Late Cretaceous to Early Tertiary agglutinated benthic foraminifera in the Labrador Sea

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ABSTRACT
A major faunal change occurred at the end of the Eocene in the deep Labrador Sea (DSDP Site 112). Predominantly agglutinated Eocene benthic foraminiferal assemblages are replaced by an Oligocene calcareous assemblage. This replacement correlates with similar changes in the Canadian margin and the North Sea where the exit of agglutinated foraminifera is associated with a change in depositional environment. In Site 112, however, lithology, percent carbonate, and percent organic carbon are relatively constant across the faunal change. Thus, at least in the deep sea, these properties may not be critical to the development of predominantly agglutinated assemblages. We infer that certain hydrographic properties (low oxygen, high CO₂, low pH, and thus more corrosive waters) favor the development of agglutinated assemblages. We suggest that the replacement of agglutinated foraminifera in the deep Labrador Sea was due to a change in hydrographic properties. Seismic evidence from this region indicates initiation of northern sources of bottom water in the late Eocene to early Oligocene which may have resulted in a change in hydrography and the exit of agglutinated foraminifera. Despite diachrony of certain occurrences in Site 112 and the Canadian margin, compared with previously reported ranges of agglutinated taxa from the North Sea, European flysch basin, and the deep sea, agglutinated foraminifera are useful in the zonation of Labrador Sea sediments.

INTRODUCTION
Agglutinated (arenaceous) foraminiferal assemblages occur in Maestrichtian to Eocene mudstones of the Labrador Shelf/northeast Newfoundland Shelf and upper Paleocene to Eocene shales of the North Sea. These taxonomically similar assemblages resemble the Rhabdammina assemblages described (Brouwer, 1965) from pelitic intervals of flysch sediments throughout the world. Gradstein and Berggren (1981) described the taxonomy, zoogeography, and biostratigraphic utility of these Late Cretaceous to Tertiary “flysch-type” agglutinated assemblages, discussed paleoecologic implications of their distribution, and related their distribution to the tectonic history of the Labrador Sea and the North Sea.

Predominantly agglutinated assemblages resembling the flysch-type Rhabdammina assemblages also have been described from deep-sea sediments recovered by the Deep Sea Drilling Project/International Phase of Ocean Drilling (text-figs. 1, 2). Our study compares the distribution of the deep-sea assemblages as reported in the Initial Reports of the Deep Sea Drilling Project, examines in detail Eocene agglutinated assemblages of DSDP Site 112 (Labrador Sea), and compares the Site 112 assemblages with Maestrichtian to Eocene agglutinated assemblages of the Labrador and East Newfoundland shelves. Various paleoecologic models for agglutinated assemblages are evaluated, using lithologic and faunal data from Site 112. We conclude that a late Eocene to early Oligocene change in abyssal circulation resulted in the demise of the agglutinated assemblages in Site 112; local tectonic and sedimentologic events may have been important in the replacement of agglutinated assemblages in the Canadian margin and the North Sea.

PREVIOUS WORK
Berggren (1972) noted relatively diverse assemblages of predominantly agglutinated benthic foraminifera in the ?Paleocene to Eocene sediments of Site 112. Subsequently, Middle Cretaceous to Early Tertiary agglutinated benthic foraminiferal assemblages have been recorded in 30 DSDP sites in various parts of the world (text-figs. 1, 2; Beckman, 1972; Krasheninnikov, 1973, 1974; Webb, 1975; Rögl, 1976; van Hinte, micropaleontology, vol. 28, no. 1, pp. 1–30, pls. 1–3, 1982
in Talwani, Udintsev et al., 1976; Krasheninnikov and Pflaumann, 1977; Tjalsma, 1977; Gradstein, 1978; McNulty, 1979). These assemblages consist of mostly agglutinated taxa, but calcareous benthic forms may be minor constituents. Planktonic foraminifera are, in general, rare or absent. Miller et al. (1979) and Gradstein and Berggren (1981) differentiated two types of deep-sea assemblages of agglutinated benthic foraminifera distinguishable by wall texture, test size, and taxonomic composition. Assemblage type A is found in bathyal and abyssal sediments; it is similar in taxonomic composition to agglutinated assemblages of the Carpathian and Alpine flysch basins (= "flysch-type" agglutinated assemblages of Gradstein and Berggren, 1981), the North Sea, and the Canadian margin. In general, this assemblage is characterized by coarse-grained, larger-sized tests. "Simple" forms including the single chambered and uniserial genera Rhabdammina, Bathysiphon, Ammodiscus, Lituotuba, Reophax, and Hormosina often dominate this assemblage (pl. 1). Biserial (Spirolectammina, Textularia), multiserial (Gaudryina, Dorothis), trochoid (Trochammina, Recurvoides, Trochamminoides), and planispiral (Cribrostomoides, Haplophragmoides, Cyclammina) forms are less abundant (pl. 2). Assemblage type B has been recorded only from abyssal sediments. This assemblage is composed of small (generally less than 150 μm), thin, smooth walled, predominantly "complex" forms of the families Lituidae, Trochamnidae, and Textulariidae. Krasheninnikov (1974) noted certain generic similarities between an Upper Cretaceous type B assemblage in Sites 260 and 261 and flysch-type (= type A) agglutinated foraminiferal assemblages. However, such genera as Plecto-
recurvoides, Haplophragmium, and Labrospira, which are usually rare to absent in type A assemblages, predominate in type B assemblages.

Some of the taxonomic differences between type A and type B assemblages may be due to different stratigraphic and facies distribution. Text-figure 2 shows the distribution of predominantly agglutinated foraminiferal assemblages and lithofacies versus age as reported from 21 DSDP/IPOD sites. Type A assemblages, reported from Sites 112, 137, 138, 140, 141, 367 (cores 15 to 18), 368, 327, 328, 323, and 263 are found in Late Cretaceous to Tertiary sediments. In the Tertiary, the only apparent post-Eocene occurrences of type A assemblages are at Sites 323 and 325 (Bellinghausen Sea; Rögl, 1976) and in the Norwegian-Greenland Sea (van Hinte, in Tailwani, Udintsev et al., 1976); however, the Norwegian-Greenland Sea assemblages may be taxonomically distinct from both Type A and Type B assemblages. In contrast, type B assemblages, reported from Sites 196, 198A, 260, 261, 263 (Krasheninnikov, 1973, 1974), 385, 387 (McNulty, 1979), and 391C (Gradstein, 1978) are found only in Cretaceous sediments. A third type of agglutinated assemblage, the Dorothia praehauteriviana assemblage, has been reported from the deep sea by Luterbacher (1972), Krasheninnikov and Pflaumann (1977), and Kuznetsova and Seibold (1978) from Sites 101, 105, 367 (cores 26–29), 370 (cores 38–49), and 391C. This assemblage is found only in Lower Cretaceous sediments. The different agglutinated assemblages also occur in different lithofacies. Text-figure 2 shows that both type A and type B assemblages are found primarily in zeolithic and variegated clays, but type B assemblages (with the possible exception of Site 385, core 12) are restricted to such sediments, while type A assemblages are found in a wider variety of lithofacies. The D. praehauteriviana assemblage, in contrast, is found only in Neocomian limestones.

Type A and type B assemblages also occur at different paleodepths. We use the "backtracking" method (Slater et al., 1971; Berger and Winterer, 1974) to estimate paleobathymetry for these deep-sea agglutinated assemblages. With the exception of the Norwegian-Greenland Sea paleodepths less than 0.7 km to 3.0 km, assemblage A occurs above crust which may be backtracked to paleodepths of 2.5 to 4.5 km (table 1). Assemblage B, however, is restricted to paleodepths greater than 4.0 km.

Predominantly agglutinated foraminiferal assemblages have been accounted for by water depth, carbonate availability, hydrographic properties, and substrate characteristics. The extensive paleobathymetric range of type A assemblages suggests that depth alone does not control the distribution of these deep-sea agglutinated foraminifera. Hesse and Butt (1976) suggested that flysch-type agglutinated foraminiferal assemblages result from the exclusion of calcareous benthic foraminifera below a local CCD (Carbonate Compensation Depth). Saidova (1960, 1965) explained the distribution of Recent abyssal agglutinated foraminiferal assemblages from the Pacific Ocean with hydrographic properties (high pressure, low temperature, low dissolved oxygen). Saidova's explanation does not exclude carbonate control, as these properties promote carbonate dissolution. Similarly, Hiltermann (1973) suggested that low temperature and low oxygen favored agglutinated foraminifera in flysch deposits. Ksiazkiewicz (1961, 1975) and Moorkens (1976) invoked substrates containing abundant organic matter as an important control on flysch-type agglutinated assemblages. This explanation does not exclude carbonate or hydrographic limitations, as low $O_2$, high $CO_2$, low pH, low Eh, and poor circulation are often associated with high organic matter. These explanations are not mutually exclusive, but they do differ in emphasis. We evaluate them using lithologic and faunal data from DSDP Site 112.

