BOREHOLE 6704/12-GB1

Fig. 1: Borehole 6704/12-GB1, summary figure for the Middle Miocene to lower Pleistocene including lithology, lithostratigraphic formations, series/subseries, benthic foraminiferal assemblages, planktonic fossil assemblages, paleobathymetry, strontium isotope ages and analysed samples (modified after Eidvin et al. 1998c).
**Middle Miocene to Pleistocene in borehole 6704/12-GB1**

Modified after Eidvin et al. (1998c).

Borehole 6704/12-GB1 (67°01′35.2″N, 04°57′25.6″E, [Map 1](#)) is a cored geotechnical boring drilled on the Gjallar Ridge on the Vøring Plateau in the Norwegian Sea as a part of the Norwegian Deepwater programme (NDP), Seabed Project which focused on the sea bed conditions, soil conditions and shallow geology in the deep-water areas on the continental slope of the Norwegian Sea continental margin.

The borehole was sampled with 50 cm long cores at 3.5-16 m intervals, and a 49 m-thick unit, from the upper part of the Kai Formation, was given a latest Middle Miocene to Late Miocene age based on analyses of planktonic and benthic foraminifera, *Bolboforma* and Sr isotopes. The unit was investigated with nine core samples. The base of the Middle Miocene was not seen. Above the Middle to Upper Miocene, Pleistocene sediments of the Naust Formation were recorded, and this unit was investigated with three core samples (95.1-76 m). The core depth is in metres below sea floor (mbsf, Fig. 1).

**Biostratigraphy**

*Middle Miocene (160-146 m, Kai Formation)*

*Bolboforma* of the *Bolboforma badenensis* assemblage date this interval to the latest Middle Miocene (Fig. 1). In addition to the nominate species, the *Bolboforma* assemblage also contains *Bolboforma pseudohystrix*, *Bolboforma compressispinosa* and *Bolboforma compressibadenensis*. The planktonic foraminiferal fauna includes *Neogloboquadrina atlantica* (dextral), *Neogloboquadrina acostaensis*, *Neogloboquadrina praeherumerosa*, *Neogloboquadrina atlantica* (sinistral) and *Globigerina bulloides* and the benthic foraminiferal fauna includes *Martinottiella communis* (agglutinated) and *Uvigerina pygmea langeri*.

From DSDP Sites 12-116, 49-408, 81-555 and 94-608 in the North Atlantic, Spiegler & Müller (1992) described a *Bolboforma reticulata* Zone from deposits with an age of slightly older than 14 to 12.3 Ma, a very short *Bolboforma danielsi* Zone from around 12.3 Ma, a *B. badenensis* Zone from 12.3 to 11.9 Ma and a *B. compressispinosa* Zone from 11.8 to 11.7 Ma. Müller & Spiegler (1993) have also investigated the boreholes ODP 104-624B and C and ODP104-643A on the Vøring Plateau, and this investigation shows that *B. reticulata* and *B. badenensis* occur together in the same samples in a *B. badenensis – B. reticulata* Zone. Above this zone they have recorded a *B. compressispinosa* Zone. In this area they have not defined a *B. danielsi* Zone between the *B. badenensis – B. reticulata* Zone and the *B. compressispinosa* Zone.

In the interval 160-146 m in borehole 6704/12-GB1, we have recorded neither *B. reticulata* nor *B. compressispinosa*, and the ages given to the range of the other recorded *Bolboforma* species at the North Atlantic DSDP sites indicate an age of younger than 12.3 Ma and older than 11.7 Ma for the unit in 6704/12-GB1.

