Quantitative foraminiferal and palynomorph biostratigraphy of the Paleogene in the southwestern Barents Sea

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ABSTRACT

The stratigraphic distribution of both foraminifera and dinoflagellate cysts is recorded from the Paleocene to Eocene Torsk Formation in 12 petroleum exploration wells drilled in the southwestern Barents Sea. The foraminiferal assemblages are wholly agglutinated, and are referred to outer shelf to middle bathyal environments. A quantitative analysis of biostratigraphic events, mainly last occurrences (first downhole occurrences), is performed by means of the Ranking and Scaling (RASC) program. This procedure combined with conventional stratigraphic treatment has enabled us to establish the most likely order of microfossil events, and to propose a new quantitative zonal scheme for the southwestern Barents Sea.

In the studied wells the following six zones and subzones are distinguished (in ascending order): BSP 1, *Psammophora fusca* – *Hyperammina rugosa*, late early to early middle Paleocene; BSP 2, *Spiroplectammina spectabilis* early middle to early late Paleocene; BSP 3A, *Reticulophragmium pauperum*, middle late Paleocene; BSP 3B, *Haplophragmoides aff. eggeri*, latest Paleocene; BSP 4, *Spiroplectammina navarroana*, earliest Eocene; BSP 5, *Reticulophragmium amplexens*, early to middle Eocene. Owing to the occurrence of cosmopolitan deep-water agglutinated foraminifera, the new zonal scheme compares well with previous zonations developed for the Paleogene of the mid-Norwegian shelf, the North Sea and Labrador Shelf.

INTRODUCTION

The present study is part of our long term project dealing with the Paleogene microfossil based stratigraphy and paleoceanography of the southwestern Barents Sea, comprising the Tromsø, Hammerfest, Nordkapp and Bjørnøya basins (Fig. 1). The research is focused on the examination of benthic foraminiferal, dinoflagellate cyst and diatom assemblages from borehole sections, to provide a firm basis for understanding the composition, systematic affinities, and distribution patterns of the Paleogene Boreal micro faunas and floras. The information gained from quantitative analysis of this material can provide much-needed constraints on the chronostratigraphy and facies assessments of the Cenozoic sedimentary successions, as well as on the subsidence history of the depositional areas.

We have previously recorded the stratigraphy and paleoecology of foraminiferal, dinocyst and diatom assemblages in a reference section for the western Barents Sea, based on data from a single well 7119/9-1 (Nagy et al. 1997). The paleobathymetric implications of Paleogene agglutinated foraminiferal assemblages has been discussed by Nagy et al. (2000), by combining the deeper water assemblages of the southwestern Barents Sea well 7119/7-1 with shallow water faunas from onshore sections sampled in the Central Basin of Spitsbergen.

The primary goal of the present study is the construction of a regional biostratigraphic zonal scheme integrating foraminiferal and dinocyst distributions in the southwestern part of the Barents Sea. The zonation is aimed to be readily applicable over wide areas with changing paleoenvironmental conditions. To achieve this goal the mathematical sequencing method RASC (Ranking and Scaling) was used for establishing the most likely order of microfossil events, and for calculating and outlining the basic zonal succession. To strengthen regional applicability, emphasis is placed on foraminiferal and dinocyst events that are relatively widespread and readily recognised.

Background to the study

For exploration of petroleum resources in the southwestern Barents Sea, offshore drilling commenced in 1980 and was concentrated to the Hammerfest and Tromsø basins. During the last two decades 54 wells have been drilled, with the main activity prior to 1990. Drilling targets were primarily Lower and Middle Jurassic sandstones, though minor hydrocarbon accumulations were found also in Permian, Upper Triassic and Lower Cretaceous strata. Because of the rather modest results and high operating costs, drilling activity has now sharply declined. The lithostratigraphical framework and nomenclature of the sedimentary formations in the area is mainly based upon petroleum exploratory borehole data (Fig. 2).

THE BARENTS SEA PALEogene SUCCESSION

Geological setting

Cenozoic sediments in the Barents Sea are restricted to the southwestern basinal areas and to the western and northern passive continental margins bounding the shelf. In the southwest, thick Paleocene to Eocene sediment packages are preserved in the Tromsø, Hammerfest and Bjørnøya basins, while in the Nordkapp Basin and on the Loppa High (Fig. 1) only strongly reduced Paleogene thicknesses are present. On the western and northern shelf margins, the Cenozoic is more complete, and includes extensive Plio-Pleistocene fan deposits. The Central Basin of Spitsbergen contains a thick sedimentary succession of Paleocene to Eocene age, deposited in marine shelf to fluvio-deltaic environments.

During much of its Mesozoic and Cenozoic history, the Barents Sea served as part of a marine passageway connecting the North Sea and North Atlantic to the Arctic Ocean. This marine connection was affected by Late Cretaceous to Paleogene plate tectonic movements which caused old seaways to close and new communications to develop. Of prime importance is the separation of the Greenland plate from the Barents Shelf and the consequent opening of the North Atlantic Ocean that established a deep water connection between the Atlantic and Arctic oceans. Accordingly, the complex tectonic and paleoceanographic history of the Barents Shelf has played an important role in the development of the Cenozoic climate and the evolution of Arctic biota.

The subsurface geology and tectonic history of the Barents Sea region have been discussed in several recent studies (e.g. Nøttvedt et al. 1992, Faleide et al. 1993, Reemst & Cloetingh 1994, Dowdeswell, 1988). However, these studies did not benefit from having access to detailed microfossil-based biostratigraphical information. Despite the fact that 54 exploratory wells were drilled during the last two decades by the petroleum industry, the Paleogene biostratigraphy of the southwestern Barents Sea was not studied in a regional manner.

**Stratigraphic framework**

Paleogene sediments of the southwestern Barents Sea comprise a single major lithostratigraphic unit, the Torsk Formation, which is the only formation currently included in the Sotbakken Group (Fig. 2). These units were formally defined by Worsley et al. (1988) in their outline of the Mesozoic and Cenozoic lithostratigraphy of the Barents Sea. The Torsk Formation is the lateral equivalent of the van Mijenford Group in Spitsbergen, but represents a more distal, deep marine environment as demonstrated by Nagy et al. (2000).

