba*, *G. bulloides* and *N. atlantica* (sinistral, upper part) assemblages. In well 6407/9-2 the Upper Pliocene corresponds to the planktonic foraminifera *N. atlantica* (sinistral) assemblage (upper part) and in well 6407/9-1 to the planktonic foraminifera *G. bulloides* assemblage (upper part). A large proportion of ice-rafted detritus in the deposits indicates that the sediments were deposited after the marked increase in the supply of ice-rafted detritus to the Norwegian Sea, which started at about 2.78 Ma (Fronval & Jansen 1996, Fig. 10).

Lower Pliocene (Molo Formation)

The Lower Pliocene is observed in all wells (Fig. 10). In well 6407/9-5 these deposits correspond to the benthic foraminifera *E. pygmeus* and *M. pseudotepida* assemblages, the planktonic foraminifera *N. atlantica* (sinistral) assemblage (lower part) and the dinoflagellate *R. actinocronata* Zone. In well 6407/9-2 the Lower Pliocene corresponds to the benthic foraminifera *E. pygmeus* and *M. pseudotepida* assemblages, the planktonic foraminifera *N. atlantica* (sinistral) assemblage (lower part) and the dinoflagellate *Achomosphaera* sp. 1 Assemblage Zone. In well 6407/9-1 these deposits correspond to the benthic foraminifera *E. pygmeus* – *S. bulloides* assemblage, the planktonic foraminiferal *G. bulloides* (lower part) and *N. atlantica* (sinistral) assemblages and the dinoflagellate *R. actinocronata* Zone. Two Sr. analyses in the lower part of the unit in well 6407/9-5 give ages of approximately 5.7 and 5.8 Ma. This is slightly older than the Early Pliocene/Late Miocene boundary according to Berggren et al. (1995, approximately 5.3 Ma), but is within the accuracy of the method (Eidvin et al. 1999).

Upper Miocene to Lower Pliocene (Molo Formation)

Sediments given a general Late Miocene to Early Pliocene age are only observed in well 6407/9-1 corresponding to the dinoflagellate *Achomosphaera* sp. 1 Assemblage Zone (Fig. 10). A Sr. analysis in the upper part of the unit gives an age of approximately 6.0 Ma (Fig. A3).

Upper Miocene (Molo Formation)

Upper Miocene deposits are only recorded in the well 6407/9-5 corresponding to the benthic foraminifera *G. subglobosa* assemblage (upper part), the planktonic fossil assemblage *B. metzmacheri* and the dinoflagellate *Achomosphaera* sp. 1 Assemblage Zone (Fig. 10). Two Sr. analyses in the upper part of this unit give ages of approximately 5.2 and 5.8 Ma (Fig. A1). These ages are somewhat younger than the occurrence of *B. metzmacheri* in the North Atlantic and Norwegian Sea (approximately 10.0–8.7 My, Spiegler & Müller 1992, Müller & Spiegler 1993). The young Sr. isotope ages may be explained by the fact that the samples could have contained caved tests, since the analysed benthic foraminiferal taxa also occur in the immediately overlying assemblage. Unfortunately, the *B. metzmacheri* tests were too small and too few to be used for the analyses.

Lower Miocene (Brygge Formation)

Lower Miocene sediments are observed in well 6407/9-5 corresponding to the planktonic fossil Diatom sp. 4 assemblage and the dinoflagellate *C. cantharellum* Zone.

Lower Oligocene

Lower Oligocene deposits are recorded in all wells (Fig. 10). In well 6407/9-5 these sediments correspond to the benthic foraminiferal *R. bulimoides* assemblage and the dinoflagellate *A. semicirculata* and *S. cooksoniae* zones. In well 6407/9-2 this unit corresponds to the benthic foraminiferal *S. compressa* and *A. scitula* assemblages, the planktonic fossil Diatom sp. and Diatom sp. 3 assemblages and the dinoflagellate *A. semicirculata* and *S. cooksoniae* zones. In well 6407/9-1 the Lower Oligocene corresponds to benthic foraminiferal *G. soldanii girardana*, *T. alsatica*, *G. soldanii mamillata* and *R. bulimoides* assemblages and the dinoflagellate *Achomosphaera* sp. 1 Assemblage Zone (lower part) and *A. semicirculata* Zone. The occurrence of *Achomosphaera* sp. 1 in the Lower Oligocene is probably caved. One Sr. analysis in the upper part of the unit in well 6407/9-5 gives an age of approximately 30.3 Ma, and one analysis somewhat lower down in the unit in well 6407/9-1 gives an age of 32.4 Ma. These ages confirm the bistratigraphic correlations.

Shallow cores in the Nordland Ridge area*Previous studies*

Sediments from the seismic unit IX, corresponding to

the coastal deposits, were sampled with vibro corer, piston corer and grab by the Continental Shelf Institute (IKU). Lithological and micropaleontological descriptions and interpretations of the sediments were reported in the unpublished report of Skarbø et al. (1983). The main results were published in Bugge et al. (1984). These authors gave the coastal deposits an Early Oligocene age. Our evaluation of the dinoflagellate flora, described in Skarbø et al. (1983), indicates that taxa are forms with a range of Oligocene to Middle Miocene. However, all taxa are probably reworked in the light of the new ages given to the distal part of the coastal deposits, in the wells 6407/9-1, /9-2 and /9-5, in the Draugen Field.

Sites

According to Skarbø et al. (1983) sediments were sampled at the sites B82-1984 (66°48'39"N, 10°42'13"E, vibro corer), B82-1985/2 (66°46'17"N, 10°43'43"E, piston corer), B82-186/5 (66°43'21"N, 10°38'01"E, vibro corer), B82-187/4 (66°43'26"N, 10°32'43"E, grab), B82-189/2 (66°38'03"N, 10°33'33"E, vibro corer) and B82-191/2 (66°37'53", 10°47'53", piston corer, Fig. 1).

Lithology

Skarbø et al. (1983) describe the sediments as rust-stained, yellow sand with rounded pebbles. Quartz and goethite dominate, but glauconite is very frequent in the fine to medium fractions.

Palynological investigations

According to Skarbø et al. (1983) six samples were analysed from the sites within this seismic unit (B82-185/2 (two samples), B82-186/5, B82-187/4, B82-189/2 and B82-191/2). None of the samples yielded age diagnostic dinoflagellate cysts of Late Miocene to Early Pliocene age.

A rich and diverse assemblage of reworked dinoflagellate cysts with an Oligocene-Middle Miocene affinity was recorded in the sample from B82-187/4 including *Spiniferites ramosus* subsp. *granomenbranaceous*, *Thalassiphora* cf. *delicata*, *Tectatodinium* cf. *pelliferum* and particularly *Palaeocystodinium golzowense*. Samples from sites B82-185/2, B82-186/5 and B82-189/2 are nearly barren although some evidence of Cainozoic sediments is present. B82-185/2 and B82-186/5 contain middle Cretaceous forms whereas some Callovian to Oxfordian forms are present in B82-189/2.

Sample B82-191/2 contains Eocene dinoflagellate cysts *Lentinia wetzelii* and *Dracodinium varielongitum*. None of the species recorded from this sample are restricted to post-Eocene strata, and the site is close to the eastern margin of the seismic unit and to Eocene outcropping strata (Skarbø et al. 1983).

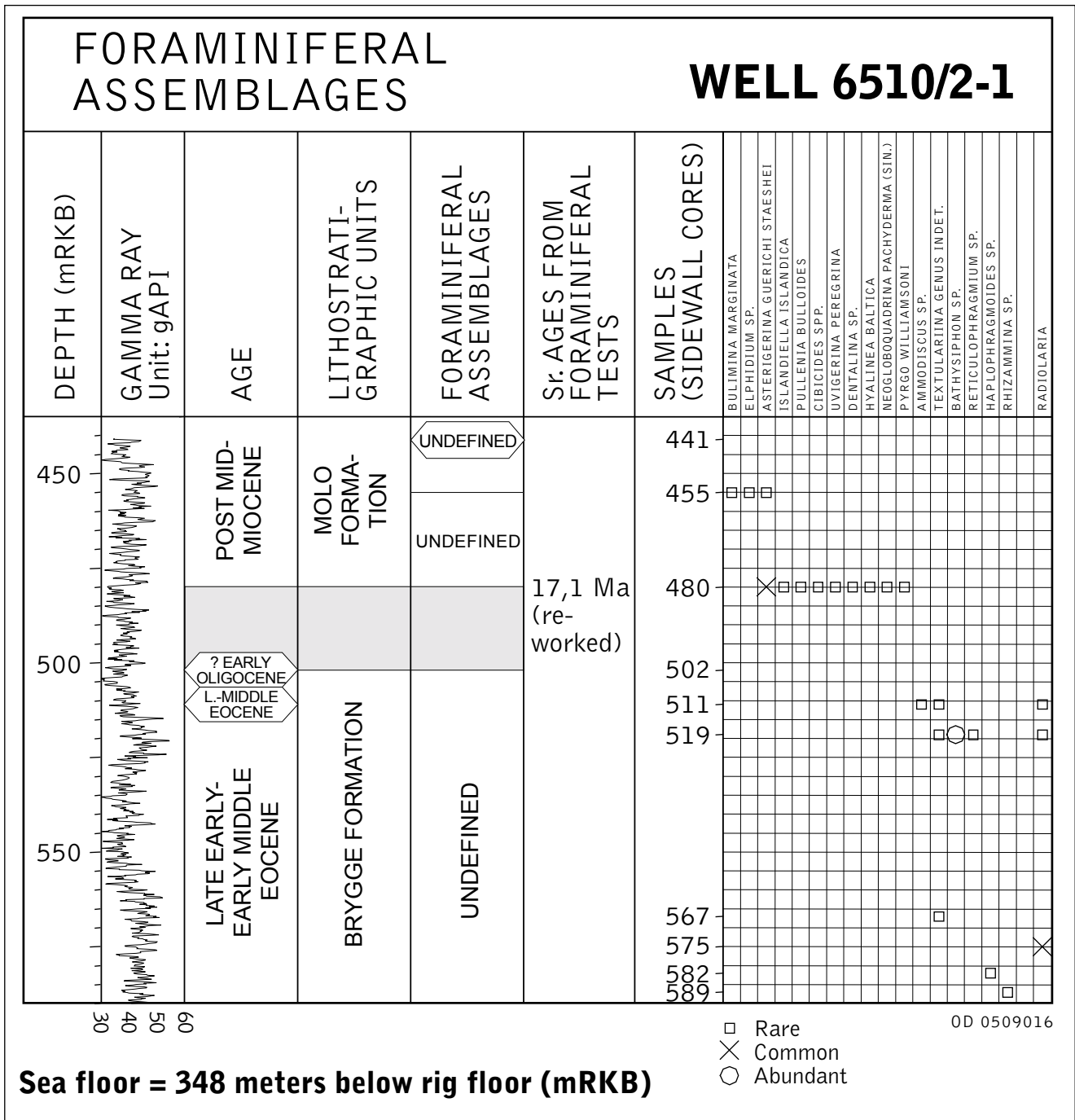


Fig. A7. Range chart of the most important foraminiferal and radiolarian index fossils in the investigated interval of well 6510/2-1. Rare = 0-5 %, common = 5-20 %, abundant = 20 % or more. MRKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units.

Micropaleontological investigations

Skarbø et al. (1983) did not report foraminifera from these sites, but they probably recorded some caved forms. T. Eidvin (personal observation, 1995) analysed one very large sample from B82-185/2 and one from B82-186/5 and found only Pliocene to Holocene forms. No Pliocene foraminiferal index forms were seen, indicating that the fossils are no older than the Pleistocene. The tests have a white, unstained and unworn appearance, typical for late Weichselian and Holocene sediments. All these tests were probably caved and mixed with the sampled material during coring.

Well 6510/2-1 on the Vega High

Well location, material and methods

Well 6510/2-1 (65°47'15.60"N, 10°25'51.33"E, Fig. 1) is the southernmost well drilled in the proximal part of the Molo Formation. The seafloor is 348 mRKB, and the well was drilled down to 1224 mRKB with no return of drill cuttings to the rig. The interval 441-722 m was sampled with sidewall cores. The upper part of this interval (sidewall core samples 441 to 480 m) corresponds to the sandy coastal deposits.

A number of 14 sidewall cores were analysed for dinoflagellates and ten samples for foraminifera. From 11-36 g material was available from the cores. The foraminiferal identification was done in the 106-500- μm fraction. In some cases the fraction larger than 500- μm was also studied. Material less than 106- μm was saved for palynological analyses.

Foraminiferal assemblages

Foraminifera of quite poor diversity and assemblage composition occur in most of the investigated samples. One sample is barren of foraminifera, one interval contains only reworked and caved forms, and one interval contains only species with very long stratigraphic ranges.

UNDEFINED INTERVAL

Material: One sidewall core at 441 m.

Age: Post mid-Miocene (based on seismic interpretation and regional considerations).

Lithostratigraphic unit: Molo Formation.

Assemblage: This interval is barren of foraminifera.

UNDEFINED INTERVAL

Depth range: 455-480 m.

Material: Two sidewall cores at 455 and 480 m.

Age: Post mid-Miocene (based on seismic interpretation and regional considerations).

Lithostratigraphic unit: Molo Formation.

Reworked assemblage: *A. guerichi staeschei* is scarce in the uppermost sample, but is quite common in the lowermost sample. One specimen of *P. bulloides* is also recorded in the lowermost sample (Fig. A7). All of the tests are eroded.

Caved assemblage: A few specimens of *Bulimina marginata*, *Elphidium* sp., *Islandiella islandica*, *Uvigerina peregrina*, *Dentalina* sp., *Hyalinea baltica*, *Pyrgo williamsoni* and *N. pachyderma* (sinistral, encrusted). All the tests have a white, unstained and unworn appearance, typical of late Pleistocene and Holocene deposits.

Remarks: The two sidewall cores in this interval contained unconsolidated sands saturated with drillings fluids. It was not possible to remove the drilling fluids during the microfossil preparation process. These fluids were probably the source of the Pleistocene and Holocene fossils. King (1989) described *A. guerichi staeschei* from basal Lower to basal Middle Miocene sediments in the North Sea area. *P. bulloides* is described from the Oligocene to recent deposits (Batjes 1958, Mackensen et al. 1985). The occurrence of *P. bulloides* may consequently be *in situ*. However, it is most likely reworked since the sole specimen is clearly eroded. It is not likely to be caved since this species is only known from deep water, continental slope sediments in Pleistocene and recent deposits (Mackensen et al. 1985, T. Eidvin personal observation). Probably none of the foraminifera recorded in this interval are *in situ*.

UNDEFINED INTERVAL

Depth range: 502-589 m.

Material: Seven sidewall cores at 502, 511, 519, 567, 575,

582 and 589 m.

Age: ?Early Oligocene-Early Eocene (based on palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Assemblage: Only rare, agglutinated foraminifera occur in this interval. *Ammodiscus* sp., *Bathysiphon* sp., *Haplophragmoides* sp., *Rhizammina* sp. and *Textulariina* sp. are recorded (Fig. A7).

Remarks: No age diagnostic foraminifera are found in this interval, and only a general Paleogene age can be inferred on the basis of the foraminifera.

Dinoflagellate cyst zones

The samples examined for palynology contained relatively rich and diverse assemblages of dinoflagellate cysts. Age interpretation based on dinoflagellates is, however, not straight forward, since several samples commonly contain reworked Palaeogene (and Mesozoic) specimens.

UNDEFINED INTERVAL

Depth range: 441-480 m.

Material: Three sidewall cores at 441 m, 455 m and 480 m.

Age: Post mid-Miocene (based on seismic interpretation and regional considerations).

Lithostratigraphic unit: Molo Formation.

Description: The interval contains common to abundant reworked Palaeogene to mid-Miocene dinoflagellate cysts, and only a few post younger Neogene specimens. The two upper samples are characterised by abundant (441 m) to common (455 m) *Cyclopsiella granosa*, together with abundant *Paralacaniella indentata* (Fig. A8). The Pliocene-Pleistocene species *Selenopemphix brevispinosa* and *Spiniferites mirabilis* were recovered in the sample at 441 m. The sample from 480 m contains *Spiniferites elongatus*, *Nematopshaeropsis labyrinthus*, *Selenopemphix quanta* and *Invertocysta lacrymosa*.

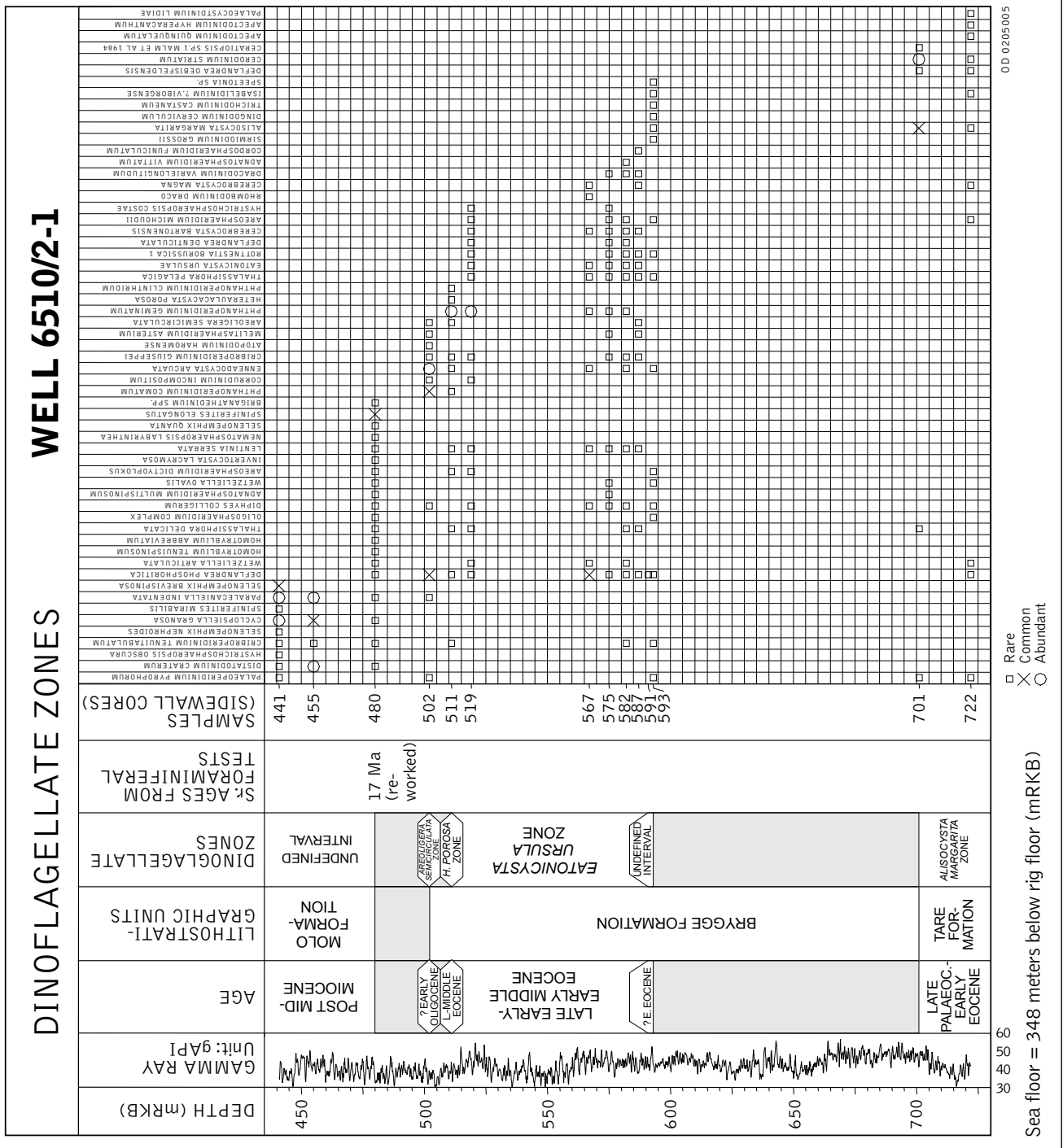
Remarks: The recovery of *Selenopemphix brevispinosa* at 441 m may suggest an Early Pliocene age at this level. *Hystriochosphaera obscura* found at 441 m, has a last occurrence datum in Late Miocene, but this species also ranges into strata as old as Oligocene. Matsuoka & Head (1992) report an Early to Late Miocene age for *Cyclopsiella granosa* based on several published observations in the North Atlantic Ocean. In a recent study on the impact of the onset of major Northern Hemisphere glaciations on dinoflagellate cyst assemblages in the Mediterranean and the North Atlantic (DSDP Site 607) Versteegh (1997) found that the LAD of *Invertocysta lacrymosa* appears to be a valuable marker for isotope stage 110. In ODP Site 986 Smelror (1999) noted the LAD of this species in sediments interpreted to lie within the Matuyama paleomagnetic chron (Channell et al. 1999), i.e. close to ~ 2.6 Ma.

