1. FORAMINIFERAL BIOSTRATIGRAPHY OF PLIOCENE DEPOSITS AT SITE 986, SVALBARD MARGIN

Tor Eidvin and Jenő Nagy

ABSTRACT

The upper Pliocene interval from 647.72 through 955.32 meters below seafloor in Ocean Drilling Program Hole 986D (77°20.408'N, 9°04.654'E) can be subdivided into one planktonic foraminiferal zone: nominate species, Neogloboquadrina atlantica (sinistral); one calcareous benthic foraminiferal zone: nominate species, Melonis sandanana–Cassidulina teretis; and four agglutinated foraminifer assemblages: AFA1 through AFA4. The whole interval was deposited between 2.6 and 2.4 Ma during a climatic regime comprising episodic incursions of warm to transitional surface-water masses into a generally cold ocean. Broken calcareous benthic foraminifers and striated deformed agglutinated foraminifers indicate considerable reworking. The planktonic and calcareous benthic assemblages are similar to faunas in Hole 910C on the Yermak Plateau (81°15.836'N, 6°35.430'E), Hole 643A on the Voring Plateau (67°42.9'N, 01°02.0'E), and the exploration Wells T1177-1 and T316-1 on the Senja Ridge (71°22.51.05'N, 17°56.5.76'E) and in the Vestbakken Volcanic Province (73°31.12.78'N, 16°25.55.87'E), respectively. The lowest 35 m of the interval was probably deposited below the local carbonate compensation depth and contains only agglutinated foraminifers.

INTRODUCTION

Along the margins of the Norwegian-Greenland Sea, three main glaciatic areas produced extensive ice sheets in Pliocene–Pleistocene times: Greenland, Scandinavia, and the Svalbard–Barents Sea. Site 986 was drilled on the Svalbard Margin (Fig. 1) to establish the history of the Svalbard–Barents Sea Ice Sheet, including the timing of the onset of glaciation, the shift of glaciation style from mountain to ice-sheet type, and the extension of marine-based ice sheets to the outer shelf. Four holes were drilled at Site 986, with a maximum penetration of 964.6 meters below seafloor (mbsf) in Hole 986D. The drilled section penetrates all the main regional reflectors (R1–R7) of the Svalbard–Barents Sea Margin, and there are strong ties between the reflectors and the main seismic sequences shown by core physical property measurements and wireline logging (Jansen, Raymo, Blum, et al., 1996). The samples analyzed for foraminifers in this study are from the upper Pliocene interval 162-986D-28R-1, 30–36 cm (647.72 mbsf), through 60R-1, 29–36 cm (955.32 mbsf; 77°20.408'N, 9°04.654'E) (Fig. 2). The seafloor lies at 2063 meters below rig floor.

In the foraminifer assemblages, an in situ and a redeposited component are distinguished, mainly based on the state of preservation. The in situ component includes both planktonic and benthic taxa, which are used for stratigraphic dating and correlation combined with magnetostratigraphic data. All absolute ages are based on Berggren et al. (1995).

In late Cenozoic time, the western margin of the Barents Shelf was an area of intensive sediment influx from a drainage area of more than 1 million km² covering most of the Svalbard–Barents Sea platform. As a result of this influx, extensive Pliocene–Pleistocene sediment wedges were deposited along the continental margin. Site 986 is located on the lower continental slope, on the northern extension of the sediment wedge developed in front (west) of the Storfjorden Trough. In the analyzed wedge, the distribution pattern of the three main components of foraminifer assemblages (the agglutinated, calcareous benthic, and planktonic groups) and the occurrence of the lower taxa (genera and species) support the interpretation of mass-wasting and redeposition processes acting on the continental slope of this region.

METHODS

The stratigraphy of the upper Pliocene succession at Site 986 was established by the investigation of planktonic, calcareous benthic, and agglutinated benthic foraminifers from 131 samples. Approximately one 30-cm³ sample per section of core was used. The samples were disaggregated with water without dispersant. Samples were soaked in water overnight and then mechanically agitated before washing over a 63-μm sieve. The residue was then dried overnight in an oven at <60°C. The fossil identifications were carried out in the 106- to 500-μm fraction. In some samples, the fractions <106 μm and >500 μm were also investigated. Whenever possible, 300 individuals were picked from each sample. In order to better identify the microfossil assemblages, a number of samples rich in mineral grains were also gravity separated in tetrachloroethylene.