The Torsk Formation is a rather monotonous succession of claystones, with some clays in the upper part of the thicker sections. These fine-grained deposits are grey and greenish grey in colour and show a relatively homogeneous composition with calcium carbonate content around 1% and organic carbon content around 0.1%. The claystones contain volcanic
The study is based on sediment samples from the probably Miocene strata. Group is more complete and includes Oligocene and western marginal unconformity is overlain by mainly Plio-Pleistocene. The study area range in age from Triassic to Maasstrichtian. The formation varies in thickness from 135 m in the central parts of the Hammerfest Basin. There is a marked thickening to more than 2 km, toward the undrilled deepest part of the Tromsø Basin.

The top of the Torsk Formation was originally cut by an erosional unconformity originating from tectonic movements associated with mid-Oligocene rifting between Greenland and Spitsbergen. The seismic reflector marking this unconformity can be traced seaward to a position between marine magnetic reflector marking this unconformity can be traced seaward to a position between marine magnetic anomaly 13 and 5 in the northern Norwegian Sea. The base of the Torsk lies transgressively upon Mesozoic strata, which in the study area range in age from Triassic to Maasstrichtian. The formation varies in thickness from 135 m near the southern end of the Nordkapp Basin to 1040 m in the central parts of the Hammerfest Basin. There is a marked thickening to more than 2 km, toward the undrilled deepest part of the Tromsø Basin.

The Torsk Formation is separated from the underlying Upper Cretaceous Nygrunnen Group by a regional unconformity. The associated hiatus in basin areas encompasses the latest Cretaceous and the earliest Paleocene, and can be traced on seismic lines throughout the southwestern Barents Sea (Rønnevik, 1981, Worsley et al. 1988). The base of the Torsk lies transgressively upon Mesozoic strata, which in the study area range in age from Triassic to Maasstrichtian. The formation varies in thickness from 135 m near the southern end of the Nordkapp Basin to 1040 m in the central parts of the Hammerfest Basin. There is a marked thickening to more than 2 km, toward the undrilled deepest part of the Tromsø Basin.

The study is based on sediment samples from the Paleogene interval of 12 exploratory wells (Table 1). The samples are U1ch cuttings in all the wells except number 7125/1-1, from which side wall core samples were available. The sample spacing is usually 10 m. All 12 wells were analysed for foraminifera while 11 wells were also analysed for palynomorphs. Well 7120/7-3 was omitted from the palynological analysis. The sample material was provided to the project by the following organisations: the Norwegian Petroleum Directorate, samples from wells 7117/9-2, 7119/9-1, 7120/7-3, 7121/5-1, 7124/3-1, 7119/12-1, 7120/12-1, 7120/2-1, 7219/9-1; Norsk Hydro A/S and the Norwegian Petroleum Directorate, samples from well 7119/7-1; Statoil, samples from well 7120/5-1; Saga Petroleum A/S, samples from well 7125/1-1.

For the foraminiferal analyses a total of 722 samples were used. In the laboratory the samples were dried, weighed, boiled in sodium carbonate solution, and washed over a sieve set of 63 µm, 125 µm and 500 µm mesh. Benthic foraminifera were hand-picked from the >125 µm fraction, and mounted on cardboard slides. Palynological analyses were carried out on a total of 604 samples, which were treated in accordance with standard laboratory techniques.

**MAIN FEATURES OF MICROFOSSIL ASSEMBLAGES**

The Torsk Formation contains relatively rich foraminiferal and dinocyst assemblages of late early Paleocene to middle Eocene age. The stratigraphic position of numerous foraminiferal and dinocyst last occurrences are consistent in the 12 analysed wells suggesting that these events may serve as an adequate basis for stratigraphic correlation across the southwestern Barents Sea.

The Paleocene foraminiferal assemblages, occurring in the lower and middle parts of the Torsk Formation in the 12 analysed wells, are characterised by intermediate species diversities and common occurrence of tubular forms (referred to *Rhizammina*, *Bathyphasphon* and *Hyperammina*). Dominant species include: *Spirammina spectabilis, Haylophragmoides walteri, Recurvoides sp. 1, Ammosphaeroidina pseudopauciloculata, and Saccammina grzybowskii*. The assemblages reveal close affinities to deep water “flysch type” faunas well known from the Carpathians, North Sea and North Atlantic margins. The Barents Sea Paleocene assemblages are interpreted as reflecting upper to middle bathyal conditions (Nagy et al. 2000).

The upper part of the Torsk Formation contains Eocene foraminiferal assemblages in six of the wells. In these assemblages the species diversities are reduced and tubular forms (referred to *Rhizammina*) occur only locally in significant amounts. Dominant species include: *Budavekevella multicamerata, Recurvoides aff. turbinatus, Ammosphaeroidina pseudopauciloculata and Reticuloplagium amplexens*. The diversity and composition of the assemblages suggest an outer neritic to upper bathyal environment (Nagy et al. 2000). The neritic faunal components display some affinities to contemporary prodelta shelf faunas recorded from Spitsbergen (Nagy et al. 2000).

**Taxonomy**

In the analysed samples over 100 foraminiferal and diatom species and more than 80 palynomorph taxa...
have been recognized. The foraminiferal taxonomy used largely follows the works of King (1989), Charnock & Jones (1990), Kaminski & Geroch (1993), Gradstein et al. (1994), Gradstein & Kaminski (1997) and Kaminski, Gradstein et al. (in prep.). The main index taxa from offshore mid-Norway and the western Barents Sea area have been illustrated by Gradstein et al. (1994) and Nagy et al. (1997, 2000). The dinocyst taxonomy corresponds generally to that of Bujak & Mudge (1994) and Mudge & Bujak (1994, 1996).

### STRATIGRAPHICAL METHODS

The stratigraphical integration of the agglutinated foraminiferal faunas with the dinocyst assemblages in the Torsk Formation is of particular importance because of the absence of calcareous planktonic micro-fossils. In these strata the dinocysts provide the best independent means of correlation with the standard plankton zonal schemes, and thus provide important chronostratigraphic constraint. As mentioned previously, the samples from all but one well are ditch cuttings. The effects of downhole caving appear to be minor, and abrupt faunal changes are observed at certain levels.

The fossil record utilised in the stratigraphic analysis consists of the last (first downhole) occurrence (LO) of foraminifaral and dinocyst taxa, as well as the last common occurrence (LCO) of selected species of these two groups. In addition the LO of a single diatom species is also included. The main database of the study consists of the total stratigraphic distribution of foraminifera and palynomorphs within the sampled intervals of the 12 wells.