AREOLIGERA SEMICIRCULATA ZONE

Definition: The body of strata between the highest/youngest occurrence of *Areoligera semicirculata* and the highest/youngest occurrence of *Svalbardella cooksoniae*.

Material: One sidewall core at 502 m.

Fig. A8. Range chart of the most important dinoflagellate index fossils in the investigated interval of well 6510/2-1. Rare = 0-5 %, common = 5-20 %, abundant 20 % = or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units.



00 0205005

□ Rare
× Common
○ Abundant

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Description: The assemblage is characterised by abundant *Areosphaeridium arcuatum*, common *Deflandrea phosphoritica* and *Phatanoperidinium comatum*, and the presence of *Corrudinium incompsitum*, *Criproperidinium giuseppei*, *Melitasphaeridium asterium* and *Areoligera semicirculata* (Fig. A8).

Reworked assemblage: *Paleoperidinium pyrophorum* is possibly reworked from Upper Palaeocene or older strata, while *Atopodinium haromense* is reworked from the lower Middle or Upper Jurassic.

Remarks: The presence of *Areoligera semicirculata* gives firm evidence of an age not younger than Early Oligocene (i.e. 28.5 Ma according to Williams & Manum, 1999). The presence (acme) of *Areosphaeridium arcuatum* supports this interpretation.

HETERAULACACYSTA POROSA ZONE

Category: Informal local taxon range zone.

Informal local boundary criteria: The top and base of the zone is defined by the highest and lowest occurrence of *Heteraulacacysta porosa* respectively.

Material: One sidewall core at 511 m.

Age: Late Middle Eocene (Bartonian).

Lithostratigraphic unit: Brygge Formation.

Description: The sample at 511 m is characterised by abundant *Phthanoperidinium geminatum*, together with *P. clinthridum* and *Heteraulacacysta porosa*.

Remarks: *H. porosa* found in this sample is a good marker for the Middle Eocene (i.e. upper NP16 to NP17 Zones, Powell 1992, Bujak 1994). The presence of *Phthanoperidinium clinthridum* and common *Phthanoperidinium geminatum* support this age interpretation (Fig. A8). In their study of ODP Site 643 on the Vøring Plateau, Manum et al. (1989) found *H. porosa* in one single sample (104-643-51-1) within their Middle Eocene *Areosphaeridium arcuatum* Zone.

EATONICYSTA URSULAE ZONE

Category: Concurrent range zone.

Informal local boundary criteria: The top of the zone is defined by the highest occurrence (LAD) of *Eatonicysta ursulae*, and the base by the highest occurrence (LAD) of *Deflandrea oebisfeldensis*.

Depth range: 519-587 m.

Material: Five sidewall cores (519 m, 567 m, 575 m, 582 m and 587 m).

Age: Late Early-early Middle Eocene.

Lithostratigraphic unit: Brygge Formation.

Description: This zone is characterised by the presence of *Eatonicysta ursulae* and *Hystrichosphaeropsis costae*. Other typical species are *Cerebrocysta bartonensis*, *Rottnestia borussica* and *Areosphaeridium michoudii* (Fig. A8).

Remarks: The presence of *Eatonicysta ursulae* at 519 m gives an age not younger than early Middle Eocene (i.e. equivalent to NP15 Zone) at this level (Powell 1992). The presence of *Hystrichosphaeropsis costae* in the same sample supports this interpretation (following the top range

of this species given in Bujak (1994)). The youngest occurrence of *Cerebrocysta magna* further suggests an age not younger than middle NP15 Zone at 567 m. The presence of *Adnatosphaeridium vittatum* at 582 m indicates an age not older than middle NP12 Zone at this level. The occurrence of *Dracodinium varielongitudum* at 575 m, 582 m and 587 m suggests an age not older than middle Early Eocene (NP 12 Zone) down to 587 m: *Deflandrea granulata* is present between 575-587 m. The lowest occurrence of this species defines the base of the *Deflandrea* sp. B Zone of Manum et al. (1989). The underlying *A. vittatum* Zone of Manum et al. (1989) was defined as the interval from the lowest occurrence of *A. vittatum* to the lowest occurrence of *Deflandrea* sp. B (herein recorded as *D. granulata*). In well 6510/2-1 *A. vittatum* has only been found in a single sample at 582 m, together with *D. granulata*. While Manum et al. (1989) dated the oldest occurrence of *A. vittatum* as Middle Eocene, Powell (1992) placed the FAD of this species within the mid Ypresian.

UNDEFINED INTERVAL

Depth range: 591-593 m.

Material: Two sidewall cores at 591 m and 593 m.

Age: ?Early Eocene.

Lithostratigraphic unit: Brygge Formation.

Description: This interval contains a characteristic Early Eocene dinoflagellate cyst assemblage which includes *Areosphaeridium dictyoplokkus*, *A. michoudii*, *Deflandrea phosphoritica*, *Rottnestia borussica*, *Thalassiphora delicata*, *T. pelagica*, *Wezeliella ovalis* and *Cordosphaeridium funiculatum*.

Remarks: An Early Eocene age (equivalent to NP Zone 12) can probably be extended down to 593 m based on the presence of *Criproperidinium tenuitabulatum*, *Deflandrea phosphoritica*, *Wezeliella ovalis*, *Areosphaeridium dictyoplokkus* and *Rottnestia borussica* (Fig. A8). According to Powell (1992) both *A. dictyoplokkus* and *W. ovalis* have their oldest appearances in beds equivalent in age to the middle Ypresian NP12 Zone. The presence of *Alisocysta margarita* and *Isabelidinium ?viborgense* at 593 m is taken as evidence of reworking from the Upper Palaeocene. Reworking from the Lower Cretaceous is seen from the presence of *Speetonia* sp., *Sirmiodinium grossii* and *Dingodinium cerviculum*.

ALISOCYSTA MARGARITA ZONE

Category: Informal local taxon range zone.

Informal local boundary criteria: The top and the bottom of the zone are defined by the highest and lowest occurrence of *A. margarita*.

Depth range: 701-722 m.

Material: Two sidewall cores at 701 m and 722 m.

Age: Late Palaeocene to Early Eocene.

Lithostratigraphic unit: Tare Formation.

Description: This zone is characterised by the presence of *Alisocysta margarita*, *Deflandrea oebisfeldensis*, *Cerodinium striatum* and *Apectodinium* spp (Fig. A8).

Remarks: The presence of common *A. margarita*, together

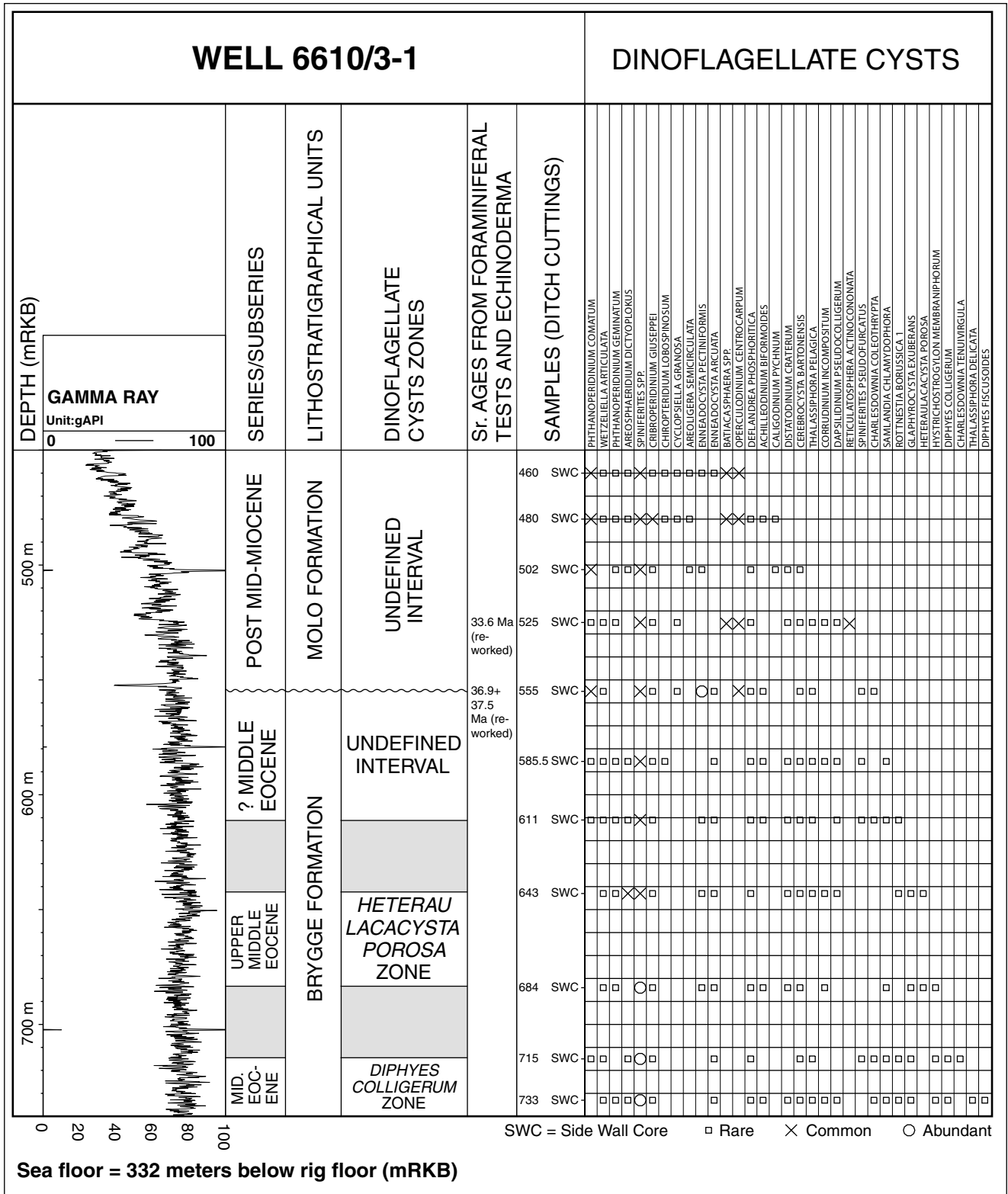


Fig. A9. Range chart of the most important dinoflagellate index fossils in the investigated interval of well 6610/3-1. Rare = 0-5 %, common = 5-20 %, abundant 20 % = or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units.

with abundant *Cerodinium speciosum* at 701 m is good evidence for a Late Palaeocene age at this level. According to Powell (1992) *A. margarita* does not range above beds equivalent in age to the NP Zone 8. In the sample at 722 m these two species occur together with *Apectodinium hyperacanthum* and *Apectodinium*

quiquelatum. According to Powell (1992) the two latter species do not range below the NP9 Zone. These ranges are not consistent the observations from the sample at 722 m. Schroder (1992), however, noted an overlap between the ranges of *A. cf. margarita* and *Apectodinium* spp. in the zonation developed for Shell U.K. for the

Palaeocene of the North Sea Basin. Following the Shell zonation the samples at 701-722 m can be related to Zone PT19.1 (and lowermost 19.2).

Strontium isotope stratigraphy

Three samples, with tests of calcareous foraminifera taken from the sidewall core at 480 m, were analysed for strontium isotopes. One sample containing tests of presumed reworked *A. guerichi staeschei* gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.708672. On the seawater Sr isotope curve of Howarth & McArthur (1997) this $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio corresponds to an age of approximately 17.2 Ma (late Early Miocene, Table 1, Fig. A7).

The two other Sr samples from the sidewall core at 480 m contained tests of presumed caved Pleistocene – Holocene forms. The $^{87}\text{Sr}/^{86}\text{Sr}$ -ratios of these samples correspond to very young ages (Nødtvedt 1999).

Stratigraphical conclusion for well 6510/2-1

Interval 441-480 m (Molo Formation, post mid- Miocene)

No specific foraminifera and dinoflagellate cyst zonal markers were recovered from the Molo Formation in this well, and the Sr-age of 17.2 Ma is derived from reworked foraminifera. However, the presence of the dinoflagellate cysts *Selenopemphix brevispinosa* (441 m) and *Invertocysta lacrymosa* (480 m) may be indicative of a Late Miocene - Early Pliocene age, but these species are also known to range into older Neogene strata.

Sample at 502 m (Brygge Formation, ?Lower Oligocene)

Dinoflagellates attributed to the *A. semicirculata* Zone indicate an Early Oligocene age for this sample. No age diagnostic foraminifera are found and the foraminifera indicate only a general Palaeogene age.

Sample at 511 m (Brygge Formation, Upper part of Middle Eocene)

Dinoflagellates attributed to the *H. porosa* Zone date this sample to late Middle Eocene. The foraminifera indicate only a general Palaeogene age.

Interval 519-589 m (Brygge Formation, Upper part of Lower Eocene-lower part of Middle Eocene)

Dinoflagellates attributed to the *E. ursulae* Zone date this interval to late Early-early Middle Eocene. The foraminifera indicate only a general Palaeogene age.

Interval 591-593 m (Brygge Formation, ?Lower Eocene)

The dinoflagellates indicate an Early Eocene age for this interval.

Interval 701-702 m (Tare Formation, Upper Palaeocene-Lower Eocene)

Dinoflagellates attributed to the *Alisocysta margarita* Zone date this interval to Late Palaeocene.

Lithology

The sidewall cores at 441, 455 and 480 m, which represent the Molo Formation contain quite coarse sand. The sand contains mainly glauconite (dominant) and quartz grains, which are angular to sub-angular. Many of the quartz grains are rust-stained.

The sidewall cores at 502, 519, 567, 575, 582, 587, 591 and 593 m which represent the Brygge Formation of ?Early Eocene to ?Early Oligocene age and the sample at 701 m of the uppermost Tare Formation of Late Paleocene – Early Eocene age contain mostly muddy, micaceous siltstones. The sample at 511 m of the Brygge Formation is, however, quite sandy, but the sand is not as coarse as the sand of the Molo Formation. The sand contains quartz, mica and a smaller portion of glauconite.

The lowermost sample at 702 m of the Tare Formation is also dominated by sand. This sand is quite coarse and several pebbles are also recorded. It is quite similar to the sand of the Molo Formation regarding mineralogy, grain forms and colour, but is even coarser.

Revised palynostratigraphy of well 6610/3-1 on the Nordland Ridge

Previous studies

Information on foraminiferal and palynological biostratigraphy and strontium isotope analyses from the Molo Formation in well 6610/3-1 (66°55'29.70"N, 10°54'6.28"E, Fig. 1) has previously been published by Eidvin et al. (1998). Their study included 5 sidewall cores from the interval between 460–555 m. From their findings they concluded that the Molo Formation in this well was of Early Oligocene age, although the foraminifera found in the interval are known to have a longer Early Oligocene to Early Miocene range in the North Sea area. The strontium isotope ages obtained from 525 m and 555 m, however, pointed towards Early Oligocene and Late Eocene ages of 35.9 Ma and 39.8 Ma, respectively (33.6 Ma and 36.9 Ma on the new strontium isotope curve of Howarth & McArthur (1997) and the time scale of Berggren et al. (1995)). The lowermost sample was believed to be contaminated, and the upper analysed sample was regarded as most reliable. One new analysis of foraminifera from 555 m gave an age of 37.5 Ma (Table 1, Fig. A9). According to Eidvin et al. (1998) the dinoflagellate cyst assemblages from this interval contain a mixture of Jurassic, Palaeocene and Early Eocene-Early Oligocene species.

Material and methods

The re-analyses of the marine palynomorphs is based on the five samples analysed by Eidvin et al. (1998). In addition six more samples from the immediately underlying section were used. The same kind of preparation methods were used for these samples as for the samples in the wells 6407/5-1, 6407/5-2 and 6407/5-5.

Dinoflagellate cyst zones

UNDEFINED INTERVAL

Depth range: 460-555 m.

Material: Five side wall cores at 460 m, 480 m, 502 m, 525 m and 555m.

Age: Post mid-Miocene (based on seismic interpretation and regional considerations).

Lithostratigraphic unit: Molo Formation.

Description: The dinoflagellate cyst assemblages from this interval are totally dominated by reworked Palaeogene and Mesozoic dinoflagellate species. A few taxa which may be *in situ* include *Batiacasphaera* spp., *Spiniferites* spp., *Reticulosphaera actinocoronata* and *Operculodinium centrocarpum* (Fig. A9).

Remarks: The single occurrence of *Reticulosphaera actinocoronata* at 525 m may indicate a correlation to the Early Pliocene *Reticulosphaera actinocoronata* Zone. However, this species has a long range in the Cainozoic, and may thus be reworked along with the other abundant reworked Tertiary dinoflagellate cysts.

UNDEFINED INTERVAL

Material: Two sidewall cores at 585.5 m and 611 m.

Age: ?Middle Eocene (Bartonian).

Lithostratigraphic unit: Brygge Formation.

Description: The assemblage is a rich and relative diverse marine microflora, which includes several typical Eocene species, including *Enneadocysta pectiniformis* (abundant at 555 m), *E. arcuata*, *E. fenestrata*, *Rottnestia borussica*, *Areosphaeridium dictyoplokkus*, *Corrudinium incompositum*, *Cribroperidinium giuseppei*, *Cerebrocysta bartonensis* and *Samlandia chalmydophora*.

Remarks: The presence of *Enneadocysta fenestrata* at 611 m (Fig. A9) points to an age not younger than early Late Eocene (early Priabonian), while the record of *Rottnestia borussica* in the same sample restricts the age to not younger than latest Middle Eocene (Powell 1992, Bujak & Mudge 1994). The appearance of *Corrudinium incompositum* up to the sample at 585.5 m is further evidence for a Middle Eocene age for this interval (following the range for this species given in Powell, 1992). Reworked dinoflagellate cysts include *Endoscrinium pharao* (Late Jurassic-Early Cretaceous) found at 585.5 m.

HETERAULACACYSTA POROSA ZONE

Category: Informal local taxon range zone.