LITHOSTRATIGRAPHY

The investigated interval from Sample 162-986D-28R-1, 30–36 cm (647.72 mbsf), through 45R-7, 29–36 cm (820.02 mbsf), belongs to lithologic Unit III (Figs. 3–6). This unit is characterized by a relatively high sand content and the absence of dropstones. The primary lithologies are very dark gray to dark greenish gray silty clay with sand, clayey silt with sand, silt, very sandy clay. Biogenic calcareous sediment is present in trace to minor amounts throughout the unit. The biocarbonate consists largely of calcareous nanofossils in amounts up to 20% (by volume) and shows a slight increase downcore. Authigenic iron sulfides, primarily in the form of disseminated pyrite, are commonly present in minor amounts (Jansen, Raymo, Blum, et al., 1995).

The section from Sample 162-986D-46R-1, 29–36 cm (820.59 mbsf), to the base (60R-1, 29–36 cm, 955.32 mbsf) belongs to lithologic Unit IV (Figs. 3–6). The transition from Unit III to Unit IV is
PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

The high-latitude planktonic foraminiferal associations are low-diversity faunas composed of long-ranging species. In general, it is not possible to apply the standard zonations established for low latitudes (Blow, 1969; 1979; Boll and Saunders, 1985) or for northern temperate regions (Berggren, 1972; Poore and Berggren, 1975; Poore, 1979; Weaver and Clement, 1986) because the index fossils used for these zonal definitions are often absent in high-latitude assemblages. Studies of Ocean Drilling Program (ODP) Leg 104 sites on the Voring Plateau in the Norwegian Sea have produced a local high-latitude Neogene zonation (Spiegler and Jansen, 1989; Spiegler, 1996) that is useful for comparison with Site 986. Data from ODP Leg 151 sites from the Fram Strait and the Yermak Plateau are also applicable (Spiegler, 1996).

Planktonic foraminifers are found in 80% of the samples in the interval from Sample 162-986D-28R-1, 30–36 cm (647.72 mbsf), through 54R-1, 29–36 cm (897.62 mbsf). The interval from 897.62 mbsf to the base of the drilled succession (Sample 162-986D-60R-1, 29–36 cm, 955.32 mbsf) is barren of planktonic foraminifers. In the 250-m-thick interval containing planktonic foraminifers, the assemblage exhibits highly variable abundance, fluctuating from rich faunas to intervals that are poor in or barren of planktonic foraminifers. Except in a few samples, most specimens are well preserved and show no signs of reworking.

The assemblage consists mainly of Neogloboquadrina atlantica (sinistr) and Globigerina bulloides. N. atlantica (dextr) occurs sporadically, mainly in the upper part of the section. Neogloboquadrina pachyderma (sin., mainly unencrusted form), N. pachyderma (dext.), Turrilina quinqueloba, and Globigerinita glutinata occur in small numbers in some intervals throughout the succession (Fig. 5).

In the high-latitude Neogene, N. atlantica (sin.) is indicative of the Neogloboquadrina atlantica (sin.) Zone, spanning Pliocene to latest Miocene age (Spiegler and Jansen, 1989). The entire carbonate-
### Figure 3: Range chart of planktic foraminifers and miscellaneous fossils in Hole 986D

#### Upper Pliocene

<table>
<thead>
<tr>
<th>Neogloboquadrina atlantica sinistral Zone</th>
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<tr>
<td><strong>FORAMINIFER ZONES</strong></td>
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<tr>
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<td><strong>CHRONOSTRATIGRAPHY</strong></td>
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<td><strong>DEPTH (mbsf)</strong></td>
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#### Hole 986D

Planktonic foraminifers and miscellaneous fossils in Hole 986D (middle part of investigated section). (Continued on next page.)