*Middle-Upper Miocene (131-111 m, Kai Formation)*

*Bolboforma* attributed to the *Bolboforma fragori – Bolboforma subfragori* assemblage date this interval to the latest Middle Miocene to earliest Late Miocene (Fig. 1). In addition to the
nominate species, the *Bolboforma* assemblage also contains *Bolboforma laevis* and *Bolboforma clodiusi*. A few specimens of probably reworked *B. reticulata* are also recorded. The planktonic foraminiferal fauna includes *N. atlantica* (dextral), *N. acostaensis*, *N. praehumerosa* and *G. bulloides* and the benthic foraminiferal fauna includes *M. communis* (agglutinated) and *U. pygmea langeri*. A *B. fragori/B. subfragori* Zone is described from deposits with an age of 11.7-10.3 Ma from the North Atlantic and the Vøring Plateau (Spiegler & Müller 1992, Müller & Spiegler 1993).

**Pleistocene (95.1-76 m, Naust Formation)**

Planktonic foraminifera of the *Neogloboquadrina pachyderma* (sinistral) assemblage date this interval to the Pleistocene (Fig. 1). An encrusted form of *N. pachyderma* (sinistral) is recorded in all of the three investigated samples (common in the uppermost). This form of *N. pachyderma* (sinistral) has its first frequent occurrence at 1.8 Ma in the North Atlantic and at the Vøring Plateau in the Norwegian Sea (Weaver & Clement 1986, Spiegler & Jansen 1989). This test morphology also has very sporadic occurrences in older sediments. Characteristic benthic foraminiferal species are *Elphidium excavatum*, *Pullenia bulloides*, *Sigmoilopsis schlumbergeri* (aggluninated), *Cibicides wuellerstorfi*, *Cassidulina teretis*, *Bulimina striata*, *Nonion affine*, *Virgulina* sp. and *Epistominella* sp. The benthic foraminifera in this unit are characteristic Pliocene-Pleistocene taxa.

**Sr isotope stratigraphy**

Seven samples from borehole 6704/12-GB1 were analysed for Sr isotopes. Tests of calcareous foraminifera were used for the analyses. Most of the obtained $^{87}\text{Sr}/^{86}\text{Sr}$ ratios gave ages close to the Middle/Late Miocene boundary (11.2 Ma according to Berggren et al. 1995) and consequently support the biostratigraphical correlations (Table 1, Fig. 1). According to Nødtvedt (1999) a second run of the residues left after the first run gave obviously too low ages for some of the samples. Consequently, the results of the second run are not included.

