CENOZOIC DEEP-WATER AGGLUTINATED FORAMINIFERA IN THE NORTH ATLANTIC

by

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SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and the
WOODS HOLE OCEANOGRAPHIC INSTITUTION

DECEMBER 4, 1987

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"I am rather inclined to think that in Paleozoic times... the ocean then had a nearly uniform high temperature and that life was then either absent or represented by bacteria and other low forms at great depths. From many considerations, one is led to suggest that cooling at the poles commenced in early Mesozoic times, that cold water, decending then in polar areas, slowly filled the greater depths, and by carrying down a more abundant supply of oxygen, life in water deeper than the mudline became possible; subsequently migrations [of deep taxa] gradually took place from the mudline into deep regions of the ocean basins."

- Sir John Murray, 1895

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Michael A. Kaminski

Submitted to the Joint Committee for Marine Geology and Geophysics at the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology on November 12, 1987 in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Oceanography.

ABSTRACT

Cenozoic (predominantly Paleogene) "flysch-type" agglutinated foraminiferal assemblages and their modern analogs in the North Atlantic and adjacent areas have been studied to provide an overview of their spatial and temporal distribution and utility for paleoenvironmental analysis. Over 200 species of agglutinated foraminifera have been recognized in Paleogene sediments from North Atlantic and Tethyan basins. This unified taxonomic data base enables the first general synthesis of biostratigraphic, paleobiogeographic and paleobathymetric patterns in flysch-type agglutinated assemblages from upper Cretaceous to Neogene sediments in the North Atlantic. The majority of taxa are cosmopolitan, but latitudinal, temporal and depth-related trends in diversity and species composition are observed among flysch-type assemblages.

Modern deep-sea agglutinated foraminiferal faunas provide an analog to fossil flysch-type assemblages and serve as models for paleoecologic studies. Core-top samples from the Panama Basin, Gulf of Mexico and Nova Scotian continental rise were examined in order to determine the habitats of modern species of agglutinated foraminifera. The ecology of modern taxa provides constraints on the paleoenvironmental significance of fossil agglutinated assemblages in the North Atlantic, and their utility for paleoceanography.

Towards this end, spade core samples from a 3912 m deep station in the Panama Basin were studied to determine abundance and microhabitat partitioning among living agglutinated foraminiferal populations and the preservation of dead assemblages. The genera Dendrophrya, Cribrostomoides and Ammodiscus have epifaunal habitats and the genus Reophax is predominantly infaunal. Species of Reophax are probably responsible for fine reticulate burrows observed in x-radiographs. An experiment using recolonization trays in the Panama Basin was designed to identify opportunistic species of benthic foraminifera, and to assess the rate at which a population can colonize an abiotic substrate. The most successful colonizer at this site is Reophax, while Dendrophrya displays the lowest capability for dispersal. After nine months the abundance of living individuals in sediment trays was one-tenth to one-third that of background abundance, but the faunal diversity did not differ greatly from control samples. Recolonization by benthic foraminifera is more rapid than among macrofaunal invertebrates.

Modern agglutinated assemblages from the Louisiana continental slope were examined to determine changes in species composition associated with hydrocarbon seeps. Organic-rich substrates are characterized by a decrease in astrorhizids and an increase in trochamminids and textulariids. Highly organic-enriched substrates with chemosynthetic macrofauna are dominated by *Trochammina glabra* and *Glomospira charoides*.

The biostratigraphy of fossil agglutinated foraminifera in the North Atlantic is based on detailed analysis of 670 samples from 14 wells and one outcrop section, and examination of additional picked faunal slides from industry wells. Local biostratigraphic schemes are established for Trinidad, Northern Spain, the Labrador Sea, Baffin Bay, and the Norwegian-Greenland Sea. These schemes are compared with existing biostratigraphic frameworks from the Labrador Margin, the North Sea, and the Polish Carpathians. A number of species show utility for biostratigraphy in the North Atlantic. Lineages which contain stratigraphically useful species include the *Haplophragmoides* cf. *glabra* - *Reticulophragmium* group, *Hormosina*, and *Karreriella*.

Significant faunal turnovers are observed at the Paleocene/Eocene, Ypresian/Lutetian and Eocene/Oligocene boundaries. A reduction in diversity occurs at the Paleocene/Eocene boundary in all bathyal sections studied, and agglutinated forminifera disappear entirely from abyssal low-latitude DSDP sites. In the Gibraltar Arch, the Labrador Sea and the Norwegian-Greenland Sea, the Ypresian/Lutetian boundary is characterized by a *Glomospira*-facies. This is attributed to a rise in the lysocline associated with increased paleoproductivity and the NP14 sealevel lowstand. The Eocene/Oligocene boundary is delimited by another major turnover and the last occurrence of a number of important taxa. At Site 647, where recovery across the Eocene/Oligocene boundary was continuous, the change from an Eocene agglutinated assemblage to a predominantly calcareous assemblage in the early Oligocene took place gradually, over a period of about 4 m.y. The rate of change of the faunal turnover accelerated near the boundary. This faunal turnover is attributed to changes in the preservation of agglutinated foraminifera, since delicate species disappeared first. Increasingly poorer preservation of agglutinated foraminifera in the late Eocene to earliest Oligocene reflected the first appearance of cool, nutrient-poor deep water in the southern Labrador Sea. The approximately coeval disappearance of agglutinated assemblages along the Labrador Margin was caused by a regional trend from slope to shelf environments, accentuated by the "mid"-Oligocene sealevel lowstand.

Paleobiogeographic patterns in flysch-type foraminifera were examined in the Paleogene of the North Atlantic. In the early Paleogene, general decrease in diversity is observed from low to high latitudes and from the continental slope to the deep ocean basins. The diversity of these microfossils declines in most studied sections throughout the Paleogene. The last common occurrence (LCO) of flysch-type foraminifera in the North Atlantic exhibits a pattern of diachrony with latitude and depth. Extinctions occurred first at abyssal depths and at low latitudes. Agglutinated assemblages disappeared from the northern Atlantic region in the early Oligocene. However, the deep Norwegian-Greenland Sea served as a refuge for many species, and agglutinated assemblages persisted there until the early Pliocene. The LCO of flysch-type foraminifera may have been related to the transition from a warm, sluggish deep sea environment to a cooler, more oxygenated, thermohaline-driven deep circulation pattern caused by bipolar cooling.

The paleobathymetry of Paleogene agglutinated assemblages in the North Atlantic differs from Cretaceous patterns. Shallow-water assemblages of Paleogene age contain robust astrorhizids, loftusiids and coarse lituolids, whereas deep assemblages possess delicate tubular forms, ammodiscids, and smooth lituolids. At low latitudes, upper bathyal assemblages contain abundant calcareous ataxophragmiids. Paleocene paleobathymetric patterns in the North Atlantic compare well with patterns observed in the Carpathian troughs.

The utility of agglutinated foraminifera in paleoceanography is illustrated by a study of the paleocommunity structure of fossil assemblages in ODP Hole 646B on the Eirik Ridge (Labrador Sea). The synecology of benthic foraminifera in Hole 646B places constraints on the history of Denmark Straits Overflow Water over that site. Below seismic horizon "R3", a Miocene assemblage contains smooth agglutinated species with abundant Nuttalides umbonifera, indicating corrosive bottom water and tranquil conditions. A coarse agglutinated assemblage with "NADW-type" calcareous benthics is observed above the seismic horizon. This faunal turnover at horizon "R3" reflects the onset (or renewal) of significant Denmark Straits overflow at ~7.5 Ma. Agglutinated species disappear between reflector "R2", and the base of the sediment drift, indicating a change in deep-water properties associated with the re-opening of the Mediterranean. The onset of drift sedimentation at the Eirik Ridge is dated at ~4.5 Ma. Drift formation ceased at ~2.5 Ma, concomitant with the appearance of ice-rafted sediments.

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PREFACE:

In September of 1981, a small group of specialists gathered together in Amsterdam at what became known as the First International Workshop on Agglutinated Foraminifera (IWAF). The purpose of the meeting was to attempt to synthesize the current state of research on the subject of fossil and living agglutinated foraminifera from shallow- and deep-water environments. In the decade preceding this workshop, deep-water agglutinated foraminiferal faunas had been discovered in economically important areas of the North Atlantic, as well as at a number of DSDP sites. These developments sparked renewed interest in these microfossils for biostratigraphic and paleoenvironmental analyses. Unfortunately, knowledge of the taxonomy, stratigraphy, and paleoecology of deep-water agglutinated foraminifera was still at a rudimentary stage. Many of the classic type specimen collections were virtually inaccessible, and the classic localities in alpine regions had little to offer in the way of continuous, well-dated sections. The paleoecologic implications of these agglutinated assemblages were not well understood, owing to a lack of basic information on the distribution and ecology of their modern analogs. At the very least, the first IWAF meeting in Amsterdam shed light on where the gaps in our understanding lay, and where future research efforts needed to be focused in order to improve our knowledge of agglutinated foraminifera.

In the five intervening years between the Amsterdam meeting and the 2nd IWAF in Vienna, a number of pioneering studies were published by some of the original participants which quickly became classic references. Biostratigraphic and taxonomic information on deep-water agglutinated foraminifera became available from high-latitude sedimentary basins such as the North Sea, Norwegian-Greenland Sea, Labrador Sea, Beaufort Sea, as well as from the classic localities in the Carpathians and Alps. Now there exists a need to expand the available data base to include additional basins and to develop a general synopsis of the taxonomy and distribution of these microfossils on an ocean-wide scale.

This thesis is a direct outgrowth of that first meeting in Amsterdam. As part of a long-term project to improve our understanding of the taxonomy, stratigraphy and paleoecology of Cenozoic deep-water foraminifera carried out by W.A. Berggren and colleagues at the Woods Hole Oceanographic Institution, I have undertaken a number of related studies on agglutinated foraminifera to help fill some of the gaps in our knowledge of this group of organisms. My earlier studies (M.Sc.) with Prof. Stan Geroch at the Jagiellonian University on the classic Grzybowski Collection of agglutinated foraminifera from the Carpathians provided valuable experience and training. The close and continuing cooperation with Dr. Felix Gradstein, who had obtained material from the classic type localities and was instrumental in planning deep drilling in the Labrador Sea, has resulted in a plethora of new and exciting data on the stratigraphy and paleoecology of agglutinated foraminifera. Cooperative studies at the HEBBLE Site, and continuing cooperation with Drs. Fred Grassle and C. Wiley Poag have provided me with unique opportunities to examine unexplored aspects of the ecology of modern agglutinated faunas, and to use these findings to help interpret the fossil record.

This study synthesizes the results of my research on living and fossil deep-water agglutinated foraminifera, mostly in the North Atlantic and in the Panama Basin. Chapter 2 discusses the major results of experiments and observations carried out on living agglutinated foraminifera, and an application of the ecologic information gained in this study to the fossil record. Section A of Chapter 2 has been accepted for publication in the Proceedings of the Second International Workshop on Agglutinated Foraminifera and is referenced throughout this volume as Kaminski et al. (in press, a). Section C of Chapter 2 is extracted from a study accepted for publication in the Proc. Init. Repts. ODP, Leg 105, and is referenced as Kaminski et al., (in press, c). The reader should refer to the pre-print for additional information about Site 646. The third, fourth and fifth chapters, respectively present the taxonomic, stratigraphic, and paleoecologic results of studies on fossil assemblages from Atlantic margin basins and Deep Sea Drilling Project/Ocean Drilling Program sites carried out under the auspices of the Deep-Water Benthic Foram Project. Stratigraphic and paleoecologic results from Trinidad are synthesized from a study that has been accepted for publication in the Proceedings of the Second International Workshop on Agglutinated Foraminifera which is referenced as Kaminski et al. (in press, b). Sections dealing with the biostratigraphy of the Labrador Sea have been extracted from a study which has been submitted for publication in the Proc. Init. Repts. ODP, Leg 105, referenced as Kaminski et al., (in press, d). The reader should refer to the respective pre-prints for additional information about these localities. This synthesis is dedicated to all the "sand boys" from Amsterdam and Vienna whose diverse scientific efforts have stimulated my interest in this group of organisms.

ACKNOWLEDGEMENTS:

Many of topics elaborated upon in this thesis have grown out of my contacts and discussions over the past five years with many individuals who have left indelible marks on the development of this work. I am especially grateful for the support and guidance given me by my thesis advisors Bill Berggren and Felix Gradstein, and the advice and encouragement provided by my thesis committee: Bill Berggren, Ed Boyle, Felix Gradstein, Fred Grassle, Ken Miller and Brian Tucholke, and everyone in the WHOI Education Office. Special thanks go to Bill Berggren, Anne S. Edwards, Lloyd Keigwin, Ken Miller, Bruce Corliss, A. Lawrence "Jake" Peirson, Dave Johnson and Charlie Hollister for all the practical advice given me during my first years in the Joint Program.

I am grateful to Bill Berggren, James M. Brooks, Stan Geroch, Felix Gradstein, Fred Grassle, Axel von Hillebrandt, Garry Jones, Robert D. Liska, Wolfgang Kuhnt, Ken Miller, Enrica Morlotti, C. Wiley Poag, John Van Couvering, and the Ocean Drilling Program for providing me with sample material from different parts of the world. I would also like to express my gratitude to the Captain and crew of the JOIDES Resolution, the R/V Knorr, the R/V Atlantis II and the submersible "Alvin", and the Johnson Sea Link. I also wish to thank Bob Commeau, Kathy MacKinnon, Amy Pallant, Frank Thomas, and UNOCAL Science & Technology Division for assistance with the sample preparation. Kozo Takahashi, Dave Lazarus, and my wife Danuta helped me with technical aspects of the study. Martin Buzas and Suzan Richardson provided much appreciated assistance during my work with the Cushman Collection. John Van Couvering provided access to collections at the American Museum of Natural History.

Various aspects of this study have benefited greatly from valuable discussions with Mike Arthur, Jack Baldauf, Jean-Pierre Beckmann, Martin Buzas, Brad Clement, Tony Charletta, Bob Commeau, Bruce Corliss, Leonard Ford, Stan Geroch, Bob Goll, Al Grant, Martin J. Head, Heinrich Hiltermann, Dave Johnson, Garry D. Jones, Bob W. Jones, John Firth, Charlie Hollister, Lloyd Keigwin, Wolfgang Kuhnt, Dave Lazarus, Robert D. Liska, Mark Leckie, Nick McCave, Dave McNeil, Linda Morse-Porteus, Jeno Nagy, Barbara Olszewska, Lisa Ostermann, C. Wiley Poag, Suzan Richardson, Fred Rogl, Howard Sanders, Charlie Schafer, Detmar Schnitker, Claudia Schroder, Dave Scott, Craig Smith, Ruetiger Stein, Shiri Srivastava, Leonard Tjalsma, Jim Weinberg, Eileen Williams, Jim Zachos and Herman Zimmerman. I am especially grateful to all of my co-authors for tolerating my writing style and self-imposed deadlines. I owe a special debt of gratitude to Garry Jones for his meticulous review of this thesis and all of the associated pre-prints.

Last but not least, I would like to thank my wife Danuta, my parents Michael and Vernita, and Helen and Michael Peters for their moral and logistic support throughout the course of my graduate studies.

Financial support for this study was provided through grants from the Ocean Drilling Program, the Texas A&M Research Foundation/US Scientific Program (1892-B05), the National Science Foundation through grants OCE-82-17586 to J.F. Grassle and OCE 82-17413 to R.B. Whitlatch, the Geological Society of America (86-3599), the WHOI Education Office, and the Margaret M. Patterson Memorial Scholarship Fund. The Dean's Office of the Jagiellonian University provided support during my work with the Grzybowski Collection.