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#### Upper Pliocene (Continued)

<table>
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<td><strong>CHRONOSTRATIGRAPHY</strong></td>
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<tr>
<td><strong>DEPTH (mbsf)</strong></td>
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</tbody>
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Planktonic foraminifers and miscellaneous fossils in Hole 986D (upper part of investigated section).
The calcareous benthic foraminifer *Cibicides grossus* occurs down to 877.34 mbsf. This also indicates a late Pliocene age for this interval.

The climatic regime in this area during the late Pliocene may be interpreted to comprise episodic immigrations of warm and transitional surface-water masses into a generally cold ocean. The occurrence of *N. pachyderma* (dext.), *T. quinqueloba*, and *G. glutinata* indicates several short, warm to transitional surface-water events. The cold conditions are documented by *N. atlantica* (sin.) and *N. pachyderma* (sin.) (Spiegler, 1996). The highly variable abundance of planktonic foraminifera seems also to be typical of alternating glacial and interglacial conditions. At high northern latitudes, planktonic foraminifera are generally less common as a result of low water temperatures and/or dissolution of the calcareous microfossils. Another reducing factor is dilution by large amounts of detrital material and ice-raftered debris (Spiegler, 1996).

**CALCAREOUS BENTHIC FORAMINIFERAL BIOSTRATIGRAPHY**

Upper Pliocene calcareous benthic foraminifera are described from open-ocean high-latitude areas at ODP Sites 642, 643, and 644 on the Voring Plateau (Leg 104; Osterman and Qvale, 1989) and Site 910 on the Yermak Plateau (Leg 151; Osterman, 1996). Paleomagnetic records from these boreholes provide good age control for the fossil zones. Upper Pliocene calcareous benthic foraminiferal assemblages are described from outer-shelf sites in exploration wells on the Senja Ridge (Eidvin et al., 1993a) and in the Vestbakken Volcanic Province (Eidvin et al., 1998b) in the western Barents Sea (Fig. 1). In the Vestbakken Volcanic Province (Well 7316-5-1), the upper Pliocene section is sampled with sidewall cores. In Wells 7177-1 and 7177-2 on the Senja Ridge, only ditch cuttings were available. The upper Pliocene deposits in Wells 7316-5-1, 7177-1, and 7177-2 lack any definitive age control, and dating is based solely on planktonic and benthic foraminifera, supported by lithostratigraphic correlation and strontium isotope stratigraphy. Numerous terrestrial outcrops of shallow-water Pliocene marine deposits occur throughout the Arctic (e.g., Brouwers et al., 1991; Brigham-Grette and Carter, 1992; Feyling-Hanssen, 1976, 1980, 1990; Feyling-Hanssen et al., 1982; Funder et al., 1985; Todd, 1957; Vincent et al., 1984). These outcrop sections also lack definitive age control. They are normally correlated either by means of amino-acid racemization values or by macro- or microfaunal fossil assemblages. Most of these localities represent isolated sections of the Pliocene, which may or may not be correlatable (Osterman, 1996).

At Hole 986D, calcareous benthic foraminifera are found in 82% of the samples in the interval between Sample 162-986D-28R-1, 30-36 cm (647.72 mbsf), and 54R-1, 29-36 cm (897.62 mbsf). The interval from 897.62 mbsf to the bottom of the sample (Sample 162-986D-60R-1, 29-36 cm, 955.32 mbsf) is barren. Calcareous benthic foraminifera are found in more than 80% of this interval, and additionally at a few other levels. As with the planktonic foraminifera, the benthic assemblage in this 250-m-thick interval exhibits highly variable abundance, fluctuating frequently from abundant to rare or barren. Contrary to the planktonic foraminifera, the tests of certain species are broken, worn, or corroded. However, most species that constitute the assemblage are well-preserved throughout the section. Consequently, only one assemblage zone is recognized above; namely the *Melonis zandvannae-Cassidulina tereis* Zone.