### METHODS

Twenty samples from the Eocene to lower Oligocene sediments of Site 112 were examined for benthic foraminiferal content (cores 11–16). All benthic foraminifera were picked from the greater than 150 μm size-fraction. The less than 150 μm size-fraction was examined to ensure that the larger size-fraction con-
### DSDP Sites

<table>
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<td>Contiguous Rise</td>
</tr>
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<td>Small Vessel</td>
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</tr>
<tr>
<td></td>
<td>Large Vessel</td>
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</tr>
</tbody>
</table>

### Age in Millions of Years

- **Cretaceous**
  - Upper Cretaceous
  - Lower Cretaceous
  - Middle Cretaceous
  - Upper Jurassic
  - Lower Jurassic

### Explanation

- **Clay Matrix**
- **Silt Matrix**
- **Sand Matrix**
- **Pseudofossil**
- **Calcite**
- **Fibrous**

### Age Assignment

- By biostratigraphy
- By magnetic polarity
- By diatoms
- By planktonic foraminifers
- By benthic foraminifers
- By sedimentology
- By ichnology

### Diagram Details

- **Discretization**
- **Calcite**
- **Fibrous**
- **Silt Matrix**
- **Sand Matrix**
- **Clay Matrix**
- **Pseudofossil**
- **Calcite**
- **Fibrous**
- **Silt Matrix**
- **Sand Matrix**
- **Clay Matrix**
- **Pseudofossil**

### References

- C. S. Miller, M. A. Gradstein, W. A. Berggren: Late Cretaceous to Early Tertiary agglutinated benthic foraminifera in the Labrador Sea
TEXT-Figure 2
Stratigraphic distribution of lithofacies and agglutinated foraminiferal assemblages. Sites containing agglutinated foraminifera from Miocene to Eocene of Norwegian-Greenland Sea (Sites 336, 340, 343, 344, 345, 347, 350) and Oligocene to early Miocene of the Bellingshausen Sea (Sites 332, 329) not shown.
made for the Canadian margin wells; only exits were used in computing ranges of agglutinated taxa in these wells.

Estimating the relative abundance of agglutinated benthic foraminifera is complicated by the fact that many taxa occur as fragments rather than whole tests. Species of *Rhizammina*, *Bathyysiphon*, *Hyperammina*, *Rhabdammina*, *Homosina*, and *Reophax* are usually recovered only as fragments. These species, however, are often abundant, and neglecting them results in an inadequate assemblage description. Thus, all identifiable fragments of agglutinated taxa were counted. All identifiable fragments of calcareous taxa were counted for consistency. Although some duplication undoubtedly resulted, we believe that the observed changes in agglutinated assemblages and the relative abundance of agglutinated versus calcareous taxa are valid.

**AGGLUTINATED ASSEMBLAGES FROM SITE 112, LABRADOR SEA**

Planktonic biostratigraphy and lithology

Site 112 was drilled in 3657-m water depth in the southern Labrador Sea (text-fig. 3). Cores 1A to 5A (79–124 m subbottom) and 5 to 11 (270–293 m subbottom) were continuously cored; however, the Eocene/Oligocene boundary (between cores 12 and 13) was not cored. Basaltic basement was penetrated at 661 m (text-fig. 5).

The cored Paleogene section consists of indurated red clays and claystones with palagonite sills (core 16), indurated, burrow mottled gray pelagic nanofossil clay and marls (cores 12 to 15), and gray pelagic burrow mottled siliceous nanofossil clay and silt and siliceous ooze (cores 3 to 11; text-fig. 5). Cores 12 to 15 are distinguished from the overlying sediments by finer grain size, greater lithification and burrowing, and increased amounts of pyrite, authigenic calcite, and goethite (Laughton, Berggren et al., 1972).

Nannofossils and planktonic foraminifera were originally used to place cores 5 and 6 in the late Oligocene, cores 7 to 12 in the early Oligocene, and cores 13 to 15 in the Eocene. Radiolarians and diatoms also indicated an Oligocene age for cores 5 to 11. Core 16 was placed in the ?Paleocene-early Eocene on the basis of extrapolation of a 1.5 cm/1000 yr (= 15 m/my) sedimentation rate for the Eocene sediments in Site 112. An unconformity was inferred from the low sedimentation rate (less than 5.5 m/my) between the upper Oligocene in the top of core 5 (270 m subbottom) and middle Miocene sediments in the base of core 4 (209 m subbottom). No other evidence for Paleogene unconformities is present (Laughton, Berggren et al., 1972).
Type A agglutinated benthic foraminifera assemblages occur in the ?Paleocene to Eocene section of Site 112 (cores 13 to 16; text-fig. 5). We have re-examined planktonic foraminifera and calcareous nannoplankton and have refined the biostratigraphic zonation of these cores as described below.

Core 16 (revised)

No planktonic foraminifera or nannoplankton were originally reported from core 16, although ?late Paleocene-early Eocene nannoplankton were reported from the center bit just above core 16 (Perch-Nielsen, 1972). We note rare specimens of Subbotina sp. and Subbotina cf. S. linaperta Finlay in 16 center bit sample and sample 16-1, 107–111 cm, which agrees with the late Paleocene-early Eocene age assignment. The center bit sample contains a mixture of green marl and red clay, suggesting that the lithologic change from nannofossil clays and marls to baked red clay occurs just above core 16 at approximately 650 m.

Sedimentation rates for the lower Oligocene to Eocene clays and marls were recomputed after assigning core 15 to middle Eocene using planktonic foraminifera (Zone P10; 47–49 Ma; this paper), core 13 to the late Eocene using nannoplankton (Zone NP19, 37.5–39 Ma; Perch-Nielsen, 1972) and core 12 to the
early Oligocene using nannoplankton (Zones NP21/ NP22; 34–37 Ma; Perch-Nielsen, 1972; Bukry, 1972). The fossil zones are dated using the time scale of Hardenbol and Berggren (1978).

Sedimentation rates range from 12–19 m/my depending on whether an upper or lower boundary age is taken for each zone; this agrees well with the original estimate of 15 m/my.

Extrapolating this rate downward yields an age of 50–53 Ma (earliest Eocene) for the top of core 16. An age of 51–54 Ma is estimated for the base of core 16 assuming a constant sedimentation rate across the lithologic change. Core 16 is thus probably early Eocene, but possibly latest Paleocene in age.

Core 15 (revised)

Subbotina frontosa (Subbotina) and S. linaperta are abundant in core 15. The first appearance of S. frontosa occurs at the base of Zone P10 (S. frontosa frontosa/Globorotalia pseudomayeri Bolli CRZ; Blow, 1979). Subbotina frontosa exits at the top of P11 (Blow, 1979).


The presence of Pseudoammoninina wilcoxensis (Cushman and Ponton) (FAD P7; LAD P10); Blow,
Relative percent of agglutinated taxa in DSDP Site 112. *Glomospira* spp. includes relative percent of agglutinated foraminifera of *G. charoides*, *G. gordialis*, and *G. irregularis*. Error bars on percent calcareous/agglutinated taxa indicate 95% confidence level.

Both Perch-Nielsen (1972) and Bukry (1972) placed core 15 in the *Discoaster sublodoensis* (NP14) Zone. Perch-Nielsen followed Martini’s (1970) assignment of this zone to the early Eocene (= P9), while Bukry (1972) placed it in the middle Eocene (= P10). Zone NP14 has been correlated with Zone P10 (Bukry and Kennedy, 1969), and nannoplankton typical of this zone have been correlated with the *P. horridus* Zone (= middle Eocene; Bouche, 1962; Hay et al., 1967). Our study agrees with the correlation of NP14 with P10. Thus, nannofossils and planktonic foraminifera support an early middle Eocene age (P10, NP14) for this core.

Core 14 (revised)

Planktonic foraminifera are rare in core 14; predominantly long-ranging *Subbotina inaperta*, *Dentoglobigerina galavisii*, *Turborotalia* sp., and *Catapsydrax* sp. were found. The occurrence of *C. unicavus* Bolli (FAD P14; Stainforth et al., 1975) suggests a late middle to late Eocene age. On the basis of calcareous nannoplankton, core 14 was originally assigned to the late Eocene *Discoaster barbadiensis* (= NP18 to NP20) Zone by Bukry (1972) and to the middle Eocene *D. tani nodifer* s.l. (= NP16) Zone by Perch-Nielsen (1972), although Perch-Nielsen acknowledged possible assignment to the *Reticulofenestra umbilicata* Zone (= NP17 to 18, late Eocene in her study; middle to late Eocene of Martini, 1970). Calcareous nannoplankton from core 14-2 were examined and assigned to the late middle Eocene Zone NP17 of Martini’s (1970) zonation (M.-P. Aubry, personal communication, 1980) based upon the simultaneous occurrence of *D. saipanensis* Bramlette and Riedel and *Neococcolithus minutus* Perch-Nielsen and the absence of both *Chiasmolithus oamaruensis* Deflandre and *C. solitus* (Bramlette and Sullivan) (Table 2). This latest middle Eocene age assignment agrees well with interpolations of the sedimentation rate. If core 15 is assigned to Zone P10 (46 Ma), a 15 m/my sedimentation rate would place core 14 in the late middle Eocene (40 Ma; text-fig. 5).
TABLE 2

<table>
<thead>
<tr>
<th>Assemblage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coccolithus pelagicus (Wallich)</td>
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<tr>
<td>Reticulofenestra umbilica (Lavin)</td>
</tr>
<tr>
<td>R. dixyoda Dellandrea</td>
</tr>
<tr>
<td>R. cf. R. insignata Roth and Hay</td>
</tr>
<tr>
<td>R. samudraviri Hay, Mohler and Wade</td>
</tr>
<tr>
<td>R. cf. R. illeae Bukry and Pectinopterus</td>
</tr>
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<td>R. bisecta Hay, Mohler and Wade</td>
</tr>
<tr>
<td>Ericsonia formosa (Kampfer)</td>
</tr>
<tr>
<td>Discoaster sapanensis Bramlette and Riedel</td>
</tr>
<tr>
<td>D. barbadensis Bramlette and Riedel</td>
</tr>
<tr>
<td>Chiasmolithus expansus Bramlette and Sullivan</td>
</tr>
<tr>
<td>Zygrhabditis bijugata (Dellandrea)</td>
</tr>
<tr>
<td>Markallus reversus Bramlette and Marini</td>
</tr>
<tr>
<td>Peneroplis sp.</td>
</tr>
<tr>
<td>Neococcolithes minutus Perch-Nielsen</td>
</tr>
<tr>
<td>Cyclococcolithus pseudogemmation Bouche</td>
</tr>
</tbody>
</table>

Zonal determination based on absence of Chiasmolithus camauroensis Dellandrea and C. scutis (Bramlette and Sullivan) and the simultaneous occurrences of Discoaster sapanensis and Neococcolithes minutus. (After M.-P. Aubry, personal communication.)