The main stratigraphic method employed in the study is RASC (Gradstein et al. 1985, Agterberg & Gradstein, 1999) which calculates the most likely succession of events by comparing the stratigraphic order of all pairs of events in all wells. In the resulting optimum succession each event position is the average of all individual positions occurring in the well (Fig. 4). The optimum succession is scaled by calculation of the frequency of cross-overs of the relative position of each pair of events from well to well. An increase in the number of cross-overs results in decreased interfossil distance within the vertical succession. The distance calculations are displayed in dendrogram format where the density of clusters expresses nearness of events along a stratigraphic scale. Distinctive bundles of events are usually interpreted as stratigraphical zones, while large interfossil distances between successive bundles are regarded as zonal boundaries expressing breaks of varying magnitude in the fossil record.

### STRATIGRAPHICAL ZONATION

The RASC analysis of biostratigraphic events supplemented with conventional stratigraphic treatment enabled us to define six zonal units within the Paleocene to Middle Eocene succession of the southwestern Barents Sea (Figure 3). The chronostratigraphy and faunal content of the zones are the main topics of this chapter. In the 12 wells studied, the record of microfossil events include the occurrence of 80 agglutinated foraminiferal species, 36 dinocyst species, and 3 siliceous microfossil events. Altogether, there are 126 dictionary entries for a total of 633 events, mostly last occurrences (listed in the Appendix). The majority of the events occur in a few wells only; 52 events were observed in 6 or more wells.

The RASC interval zonation presented in this paper was run with the threshold values kc = 6, mc1 = x and mc2 = x where kc is the minimum number of wells in which each event must occur in order to be ranked, mc1 is the number of wells in which each pair of events in the ranked optimum sequence must occur, mc2 is the minimum number of wells in which each pair of events in the scaled optimum sequence occur. The RASC interval zonation contains 52 microfossil events that occur in at least 6 of the 12 wells (Figs. 3 & 4). In addition it includes 4 “unique” events that occur in 5 or fewer wells. The unique events are listed below in descending stratigraphic order:

1. Deflandrea oebisfeldensis
2. Aschomelona grandis
3. Sphaerammina gerochi
4. Alisocysta margarita LCO

The unique events supplement the stratigraphic zonation and correlation of the well sections, and assist with the integration of the dinocyst and foraminiferan records. Summary range charts for the most important agglutinated foraminifera and palynomorphs are given in Figures 5 and 6, respectively. The scaled optimum sequence enables us to define the following zones:

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Table 1. List of the studied Barents Sea wells with water depth, sampled interval and number of samples studied.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Well no.</th>
<th>Water depth</th>
<th>Interval studied</th>
<th>No. of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Norsk Hydro</td>
<td>7117/9-2</td>
<td>271 m</td>
<td>1095-1405 m</td>
<td>32</td>
</tr>
<tr>
<td>2. Elf Aquitaine</td>
<td>7119/7-1</td>
<td>238 m</td>
<td>450-1350 m</td>
<td>78</td>
</tr>
<tr>
<td>3. Statoil</td>
<td>7119/9-1</td>
<td>201 m</td>
<td>510 - 1450 m</td>
<td>126</td>
</tr>
<tr>
<td>4. Statoil</td>
<td>7120/7-3</td>
<td>258 m</td>
<td>332 -1380 m</td>
<td>118</td>
</tr>
<tr>
<td>5. Statoil</td>
<td>7120/5-1</td>
<td>318 m</td>
<td>410 - 1208 m</td>
<td>99</td>
</tr>
<tr>
<td>6. Statoil</td>
<td>7121/5-1</td>
<td>336 m</td>
<td>440 - 1013 m</td>
<td>38</td>
</tr>
<tr>
<td>7. Saga</td>
<td>7124/3-1</td>
<td>273 m</td>
<td>400 - 570 m</td>
<td>18</td>
</tr>
<tr>
<td>8. Saga</td>
<td>7125/1-1</td>
<td>228 m</td>
<td>403 - 580 m</td>
<td>16</td>
</tr>
<tr>
<td>9. Statoil</td>
<td>7119/12-1</td>
<td>200 m</td>
<td>403 - 625 m</td>
<td>43</td>
</tr>
<tr>
<td>10. Norsk Hydro</td>
<td>7120/12-1</td>
<td>167 m</td>
<td>440 - 750 m</td>
<td>32</td>
</tr>
<tr>
<td>11. Norsk Hydro</td>
<td>7120/2-1</td>
<td>387 m</td>
<td>480 - 635 m</td>
<td>17</td>
</tr>
<tr>
<td>12. Norsk Hydro</td>
<td>7219/9-1</td>
<td>333 m</td>
<td>720 - 1490 m</td>
<td>78</td>
</tr>
</tbody>
</table>
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BSP 1: *Psammosphaera fusca – Hyperammina rugosa* Zone
Type section: Well 7119/9-1, interval 1410-1450 m.
Age: late early to early late Paleocene.

**Taxa:** The following foraminiferal species have their average last occurrences in this interval zone: *Psammosphaera fusca, Reticulophragmium jarvisi and Cystammina sveni.* The last common occurrence of *Hyperammina rugosa* is typical for the zone. Amongst...
the dinocysts *Paleocystodinium bulliforme* and *Isabelidinium* cf. *viborgense* have their average last occurrences in this zone, although outliers of the latter species are found much higher in the succession. *Palaeoperidinium pyrophorum* displays its last occurrence in the interval.

**Discussion:** The benthic foraminiferal assemblages at the base of the Torsk Formation display the highest diversity and abundance found within the formation. An example is the lower ca. 40m of the Paleocene in well 7119/9-1, comprising this zone (Nagy et al. 1997). The assemblages are dominated by species that agglu-
### Figure 5. Stratigraphical range chart of selected foraminiferal species in the Paleogene Torsk Formation of the southwestern Barents Sea. The average stratigraphic range is in solid, while outliers and local extensions upward and downward in wells are dashed.

In the Torsk Formation, foraminiferal species having their average last occurrence in the interval include:

- **BSP 1**: S. spectabilis, P. fusca, A. glabratus, C. excelsa, R. amplectens, and H. aff. eggeri.
- **BSP 2**: C. spectabilis, P. fusca - S. spectabilis, H. rugosa, A. cretaceus, and H. aff. eggeri.
- **BSP 4**: S. navarroana, R. amplectens, and S. spectabilis.
- **BSP 5**: R. amplectens and S. navarroana.