Tests of the nominate species occur quite frequently throughout the succession. Other important taxa are *Pulvilia subcarinata*, *Cassidulina rotiforme*, *Epistominella exigua*, *Epistominella spp.*, *Puleenia bulboides*, and *Cibicides lobatula* (Fig. 4). Other characteristic forms that occur more sporadically include *Buccella tenerrima*, *Elphidium excavatum*, *Elphidium spp.*, *Elphidium altaicum*, *Angulogerina angulosa*, *Quinqueloculina seminulum*, *Buccella frigida*, *Virgulina loebichii*, *Triloculina sp.*, *Angulogerina fluens*, *Cib-
### Upper Pliocene

#### Melonis zaandamae - Cassidulina teretis Zone

| Depth (mbsf) | 0 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 2400 | 2500 | 2600 |
|--------------|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| **FORAMINIFER ZONES** |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| **LITHOSTRATIGRAPHIC UNITS** |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| **CHRONOSTRATIGRAPHY** |   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

*Calcareous benthic foraminifers*
cides grossus, Elphidium hamulatum (one specimen at 871.54 mbsf), Elvenbergina variabilis, Cibicides telegdi, and Eponides pygmeus.

With the exception of C. grossus, E. hamulatum, E. variabilis, C. telegdi, and E. pygmeus, all the calcareous benthic foraminifers are extant species. E. variabilis, C. telegdi, and E. pygmeus are probably reworked from Oligocene or Miocene deposits (Ulleberg, 1974; Stratlab, 1988; Gradstein and Bäckström, 1996; Eidvin et al., 1998a).

C. grossus and E. hamulatum are known from upper Pliocene deposits in the western Barents Sea (Eidvin et al., 1993a, 1998b), from the Norwegian Sea continental shelf (Eidvin and Riis, 1991; Eidvin et al., 1998a; Poole and Vorren, 1993; Stratlab, 1988), and in the North Sea (King, 1989; Knudsen and Asbjørndottir, 1991; Eidvin and Riis, 1992; Eidvin et al., 1993b; Pedersen, 1995). C. grossus is, however, recorded in deposits as old as the late Miocene in the Netherlands. E.
### Figure 4: (continued) C. Range chart of upper Pliocene calcareous benthic foraminifers

<table>
<thead>
<tr>
<th>Upper Pliocene</th>
<th>Chronostratigraphy</th>
<th>Lithostratigraphic Units</th>
<th>Foraminifer Zones</th>
<th>Depth (mbfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B IV</td>
<td>M. zaandamae-</td>
<td>B. terriss Zone</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>C. sp.</td>
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</table>

### Figure 5: A. Range chart of upper Pliocene calcareous benthic foraminifers in Hole 965D. B. Range chart of upper Pliocene foraminifers in Hole 965D.

### Table 6: Summary of upper Pliocene calcareous benthic foraminifers in Hole 965D.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Age</th>
<th>Depth (mbsf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. sp.</td>
<td></td>
<td></td>
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<tr>
<td>B. sp.</td>
<td></td>
<td></td>
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</tbody>
</table>

Many of these specimens are probably in situ, but some of the broken specimens, as well as some of the specimens that are worn or eroded, may represent species of C. terriss and some taxa of E. antarctica, respectively. The foraminifer specimens from this interval are also probably collected from the sediments, as indicated by their position in the stratigraphic column and their association with other types of fossils.
Figure 5 (continued). B. Range chart of upper Pliocene agglutinated foraminifers in Hole 986D (middle part of investigated section).
tests might have been reworked from shallower water-depth environments (Mackensen et al., 1985). E. exigua, P. bullioleae, P. subcarna-
tata, Triloculina trihedra, Pyrgo murhukina, and Cibicides wueller-
storfi are all deep-water forms (Scirrup et al., 1981; Mackensen et al.,
1985; Skarbø and Verdenius, 1986).

In samples containing calcareous benthic foraminifers, the num-
ber of species ranges from one to 25 and the number of specimens
(per cubic centimeter sediment) from one to 20. An overall low num-
ber of species and specimens in this succession indicates a generally
cold oceanic climatic regime. Samples that are barren or have low
diversities of calcareous foraminifers probably represent episodes of
severe glaciation. Samples containing faunas with comparatively
high diversities suggest warmer episodes (Osterman, 1996). This
interpretation is consistent with the varying contents of Arctic species
such as E. excavatum 1. elevata, C. reniforme, V. leeblichii, Elphidium
subarticum, and Elphidium askingi as well as with changing
amounts of boreal species, including A. angulosa, C. territis, Bolivina
cf. robusta, E. exigua, and E. altibimbulcatum (Feyling-Hanssen,
1983). However, the presence of reworked forms introduces some
uncertainties into this interpretation.