Core 13 (revised)

Subbotina linaperta (LAD P17; Stainforth et al., 1975; Blow, 1979) and Catapsydrax dissimilis (Cushman and Bermudez) are the predominant planktonic foraminifera in core 13. The simultaneous occurrence of C. unicus Bolli (FAD P14; Stainforth et al., 1975) and S. linaperta suggests latest middle to late Eocene age (P14 to P16). This agrees with the assignment of core 13 to the late Eocene nanoplankton Isthmolithus recurvus (= NP19; Perch-Nielsen, 1972) and Discoaster barbadiensis (= NP18 to 20; Bukry, 1972) Zones. Acarinina cf. A. rotundimarginata Subbotina (= Truncorotaloides collacteus (Finlay)) also occurs in this core. Berggren (1977) noted that A. rotundimarginata ranges into the late Eocene in high latitudes at least as far up as the I. recurvus Zone; this supports the assignment of core 13 to this zone.

The presence of Pseudohastigerina wilcoxensis in this core is apparently anomalous. Cordey et al. (1970), Stainforth et al. (1975), and Blow (1979) suggested a middle Eocene extinction of this species (middle Eocene; P12, P11, respectively). The specimens we have identified as P. wilcoxensis (pl. 3, figs. 11–12) are larger and less compressed than P. micra (Cole) and have a much more rounded, inflated axial-apertural aspect to the last chamber which is cited by Blow (1979) as characteristic of P. wilcoxensis. Our species can be differentiated from P. danvilensis (Howe and Wallace) by lack of an ovoid to pinched axial-apertural aspect (Blow, 1979). Only if we assume that P. wilcoxensis extends into the late middle Eocene as inferred by Cordey et al. (1970) and core 13 is reassigned as latest middle Eocene (P14) can this distribution be explained in terms of previous authors’ ranges. As this results in a significant disagreement with the nanoplankton age assignment (late Eocene), we accept core 13 as late Eocene (NP19; P15–16) and note the occurrence of P. wilcoxensis as anomalous.

Core 12 (revised)

Core 12 is assigned to the early Oligocene Helicosphaera reticulata (= NP22) by Bukry (1972) and the Erisconia obtusa (= E. subdisticha = NP21) Zone by Perch-Nielsen (1972). Planktonic foraminifera include rare Catapsydrax dissimilis and Subbotina spp. which are not age diagnostic.

The Eocene/Oligocene boundary may lie in a 48 m uncorred interval between cores 12 and 13. Assuming a 15 m/Myr sedimentation rate, the unsampled interval represents 3 m. The assignment of core 13 to NP19 and core 12 to NP21/NP22 requires a separation of 1 to 4 m. This suggests that either continuous sedimentation or only a short hiatus (less than 1 m) occurs across the Eocene/Oligocene in this corehole.

Benthic assemblages of Site 112

We recognize 43 agglutinated species belonging to 23 genera and 8 families in the Eocene section of Site 112 (cores 13 to 16). The generic composition and number of species identified are similar to those reported from other DSDP sites where special studies were made of type A agglutinated assemblages (Sites 367, 368—Krasheninnikov and Pflaumann, 1977; Site 323—Rog, 1976; Site 283—Webb, 1975; see table 3 of Gradstein and Berggren, 1981). All principal genera (i.e., those noted by more than two authors) noted in previous studies of type A assemblages in the deep sea are present in Site 112. In addition, 20 of the agglutinated species in Site 112 have been noted from the central North Sea, Labrador Shelf, Newfoundland Shelf, and West Greenland (Gradstein and Berggren, 1981). These taxa are indicated with an asterisk in table 3. The presence of the same taxa in Site 112 (paleodepth approximately 3 km; table 1) and the Labrador Shelf and central North Sea (both paleodepths less than 1 km) illustrates the wide bathymetric ranges of these agglutinated taxa.

Several of the stratigraphic ranges (text-fig. 4) of the agglutinated taxa in Site 112 are significantly restricted. The stratigraphic utility of these species is discussed in conjunction with the Canadian margin wells (below).

Abundances of benthic foraminifera range from 0 to 188 individuals/sample in Site 112. In the Eocene section, agglutinated foraminifera comprise from 40 to 100% of the benthic foraminifera, and agglutinated diversity ranges from 5 to 22 species/sample (table 4).
### TABLE 3
Abundance of agglutinated species, DSDP Site 112. Number of each specimens/sample is given. Asterisks indicate species noted from Canadian margin or North Sea by Gradstein and Berggren (1981).

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Although 43 agglutinated species are found in Site 112, only 9 species constitute more than 10% of agglutinated foraminifera in two or more samples. The relative abundances of these nine species are used to identify four agglutinated assemblages in the Eocene section: GLomospira, Cribrostomoides/Recuuroidae, Spiroplectammina spectabilis (Grzybowski), and Cyclammina amblectens assemblages (text-fig. 6). Rhizammina sp. is abundant (approximately 25% of agglutinated foraminifera) in all assemblages. The Glomospira assemblage is found in core 16 and is composed of highest abundances of G. charoides (Jones and Parker), G. gordialis (Jones and Parker), G. irregularis (Grzybowski), and Ammodiscus globatus Cushman and Jarvis. This assemblage is characterized by exclusively agglutinated foraminifera (table 4; text-fig. 5) and is associated with the baked red clay lithologic unit (unit 5; text-fig. 5). Haplophragmoides eggeri Cushman, H. sp., and Trochammina globigeriniformis (Parker and Jones) are restricted to this early Eocene assemblage.

The following assemblages occur within the silty clays and nanofossil marls of lithologic unit 4.

The middle Eocene Cribrostomoides/Recuuroidae assemblage occurs in core 15 and core 14 (14-CC; 14-5). It is distinguished from the overlying assemblage by the low percentages of Spiroplectammina spectabilis and the high percentages of "Cribrostomoides" subglobosus (Sars) and Recuuroidae ex. gr. walteri (Grzybowski). It is associated with approximately 25% calcareous benthic foraminifera.

The S. spectabilis assemblage (14-3; 14-2, 144-146 cm; 14-2, 102-113 cm) is composed predominantly of the nominate species (25-50% of the agglutinated foraminifera) and high relative abundances of calcareous benthic foraminifera (30-60% of total benthic foraminifera).

The sample with highest abundance of S. spectabilis and calcareous foraminifera (14-2, 140-142 cm) is described in the initial core description as a light gray indurated layer distinct from overlying and underlying lithologies (Laughton, Berggren et al., 1972). We noted abundant sand-sized planktonic foraminifera in this sample which are not found in any other Eocene sample. Since S. spectabilis is thought to have calcareous cement, this assemblage may reflect a paleoenvironment favorable for the deposition or preservation of calcium carbonate. Unfortunately, no carbonate percentage data are available for this interval.

The middle to late Eocene assemblage found in core 14 (14-2, 50-54 cm) and core 13 contains abundant Cyclammina amblectens and variable percentages of calcareous benthic species (10-60%; table 4). These variable percentages of calcareous species are not correlated with the fluctuations of calcium carbonate (24% ± 3%) in the bulk sediment.

As was first noted by Berggren (1972), the Eocene agglutinated assemblages are replaced in cores 12 and above by an Oligocene calcareous benthic assemblage. This exit is shown in text-fig. 4, where the diverse (15 species/sample) late Eocene C. amblectens assemblage is replaced by an early Oligocene benthic foraminiferal assemblage with sparse agglutinated species (0-2 species/sample). Table 4 shows moderate percentages of calcareous taxa in core 13 (25-60%) which increase to nearly 100% in cores 11 and 12. This faunal turnover occurred between the upper Eocene at 444 m subbottom and the lower Oligocene core at 385 m subbottom (discontinuous coring). Assuming a 15 m/my sedimentation rate, this interval represents approximately 4 my.

AGGLUTINATED ASSEMBLAGES OF THE EASTERN CANADIAN MARGIN AND NORTH SEA

Diverse agglutinated foraminiferal assemblages resembling flysch-type and type A assemblages occur in Maestrichtian through Eocene beds on the Labrador and Newfoundland shelves (text-figs. 3, 8). Similar assemblages have been noted from the late Paleocene through Eocene strata in the central North Sea. Lithologies associated with these assemblages are predominantly mudstones and shales. Localized late Paleocene to early Eocene intercalations termed Gudrid sands occur on the Labrador shelf (Umpleby, 1979); stratigraphic equivalents occurring in the central North
Sea form oil and gas producing horizons in the Forties, Montrose, Frigg, Lomond, Cod, and other oil and gas fields (e.g. Ziegler, 1980). These sandy layers are largely devoid of indigenous microfauna. Both in the North Sea and on the Canadian margin the agglutinated fauna largely disappear at the end of the Eocene.

The stratigraphic ranges of the agglutinated taxa are calibrated to foraminiferal zonations developed for the Canadian margin (16 wells) and central North Sea (15 wells). The central North Sea correlation is based on last appearance levels of planktonic and benthiic taxa. However, in the Paleocene section, such exits are rare (see Berggren and Gradstein, 1981); therefore, the dinoflagellate biostratigraphy of Ioakim (1979) was also used. On the Canadian margin, we used a probabilistic approach to Cenozoic foraminiferal stratigraphy. Exits of over 150 benthic and planktonic taxa were used in conjunction with a locally derived planktonic zonation (see Gradstein and Agterberg, in press). Rather than emphasizing individual wells, these zonations aim at a broad regional application. As a result, stratigraphic resolution is relatively conservative with an eight- to tenfold subdivision of the Cenozoic beds.