Informal local boundary criteria: The top and base of the zone are defined by the highest and lowest occurrence of *Heteraulacacysta porosa* respectively.

Material: Two sidewall cores at 643 m and 684m.

Age: Late Middle Eocene (Bartonian).

Lithostratigraphic unit: Brygge Formation.

Description: Characteristic species from this zone include *Heteraulacacysta porosa*, *Areosphaeridium michoudii*, *Glaphyrocysta exuberans*, *Diphyes pseudofiscusoides* and *Cerebrocysta bartonensis* (Fig. A9).

Remarks: *Heteraulacacysta porosa* found in both samples from this zone is a good marker for the Middle Eocene (i.e. upper NP16 to NP17 Zones, Powell 1992, Bujak 1994)

DIPHYES COLLIGERUM ZONE

Definition: The body of strata between the highest/youngest occurrence of *Diphyes colligerum* and the highest/youngest occurrence of abundant *Systematophora placacantha* (Bujak & Mudge 1994).

Depth range: 715-733 m.

Material: Two sidewall cores at 715 m and 733 m.

Age: Middle Eocene (late Lutetian).

Lithostratigraphic unit: Brygge Formation.

Description: This zone is characterised by the presence of *Diphyes colligerum*, together with *Areosphaeridium dictyoplokkus*, *Corrudinium incompositum*, *Distatodinium craterum* and *Rottnestia borussica* (Fig. A9).

Remarks: According to Powell (1992) *Corrudinium incompositum* and *Distatodinium craterum* have their oldest appearances in beds equivalent in age to the upper Lutetian NP16 Zone: The presence of *Apectodinium augustum* at 733 m is taken as evidence of reworking from the Upper Palaeocene.

Stratigraphy of well 6610/2-1S on the Nordland Ridge

Well location, material and methods

Well 6610/2-1S (66°48'48.73"N, 10°30'26.70"E) was drilled just to the west of well 6610/3-1 (Fig. 1). In well 6610/2-1S the sediments immediately under the Molo Formation were sampled with ditch cuttings. Eleven sidewall cores were analysed for dinoflagellates and seven samples analysed for foraminifera. The same amount of material and the same kind of fossil preparation methods were used for well 6610/2-1S as for wells 6407/5-1, 6407/5-2 and 6407/9-5.

Foraminiferal assemblages

The upper part of the of the analysed interval, from 950 to 1000 m, contains calcareous foraminiferal assemblages, while *in situ* agglutinated foraminifera are absent. In the sample at 1010 m a marked change takes place from calcareous assemblages to mixed calcareous – agglutinated assemblages. It is supposed that this faunal turnover reflects a change in depositional conditions from shallow water (above) to deeper water (below).

TURRILINA ALSATICA ASSEMBLAGE

Definition: The top of the assemblage extends to the uppermost investigated sample. The base is marked by

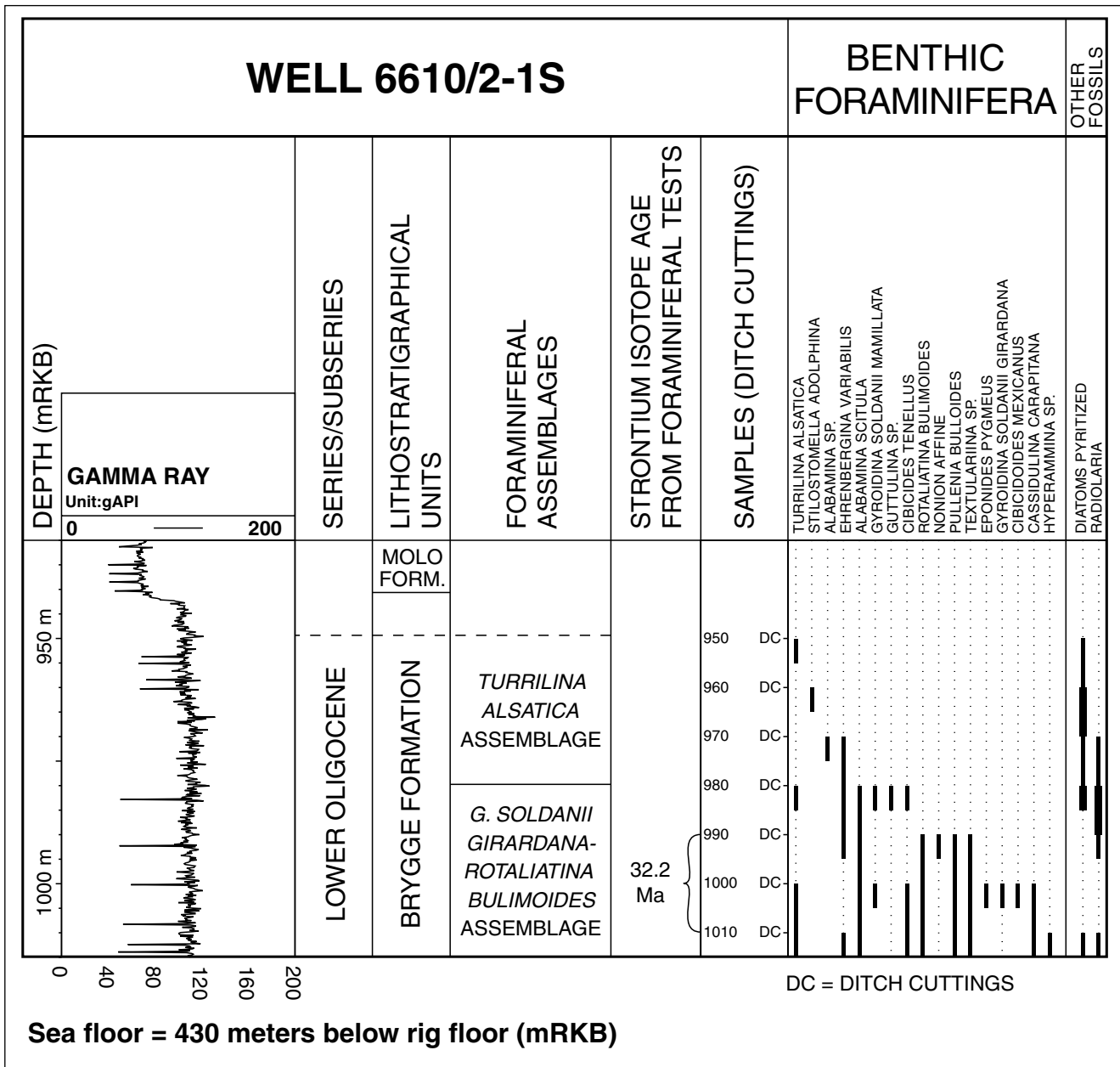


Fig. A10. Range chart of the most important foraminiferal index fossils in the investigated interval of well 6610/2-1S. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units.

the highest occurrence of *G. soldanii mamillata*.
Depth range: 950-980 m.

Material: Three ditch cuttings samples at 950, 960 and 970 m.
Age: Early Oligocene (partly based on palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Subzone NSB 7b of King (1989) and Zones NSR 7A or 7B of Gradstein and Bäckström (1996).

Description: The fossil assemblage in this interval is dominated by radiolaria and pyritized diatoms. Benthic foraminifera are quite sparse, but include *T. alsatica*, *Stilostomella adolphina*, *Q. seminulum* and *E. variabilis* (Fig. A10).

Remarks: *T. alsatica* is known from the Lower Oligocene to the lowermost Lower Miocene succession in the North Sea (King 1989). According to Gradstein & Bäckström

(1996) this species is known from the Lower Oligocene to the lowermost Upper Oligocene in the same area. *S. adolphina* is recorded from the upper part of the Lower Oligocene succession in Denmark (Ulleberg 1974).

GYROIDINA SOLDANII MAMILLATA – ROTALIATINA BULIMOIDES ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest occurrence of *G. soldanii mamillata*. The base is undefined.

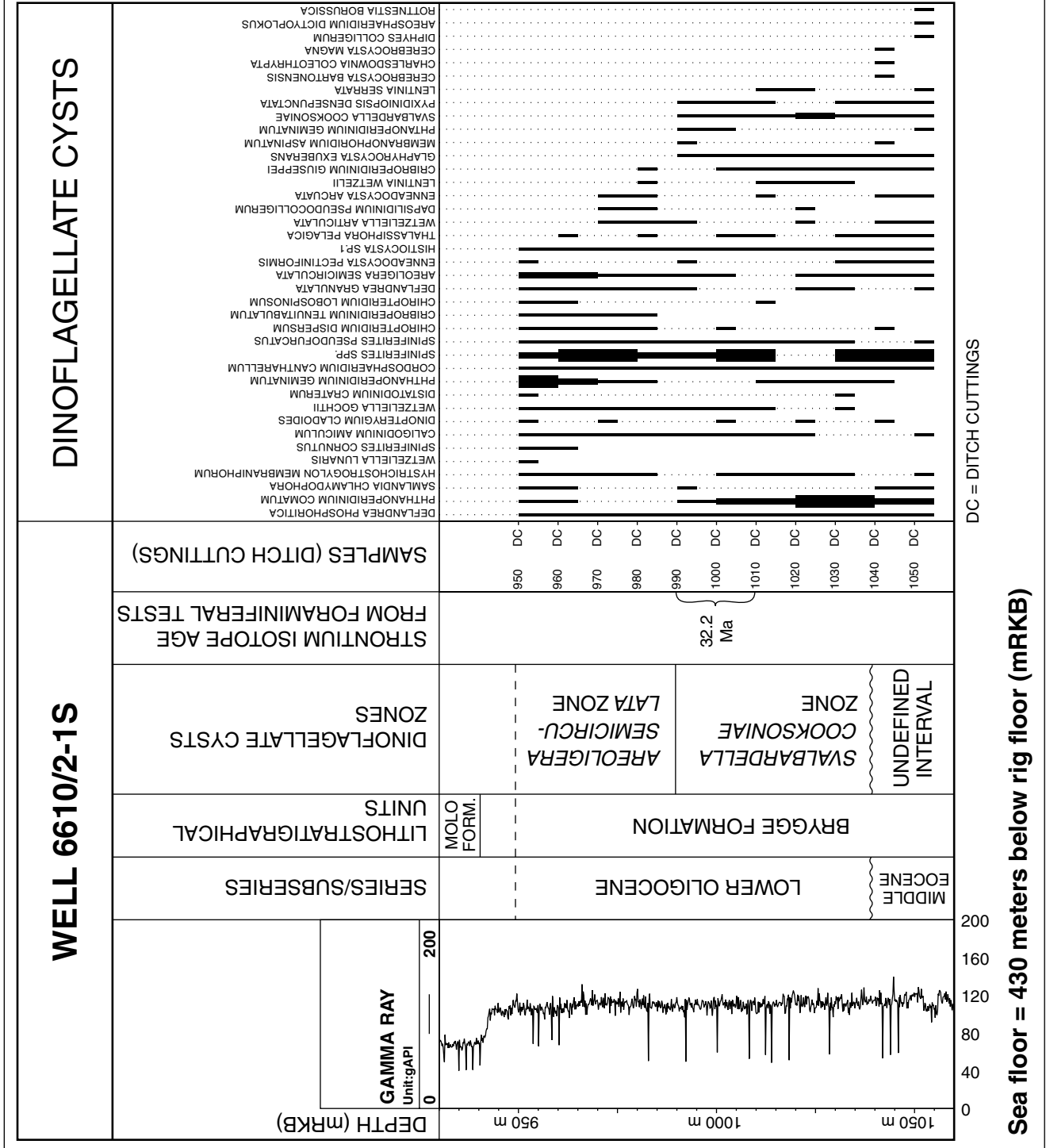
Depth range: 980-1010 m.

Material: Four ditch cutting samples at 980, 990, 1000 and 1010 m.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Fig. A11. Range chart of the most dimo-
flagellate index fossils in the investiga-
ted interval of well 6610/2-1S. Legend
for columns: thin (rare) 0-5 %, middle
(common) 5-20 %, thick (abundant) 20
% or more. M RKB = meters below rig
floor, gAPI = American Petroleum Insti-
tute gamma ray units.



Correlation: Subzone NSB 7a of King (1989) and Zones NSR 7A or 7B of Gradstein & Bäckström (1996).

Description: This assemblage contains a moderately rich fossil assemblage of radiolaria, pyritized diatoms and benthic foraminifera. Radiolaria and pyritized diatoms are dominant in the upper part while benthic foraminifera are dominant in the lower part. Mainly calcareous benthic foraminifera are recorded, but a few agglutinated forms are found in the lowermost sample. Benthic foraminifera are not common, but important taxa include *T. alsatica*, *E. variabilis*, *A. scitula*, *G. soldanii mamillata*, *Cibicides tenellus*, *R. bulimoides*, *P. bulloides* and *Cassidulina carpitana* (lower part, Fig. A10).

Remarks: In the North Sea area *G. soldanii mamillata* is described from the Lower Oligocene to the lowermost Upper Oligocene according to King (1989) and from the Upper Eocene to the lowermost Upper Oligocene according to Gradstein & Bäckström (1996). *R. bulimoides* is known from the Lower Oligocene to the lowermost Upper Oligocene according to King (1989) and from the Upper Eocene to the Lower Oligocene according to Gradstein & Bäckström (1996). *C. carpitana* is described from Lower Oligocene deposits in the same area. *A. scitula* is known from the Lower Oligocene to Lower Miocene in the North Sea and from the Lower Oligocene to the basal Middle Miocene in the Haltenbanken area according to Gradstein & Bäckström (1996). *C. tenellus* is known from Oligocene sediments in Belgium (Batjes 1958).

Dinoflagellate cyst zones

AREOLIGERA SEMICIRCULATA ZONE

Definition: The body of strata between the highest/youngest occurrence of *Areoligera semicirculata* and the highest/youngest occurrence of *Svalbardella cooksoniae*.

Depth range: 950-990 m.

Material: Four ditch cutting samples at 950 m, 960 m, 970 m and 980 m.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains abundant and relatively diverse dinoflagellate cysts assemblages. *Areoligera semicirculata* is common at 950 m and 960 m, while *Spiniferites* spp. is common to abundant throughout the zone. Characteristic species with last occurrences in the zone are *Chiropteridium lobospinosum*, *Enneadocysta arcuata*, *Histocysta* sp. 1 and *Cribroperidinium giuseppi* (Fig. A11). The zone contains reworked Late-Middle Eocene and Jurassic dinoflagellate cysts.

Remarks: According to Powell (1992) the last appearance datum (LAD) of *A. semicirculata* lies within the lower NP25 calcareous nannoplankton biozone in Britain and in the North Sea area. Manum et al. (1989) found that the LAD of this species (named *Glaphyrocysta intricata* in their publication) corresponded to the upper boundary of their Early/Late Oligocene *Areosphaeridium? actinocoronatum* in ODP Hole 643 in the Norwegian Sea. The LAD of this species also defines the upper boundary of the Oli4 Zone of Poulsen et al. (1996) as defined in ODP Hole 908 on the

Hovgaard Ridge between Svalbard and NE Greenland.

SVALBARDELLA COOKSONIAE ZONE

Category: Informal local taxon range zone.

Informal local boundary criteria: The top of the zone is placed at the last appearance datum (LAD) of *S. cooksoniae*, while the base is defined by the first appearance datum (FAD) of *Areosphaeridium dictyoplokkus*.

Depth range: 990-1040 m.

Material: Five ditch cutting samples at 990m, 1000 m, 1010 m, 1020 m and 1030 m.

Age: Earliest Oligocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains abundant and relatively diverse dinoflagellate cysts assemblages. *Spiniferites* spp. are common to abundant throughout the zone, while *Phthanoperidinium comatum* is common at 1000-1030 m. *Glaphyrocysta exuberans*, *Membranophoridium aspinatum*, *Pyxidiniopsis denespunctata* and *Phthanoperidinium geminatum* have their last occurrences at the top of the zone (Fig. A11).

Reworked assemblage: The zone contains reworked Late Palaeocene, Cretaceous and Jurassic dinoflagellate cysts.

Remarks: In ODP Hole 643 Manum et al. (1989) found *S. cooksoniae* to have a restricted occurrence in the earliest Oligocene. According to Williams & Manum (1999) the last appearance datum of *S. cooksoniae* can be calibrated to 32 Ma.

UNDEFINED INTERVAL

Depth range: 1040-1050 m.

Material: Two ditch cutting at 1040m and 1050 m.

Age: Middle Eocene.

Lithostratigraphic unit: Brygge Formation.

Description: This interval contains relative abundant and diverse Middle Eocene marine microfloras. An age not younger than Middle Eocene at 1040 m is inferred by the last appearance datum of *Cassiculosphaera magna* at this level. According to Bujak & Mudge (1994) the youngest occurrence of this species is within middle NP15 Zone. The presence of *Cerebrocysta bartonensis* at 1040 m and *Rottnestia borussica* at 1050 (Fig. A11) are further taken as evidence for an age not younger than Middle Eocene for this un-zoned interval. The single occurrence of *Diphyes colligerum* at 1050 m may suggest that strata correlatable to the *Diphyes colligerum* Zone are reached at this level. According to Bujak & Mudge (1994) the *D. colligerum* Zone is of Late Lutetian age. The interval also contains reworked Late Palaeocene dinoflagellate cysts.

Strontium isotope stratigraphy

One sample based on tests of presumed *in situ* *R. bulimoides* and *G. soldanii mamillata* was analysed for strontium isotopes. The tests were picked from the ditch cutting samples at 990, 1000 and 1010 m. The sample gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.707886 corresponding to an age of approximately 32.2 Ma (Early Oligocene) on the seawater Sr isotope curve of Howarth & McArthur (1997, Table 1, Fig. A10).

Fig. A12. Range chart of the most important benthic and planktonic foraminifera, Bolboforma and other planktonic index fossils in the investigated interval of well 6609/11-1. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units, $\mu\text{s}/\text{f}$ = microseconds per foot.



*Stratigraphical conclusion for well 6610/2-1S**Interval 950-1040 m (Brygge Formation, Lower Oligocene)*

Dinoflagellates attributed to the *A. semicirculata* Zone and the *S. cooksoniae* Zone (950-1040 m) and benthic foraminifera attributed to the *T. alsatica* assemblage, *G. soldanii mamillata* – *R. bulimoides* assemblage (950-1010 m) date the interval to Early Oligocene. One strontium isotope analysis of foraminiferal tests corresponding to an age of approximately 32.2 Ma (990-1010 m) confirms the biostratigraphical correlations.

Interval 1040-1050 m (Brygge Formation, Middle Eocene)

Dinoflagellates date this interval to Middle Eocene.

Lithology

All the investigated samples in well 6610/2-1S contain silty mudstone.

Investigation of the Kai Formation

Stratigraphy and lithology of well 6609/11-1 on the Trøndelag Platform

Well location, material and methods

Well 6609/11-1 (66°08'13.90"N, 09°33'47.89"E, Fig.1) was drilled on the Trøndelag Platform, west of the area where the Molo Formation wedges out, and sampled the Kai Formation. A number of 25 ditch cuttings were analysed for foraminifera, *Bolboforma* and diatoms, and 24 samples were analysed for dinoflagellates. The same amount of material and the same kind of fossil preparation methods were used for wells 6609/11-1 as for the wells 6407/5-1, 6407/5-2 and 6407/9-5.