AGGLUTINATED FORAMINIFERAL BIOSTRATIGRAPHY
Main Faunal Features

Agglutinated foraminifers occur in varying amounts in all the
analyzed samples from 162-986D-28R-1, 30–36 cm (647.72 mbaf),
through 60R-1, 29–36 cm (955.32 mbaf), as shown in Figure 5. Within
this interval, four agglutinated foraminiferal assemblages (APA)
are distinguished. The preservation of the assemblages varies from
dominantly porous noncompressed through mixed to dominantly
silicified compressed. These preservational types occur in repeated units of changing thicknesses throughout the analyzed succession. Based on this distribution pattern, 14 preservational units (PU) are distinguished (Fig. 7).

The porous noncompressed faunal component is composed of specimens showing the original shape of the chambers (which usually are empty) and the slightly porous texture of unaltered agglutinated tests. In the silicified compressed component, the tests are flattened to disappearance of the chamber cavities. Owing to diagenetic silification, the silt grains forming the walls are no longer discernible.

Agglutinated Assemblages

**AFA1, Cyclammina pusilla assemblage**

This fauna describes the lowermost part of the cored section from Sample 162-986D-60R-1, 29–36 cm (955.32 mbsf), through 55R-1, 24–31 cm (907.22 mbsf). It is dominated by Cyclammina pusilla, Recurvoides turbinatus, Rhizammina sp., and Thurrammina papillata. Characteristic species include Rhizammina alveolaris, Verneuilinoides scitulus, Ammonitina limata, Karreriella apiculata, and Reophax mortenseni. Owing to the poor state of preservation, a large number of specimens could not be identified at the generic level and are designated as Textulariidae genus indeterminate on the rate chart (Fig. 5). Based on its composition and preservational features, the assemblage is interpreted to represent a bathyal in situ fauna. It is identical to the porous noncompressed interval PU1 (Fig. 7).

**AFA2, Trochammina cf. nana assemblage**

This assemblage comprises three intervals characterized by silicified compressed taxa or mixed faunas. It is subdivided into a lower, middle, and thick upper segment by two intervening porous noncompressed assemblages (Fig. 5). Trochammina cf. nana is dominant through each of the three segments. The undifferentiated group, Textulariidae genus indeterminate, is also quantitatively important. The assemblage is interpreted to consist mainly of redeposited specimens.

The lower T. cf. nana assemblage extends from Sample 162-986D-54R-1, 29–36 cm (897.62 mbsf), through 49R-1, 29–36 cm (849.52 mbsf). Characteristic species include Ammodiscus incertus, Rhizammina sp., and Thurrammina aff. albicans in addition to more sporadic occurrences of Glomospira sp., Haplophragmoides cf. bradyi, and Verneuilinoides sp. This assemblage segment corresponds to the silicified compressed interval PU2.

The middle segment characterized by this assemblage extends from Sample 162-986D-46R-4, 29–36 cm (825.12 mbsf), to 44R-1, 29–36 cm (801.42 mbsf). Besides the dominant forms, significant taxa include A. incertus, Rhizammina sp. T. aff. albicans, Haplophragmoides sp., and Verneuilinoides sp. This segment contains the silicified compressed intervals PU4 and PU6 as well as the mixed interval PU5.

The upper part of the T. cf. nana assemblage extends from Sample 162-986D-43R-2, 29–36 cm (793.22 mbsf), through 28R-1, 30–36 cm (647.72 mbsf). Thus, it makes up almost half of the upper Pliocene part of the cored section. Characteristic, but quantitatively subordinate, species include Eggerellidae cf. scaber, A. incertus, Rhizammina sp., and T. cf. albicans. Many taxa, such as Glomospira geniculata, Repunina charoides, C. pusilla, and Haplophragmoides sp., occur in low numbers restricted to scattered samples. Within this segment, seven preservational units are distinguished. Four of these are of the silicified compressed type (PU8, PU10, PU12, and PU14), whereas three are of mixed nature (PU9, PU11, and PU13).