Approximately 60 agglutinated species representing 32 genera have been recognized in wells from the Canadian margin and North Sea. Most of these taxa have been described by Gradstein and Berggren (1981). Few taxa are endemic within these two regions.

In the Maestrichtian through Paleocene shales of Labrador wells, Bathysiphon, Saccammina, Glomospira, Karreniella, Trochammina, Haplophragmoides, and Recurvoides are dominant genera. In the Maestrichtian of the Indian Harbour well (text-figs. 3, 4), Reophax and Uvigerinammina are also important. Eocene mudstones both on the Canadian margin and in the North Sea contain frequent Bathysiphon, Ammodiscus, Haplophragmoides, Trochammina, Cribrostomoides, and Karreniella. Cyclammina spp. are locally abundant (e.g. Karlsefni H-13); species include Cyclammina placenta (Reuss), C. amplexdens Grybovski, C. rotundidorsata (Hantken), and forms classified as C. placenta (Reuss) or C. cancellata Brady.

In the Labrador Shelf shales (Indian Harbour M-52 well) agglutinated foraminifera are found associated with Globotruncanella mayaroensis (Bolli) (also reported by Dufaur et al., 1976, from the adjacent Gudrid U-55 well) and a rich assemblage of G. havanensis (Voorwijk), Globigerinelloides messinae Bronnimann, Rugoglobigerina aff. rotundata Bronnimann, and Bolivinoides draco (Marsson). These species indicate a late Maestrichtian age. The agglutinated taxa Uvigerinammina jankoi Majzor, Dorothia oxyconae (Reuss), and Arenobulimina dorbignyi (Reuss) are restricted to these Maestrichtian shales. Of these species U. jankoi has been reported from many Upper Cretaceous flysch deposits in Europe and from the Upper Cretaceous clays in the Atlantic and Indian oceans (Geroch, 1959; Krasheninnikov, 1974; Krasheninnikov and Pflaum, 1977). Dorothia oxyconae (Reuss) is a cosmopolitan Cretaceous form; it locally extends in Paleocene beds (Aubert and Berggren, 1976). Arenobulimina dorbignyi (Reuss) was reported by Hanzlikova (1972) from Turonian-Campanian strata in Europe.

In the North Sea, Rzehakina epigona (Rzepek) is restricted to Upper Cretaceous deposits. On the Canadian margin R. epigona is found more frequently in Upper Cretaceous shales, but also consistently occurs in Paleocene beds. Isolated individuals occur as high as Zone P9 (= Acaninna densa Zone; late early Eocene).

A distinctive species of Ammobaculites with 10 or more chambers in the last whorl and undulating, dark sutures is common in the Labrador and Newfoundland Shelf wells. It is rare in the North Sea. It ranges from Maestrichtian through Eocene beds and is provisionally assigned to A. aff. A. polythalamus Loeblich.

Three distinct taxa, important in the North Sea, are absent from the Canadian margin. Trochammina subvesicularis Homola and Hanzlikova and a form provisionally assigned to T. aff. T. albertensis Wickenden are both homeomorphic with "conical" planktonic foraminifera. Occurring in North Sea wells in beds overlying Danian carbonates and underlying Cyclammina bearing (Eocene) strata, they are probably Paleocene in age. Thurammina sp. has been reported by Bettenstaedt et al. (1962) from lower middle Eocene beds; it has a similar range in the central North Sea.

The absence of pre-Maestrichtian and post-Eocene to Miocene agglutinated foraminiferal assemblages in the Canadian margin and North Sea probably results in the limited stratigraphic ranges of some of the taxa mentioned. These truncated ranges may result from paleoenvironmental changes, and therefore may be useful only in local zonations.

**COMPARISON OF SITE 112 WITH EASTERN CANADIAN MARGIN**

Calibration of the distribution of benthic agglutinated taxa with the zonations discussed above allowed us to compare their ranges from the deep Labrador Sea (Site 112) with the Canadian margin and previously reported ranges from the North Sea, flysch deposits of Europe, and the deep sea. The long stratigraphic ranges of agglutinated species poses one of the major problems in the use of these taxa in biostratigraphy. For example, 12 agglutinated species range throughout the Eocene in Site 112. Other biostratigraphic
TABLE 5
Stratigraphic ranges of agglutinated taxa.

<table>
<thead>
<tr>
<th>Species</th>
<th>Age</th>
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<tr>
<td><em>Uvigerinammina jankoi</em> Majzon</td>
<td>Maestrichtian shales (C.M.)</td>
</tr>
<tr>
<td><em>Dorothy oxycrea</em> (Reuss)</td>
<td>Late Cretaceous (E.F., D.S.)</td>
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<tr>
<td><em>Arenobulimina dohignyi</em> (Reuss)</td>
<td>Maestrichtian shales (C.M.)</td>
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<tr>
<td><em>Rzehakina epigona</em> (Rzehak)</td>
<td>Late Cretaceous (N.S.)</td>
</tr>
<tr>
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<td>Late Cretaceous (C.M., N.S.)</td>
</tr>
<tr>
<td><em>Spiroplectammina spectabilis</em> (Grzybowski)</td>
<td>Maestrichtian to middle Eocene (C.M., N.S.)</td>
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<tr>
<td><em>Cyclammina</em> spp.</td>
<td>Post-Paleocene (C.M., E.F.)</td>
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<tr>
<td><em>C. amplexans</em> (Grzybowski)</td>
<td>Eocene (C.M.)</td>
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<tr>
<td><em>C. placenta</em> (Reuss) and <em>C. rotundidorsata</em> (Hantken)</td>
<td>Eocene (acme in middle Eocene, E.F.) to Oligocene, possibly Miocene (C.M., N.S.)</td>
</tr>
<tr>
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<td>Middle Eocene to early Miocene (C.M., N.S.)</td>
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<td><em>Trochammina subvesiculans</em> Hornola and Handzikova and <em>T. aff. albertainsis</em> Wickamend</td>
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<tr>
<td><em>Thuraminea</em> sp.</td>
<td>Early middle Eocene (N.S., E.F.)</td>
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C.M. = Canadian Margin; N.S. = North Sea; E.F. = European flvich basins; D.S. = deep sea; 112 = Site 112.

problems arise from agglutinated taxa that have diachronous ranges. This is illustrated by the genus *Glo-
mospira*, which is represented in our samples by *G. charoides* (Jones and Parker), *G. gordialis* (Jones and Parker), and *G. irregularis* (Grzybowski). On the Canadian margin these species are fairly common to abundant in Maestrichtian through Paleocene beds; they disappear in the early middle Eocene. These same species are found throughout the Eocene in Site 112, exit in the middle Miocene in the North Sea (text-fig. 7), but are found in the present-day Atlantic (Brady, 1884; Pacific (Brady, 1884; Saidova, 1961), and Gulf of Mexico (Pelger and Parker, 1951; Pflum and Freichs, 1976). Despite these problems, we have been able to use many agglutinated taxa for regional zonations (see text-figs. 4, 7 and table 5 for summary of ranges).

The taxonomic position and stratigraphic range of the genus *Preacystammina* is unclear. Krasheninnikov (1973) used the new taxon *Cystammina globigerinaeformis* (Krasheninnikov) as a Late Cretaceous marker in abyssal Pacific and Indian Ocean deposits. Specimens resembling this form occur in the Maestrichtian of the Labrador Shelf (Indian Harbour M-52 well) and Paleocene to Eocene of the central North Sea. In Site 112, *C. globigerinaeformis* exits at the end of the middle Eocene. Further studies are needed to determine to what extent *Preacystammina* really differs from *Cystammina* and the chronostratigraphic range of *C. globigerinaeformis*.

On the Canadian margin, *Spiroplectammina spectabilis* (Grzybowski), *S. navarroana* Cushman, and *S. dentata* (Alth) have been found from Maestrichtian to middle Eocene beds. *Spiroplectammina spectabilis* is rare above the Paleocene. In the central North Sea *S. spectabilis* and *S. navarroana* were observed in beds overlying Danian carbonates and locally range into or just above sediments with *Subbotina patagonica* (Todd and Knicker) and rare *Acarinina aff. pentacamera* (early Eocene). *Spiroplectammina spectabilis* has been reported from West Germany from upper Paleocene to lower Eocene beds (Bettenstaedt et al., 1962). In Site 112 *S. spectabilis* is found throughout the Eocene, suggesting that it has a longer range in the deep sea.

In the regions under discussion, *Cyclammina* is thought to be restricted to post-Paleocene beds, although in the North Sea some relatively small specimens occur slightly below the tuff marker at the Paleocene-Eocene boundary. Otherwise, in the North Sea *C. amplexans* occurs in strata with *Acarinina pentacamera* (Zones P8 to P12; lower to middle Eocene; Stainforth et al., 1975) and *Spiroplectammina spectabilis*. Although it may range higher, it is mostly restricted to the Eocene. On the Canadian margin *C. amplexans* occurs throughout the Eocene (associated with *Subbotina patagonica*, *Acarinina densa*, and *Turborotalia portorofl*). In Site 112 it is restricted to the middle to upper Eocene section. In Central Europe (Carpathians) *C. amplexans* has been reported from the Eocene; it occurs in greatest abundance in middle Eocene strata (Geroch, 1960).