This is a contribution of the Deep-Water Benthic Foram Project, which is conducted by W.A. Berggren and colleagues at the Woods Hole Oceanographic Institution and is sponsored by a consortium of oil companies (ARCO, B.P., Chevron-Gulf, Elf-Aquitane, Exxon, Mobil, Phillips, Shell International, Shell USA, SOHIO, Texaco, and UNOCAL).

CHAPTER 1

GENERAL INTRODUCTION:

Most studies of Cenozoic biostratigraphy and paleoceanography to date have primarily utilized calcareous planktonic and benthic microfossil groups. Unfortunately, in high-latitude basins in the North Atlantic and on the abyssal plains where pelitic sedimentation dominates, the stratigraphic record of calcareous microfossils is often poor and incomplete. In intervals where these microfossils are present, low species diversity usually renders this group useless for detailed study. Therefore the conventional tools of stratigraphy and paleoceanography - stable isotopes and studies of calcareous plankton assemblages - are inadequate in these areas. Instead, the micropaleontologist must use noncalcareous plankton (palynomorphs, diatoms, radiolarians, silicoflagellates) and benthos as stratigraphic and paleoceanographic tools. This thesis focuses attention on a ubiquitous, yet poorly documented group of noncalcareous benthic foraminifera which has demonstrated utility in petroleum-bearing basins such as the North Sea and southern Labrador Sea.

The only group of foraminifera with a relatively complete stratigraphic record in these basins are the Textulariida, or agglutinated foraminifera. This group possesses a long stratigraphic record and is among the most diverse groups of microfossils in high latitudes. Agglutinated foraminifera are also common components of lower Cenozoic benthic foraminiferal assemblages in areas where the rapid deposition of fine-grained clastic sediments result in a benthic environment unfavorable to the preservation of calcareous foraminifera. These microfossils have been used for stratigraphic purposes in economically important sedimentary basins since the late 19th Century (Grzybowski, 1898). In the 1970's, the discovery of diverse flysch-type assemblages in offshore wells on continental margins and DSDP Sites in North Atlantic basins led to special taxonomic and paleoecological studies of these organisms.

Some of the early studies of flysch-type agglutinated foraminiferal assemblages from pelitic intervals of flysch sediments (Brouwer, 1965, Gradstein and Berggren, 1981) and from DSDP Sites throughout the world (Miller _et al_. 1982) have revealed the cosmopolitan nature of many deep-water agglutinated species. At present count, over 200 species of agglutinated foraminifera have been recorded from Paleogene sediments in North Atlantic and

Tethyan basins, but the stratigraphic and paleobiogeographic distribution of these organisms is still poorly documented in the available literature. The utility of agglutinated foraminifera for interregional studies is limited at present by the lack of a standardized taxonomic nomenclature and a standard biochronology. No single study has attempted to synthesize the distribution of these organisms in the North Atlantic. A major goal of this thesis is to examine Paleogene flysch-type assemblages to determine their biostratigraphy in a number of well-dated reference sections, and to recognize first-order patterns in diversity and the distribution of important genera along latitudinal and paleodepth gradients. By documenting major distributional patterns of these organisms in the North Atlantic, I seek to improve the utility of this group for biostratigraphy, paleoecology and deep-water paleoceanography.

In general, two main types of flysch-type assemblages can be distinguished which probably reflect faunistic trends (Gradstein and Berggren, 1981). The "type-A" assemblage is comprised of large, coarsely agglutinated simple forms, and corresponds to the Rhabdammina-fauna of Brouwer (1965). This assemblage is found in slope basins and in rapidly subsiding troughs where restricted bottom water circulation leads to oxygen-deficient substrates that may limit the occurrence of normal marine taxa and favor the development and preservation of agglutinated forms. Cretaceous and lower Paleogene type-A assemblages have also been recovered from DSDP Sites with paleodepths between 2.5 and 4.5 km (Miller et al. 1982). The "type-B" agglutinated assemblage is comprised of minute, smooth-walled varieties and was apparently restricted to deep Cretaceous paleodepths (>4 km), such as at DSDP Sites 196, 198A, 260, 261, 263 (Krasheninnikov, 1973, 1974) and at selected sites in the North Atlantic, most notably at Sites 137 and 138 (Beckmann, 1972), 543A (Hemleben and Troester, 1985), and 641A. This fauna is generally restricted to zeolitic clays, and probably lived in ridge-flank environments and on the abyssal plains beneath the oceanic lysocline.

The distribution of benthic foraminiferal species on the sea floor is influenced by depth-related water mass and sedimentological properties. Because benthic foraminiferal biofacies change with increasing depth and distance from shore, these organisms are used as tools to reconstruct the paleobathymetric and subsidence/burial history of sedimentary basins. The use of benthic foraminifera as paleobathymetric indicators in sedimentary basins is influenced by our knowledge of their distribution in modern sediments. Interpretations of paleobathymetry of fossil assemblages are usually based on the principle of taxonomic uniformitarianism, whereby the distribution of modern benthic species along bathymetric gradients serves as a key that allows us to assign paleodepths to fossil assemblages. This approach has been used with great success in reconstructing sea level curves for the Pleistocene. But in contrast with earlier epochs, the Pleistocene is a time of strong climatic gradients and increased contrasts between associated biotic provinces. In the early Paleogene, latitudinal climatic zonation was weaker (Wolf, 1987), there is no evidence for polar ice, and deep-water temperatures were about 10 degrees warmer than today (Miller et al., 1987). In the late Cretaceous and early Paleogene, analogies between modern and fossil distribution patterns are more tenuous due to evolutionary turnovers and changes in habitat preference of benthic taxa. As a result, some ancient sedimentary environments and their associated faunas have no modern analogs. This breakdown in the uniformitarian approach to paleoecology makes it increasingly difficult to calibrate the distribution of benthic microfossils in ancient sediments to paleobathymetry.

Nevertheless, the uniformitarian approach has been used by some authors to construct "paleobathymetric models" of benthic foraminiferal distribution patterns for sediments as old as mid-Cretaceous. For example, Sliter and Baker (1972) compiled a model of the bathymetric distribution of species on the Pacific Margin, and used this information to interpret the depositional environment of upper Cretaceous deposits in Southern California. A more generalized model was compiled by Haig (1979), who used both modern and fossil data to interpret global distribution patterns for mid-Cretaceous foraminiferids. Haig divided benthic assemblages into three general paleobathymetric associations. His classification of benthic assemblages into a neritic "_Ammobaculites_ association", a bathyal "_Marssonella_ association" and an abyssal "_Recurvoides_ association" was well-received by paleontologists familiar with benthic foraminiferal assemblages in the alpine basins and these terms have become widely used in the literature. But what exactly are these associations and can they be applied to Paleogene flysch-type assemblages? One of the goals of this thesis is to examine the paleobathymetric distribution of Paleogene agglutinated species in different areas of the North Atlantic to determine whether consistent paleobathymetric patterns can be recognized and to test Haig's tripartate classification of assemblages.

A rigid paleobathymetric differentiation between the type-A and type-B faunas may be an oversimplification and other paleoecological factors must be taken into account. The faunas were no doubt influenced by factors such as physiographic province (slope, rise, abyssal plain or ridge crest), the type of substrate, and the availability of nutrients. For example, the modern analog of Type-A agglutinated assemblages can be found living in continental slope and rise environments along the northwest Atlantic Margin. Several recent studies have documented the distribution of agglutinated species off Newfoundland (Schafer et al., 1983), and off Nova Scotia (Williamson, 1983; Thomas, 1985; Schroder, 1986a). In both areas, large coarsely agglutinated forms are associated with coarse substrates that reflect winnowing by bottom currents. The modern equivalent of a Type-B assemblage has been studied by Schroder (1986a). Although these faunas can occur at similar depths as the faunas from the continental rise, the type B faunas are found on the abyssal plains below the oligotrophic North Atlantic central gyres. In this setting, the depositional environment is tranquil, the substrate typically fine-grained, and the availability of nutrients low.

An extreme example of an area with increased food availability is the benthic community associated with hydrocarbon seeps on the Louisiana continental slope. In these areas, abundant bacteria which metabolize hydrocarbons and hydrogen sulfide support dense colonies of "vent-type" macrobenthos (Kennicutt et al. 1985). The study of agglutinated foraminifera from these areas provides a modern analog for some fossil assemblages in organic-rich sediments, and may furnish a biological tracer of such environments.

Our knowledge of the ecology of modern deep-sea agglutinated foraminiferal communities is still at an early stage. Studies of the distribution of modern deep-sea species of agglutinated foraminifera in the North Atlantic from the slope to the abyssal plain have demonstrated that many species have wide geographic and bathymetric ranges (Schroder, 1986a). This suggests that agglutinated foraminifera may be less affected by water mass properties than calcareous foraminifera. The community structure of agglutinated faunas is certainly influenced by environmental factors which may be independent of depth or watermass. If our goal is to interpret the fossil record, it is essential to extend our investigations of modern species beyond the biogeographic stage. First, it is necessary to better quantify the assemblage composition for well-defined ecologic niches (Schafer et al., 1983), and second, it is neccessary to gather data on the life history of agglutinated foraminifera and examine the response of these organisms to changes in their environment on a time-frame comparable to the lifespan of individuals. Only then shall we understand the niche of agglutinated foraminifera in the benthic community and be able to apply this knowledge to interpret the paleoenvironmental significance of fossil assemblages.

By applying uniformitarian principles, it ought to be possible to use the modern agglutinated faunas as a model to help interpret the paleoecological significance of fossil agglutinated assemblages. This approach has been successfully used with calcareous benthic foraminifera, which have a demonstrated utility in reconstructing the subsidence and water mass history of sedimentary basins. Many of the Tertiary basins in the North Atlantic, however, contain predominantly or exclusively agglutinated assemblages. The amount of paleoenvironmental information that can be extracted from these assemblages is a function of how well we understand the ecology of modern deep-sea agglutinated faunas. Therefore, synecological studies of modern agglutinated foraminifera play an essential role in establishing a baseline for paleoenvironmental analyses using flysch-type assemblages.

In the North Atlantic, it has been suggested that the composition of modern foraminiferal assemblages may be influenced by water mass properties, and variations in the distribution of calcareous benthic assemblages in space and time have been interpreted as reflecting changing water masses (Streeter, 1973; Schnitker, 1974). Furthermore, turnovers in benthic foraminiferal assemblages at major stratigraphic boundaries have been attributed to the establishment of deep-water connections between basins (Berggren and Hollister, 1974). Our knowledge of the possible water mass dependence of agglutinated foraminifera is still in an early stage, but by examining assemblages in key areas it may be possible to identify species associations which can help us interpret the the chronology of deep-water connections between high-latitude ocean basins. Until now, studies of the history of deep-water connections between the Arctic and North Atlantic have been based primarily on geophysical evidence. Because the record of calcareous benthic foraminifera is poor or missing in the Norwegian-Greenland and Labrador Seas, no benthic foraminiferal studies have been performed to test the geophysical models of early Cenozoic paleoceanography in these areas.

The primary objectives of this study are to:

1. document the life history and ecology of benthic foraminifera in well-documented ecologic settings, in order to better constrain the paleoenvironmental significance of "flysch-type" assemblages and identify potential tools for petroleum exploration and paleoceanography. To attain this objective, two separate studies were carried out with the goals of:

a. assessing the response of agglutinated foraminifera to community disequilibrium in the Panama Basin by examining biocoenoses and taphocoenoses in spade cores and recolonization trays placed on the sea floor, and

b. assessing how benthic foraminiferal biofacies are affected by organic-rich substrates at hydrocarbon seeps.

2. summarize the stratigraphic distribution of flysch-type agglutinated foraminifera from North Atlantic and Tethyan localities and present new data from the Zumaya Flysch in Northern Spain, and ODP Site 643A in the Norwegian-Greenland Sea. Another goal in this respect is to document the nature of benthic foraminiferal assemblages in the high-latitude basins to help constrain the timing of deep-water connections between basins.

3. conduct a survey of agglutinated taxa from the Labrador Sea, North Sea, Norwegian-Greenland Sea, West Greenland, Trinidad, Jamaica, Poland, Spain, and Morocco based on standardized taxonomy, and identify paleobiogeogeographic patterns in their distribution.

4. develop a generalized paleoslope model for the North Atlantic which relates the composition and relative abundance of agglutinated foraminiferal taxa to paleobathymetry. Another goal is to compare the paleobathymetric distribution of assemblages from the North Atlantic with contemporaneous flysch-type agglutinated faunas from the Carpathian basins to determine whether consistent paleobathymetric patterns exist in these regions. Finally, it is necessary to compare the paleobathymetry of Paleogene agglutinated foraminifera in the North Atlantic with Cretaceous paleobathymetric models.

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CHAPTER 2.

OBSERVATIONS ON THE ECOLOGY OF MODERN AGGLUTINATED FORAMINIFERA AND A CASE HISTORY OF PALEOENVIRONMENTAL ANALYSIS USING NEOGENE AGGLUTINATED ASSEMBLAGES AT ODP SITE 646, LABRADOR SEA.

SECTION A:

LIFE HISTORY AND RECOLONIZATION BY AGGLUTINATED FORAMINIFERA IN THE PANAMA BASIN:

INTRODUCTION

The life history and community structure of deep-sea benthic foraminifera is a subject which has received little attention over the years, yet this information is essential to help assess the rates of disequilibrium processes such as disturbance and succession in abyssal assemblages. Recolonization of substrates by benthic foraminifera has been empirically observed in modern shallow water environments (Schafer, 1983) and in the deep sea (Kaminski, 1985). Successive recolonization of the sea floor has also been postulated as the cause of small-scale vertical changes in fossil foraminiferal assemblages in hemipelagic sediments above turbidites in alpine flysch deposits (Grun *et al*., 1964; Butt, 1981). In shallow water environments, benthic macrofaunal communities have been shown to recover from physical disturbance in a few months (Levin, 1984), but in the deep sea, rates of recolonization are typically one or two orders of magnitude slower (Grassle, 1977; 1978). No experimental study, however, has focused attention on the patterns of benthic foraminiferal response to conditions of community disequilibrium in an abyssal habitat, yet these organisms serve an important role in the trophic structure of deep-sea benthic communities. By studying the life history of benthic foraminifera and estimating the rate at which biological succession takes place, one can better interpret patterns observed in fossil assemblages.

The deep Panama Basin is an excellent environment in which one can test the response of benthic foraminifera to substrate disturbance. The area has no observable nepheloid layer or current-derived bedforms, and x-radiographs have demonstrated that bottom sediment at the station is dominated by biogenic rather than physically formed structures (Aller and DeMaster, 1984). Therefore, one can be reasonably certain that the benthic community is not disturbed by bottom currents and that any artificial disturbance introduced in the area will not be augmented by natural causes.

In this study, I document the life history and ecology of benthic foraminifera in the Panama Basin by examining biocoenoses and taphocoenoses in spade cores and recolonization trays placed on the sea floor and assessing their response to community disequilibrium.

STATION LOCATION

The Panama Basin station is located at 5° 20.65'N, 81° 56.19'W at a depth of 3912 m (Fig. 2-1). Bottom water potential temperature and salinity in this area are 1.8°C and 34.67°/oo, respectively, and dissolved oxygen concentration is 2.4-2.6 ml/l (Laird, 1971; Lonsdale, 1976). Bottom current velocities in the area are slow, 2-5 cm/s, and generally east to west in direction (Laird, 1971; Lonsdale, 1976; Honjo *et al*. 1982). No nepheloid layer is detected, so there is little chance that benthic fauna might be resuspended and advected into sediment trays by bottom currents.