<table>
<thead>
<tr>
<th>Borehole 6704/12-GB1</th>
<th>Sample (cores)</th>
<th>Corrected $^{87}\text{Sr}/^{86}\text{Sr}$</th>
<th>Age (Ma)</th>
<th>Analysed fossil species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kai Fm 111 m</td>
<td>0.708892</td>
<td>0.000014</td>
<td>9.84</td>
<td>44 tests of <em>N. atlantica</em> (dextral), <em>N. atlantica</em> (sinistral), <em>G. bulloides</em>, <em>N. acostaensis</em>, <em>U. pygmea langeri</em>, <em>Eponides umbonatus</em>, <em>N. affine</em>, <em>Cibicides dutemplei</em>, <em>Pullenia subcarinata</em> and <em>Globulina</em> sp.</td>
</tr>
<tr>
<td>Kai Fm 118.5 m</td>
<td>0.708838</td>
<td>0.000023</td>
<td>11.78</td>
<td>41 tests of <em>G. bulloides</em>, <em>N. atlantica</em> (dextral), <em>Globigerinita glutinata</em>, <em>P. bulloides</em>, <em>Fissurina</em> sp., <em>P. subcarinata</em>, <em>Pullenia bulloides</em>, <em>C. dutemplei</em>, <em>U. pygmea langeri</em>, <em>N. affine</em>, <em>C. teretis</em>, <em>Globocassidulina subglobosa</em></td>
</tr>
<tr>
<td>Kai Fm 119 m</td>
<td>0.708861</td>
<td>0.000009</td>
<td>10.94</td>
<td>59 tests of <em>N. atlantica</em> (dextral), <em>N. atlantica</em> (sinistral), <em>N. acostaensis</em>, <em>G. bulloides</em>, <em>C. dutemplei</em>, <em>U. pygmea langeri</em>, <em>P. bulloides</em>, <em>Sphaeroidina bulloides</em>, <em>Fissurina</em> spp., <em>Triloculina trihedral</em></td>
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<tr>
<td>Kai Fm 131 m</td>
<td>0.708868</td>
<td>0.000010</td>
<td>10.97</td>
<td>45 tests of <em>N. atlantica</em> (dextral), <em>N. atlantica</em> (sinistral), <em>G. bulloides</em>, <em>N. acostaensis</em></td>
</tr>
<tr>
<td>Kai Fm 146 m</td>
<td>0.708856</td>
<td>0.000009</td>
<td>11.12</td>
<td>46 tests of <em>N. atlantica</em> (dextral), <em>N. atlantica</em> (sinistral), <em>N. acostaensis</em>, <em>G. glutinata</em>, <em>C. dutemplei</em>, <em>Ehrenbergina variabilis</em>, <em>E. umbonatus</em>, <em>P. bulloides</em></td>
</tr>
<tr>
<td>Kai Fm 155.8 m</td>
<td>0.708843</td>
<td>0.000013</td>
<td>11.59</td>
<td>58 tests of <em>N. atlantica</em> (dextral), <em>N. atlantica</em> (sinistral), <em>N. acostaensis</em>, <em>N. praehumerosa</em>, <em>E. umbonatus</em>, <em>N. affine</em>, <em>P. bulloides</em>, <em>T. trihedral</em>, <em>C. dutemplei</em>, <em>P. subcarinata</em>, <em>C. teretis</em></td>
</tr>
<tr>
<td>Kai Fm 160 m</td>
<td>0.708840</td>
<td>0.000009</td>
<td>11.70</td>
<td>60 tests of <em>N. atlantica</em> (dextral), <em>N. atlantica</em> (sinistral), <em>G. bulloides</em>, <em>N. acostaensis</em>, <em>N. affine</em>, <em>E. umbonatus</em>, <em>C. dutemplei</em>, <em>P. bulloides</em></td>
</tr>
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</table>

Table 1: Strontium isotope data from borehole 6704/12-GB1 according to Nødtvedt (1999). The samples were analysed at the University of Bergen. Sr ratios were corrected to NIST 987 = 0.710248. The numerical ages were derived from the SIS Look-up Table Version 3:10/99 of Howard & McArthur (1997). NIST = National Institute for Standard and Technology.

**Lithology and lithostratigraphy**
According to Eidvin et al. (1998c), the samples contain mainly pelagic sediments (biogenic ooze) and the fraction >63 μm consists of microfossils and some pyrite. An exception to this is sample 118.5 m where a large number of coarse minerogenic grains were discovered. The fragments are mainly quartz/feldspar mineral fragments and rock fragments of crystalline rocks. The shapes are subangular and fragmented, typical of grains related to glacial sediments. The size varies from 100 μm to a few mm. The observation of such grains in pelagic settings clearly indicates that they have been ice rafted to the location, and the grain distribution, surface texture and shape is clearly indicative of glacial origin. The coarseness of the grains is distinctive, as previous reports of Miocene minerogenic grains believed to represent ice rafted detritus (IRD) in Neogene deposits from the Vøring Plateau have been in the size range 125-250 μm (Jansen & Sjøholm 1991, Fronval & Jansen 1996). Hence, this is the most conclusive proof of the existence of glaciers large enough to calve and form icebergs hitherto found from the Miocene on the Vøring Plateau. The Bolboforma biostratigraphy documents that the age of the sample is 11.7-10.3 Ma. This fits very well with the first peaks of smaller size IRD observed in ODP Site 642 (Fronval & Jansen 1996). The origin of the grains is not easy to identify, and we propose that they originate from icebergs that had drifted across from Greenland. A Miocene glaciation is identified in Greenland from a number of ODP Sites, while large-scale glaciation is believed to have started later on the eastern side of the Nordic Seas.

References