In the central North Sea and on the Canadian margin both *Cylammina placenta* (Reuss) and *C. rotundidorsata* (Hantken) are longer ranging than *C. amplexans*; these species extend into beds with *Turillina alisatric* (Andreae) (Oligocene) and *Globigerinoides/Globorotalia* (Miocene). These species are absent from Site 112.
In the North Sea, Spirosigmolinella compressa Matsunaga extends from the upper part of the range of Cyclammina amplexaenstes into beds with Globigerinoides and Globorotalia acrostoma; the chronostratigraphic range is middle Eocene to early Miocene. This species occurs in the Arosphaeridium dictorytopilus Zone of loakim (1979) of Bartonian age (middle Eocene). It also occurs in the middle upper Eocene in Site 112; it was not found in the Canadian margin wells. Specimens of S. compressa Matsunaga differ from Rzehakina epigona by having an evolute rather than involute test, a variable but often slenderer width of the test, and an early stage which coils in a different plane from the last few chambers. Rzehakina epigona, in contrast, is planispiral. S. compressa was originally described from the Miocene of Japan. Hormosina ovulum (Grzybowsk) disappears in the lower Eocene in the Carpathians, Caucasus, Eastern Alps (Gerich, 1959); and Site 112.

Of the important indicator taxa noted in the Canadian margin and North Sea, Trochammina subvesiculais, T. aff. T. albentensis, Thurammina sp., Amphobulities aff. A. polythalamus, Uvigerinammina jankoi, Dorothis oxycona, Arenobulimina dorbignyi, and Rzehakina epigona were not found in Site 112.

In addition to the replacement of the late Eocene agglutinated assemblage by an early Oligocene calcareous assemblage in Site 112, agglutinated assemblages also exit across the Eocene/Oligocene boundary in many of the Canadian margin wells (text-fig. 8). In the North Sea, Gradstein and Berggren (1981) noted the disappearance of agglutinated foraminifera in most of the wells studied at the end of the Eocene. Only in a few wells in the center of the basin do agglutinated taxa extend into stratigraphically younger beds. Thus, a major faunal turnover occurs in the late Eocene to early Oligocene of the North Sea, Labrador Shelf, Newfoundland Shelf, and the Labrador Sea.

PALEOENVIRONMENT OF AGGLOMENATED FORAMINIFERA

Agglutinated foraminifera in the Labrador Shelf and North Sea are associated with high sedimentation rates, high organic content, and deepest paleowater depths. The best preserved and highest diversity agglutinated assemblages are found in shales high in organic matter in wells in the depositional center of the basins. In general, these centrally situated wells have relatively high sedimentation rates and calcareous benthic foraminifera which suggest deeper water conditions than in updp wells that have a lower diversity agglutinated assemblage dominated by Bathy- siphon and Trochammina.

Paleoenvironmental factors controlling the distribution of flysch-type agglutinated assemblages in the Labrador and East Newfoundland shelves and the North Sea may be related to the model suggested by Ksiazekwicz (1961, 1975) and Moorkens (1976), which invokes rapid deposition of organic-rich, fine-grained clastics with restricted bottom water circulation (see discussion in Gradstein and Berggren, 1981). Such conditions developed in the Maestrichtian through Eocene of the Labrador Shelf and in the late Paleocene to Eocene of the central North Sea. Differential subsidence, leading to paleogeographically separated and paleoceanographically restricted basins, coincided with rapid deltaic outbuilding into the deeper, more centrally situated parts of the basins (Gradstein and Berggren, 1981). Nevertheless, evidence from Site 112 suggests that, at least in the deep sea, high organic matter is not a prerequisite for the development of predominantly agglutinated foraminiferal assemblages.

Few cores are available from the North Sea and Canadian margin; therefore, the cored Eocene-lower Oligocene section of Site 112 was used to make a detailed comparison of lithologic characteristics with the distribution of agglutinated benthic foraminifera.

The change from agglutinated to calcareous benthic foraminiferous assemblages occurs in Site 112 within lithologic unit 4. Grain size (silty clays), percent calcium carbonate (approximately 30%), and percent organic carbon 0.3%) do not change in the upper Eocene to lower Oligocene section (text-fig. 5). The constancy of these lithologic parameters across this faunal change shows that the exit of the agglutinated assemblages was not caused by a change in substrate.

The presence and relatively constant values of abundant calcium carbonate throughout the middle Eocene to lower Oligocene section does not support the suggestion by Hesse and But (1976) that the dominant factor controlling flysch-type (type A) agglutinated assemblages is deposition below the CCD. With the exception of core 16, which is barren of calcium carbonate and calcareous benthic foraminifera, and possibly the Spiroplectammina spectabilis assemblage, there is no clear correlation between percent carbonate and agglutinated and/or calcareous benthic foraminiferal abundance (text-fig. 5). Despite this, carbonate availability may play a role in the development of predominantly agglutinated foraminiferous assemblages, as the exit in Site 112 correlates with a global drop in the CCD (Heath, 1969; Berger, 1973; van Andel et al., 1975; Kennett and Shackleton, 1976). Nevertheless, factors which caused this drop (see below) may also be related to the faunal change.

Due to diagenetic reduction of the carbon content of
marine sediments (Heath et al., 1977), the absolute carbon values observed in Site 112 may reflect only a portion of the carbon present at the time of deposition. Nevertheless, the constant values of organic carbon associated with the faunal turnover (text-fig. 5) do not support the idea that organic carbon is the dominant control on flysch-type agglutinated foraminiferal assemblages. Although agglutinated foraminifera may be favored in areas of high organic matter, high organic carbon is not a prerequisite for predominantly agglutinated foraminiferal assemblages. This is shown by the presence of exclusively agglutinated foraminiferal assemblages in the present-day deep North Pacific by Saidova (1960) and Bernstein et al. (1978), where carbon values are invariably low (Heath et al., 1977).

The exit of the agglutinated foraminifera and their replacement by a deep-water calcareous assemblage may have resulted from changes in hydrographic properties. The Tertiary climatic record shows that a major period of cooling occurred in the middle Eocene to early Oligocene, and that the greatest temperature drop occurred close to the Eocene/Oligocene boundary (Dorman, 1966; Devereaux, 1967; Savin et al., 1975; Shackleton and Kennett, 1975; Wolfe, 1978; Vergnaud-Graffini et al., 1979). The development of the psychrosphere (the deep, cold water layer of the oceans; Benson, 1975), and the formation of cold bottom water production in the southern ocean (Kennett and Shackleton, 1976) also began near the end of Eocene time. This initiation of cold bottom water resulted in an inferred 4 to 5°C temperature decrease in bottom water temperatures in the southern ocean (Site 277) in the earliest Oligocene time (Kennett and Shackleton, 1976).

In addition to lowering the temperature and supplying more oxygen to bottom waters, a presumed increase in oceanic turnover in the late Eocene to early Oligocene (Kennett and Shackleton, 1976) may have decreased CO₂ and thereby increased pH. This turnover contributed to the lowering of the CCD which is reflected in the deep-sea stratigraphic record as a well-documented increase in preservation of calcium carbonate (Heath, 1969; Berger, 1973; van Andel et al., 1975; Kennett and Shackleton, 1976).

Such changes in hydrography could have eliminated the indigenous agglutinated benthic foraminiferal assemblages and favored the migration of calcareous benthic assemblages to Site 112. Moorjens (1976) and Saidova (1960, 1965) both explain the preponderance of agglutinated foraminifera in abyssal depths by the tolerance of these foraminifera to low oxygen and pH. The modern deep North Pacific, with its low oxygen, high CO₂, and low pH (Sverdrup et al., 1942), and exclusively agglutinated benthic foraminiferal assemblages (Saidova, 1961, 1965, 1970, 1976; Bernstein et al., 1978) may be a modern analog to the Eocene deep Labrador Sea, although carbonate sediments are absent from the former but are present in the Eocene Labrador Sea.

Although the faunal turnover in Site 112 approximately coincides with the formation of the psychrosphere, increased oceanic turnover, and the initiation of southern sources of bottom waters, it is not clear that the only late Eocene to early Oligocene source of low-temperature, high-oxygen bottom water in the Labrador Sea is from the Antarctic region. Despite the contention of some authors (Shor and Poore, 1979; Blanc et al., 1980; Schnitker, 1980a, 1980b) that bottom water from northern sources (i.e. the Arctic, Norwegian-Greenland Sea, or other northern North Atlantic sources including the Labrador Sea) did not form until the early to middle Miocene, seismic evidence from the northern North Atlantic suggests the presence of a northern cold-water source as early as late Eocene.

Johnson and Schneider (1969), Jones et al. (1970), and Ruddiman (1972) have clearly demonstrated that bottom water circulation (predominantly North Atlantic Deep Water, NADW) profoundly influences sedimentation patterns in the northern North Atlantic (north of 45°N). The earliest effect of this deep circulation is in the form of sediment drifts overlying a subhorizontal sedimentary reflector, R4 (Roberts, 1975; = reflector R of Jones et al., 1970). In this region, reflector R4 has been firmly established as pre-late Oligocene by Jones et al. (1970). It has been suggested that reflector R4 is latest Eocene age in the Rockall Plateau and Rockall Trough (Roberts, 1975) and Iceland Basin (Ruddiman, 1972).

In the Labrador Sea near Site 112, reflector R4 lies at 0.41 seconds two-way travel time (Laughton, Berggren et al., 1972). A hard layer encountered in Site 112 in core 10 (upper lower Oligocene) at 315 m subbottom was thought to correspond to this reflector (Laughton, Berggren et al., 1972); however, this correlation is not in agreement with evidence suggested by sediment velocity and changes in grain size. Placing reflector R4 at a depth of 315 m, results in a mean seismic velocity of 1536 m/sec in the drifted sediments. This velocity is considerably lower than that expected for sediments of this thickness. In addition, a grain size change might be expected in the change from pelagic clay to current-controlled deposition. A grain size increase from clays to silty clays and clayey silts occurs between cores 11 and 12 in Site 112 (text-fig. 5), suggesting that a major change in depositional regime occurred in the lower Oligocene section between 333 and 383 m subbottom. Assuming reflector...
BRADOR SHELF AND CENTRAL NORTH SEA AND STRATIGRAPHICAL RANGES OF SELECTED AGGLUTININ

Globospira spp.