#### Discussion

As mentioned previously, the Torsk Formation rests unconformably on Upper Cretaceous deposits belonging to the Kving or Kveite formations of the Nygrunnen Group. The sediments occurring immediately below the unconformity contain highly diverse and entirely agglutinated assemblages. A Campanian to Maastrichtian age is indicated for these deposits by the occurrence of the dinocysts *Alysocysta margarita*, *P. fusca*, and *H. aff. eggeri*.

As the Torsk Formation is observed in the type section of this zone in the well 7119/9-1 from 1180 to 1400 m, the LCO of *S. spectabilis* also appears within the upper Paleocene in the North Sea and offshore mid-Norway, where it is observed near the base of Zone NSR2B of Gradstein & Bäckström (1996). In the Barents Sea, this event occurs on average just below the LO of *Impagidinium densis* (of Heilmann-Clausen), and by the LCO of *A. margarita*.

An unusual feature of this zone is the large proportion of juvenile forms of *S. spectabilis*, consisting only of the planispiral coil. Other common taxa include *R. pauperum*, *A. pseudopauciloculata*, *H. aff. eggeri*, and *C. excelsa*. In the lower part of the zone, single occurrences of *Rzehakina minima* were observed.

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**Table: Stratigraphical range chart of selected foraminiferal species in the Paleogene Torsk Formation of the southwestern Barents Sea.**

<table>
<thead>
<tr>
<th>Epoch/Stage</th>
<th>Foraminiferal Zone</th>
<th>Type section</th>
<th>Age</th>
<th>Stratigraphical range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle Eocene</td>
<td>C. spectabilis</td>
<td>Well 7119/9-1, interval 1180-1400 m.</td>
<td>Early late Paleocene</td>
<td></td>
</tr>
</tbody>
</table>
Our *S. spectabilis* LCO Zone is roughly equivalent to the *Ammoanita ruthvenmurrayi* Zone in the North Sea and on the mid-Norwegian shelf defined by Gradstein *et al.* (1992) and Gradstein & Bäckström (1996), respectively. In the Barents Sea wells analysed in the present study, *A. ruthvenmurrayi* is rare or even absent. We therefore selected the *Spiroplectammina spectabilis* LCO, which occurs regionally in the south-western Barents Sea, to be the nominate event of this zone.

**BSP 3A: Reticulophragmium pauperum Subzone**

*Type section:* Well 7119/9-1, interval 1080-1160 m.

*Age:* middle late Paleocene.

*Taxa:* This interval zone contains the average last occurrence of the following species: *Reticulophragmium pauperum, Karrerulina horrida* and *Aschemonella grandis.* Local outliers of the latter two species occur, however at higher stratigraphic levels.

*Discussion:* This zone is characterised by the consistent common occurrence of *Reticulophragmium pauperum,* an index taxon for the upper Paleocene of the North Sea and the mid-Norwegian shelf. In the later area, this is the nominate species of the upper Paleocene Zone NSR 2B of Gradstein & Bäckström (1996). In our RASC solution in the Barents Sea, the *R. pauperum* Zone is well separated from the underlying cluster of Paleocene species and actually forms a subcluster at the base of the overlying *Haplophragmoides aff. eggeri* Zone (Fig. 3). Other important species of the type section include *Haplophragmoides walteri, Haplophragmoides porrectus,* *Rhabdammina discreta,* *Glomospira charoideas,* *Palaeocystodinium bulliforme,* *Palaeoperidinium pyrophorum,* *Alisocysta margarita,* *Isabelidinium wiborgense,* and *Aeroligeria senonensis.*

**BSP 3B: Haplophragmoides aff. eggeri Subzone**

*Type section:* Well 7119/9-1, interval 890-1070 m.

*Age:* latest Paleocene.

*Taxa:* The following foraminferal species have their last average occurrence in this interval zone: *Spiroplectammina spectabilis,* *Haplophragmoides porrectus,* *Rhabdammina discreta,* *Glomospira charoideas,* *Haplo-

![Figure 6. Stratigraphical range chart of selected dinocyst species in the Paleogene Torsk Formation of the southwestern Barents Sea. The average stratigraphic range is in solid, while outliers and local extensions upward and downward in wells are dashed.](image-url)
phragmoides walteri, Verneuilinoides sp., Haplophragmoides egeri, H. kirki, Ammodiscus macilentus, Ammonia marginulina aubertae, Glomospira gordialis and Ammodiscus peruvianus. Amongst the dinocysts, Alisocysta sp. 2 (of Heilmann-Clausen) and Apectodinium augustum have their last occurrence within this zone.

Discussion: The diversity of benthic foraminifera is generally low in this zone, and in addition the abundance is markedly reduced near the top of the unit. The assemblages are dominated by tubular forms and by specimens of Haplophragmoides tentatively designated as H. aff. egeri. The LO of this species was observed at 910 m in well 7119/9-1. The foraminifera are not age-diagnostic, but the occurrence of the dinocyst Apectodinium augustum suggests that the zone encompasses the Paleocene/Eocene boundary interval. However, this event still lacks direct calibration to the carbon isotope excursion which defines the P/E boundary in carbonate-bearing sequences.

BSP 4: Spiroplectammina navarroana Zone

Type section: Well 7119/9-1, interval 710-890 m.
Age: earliest Eocene.

Taxa: The following foraminiferal taxa have their average last occurrence in this interval zone: Ammodiscus planus, Ammosphaeroidina pseudopauciculata, Spiroplectammina navarroana, Notitia robusta, Karrerulinina conversa, Bathysiphon sp. and Basiasphaera multicamerata. The dinocysts Deflandrea oebisfeldensis, Cerodinium speciosum, Hystrichosphaeridium tubiferum, and Cerodinium wendenense have their last occurrences within the zone.

Discussion: The whole interval is characterised by a taxonomic turnover, and the LOs of many taxa are observed near 710 m in well 7119/9-1, including Spiroplectammina navarroana, Ammosphaeroidina pseudopauciculata, Haplophragmoides kirki and Ammodiscus macilentus. The planktonic species Subbotina patagonica has not been observed in our western Barents Sea wells, therefore the agglutinated species have not been observed in our western Barents Sea wells, therefore the agglutinated species has not been observed in our western Barents Sea wells. While on the Mid-Norwegian Shelf, the same event is recognised within the middle part of Zone NSR 5A of Gradstein & Bäckström (1996). Mudge & Bujak (1996) correlated the LO of S. navarroana with the top of the Ypresian.