Micropalaeontological assemblages

The sections from Late Miocene to Late Pliocene contain moderately rich benthic faunas of mainly calcareous foraminifera. The planktonic fossil assemblages are sparse in these units except for the lower part of the Upper Miocene which contains a rich planktonic assemblage of *Bolboforma*, planktonic foraminifera, radiolaria and pyritized diatoms. The fossil assemblages in the Oligocene and Lower Miocene sections are dominated by radiolaria, pyritized diatoms and sponge spicules. Sparse faunas of agglutinated foraminifera and some calcareous forms are also recorded in most sections. The faunal turnover at the mid-Miocene unconformity reflects a change in depositional conditions from shelfal water (above) to deeper shelfal water (below).

*Benthic foraminiferal assemblages**CIBICIDES GROSSUS ASSEMBLAGE*

Definition: The top of the assemblage extends to the

uppermost investigated sample (1180 m). The base is marked by the highest/youngest occurrence of *C. telegdi*.
Depth range: 1180-1240 m.

Material: Six ditch cutting samples.

Age: Late Miocene/Early Pliocene to Late Pliocene.

Lithostratigraphic unit: Kai and Naust Formation.

Correlation: Zone NSB 15 of King (1989), *Cibicides grossa* zone of Stratlab (1988) and Zone NSR 12 B of Gradstein & Bäckström (1996).

Description: This unit contains a moderately rich benthic fauna of calcareous foraminifera. *C. scaldisiensis* is common throughout. Other characteristic taxa include *C. grossus*, *N. affine* (common in lower part), *C. lobatulus*, *E. albiumbilicatum*, *E. hannai*, *B. marginata*, *B. tenerima*, *E. excavatum*, *C. teretis* and *A. fluens* (lower part, Fig. A12).

Remarks: The occurrence of *C. grossus* and *E. hannai* indicates a Late Pliocene age (Doppert 1980, King 1989), but log correlations show the top of the Kai Formation of Late Miocene – Early Pliocene age reach as high as 1222 m. However, index fossils for Late Miocene – Early Pliocene are not recorded higher than 1240 m (see below).

CIBICIDES TELEGDI ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *C. telegdi*. The base is marked by the highest/youngest occurrence of *E. pygmeus* and *G. subglobosa*.

Depth range: 1240-1250 m.

Material: One ditch cutting sample.

Age: Late Miocene to Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Probably *Cibicides telegdi* – *Eponides pygmeus* – *Neogloboquadra atlantica* (dextral) zone of Eidvin et al. (1998) and probably lower part of *Melonis* – *Trifarina* zone of Stratlab (1988).

Description: The sole sample which constitutes this unit contains a moderately rich benthic fauna of calcareous foraminifera. *N. affine* occurs most frequently. Other important species include *C. telegdi*, *B. marginata*, *C. teretis* and *A. fluens* (Fig. A12).

Remarks: Most of the recorded benthic specimens are known from sediments from almost the entire Neogene. However, *C. telegdi* is described from the Oligocene in Denmark and Germany (Grossheide & Trunko 1965, Hausmann 1964, Kummerle 1963, Ulleberg 1974). This species is recorded in deposits from the Oligocene to the Lower Pliocene in the North Sea and on the Norwegian Sea continental shelf (Stratlab 1988, Eidvin et al. 1998, Eidvin & Rundberg 2001 and Eidvin & Rundberg in press). Since taxa no older than Late Miocene are recorded in underlying units this assemblage is most likely of Late Miocene to Early Pliocene age.

EPONIDES PYGMEUS – GLOBOCASSIDULINA SUBGLOBOSA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *E. pygmeus* and *G. subglobosa*. The base is marked by the highest/youngest occurrence

of *Uvigerina venusta saxonica*.

Depth range: 1250-1260 m.

Material: One ditch cutting sample.

Age: Late Miocene to Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Probably *Ehrenbergina variabilis* – *Globigerina subglobosa* – *Neogloboquadrina atlantica* (dextral) zone and *Cibicides telegdi* – *Eponides pygmeus* – *Neogloboquadrina atlantica* (dextral) zone of Eidvin et al. (1998) and probably *Globocassidulina subglobosa* – *Ehrenbergina variabilis* zone and lower part of *Melonis* – *Trifarina* zone of Stratlab (1988).

Description: The sole sample from this unit contains a moderately rich benthic fauna of calcareous foraminifera. *N. affine* and *C. teretis* occur most frequently. Other characteristic species include *E. pygmeus*, *G. subglobosa*, *C. telegdi* and *A. fluens* (Fig. A12).

Remarks: Most of the recorded benthic specimens, also in this unit, are known from sediments from almost the entire Neogene. However, *E. pygmeus* is described from the Oligocene in Denmark and Germany (Grossheide & Trunko 1965, Hausmann 1964, Kummerle 1963, Ulleberg 1974). This species is recorded in deposits from the Oligocene to the Lower Pliocene in the North Sea and on the Norwegian Sea continental shelf (Stratlab 1988, Eidvin et al. 1998, Eidvin & Rundberg 2001 and Eidvin & Rundberg in press). *G. subglobosa* is recorded from the Oligocene to the Lower Pliocene in the North Sea (Eidvin & Rundberg 2001 and Eidvin & Rundberg in press). Since taxa no older than Late Miocene are recorded in the immediately underlying unit, this assemblage is most likely of Late Miocene to Early Pliocene age.

UVIGERINA VENUSTA SAXONICA ASSEMBLAGE

Definition: The top and base of the assemblage are taken at the highest/youngest and lowest/oldest occurrence of *U. venusta saxonica*.

Depth range: 1260-1280 m.

Material: Two ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Subzone NSB 13b of King (1989).

Description: This assemblage contains a moderately rich benthic fauna of calcareous foraminifera. *U. venusta saxonica* occurs most frequently. Other characteristic species include *Chilostomellina fimbriata*, *N. affine*, *C. teretis*, *C. telegdi*, *E. pygmeus*, *G. subglobosa*, *P. bulloides* and *C. dutemplei* (Fig. A12).

Remarks: According to King (1989) *U. venusta saxonica* and *C. fimbriata* are known from Upper Miocene to Lower Pliocene deposits in the North Sea area. Sr. analyses of tests of *U. venusta saxonica* from 1260 m gave an age of 6.3 Ma (Late Miocene) and consequently rule out an Early Pliocene age for this assemblage in well 6609/11-1.

UNDEFINED INTERVAL

Depth range: 1280-1290 m

Material: One ditch cutting sample.

Age: Early Miocene in the lower part and Late Miocene in

the upper part (based on palynological evidence and log correlation).

Lithostratigraphic unit: Upper part of Brygge Formation and Kai Formation.

Description: This interval contains just a few, probably caved, benthic foraminifera (Fig. A12).

TRIFARINA GRACILIS VAR. A ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest occurrence of *T. gracilis* var. A (Batjes, 1958). The base of the assemblage is undefined.

Depth range: One ditch cutting sample at 1290 m.

Age: Early Miocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Probably Zone NSB 10 or NSB 9 of King (1989) and probably Zone NSR 8B of Gradstein & Bäckström (1996).

Description: Just a few specimens of *T. gracilis* var. A, *Martinottiella communis* sp. (agglutinated) and *Cassidulina* sp. are recorded in the sole sample of this unit (Fig. A12).

Remarks: According to Skarbø & Verdenius (1986) *T. gracilis* var. A is known from Upper Oligocene to Lower Miocene sediments on the Norwegian continental shelf, and *M. communis* is described from the Miocene in the same area. In well 6507/12-1 a co-occurrence of the upper part of the *T. gracilis* assemblage with the planktonic *B. badenensis* – *B. reticulata* assemblage indicates that *T. gracilis* var. A lived into the Middle Miocene. However, these *Bolboforma* taxa are not recorded here and consequently the assemblage is probably of Early Miocene age in well 6609/11-1.

UNDEFINED INTERVAL

Depth range: 1300-1375 m.

Material: Eight ditch cutting samples.

Age: Oligocene to Early Miocene (based on planktonic fossil and palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Description: Just a few undetermined agglutinated foraminifera are recorded in this interval.

BATHYSIPHON EOCENICUS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. eocenicus*. The base is marked by the highest/youngest occurrence of *Spiroplectammia spectabilis*.

Depth range: 1375-1410 m.

Material: Four ditch cutting samples.

Age: Late Eocene to Early Oligocene (partly based on palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Probably Zone NSA 7 and NSA 8 of King (1989) and probably Zone NSR 7A and NSR 7B of Gradstein & Bäckström (1996).

Description: This interval contains a sparse fauna of mainly agglutinated foraminifera. Recorded species include *B. eocenicus*, *S. compressa* and *Ammodiscus* sp. (Fig. A12).

Remarks: *B. eocenicus* is known from Eocene to Lower

Oligocene deposits in the North Sea area. *Spirosigmoinella* sp. A (synonymous with *S. compressa*) is known from the Lower Oligocene to Lower Miocene succession in the North Sea (King, 1989). According to Gradstein & Bäckström (1996) this species is known from the Middle Eocene to the Upper Oligocene in the North Sea and from the Middle Eocene to the Lower Oligocene in the Haltenbanken area.

SPIROPLECTAMMINA SPECTABILIS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *S. spectabilis*. The base is undefined.

Depth range: One ditch cutting sample at 1410 m.

Age: Middle Eocene (partly based on palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSA 5 of King (1989), *Spiroplectammina spectabilis* zone of Stratlab (1988) and probably Zone NSR 5A or NSR 5B of Gradstein & Bäckström (1996).

Description: Just a few specimens of *S. spectabilis* and *Cyclammina rotundidorsata* are recorded in the sole sample of this unit (Fig. A12).

Remarks: According to King (1989) *S. spectabilis* is known from the Lower to Middle Eocene in the North Sea area. According to Gradstein & Bäckström (1996) this species is described from upper Palaeocene to Middle Eocene deposits in the North Sea and the Haltenbanken areas. *C. rotundidorsata* is known from the Eocene to the Lower Miocene in the North Sea area according to Gradstein & Bäckström (1996).

Planktonic fossil assemblages

UNDEFINED INTERVAL

Depth range: 1180-1230 m.

Material: Five ditch cutting samples.

Age: Late Miocene/Early Pliocene to Late Pliocene (based on log correlation and benthic foraminiferal evidence).

Lithostratigraphic unit: Kai and Naust Formation.

Description: This interval is nearly barren of planktonic foraminifera. Just one specimen of *N. pachyderma* (dextral) is recorded (Fig. A12).

GLOBIGERINA BULLOIDES ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *G. bulloides*. The base is marked by the highest/youngest occurrence of *N. atlantica* (sinistral).

Depth range: 1230-1240 m.

Material: One ditch cutting sample.

Age: Late Miocene to Early Pliocene.

Lithostratigraphic units: Kai Formation.

Correlation: *Globigerina bulloides* Zone of Weaver & Clement (1986).

Description: Just a few specimens of *G. bulloides* and *N. pachyderma* (dextral) are recorded in the sole sample from this unit (Fig. A12).

Remarks: *G. bulloides* is known from the North Atlantic and the Vøring Plateau in Late Miocene to Late Pliocene

sediments (Weaver & Clement 1986, Spiegler & Jansen 1989).

NEOGLOBOQUADRINA ATLANTICA (SINISTRAL) ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *N. atlantica* (sinistral). The base is marked by the highest/youngest occurrence of *B. laevis*.

Depth range: 1240-1260 m.

Material: Two ditch cutting samples.

Age: Late Miocene to Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *N. atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).

Description: The assemblage is characterized by a sparse fauna of planktonic foraminifera. Recorded species include *N. atlantica* (sinistral), *G. bulloides* and *T. quinqueloba* (Fig. A12).

Remarks: *N. atlantica* (sinistral) is known from the North Atlantic and the Vøring Plateau in Late Miocene to Late Pliocene sediments (Weaver & Clement 1986, Spiegler & Jansen 1989).

BOLBOFORMA LAEVIS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. laevis*. The base is marked by the highest/youngest occurrence of *B. subfragori*.

Depth range: 1260-1270 m.

Material: One ditch cutting sample.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *Bolboforma laevis*/*Bolboforma capsula* Zone of Spiegler & Müller (1992) and *Bolboforma laevis* Zone of Müller & Spiegler (1993).

Description: The sole sample from this unit contains a sparse fossil assemblage of *Bolboforma* and planktonic foraminifera. *B. laevis* is the only *Bolboforma* species recorded. Recorded foraminifera include *G. bulloides*, *N. atlantica* (sinistral) and *G. glutinata* (Fig. A12).

Remarks: Spiegler & Müller (1992) and Müller & Spiegler (1993) have recorded a *B. laevis*/*B. capsula* Zone from the North Atlantic and a *B. laevis* Zone from the Vøring Plateau. These zones are described from deposits with an age of approximately 10.3-10.0 My.

BOLBOFORMA SUBFRAGORI ASSEMBLAGE

Definition: The top and base of the assemblage are taken at the highest/youngest and lowest/oldest occurrence of *B. subfragori*.

Depth range: 1270-1280 m.

Material: Two ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *Bolboforma fragori*/*B. subfragori* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993), Subzone NSP 14a of King (1983) and *Bolboforma spiralis* zone of Stratlab (1988).

Description: This unit is characterized by a rich fossil assemblage of radiolaria, pyritized diatoms, *Bolboforma*

and planktonic foraminifera. Radiolaria, pyritized diatoms and *Bolboforma* are dominant, with subordinate foraminifera. *B. subfragori* is common. Other recorded *Bolboforma* include *B. laevis*, *B. metzmacheri* (one specimen) and *B. fragori*. Recorded planktonic foraminifera include *N. pachyderma* (caved), *G. bulloides*, *Neogloboquadrina acostaensis* and *N. atlantica* (dextral, Fig. A12). *Remarks:* A *B. fragori/B. subfragori* Zone is known from deposits with an age of approximately 11.7-10.3 My from the North Atlantic and the Vøring Plateau (Spiegler & Müller 1992 and Müller & Spiegler 1993). Spiegler & Jansen (1989) describe a lower *N. atlantica* (dextral) Zone from Upper Miocene sediments on the Vøring Plateau. *N. acostaensis* is reported from deposits of Middle to Late Miocene age in the same area.

UNDEFINED INTERVAL

Depth range: 1280-1310 m.

Material: Three ditch cutting samples.

Age: Early Miocene in the lower part and Late Miocene in the upper part (based on benthic foraminiferal and palynological evidence).

Lithostratigraphic unit: Upper part of Brygge Formation and lower part of Kai Formation.

Description: This interval contains a rich planktonic fossil assemblage of pyritized diatoms and radiolaria, but no diatom index fossil is recorded (Fig. A12).

DIATOM SP. 4 ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of Diatom sp. 4. The base is marked by the highest/youngest occurrence of Diatom sp. 3.

Depth range: 1310-1350 m.

Material: Four ditch cutting samples.

Age: Early Miocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSP 10 of King (1983).

Description: This unit contains a rich planktonic fossil assemblage of radiolaria (dominant), and pyritized diatoms (including common Diatom sp. 4, Fig. A12).

Remarks: Diatom sp. 4 is described from Lower Miocene deposits in the North Sea area (King 1983).

DIATOM SP. 3 ASSEMBLAGE

Definition: The top and base of the assemblage is taken at the highest/youngest and lowest/oldest occurrence of Diatom sp. 3.

Depth range: 1350-1385 m.

Material: Five ditch cutting samples.

Age: Early to Late Oligocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Subzone NSP 9c of King (1989).

Description: Also this interval contains a rich planktonic fossil assemblage of radiolaria (dominant) and pyritized diatoms (including Diatom sp. 3, Fig. A12).

Remarks: Diatom sp. 3 is known from the upper part of the Lower Oligocene to the lowermost part of Lower Miocene in the North Sea area (King 1989).

UNDEFINED INTERVAL

Depth range: 1385-1410 m.

Material: Four ditch cutting samples.

Age: Middle Eocene and Early Oligocene (based on benthic foraminiferal and palynological evidence).

Lithostratigraphic unit: Brygge Formation.

Description: This unit contains a rich planktonic fossil assemblage of pyritized diatoms and radiolaria (dominant), but no diatom or radiolarian index fossil are recorded (Fig. A12).

Dinoflagellate cyst zones

The investigated Upper Pliocene succession contains few *in situ* dinoflagellate cysts (with typically less than 5 species present), but common to abundant reworked older Cenozoic and Mesozoic specimens. A slightly more rich and diverse marine microflora is encountered from the Lower Pliocene, and the abundance and diversity increases further downward into Upper-Middle Miocene strata. Rich and diverse dinoflagellate cyst assemblages are found in the Lower Miocene, Oligocene and Upper-Middle Eocene deposits, allowing a relatively detailed biostratigraphic breakdown of the interval between 1300-1410 m in the well.

UNDEFINED INTERVAL

Depth range: 1180-1240 m.

Material: Six ditch cutting samples.

Age: Late Miocene/Early Pliocene to Late Pliocene (based on log correlation and benthic foraminiferal evidence).

Lithostratigraphic unit: Kai and Naust Formation.

Description: This interval contains only few *in situ* dinoflagellate cysts, but includes common to abundant reworked older Cenozoic and Mesozoic specimens. The *in situ* marine microfloras include *Batiacasphaera* spp., *Operculodinium centrocarpum* and *Spiniferites* spp. (Fig. A13).

Remarks: There are no age-diagnostic dinoflagellate cyst species in this interval.

UNDEFINED INTERVAL

Depth range: 1240-1250 m.

Material: One ditch cutting sample.

Age: Late Miocene to Early Pliocene (based on benthic and planktonic foraminiferal evidence).

Lithostratigraphic unit: Kai Formation.

Description: The ditch cutting sample from 1240 m contains a low diversity dinoflagellate cyst assemblage comparable to that recovered from the Upper Pliocene sequence.

Remarks: There are no age-diagnostic dinoflagellate cyst species and the age of this interval is determined by the presence of the *Cibicides telegdi* foraminiferal assemblage.

ACHOMOSPHERA SP. 1 ASSEMBLAGE ZONE

Definition: The body of strata defined by the presence of *Achomosphaera* sp. 1.

Depth range: 1250-1260 m.

Material: One ditch cutting sample.

Age: Late Miocene to Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Description: The ditch cutting sample from 1250 m contains a moderate diversity of dinoflagellate cysts, including common *Batiacasphaera* together with *Amiculospaera umbracula*, *Achomosphaera* sp. 1, *Barssidinium graminosum* and *Hystrichokolpoma* spp. (Fig. A13).

Remarks: This species has previously been consistently recorded in Lower Pliocene-Upper Miocene strata at ODP Sites 907, 908 and 909 in the Norwegian-Greenland Sea (Poulsen et al. 1996). The highest occurrence of *Spiniferites pseudofurcatus* at 1250 m may suggest that the age of the zone in this well is Late Miocene, rather than Early Pliocene. The presence of Middle – Late Miocene marker species *Labyrinthodinium truncatum* in this zone is considered to be due to reworking.

UNDEFINED INTERVAL

Depth range: 1260-1290 m.

Material: Three ditch cutting samples.

Age: Early Miocene in the lower part (based on log correlation) and Late Miocene in the upper part (based on benthic foraminiferal and planktonic fossil evidence).

Lithostratigraphic unit: Upper part of Brygge Formation and lower part of the Kai Formation.

Description: The interval contains moderate to rich and diverse assemblages of dinoflagellate cysts, and recovered key species include *Barssidinium graminosum*, *Spiniferites pseudofurcatus*, *Hystrichokolpoma* spp., *Hystrichosphaeropsis obscura* and *Reticulosphaera actinocoronata* (Fig. A13).