Spiroplectammina navarrana Cushman (incl. Textularia plummerae (Lalicker))

Spiroplectammina spectabilis (Grzybowski)

Spiroplectammina dentata (Alth)

Thurammina spp.

Ammobaculites all. polythalamus Loeblich

Cyclus amplexa (Grzybowski)
TEXT-Figure 8
Late Mesozoic-Cenozoic depositional history of Canadian margin and DSDP Sites 111 and 112.

R4 correlates with this change in grain size (text-fig. 5) in Site 112 we obtain a 1625–1875 m/sec mean seismic velocity which is more realistic for sediments of this thickness from this region (cf. typical mean velocities for the upper 300–350 m of sediment from Leg 48 determined from sonic logs of approximately 1750 m/sec; Montadert, Roberts et al., 1979). This correlation of R4 in the Labrador Sea as a lower lower Oligocene reflector separating pelagic from current-controlled deposition suggests that the formation of northern sources of bottom water influenced the Labrador Sea by early Oligocene time.

Within the biostratigraphic limits of error, reflector R4 has been identified as a synchronous reflector in other parts of the northern North Atlantic. The correlation of reflector R4 in this region as latest Eocene to earliest Oligocene (Ruddiman, 1972; Roberts, 1975) suggests that the change in depositional regime associated with reflector R4 occurred throughout the northern North Atlantic at this time (for further discussion, see Miller and Tucholke, in press).

Hiatuses are widespread in the late Eocene to Oligocene sections of the World Ocean, particularly the North Atlantic (Moore et al., 1978). Of the DSDP sites drilled in the northern North Atlantic (Legs 12, 38, 48, 49) only Sites 112 and 116 may be inferred to have continuous deposition across the Eocene/Oligocene boundary (cf. fig. 3 of Shor and Poore, 1979; figs. 3–6 of Miller and Tucholke, in press). Although factors other than bottom water flow influence the development of deep-sea hiatuses (Moore et al., 1978 and references therein), the development of a regional late Eocene to Oligocene hiatus in the northern North Atlantic supports the idea that bottom water formation began in this region at this time.

The change in depositional regime and the inferred initiation of bottom water in the northern North Atlantic approximately coincides with the disappearance of agglutinated assemblages from Site 112. Still, we cannot firmly extrapolate the faunal change to the entire deep southern Labrador Sea, and therefore the possibility exists that the faunal turnover resulted from a local
phenomenon restricted to the immediate environs of Site 112.

The early Oligocene change in depositional regime (between cores 11 and 12) in Site 112 slightly post-dates the exit of the agglutinated foraminiferan assemblages (between cores 12 and 13) by 1–7 my (text-fig. 5). This time lag may be due to the gradual intensification of currents during the middle Eocene to Oligocene due to increased climatic cooling. As bottom water began to form in the middle to late Eocene, hydrographic properties began to change, resulting in the replacement of agglutinated foraminifera in Site 112. By the early Oligocene, bottom currents were sufficiently competent to transport silty sediments into the Labrador Sea. There is, in fact, a slight suggestion that percent calcareous taxa gradually increased and replaced the agglutinated foraminifera in Site 112 in the middle Eocene to Oligocene (text-fig. 5). This scenario would agree with the gradual development of the psychrosphere proposed by Corliss (1979). Unfortunately, due to coring gaps and the uncertainties attached to the relative percentages of calcareous species (text-fig. 6) our data are insufficient to convincingly show a gradual change in benthic foraminifera in Site 112.

CONCLUSIONS

(1) Late Cretaceous to Paleogene predominantly agglutinated foraminifera reported from the deep sea (= flysch-type, type A assemblages) are taxonomically similar to assemblages noted on the Canadian margin, in the North Sea, and in European flysch basins. These assemblages range from bathyhal (hundreds of meters) to abyssal (approximately 4.5 km) paleodepths. Smooth-walled, smaller-sized (< 150 μm) Cretaceous assemblages (= type B assemblages) noted only from abyssal paleodepths are easily differentiated from these type A assemblages.

(2) Comparison of ranges of type A assemblages in Site 112, the Canadian margin, and the North Sea shows that some taxa are biostratigraphically useful (text-fig. 4; table 5).

(3) Although high organic content, deposition below the CCD, and inferred poor circulation are often associated with many type A assemblages, these properties are not necessary for faunal development. Rather, we infer that, at least in the deep sea, hydrographic properties (low oxygen, low pH, high CO₂, and thus more corrosive waters) are critical to the development of the predominantly agglutinated assemblages. Since these properties affect carbonate availability, the development of agglutinated assemblages may co-vary with percent calcium carbonate, although this is not the case in Site 112. In addition, similar conditions may develop in reducing substrates associated with high organic matter and poor circulation. Predominantly agglutinated assemblages are probably favored in such substrates and/or in areas with the given hydrographic properties.

(4) The late Eocene exit of agglutinated foraminifera from Site 112, the Canadian margin, and the North Sea coincides with changes in hydrographic properties associated with the development of a more vigorous abyssal circulation and the psychrosphere. We speculate that the late Eocene to early Oligocene initiation of bottom water formation in the northern North Atlantic and/or Norwegian-Greenland Sea, inferred from sediment distribution patterns, caused the replacement of the agglutinated assemblage in Site 112 by a calcareous assemblage, but that local tectonic and sedimentologic changes may have been important in the elimination of agglutinated assemblages in the Canadian margin and North Sea.

SYSTEMATIC PALEONTOLOGY

Agglutinated foraminifera Site 112

Rare = less than 5 individuals in all samples
Common = 5 to 25 individuals/sample
Abundant = greater than 25 individuals/sample

Order FORAMINIFERIDA Eichwald, 1830
Suborder TEXTULARIINA Delage and Herouard, 1896
Superfamily AMMODISCACEA Reuss, 1862
Family ASTORDEZIADAE Brady, 1881
Subfamily RHIZAMMENAE Rhumbler, 1895

Rhizammina sp.
Plate 1, figure 2


Bathysiphon sp.
Plate 1, figure 1

Remarks: Very fine-grained straight tube with lateral projection similar to Bathysiphon of the North Sea and Canadian margin; may be a central chamber characteristic of the genus Rhambammina. Common.

Bathysiphon sp.


Subfamily HIPPONECINAE Rhumbler, 1895

Hyperammina sp.

Remarks: Initially globular, later as in Rhizammina and Bathysiphon. Rare.
Family SACCAMMINIDAE Brady, 1884
Subfamily SACCAMMINIDAE Brady, 1884

**Saccammina complanata** (Franke)
Plate 1, figure 3
Pelosina complanata FRANKE, 1912, pl. 3, fig. 1—CUSHMAN and JARVIS, 1932, p. 5, pl. 1, figs. 4–6.
Saccammina placenta Grzybowsk,
—GEROCH, 1960, pp. 37–38, pl. 2, figs. 1–6—JURKIEWICZ, 1967, p. 41, pl. 1, fig. 5.—GRADSTEIN and BERGGREN, 1981, pl. 2, fig. 5.
Saccammina complanata (Franke).—ROGL, 1976, pl. 3, figs. 7–8.—KRASHENINNIKOV and PFLAUMANN, 1977, pl. 1, fig. 14.

**Remarks:** Franke illustrated a specimen with a pronounced neck and a disk-shaped depression similar to our specimens. Found only in core 16. Rare.

**Saccammina placenta** (Grzybowsk)
Plate 1, figure 4
Reophax placenta GRZYBOWSKI, 1896, pl. 10, figs. 9–10.
Saccammina placenta (Grzybowsk).—KRASHENINNIKOV and PFLAUMANN, 1977, pl. 1, fig. 16.

**Remarks:** Grzybowsk did not describe the type of aperture but, as he illustrated a specimen with no neck, we assign specimens without a neck to S. placenta and those with a distinct neck to S. complanata. As noted by Krasheninnikov, S. placenta has a thin lip. Found only in cores 13 and 14. Rare.

**Saccammina diffugiformis** (Brady)
Plate 1, figure 5
Reophax diffugiformis BRADY, 1879, pl. 4, fig. 3.

**Remarks:** Vaselike test; may be initial chamber of uniserial form such as “Hormosina” sp. 4. Rare.

Family AMMODISCIDAE Reuss, 1862
Subfamily AMMODISCINAE Reuss, 1862

**Ammodiscus cretaceus** (Reuss)
Plate 1, figure 6
Operculina cretacea REUSS, 1845, p. 25, figs. 64–65.
Ammodiscus cretaceus (Reuss).—FRIZZELL, 1964, p. 58, pl. 1, fig. 15.—KRASHENINNIKOV, 1974, pl. 7, fig. 8.—WEBB, 1975, p. 834, pl. 1, fig. 9.—ROGL, 1976, pl. 2, fig. 22.—GRADSTEIN and BERGGREN, 1981, pl. 2, figs. 12–13.
Ammodiscus cretaceus cretaceus (Reuss).—KRASHENINNIKOV and PFLAUMANN, 1977, pl. 2, fig. 6.

**Remarks:** Large, very fine-grained, numerous whorls (more than 8), tightly coiled test, biconvex in axial view. Common.