In well 7119/9-1 we observed a diminutive form of Ammomarginulina aubertae; a species first described from the North Sea and Labrador Shelf by Gradstein & Kamienski (1989). The distribution of this species is apparently diachronous in offshore Norway, as it characterises the late Middle Eocene Zone NSR 6 of Gradstein & Bäckström (1996) on the mid-Norwegian shelf and in the northern North Sea. It is rare in our Lower Eocene samples from the Barents Sea.

We did not observe any planktonic or calcareous benthic foraminifera in the lower Eocene in any of the wells in the south-western Barents Sea. Calcareous assemblages characterising the Subbotina patagonica Zone of Gradstein et al. (1994) have been observed as far north as the mid-Norwegian shelf (Gradstein & Bäckström 1996) and the outer Voring Plateau (Hulsbos et al., 1989). Either the northern limit of the Early Eocene planktonic foraminifera must have existed south of the Barents Sea area, or the deep waters of the southwestern Barents Sea were too corrosive to allow the preservation of calcareous microfossils.

BSP 5: Reticulophragmium amplectens Zone

Type section: Well 7119/9-1, interval 510-710 m.
Age: late early to early middle Eocene.

Taxa: The following foraminiferal taxa have their average last occurrence in this interval zone: Rhizammina spp., Reticulophragmium amplectens, and Recurvoides spp. The zone also contains common Karrerulina spp., Haplophragmoides excavatus, and Basiasphaera multicamerata. A characteristic event is the LO of the diatom species Fenestrella antiqua.

Discussion: Because of the truncated nature of the top of the Torsk Formation, this zone was only found in five wells located in the axial trend of the Tromsø and Hammerfest Basins, and in a single well in the westemmost Nordkapp Basin. In the uppermost part of the Torsk in these wells, both the abundance and diversity of foraminifera are low, and the LO of R. amplectens is observed near the eroded upper contact of the formation. Therefore, these last stratigraphic occurrences are most probably not correlative to the true local extinction of the species.

At 710 m in well 7119/9-1 there is a sharp decrease in foraminiferal abundance, associated with a peak in the frequency of R. amplectens. The population of R. amplectens contains both the small compact variant referred to as Reticulophragmium intermedium (Mjåtiuk) and the larger form with a marked umbilical depression and more rounded periphery. The smaller and more primitive form is characteristic of the Early Eocene while the larger variant is typical of the Late Eocene (Kaminski, Gradstein et al. in prep.). In the North Sea and on the mid-Norwegian shelf R. intermedium is the nominate form of the late Early Eocene to early Middle Eocene Zone NSR 5A, while R. amplectens is the nominate taxon of the late Middle Eocene Zone NSR 6 of Gradstein & Bäckström (1996). In the deep Labrador Sea R. amplectens ranges from the Early Eocene (P7) to the Eocene/Oligocene boundary (Kaminski et al., 1989).

Pyritised diatoms are relatively common in the Barents Sea Paleogene. The youngest diatom event is the LO of Fenestrella antiqua, which is an important stratigraphic marker of Zone BSP 5. Rich occurrences of the species are recorded from the Sele and Balder formations of the North Sea and the Fur Formation of Denmark. The stratigraphy and morphology of F. antiqua in the North Sea Paleogene have been recently discussed by Bidgood et al. (1999), who distinguished four morphotypes interpreted as stages in the life cycle of the species. Three of these stages (initial cell, normal vegetative cell and resting spores) are observed in zone BSP 5. The stratigraphic range of the species is Late Paleocene to Early Eocene, with the top (LO) depressed to earliest Eocene in the North Sea as is apparent from Bigdood et al. (1999).
REGIONAL CORRELATIONS

The stratigraphical succession of the Paleogene Barents Sea zones compares well with the zonations constructed for other circum North Atlantic areas (Figure 7): the Mid-Norwegian Shelf by Gradstein & Bäckström (1996); the Viking Graben of the North Sea by Gradstein et al. (1988, 1992, 1994) and Mudge & Bujak (1994, 1996); the Labrador Shelf & Grand Banks by Gradstein et al. (1994). Many of the stratigraphically important cosmopolitan deep-water foraminifera of the Barents Sea reveal last occurrences in a similar stratigraphic order to that observed in the North Sea and on the North Atlantic margins, such as: Caudammina gigantea, Cystammina svenni, Caudammina excelsa, Spiroplectammina spectabilis, Reticulophragmium pauperum, Reticulophragmoides jarvisi, Spiroplectammina navarroana and Reticulophragmium amplectens. Additionally, the occurrence of the diatom species Fenestrella antiqua provides a correlation with the North Sea “Coscinodiscus Zone” of Gradstein et al. (1988).

The analysed sections are arranged in two transects (Figure 1), to provide an overview of the chemostratigraphy and thickness variation of the Torsk Formation expressed by the lateral development of the RASC zonation (Figure 8). The first transect comprises eight wells, and extends along a W-E line from the Senja Ridge (on the western border of the Tromsø Basin) to the western extension of the Nordkapp Basin. The second transect consists of four wells, and extends along a S-N line from the southern margin of the Hammerfest Basin over the Loppa High into the Bjørnøya Basin. The two transects intersect at the 7120/5-1 well site. The 12 biostratigraphical events depicted in Figure 8 display a remarkable degree of consistency between individual wells, with nearly no cross-over.

In well 7117/9-2, located on the Senja Ridge, the Torsk Formation is 285m thick, measured between its unconformable lower and upper contacts with the Campanian and Plio-Pleistocene, respectively. In spite of its small thickness, the Torsk of the well contains all of the faunal zones that are recognised in the much thicker basinal sediment packages (Figure 8).
Figure 8. Stratigraphic correlation within the Paleogene Torsk Formation showing distribution of 12 microfossil events taken from the optimum succession (Figs 3,4). The wells are arranged in two transects: from Senja Ridge to Nordkapp Basin, and from Hammerfest Basin to Bjørnøya Basin (for location see Fig. 1). The zones BSP1 to BSP5 recognised in this study are numbered successively in each well column.
This indicates that the Senja Ridge well does not contain large hiatuses, in spite of the relatively small Paleogene thicknesses at this site. If hiatuses are present they are not more extensive than the stratigraphic resolution of the faunal zones.