Remarks: The occurrence of *Hystrichosphaeropsis obscura* at 1270 m suggests an age older than 7.25 Ma according to the last occurrence datum for this species given by Smelror et al. (in press).

DISTATODINIUM PARADOXUM ZONE

Definition: The body of strata between the highest/youngest occurrence of *Distatodinium paradoxum* and the highest/youngest occurrence of *Cribroperidinium tenuitabulatum* (Smelror et al. in press).

Depth range: 1290-1300 m.

Material: One ditch cutting sample.

Age: Latest Early Miocene (partly based on benthic foraminiferal evidence).

Lithostratigraphic unit: Brygge Formation.

Description: The interval contains a fairly rich and diverse assemblage of dinoflagellate cysts. Recovered key species are *Distatodinium craterum*, *Palaeocystodinium* spp., *Homotrybilum floripes*, *Tuberculodinium vancampoae*, common *Systematophora placacantha*, *Invertocysta tabulata* and *Palaeocystodinium* sp. A Costa & Downie (1979, Fig. A13).

CRIBROPERIDINIUM TENUITABULATUM ZONE

Definition: The body of strata between the highest/youngest occurrence of *Cribroperidinium tenuitabulatum* and the highest/youngest occurrence of *Cordosphaeridium cantharellum* (Smelror et al. in press).

Depth range: 1300-1310 m.

Material: One ditch cutting sample.

Age: Early Miocene.

Lithostratigraphic unit: Brygge Formation.

Description: The interval contains a fairly rich and diverse assemblage of dinoflagellate cysts. Recovered key species include *Apteodinium spiridoides*, *Cribroperidinium tenuitabulatum*, *Distatodinium craterum*, *Spiniferites pseudofurcatus*, *Palaeocystodinium* spp., *Homotrybilum floripes*, *Tuberculodinium vancampoae* and common *Systematophora placacantha* (Fig. A13).

Remarks: The present *Cribroperidinium tenuitabulatum* Zone can be correlated to the Mio2 Zone as defined by Poulsen et al. (1996) at ODP Site 909 in the Greenland-Spitsbergen Sill.

CORDOSPHAERIDIUM CANTHARELLUM ZONE

Definition: The body of strata between the highest/youngest occurrence of *Cordosphaeridium cantharellum* and the highest/youngest occurrence of *Caligodinium amiculum* (Smelror et al. in press).

Depth range: 1310-1325 m.

Material: One ditch cutting sample.

Age: Mid Early Miocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a fairly rich and diverse assemblage of dinoflagellate cysts. Recovered key species include *Cordosphaeridium cantharellum*, *Cribroperidinium tenuitabulatum*, *Distatodinium* spp., *Spiniferites pseudofurcatus*, *Palaeocystodinium* spp. and common *Systematophora placacantha* (Fig. A13).

Remarks: Powell (1992) calibrated the LAD of *Cordosphaeridium cantharellum* to the lower NN 4 Zone in the British Tertiary, while de Verteuil & Norris (1996) placed the LAD in the upper NN 2 in their study on the Miocene of the U.S. Atlantic Margin. Williams and Manum (1999) give an age of 17.95 Ma for the LAD of *C. cantharellum*, which is in agreement with a calibration to the lower NN 4 Zone.

CHIROPTERIDIUM SPP. ZONE

Definition: The body of strata between the highest/youngest occurrence of *Chiropteridium* spp. and the highest/youngest occurrence of *Distatodinium biffii* (Smelror et al. in press).

Depth range: 1325-1355 m.

Material: Three ditch cutting samples.

Age: Late Oligocene (lowermost part) to Early Miocene (partly based on planktonic fossil evidence).

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a relatively rich and diverse marine microflora. Characteristic and common species of this zone are *Chiropteridium* spp., *Deflandrea phosphoritica*, *Caligodinium* spp., *Homotrybilum floripes* and *Cordosphaeridium cantharellum* (Fig. A13).

DISTATODINIUM BIFFII ZONE

Definition: The body of strata between the highest/youngest occurrence of *Distatodinium biffii* and the highest/youngest occurrence of *Areoligera semicirculata*.

Depth range: 1355-1365 m.

Material: One ditch cutting sample.

Age: Late Oligocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a relatively rich and

diverse marine microflora. In overall character the dinoflagellate cyst assemblage in this zone resembles that over the overlying *Chiropteridium* spp. Zone, the main difference being the presence of *Distatodinium biffii* in the present zone (Fig. A13).

Remarks: According to Brinkhuis & Biffii (1993) and de Verteuil & Norris (1996) the last occurrence datum of *D. biffii* is found just below the Oligocene/Miocene boundary in the Mediterranean and on the US Coastal Plain. A concurrent last appearance datum is also well documented in the Norwegian-Greenland Sea by Smelror et al. (in press.).

AREOLIGERA SEMICIRCULATA ZONE

Definition: The body of strata between the highest/youngest occurrence of *Areoligera semicirculata* and the highest/youngest occurrence of *Svalbardella cooksoniae*.

Depth range: 1365-1375 m.

Material: One ditch cutting sample.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a relatively rich and diverse marine microflora. Characteristic for this zone in well 6609/11-1 is the acme of *Areoligeras semicirculata*, and the presence of *Chiropteridium lobospinosum* and *Evittosphaerula paratabulata* which are restricted to this zone in the well (Fig. A13).

Remarks: According to Powell (1992) the last appearance datum (LAD) of *A. semicirculata* lies within the lower NP25 calcareous nannoplankton biozone in Britain and in the North Sea area. Manum et al. (1989) found that the LAD of this species (named *Glaphyrocysta intricata* in their publication) corresponded to the upper boundary of their Early/Late Oligocene *Areosphaeridium? actinocoronatum* in ODP Hole 643 in the Norwegian Sea. The LAD of this species also defines the upper boundary of the Oli4 Zone of Poulsen et al. (1996) as defined in ODP Hole 908 on the Hovgaard Ridge between Svalbard and NE Greenland.

SVALBARDELLA COOKSONIAE ZONE

Definition: The body of strata between the highest/youngest occurrence of *Svalbardella cooksoniae* and the highest/youngest occurrence of *Areosphaeridium dictyoplokkus*.

Depth range: 1375-1385 m.

Material: One ditch cutting sample.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a relatively rich and diverse marine microflora, with *Svalbardella cooksoniae*, *Deflandrea granulata*, *Samlandia chalmydophora* and *Cordosphaeridium gracile* being characteristic species (Fig. A13).

Remarks: Manum et al. (1989) found that *Svalbardella cooksoniae* was restricted to their Early Oligocene *Chiropteridium lobospinosum* Zone in ODP Hole 643 in the Norwegian Sea.

AREOSPHAERIDIUM DICTYOPLOKKUS ZONE

Definition: The body of strata between the highest/

youngest occurrence of *Areosphaeridium dictyoplokkus* and the highest/youngest occurrence of *Heteraulacacysta porosa* (Bujak & Mudge 1994).

Depth range: 1385-1410 m.

Material: Three ditch cutting sample.

Age: Late Eocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a rich and diverse marine microflora. Species having their youngest occurrence in this zone are *Areosphaeridium dictyoplokkus*, *Areosphaeridium michoudii* and *Cordosphaeridium funiculatum*. Other characteristic species found in the zone are *Cereborycta bartonensis*, *Homotrybilum tenuispinosum*, *Enneadocysta pectiniformis*, *Dracodinium condylos* and *Thalassiphora delicate* (Fig. A13).

Remarks: The last occurrence datum of *Areosphaeridium dictyoplokkus* appears to be a well documented marker of the uppermost Eocene in the North Sea area (Powell 1992, Bujak & Mudge 1994) and the Norwegian-Greenland Sea (Firth, 1996, Mangerud & Charnock, 1999).

DIPHYES COLLIGERUM ZONE

Definition: The body of strata between the highest/youngest occurrence of *Diphyes colligerum* and the highest/youngest occurrence of abundant *Systematophora placacantha* (Bujak & Mudge, 1994).

Depth range: 1410 m.

Material: One ditch cutting sample.

Age: Middle Eocene.

Lithostratigraphic unit: Brygge Formation.

Description: The zone contains a rich and diverse marine microflora, which includes *Areosphaeridium dictyoplokkus*, *Areosphaeridium michoudii*, *Cereborycta bartonensis*, *Charlesdownie coleothrypta*, *Homotrybilum tenuispinosum*, *Enneadocysta pectiniformis*, *Thalassiphora delicata* and *Phthanoperidinium distictum* (Fig. A13).

Remarks: The presence of *Phthanoperidinium distictum* suggest a correlation to Subzone E6b of Bujak & Mudge (1994) dated as Late Lutetian. The present dinoflagellate cyst data suggest that there is a minor hiatus between the *Diphyes colligerum* Zone and the overlying *Areosphaeridium dictyoplokkus* Zone and that Bartonian strata (correlatable to the *H. porosa* Zone of Bujak & Mudge (1984)) equivalent are missing.

Strontium isotope stratigraphy

One interval from well 6609/11-1 was analysed for strontium isotopes. 34 tests of *U. venusta saxonica* were picked from the sample at 1260 m. The sample gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.708968. On the seawater Sr isotope curve of Howarth & McArthur (1997) this $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio corresponds to an age of approximately 6.3 Ma (Table 1, Fig. A12).

Lithology

Upper Pliocene (Naust Formation)

The ditch cutting samples from the Upper Pliocene unit contain a clay-rich diamicton which is also rich in sand,

silt and pebbles of mainly crystalline rocks. The pebbles are interpreted as ice-rafted and indicate that the sediments were deposited after the marked increase in the supply of ice-rafted detritus to the Norwegian Sea, which started at about 2.78 Ma (Fronval & Jansen 1996).

Upper Miocene and Upper Miocene to Lower Pliocene (Kai Formation)

The ditch cutting samples from this unit contain mostly fine-grained material. Clay dominates the samples, but the content of sand and silt is also considerable. Some pebbles of crystalline rock are also recorded. The sand is mainly glauconitic, but some quartzose sand is also recorded. Most of the quartzose sand and the pebbles are probably caved.

Lower Oligocene and Lower Miocene (Brygge Formation)

This unit is dominated by clay. Some silt and sand (mainly glauconitic) are also recorded. Some of the sand may be caved from the immediately overlying unit.

Stratigraphy and lithology of well 6508/5-1 on the Nordland Ridge

Well location, material and methods

Well 6508/5-1 (65°42'51.23"N, 08°28'35.44"E, Fig. A14) was drilled on the Nordland Ridge and sampled the Kai Formation. A number of 29 ditch cutting samples were analysed for foraminifera, *Bolboforma* and radiolarias. The same amount of material and the same kind of fossil preparation methods was used for well 6508/5-1 as for wells 6609/11-1, 6407/9-1, 6407/9-2 and 6407/9-5.

Micropalaeontological assemblages

The sections from the Upper Miocene to Late Pliocene contain moderately rich to rich benthic faunas of mainly calcareous foraminifera. Quite sparse planktonic foraminiferal faunas are recorded in the upper part of the Upper Miocene to Upper Pliocene sections. The lower part of the Upper Miocene contains a rich planktonic assemblage of *Bolboforma*, radiolaria, pyritized diatoms and planktonic foraminifera. The Lower-Middle Eocene section is characterized by a very large population of radiolaria and a sparse population of agglutinated foraminifera.

Benthic foraminiferal assemblages

CIBICIDES GROSSUS ASSEMBLAGE

Definition: The top of the assemblage extends to the uppermost investigated sample (1120 m). The base is marked by the highest/youngest occurrence of *E. pygmeus*.

Depth range: 1120-1170 m.

Material: Five ditch cutting samples.

Age: Late Pliocene.

Lithostratigraphic unit: Naust Formation.

Correlation: Zone NSB 15 of King (1989), *Cibicides grossa* zone of Stratlab (1988) and Zone NSR 12 B of Gradstein & Bäckström (1996).

Description: This unit contains a moderately rich benthic fauna of calcareous foraminifera. *C. teretis* is common throughout. Other important species include *C. grossus*, *N. affine*, *E. groenlandicum*, *B. marginata*, *A. fluens*, *B. tenerrima* and *E. excavatum*. *E. hannai* is recorded in some samples (Fig. A14).

Remarks: The occurrence of *C. grossus* and *E. hannai* shows that this unit is of Late Pliocene age (Doppert 1980, King 1989).

EPONIDES PYGMEUS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *E. pygmeus*. The base is marked by the highest/youngest occurrence of *C. telegdi*.

Depth range: 1170-1210 m.

Material: Four ditch cutting samples.

Age: Early Miocene to Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Probably *Cibicides telegdi* – *Eponides pygmeus* – *Neogloboquadrina atlantica* (dextral) zone of Eidvin et al. (1998) and probably lower part of *Melonis* – *Trifarina* zone of Stratlab (1988).

Description: This unit contains a rich benthic fauna of calcareous foraminifera. *N. affine* and *C. teretis* occur most frequently. Other important taxa include *E. pygmeus*, *A. fluens*, *B. tenerrima* and *Epistominella* sp. (Fig. A14).

Remarks: This assemblage is correlated with the *E. pygmeus* assemblage in wells 6407/9-5, 6407/9-1 and 6507/12-1, the *E. pygmeus* – *S. bulloides* assemblage in well 6407/9-1 and the *E. pygmeus* – *G. subglobosa* assemblage in well 6609/11-1 and is of Late Miocene to Early Pliocene age.

EPONIDES PYGMEUS – CIBICIDES TELEGDI ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *C. telegdi*. The base is marked by the highest/youngest occurrence of *U. venusta saxonica*.

Depth range: 1210-1230 m.

Material: Two ditch cutting samples.

Age: Late Miocene to Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Probably *Cibicides telegdi* – *Eponides pygmeus* – *Neogloboquadrina atlantica* (dextral) zone of Eidvin et al. (1998) and probably lower part of *Melonis* – *Trifarina* zone of Stratlab (1988).

Description: This unit contains a rich benthic fauna of calcareous foraminifera. *N. affine* and *C. teretis* are both common. Other characteristic forms include *E. pygmeus*, *A. fluens* and *B. tenerrima* (Fig. A14).

Remarks: This assemblage is correlated with the *E. pygmeus* assemblage in wells 6407/9-5, 6407/9-1 and 6507/12-1, the *E. pygmeus* – *S. bulloides* assemblage in well 6407/9-1 and the *E. pygmeus* – *G. subglobosa* assemblage in well 6609/11-1 and is of Late Miocene to Early Pliocene age.

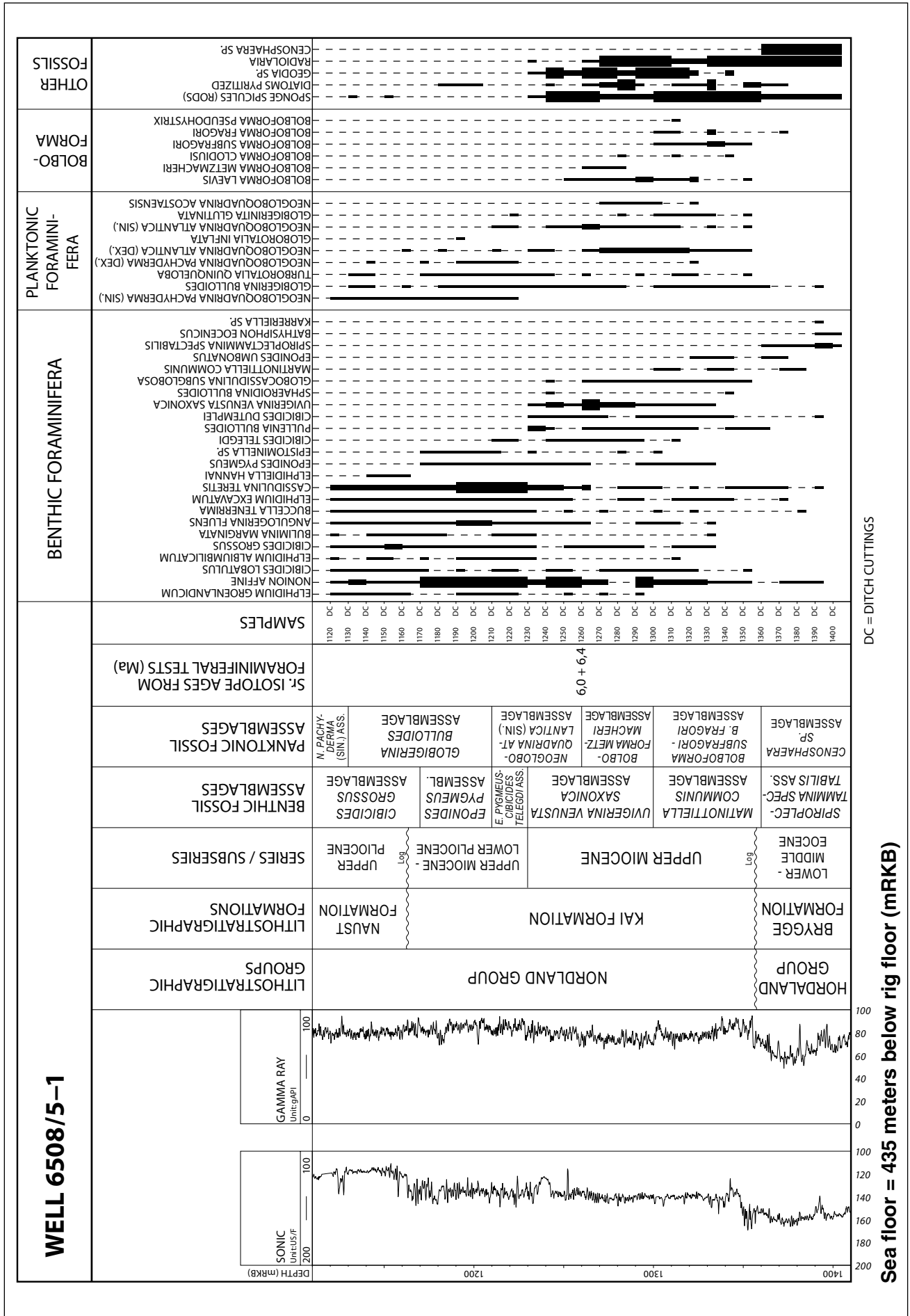


Fig. A14. Range chart of the most important benthic and planktonic foraminifera, Bolboforma and other planktonic index fossils in the investigated interval in well 6508/5-1. Legend for columns: thin (rare) 0-5%, middle (common) 5-20%, thick (abundant) 20% or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units, μs/f = microseconds per foot.

UVIGERINA VENUSTA SAXONICA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *U. venusta saxonica*. The base is marked by the highest/youngest occurrence of *M. communis*.
Depth range: 1230-1300 m.

Material: Seven ditch cutting samples.

Age: Late Miocene (partly based on Sr. analyses).

Lithostratigraphic unit: Kai Formation.

Correlation: Subzone NSB 13b of King (1989).

Description: Also this unit contains a rich benthic fauna of calcareous foraminifera. *U. venusta saxonica* and *N. affine* occur most frequently. Other characteristic forms include *C. teretis*, *P. bulloides*, *C. dutemplei* and *G. subglobosa* (Fig. A14).

Remarks: According to King (1989) *U. venusta saxonica* is known from Upper Miocene to Lower Pliocene sediments in the North Sea. Sr. analyses of tests of *U. venusta saxonica* from 1260 m gave ages of approximately 6.0 and 6.4 Ma (Late Miocene) and consequently rule out an Early Pliocene age.