Panama Basin sediments are typically hemipelagic mud, containing about 30% biogenic components ($CaCO_3$, SiO_2). The organic carbon content is around 2.5%, and the clay fraction is composed of 50-70% smectite, 15-20% chlorite, 5-10% illite and 10-15% kaolinite (Heath *et al*. 1974). Studies of Pb-210 distribution in surface sediments at the site indicate rapid biogenic reworking in the upper few centimenters (Aller and DeMasters, 1984). The surface mixed layer is approximately 6 cm thick. Beneath this zone, mixing is about 10X slower but is present to at least 20 cm depth. Primary productivity in Panama Basin surface waters displays an east-west spatial gradient between 500 and 1000 mg C/m^2 day, with highest seasonal production in February-March and June-July (Moore *et al*. 1973: Honjo *et al*. 1982). The long term sediment accumulation rate is about 6-10 mg/cm $yr^{\overline{2}}$ based on C-14 measurements at the seafloor (Swift, 1977).

SAMPLING

The samples examined in this study were collected by the R/V Atlantis II and the submersible "Alvin" in summer of 1982. These consist of surface sediment from two spade cores and three sediment trays, or "mudboxes" which were collected within 100 m of one another. The spade cores were gathered to

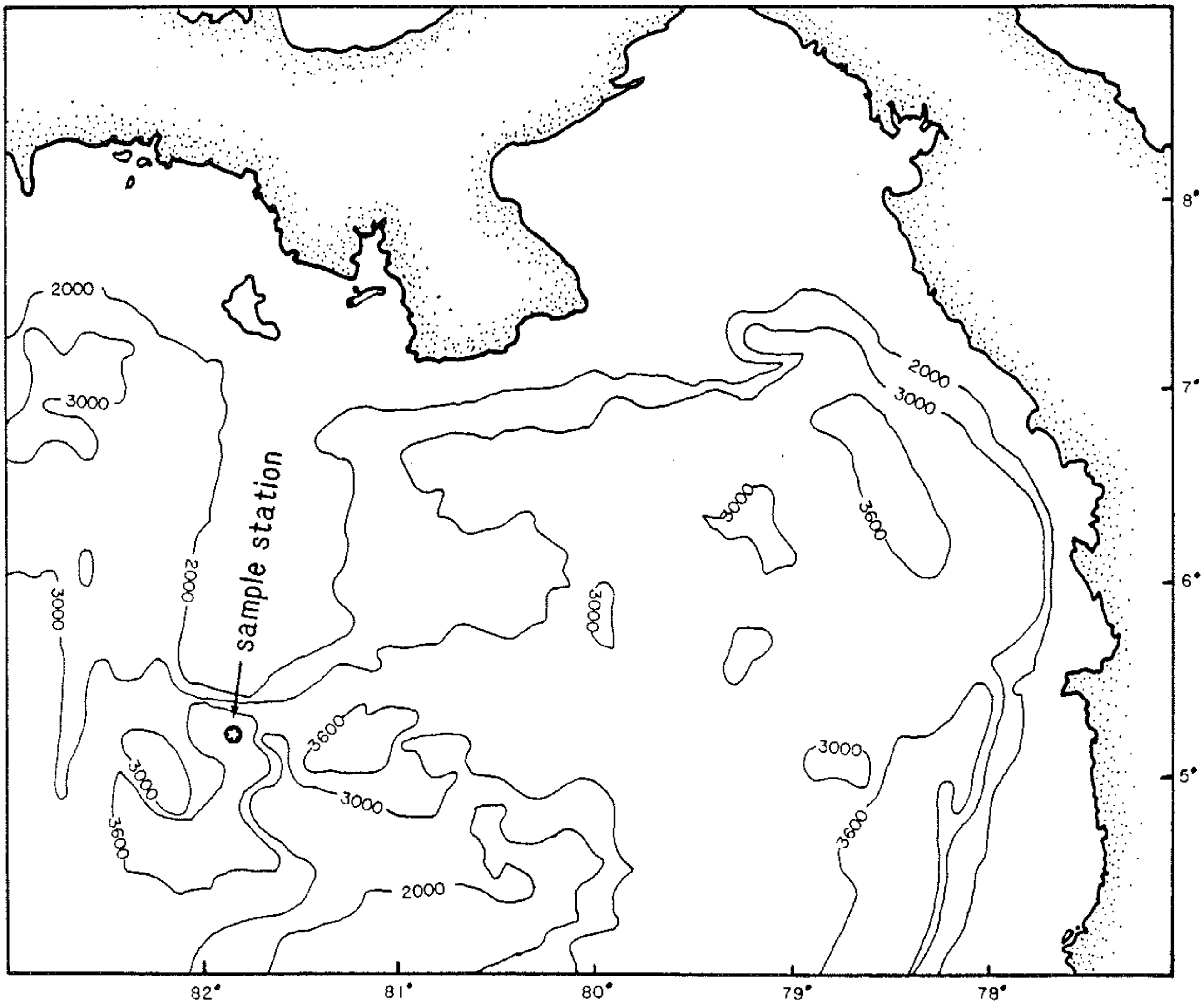


Figure 2-1. Map of study area showing location of sample station. Base map from Van Andel et al. (1971), depth in meters.

provide control samples to determine faunal composition and abundance of taxa at this site.

A portion of the sediment collected in spade cores was subdivided into 9 sections 10 x 10 cm in area, and each section was sampled at depth intervals of 0-2, 2-5, 5-10, and 10-15 cm. Another portion of the sediment was allowed to equilibrate to ambient room temperature, then frozen in the ship's refrigerator at -15°C, to eliminate any biota present. This mud was allowed to thaw and transferred to 30 cm X 30 cm X 5 cm fiberglass trays for emplacement on the sea floor. In each recolonization tray, the sediment was approximately 5 cm thick. Sediment from different depth sections of the spade core was handled separately and placed in different sectors of each tray (Fig. 2-2). The trays were fitted with a hinged PVC lid to prevent loss of mud during emplacement and recovery. The submersible "Alvin" deployed the trays on September 11, 1981, close to the site where spade cores were taken, and once in place on the sea floor, the lids were opened to expose the abiotic mud. After nine months (June 10-12, 1982), the trays were recovered. The Alvin closed the lids on the trays and carried them to the surface for sampling.

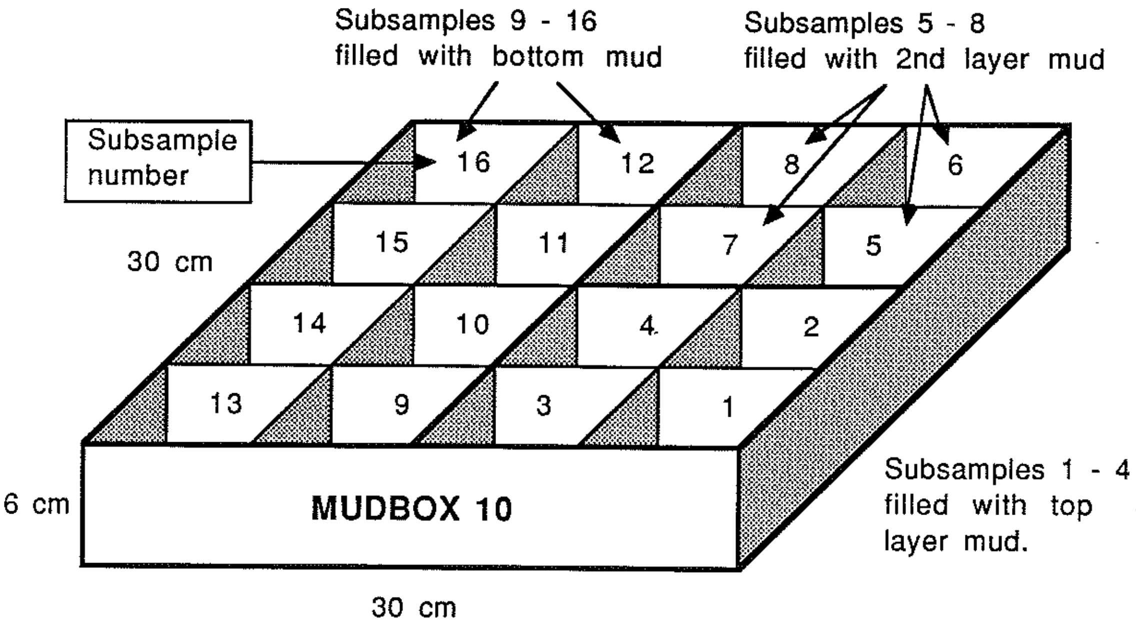
Each tray was subsampled in 16 sections 7.5 x 7.5 cm in area, and these were not further subdivided with depth. Mud samples from spade cores and trays were fixed overnight in a buffered formalin solution, sieved through a 297 micron sieve, transfered to storage jars and preserved in ethyl alcohol. In the labratory, preserved samples were stained overnight with Rose Bengal, and prior to picking, samples were again gently sieved and washed into a petri dish with ethyl alcohol. Foraminifera were picked using an eyedropper to transfer specimens to glass vials for storage. All specimens of foraminifera were picked from each subsample and the numbers of live and dead individuals were recorded. With some species it was necessary to crush specimens or make a small hole in the last chamber with a dissecting needle to determine whether red protoplasm was present.

RESULTS:

FORAMINIFERAL ABUNDANCE AND DIVERSITY

A. Control Samples --

The numbers of living and dead individuals were tallied separately for 4 subsamples (totalling 400 cm^2) from each of two spade cores taken in close



2-2. Diagram of Mudbox 10 showing configuration of subsamples and the type of sediment used.

proximity to each other (Table 2-1). Spade core 13 was sampled at four depth intervals (0-2, 2-5, 5-10, and 10-15 cm) and therefore provides a more complete data set than Spade core 9, which was only sampled at 0-2, 2-5, and 5-10 cm. No living calcareous benthics were observed in any of the samples, but occasionally, dead specimens of _Pyrgo murrhina_, _Planulina wuellerstorfi_ and entosolenians were found. These were rare and were not included in the counts. The living fauna consisted entirely of agglutinated foraminifera.

The 400 cm^2 area from Spade core 13 contained a total of 497 live individuals of agglutinated foraminifera belonging to 16 species, while 3,058 dead specimens belonging to 29 species were found. The same area from Spade core 9 contained 475 live individuals belonging to 18 species, and 3,593 dead specimens belonging to 26 species. Only 12.75% of the total agglutinated foraminiferal assemblage was living at the time of collection, as determined by Rose Bengal. This number contrasts with values of 30-40% in abyssal areas in the western North Atlantic determined by Schroder (1986a), with the difference probably a result of faster degradation of dead tests in the organic carbon-poor North Atlantic.

The data presented in Tables 2-1 and 2-2 show that the major difference in populations between the two spade cores lies in the numbers of _Dendrophrya_, which is more abundant in Spade core 9 by a factor of two, and _Reophax dentaliniformis_, which is three times more abundant in Spade core 13. These differences may be due in part to differential handling and sample quality (the problems of counting fragments of tubular species are legendary and need not be repeated here). Assuming equal fragmentation, the discrepancy in counts may be partly due to loss of some of the flocculent surface layer in Spade core 13, which would introduce a bias towards infaunal species. However, the cores did not appear to be disturbed, and an equally likely explanation is that the difference in abundance of the two taxa is real, and simply reflects the patchy distribution of species on the sea floor.

B. Recolonization Tray Samples --

The numbers of living and dead specimens in replicate subsamples from the three recolonization trays are tabulated in Tables 2-3 to 2-5. Because the size of the subsamples from the trays differed in area from those taken from

Table 2-1. Faunal data from Spade Core 9, Panama Basin.

PANAMA BASIN, AII 112, SPADE CORE 9, LIVE/DEAD INDIVIDUALS

DEPTH INTERVAL:	0-2 cm				2-5 cm				5-10 cm			
SUBCORE:	**2**	**4**	**7**	**8**	**2**	**4**	**7**	**8**	**2**	**4**	**7**	**8**
Dendrophrya arborescens	37/396	61/362	26/663	8/125	5/32	18/56	3/61	18/36	0/1	0/0	0/2	0/0
Reophax dentiliniformis	2/14	0/6	1/7	3/6	0/22	3/21	10/25	5/17	4/12	1/22	6/23	2/20
Hormosina ovicula	0/6	1/4	0/6	1/5	1/21	1/19	1/15	3/16	0/34	1/30	0/25	2/49
Hormosina distans	0/2	0/0	2/1	0/0	0/0	0/0	0/0	0/0	0/1	0/0	0/0	0/1
Reophax excentricus	0/8	0/6	2/20	1/3	2/13	5/41	10/25	3/11	5/28	4/31	9/20	14/41
Saccammina sp.	0/3	0/3	2/5	2/4	1/12	0/20	0/12	0/19	0/31	0/25	0/30	0/34
Trochammina globigeriniformis	0/7	0/8	1/2	0/4	0/9	1/17	0/16	0/2	0/21	0/15	1/26	1/23
Rhizammina sp. (large)	0/15	2/3	0/3	1/2	0/4	0/6	0/3	0/1	0/1	0/4	0/1	0/3
Lana sp.	5	4	3	2	4	4	2	3	0	1	0	2
Cribrostomoides subglobosus	0/2	2/1	1/2	1/3	0/0	0/1	0/6	0/3	0/8	0/6	0/10	1/9
Recurvoides spp.	2/5	0/3	1/4	0/6	0/6	0/3	4/5	0/3	0/7	0/7	0/7	1/11
Buzasina ringens	0/1	0/0	1/1	0/2	0/1	0/3	0/4	0/0	0/1	0/6	0/1	0/2
Ammodiscus incertus	0/2	0/0	1/2	2/5	1/4	0/2	0/1	0/4	0/8	0/10	0/11	0/12
Ammobaculites sp.	0/1	0/0	0/0	0/0	0/2	0/2	0/2	0/2	0/8	0/1	0/7	0/4
Hormosina globulifera	0/2	0/1	0/1	0/1	0/1	0/1	1/2	0/1	0/2	0/2	0/5	0/3
Eggerella propinqua	0/0	0/0	1/0	0/0	0/2	0/0	1/1	0/1	0/0	0/2	0/1	0/1
Eggerella bradyi	0/0	0/0	0/0	0/0	0/0	0/1	0/0	0/0	0/1	0/0	0/0	0/0
Pelosina sp.	1/3	1/1	0/0	3/3	0/1	0/1	1/1	0/0	1/1	0/0	0/0	0/0

Table 2-2. Faunal data from Spade Core 13, Panama Basin.