Wells 7119/7-1, 7119/9-1, 7120/7-3 and 7120/5-1, are located in the deep axial part of the Tromsø and Hammerfest basins, where the Torsk Formation attains large thicknesses varying from 819 m to 1040 m. The formation here includes all five zones ranging in age from Early Paleocene (BSP 1) to Middle Eocene (BSP 5). In Well 7121/5-1, which is the easternmost site studied in the Hammerfest Basin, the thickness of the Torsk is reduced to 567 m, and the Eocene BSP 5 Zone is absent from the top of the formation.

Wells 7124/3-1 and 7125/1-1 are located in the westernmost part of the Nordkapp Basin, and in both of these the Paleogene Torsk Formation shows strongly reduced thicknesses, to 170 m and 177 m, respectively. In spite of this decrease, well 7124/3-1 contains the zones BSP 1 to BSP 4, while BSP 5 is entirely removed by Pleistocene erosion. Well 7125/1-1 comprises zone BSP 2 to BSP 4, while BSP 1 and BSP 5 are missing from the base and top of the Torsk, respectively.

Close to the southeastern border of the Hammerfest Basin the Paleocene thicknesses are markedly reduced (Figure 8). In well 7119/12-1, the Torsk Formation is 330 m thick and contains the Early Paleocene to Early Eocene zones BSP 1 to BSP 4. The other site in this area, Well 7120/12-1, contains a 260 m thick Torsk Formation including the Paleocene zones BSP 1 to BSP 3. From the top of the formation, zone BSP 5 is lacking in well 7119/12-1, while zones BSP 4 and BSP 5 are absent from Well 7120/12-1. The reduced zonal thicknesses are attributed to the basin-marginal position of the two wells, while the absence of the uppermost one or two zones are explained by Pleistocene-Early Pleistocene truncation.

On the Loppa High, in well 7120/12-1, the Torsk Formation attains only 135 m but includes the zones BSP 1 to BSP 4 of Early Paleocene to Early Eocene age. The strong thickness reduction suggests condensed deposition, or the presence of hiatuses with duration shorter than the time resolution of the zonal scheme. The position of the well on a platform area is in accordance with features suggesting erosion and sediment starvation.

In the Bjørnøya Basin the thickness of the Paleogene has markedly increased as it is apparent from Well 7219/9-1 where the Torsk Formation is 760 m thick. Zones BSP 1 to BSP 4 are present at this site, while BSP 5 is apparently removed in the Pleistocene.

CONCLUSIONS
The Paleogene Torsk Formation, studied in 12 wells in the southwestern Barents Sea, contains relatively rich foraminiferal and palynomorph assemblages that are suitable for quantitative stratigraphic and biofacies analyses. The foraminiferal assemblages consist exclusively of agglutinating taxa showing deeper water, outer neritic to middle bathyal aspects. Both the foraminiferal and dinocyst successions reveal strong affinities to Paleogene assemblages recorded from bathyal facies of the mid-Norwegian Shelf, the North Sea and the Labrador Margin, facilitating stratigraphical correlation. The Eocene foraminiferal assemblages of the Torsk, however, display closer similarities also to neritic (prodelta shelf) faunas recorded from Spitsbergen.

The stratigraphical analysis combines foraminiferal (benthic) and palynomorph (planktonic) distribution data, mainly last occurrences. A single diatom species is also included. The analysis was performed by means of the RASC method combined with conventional stratigraphy, and resulted in a zonal scheme that includes the following: 1) Late early to late Paleocene zones: BSP 1, Psammosphaera fusca – Hyperammina rugosa; BSP 2, Spiroplectammina spectabilis; BSP 3A, Reticulophragmium pauperum; BSP 3B, Haplophragmoides aff. eggeri. 2) Early to middle Eocene zones: BSP 4, Spiroplectammina navarroana; BSP 5, Reticulophragmium amplectens.

On elevated structures and in basin marginal settings, the Paleogene Torsk Formation reveals strongly reduced thicknesses, usually coupled with the absence of one or both of the Eocene zones. Such reduced thicknesses are observed on the Senja Ridge, Loppa High, southeastern margin of the Hammerfest Basin and in the westernmost part of the Nordkapp Basin. The absence of the Eocene zones is attributed to truncation of the Torsk Formation by Pleistocene-Early Pleistocene erosion. The thickness reduction of zones recognised in the formation is explained by condensation or hiatuses smaller in extent than the biostratigraphical resolution of the microfossil event succession.

In deeper basinal areas, such as the axial part of the Tromsø, Hammerfest and Bjørnøya basins, the thickness of the Torsk Formation is strongly increased, and attains a maximum of 1040 m. The three Paleogene zones are well developed here, and usually both of the Eocene zones are present, suggesting reduced effects of the Pleistocene-Early Pleistocene erosional truncation.

ACKNOWLEDGEMENTS
This study is based on sample material obtained from the following organisations: Norsk Hydro A/S (Oslo), Norwegian Petroleum Directorate (Stavanger), Saga Petroleum A/S (Oslo), Statoil (Stavanger). The project was funded by the Statoil-VISTA Programme. Grateful thanks are due to Mufak Naoroz and Ingvild Hudøy for laboratory processing of the samples. We are grateful to Bob Jones (BP) for reviewing the manuscript. This is contribution nr. 69 of the Deep-Water Agglutinated Foraminiferal Project.

REFERENCES


Charnock, M.A. & Jones, R.W. 1990. Agglutinated foraminifera from the Palaeogene of the North Sea. *In: Hemleben,
Quantitative biostratigraphy of the Paleogene in the southwestern Barents Sea


PLATE 1. Selected foraminiferal taxa from the Torsk Formation. All specimens from Well 7119/7-1, except Figs. 4, 15, 16.