MARTINOTTIELLA COMMUNIS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *M. communis*. The base is marked by the highest/youngest occurrence of *S. spectabilis*.

Depth range: 1300-1360 m

Material: Six ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Probably Zone FC of Doppert (1980).

Description: This assemblage contains a moderately rich benthic fauna of mainly calcareous foraminifera. There are fewer specimens in this unit than in the overlying units. No specimens are common, but characteristic taxa include *N. affine*, *C. teretis*, *E. pygmeus*, *P. bulloides*, *U. venusta saxonica* (upper part), *G. subglobosa*, *M. communis* (agglutinated) and *E. umbonatus* (Fig. A14).

Remarks: *M. communis* is known from the Middle Miocene to Lower Pliocene of the Netherlands (Doppert 1980) and from the Miocene on the Norwegian continental shelf (Skarbø & Verdenius 1986).

SPIROPLECTAMMINA SPECTABILIS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *S. spectabilis*. The base is undefined.

Depth range: 1360-1400 m.

Material: Five ditch cutting samples.

Age: Lower to Middle Eocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSA 5 of King (1989), *Spiroplectammina spectabilis* zone of Stratlab (1988) and probably Zone NSR 5A or NSR 5B of Gradstein & Bäckström (1996).

Description: This unit contains a sparse fauna of agglutinated foraminifera. *S. spectabilis* occurs most frequently. *Bathysiphon* sp. and *Karrerella* sp. are also recorded in some samples (Fig. A14).

Remarks: According to King (1989) *S. spectabilis* is known from the Lower to Middle Eocene in the North Sea area. According to Gradstein & Bäckström (1996) this species is described from upper Palaeocene to Middle Eocene deposits in the North Sea and the Haltenbanken areas.

Planktonic fossil assemblages**NEOGLOBOQUADRINA PACHYDERMA (SINISTRAL) ASSEMBLAGE**

Definition: The top of the assemblage extends to the uppermost investigated sample (1120 m). The base is marked by the highest/youngest occurrence of *G. bulloides*.

Depth range: 1120-1130 m.

Material: One ditch cutting sample.

Age: Late Pliocene (partly based on benthic foraminiferal evidence).

Lithostratigraphic unit: Naust Formation.

Correlation: *N. pachyderma* (sinistral) Zone of Spiegler & Jansen (1989).

Description: Just a few specimens of unencrusted forms of *N. pachyderma* (sinistral) are recorded in the sole sample which constitutes this unit (Fig. A14).

Remarks: The unencrusted form of *N. pachyderma* (sinistral) is known from Late Pliocene and Pleistocene sediments in the Norwegian Sea. Pleistocene deposits (younger than approximately 1.8 Ma) are totally dominated by the encrusted form of *N. pachyderma* (sinistral).

GLOBIGERINA BULLOIDES ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *G. bulloides*. The base is marked by the highest/youngest occurrence of *N. atlantica* (sinistral).

Depth range: 1130-1210 m.

Material: Eight ditch cutting samples.

Age: Late Miocene-Early Pliocene to Late Pliocene.

Lithostratigraphic units: Kai and Naust formations.

Correlation: *Globigerina bulloides* Zone of Weaver & Clement (1986).

Description: The assemblage is characterized by a sparse fauna of planktonic foraminifera. Characteristic species include *G. bulloides*, *N. pachyderma* (sinistral, unencrusted), *T. quinqueloba* and *N. pachyderma* (dextral). *N. atlantica* (dextral) and *G. inflata* are also recorded in a few samples (Fig. A14).

Remarks: *G. bulloides* Zone is described from the North Atlantic (DSDP Leg 94) in Miocene to Pliocene sediments as young as 2.2 Ma (Weaver & Clement 1986). On the Vøring Plateau *G. bulloides* is common in Miocene to Pliocene deposits older than 2.4 Ma (Spiegler & Jansen 1989).

NEOGLOBOQUADRINA ATLANTICA (SINISTRAL)

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *N. atlantica* (sinistral). The base is marked by the highest/youngest occurrence of *B. laevis*.

Depth range: 1210-1260 m.

Material: Five ditch cutting samples.

Age: Late Miocene to Late Miocene-Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *N. atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).

Description: Planktonic foraminifera are also sparse in this unit. Characteristic taxa include *N. atlantica* (sinistral), *G. bulloides* and *T. quinqueloba*. *N. pachyderma* (dextral), *N. atlantica* (dextral) and *G. glutinata* are also recorded in a few samples (Fig. A14).

Remarks: *N. atlantica* (sinistral) is known from the North Atlantic and the Vøring Plateau in Late Miocene to Late

Pliocene sediments (Weaver & Clement 1986, Spiegler & Jansen 1989). A few reworked specimens of *B. laevis* are recorded in the lowermost sample.

BOLBOFORMA METZMACHERI ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. metzmacheri*. The base is marked by the highest/youngest occurrence of *B. subfragori* and *B. fragori*.

Depth range: 1260-1300 m.

Material: Four ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *Bolboforma metzmacheri* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993), *Bolboforma metzmacheri* zone of Stratlab (1988), Zone NSR 10 of Gradstein & Bäckström (1996) and Subzone NSP 14b of King (1983).

Description: This unit contains a rich planktonic fossil assemblage of *Bolboforma*, foraminifera, radiolaria and pyritized diatoms. Radiolaria and pyritized diatoms are dominant, with subordinate *Bolboforma* and planktonic foraminifera. *B. laevis* and *B. metzmacheri* are the most common *Bolboforma* species. *B. clodiusi* is also recorded. *N. atlantica* (dextral) is the most common foraminifera. Other characteristic taxa include *G. bulloides*, *N. atlantica* (sinistral) and *N. acostaensis* (Fig. A14).

Remarks: *B. metzmacheri* is described from sediments with an age of approximately 10.0-8.7 My on the Vøring Plateau (Spiegler & Müller 1992 and Müller & Spiegler 1993).

BOLBOFORMA SUBFRAGORI- BOLBOFORMA FRAGORI ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. subfragori* and *B. fragori*. The base is marked by the highest/youngest occurrence of the radiolaria genus *Cenosphaera* sp.

Depth range: 1300-1360 m.

Material: Six ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *Bolboforma fragori*/*B. subfragori* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993), Subzone NSP 14a of King (1983) and *Bolboforma spiralis* zone of Stratlab (1988).

Description: This unit is characterized by a rich planktonic fossil assemblage of radiolaria, pyritized diatoms, *Bolboforma* and foraminifera. Radiolaria and pyritized diatoms are dominant, with subordinate *Bolboforma* and planktonic foraminifera. *B. subfragori* is the most common *Bolboforma* species. Other important forms include *B. fragori* and *B. laevis*. *B. clodiusi* and *B. pseudohystrix* are also recorded. Characteristic planktonic foraminifera include *G. bulloides*, *N. atlantica* (sinistral), *N. atlantica* (dextral), *G. glutinata* and *N. acostaensis* (upper part, Fig. A14).

Remarks: A *B. fragori*/*B. subfragori* Zone is known from deposits with an age of approximately 11.7-10.3 My from the North Atlantic and the Vøring Plateau (Spiegler & Müller 1992 and Müller & Spiegler 1993).

CENOSPHERA SP. ASSEMBLAGE

Definition: The top of the assemblage is taken at the high-

est/youngest occurrence of radiolarian of genus *Cenosphaera* sp. The base of the assemblage is undefined.

Depth range: 1360-1400 m.

Material: Five ditch cutting samples.

Age: Lower to Middle Eocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSP 6 of King (1989).

Description: The greater proportion of the planktonic fossils in this interval is radiolarian including abundant specimens of the genus *Cenosphaera*. A few pyritized diatoms are recorded in the upper part of the unit (Fig. A14).

Remarks: A *Cenosphaera* sp. acme is known from the Lower to Middle Eocene of the North Sea (King 1989).

Strontium isotope stratigraphy

Two samples from one interval in well 6508/5-1 were analysed for strontium isotopes. Tests of *U. venusta saxonica* were picked from the interval 1260 m and the samples gave corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratios of 0.708991 and 0.708965 corresponding to ages of approximately 6.0 and 6.4 Ma respectively on the seawater Sr isotope curve of Howarth & McArthur (1997, Table 1, Fig. A14).

Lithology

Upper Pliocene (Naust Formation)

The samples from the Upper Pliocene unit contain a clay-rich diamicton with sand, silt and ice-rafted pebbles of mainly crystalline rocks.

Upper Miocene to Lower Pliocene (Kai Formation)

The ditch cutting samples from this interval are mostly fine-grained. Clay dominates in the samples, but the content of silt, sand (mainly quartzose) and pebbles of crystalline rocks is also considerable. The pebbles and most of the sand are probably caved from the Upper Pliocene section.

Upper Miocene (Kai Formation)

The Upper Miocene samples are also mostly fine grained. However, the upper and lower parts are rich in glauconitic sand. Some quartzose sand and pebbles of crystalline rocks are recorded in most samples, but these are probably caved.

Lower to Middle Eocene (Brygge Formation)

The samples in the Lower to Middle Eocene unit are dominated by clay. Some silt and sand (mostly glauconitic) are also recorded. A few caved pebbles of crystalline rock are recorded in some samples.

Stratigraphy and lithology of well 6609/5-1 on the Nordland Ridge

Well location, material and methods

Well 6609/5-1 (66°37'42.73"N, 09°24'52.17"E, Fig. 1) was

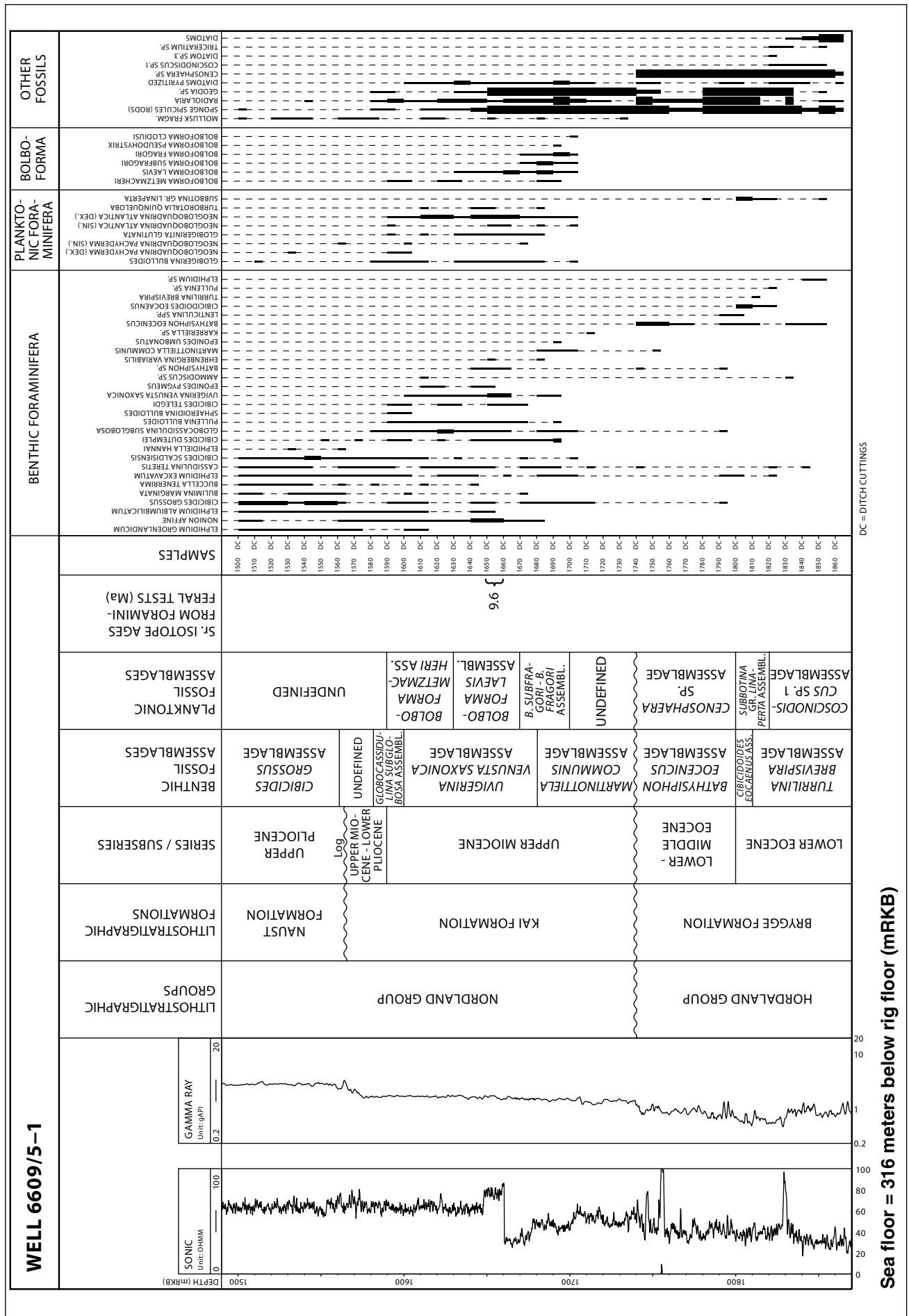


Fig. A15. Range chart of the most important benthic and planktonic index fossils in the investigated interval of well 6609/5-1. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units, μs/f = microseconds per foot.

drilled on the Nordland Ridge and in to the Kai Formation. A number of 37 ditch cutting samples were analysed for foraminifera, *Bolboforma* and radiolaria. The same amount of material and the same kind of fossils preparation methods were used for well 6609/5-1 as for wells 6508/5-1, 6609/11-1, 6407/9-1, 6407/9-2 and 6407/9-5.

Micropalaeontological assemblages

The Upper Pliocene unit contains a moderately rich benthic fauna of mainly calcareous foraminifera and a sparse planktonic fossil assemblage. The Upper Miocene – Lower Pliocene unit contains sparse benthic and planktonic assemblages. The Upper Miocene unit contains moderately rich benthic and planktonic faunas, except in the lowermost part with few benthic foraminifera and hardly any planktonic foraminifera or *Bolboforma*. The Lower – Middle Eocene unit contains a sparse fauna of agglutinated foraminifera and a rich planktonic assemblage of mainly radiolaria. The interval dated to Early Eocene contains a sparse benthic assemblage of both agglutinated and calcareous foraminifera and a rich planktonic assemblage of radiolaria and diatoms.

Benthic foraminiferal assemblages

CIBICIDES GROSSUS ASSEMBLAGE

Definition: The top of the assemblage extends to the uppermost investigated sample (1500 m). The base is marked by the lowest/oldest consistent occurrence of *C. grossus*.

Depth range: 1500-1560 m.

Material: Seven ditch cutting samples.

Age: Late Pliocene.

Lithostratigraphic unit: Naust Formation.

Correlation: Zone NSB 15 of King (1989), *Cibicides grossa* zone of Stratlab (1988) and Zone NSR 12 B of Gradstein & Bäckström (1996).

Description: This interval contains a moderately rich benthic fauna of mainly calcareous foraminifera. *C. grossus* is common. Other important species include *E. groenlandicum*, *E. albiumbilicatum*, *B. tenrerrima*, *E. excavatum*, *C. teretis* and *C. scaldiensis* (Fig. A15).

Remarks: The occurrence of *C. grossus* and *E. hannai* shows that this unit is of Late Pliocene age (Doppert 1980; King 1989).

UNDEFINED INTERVAL

Depth range: 1560-1580 m.

Material: One ditch cutting.

Age: Late Miocene to Early Pliocene (partly based on log correlation).

Lithostratigraphic unit: Kai Formation.

Description: The sole sample which constitutes this interval contains a sparse benthic fauna of calcareous foraminifera including *E. groenlandicum*, *N. affine*, *E. albiumbilicatum*, *E. excavatum*, *C. teretis*, *C. scaldiensis* and *C. dutemplei* (Fig. A15).

Remarks: Most of the recorded specimens are known

from almost the entire Neogene. The exception is *C. dutemplei* which is known from the Upper Oligocene to the Lower Pliocene in the Netherlands (Doppert, 1980) and from the Upper Oligocene to the Upper Miocene on the Norwegian continental shelf (Skarbo & Verdenius 1986). However, this species is also recorded in the lowermost part of the overlying unit where it is probably reworked. Reworking may also be the reason for the occurrence in this unit.

GLOBOCASSIDULINA SUBGLOBOSA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *G. subglobosa*. The base is marked by the highest/youngest occurrence of *U. venusta saxonica*.

Depth range: 1580-1600 m.

Material: Two ditch cutting samples.

Age: Late Miocene to Late Pliocene-Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Probably Subzone NSB 13b and Subzone 14a of King (1989) and probably *G. subglobosa* – *Ehrenbergina variabilis* zone of Stratlab (1988).

Description: The unit contains a sparse benthic fauna of calcareous foraminifera. No species is common, but characteristic taxa include *G. subglobosa*, *N. affine*, *E. albiumbilicatum*, *P. bulloides* (lower part), *S. bulloides* (lower part) and *C. telegdi* (lower part, Fig. A15).

Remarks: *G. subglobosa* is recorded from the Oligocene to the Lower Pliocene in the North Sea (Eidvin & Rundberg 2001; Eidvin & Rundberg in press). *S. bulloides* is described from Upper Oligocene to Upper Miocene deposits in the Netherlands (Doppert 1980).

UVIGERINA VENUSTA SAXONICA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *U. venusta saxonica*. The base is marked by the highest/youngest occurrence of *M. communis*.

Depth range: 1600-1680 m.

Material: Eight ditch cutting samples.

Age: Late Miocene (partly based on Sr. analyses and *Bolboforma* evidence).

Lithostratigraphic unit: Kai Formation.

Correlation: Subzone NSB 13b of King (1989).

Description: This assemblage contains a moderately rich benthic fauna of mainly calcareous foraminifera. Taxa are significantly more numerous in this interval than in the immediately overlying unit. *U. venusta saxonica*, *G. subglobosa* and *N. affine* occur most frequently. Other important species include *C. teretis*, *C. dutemplei*, *P. bulloides*, *E. pygmeus* and *C. telegdi* (Fig. A15).

Remarks: According to King (1989) *U. venusta saxonica* is known from Upper Miocene to Lower Pliocene sediments in the North Sea area. Sr. analyses of tests of *U. venusta saxonica* from 1650-1660 m give an age of approximately 9.6 Ma (Late Miocene).

MARTINOTTIELLA COMMUNIS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *M. communis*. The base is marked

by the highest/youngest occurrence of *B. eocenicus*.

Depth range: 1680-1740 m.

Material: Six ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Probably Zone FC of Doppert (1980).

Description: There are considerably fewer taxa in this unit than in the immediately overlying interval. The unit contains a sparse benthic fauna of mainly calcareous foraminifera and the lower part of the unit is nearly barren of benthic foraminifera. Characteristic species in the upper part include *M. communis* (agglutinated), *C. dutemplei*, *C. teretis*, *G. subglobosa*, *E. umbonatus* and *Karrerella* sp. (lower part, agglutinated, Fig. A15).

Remarks: *M. communis* is known from the Middle Miocene to Lower Pliocene of the Netherlands (Doppert 1980).

BATHYSIPHON EOCENICUS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. eocenicus*. The base is marked by the highest/youngest occurrence of *Cibicidoides eocaenus*.

Depth range: 1740-1800 m.

Material: Six ditch cutting samples.

Age: Lower to Middle Eocene (partly based on planktonic fossil evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSB 4 and Zone NSA 4 of King (1989).