**Ammodiscus rugosus** Schijffma (not Terquem)
Plate 1, figure 7
Ammodiscus cretaceus (Reuss) var. rugosa SCHIJFMA, 1946, pl. 6, fig. 2.
Ammodiscus cretaceus rugosus Schijffma.—KRASHENINNIKOV, 1974, pl. 7, fig. 9.—KRASHENINNIKOV and PFLAUMANN, 1977, pl. 2, fig. 6.

**Remarks:** Smaller, coarser grained, more loosely coiled, with a tendency toward irregular coiling, and fewer whorls (2½ to 4) than A. cretaceus.

**Ammodiscus glabrat us** Cushman and Jarvis
Plate 1, figure 8
Ammodiscus glabrat us CUSHMAN and JARVIS, 1926, pl. 12, fig. 6.—KRASHENINNIKOV and PFLAUMANN, 1977, pl. 2, figs. 9–9.

**Remarks:** Small, finer grained than A. rugosus and often coarser grained than A. cretaceus, very slightly concave in axial view, numerous whorls (more than 9). Common.

**Glomospira charoides** (Jones and Parker)
Plate 1, figures 10–11
Trochammina squamata Jones and Parker var. charoides JONES and PARKER, 1960, p. 304.
Ammodiscus charoides (Jones and Parker).—GRZYBOWSKI, 1896, figs. 39–43.
Glomospira charoides (Jones and Parker).—BARKER, 1960, pl. 2, figs. 6–10.—GEROCH, 1960, pp. 46–47, pl. 4, figs. 1, 2, 5.—JURKIEWICZ, 1967, pp. 58–59, text-fig. 7, pl. 2, figs. 16–17.—WEBB, 1975, pl. 1, figs. 13–14.—ROGL, 1976, pl. 2, figs. 26–27.—GRADSTEIN and BERGGREN, 1981, pl. 3, figs. 5–7.
Glomospira charoides (Jones and Parker) var. corona CUSMAN and JARVIS, 1926, pl. 8, pl. 12, figs. 9–11—1932, pl. 10, pl. 2, figs. 8–10.
Glomospira corona (Cushman and Jarvis).—KRASHENINNIKOV, 1974, pl. 7, fig. 5.—KRASHENINNIKOV and PFLAUMANN, 1977, pl. 2, fig. 2.


**Glomospira gordialis** (Jones and Parker)
Plate 1, figures 14–15
Trochammina squamata Jones and Parker var. gordialis JONES and PARKER, 1960, p. 304.
Ammodiscus gordialis (Jones and Parker).—GRZYBOWSKI, 1896, figs. 44–45.
Glomospira gordialis (Jones and Parker).—BARKER, 1960, pl. 38, figs. 7–9.—GEROCH, 1960, pp. 46–47, pl. 4, figs. 1, 2, 5.—JURKIEWICZ, 1967, pp. 59–60, text-fig. 8, pl. 2, fig. 23.—WEBB, 1975, pl. 1, fig. 12.—ROGL, 1976, pl. 2, fig. 28.—GRADSTEIN and BERGGREN, 1981, pl. 3, figs. 2–3.

**Remarks:** More irregularly coiled than G. charoides. Common.

**Glomospira irregularis** (Grzybowsk)
Plate 1, figure 12
Ammodiscus irregularis GRZYBOWSKI, 1898, pl. 11, figs. 2–3.
Glomospira irregularis (Grzybowsk).—GEROCH, 1960, pp. 47–48, pl. 4, figs. 9–10.—JURKIEWICZ, 1967, pp. 61–62, text-fig. 9, pl. 2, figs. 18–19.—ROGL, 1976, pl. 3, fig. 12.—GRADSTEIN and BERGGREN, in press, pl. 3, figs. 1–4.

**Remarks:** Irregularly coiled. Common.
**Gloosia spinosa** (Grzybowski)
Plate 1, figure 13

Ammolitiscus serpens GRZYBOWSKI, 1898, pl. 10, figs. 31–33.
Gloosia spinosa (Grzybowski).—GEROCH, 1960, pp. 47–48, pl. 4, fig. 13.—JURKIEWICZ, 1967, pp. 61–62, pl. 2, figs. 24–27.—WEBB, 1975, pl. 1, fig. 15.

**Remarks:** Oval, slightly irregularly coiling. Found only in cores 13 and 14. Rare.

**Gloosia spinulosa** sp.
Plate 1, figures 16–17

**Remarks:** Initial coil as in *G. irregularis*, later as in *Ammodiscus*. Common.

Subfamily TOLYMPAMMINAEE Cushman, 1928

**Ammolitiscus clavata** (Jones and Parker)
Plate 1, figure 9

**Remarks:** Bulbous test with elongate tubular neck found attached to *Ammodiscus cretaceus*. Rare.

Superfamily LITUOLACEAE de Blainville, 1825
Family HORMOSINIDAE Heeckel, 1894
Subfamily HORMOSININAE Heeckel, 1894

**Hormosina ovulum** (Grzybowski)
Plate 1, figure 20

**Remarks:** Found only as single chambers. Rare.

**Hormosina globulifera** Brady Plate 1, figure 19

**Remarks:** Common.

**Hormosina sp. 3**
Plate 1, figure 21

**Remarks:** Fine-grained, smaller-sized tests. Occur predominantly as multi-chambered individuals. Common.

**Remarks:** Found only as single chambers, and therefore may belong to the genus *Pelosina*. One or both “apertures” are often jagged, suggesting that whole individuals are uniserial. We assign these oval-chambered individuals to *Hormosina*. Common.

**Reophax pilularis** Brady Plate 1, figure 22

**Remarks:** Only flattened specimens found. Rare.

**Reophax nodulosus** Brady Plate 1, figure 23

**Remarks:** Rare.

**Spixosomolinella compressa** Matsunaga Plate 2, figure 5

**Remarks:** First described from the middle Miocene of Japan, occurs in the late middle to late Eocene of site 112 and the later Eocene of the North Sea associated with *Cyclammina amplicenst*. Noted by Gradstein and Berggren (1981) as “Rzehakins” sp. 1. Evolute test is insoluble in HCl and lacks a tooth; it is therefore distinct from *R. epigona*. Rare.

Family LITUOLIDAE de Blainville, 1825
Subfamily HAPLOPHRAGMOIDINAE Maync, 1952

**Haplophragmoides eggeri** Cushman Plate 2, figure 6

**Remarks:** Small, 5½ to 6½ chambers in last whorl. Fine-grained, smooth-walled as opposed to Cushman’s coarser-grained specimens. The interior of some specimens appears to be complex, and thus may be referred to *Aveolophragmium*. Occurs only in core 16. Common.

**Haplophragmoides walkerii** (Grzybowski)
Plate 2, figure 7

**Remarks:** Only flattened specimens found. Rare.
"Haplophragmoides" sp.  
Plate 2, figure 8

Remarks: This species is similar to *H. eggeri*, except for more rounded chambers, incised sutures, and a tendency toward trochosiral (as in *Trochammina*) development. Common.

"Cribrostomoides" subglobosus (Sars)  
Plate 2, figure 9

Alveolophragmium subglobosum (*G. Sars*).—Barker, 1980, p. 34, figs. 7, 8, 10.  
Cribrostomoides subglobosus (*G. Sars*).—LEROY and HODGKINSON, 1975, p. 432, pl. 4, figs. 2–4.—ROGL, 1976, pl. 4, fig. 21.  
Haplophragmoides subglobularis (Grzybowski).—GEROCH, 1960, pl. 5, fig. 1.—JURKIEWICZ, 1967, p. 77, pl. 4, figs. 12–13.—WEBB, 1975, p. 834, pl. 2, figs. 8–9.  
"Cribrostomoides" subglobosus (*G. Sars*).—GRADSTEIN and BERGGREN, 1981, pl. 6, figs. 10–11.

Remarks: Ranges from flaring to narrow final chamber. Latter specimens approach *C. scitulus* (Brady) of Gradstein and Berggren (1981) and Barker (1960) in axial view but are more like *C. subglobosus* in plane view. Included here are specimens with and without visible aperture slit. Common.

Paratrochamnoides sp.  
Plate 2, figure 10

Remarks: Large, irregularly coiled tests. Sutures may be poorly developed, therefore, some specimens are difficult to differentiate from *Glomospira irregularis*. Rare.

Recurvoides walteri (Grzybowski)  
Plate 2, figure 11

Haplophragmoides walteri *GRZYSKOWSKI*, 1898, pl. 10, fig. 24.  
Recurvoides walteri (Grzybowski).—JURKIEWICZ, 1967, p. 78, pl. 4, fig. 14.  
Thalmanammina walteri (Grzybowski).—HANZLIKOVÁ, 1972, p. 44, pl. 7, fig. 6.  
Recurvoides ex. gr. walteri (Grzybowski).—GRADSTEIN and BERGGREN, 1981, pl. 8, figs. 1–7.

Remarks: In poorly preserved specimens, this streptospirally coiled species may be difficult to differentiate from *Cribrostomoides subglobosus*. Occurs only in cores 15 and 14-CC (*Cribrostomoides-Recurvoides* assemblage). Common.

Trochamnoides sp.  
Plate 2, figure 18

Remarks: Planispiral, multi-chambered (greater than 10 chambers in last whorl), partially evolute form. Probably equivalent to *T. subtrullissatus* (Grzybowski).

Labiospira pacifica Krasheninnikov  
Labiospira pacifica KRASHEINNIKOV, 1973, pl. 2, figs. 4–5; 1974, p. 638, pl. 3, figs. 1–2.

Remarks: One individual noted in core 16.