PANAMA BASIN, AII 112, SPADE CORE 13, LIVE/DEAD INDIVIDUALS

DEPTH INTERVAL:	0-2 cm				2-5 cm				5-10 cm				10-15 cm			
SUBCORE	**1**	**3**	**9**	**6**	**1**	**3**	**9**	**6**	**1**	**3**	**9**	**6**	**1**	**3**	**9**	**6**
D. arborescens	85/176	75/211	14/98	37/222	7/10	2/14	0/5	1/17	0/1	0/0	0/0	0/0	0/0	0/0	0/0	0/0
R. dentaliniformis	1/11	4/17	2/9	3/10	15/45	19/36	15/30	23/54	5/35	12/52	22/50	11/46	5/27	8/33	6/38	5/50
H. ovicula	3/3	3/6	3/10	0/6	1/21	0/19	1/12	0/20	0/21	0/26	0/36	0/26	0/1	1/12	0/20	0/7
R. excentricus	2/9	1/3	1/2	0/4	3/15	1/15	2/7	3/11	7/17	6/47	3/32	2/38	7/92	2/65	2/54	6/66
Saccammina sp.	2/5	1/1	0/5	0/4	2/8	0/6	0/4	0/11	1/16	0/21	0/27	0/31	0/27	0/19	1/18	0/18
T. globigeriniformis	3/5	1/5	1/8	2/4	0/10	0/14	0/9	0/18	3/28	0/16	0/19	0/18	0/41	0/31	0/21	0/28
Rhizammina sp. (large)	1/3	0/7	0/5	0/4	0/3	0/6	0/10	0/22	0/7	0/19	0/12	0/17	0/3	0/8	0/2	0/4
Lana sp.	3	5	5	3	0	1	2	1	0	1	1	0	1	0	0	0
C. subglobosus	3/0	1/0	0/3	1/2	0/6	0/7	0/3	0/4	0/7	0/7	0/8	0/6	0/7	0/9	0/18	0/10
Recurvoides sp.	0/0	4/1	0/8	0/2	3/9	0/1	0/6	0/3	0/5	0/7	0/9	0/9	0/10	0/5	0/3	0/7
B. ringens	0/0	1/1	1/2	1/0	0/3	0/1	0/0	1/2	0/6	0/5	0/5	0/1	0/4	0/5	0/6	0/3
A. incertus	1/1	0/1	0/0	0/1	0/0	0/0	0/0	0/0	0/3	0/0	0/0	0/0	0/0	0/1	0/3	0/1
Ammobaculites sp.	0/0	0/0	0/0	0/0	0/1	0/1	0/2	0/4	0/3	0/0	0/0	0/0	0/5	0/6	0/2	0/6
H. globulifera	0/0	2/0	0/0	0/1	0/0	0/0	0/2	0/1	0/1	0/2	0/2	0/2	0/2	1/2	0/2	0/0
E. propinqua	0/1	0/2	0/0	0/0	0/2	0/0	0/0	0/0	0/0	0/1	0/0	0/1	0/2	0/2	0/4	0/1
E. bradyi	0/0	0/0	0/1	0/0	0/0	0/0	0/0	0/0	0/0	0/2	0/0	0/0	0/1	0/0	0/2	0/0
Pelosina sp.	0/0	0/0	3/0	0/0	0/0	0/0	5/0	2/0	0/0	0/0	0/0	0/0	0/0	0/2	1/0	0/0

Table 2-3. Faunal data from Mudbox 7, Panama Basin.

PANAMA BASIN, AII-112, MUDBOX 7, LIVE/DEAD INDIVIDUALS

SUBCORE :	1	6	7	8	9	11	12	13	14
Dendrophrya arborescens	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Reophax dentaliniformis	1/7	0/6	2/12	3/11	0/16	2/18	0/7	2/18	5/25
Hormosina ovicula	0/3	1/1	0/1	1/3	0/13	1/11	0/9	1/18	1/9
Hormosina distans	0/0	0/0	0/0	0/1	0/1	0/0	0/0	1/0	0/1
Reophax excentricus	4/34	5/44	4/18	2/44	0/48	0/23	0/11	4/32	5/40
Saccammina sp.	0/2	0/1	0/5	0/6	0/8	0/6	0/1	0/24	0/16
Trochammina globigeriniformis	0/10	0/18	0/20	0/26	0/25	1/17	0/4	1/34	0/38
Rhizammina sp. (large)	0/3	0/1	0/1	0/3	0/13	1/3	0/5	0/12	0/7
Lana sp.	0	0	0	0	0	2	2	0	0
Cribrostomoides subglobosus	0/5	0/2	0/3	0/3	0/5	0/2	0/2	0/12	1/7
Recurvoides spp.	0/3	0/1	0/2	0/2	0/7	0/2	0/0	0/9	0/7
Buzasina ringens	0/3	0/3	0/4	0/0	0/5	1/3	0/1	1/3	0/3
Ammodiscus incertus	0/0	1/1	0/0	1/2	0/2	0/4	0/1	0/14	0/1
Ammobaculites sp.	0/2	0/3	0/3	0/3	0/5	0/0	0/0	0/8	0/8
Hormosina globulifera	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/1
Eggerella propinqua	0/0	0/0	0/0	0/0	0/0	0/1	0/0	0/0	0/0
Eggerella bradyi	0/0	0/0	0/0	0/3	0/0	0/0	0/0	0/3	0/0
Pelosina sp.	0/0	0/0	0/0	0/1	0/0	0/0	0/0	0/0	1/0

Table 2-4. Faunal data from Mudbox 10, Panama Basin.

PANAMA BASIN, AII-112, MUDBOX 10, LIVE/DEAD INDIVIDUALS

SUBCORE:	**3**	**6**	**8**	**9**	**11**	**12**	**13**	**14**	**16**
Dendrophrya arborescens	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Reophax dentaliniformis	4/14	1/9	11/21	2/15	3/9	0/17	7/11	12/23	8/23
Hormosina ovicula	0/1	1/4	1/2	0/6	0/0	0/0	0/13	1/10	1/17
Hormosina distans	0/0	0/0	0/1	1/0	0/0	0/0	0/0	2/3	0/0
Reophax excentricus	2/78	7/73	12/140	5/69	5/63	2/71	5/41	9/63	6/50
Saccammina sp.	2/8	0/8	2/10	0/8	0/11	0/7	0/6	0/18	0/7
Trochammina globigeriniformis	0/28	0/33	3/31	0/25	1/23	0/19	0/16	1/27	0/19
Rhizammina sp. (large)	0/8	0/4	1/12	0/5	0/2	0/3	0/5	0/13	2/13
Lana sp.	1	0	0	0	4	2	0	1	0
Cribrostomoides subglobosus	1/4	4/1	0/0	4/2	2/1	1/4	0/3	1/6	2/8
Recurvoides spp.	1/3	0/1	1/2	0/1	0/3	0/0	1/3	1/6	0/2
Buzasina ringens	0/0	0/0	0/0	0/2	1/0	0/1	0/1	0/3	0/2
Ammodiscus incertus	0/0	0/0	0/0	0/2	0/0	0/1	0/1	0/4	2/6
Ammobaculites sp.	0/5	0/6	1/13	1/11	0/7	0/8	0/5	1/6	1/9
Hormosina globulifera	0/1	0/3	0/0	0/2	0/2	0/0	0/0	0/0	0/2
Eggerella propinqua	0/0	0/1	0/0	0/0	0/0	0/0	0/0	0/2	0/1
Eggerella bradyi	0/0	0/0	0/1	0/1	0/0	0/0	0/0	0/0	0/1
Pelosina sp.	0/0	0/0	0/0	1/0	0/0	0/0	0/0	0/1	0/0

Table 2-5. Faunal data from Mudbox 11, Panama Basin.

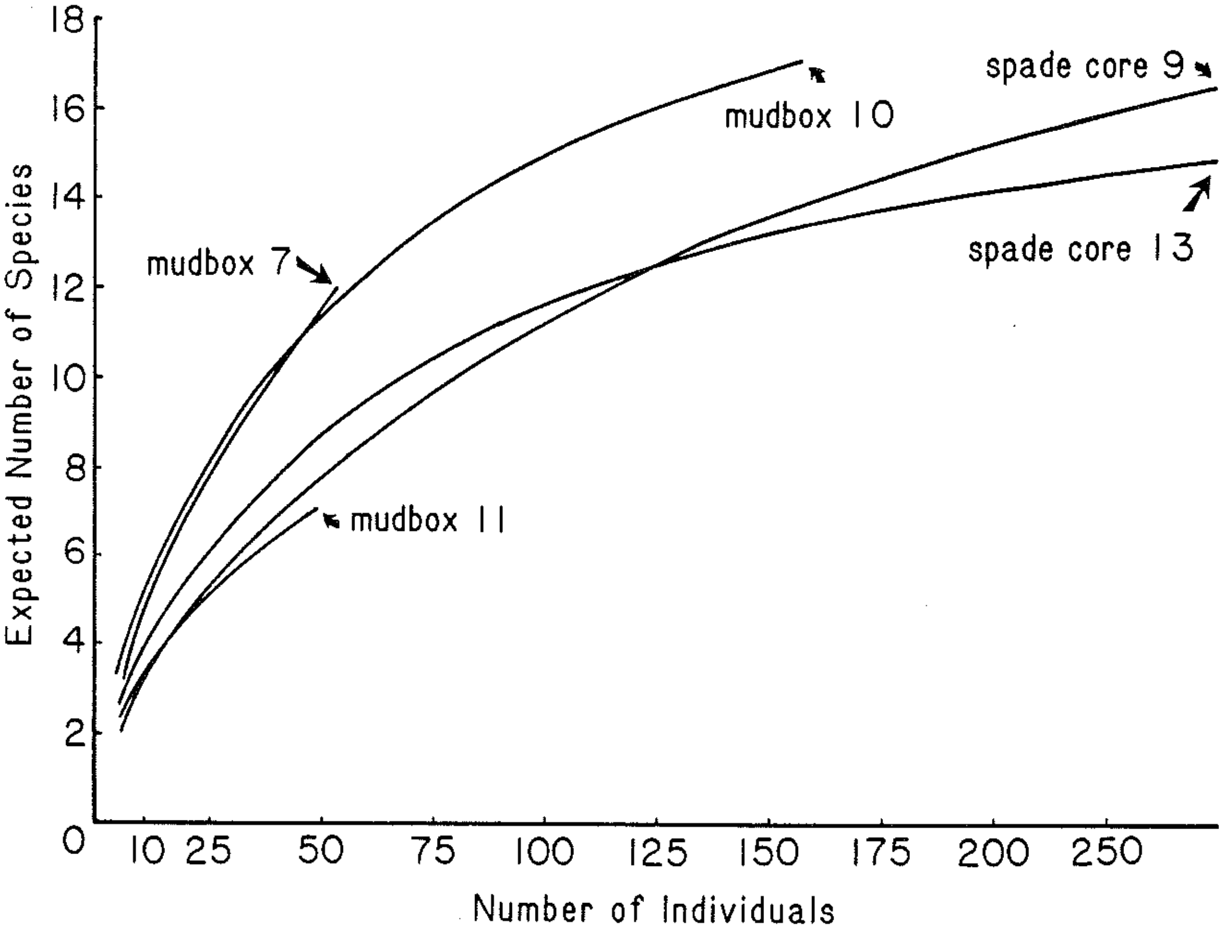
PANAMA BASIN, AII-112, MUDBOX 11, LIVE/DEAD INDIVIDUALS

SUBCORE:	4	5	6	8	9	10	11	13	14
Dendrophrya arborescens	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Reophax dentaliniformis	3/23	3/17	0/12	1/3	1/11	0/5	0/8	2/6	0/7
Hormosina ovicula	1/13	0/3	0/1	0/0	0/2	0/1	0/1	0/2	0/0
Hormosina distans	0/2	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Reophax excentricus	4/72	5/49	4/53	2/27	2/42	4/35	5/48	2/40	3/39
Saccammina sp.	0/17	0/13	0/11	0/3	0/5	0/11	0/9	0/3	0/5
Trochammina globigeriniformis	0/39	0/17	0/17	0/16	0/21	0/26	0/13	0/16	1/19
Rhizammina sp. (large)	0/11	0/7	0/5	0/3	0/1	0/1	0/2	0/4	0/4
Lana sp.	1	0	1	0	0	0	0	0	1
Cribrostomoides subglobosus	1/11	1/2	0/5	0/4	0/3	0/7	0/6	0/3	0/7
Recurvoides spp.	0/5	0/1	0/3	0/0	0/2	0/2	0/2	0/1	0/1
Buzasina ringens	0/4	0/1	0/2	0/0	0/3	0/5	0/0	0/0	0/0
Ammodiscus incertus	0/4	0/2	0/0	0/0	0/0	0/0	0/1	0/1	0/0
Ammodiscus sp.	0/15	0/3	0/6	0/3	0/11	0/6	0/3	0/3	0/3
Hormosina globulifera	0/0	0/1	0/1	0/0	1/2	0/2	0/1	0/1	0/0
Eggerella propinqua	0/0	0/0	0/3	0/1	0/3	0/0	0/1	0/1	0/1
Eggerella bradyi	0/2	0/1	0/3	0/1	0/0	0/0	0/1	0/0	0/0
Pelosina sp.	0/1	0/0	0/1	0/1	0/0	0/0	0/0	0/0	0/0

spade cores (7.5 x 7.5 cm for the trays versus 10 x 10 cm for spade cores), more subsamples from the trays were counted to obtain comparable data (9 subsamples from a tray corresponds to an area of 506.25 cm^2). The abundance of dead specimens did not differ greatly from tray to tray, and totaled 999 specimens in Mudbox 7, 1029 specimens in Mudbox 11, and 1,432 specimens in Mudbox 10.

The numbers of live individuals were small in comparison with control samples, with 48 live individuals in Mudbox 11, 56 individuals in Mudbox 7, and 156 in Mudbox 10. Collectively, only 6.9% of the individuals in trays were alive at the time of retrieval. This compares with 15.6% living individuals in the upper 5 cm of the control samples. In each tray, sediment from different layers of the spade core was handled separately and placed in different areas of the tray (Fig. 2-2). This differential treatment is not reflected in the numbers of dead individuals present in different subsamples. The Shannon-Wiener diversity of live populations from recolonization trays does not differ greatly from that of the control samples, at 2.48 for Mudbox 7, 1.61 for Mudbox 11, and 2.79 for Mudbox 10, versus values of 1.55 and 2.09 for control samples. When Hulburt's Rarefaction Method (Hulburt, 1971) is used to calculate E(Sn) the expected number of species at a given sample size (Fig. 2-3), the differences in diversity between trays becomes apparent. At a sample size of 40, the calculated species richness in Mudbox 10 is 10.19, but in Mudbox 11 is only 6.44. The value of E(S40) of control samples falls between those of the trays, at 6.86 and 7.73.

The abundance of macrofaunal invertebrates in the trays reflects the same pattern as that of the foraminifera, with 7 living individuals in Mudbox 11, eleven individuals in Mudbox 7, and 19 individuals in Mudbox 10. About 70% of the individuals are polychaetes, 22% are crustacea, and 8% molluscs. Two new species of spionid polychaete in the genus Prionospio are the only species represented by more than two individuals. The mean abundance of macrofaunal invertebrates in the recolonization trays is 1.4 live individuals/100 cm^2. This compares with a mean abundance of 15.6 live individuals/100 cm^2 in control samples from nine Alvin boxcores gathered at the same site.



2-3. Rarefaction curve showing diversity of spade core and recolonization tray samples examined in this study.

DISCUSSION:

A. Habitat partitioning --

A number of studies have suggested microhabitat partitioning as an important factor for the maintenance of diversity in deep sea benthic communities (Jumars, 1975; 1976; Bernstein et al., 1978). Under equilibrium conditions, species which do not share the same microhabitat do not compete with one another, and the diversity of the community can be maintained at high levels.

Among foraminifera, Corliss (1985) has reported vertical stratification of living calcareous benthic taxa in boxcores from the western North Atlantic. Flat, planoconvex genera such as Planulina and Cibicidoides were found to prefer an epifaunal habitat, while smooth planispiral forms and globular-elongate forms such as Melonis and Chilostomella prefer an infaunal habitat. A similar relationship between microhabitat and shape is apparent in the observations of Kitazato (1984). In the shallow-water environment of Otsuchi Bay, Japan, the pyriform species Sigmoidella pacifica and Guttalina cf. yabei occupy an infaunal habitat and are reported to move through the sediment. Burrowing behavior has also been observed in the miliolid genus Quinqueloculina in shallow-water sediments (Severin et al., 1982).