1. *Reticulophragmoides jarvisi* (Thalmann, 1932), 1290m, x104; 2. *Psammosphaera fusca* Schulzke, 1875, 1110m, x36; 3. *Anmodiscus glabatus* Cushman & Jarvis, 1928, 1270m, x45; 4. *Caudammina excelsa* (Dylaznka, 1923), 7119/9-1, 1350m, x45; 5-6. *Hyperammina rugosa* Verdenius & Van Hinte, 1983, 5. 1290m, x54, 6. 1200m, x54; 7-8. *Bathyssiphon sp.* 1 Nagy et al. 2000, 7. 1230m, x110. 8. 1200m, x70; 9. *Kalamopsis grzybowskii* (Dylà˝anka, 1923), 10. *Saccammina placenta* (Grzybowski, 1898), 1270m, x90; 11. *Saccammina grzybowskii* (Schubert, 1902), 1250m, x85; 12. *Repaminina charoides* (Jones & Parker, 1860), 1040m, x60. 13. *Glomospira gordialis* (Jones & Parker, 1860), 1320m, x75. 14. *Spiroplectammina spectabilis* (Grzybowski, 1898), 1060m, x110; 15. *Reticulophragmium pusorum* (Chapman, 1904), 7119/9-1, 1380m, x90. 16. *Haplophragmoides walteri* (Grzybowski, 1898), 7119/9-1, 590m, x90; 17. *Haplophragmoides porrectus* Maslakova, 1955, 1260m, x100; 18. *Haplophragmoides kirki* Wickenden, 1932, 1140m, x90. 19. *Karrerulina conversa* (Grzybowski, 1901), 710m, x160. 20. *Karrerulina horrida* (Mjatliuk, 1970), 750m, x140. 21. *Ammosphaeroidina pseudopauciloculata* (Mjatliuk, 1966), 1290m, x90; 22. *Reticulophragmium amplectens* (Grzybowski, 1898), 510m, x80.
## Data List Output

The list contains 633 microfossil events, which is the total registered in the 12 wells studied. The majority of events are last occurrences, unless marked otherwise (e.g., LCO).

**Norsk Hydro 7117/9-2**

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<td>1370</td>
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<td>1380</td>
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<td>1390</td>
<td>Cystammina sveni</td>
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<td>1395</td>
<td>Pseudobolivina lagenaria</td>
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<tr>
<td>1396</td>
<td>Spirosigmoilinella sp. 1 (Ch. &amp; J.)</td>
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Elf Aquitaine 7119/9-1
Rotary table height: 24 m
Water depth: 201 m

<table>
<thead>
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<tbody>
<tr>
<td>405</td>
<td>Deflandrea oebisfeldensis</td>
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<td>486</td>
<td>Fenestrela antiqua (large)</td>
</tr>
<tr>
<td>510</td>
<td>Karrerulina horrida</td>
</tr>
<tr>
<td>520</td>
<td>Rhizammina spp.</td>
</tr>
<tr>
<td>526</td>
<td>Reticuloophragmium amplectens</td>
</tr>
<tr>
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<td>Haplophragmoids excavatus</td>
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<td>Budashevaella multicamerata</td>
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<tr>
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<tr>
<td>700</td>
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<tr>
<td>710</td>
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Quantitative biostratigraphy of the Paleogene in the southwestern Barents Sea
### Statoil 7120/7-3

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<thead>
<tr>
<th>Depth (m)</th>
<th>Event (fossil) name</th>
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<tbody>
<tr>
<td>332</td>
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<tr>
<td>350</td>
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</tr>
<tr>
<td>356</td>
<td>Fenestrella antiqua (large)</td>
</tr>
<tr>
<td>360</td>
<td>Rhizammina spp.</td>
</tr>
<tr>
<td>370</td>
<td>Spirolectammina spectabilis LO</td>
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<tr>
<td>380</td>
<td>Recurvoides spp.</td>
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<tr>
<td>390</td>
<td>Aschemonella grandis</td>
</tr>
<tr>
<td>400</td>
<td>Saccammina grzybowskii</td>
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<td>Evolutinella rotulata</td>
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<td>Rhabdamaquina discreta</td>
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<tr>
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<td>Verneuilinoides sp.</td>
</tr>
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<td>460</td>
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<tr>
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<td>Ammodiscus peruvianus</td>
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<tr>
<td>550</td>
<td>Ammodiscus cretaceus</td>
</tr>
<tr>
<td>620</td>
<td>Glomospira gordialis</td>
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<td>650</td>
<td>Ammodiscus glabratus</td>
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<td>660</td>
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</tr>
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<td>690</td>
<td>Tuff</td>
</tr>
<tr>
<td>940</td>
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</tr>
<tr>
<td>960</td>
<td>Reticulophragmium pauperum</td>
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<td>Caudamina excelsa</td>
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<td>1040</td>
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<td>Bathysiphon microphridius</td>
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<td>Cystammina sveni</td>
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### Statoil 7120/5-1

<table>
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<tbody>
<tr>
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<td>Fenestrella antiqua (large)</td>
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<tr>
<td>396</td>
<td>Karrerulina conversa</td>
</tr>
<tr>
<td>420</td>
<td>Rhizammina spp.</td>
</tr>
<tr>
<td>440</td>
<td>Rhabdamaquina discreta</td>
</tr>
<tr>
<td>490</td>
<td>Saccammina grzybowskii</td>
</tr>
<tr>
<td>510</td>
<td>Dracodinium varielongitudum</td>
</tr>
<tr>
<td>530</td>
<td>Ammosphaeroidina pseudopauciloculata</td>
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<tr>
<td>550</td>
<td>Cerodinium wardenense</td>
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<tr>
<td>560</td>
<td>Ammomarginulina folicia</td>
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<tr>
<td>670</td>
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<tr>
<td>710</td>
<td>Apectodinium homomorphium</td>
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<tr>
<td>750</td>
<td>Caryapollenites simplex</td>
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<tr>
<td>810</td>
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<tr>
<td>901</td>
<td>Alisocysta margarita</td>
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<tr>
<td>920</td>
<td>Haplophragmoides eggeri</td>
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<td>930</td>
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<td>Jacuella sp.</td>
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<td>Hormosina velascoensis</td>
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Statoil 7120/7-3

- Rotary table height: 24 m
- Water depth: 258 m

Statoil 7120/5-1

- Rotary table height: 24 m
- Water depth: 318 m
### Quantitative biostratigraphy of the Paleogene in the southwestern Barents Sea