Subfamily CYCLAMMININAEC Marie, 1941

*Cyclammina amplexaents* Grzybowski  
Plate 2, figure 16

*Cyclammina amplexaents* GRZYSKOWSKI, 1898, pl. 12, figs. 1–3.—MUYLAERT, 1966, p. 128, pl. 40, figs. 15–16.—JURKIEWICZ, 1967, pp. 82–85, pl. 10, fig. 10, text-fig. 17.—MJATLIUK, 1970, pp. 90–91, pl. 21, figs. 5, 11, 12; pl. 25, figs. 4–6; pl. 28, figs. 2–3.—GRADSTEIN and BERGGREN, 1981, pl. 7, figs. 13–17.

Remarks: Found in the middle to late Eocene in Site 112. Common.

*Cyclammina trullissata* Brady  
Plate 2, figures 14–15

Trochammina trullissata *BRADY*, 1879, pl. 5, fig. 10.  
*Cyclammina bradyi* CUSHMAN, 1910, fig. 174.  
*Cyclammina trullissata* (Brady).—PARKER, 1952, p. 400.—BARKER, 1960, pl. 40, fig. 13.

Remarks: Fewer chambers (approximately 9) in last whorl than in *C. amplexaents*, axial periphery more pinched, chambers more incised. Rare.

Family TROCHAMMINIDAE Schwager, 1877  
Subfamily TROCHAMMININAE Schwager, 1877

*Trochamminida globigeriniformis* (Parker and Jones)  
Plate 2, figure 19

Litula nautiloida Lamark var. globigeriniformis PARKER and JONES, 1865, p. 407, pl. 15, figs. 46–47; pl. 17, figs. 96–99.  
Trochammina globigeriniformis (Parker and Jones).—CUSHMAN, 1946, p. 51, pl. 15, figs. 8, 10, 11.—JURKIEWICZ, 1967, p. 92, pl. 6, fig. 13.—HILDEBRAND, 1972, pp. 643–652.—GRADSTEIN and BERGGREN, 1981, pl. 8, fig. 13.

Remarks: This globigeriniform agglutinated species varies from quadrate with an umbilical aperture and a higher spire similar to *T. globigeriniformis* var. *altiformis* Cushman and Renz to a low-spired form with an umbilical-extraumbilical aperture as illustrated in plate 2, figure 19. Typically 8½ chambers in final whorl. Restricted to core 16. Common.

Trochammina sp.  
Plate 2, figure 12

Remarks: Distinguishable from *Trochamnoides* sp. by greater number of chambers (greater than 10) in the last whorl and trochosiral development.

*Cystammina globigerinaeformis* (Krasheininnikov)  
Plate 2, figures 13, 17, 21

Praecystammina globigerinaeformis KRAshENINNIKOV, 1973, p. 211, pl. 2, figs. 1–2; 1974, p. 641, pl. 6, figs. 1–3.—GRADSTEIN and BERGGREN, in press, figs. 11–15.

Remarks: This streptospiral, globigeriniform agglutinated species is characterized by its distinct, narrow areal aperture with prominent lip. Common.
Family TEXTULARIIDAE Ehrenberg, 1838
Subfamily SPIROPECTAMMINIDAE Cushman, 1927

**Spiropectamminia cubensis** (Cushman and Bermudez) Plate 2, figure 1

**Spiropectoides cubensis** CUSHMAN AND BERMUDEZ, 1937, pl. 1, figs. 44–46.

**Bolivinopsis cubensis** (Cushman and Bermudez) — DOUGLAS, 1973, pl. 3, fig. 5.

**Remarks:** Two initial planispiral whorls; later biserial portion has a tendency to flare slightly. Rare.

**Spiropectamminia spectabilis** (Grzybowski) Plate 2, figures 2–3

**Spiropecta spectabilis** GRZYBOWSKI, 1898, pl. 12, fig. 12.

**Bolivinopsis spectabilis** (Grzybowski). — HANZLIKOVA, 1972, p. 48, pl. 10, fig. 8.— WEBB, 1975, pl. 3, figs. 1–3.— ROGL, 1976, pl. 3, figs. 23–25.

**Spiropectamminia spectabilis** (Grzybowski). — HILTERMANN, 1972, pp. 43–61, pl. 1–2.— JURKIEWICZ, 1967, pp. 89–90, text-fig. 15, pl. 5, figs. 12, 15. — GRADSTEIN and BERGGREN, in press, pl. 5, fig. 1–5.

**Remarks:** Narrower cross section than Maastrichtian to Paleocene forms in the North Sea and Canadian margin. Both megalospheric and microspheric forms noted. Ranges throughout the Eocene. Abundant.

Family ATAXOPHRAGMIDAE Schweiger, 1877
Subfamily GLOBOTEXTULARIIDAE Cushman, 1927

**Dorothia** sp.

**Remarks:** Rapidly inflating chambers. Rare.

Subfamily VALUVINIDAE Berthelin, 1880

**Martinottielia** sp.
Plate 2, figure 4

**Remarks:** Uniserial portion not always preserved. Common.

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PLATE 1

"Simple" agglutinated foraminifera
Astorhizidae, Saccaminidae, Ammodiscidae and Hormosinidae

1 ?Bathysiphon sp.
Sample 14-2, 102–113 cm, × 30.

2 Rhizammina sp.
Sample 15-CC, × 40.

3 Saccammina compleana (Franke)
Sample 16-1, 107–111 cm, × 112.

4 Saccammina placenta (Grzybowski)
Sample 14-2, 102–113 cm, × 74.

5 Saccammina diffugiformis (Brady)
Sample 16-1, 46–49 cm, × 93.

6 Ammodiscus cretaceus (Reuss)
Sample 15-CC, × 42.

7 Ammodiscus rugosus Schijfsma (not Terquem)
Sample 13-CC, × 93.

8 Ammodiscus glabratust Cushman and Jarvis
Sample 16-1, 78–84 cm, × 88.

9 Ammolagenia clava (Jones and Parker)
Sample 14-3, 141–144 cm, × 42.

10–11 Glomospira charoides (Jones and Parker)
10, sample 16-1, 78–84 cm, × 200; 11, sample 16-1, 46–49 cm, × 163.

12 Glomospira irregularis (Grzybowski)
Sample 16-1, 78–84 cm, × 70.

13 Glomospira serpens (Grzybowski)
Sample 14-CC, × 47.

14–15 Glomospira gordialis (Jones and Parker)
14, sample 16-1, 46–49 cm, × 151; 15, sample 16-1, 78–84 cm, × 153.

16–17 Glomospirella sp.
16, sample 16-1, 46–49 cm, × 130; 17, sample 16-1, 46–49 cm, × 128.

18 "Hormosina" sp. 4
Sample 16-1, 46–49 cm, × 70.

19 Hormosina globulifera Brady
Sample 14-2, 102–113 cm, × 53.

20 Hormosina ovulum (Grzybowski)
Sample 16-1, 46–49 cm, × 93.

21 Hormosina sp. 3
Sample 16-1, 107–111 cm, × 47.

22 Reophax piilinea Brady
Sample 14-2, 102–113 cm, × 47.

23 Reophax nodulus Brady
Sample 15-1, 12–25 cm, × 27.


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PLATE 2

"Complex" agglutinated foraminifera, Site 112

Litulidae, Trochamminidae, Textulariidae and Ataxophragmiidae

1 Spiroplectamina cubensis (Cushman and Bermudez)
   Sample 14-3, 141–144 cm, × 116.

2–3 Spiroplectamina spectabilis (Grzybowski)
   2, sample 16-1, 78–84 cm, × 37; 3, sample 13-5, 146–149 cm, × 37.

4 Martinottiella sp.
   Sample 14-CC, × 98.

5 Spirosigmoilinella compressa Matsunaga
   Sample 13-2, 107–117 cm, × 88.

6 Haplophragmoides eggeri Cushman
   Sample 16-1, 46–49 cm, × 130.

7 Haplophragmoides walteri (Grzybowski)
   Sample 16-1, 78–84 cm, × 112.

8 "Haplophragmoides" sp.
   Sample 16-1, 46–49 cm, × 56.

9 "Cribrostomoides" subglobosus (G. Sars)
   Sample 14-CC, × 70.

10 Paratrochamminoides sp.
   Sample 16-1, 78–84 cm, × 70.


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PLATE 3
Calcareous foraminifera, Site 112

1 Pleurostomella sp.  
Sample 13-4, 86–96 cm, × 44.

2 Stilostomella aculeata (Cushman and Jarvis)  
Sample 15-CC, × 37.

3 Stilostomella sp.  
Sample 14-3, 141–144 cm, × 140.

4 Dentiliina sp.  
Sample 12-1, 100–102 cm, × 34.

5 Gyroidina sp.  
Sample 14-CC, × 120.

6 Nuttallides truempyi Nuttall  
Sample 14-3, × 242.

7 Pullenia quinquela (Reuss)  
Sample 14-3, 141–144 cm, × 140.

8 Pullenia eocenica Cushman and Siegfuß  
Sample 14-CC, × 140.

9 Globobulimina sp.  
Sample 13-CC, × 74.

10 Abalama sp.  
Sample 14-3, 141–144 cm, × 237.

11–12 Pseudohastigerina wilcoxensis (Cushman and Ponton)  
11, sample 15-CC, × 191; 12, sample 13-5, 146–149 cm, × 195.

13 Acarinina bulbrooki (Boll.)  
Sample 15-CC, × 233.

14–15 Subbotina linaperta Finlay  

16 Subbotina frontosa Subbotina  
Sample 15-CC, × 126.

17–18 Dentoglobigerina galavis (Bermudez)  
17, sample 14-2, 102–113 cm, × 116; 18, sample 14-2, 102–113 cm, × 177.

19 Catapsydrax unicus Bolli  
Sample 14-2, 144–146 cm, × 149.

20 Catapsydrax perus (Todd)  
Sample 15-1, 12–25 cm, × 153.

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