Analogies can be drawn between the test shape of agglutinated foraminifera from the Panama Basin and patterns observed by Corliss (1985). In our material, the elongate uniserial species Reophax dentaliniformis and Reophax excentricus clearly prefer, but are not confined to, an infaunal habitat. The elongate shape of the test may be an adaptation for mobility in the mixed layer of the sediment. Agglutinated foraminifera have been suspected of being responsible for causing the fine, apparently randomly oriented burrows which is laconically known as "vermicelli bioturbation" (C.D. Hollister, personal communication) observed in x-radiographs from the High Energy Benthic Boundary Layer Experiment (HEBBLE) Site on the lower continental rise off Nova Scotia.

A similar type of "vermicelli bioturbation" is ubiquitous in x-radiographs from the site in the Panama Basin, as example of which is shown in figure 2-4. I attribute the small burrows to Reophax, since it is the most abundant macrofaunal-size (2 mm or more) infaunal taxon present at this site.

Several species of agglutinated foraminifera were found living mainly in

2-4. X-radiograph of sediment surface layer from a spade core collected at our station (courtesy of Robert C. Aller). The fine reticulate burrows ("vermicelli bioturbation") are attributed to agglutinated foraminifera. Scale approximately 1:1.

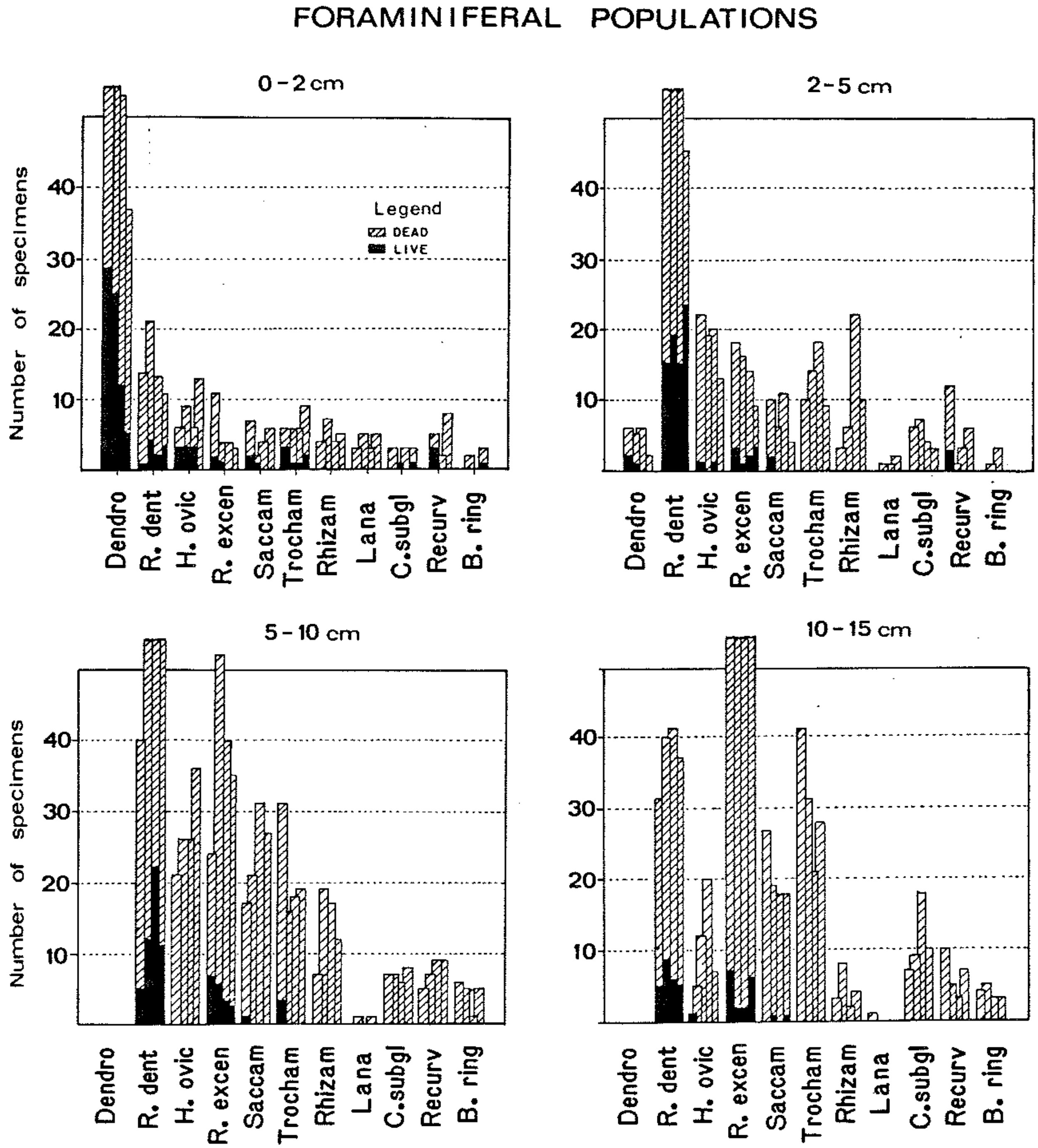
the flocculent surface layer, which at the site has a thickness of approximately 2 cm. These are the Komokiaceans, Dendrophrya arborescens, Cribrostomoides subglobosus, and Ammodiscus incertus. The branching species are assumed to be immobile suspension feeders (Jones and Charnock, 1985), and planispiral and disc-shaped forms have been interpreted as being adapted to an epifaunal mode of life (Corliss, 1985).

B. Taphonomy --

Agglutinated foraminifera construct their tests with an organic cement which in some species contains oxidized iron compounds (Hedley, 1963; Schroder, 1986a), which probably serve as an electron acceptor during the bacterial degradation of organic matter. Some species of agglutinated foraminifera are more susceptible to degradation than others, therefore the compostion of the death-assemblage will change with time after the death of the organism. The differential preservation of agglutinated species has a profound effect on the composition of faunal assemblages.

In the Panama Basin, I observed a change from a Dendrophrya-dominated assemblage in the surface layer of the sediment to an assemblage dominated by Reophax at depth. This is expressed in figure 2-5. The abundance of Dendrophrya drops dramatically beneath the flocculent surface layer, being entirely absent below 5 cm. The absence of dead specimens of Dendrophrya in the recolonization trays indicates that degradation of this species is very rapid, taking place in less than nine months. The disappearance of Dendrophrya in the trays may have been assisted by the feeding activities of Reophax, which is included by Jones and Charnock (1985) in the group of detrital feeding scavengers.

The transition from brownish to greyish-brown sediments at the site is located about 6-7 cm below the surface, indicating reducing conditions, and foraminiferal tests from deeper subsamples are sometimes coated with manganese. In this zone, most empty tests which contain iron compounds in their cement, such as C. subglobosa, H. ovicula, Recurvoides, Buzasina ringens, Saccammina, Trochammina globigeriniformis, Hormosina globulifera, and Eggerella propinqua are bleached white in color. A good measure of the fossilization potential of agglutinated species is the ratio of living to dead



2-5. Composite diagram showing changing agglutinated foraminiferal populations and dead assemblages with depth in Spade core 13. The four bars per species indicate values for each subcore. The abundance of Dendrophrya was arbitrarily divided by three.

tests in the assemblage. In spade core 13, the least preservable form is Pelosina sp., since 11 live individuals but only 2 dead specimens were found. The most resistant species is Rhizammina sp. (large), which constructs its test from diatom frustules and other siliceous debris and makes an audible high-pitched crunching sound when pierced with a dissecting needle.

Table 2-6 ranks the common species recovered from Spade cores 9 and 13 according to their fossilization potential. The Komokiaceans are not included because of the difficulty in distinguishing living from dead tests, but are no doubt the least preservable group of benthic foraminifera. From this ranking, it would appear that the presence of iron compounds in the cement increases the preservability of specimens, since the four least preservable species in our samples are not brown in color. This data are in general agreement with the observations of Schroder, (1986a) who ranked agglutinated foraminifera from the western North Atlantic in terms of test stability.

C. Recolonization by Agglutinated Foraminifera --

In studies of fossil assemblages from alpine flysch regions (Grun et al. 1964; Butt, 1981) and the Norwegian-Greenland Sea (Verdenius and Van Hinte, 1983), the simple tubular species were assumed to represent opportunistic species. Small-scale vertical changes in assemblage composition from an astrorhizid-dominated assemblage directly above the coarse layer of a turbidite to a more diverse assemblage higher in the hemipelagite was interpreted as evidence of recolonization of the sea floor after a catastrophic event. Verdenius and Van Hinte further elaborated on this subject, describing a "frontier-area subfauna" of primitive forms and a species-rich "mature subfauna" which was interpreted as a later stage of faunal succession. A change from a frontier fauna to a mature fauna at younger levels at Site 345 was attributed to a reduction in turbidite intensity with time.

More recent studies, however, have interpreted concentrations of tubular species as a result of hydrodynamic sorting. Schroder (1986a) reported "countless" tubular fragments in a turbidite layer from the Nares Abyssal Plain. By comparing sedimentological evidence with benthic faunal data, Kaminski et al. (in press, a) distinguished a redeposited "Dendrophrya Assemblage" in turbidite clays of the lower Lizard Springs Formation of Trinidad. Considering the epifaunal habitat of Dendrophrya in the Panama

Table 2-6. Agglutinated foraminifera from the Panama Basin ranked in terms of increasing fossilization potential, defined as the ratio of living to dead tests observed in spade core samples. At the top of the list are species least likely to be preserved.

1. *Pelosina* sp.
2. *Reophax dentaliniformis*
3. *Dendrophrya arborescens*
4. *Reophax excentricus*
5. *Hormosina globulifera*
6. *Eggerella propinqua*
7. *Recurvoides* spp.
8. *Buzasina ringens*
9. *Cribrostomoides subglobosus*
10. *Ammodiscus incertus*
11. *Hormosina ovicula*
12. *Trochammina globigeriniformis*
13. *Saccammina* sp.
14. *Rhizammina* sp. (large)

Basin, this taxon would no doubt be entrained and redeposited by downslope currents. If erosion by a turbidity current occurs mainly in the flocculent surface sediment, one would expect to see concentrations of Dendrophrya in the turbidite "d" layer of the Bouma Sequence.

Although it is not possible to recreate the large-scale devastation of benthic biota caused by a turbidity current, I believe that the recolonization trays provide a good approximation as to which organisms are likely to recolonize a naturally disturbed patch of the sea floor. This experiment is not free of bias, however, because the type of disturbance introduced in mudboxes is unlike anything known in nature. A discussion of the type of experimental bias introduced by the sampling design is given by Smith (1985).

The abundance of living individuals in the mudboxes, summarized in Table 2-7, identifies the opportunistic species. The control sample is the pooled data from the 0-2 and 2-5 cm subsections of both spade cores. Contrary to a priori expectations, the tubular species Dendrophrya arborescens was found to be a poor colonizer, since no living individuals were found in any of the trays. The best colonizers in the samples were Reophax excentricus and Reophax dentaliniformis. The species R. excentricus was present in greater abundance in the mudbox samples than in control samples, which suggests it is a particularly good colonizer. Other species which display good dispersial capabilities are Hormosina ovicula, Cribrostomoides subglobosus, Psammosphaera sp., and Trochamminina globigeriniformis.

The mode of colonization of the substrate by Reophax cannot be confirmed without in-situ observation of the living animal. An interesting point is that the spade-core data indicate that this genus is predomiantly infaunal, and one would expect infaunal taxa to be less likely to colonize a sediment tray (Smith, 1985). Whether this genus has free-swimming zygotes as in other benthic foraminifera is not known, and I cannot discount the possibility that some or all individuals did not colonize the samples by crawling up the sides of the trays. Crawling behavior in the shallow water species Reophax moniliformis has recently been described by Knight (1986). Knight reports that when a specimen of R. moniliformis is placed in an observation cell with its aperture close to a vertical surface, the animal will attach its pseudopodia and climb the wall of the container while holding its test horizontally. Presumably, mobile taxa are better adapted to recolonize disturbed patches of sea floor.

Table 2-7. Abundance of live individuals/100 cm^2 in control samples and colonization trays in the Panama Basin. Control samples are the combined abundance from 0-5 cm layers of both spade cores.

Species	Control	MB 10	MB 11	MB 7
Dendrophrya arborescens	68.3	0.0	0.0	0.0
Reophax dentaliniformis	13.1	9.5	2.0	3.0
R. excentricus	4.6	10.5	6.1	4.8
Hormosina ovicula	2.4	0.8	0.2	1.0
Pelosina sp.	1.6	0.2	0.0	0.2
Recurvoides spp.	1.6	0.6	0.0	0.0
Saccammina sp.	1.3	0.8	0.0	0.0
Cribrostomoides subglobosus	1.1	3.0	0.4	0.2
Trochammina globigeriniformis	1.1	0.8	0.4	0.4
Buzasina ringens	0.8	0.2	0.0	0.4
Ammodiscus incertus	0.6	0.4	0.0	0.4
Bathysiphon sp.	0.6	0.0	0.0	0.0
Rhizammina sp. (large)	0.5	0.6	0.0	0.2
Hormosina globulifera	0.4	0.0	0.2	0.2
Hormosina distans	0.3	0.8	0.0	0.2
Ammobaculites sp.	0.0	0.8	0.0	0.0
Psammosphaera sp.	0.0	1.8	0.4	0.2
TOTAL:	97.8	30.2	9.5	11.1