**AFA3, Recurvoides turbinatus assemblage**

This assemblage is developed from Sample 162-986D-48R-2, 29–36 cm (841.32 mbsf), through 47R-1, 29–36 cm (830.22 mbsf).
<table>
<thead>
<tr>
<th>AGGLUTINATED FORAMINIFER ASSEMBLAGES</th>
<th>AGGLUTINATED FORAMINIFER PRESERVATIONAL UNITS</th>
<th>SILICIFIED COM-PRESSED TESTS %</th>
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<tbody>
<tr>
<td><strong>AFA2</strong> Trochammina cf. nana</td>
<td>PU 14 162-986D-28R-01 (64.77 mbsf)</td>
<td>0 - 25</td>
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<tr>
<td></td>
<td>Mixed</td>
<td>25-75</td>
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<td></td>
<td>PU 12 162-986D-29R-02 (658.22 mbsf)</td>
<td>75-100</td>
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<td>PU 11 162-986D-35R-01 (714.92 mbsf)</td>
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<td>PU 10 162-986D-35R-02 (716.42 mbsf)</td>
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<td>PU 8 162-986D-40R-06 (772.53 mbsf)</td>
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<td>PU 9 162-986D-41R-01 (774.72 mbsf)</td>
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<td>Porous non-compressed</td>
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<td>PU 7 162-986D-43R-03 (794.72 mbsf)</td>
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<td>PU 4 162-986D-46R-02 (821.12 mbsf)</td>
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<td></td>
<td>PU 3 162-986D-47R-01 (830.22 mbsf)</td>
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In addition to the nominate species, the unit is dominated by *R. algaeformis* and *C. pusilla*. *Textularina* genus indet. is quantitatively important, whereas the frequency of *C. cf. nana* is strongly reduced. Characteristic species are *Cyclammina trilissata*, *Paratrochammina cf. challengeri*, *Haplophragmoides bradyi*, *Bathyphison hirudineus*, and *Reophax biloculatus*. The assemblage is a porous noncompressed type, corresponding to the interval PU3.

**AFA4, Ammodiscus tenuis assemblage**

This is recognized only in Sample 162-986D-43R-3, 29–36 cm (794.72 mbsf), strongly dominated by *C. pusilla* and characterized by *A. tenuis* and *R. algaeformis*. The fauna is of porous noncompressed preservation designated as PU7.

**DEPOSITIONAL SIGNIFICANCE OF PRESERVATIONAL UNITS**

**Porous Noncompressed Fauval Units**

In the samples referred to in these preservational units, 75%–100% of the specimens are classified as porous noncompressed. Both small and large specimens are present, although large tubular forms commonly dominate. The porous wall texture indicates that no sig-
significant diagenetic cementation of the agglutinated material has taken place. The tests retain their original shape with no, or only very weak, compressional deformation. In most species the color is white or yellowish, but some are reddish or light brown.

The generally well-preserved nature of the assemblages suggests that they have not been significantly affected by post-mortem transport and resedimentation processes. In accordance with this, the taxonomic composition of the faunas indicates benthal to abyssal conditions and is consistent with a late Pliocene age.

Tubular taxa are abundant in the Cyclammina pulsilla assemblage, common in the Recurvoides turbinatus assemblage, and are present in low numbers in the Ammodiscus tensus assemblage. The group is generally regarded to be characteristic of deep-water, mainly benthal environments (Gradstein and Berggren, 1981; Miller et al., 1982; Jones, 1988; Gradstein and Bäckström, 1996). In the C. pulsilla assemblage, the tubular group is represented by Rhizammina algaeformis, Rhabdammina discreta, and Rhizamminina sp., whereas in the R. turbinatus assemblage, R. algaeformis is dominant. As shown by Schröder (1986), R. algaeformis is abundant in modern benthal to abyssal faunas of the northwestern Atlantic Ocean (Nova Scotia Rise, Bermuda Rise, and Nares Abyssal Plain). On the Nova Scotia Rise, R. discreta occurs mainly in the depth interval 2750–3550 m.