Description: This interval contains a very sparse benthic fauna of agglutinated foraminifera. *B. eocenicus* has a consistent occurrence throughout the assemblage. *Bathysiphon* sp. is also recorded in some samples (Fig. A15).

Remarks: According to King (1989) *B. eocenicus* is known from the uppermost Lower Eocene to the Lower Miocene in the North Sea area.

CIBICIDOIDES EOCENICUS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *C. eocenicus*. The base is marked by the highest/youngest occurrence of *Turrilina brevispira*.

Depth range: 1800-1810 m.

Material: One ditch cutting sample.

Age: Lower Eocene (partly based on planktonic fossil evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSB 3 of King (1989).

Description: The sole sample which constitutes this interval contains a very sparse benthic fauna of calcareous and agglutinated foraminifera. *C. eocenicus* is common. Other recorded taxa include *Lenticulina* spp. (Fig. A15).

Remarks: According to King (1989) *C. eocenicus* is known from Lower to Upper Eocene sediments in the North Sea.

TURRILINA BREVISPIRA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *T. brevispira*. The base of the assemblage is undefined.

Depth range: 1810-1860 m.

Material: Five ditch cutting samples.

Age: Lower Eocene (partly based on planktonic fossil evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSB 3 of King (1989).

Description: Also this unit contains a very sparse benthic fauna of calcareous and agglutinated foraminifera. Recorded taxa include *T. brevispira*, *Ammodiscus* sp. (agglutinated), *Pullenia* sp. and *Elphidium* sp. (Fig. A15).

Remarks: According to King (1989) *T. brevispira* is known from the Lower Eocene to lowermost Middle Eocene in the North Sea area.

Planktonic fossil assemblages

UNDEFINED INTERVAL

Depth range: 1500-1590 m.

Material: Nine ditch cutting samples.

Age: Late Miocene-Lower Pliocene to Late Pliocene (based on benthic foraminiferal evidence).

Lithostratigraphic unit: Kai and Naust Formation.

Description: Planktonic foraminifera are very sparse in this interval. Just a few specimens of *G. bulloides*, *N. pachyderma* (dextral) and *N. pachyderma* (sinistral) are recorded in some samples (Fig. A15).

BOLBOFORMA METZMACHERI ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. metzmacheri*. The base is marked by the highest/youngest occurrence of *B. laevis*.

Depth range: 1590-1630 m.

Material: Four ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *Bolboforma metzmacheri* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993), *Bolboforma metzmacheri* zone of Stratlab (1988), Zone NSR 10 of Gradstein & Bäckström (1996) and Subzone NSP 14b of King (1983).

Description: The unit contains a moderately rich planktonic fossil assemblage of *Bolboforma*, foraminifera, radiolaria and pyritized diatoms. *B. metzmacheri* is the only recorded *Bolboforma*. *N. atlantica* (dextral) is the most frequently occurring of the foraminifera. Other species include *G. bulloides*, *G. glutinata*, *N. pachyderma* (dextral, upper part) and *N. atlantica* (sinistral, upper part, Fig. A15).

Remarks: *B. metzmacheri* is described from deposits with an age of approximately 10.0-8.7 My on the Vøring Plateau (Spiegler & Müller 1992 and Müller & Spiegler 1993).

BOLBOFORMA LAEVIS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. laevis*. The base is marked by the highest/youngest occurrence of *B. subfragori* and *B. fragori*.

Depth range: 1630-1670 m.

Material: Four ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *Bolboforma laevis/Bolboforma capsula* Zone of Spiegler & Müller (1992) and *Bolboforma laevis* Zone of Müller & Spiegler (1993).

Description: The interval contains a moderately rich planktonic fossil assemblage of planktonic foraminifera, *Bolboforma*, radiolaria and pyritized diatoms. *B. laevis* is recorded throughout the unit. *B. metzmacheri* is recorded in the uppermost sample. *N. atlantica* (dextral) is common. Other characteristic foraminifera include *G. bulloides*, *G. glutinata* and *N. atlantica* (sinistral, Fig. A15).

Remarks: Spiegler & Müller (1992) and Müller & Spiegler (1993) have recorded a *B. laevis*/*B. capsula* Zone from the North Atlantic and a *B. laevis* Zone from the Vøring Plateau. These zones are described from deposits with an age of approximately 10.3-10.0 My.

BOLBOFORMA SUBFRAGORI – BOLBOFORMA FRAGORI ASSEMBLAGE

Definition: The top and base of the assemblage are taken at the highest/youngest and lowest/oldest occurrence of *B. subfragori* and *B. fragori*.

Depth range: 1670-1700 m.

Material: Four ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *Bolboforma fragori*/*B. subfragori* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993), Subzone NSP 14a of King (1983) and *Bolboforma spiralis* zone of Stratlab (1988).

Description: The unit contains a moderately rich planktonic fossil assemblage of foraminifera, *Bolboforma*, radiolaria and pyritized diatoms. *B. subfragori*, *B. fragori* and *B. laevis* occur frequently. *B. pseudohystrix* and *B. clodiusi* are also recorded in a few samples. Planktonic foraminifera include *G. bulloides*, *N. atlantica* (dextral), *N. atlantica* (sinistral) and *G. glutinata* (upper part, Fig. A15).

Remarks: A *B. fragori*/*B. subfragori* Zone is known from deposits with an age of approximately 11.7-10.3 My from the North Atlantic and the Vøring Plateau (Spiegler & Müller 1992 and Müller & Spiegler 1993).

UNDEFINED INTERVAL

Depth range: 1700-1740 m.

Material: Four ditch cutting samples.

Age: Late Miocene (based on benthic fossil evidence).

Lithostratigraphic unit: Kai Formation.

Description: The unit contains no planktonic foraminifera or *Bolboforma*. Just some indefinite radiolaria and pyritized diatoms are recorded in some of the samples (Fig. A15).

CENOSPHAERA SP. ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *Cenosphaera* sp. The base is marked by the highest/youngest consistent occurrence of *Subbotina* gr. *linaperta*.

Depth range: 1740-1800 m.

Material: Six ditch cutting samples.

Age: Lower to Middle Eocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSP 6 of King (1989) and *Caenosphaera* spp. Zone of Stratlab (1988).

Description: This interval contains a rich planktonic fossil

assemblage of mainly radiolaria including abundant *Cenosphaera* sp. Pyritized diatoms are recorded in some samples and one, probably reworked specimen of the planktonic foraminifera *Subbotina* gr. *linaperta* is also recorded (Fig. A15).

Remarks: A *Cenosphaera* sp. acme is known from the Lower to Middle Eocene in the North Sea (King 1989).

SUBBOTINA GR. LINAPERTA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest consistent occurrence of *Subbotina* gr. *linaperta*. The base is marked by the highest/youngest occurrence of *Coscinodiscus* sp. 1 (King, 1993).

Depth range: 1800-1820 m.

Material: Two ditch cutting samples.

Age: Lower Eocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSP 5 of King (1989), *Globigerina linaperta* zone of Stratlab (1988) and Zone NSR 4 of Gradstein & Bäckström (1996).

Description: The unit contains a rich planktonic fossil assemblage of radiolaria, mainly *Cenosphaera* sp. and planktonic foraminifera of the species *Subbotina* gr. *linaperta*. Pyritized diatoms are also recorded in some samples (Fig. A15).

Remarks: *Subbotina* gr. *linaperta* is known from Lower Eocene sediments in the North Sea area (King, 1989).

COSCINODISCUS SP. 1 ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *Coscinodiscus* sp. 1. The base of the assemblage is undefined.

Depth range: 1820-1860 m.

Material: Five ditch cutting samples.

Age: Lower Eocene (partly based on benthic foraminiferal evidence).

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSP 4 of King (1989), Zone NSR 3 of Gradstein & Bäckström (1996) and *Coscinodiscus* sp. 1 zone of Stratlab (1988).

Description: The greater proportion of the planktonic fossils from this interval is radiolarian, mainly *Cenosphaera* sp. Diatoms are also recorded in most samples including *Coscinodiscus* sp. 1 and *Triceratium* sp. (Fig. A15).

Remarks: King (1989) employs *Coscinodiscus* sp. 1 as the nominate taxon for the Upper Paleocene – Lower Eocene Zone NSP 4 of the North Sea.

Strontium isotope stratigraphy

One sample from well 6609/5-1 was analysed for strontium isotopes. Tests of *U. venusta saxonica* were picked from the interval 1650-1660 m and the sample gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratios of 0.708900 corresponding to an age of approximately 9.6 Ma on the seawater Sr isotope curve of Howarth & McArthur (1997, Table 1, Fig. A15).

Lithology

Upper Pliocene (Naust Formation)

The ditch cutting samples from the Upper Pliocene inter-

val contain a clay-rich diamicton which is also rich in sand, silt and ice-rafted pebbles of mainly crystalline rocks.

Upper Miocene to Lower Pliocene (Kai Formation)

The samples from this unit contain mostly fined-grained material. Clay dominates in the samples, but the content of silt sand (quartzose and glauconitic) and pebbles of crystalline rocks is also considerable. Most of the quartzose sand and all the pebbles are probably caved.

Lower Eocene to Lower-Middle Eocene (Brygge Formation)

The samples from the Lower Eocene to Lower-Middle Eocene interval are dominated by clay. Some silt is also recorded.

Stratigraphy and lithology of well 6507/12-1 on the Trøndelag Platform.

Well location, material and methods

Well 6507/12-1 (65°07'01.62"N, 07°42'42.61"E, Fig.1) was drilled on the Trøndelag Platform and sampled a nearly complete section of the Kai Formation. A number of 31 ditch cutting samples were analysed for foraminifera, *Bolboforma* and diatoms. The same amount of material and the same kind of fossil preparation methods were used for well 6507/12-1 as for wells 6508/5-1, 6609/5-1, 6609/11-1, 6407/9-1, 6407/9-2 and 6407/9-5.

Micropalaeontological assemblages

The sections from the Upper Miocene to Late Pliocene contain moderately rich to rich benthic faunas of mainly calcareous foraminifera. Quite sparse planktonic foraminiferal faunas are recorded in the upper part of the Upper Miocene to Upper Pliocene sections. The lower part of the Upper Miocene contains a rich planktonic assemblage of *Bolboforma*, radiolaria and planktonic foraminifera. The Middle Miocene unit contains a moderately rich benthic fauna of mainly calcareous foraminifera and a rich planktonic assemblage of radiolaria, pyritized diatoms, *Bolboforma* and planktonic foraminifera. The fossil assemblages in the Oligocene and Lower Miocene sections are dominated by radiolaria, pyritized diatoms and sponge spicules. Sparse faunas of benthic calcareous foraminifera and some agglutinated and planktonic forms are also recorded in some sections.

Benthic foraminiferal assemblages

ELPHIDIELLA HANNAI ASSEMBLAGE

Definition: The top of the assemblage extends to the uppermost investigated sample (1300 m). The base is marked by the highest/youngest occurrence of *E. pygmeus*.

Depth range: 1300-1350 m.

Material: Five ditch cutting samples.

Age: Late Pliocene.

Lithostratigraphic unit: Naust Formation.

Correlation: Zone NSB 15 of King (1989), *Cibicides grossa* zone of Stratlab (1988) and Zone NSR 12 B of Gradstein & Bäckström (1996).

Description: This assemblage contains a moderately rich benthic fauna of mainly calcareous foraminifera. Characteristic taxa include *E. excavatum*, *C. grossus*, *E. hannai*, *E. groenlandicum*, *N. affine*, *C. lobatulus*, *B. marginata*, *C. teretis* and *E. albiumbilicatum* (Fig. A16).

Remarks: The occurrence of *E. hannai* and *C. grossus* shows that this unit is of Late Pliocene age (Doppert 1980, King 1989).

EPONIDES PYGMEUS ASSEMBLAGE

Definition: The top of the unit is taken at the highest/youngest occurrence of *E. pygmeus*. The base is marked by the highest/youngest occurrence of *C. telegdi*.

Depth range: 1350-1370 m.

Material: Two ditch cutting samples.

Age: Late Miocene to Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Probably *Cibicides telegdi* – *Eponides pygmeus* – *Neogloboquadrina atlantica* (dextral) zone of Eidvin et al. (1998) and probably the lower part of the *Melonis* – *Trifarina* zone of Stratlab (1988).

Description: This unit contains a rich benthic fauna of calcareous foraminifera. *N. affine* and *B. marginata* are both common. Other important species include *E. pygmeus*, *A. fluens* and *C. scaldiensis* (Fig. A16).

Remarks: This unit is correlated with the *E. pygmeus* assemblage in wells 6407/9-5 and 6407/9-1, the *E. pygmeus* – *S. bulloides* assemblage in well 6407/9-1 and the *E. pygmeus* – *G. subglobosa* assemblage in well 6609/11-1 and is of Late Miocene to Early Pliocene age.

EPONIDES PYGMEUS – CIBICIDES TELEGDI ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *C. telegdi*. The base is marked by the highest/youngest occurrence of *U. venusta saxonica*.

Depth range: 1370-1410 m.

Material: Four ditch cutting samples.

Age: Late Miocene to Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Probably with the *Cibicides telegdi* – *Eponides pygmeus* – *Neogloboquadrina atlantica* (dextral) zone of Eidvin et al. (1998) and probably with the lower part of *Melonis* – *Trifarina* zone of Stratlab (1988).

Description: This assemblage contains a rich benthic fauna of mainly calcareous foraminifera. *N. affine* and *C. teretis* are both common. Other characteristic taxa include *E. pygmeus*, *C. telegdi*, *B. marginata*, *A. fluens* and *S. schlumbergeri* (agglutinated). *C. dutemplei* and *G. subglobosa* are also recorded in some samples (Fig. A16).

Remarks: This assemblage is correlated with the *E. pygmeus* assemblage in wells 6407/9-5 and 6407/9-1, the *E. pygmeus* – *S. bulloides* assemblage in well 6407/9-1 and the *C. telegdi* and *E. pygmeus* – *G. subglobosa* assemblages in well 6609/11-1. The age is Late Miocene to Early Pliocene.

UVIGERINA VENUSTA SAXONICA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *U. venusta saxonica*. The base is marked by the highest/youngest occurrence of *M. communis*.

Depth range: 1410-1440 m.

Material: Three ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Subzone NSB 13b of King (1989).

Description: This unit contains a rich benthic fauna of calcareous foraminifera. *N. affine* and *C. teretis* occur most frequently. Other important forms include *U. venusta saxonica*, *A. fluens*, *E. pygmeus*, *C. dutemplei*, *C. telegdi*, *G. subglobosa* and *P. bulloides* (Fig. A16).

Remarks: According to King (1989) *U. venusta saxonica* is known from Upper Miocene to Lower Pliocene sediments in the North Sea. Sr. analyses of tests of *U. venusta saxonica* from 1430-1450 m gave an age of 10.0 Ma (Late Miocene) and consequently this rules out an Early Pliocene age.

MARTINOTTIELLA COMMUNIS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *M. communis*. The base is marked by the highest/youngest occurrence of *T. gracilis*.

Depth range: 1440-1480 m.

Material: Four ditch cutting samples.

Age: Late Miocene (partly based on planktonic fossil evidence).

Lithostratigraphic unit: Kai Formation.

Correlation: Probably Zone FC of Doppert (1980).

Description: This assemblage contains a moderately rich benthic fauna of mainly calcareous foraminifera. *N. affine* occurs most frequently. Other characteristic species include: *M. communis* (agglutinated), *C. dutemplei*, *G. subglobosa*, *U. venusta saxonica*, *P. bulloides*, *S. bulloides* and *E. variabilis* (Fig. A16).

Remarks: *M. communis* is known from the Middle Miocene to Lower Pliocene of the Netherlands (Doppert 1980) and from the Miocene on the Norwegian continental shelf (Skarbø & Verdenius 1986). *S. bulloides* is described from Upper Oligocene to Upper Miocene deposits in the Netherlands (Doppert 1980).

TRIFARINA GRACILIS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *T. gracilis*. The base is marked by the highest/youngest occurrence of *T. alsatica*.

Depth range: 1480-1550 m.

Material: Seven ditch cutting samples.

Age: Early to Middle Miocene (partly based on planktonic fossil evidence).

Lithostratigraphic unit: Brygge Formation and lowermost part of Kai Formation.

Correlation: Probably Zone NSB 10 and NSB 9 of King (1989) and probably Zone NSR 8B of Gradstein & Bäckström (1996).

Description: This unit contains a moderately rich to sparse benthic fauna of mainly calcareous foraminifera. There are considerably fewer taxa in this unit than in

the immediately overlying unit. Important taxa include *T. gracilis*, *T. gracilis* var. A, *C. dutemplei* and *P. bulloides*. *K. siphonella* (agglutinated) and *B. elongate* are also recorded (Fig. A16).

Remarks: According to Skarbø & Verdenius (1986) *T. gracilis* is known from Lower Oligocene to Lower Miocene deposits, and *T. gracilis* var. A is known from Upper Oligocene to Lower Miocene sediments on the Norwegian continental shelf. *K. siphonella* is recorded from the Middle Eocene to the Lower Miocene, and *B. elongate* is described from the Upper Oligocene to basal Upper Miocene in the North Sea area (King 1989). The co-occurrence with the planktonic *B. badensis* - *B. reticulata* assemblage in the upper part of this assemblage indicates that *T. gracilis* var. A and *K. siphonella* lived into the Middle Miocene in this area.

TURRILINA ALSATICA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *T. alsatica*. The base is taken at the highest/youngest occurrence of *R. bulimoides*.

Depth range: 1550-1570 m.

Material: Two ditch cutting samples.

Age: Late Oligocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: NSB 8 of King (1989) and probably Zone NSR 8A and the upper part of Zone 7B of Gradstein & Bäckström (1996).

Description: This assemblage contains a sparse benthic fauna of mainly calcareous foraminifera. Recorded species include *T. alsatica*, *B. elongate* and *Spirosigmoilinella* sp. (agglutinated, Fig. A16).

Remarks: *T. alsatica* is known from the Lower Oligocene to the lowermost Lower Miocene succession in the North Sea (King, 1989). According to Gradstein & Bäckström (1996) this form is known from Lower Oligocene to lowermost Upper Oligocene deposits in the same area.

ROTALIATINA BULIMOIDES ASSEMBLAGE

Definition: The top of the unit is taken at the highest/youngest occurrence of *R. bulimoides*. The base of the unit is not defined.

Depth range: 1570-1600 m (lowermost investigated sample).

Material: Four ditch cutting samples.

Age: Early Oligocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Subzone NSB 7b of King (1989), *Rotaliatina bulimoides* zone of Stratlab (1988) and probably Zone NSR 7A and the lower part of Zone NSR 7B of Gradstein & Bäckström (1996).

Description: This unit contains a sparse benthic fauna of mainly calcareous foraminifera. *C. tenellus* occurs most frequently. Other recorded taxa include *R. bulimoides*, *B. elongate*, *G. soldanii girardana* (Fig. A16).