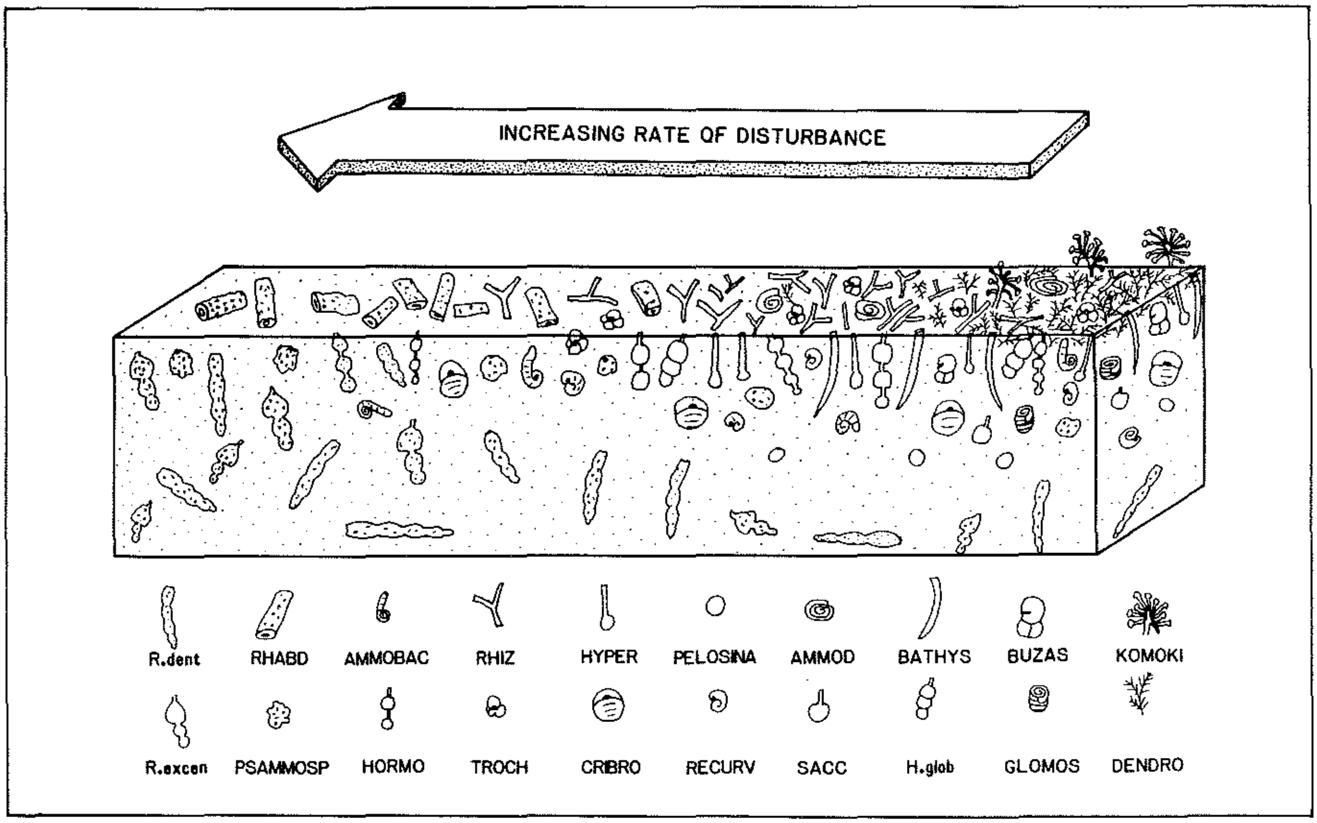
D. Rates of Succession --

The total abundance of live individuals in control samples is 97.8 individuals/100 cm^2. However, if one ignores Dendrophrya, the abundance of remaining species is 29.4 individuals/100 cm^2. This figure compares well with the abundance in Mudbox 10 (30.2 live individuals/100 cm^2), which suggests that except for tubular forms, nine months may be sufficient time for an agglutinated foraminiferal fauna to recover to background levels of abundance after a disturbance. This finding is in contrast with the density of macrofaunal invertebrates, which did not recover to background levels in any of the trays over the nine month period.

There is evidence in the data that faunal recolonization occurs at different rates. This increases the likelihood that localized disturbance of benthic communities may result in patches of organisms in different stages of succession, or contemporaneous disequilibrium (Grassle and Sanders, 1973). The expected number of species in a given sample size differs by nearly a factor of two, and abundance differs by a factor of three between MB 10 and MB 11. These differences are greater than those observed in control samples. The observation of patches of agglutinated foraminifera with diversity differing significantly from other patches within a 4 km^2 area was reported by Kaminski (1985) from the HEBBLE Site. The results from both the Panama Basin and the HEBBLE Site indicate that physical disturbance resulting in severe population reduction, and different rates of recovery to background faunal abundance is an important source of spatial heterogeneity in the distribution of deep-sea benthic organisms.

E. A General Model Relating Community Structure to Disturbance --

To study the effect of the sedimentary environment on the community structure of agglutinated foraminiferal faunas, I examined whether particular "morphogroups" (in the sense of Jones and Charnock, 1985) exhibit preference for tranquil or disturbed environments. By synthesizing data from the recolonization experiment and from studies of the distribution of modern agglutinated foraminifera in the western North Atlantic (Kaminski 1985, Schroder, 1986a; Kaminski and Schroder, 1987; Kaminski et al., in press, b), it is now possible to develop a generalized model of the effect of substrate disturbance on the structure of agglutinated foraminiferal communities (Fig. 2-6).



2-6. Generalized model showing the effect of substrate disturbance on the structure of agglutinated foraminiferal communities, synthesized from Kaminski, 1985; Schroder, 1986a,; Kaminski and Schroder, 1987; Kaminski *et al.*, in press, b.

Tranquil areas such as the Panama Basin site and the Nares Abyssal Plain (Schroder 1986a) are covered by fine-grained pelagic sediment, and provide stable environments for benthic organisms. No evidence of turbidites or winnowing was observed in boxcores collected at either site. The agglutinated fauna in such an environment is dominated by species of Komokiacea and Astrorhizidae, which have branching tubular tests and live in the flocculent surface layer. Some of these taxa have an erect epifaunal life position and comprise the trophic morphogroup of primary suspension feeders according to Jones and Chernock (1985). Other common genera on the Nares Abyssal Plain are Adercotrema, Reophax, and Nodellum (Schroder 1986a). These genera possess a coiled or elongate chamber arrangement and prefer an infaunal mode of life. They belong to the morphogroup of sediment-dwelling herbivores and detritivores and are most common 2-2 cm below the sediment surface (Schroder 1986a; in press). At the Panama Basin Site, branching tubular species comprise up to 90% of the fauna. Nearly all living tubular specimens were found in the upper 2 cm. Lituolids and ammodiscids also live mainly in the surface layer. Below 5 cm the live fauna consists mainly of Reophax.

Another example of a relatively tranquil environment is the upper continental rise off Nova Scotia. The region between 2200 m and 2500 m lies above the influence of the Western Boundary Undercurrent (WBUC). The sediment contains abundant light particles such as diatom shells, fragments of planktonic foraminifera and organic debris. These components suggest a lack of strong bottom currents, although some downslope transport is indicated by the occurrence of calcareous slope foraminifera (Schroder 1986a). At this site, the assemblage is dominated by the suspension-feeding species Rhizammina algaeformis. At a relatively tranquil location at 4185 m on the continental rise (the HEBBLE Shallow Site of Kaminski, 1985), the agglutinated assemblage contains a large proportion of species which utilize fine-grained material in the construction of their test.

Disturbed environments are found along the western margin of the North American Basin, which is characterized by two zones of increased current velocity (Tucholke et al., 1985). The WBUC flows in a southwesterly direction along the middle continental rise between 2500 and 4000 m. Abundant intact planktonic foraminiferal tests, coarse detrital sand and reduced numbers of diatom tests form a relatively coarse grained substrate that has been winnowed by currents. The agglutinated component is diverse and includes reworked specimens. The assemblage contains a large proportion of species which utilize coarse-grained material in the construction of their tests, reflecting the coarse nature of the substrate. The fauna is dominated by robust, non-branching species of Astrorhizidae and a number of lituolids and trochamminids. These groups are epifaunal, and constitute the morphogroup of surface-dwelling herbivores, detritivores and omnivores (Jones and Chernock, 1985).

The second zone of high currents is the lower continental rise (below 4200m) south of Nova Scotia which was studied in detail at the HEBBLE Area (Kaminski, 1985; Schroder, 1986a). This region is subjected to brief periods of disturbance by "benthic storms" which are caused by the interaction between a southwesterly mean flow and eddies and rings of the Gulf Stream. The sediment is relatively coarse grained, with increasing sand content (>50%) towards the base of the continental rise (Driscoll *et al*., 1985). The agglutinated assemblage on the lower rise displays reduced diversity in comparison with the HEBBLE Shallow Site, and consists of branching specimens of *Rhizammina* and abundant specimens of the infaunal genus *Reophax*. Detailed examination of assemblages at the HEBBLE Area by means of factor analysis (Kaminski, 1985) revealed an end-member assemblage characterized by *Reophax*. At the HEBBLE Site two benthic storms were recorded in early spring of 1983 which disturbed the sediment surface layer to a depth of up to 6 cm. Boxcore samples recovered in June of that year revealed an agglutinated foraminiferal assemblage dominated by species of *Reophax*, including *Reophax dentaliniformis*, which was interpreted by Kaminski (1985) as an opportunistic form. The *Reophax* assemblage was dominant in box-core samples with a thick, finely laminated surface layer visible in X-radiographs, which was apparently deposited after a benthic storm. In the deep Panama Basin, the most effective colonizers were also species of *Reophax*. Unexpectedly, the branching tubular forms were found to have limited dispersial capability in the Panama Basin. The common occurrence of *Reophax* in recolonization trays in the Panama Basin and at the HEBBLE Site support the idea of this genus being opportunistic and capable of invading newly deposited sediment after a benthic storm.

CONCLUSIONS

The study of living and dead assemblages in recolonization trays and with depth in spade cores allows us to reconstruct the life history of agglutinated benthic foraminifera in the deep Panama Basin. Tubular and planispiral forms such as Dendrophrya, Cribrostomoides and Ammodiscus, have an epibenthic habitat, whereas the elongate uniserial genus Reophax prefers an infaunal mode of existance and is credited with causing the fine network of burrows observed in x-radiographs. A smaller proportion of the total assemblage was living at the time of collection when compared with data from the North Atlantic (12.75% vs 30-40%).

The tubular species Dendrophrya arborescens is a delicate form which disintegrates within nine months after the death of the animal and possesses poor dispersal capabilities, since it was not found in recolonization trays. This finding contradicts the idea of "primitive" tubular forms being more opportunistic than "advanced" species. The most effective colonizers were two species of Reophax, a finding which is corroborated by observations on the lower continental rise off Nova Scotia. The density of taxa in recolonization trays differed from one another by a factor of three, which may suggest recolonization taking place at different rates among different patches of fauna. Recolonization by benthic foraminifera in the deep Panama Basin is more rapid than among macrofaunal invertebrates in the same samples.

A comparison of tranquil and disturbed habitats indicates that the composition and trophic structure of agglutinated foraminiferal communities are influenced by the deposional environment. There appears to be a predictable response of agglutinated foraminifera to substrate disturbance. Tranquil environments are dominated by suspension feeders with branching, fragile tests, and contain a large proportion of finely agglutinated forms. Disturbed environments with strong bottom currents are characterized by robust, coarse-grained epifaunal and infaunal species. Elongate species of Reophax are well suited for colonizing substrates after physical disturbance of their habitat. Therefore, modern faunas with large proportions of this genus can be interpreted as indicating a disturbed environment or a fauna in an early stage of faunal succession.

SECTION B:

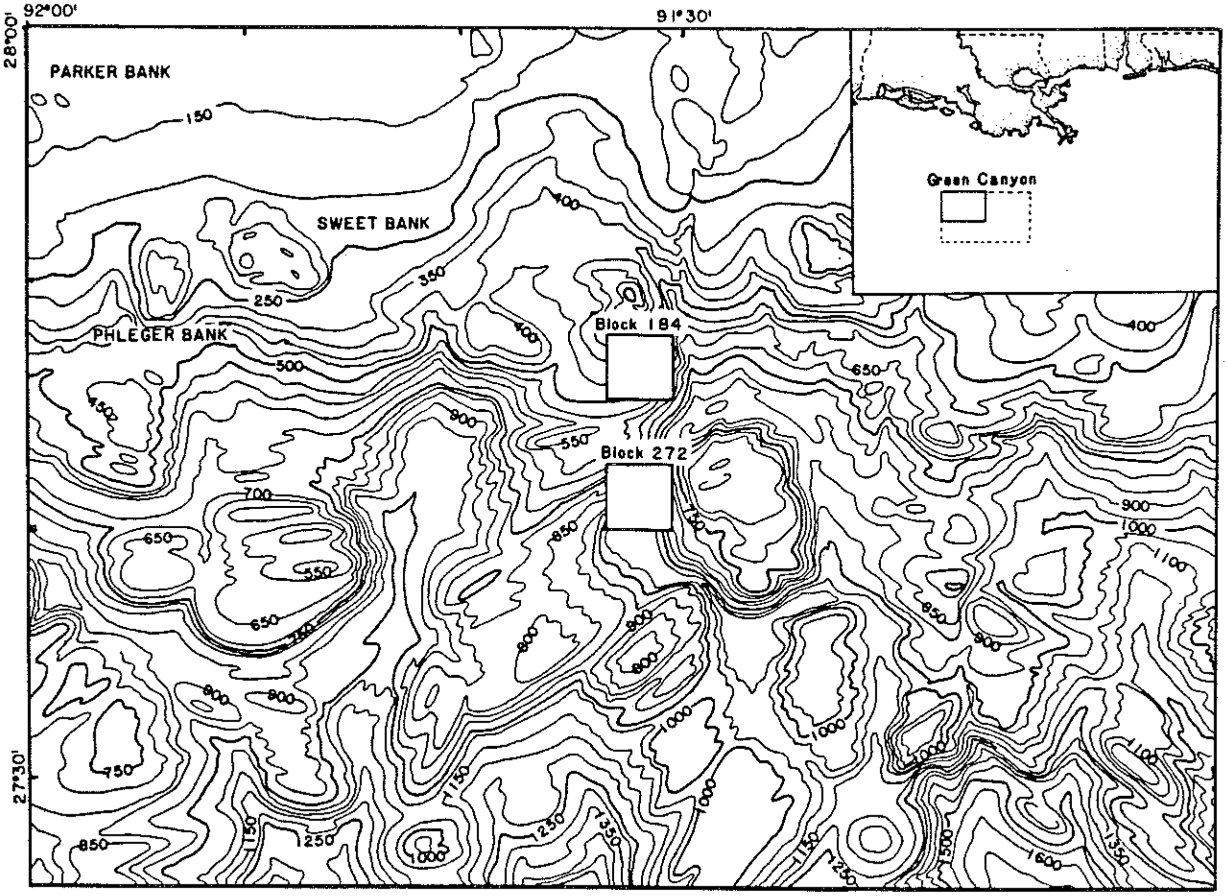
AGGLUTINATED FORAMINIFERA FROM A HYDROCARBON SEEP REGION ON THE LOUISIANA CONTINENTAL SLOPE

INTRODUCTION:

Recent discoveries of a biological community of hydrothermal vent-type organisms in areas of active hydrocarbon seepage (Brooks *et al*., 1985; 1987; Kennicutt *et al*., 1985) have provided new insight into the effect of high organic-carbon substrates on benthic marine communities. Carbon isotope studies of organisms collected from hydrocarbon seeps indicate that animals utilize hydrogen sulfide and methane as their primary energy source (Kennicutt *et al*., 1985). Chemosynthetic communities containing bivalves and tube worms have now been indentified at 17 locations in the Green Canyon, Garden Banks, Ewing Bank and East Breaks lease areas on the Louisiana continental slope (Brooks *et al*., 1987), which is evidence that these faunas may be locally abundant in regions of submarine hydrocarbon seeps. Because of the utility of benthic foraminifera in petroleum exploration, it is important that we assess how this component of the benthic community is affected by organic-rich substrates at hydrocarbon seeps. By studying benthic foraminiferal faunas that are associated with chemosynthetic communities, it is possible to better constrain the paleoenvironmental significance of fossil assemblages and identify a potential tool for petroleum exploration and paleoceanography.

SAMPLE LOCALITIES:

Areas of hydrocarbon seepage are known from seismic lines recorded from at least 34 locations on the Louisiana continental slope (Brooks *et al*., 1987). Foraminiferal assemblages examined in this study were collected from Green Canyon OCS Lease Blocks 184 and 272 (figure 2-7). The environment and macrofauna from Lease Block 184 has been studied by Brooks *et al*. 1987. In an area of Block 184 known as "Bush Hill", a photographic survey undertaken using the submersible Johnson Sea-Link documented large clusters of vestamentiferian tube worms up to 2 m in length, mussel beds associated with active methane seepage, and bacterial mats associated with oil. Sediment cores recovered from the vicinity of the chemosynthetic community contain extractible hydrocarbon contents of between 0.02 and 12% (Brooks *et al*., 1987).