According to information published by Schröder (1986), Charnock and Jones (1990), and Jones (1994), the following species of the porous noncompressed assemblages are generally confined to benthal and greater depths in the present-day North Atlantic Ocean: Ammodiscus tensus, Cyclammina pulsilla, Thracammina papillata, Recurvoides turbinatus, Haplophragmoides broadyi, Ammonomarginulina foliacea, Karreriella apiculata, Cribrastooides subglobosus, Techniella lagunae, Reophax guttifer, Ammonomarginulina recurva, Cyclammina trilatissae, and Reophax biculiculux.

Silicified Compressed Faunal Units

In the samples belonging to these faunal units, 75%–100% of the foraminifers show the silicified compressed type of preservation. The specimens are small in size, markedly deformed by compression, and are strongly silicified by diagenetic processes. Their color is usually gray or brownish. The poor preservation and small size of the tests made taxonomic determinations difficult, which explains the extensive use of open nomenclature.

The preservational features of this fauna suggest reworking from pre-existing strata, with subsequent transport and resedimentation in the upper Pliocene lower slope environment. The small and relatively uniform size of the tests (usually 130–200 μm) suggests sorting by a hydrodynamic process.

The redeposited faunal component is dominated by Textularia genus indet. and T. cf. nana. In addition to the redeposited forms, many samples contain scattered, well-preserved tests of more or less in situ origin belonging to species such as R. algaeformis, C. pulsilla, and Repmannia charoides.

Mixed Faunal Units

The samples grouped in the mixed units contain 25%–75% porous noncompressed specimens, whereas the rest is silicified compressed. These fauna are developed in four thin intervals between silicified compressed units (Fig. 7). The increased frequency of the in situ faunal component in the mixed assemblages suggests periods with reduced influx of material from extrabasinal sources, or increased benthic productivity within the depositional area.

**DISCUSSION**

There are marked similarities between the Pliocene section in Hole 986D and some of the other Pliocene-aged deposits mentioned above, in particular the Geodia sp.-Globigerina bulloides Zone (D) in Well 71179-1 on the Senja Ridge (Eidvin et al., 1993a) and the Globigerina bulloides-Cassidulinia teretis Zone (BB-FB) in Well 71176-1 in the Vestshakken Volcanic Province (Eidvin et al., 1998b; Fig. 8). Although the foraminifer assemblages in Wells 71179-1 and 71365-1 differ somewhat from those of Hole 986D in their generally lower diversity and poorer preservation, many of the recorded species are the same. In all sections, C. teretis and M. zaandamae dominate the calcareous benthic assemblages, whereas G. bulloides dominates the planktonic faunas. In addition, all sections contain many reworked calcareous and agglutinated specimens from Miocene to Eocene deposits. However, the analyzed section in Hole 986D contains more benthic species of deep-water affinity.

A maximum age of 2.7 Ma is assigned to the sections in Wells 71179-1 and 71365-1, and these sections probably represent sediments deposited after the great increase in the supply of ice-dropped material at the Leg 104 sites at the Voring Plateau (Jansen and Sjøholm, 1991; Eidvin et al., 1993a, 1998b). A minimum age of 2.4 Ma is based on the fact that G. bulloides is common in Pliocene sediments older than 2.4 Ma at the Voring Plateau sites (Spieglner and Jansen, 1989). However, G. bulloides is also found in the warmest interglacials of the last 1 Ma (Kellogg, 1977).

The assemblages in Hole 986D also have a strong affinity with the faunas recorded from the section between 151.27 and 502.97 mbsf in Hole 910C (Leg 141). This section also has a benthic assemblage with C. grossus (Osterman, 1996) and common C. teretis, M. zaandamae, and Epiostominaella associated with rare E. albittubulata. The planktonic assemblage is dominated by N. atlantica (sin.) and G. bulloides. Paleomagnetic and fossil evidence date this section to the late Pliocene. A maximum age of 2.7 Ma is assigned to the base of the section (Spieglner, 1996; Fig. 8).

The interval in between Sample 104-643A-7H-2, 74–78 cm, and 7H-5, 74–78 cm, on the Voring Plateau also contains common C. teretis, M. zaandamae, N. atlantica (sin.), and G. bulloides. Paleomagnetic records date this section from latest early Pliocene to earliest late Pliocene (Spieglner and Jansen, 1989; Osterman and Quave, 1989; Fig. 8).