Remarks: *R. bulimoides* is described from the Lower Oligocene to lowermost Upper Oligocene in the North Sea area according to King (1989). According to Gradstein & Bäckström (1996) this species is known from Eocene to Lower Oligocene deposits in the North Sea and the

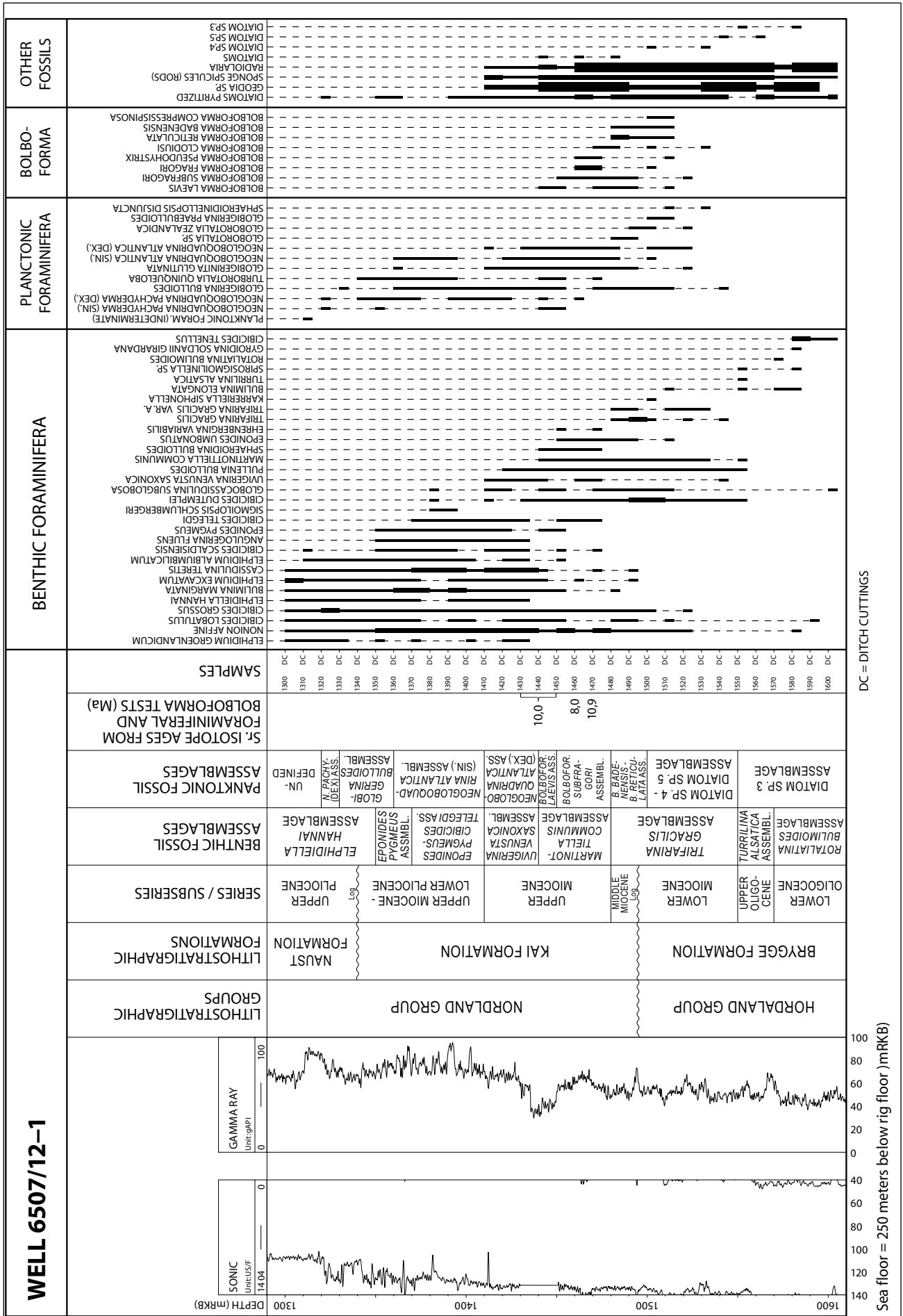


Fig. A.16. Range chart of the most important benthic and planktonic foraminifera, Bolboforma and other planktonic index fossils in the investigated interval of well 6507/12-1. Legend for columns: thin (rare) 0-5 %, middle (common) 5-20 %, thick (abundant) 20 % or more. M RKB = meters below rig floor, gAPI = American Petroleum Institute gamma ray units, μs/f = microseconds per foot.

Haltenbanken area. *C. tenellus* is known from the Oligocene in Belgium (Batjes 1958).

Planktonic fossil assemblages

UNDEFINED INTERVAL

Depth range: 1300-1320 m.

Material: Two ditch cutting samples.

Age: Late Pliocene (based on benthic foraminiferal evidence).

Description: Just a few unidentified planktonic foraminifera are recorded in this unit (Fig. A16).

NEOGLOBOQUADRINA PACHYDERMA (DEXTRAL) ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *N. pachyderma* (dextral). The base is marked by the highest/youngest occurrence of *G. bulloides*.

Depth range: 1320-1330 m.

Material: One ditch cutting sample.

Age: Late Pliocene.

Lithostratigraphic unit: Naust Formation.

Correlation: *N. pachyderma* (dextral) Zone of Weaver (1986), Weaver & Clement (1986) and Spiegler & Jansen (1989) and Subzone NSP 16a of King (1989).

Description: This assemblage is characterized by a sparse fauna of planktonic foraminifera. Recorded species include *N. pachyderma* (sinistral) and *N. pachyderma* (dextral, Fig. A16).

Remarks: A latest Pliocene *N. pachyderma* (dextral) Zone is described by King (1989) from the North Sea, by Weaver (1986) and Weaver & Clement (1986) from the North Atlantic (DSDP Leg 94) and by Spiegler & Jansen (1989) from the Vøring Plateau (ODP Leg 104). On the Vøring Plateau the zone is dated to 1.9-1.8 Ma. The zone is characterized by common *N. pachyderma* (dextral). However, *N. pachyderma* (dextral) is also recorded, in smaller numbers, in Pleistocene sections in these areas, and is quite numerous in the warmest interglacials of the last 0.5 My (Kellogg 1977, Spiegler & Jansen 1989).

GLOBIGERINA BULLOIDES ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *G. bulloides*. The base is marked by the highest/youngest occurrence of *N. atlantica* (sinistral).

Depth range: 1330-1360 m.

Material: Three ditch cutting samples.

Age: Late Miocene-Early Pliocene to Early Pliocene.

Lithostratigraphic unit: Uppermost Kai Formation to lowermost Naust Formation.

Correlation: *G. bulloides* Zone of Weaver & Clement (1986) and probably upper part of *N. atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).

Description: Planktonic foraminifera are sparse in this unit. Taxa include *G. bulloides*, *N. pachyderma* (dextral) and *T. quinqueloba* (Fig. A16).

Remarks: *G. bulloides* Zone is described from the North Atlantic (DSDP Leg 94) in Miocene to Pliocene sediments

as young as 2.2 Ma (Weaver & Clement 1986). On the Vøring Plateau *G. bulloides* is common in Miocene to Pliocene deposits older than 2.4 Ma (Spiegler & Jansen 1989). *G. bulloides* is also common in the warmest interglacials of the last 0.5 My in the North Atlantic (Kellogg 1977).

NEOGLOBOQUADRINA ATLANTICA (SINISTRAL) ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *N. atlantica* (sinistral). The base is marked by the highest/youngest occurrence of *N. atlantica* (dextral).

Depth range: 1360-1410 m.

Material: Five ditch cutting samples.

Age: Late Miocene to Early Pliocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *N. atlantica* (sinistral) Zone of Weaver & Clement (1986) and Spiegler & Jansen (1989).

Description: The assemblage is characterized by a sparse fauna of planktonic foraminifera. Recorded species include *N. atlantica* (sinistral), *N. pachyderma* (dextral), *G. bulloides*, *T. quinqueloba* and *G. glutinata* (Fig. A16).

Remarks: *N. atlantica* (sinistral) is known from the North Atlantic and the Vøring Plateau in Late Miocene to Late Pliocene sediments (Weaver & Clement 1986, Spiegler & Jansen 1989).

NEOGLOBOQUADRINA ATLANTICA (DEXTRAL) ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *N. atlantica* (dextral). The base is marked by the highest/youngest occurrence of *B. laevis*.

Depth range: 1410-1440 m.

Material: Three ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: Lower *N. atlantica* (dextral) Zone of Spiegler & Jansen (1989) and *N. atlantica* (dextral)/*N. acostaensis* Zone of Weaver (1987) and Weaver & Clement (1987).

Description: This unit contains a sparse assemblage of planktonic foraminifera, pyritized diatoms and radiolaria. Recorded planktonic foraminifera include *N. atlantica* (dextral), *N. atlantica* (sinistral), *G. glutinata* and *G. bulloides* (Fig. A16).

Remarks: Spiegler & Jansen (1989) describe a lower *N. atlantica* (dextral) Zone from Upper Miocene sediments on the Vøring Plateau, and Weaver (1987) and Weaver & Clement (1987) record a *N. atlantica* (dextral)/*N. acostaensis* Zone from Upper Miocene sediments in the North Atlantic (DSDP Leg 94).

BOLBOFORMA LAEVIS ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. laevis*. The base is marked by the highest/youngest occurrence of *B. subfragori*.

Depth range: 1440-1450 m.

Material: One ditch cutting sample.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *Bolboforma laevis*/*Bolboforma capsula* Zone of Spiegler & Müller (1992) and *Bolboforma laevis* Zone of Müller & Spiegler (1993).

Description: The sole sample which representative of this unit contains a sparse fossil assemblage of *Bolboforma* and planktonic foraminifera. *B. laevis* is the only *Bolboforma* species recorded. Recorded foraminifera include *G. bulloides*, *N. atlantica* (sinistral), *N. atlantica* (dextral), *T. quinqueloba* and *G. glutinata* (Fig. A16).

Remarks: Spiegler & Müller (1992) and Müller & Spiegler (1993) have recorded a *B. laevis*/*B. capsula* Zone from the North Atlantic and a *B. laevis* Zone from the Vøring Plateau. These zones are described from deposits with an age of approximately 10.3-10.0 My.

BOLBOFORMA SUBFRAGORI ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. subfragori*. The base is marked by the highest/youngest occurrence of *B. badenensis* and *B. reticulata*.

Depth range: 1450-1480 m.

Material: Three ditch cutting samples.

Age: Late Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *Bolboforma fragori*/*B. subfragori* Zone of Spiegler & Müller (1992) and Müller & Spiegler (1993), Subzone NSP 14a of King (1983) and *Bolboforma spiralis* zone of Stratlab (1988).

Description: This unit is characterized by a rich fossil assemblage of radiolaria, pyritized diatoms, *Bolboforma* and planktonic foraminifera. Radiolarian and pyritized diatoms are dominant, with subordinate *Bolboforma* and planktonic foraminifera. Recorded *Bolboforma* include *B. subfragori*, *B. laevis*, *B. fragori*, *B. pseudohystrix* and *B. clodiusi*. Recorded planktonic foraminifera include *N. atlantica* (dextral), *N. atlantica* (sinistral), *G. bulloides*, *T. quinqueloba* and *G. glutinata* (Fig. A16).

Remarks: A *B. fragori*/*B. subfragori* Zone is known from deposits with an age of approximately 11.7-10.3 My from the North Atlantic and the Vøring Plateau (Spiegler & Müller 1992 and Müller & Spiegler 1993).

BOLBOFORMA BADENENSIS – BOLBOFORMA RETICULATA ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of *B. badenensis* and *B. reticulata*. The base is marked by the highest/youngest occurrence of Diatom sp. 4.

Depth range: 1480-1500 m.

Material: Two ditch cutting samples.

Age: Middle Miocene.

Lithostratigraphic unit: Kai Formation.

Correlation: *B. badenensis* and *B. reticulata* zones of Spiegler & Müller (1992), *B. badenensis*/*B. reticulata* Zone of Müller & Spiegler (1993) and probably Zone NSP 13 of King (1983).

Description: Also this unit contains a rich fossil assemblage of radiolaria, pyritized diatoms, *Bolboforma* and planktonic foraminifera. Radiolaria and pyritized dia-

toms are dominant, with subordinate *Bolboforma* and planktonic foraminifera. *B. reticulata* is the most common *Bolboforma*. Other species include *B. badenensis* and *B. clodiusi*. Recorded planktonic foraminifera include *N. atlantica* (dextral), *N. atlantica* (sinistral), *G. bulloides*, *G. glutinata* and *G. zealandica* (lower part, Fig. A16).

Remarks: Spiegler & Müller (1992) describe a *B. badenensis* Zone and a *B. reticulata* Zone from the North Atlantic and Müller & Spiegler (1993) describe a *B. badenensis*/*B. reticulata* Zone from the Vøring Plateau. These zones are recorded from deposits with an age slightly older than 14 to 11.9 My (Spiegler & Müller, 1992). *G. zealandica* is known from the Lower to lower Middle Miocene in the North Atlantic (Poore 1979) and in the North Sea (King 1983).

DIATOM SP. 4 – DIATOM SP. 5 ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of Diatom sp. 4. The base is marked by the highest/youngest occurrence of Diatom sp. 3.

Depth range: 1500-1550 m.

Material: Five ditch cutting samples.

Age: Early Miocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Zone NSP 10 of King (1983).

Description: This interval contains a rich planktonic fossil assemblage of pyritized diatoms (including Diatom sp. 4 and Diatom sp. 5) and radiolaria. A few caved *Bolboforma* are also recorded in the upper part of the unit. In this part a few planktonic foraminifera are also recorded. Most of these are also probably caved, but *G. zeandica*, *G. praebulloides* and *S. disjuncta* may be *in situ* (Fig. A16).

Remarks: *G. praebulloides* is known from Oligocene to lower Upper Miocene deposits in the North Atlantic (Poore, 1979) and from Oligocene to lower Middle Miocene deposits in the North Sea (Gradstein & Bäckström 1996). *S. disjuncta* is known from Lower to Middle Miocene deposits in the North Sea (Gradstein & Bäckström 1996). Diatom sp. 4 and Diatom sp. 5 are described from the Lower Miocene in the North Sea (King 1983, 1989). According to King (1989) Diatom sp. 4 is not known from the uppermost part of Lower Miocene and that can indicate that there is a small hiatus between this assemblage and the immediately overlying assemblage.

DIATOM SP. 3 ASSEMBLAGE

Definition: The top of the assemblage is taken at the highest/youngest occurrence of Diatom sp. 3. The base of the assemblage is undefined.

Depth range: 1550-1600 m.

Material: Six ditch cutting samples.

Age: Early Oligocene to Late Oligocene.

Lithostratigraphic unit: Brygge Formation.

Correlation: Subzone NSP 9c of King (1989).

Description: This unit is characterized by a moderately rich planktonic fossil assemblage of radiolaria and pyritized diatoms including Diatom sp. 3 (Fig. A16).

Remarks: Diatom sp. 3 is known from the upper part of the Lower Oligocene to the lower part of the Lower Miocene in the North Sea area (King, 1989).

Strontium isotope stratigraphy

Three intervals from well 6507/12-1 were analysed for strontium isotopes. Tests of *E. variabilis*, *C. dutemplei* and *S. bulloides* were picked from the samples at 1430–1450 m. This analysis gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.708897. On the seawater Sr isotope curve of Howarth & McArthur (1997) this $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio corresponds to an age of approximately 9.7 Ma. Tests of *B. fragori*, *B. subfragori* and *B. clodiusi* from the sample at 1460 m gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.708931 corresponding to an age of approximately 8.0 Ma. Tests of *B. fragori* and *B. subfragori* from the sample at 1470 m gave a corrected $^{87}\text{Sr}/^{86}\text{Sr}$ -ratio of 0.708865 corresponding to an age of approximately 10.9 Ma (Table 1, Fig. A16).

Lithology

Upper Pliocene (Naust Formation)

The ditch cutting samples from the Upper Pliocene unit contain a clay-rich diamicton which is also rich in sand, silt and pebbles of mainly crystalline rocks. The pebbles are interpreted as ice-rafted and indicate that the sediments were deposited after the marked increase in the supply of ice-rafted detritus to the Norwegian Sea, which started at about 2.78 Ma (Fronval & Jansen 1996).

Middle Miocene to Lower Pliocene (Kai Formation)

The ditch cutting samples from this unit contains mostly fine-grained material. Clay dominates in the samples, but the content of sand and silt is also considerable. Pebbles of crystalline rock are also recorded. The sand is mainly glauconitic, but quartzose sand is also recorded. Most of the quartzose sand and the pebbles are probably caved.

Lower Oligocene and Lower Miocene (Brygge Formation)

The ditch cutting samples in this unit contain clay, silt and sand (mainly glauconitic).

Appendix 2

Definition of the Molo Formation

Name: Molo is the Norwegian name for jetty.

Well type section: Well 6610/3-1 (Statoil) from approximately 349 m (the top is not sampled and logged in the well) to 555 m (Fig. A9), coordinates 66°55'29.70"N, 10°54'06.28"E (Nordland Ridge, Fig. 1).

Well reference section: Well 6407/9-5 (Shell) from 670 to 787 m (Fig. A1), coordinates 64°16'42.35"N, 07°44'14.66"E (Trøndelag Platform, Fig. 1).

Thickness: A total thickness of 206 m in the type well is only sampled with five side wall cores (Fig. A9). In the reference well a total thickness of 117 m is sampled with ditch cutting samples at ten meters interval (Fig. A1). Some short vibro cores are sampled in the Nordland Ridge area (Fig. 1). Close to its northern boundary (block 6610/2 and 6610/5) the unit increases to more than 500 m (Fig. 1).

Distribution: The formation extends from the coast off Møre at approximately 63°30'N, along the inner Mid Norwegian shelf up to the Nordland Ridge and Lofoten area at approximately 67°40' N (Fig. 1)

Lithology: The lithology varies considerably throughout its distribution area. In most wells and boreholes from proximal parts, the unit consists mainly of red to yellow coloured sand. Some sections also contain well rounded, rust-tinted pebbles. In some wells glauconitic sand and mica-rich sand are recorded. In the Draugen Field (Trøndelag Platform), where the distal part has been investigated, the unit contains glauconitic sand, silt and clay.

Basal boundary: In the type well the lower boundary is recognised by an abrupt change from greyish claystone of the Brygge Formation to grey mica-rich sand of the Molo Formation. The boundary is marked by a strong negative spike at approximately 555 m on the gamma log (Fig. A9). In the reference well the lower boundary is recognised by an abrupt change from greyish claystone of the Brygge Formation to dark (nearly black) glauconitic sand of the Molo Formation. The boundary is further marked by an increase in the gamma ray response and a decrease in velocity (Fig. A1).

Characteristics of the upper boundary: The upper boundary is not sampled and logged in the type well and it is only recognised on seismic lines. In the reference well the upper boundary is recognised by a marked decrease in velocity and a slight decrease in the gamma ray response into the overlying glacio-marine diamicton (Fig. A1).

Age: Late Miocene – Early Pliocene.

Depositional environment: The formation was deposited

in a coastal shallow marine to prograding deltaic environment, probably formed in a wave-dominated environment with extensive long-shore drift.

Remarks: It is only in wells from the distal part, including the reference well, that it is possible to date the Molo Formation by means of biostratigraphical and strontium isotope analyses. In wells from the proximal part, including the type well, only reworked fossils are recorded. Most of the sediments in this part are probably reworked from other formations including the Brygge and Tare formations.

The Molo Formation has previously informally been called the “Delta” by Bugge et al. (1976), IKU Bedrock Unit IX by Bugge et al. (1984) and Rokoengen et al. (1988, 1995), the “Frøyrygg formation” by Askvik & Rokoengen (1985) and informally introduced as the “Molo formation” by Gustavson & Bugge (1995).

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