2-7. Location of OCS Blocks 184 and 272 in the Green Canyon area of the Louisiana continental slope. Bathymetry in meters. Base map redrawn from NOS Map 15-3.

Two box cores from OCS Block 184 were examined for benthic foraminifera. Box core 34 was collected at 27°47.05′N; 91°30.5′W from a depth of 542 m (uncorrected wire length). This sampling site is situated in a seismic "wipe-out zone" (Kennicutt *et al.*, 1985), an area in which the stratification of sediments in seismic records is masked by the presence of gas or gas hydrates. This box core recovered an entanglement of tube worms and bivalves which were associated with visibly oil-stained sediment. A piston core taken at the same location as Box core 34 recovered authigenic carbonate rubble and gas hydrates in sediments that were oil-stained, gassy and emitted a strong H_2S odor (R.F. Commeau, personnal communication 1987). A second nearby box core (BC-32) collected in a non-wipe-out zone (27°48.1′N; 91°30.7′W, 532 m uncorrected water depth) did not contain chemosynthetic macrofauna and serves as a control station for Block 184. Sediments in a piston core taken in the non-wipe-out zone were not visibly oil-stained and did not emit a noticeable H_2S odor (R.F. Commeau, personnal communication 1987).

A second set of box cores was gathered in OCS Block 272, which is situated downslope from Block 184. Box core 10 was collected in a wipe-out zone at 27°40.39′N, 91°31.80′W from a depth of 685 m. This box core contained visibly oil-stained sediment, but did not recover any macrofauna typical of the oil seep community. The control station in this area (non-wipe-out zone, box core 11) was recovered at 27°40.34′N, 91°29.93′W from a depth of 696 m. This station is outside the area of hydrocarbon seepage identified on seismic records. Sediments in a piston core taken at the control station were not visibly oil-stained or gassy and did not have a H_2S odor.

METHODS:

Samples from all of the box cores were collected from the surface layer (0 - 1.5 cm) and sieved through a 63 micron screen. Agglutinated foraminifera were picked from the >63 micron fraction from each sample and mounted on cardboard slides. The taxonomic classification used here is adopted from Schroder (1986a,b). Although these samples were not stained, one can assume that a large portion of the agglutinated assemblage was alive at the time of collection, because dead tests readily disintegrate. In the modern North Atlantic, Schroder (1986a) reported that ~40% of the total agglutinated assemblage in the surface layer of sediment was alive at the time of collection. In Leg 96 Holes in the Gulf of Mexico, agglutinated foraminifera which utilize organic cement are absent below the oxidized surface layer (Schroder 1986b).

RESULTS:

Tables 2-6 and 2-7 present a faunal census of agglutinated taxa from the two Block 184 and Block 272 samples, respectively. Calcareous benthic taxa from these samples are currently being studied by other workers and will be reported elsewhere. The control sample from Block 184 contains 33 species of agglutinated foraminifera represented by 254 individuals. The agglutinated fauna in this core is numerically dominated by hormosinids and astrorhizids (Fig. 2-8). Both infaunal varieties (hormosinids) and epifaunal components (astrorhizids, ammodiscids, trochamminids) are well represented in the total assemblage.

In contrast to the control sample, the agglutinated fauna from the Block 184 hydrocarbon seep area (BC-34) is depauperate, consisting of only 16 species which are numerically dominated by the trochamminids, ammodiscids and textulariids (Fig. 2-8). Relative to the control sample, this assemblage displays an increased dominance of Trochammina glabra, Glomospira charoides, and Textularia wiesneri. The infaunal genus Reophax is noticeably lacking. One species (Ammobaculites agglutinans) was present in the hydrocarbon seep area, but not in the control sample.

Block 272 is located farther offshore and downslope from Block 184, and the microfauna from this area differs in the relative proportions of faunal groups (Fig. 2-9). The control sample (BC-11) contains 36 species of agglutinated foraminifera, and astrorhizids comprise of over 50% of the assemblage. The assemblage in BC-11 is dominated by Rhizammina indivisa, with subdominant Saccorhiza ramosa, Glomospira spp., Karreriella sp. (minute), and H. bradyi.

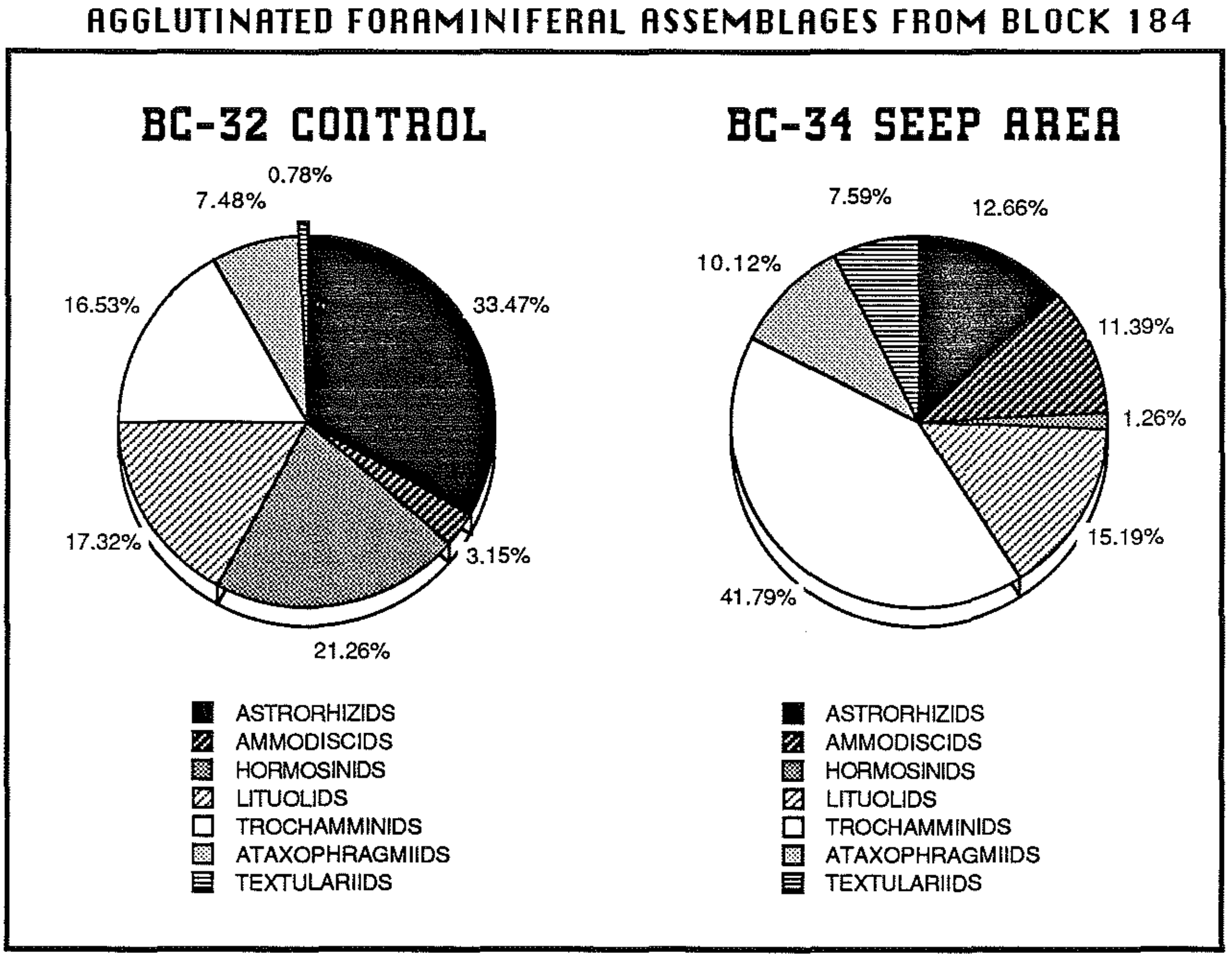
The sample from the hydrocarbon seep area (BC-10) in Block 272 is less diverse (with 25 species) and is co-dominated by Saccammina spherica, Trochammina glabra, Reophax dentaliniformis, H. bradyi and R. indivisa. Most noteable in this sample are the presence of Textularia wiesneri and Ammobaculites agglutinans, which were not found at the control station. In contrast with the samples from Block 184, the seep assemblage in Block 272 contains an increased proportion of hormosinids.

Table 2-8. Faunal data from OCS Block 184, Louisiana continental slope.

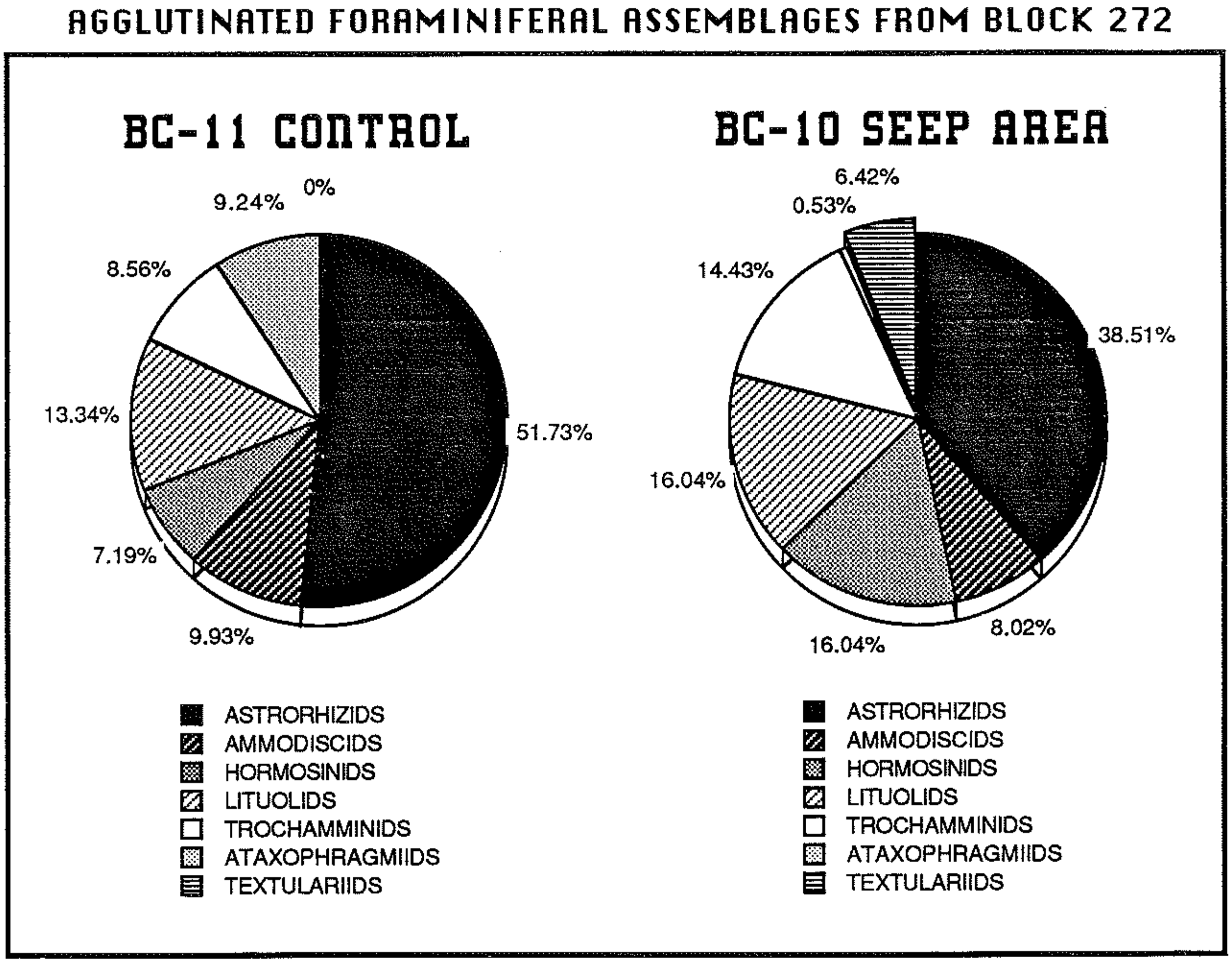
SPECIES NAME	CONTROL BC-32	SEEP AREA BC-34
ASTRORHIZIDS --		
Saccorhiza ramosa (Brady)	19	0
Technitella legumen Norman	3	4
Rhabdammina discreta Brady	16	0
Rhizammina indivisa Brady	16	0
Bathysiphon sp.	6	0
Hyperammina laevigata Wright	9	1
Saccammina sphaerica Brady	15	5
Lagenammina sp.	1	0
AMMODISCIDS --		
Glomospira charoides (Jones & Parker)	6	8
Ammodiscus incertus (d'Orbigny)	2	1
HORMOSINIDS --		
Astrammina sphaerica (Heron-Allen & Earland)	1	0
Reophax agglutinans Cushman	8	0
Reophax scorpiurus Montfort	7	0
Reophax dentaliniformis Brady	16	0
Reophax horrida Cushman	19	1
Reophax guttifer Brady	3	0
LITUOLIDS and LOFTUSIIDS --		
Ammobaculites agglutinans (d'Orbigny)	0	7
Ammobaculites exiguus Cushman	1	0
Haplophragmoides sphaeriloculus Cushman	2	0
Haplophragmoides bradyi (Robertson)	31	5
Cyclammina trulissata (Brady)	2	0
Recurvoides scitulus (Brady)	3	0
Adercotryma glomerata (Brady)	5	0
TROCHAMMINIDS --		
Conotrochammina sp.	11	10
Cystammina pauciloculata (Brady)	4	0
Trochammina glabra Heron-Allen & Earland	7	19
Trochammina globigeriniformis (Parker & Jones)	15	4
Trochammina rotaliniformis Heron-Allen & Earland	5	0
ATAXOPHRAGMIIDS --		
Clavulina sp.	1	1
Karreriella conversa (Grzybowski)	9	3
Karreriella sp. (minute)	7	4
Eggerella bradyi (Cushman)	2	0
TEXTULARIIDS --		
Textularia wiesneri Earland	2	6
SUM	254	79

Table 2-9. Faunal data from OCS Block 272, Louisiana continental slope.

SPECIES NAME	Control BC-11	Seep BC-10
ASTRORHIZIDS --		
Saccorhiza ramosa (Brady)	26	3
Technitella legumen Norman	1	2
Rhabdammina discreta Brady	11	8
Rhizammina indivisa Brady	62	16
Rhizammina (with planktonic tests)	3	2
Hyperammina cylindrica Parr	2	0
Rhabdammina (large, coarse)	13	13
Hyperammina laevigata Wright	15	2
Dendrophrya arborescens Brady	1	4
Saccammina sphaerica Brady	14	22
Lagenammina sp.	3	0
AMMODISCIDS --		
Glomospira charoides (Jones & Parker)	23	8
Ammodiscus incertus (d'Orbigny)	3	7
Tolypammina sp.	3	0
HORMOSINIDS --		
Hormosina carpenteri Brady	4	0
Reophax agglutinans Cushman	4	0
Reophax scorpiurus Montfort	4	0
Reophax dentaliniformis Brady	3	18
Reophax horrida Cushman	3	8
Reophax guttifer Brady	1	0
Reophax pilulifer Brady	0	1
Hormosina ovicula Brady	0	3
Subreophax aduncus (Brady)	2	0
LITUOLIDS and LOFTUSIIDS --		
Ammobaculites agglutinans (d'Orbigny)	0	3
Ammobaculites exiguus Cushman	1	0
Haplophragmoides sphaeriloculus Cushman	4	4
Haplophragmoides bradyi (Robertson)	19	17
Cyclammina trulissata (Brady)	2	0
Recurvoides scitulus (Brady)	3	4
Recurvoides (large)	3	0
Adercotryma glomerata (Brady)	6	0
Discammina compressa (Goes)	1	0
Cribrostomoides wiesneri (Parr)	0	2
TROCHAMMINIDS --		
Cystammina pauciloculata (Brady)	1	1
Trochammina glabra Heron-Allen & Earland	13	20
Trochammina globigeriniformis (Parker & Jones)	10	6
Trochammina (with planktonic tests)	1	0
ATAXOPHRAGMIIDS --		
Clavulina sp.		
Karreriella conversa (Grzybowski)	5	0
Karreriella sp. (minute)	20	0
Eggerella propinqua (Brady)	2	1
TEXTULARIIDS --		
Textularia wiesneri Earland	0	12
SUM	292	187



2-8. Relative proportions of superfamily groups in control sample and at hydrocarbon seep stations in Block 184.