According to Channell et al. (Chap. 10, this volume), the uppermost 150 m at Site 986 appears to record the Brunhes/Matuyama boundary and the Jaramillo Subchron. The base of the drilled section (at ~950 mbsf) is interpreted to lie within the Matuyama Chron (age <2.58 Ma) with the normal polarity interval (interpreted as the Olduvai Subchron) occurring from ~730 to 750 mbsf. The age of the Olduvai Subchron is 1.76–1.98 Ma according to Cande and Kent (1992). This implies that the LO of N. atlantica (sin.) and the last common occurrence of G. bulloides are <1.7 Ma. In other words, this results in an apparent discrepancy of 0.7 m.y. at Site 986 compared to other ODP/Deep Sea Drilling Project Sites in the Norwegian Sea or the North Atlantic. This discrepancy is especially unlikely for the transitional dwelling G. bulloides. Extensive reworking of planktonic foraminifera at Site 986 could explain this problem, but few of the tests show any sign of wear. Less than 200 k.y. is an extremely short time to deposit the analyzed section. However, such extreme accumulation rates, in the 2.7–2.4 Ma time interval, are recorded from the western margin of the Barents Shelf (Eidvin et al., 1993a, 1998b), the Norwegian Sea continental shelf (Eidvin et al., 1998a), and the northern North Sea (Eidvin and Riis, 1992). For the time being, we are unable to find a solution on the mentioned discrepancy between the paleomagnetic and biostratigraphic data.

The porous noncompressed assemblages observed between 907.22 and 935.32 mbsf, between 830.22 and 841.32 mbsf, and at 794.72 mbsf consist exclusively of agglutinated taxa. The absence of calcareous benthic and planktonic foraminifers from these intervals indicates that the deposition of the assemblages has taken place most likely below the local carbonate compensation depth, although diagenetic dissolution of carbonate cannot be totally excluded.

The four silicified compressed assemblages and the seven mixed agglutinated assemblages are associated with a calcareous faunal component consisting of relatively few benthic specimens and more
common planktonic taxa. It seems also likely that the calcareous benthic component is at least partly reworked, as suggested by the common occurrences of broken specimens.

**SUMMARY**

The studied interval from 647.72 to 953.32 mbsf in Hole 986D contains the following stratigraphic units based on foraminifers: the planktonic *Neogloboquadrina atlantica* (sinistral) Zone, the benthic *Melonis zambeziense–Cassidulina teretis* Zone, and four agglutinated assemblages designated as AFA1 through AFA4. The lowermost 55 m of the interval are barren of planktonic and calcareous benthic foraminifers but contain varying amounts of agglutinated taxa (Fig. 6).

Paleomagnetic data show that the bottom of the hole is in the Matuyama Chron, which implies an age of <2.6 Ma (Channell et al., Chap. 10, this volume). The occurrence of *N. atlantica* (sin.) implies an age not younger than 2.4 Ma for the top of the interval. The paleomagnetic data indicate a maximum age of ~1.7 Ma for the top of the interval (Channell et al., Chap. 10, this volume) and show a discrepancy between the paleomagnetic and the biostratigraphic data in this part of the hole.

A strongly variable abundance of planktonic and calcareous benthic foraminifers indicates alternating glacial and interglacial conditions. The planktonic fauna suggests a generally cold ocean with short warm to transitional surface-water ingestions and is consistent with the changing content of calcareous benthic Arctic and boreal species. Most of the planktonic specimens are well preserved and show no sign of having been reworked. Many of the calcareous benthic specimens, however, are broken, indicating considerable reworking.

The planktonic and calcareous benthic assemblages are correlated with similar faunas in Hole 910C on the Yermak Plateau, Hole 643A on the Voring Plateau, the exploration Well 7117-9-1 on the Senja Ridge, and the exploration Well 7316-5-1 in the Vestbakken Volcanic Province.

The agglutinated assemblages represent alternating porous non-compacted bathyal in situ faunas and silicified compressed redeposited taxa as well as mixed faunas of in situ and redeposited specimens (see Fig. 7). The exclusively agglutinated assemblages occurring in three segments of Hole 966D indicate that the deposition has taken place below the local carbonate compensation depth.

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