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Event (fossil) name</th>
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<tbody>
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<td>Cerodinium speciosum</td>
</tr>
<tr>
<td>560</td>
<td>Rhizammina spp.</td>
</tr>
<tr>
<td></td>
<td>Ammodiscus planus</td>
</tr>
<tr>
<td></td>
<td>Recurvoides spp.</td>
</tr>
<tr>
<td></td>
<td>Ammosphaeroidina pseudopauciloculata</td>
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<tr>
<td>570</td>
<td>Spiroplectammina navarroana</td>
</tr>
<tr>
<td></td>
<td>Glomospira charoides</td>
</tr>
<tr>
<td>600</td>
<td>Glomospira gordialis</td>
</tr>
<tr>
<td>610</td>
<td>Haplophragmoides walteri</td>
</tr>
<tr>
<td>620</td>
<td>Nothia robusta</td>
</tr>
<tr>
<td></td>
<td>Rhabdammina discreta</td>
</tr>
<tr>
<td></td>
<td>Ammodiscus peruvianus</td>
</tr>
<tr>
<td></td>
<td>Sphaerammina gerochi</td>
</tr>
<tr>
<td></td>
<td>Saccammina placenta</td>
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<td>Haplophragmoides porrectus</td>
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<td>Haplophragmoides eggeri</td>
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<tr>
<td>800</td>
<td>Cerodinium dartmoorium</td>
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<tr>
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<td>Kalamopsis grzybowskii</td>
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<td>Paratrochamminoides spp.</td>
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<tr>
<td></td>
<td>Haplophragmoides stomatus</td>
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<tr>
<td></td>
<td>Karrerulina horrida</td>
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<td>998</td>
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<tr>
<td>1010</td>
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**Saga 7124/3-1**

Rotary table height: 24 m  
Water depth: 273 m

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<tr>
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<tr>
<td></td>
<td>Ammodiscus planus</td>
</tr>
<tr>
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<td>Rhabdammina discreta</td>
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<tr>
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<td>Spiroplectammina spectabilis LO</td>
</tr>
<tr>
<td>410</td>
<td>Azolla spp.</td>
</tr>
<tr>
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</tr>
<tr>
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<td>Haplophragmoides eggeri</td>
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<td>Subreophax scalaris</td>
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<tr>
<td></td>
<td>Ammodiscus macilentus</td>
</tr>
<tr>
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<td>Recurvoides spp.</td>
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<tr>
<td>420</td>
<td>Haplophragmoides porrectus</td>
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<tr>
<td>430</td>
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<td>Reticulophragmium pauperum</td>
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<tr>
<td>440</td>
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<tr>
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<td>Kalamopsis grzybowskii</td>
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<td>Hyperammina rugosa</td>
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<tr>
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<td>Glomospira charoides</td>
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<td>Glomospira gordialis</td>
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<tr>
<td>550</td>
<td>Verneuilinoides sp.</td>
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<tr>
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**Saga 7125/1-1**

Rotary table height: 24 m  
Water depth: 228 m

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<td>403</td>
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<tr>
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<tr>
<td>435</td>
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</tr>
<tr>
<td></td>
<td>Ammodiscus cretaceus</td>
</tr>
<tr>
<td></td>
<td>Ammosphaeroidina pseudopauciloculata</td>
</tr>
<tr>
<td></td>
<td>Recurvoides spp.</td>
</tr>
<tr>
<td>445</td>
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</tr>
<tr>
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<td>Ammodiscus peruvianus</td>
</tr>
<tr>
<td></td>
<td>Fenestrella antiqua (large)</td>
</tr>
<tr>
<td>455</td>
<td>Cerodinium dartmoorium</td>
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<tr>
<td>465</td>
<td>Alisocysta sp. 2 Heilmann-Clausen</td>
</tr>
<tr>
<td></td>
<td>Bathysiphon sp.</td>
</tr>
<tr>
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<td>Budashevaella multicamerata</td>
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<td>475</td>
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<tr>
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### Statoil 7120/12-1

**Rotary table height:** 24 m  
**Water depth:** 200 m

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<td>Cerodinium speciosum</td>
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<td>Ammodiscus planus</td>
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<td>510</td>
<td>Hystrichosphaeridium tubiferum</td>
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<tr>
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<td>Cerodinium augustinum</td>
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<td>600</td>
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<tr>
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<td>Palaeoperidinium pyrophorum LCO</td>
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<tr>
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<td>Isabelidinium cf. viborgense</td>
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<tr>
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<td>Kalamopsis grzybowski</td>
</tr>
<tr>
<td>670</td>
<td>Alisocysta margarita</td>
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<tr>
<td>680</td>
<td>Saccammina placenta</td>
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<tr>
<td>690</td>
<td>Subreophax scalaris</td>
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<tr>
<td>700</td>
<td>Alisocysta margarita LCO</td>
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<tr>
<td>710</td>
<td>Caudammina ovula</td>
</tr>
<tr>
<td>720</td>
<td>Caudammina gigantea</td>
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### Norsk Hydro 7119/12-1

**Rotary table height:** 24 m  
**Water depth:** 167 m

<table>
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<th>Event (fossil) name</th>
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<tr>
<td>500</td>
<td>Alisocysta sp. 2 Heilmann-Clausen</td>
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<tr>
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<tr>
<td>520</td>
<td>Ammodiscus planus</td>
</tr>
<tr>
<td>530</td>
<td>Ammodiscus peruvianus</td>
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<td>Ammodiscus planus</td>
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<td>Caudammina excelsa</td>
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<td>Subreophax scalaris</td>
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<tr>
<td>600</td>
<td>Impagidinium sp. 1 Heilmann-Clausen</td>
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<td>Hyperammina rugosa</td>
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<td>Hyperammina rugosa</td>
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<tr>
<td>640</td>
<td>Isabelidinium cf. viborgense</td>
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<td>680</td>
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<td>Psammosphaera fusca</td>
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<tr>
<td>700</td>
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<td>Caudammina ovula</td>
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<tr>
<td>720</td>
<td>Psammosphaera fusca</td>
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</table>

**Depth (m) | Event (fossil) name**
<table>
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<th></th>
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<tbody>
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</tr>
<tr>
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<td>Labrosira pacifica</td>
</tr>
<tr>
<td>820</td>
<td>Caudammina ovula</td>
</tr>
</tbody>
</table>

**J. Nagy, M.A. Kaminski, F.M. Gradstein & K. Johnson**
### Norsk Hydro 7120/2-1

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Event (fossil) name</th>
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<tbody>
<tr>
<td>480</td>
<td>Cerodinium wardenense</td>
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<tr>
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<td>Cerodinium speciosa</td>
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<tr>
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### Norsk Hydro 7219/9-1

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