2-9. Relative proportions of superfamily groups in control sample and at hydrocarbon seep stations in Block 272.

DISCUSSION:

The identification of bathyal agglutinated foraminiferal assemblages associated with organic-rich substrates and chemosynthetic macrofauna places ecological constraints on some common modern agglutinated species. In both study areas, the hydrocarbon seep assemblage is characterized by a decrease in the proportion of astrorhizids and a corresponding increase in the relative abundance of trochamminids and textulariids. The most pronounced differences beween control and hydrocarbon seep assemblages are observed in Block 184, which was not unexpected because the hydrocarbon seep site sampled in this area harbors a chemosynthetic community. Although chemosynthetic communities do exist in Block 272, the samples did not recover chemosynthetic macrofauna at this site.

The genera _Technitella_ and _Trochammina_ are considered to be epifaunal, some species of which live as epiphytes attached to algae or other objects above the sediment/water interface (Haynes, 1981; Jones and Charnock, 1985). Since Box core 34 contained a chemosynthetic community including vestamentiferian tube worms, the abundance of _Trochammina_ is not suprising. Although the seep sample from Block 272 did not contain tube worms, the assemblage from Box core 10 possesses an increased percentage of _T. glabra_. However, whether the trochamminids and technitellids are more closely associated with the substrate or the tube worms awaits further study. Fossil associations with abundant _Trochammina_ have also been found in organic carbon-rich sediments from the Jurassic Agardhfjellet member in Spitsbergen (Nagy _et al._, in press). These authors also found an inverse relationship between TOC values and the diversity of benthic foraminifera, a pattern also evident in the Green Canyon area box cores.

A species which is clearly associated with the hydrocarbon seep community in Block 184 is _Glomospira charoides_. This is a stratigraphically long-ranging species that is known to occur in presumed carbon-rich, oxygen-deficient paleoenvironments such as those represented by the Mediterranean Pleistocene sapropels (Cita and Grignani, 1982) and by the Cenomanian/Turonian "Black Band" of northwest Europe (Hart and Bigg, 1983). The finding of _G. charoides_ in Box core 34 confirms the observation that this species tolerates or favors organic-rich substrates. The paleoceanographic significance of Eocene _Glomospira_ assemblages is discussed in Chapter 5.

The lack of infaunal forms at the hydrocarbon seep site in Block 184 may indicate anoxic or otherwise toxic conditions at shallow depth in the sediment. However, the epifaunal tubular varieties also occur in much reduced numbers compared with the control site. According to Jones and Charnock, tubular forms such as Rhizammina and Rhabdammina are regarded as suspension feeders. By analogy with hydrothermal vent communitiies (Lonsdale, 1976), submarine hydrocarbon seep communities ought to be enriched in the suspension-feeding organisms owing to the abundance of chemosynthetic bacteria. If tubular varieties are indeed suspension feeders, their near absence in BC-34 is enigmatic and warrents further study.

CONCLUSIONS:

Agglutinated foraminiferal assemblages on the Louisiana continental slope display distinct changes in connection with organic-rich substrates and hydrocarbon seep communities. At both locations studied, the hydrocarbon seep samples contain Textularia wiesneri and Ammobaculites agglutinans, species which are absent or rare in control samples. Both sites also display changes in the relative abundance of superfamily groups. Trochamminids and textulariids display increased relative abundance at the hydrocarbon seeps, but contrary to expectations the astrorhizids are less common in hydrocarbon seep samples than in control samples. At the highly organic-rich substrate in Block 184, infaunal morphotypes are absent and the predominant species are Trochammina glabra and Glomospira charoides. Similar types of assemblages have been reported from organic-rich sediments as old as Jurassic in age.

SECTION C:

PALEOENVIRONMENTAL ANALYSIS USING AGGLUTINATED ASSEMBLAGES: THE NEOGENE RECORD OF ODP SITE 646, EIRIK RIDGE

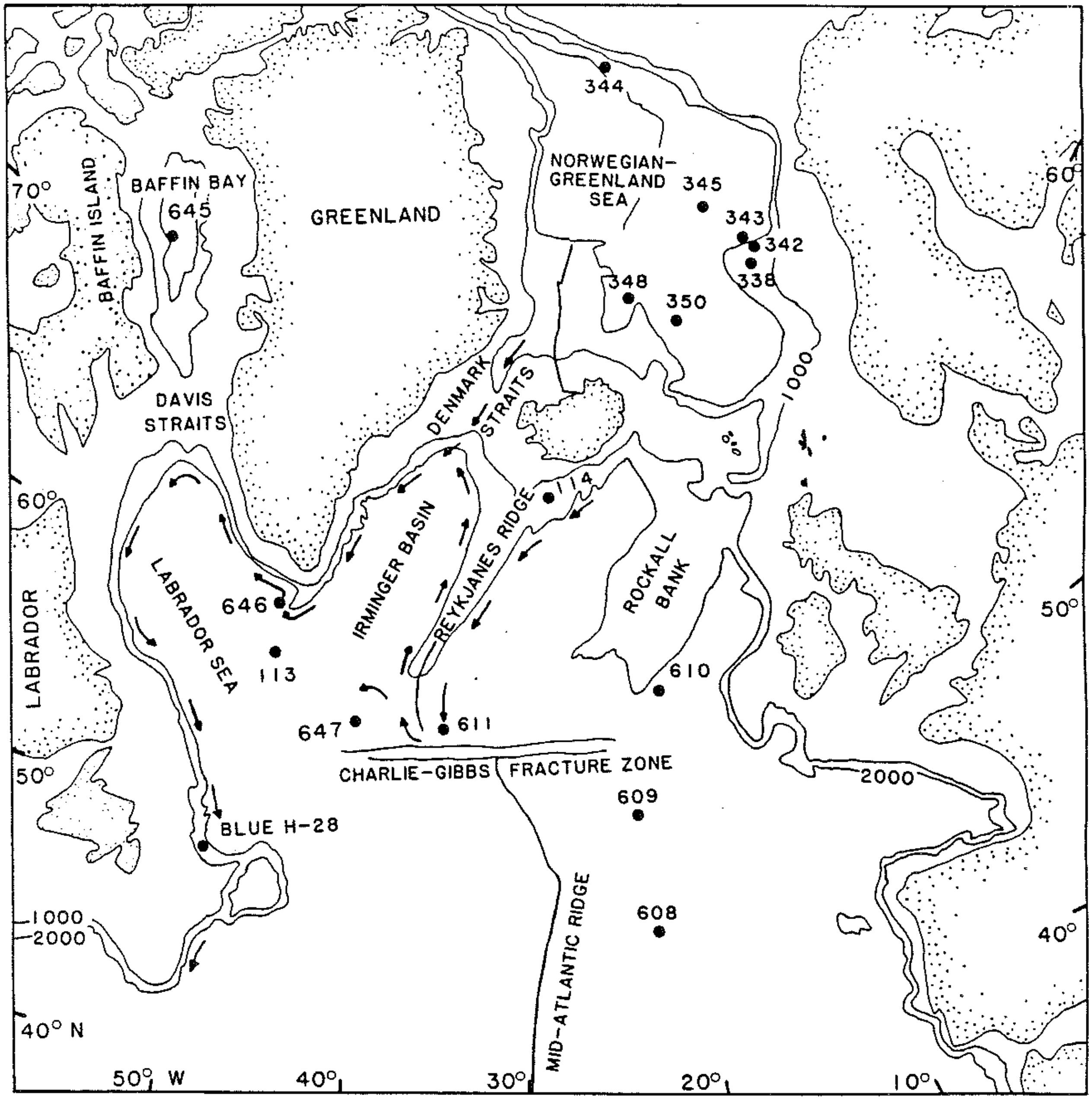
INTRODUCTION

In areas where disturbance by bottom currents results in population reduction, epifaunal species may be at risk and the rigorous environment may favor infaunal or opportunistic species. This information, if preserved in the fossil record, may be useful for determining whether vigorous deep currents were present in a given area. In this study, I test this assumption by examining the agglutinated component in modern deep-sea settings and using the resultant ecologic information to interpret the paleoenvironment of Neogene agglutinated assemblages recovered on ODP Leg 105.

Another aspect of the ecology of agglutinated foraminifera that has been studied is their agglutinating behavior (Schroder 1986a). Since this group incorporates particles of the local sediment into their tests with a varying degree of selectivity, agglutinated species respond to changes in the substrate (Schroder 1986a). Both substrate and stability of the benthic environment are influenced by the local hydrographic regime, such as the presence of a nepheloid layer or strong bottom currents which scour or otherwise disturb the sea floor. Therefore, one might ask whether agglutinated assemblages reflect the dynamic properties of their environment.

SAMPLE LOCATION:

Site 646 was drilled in 3450 meters of water on the northwest flank of the Eirik Ridge, a prominent sediment drift located off the southern tip of Greenland (Fig 2-10). The Eirik Ridge is a current-generated feature which is situated close to the present pathway of Denmark Straits Overflow Water. Drilling in Hole 646B recovered 766.7 m of terrigenous silty clays and silts with varying amounts of biogenic components. Dropstones are present to a depth of 236.4 mbsf and define the base of Lithologic Unit 1. Biogenic silica is present to a depth of 330 mbsf. Lithologic Unit 2 extends from 236.4 mbsf to the base of Hole 646B, and consists of silty claystones and clayey siltstones with layers containing up to 50-60% nannofossils.



2-10. Location of ODP and DSDP Sites and exploration wells in the Labrador Sea and Baffin Bay. Arrows indicate inferred pathways of deep circulation in the western North Atlantic. Base map is from Srivastava and Tapscott (1986).

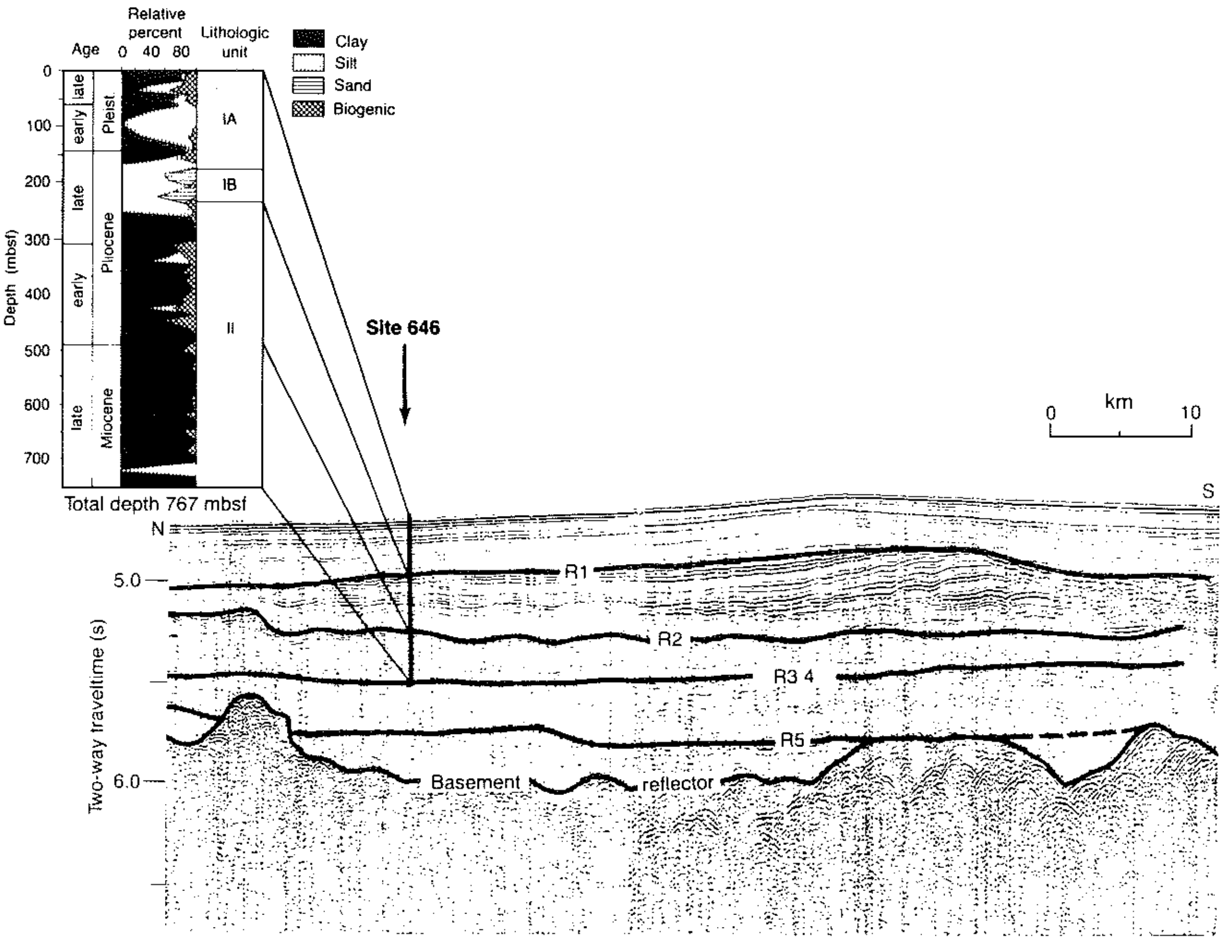
Prominent seismic reflectors subdivide the sedimentary record of Hole 646B into four major seismic units (Fig 2-11). Seismic reflector "R1" defines the base of Seismic Unit 1, and corresponds to a lithologic break between ice-rafted sediments and pre-glacial Pliocene sediments at 236.4 mbsf. Seismic Unit 1 therefore coincides with Lithologic Unit 1. Seismic Unit 2 encompasses the drift sequence between 236.4 and 377 mbsf. The base of Seismic Unit 2 in Hole 646B lies conformably on Seismic Unit 3 and delineates the base of the sediment drift sequence visible in seismic profiles across the Eirik Ridge. Locally, the base of Unit 2 is expressed as an erosional unconformity, but there is no evidence of a hiatus in Hole 646B. Reflector "R2" corresponds to a change in carbonate content at ~500 mbsf, about 0.05 seconds below the top of Seismic Unit 3. Seismic Unit 3 extends from 377 to 680 mbsf, and its base is delineated by seismic reflector "R3". Reflector "R3" is actually a couplet of closely-spaced reflectors corresponding to changes in the carbonate content of the sediment at 680 and 710 mbsf. Below 710 mbsf, the sediments of Seismic Unit 4 are comprised of dark gray silty claystones with carbonate contents below 10%.

RESULTS

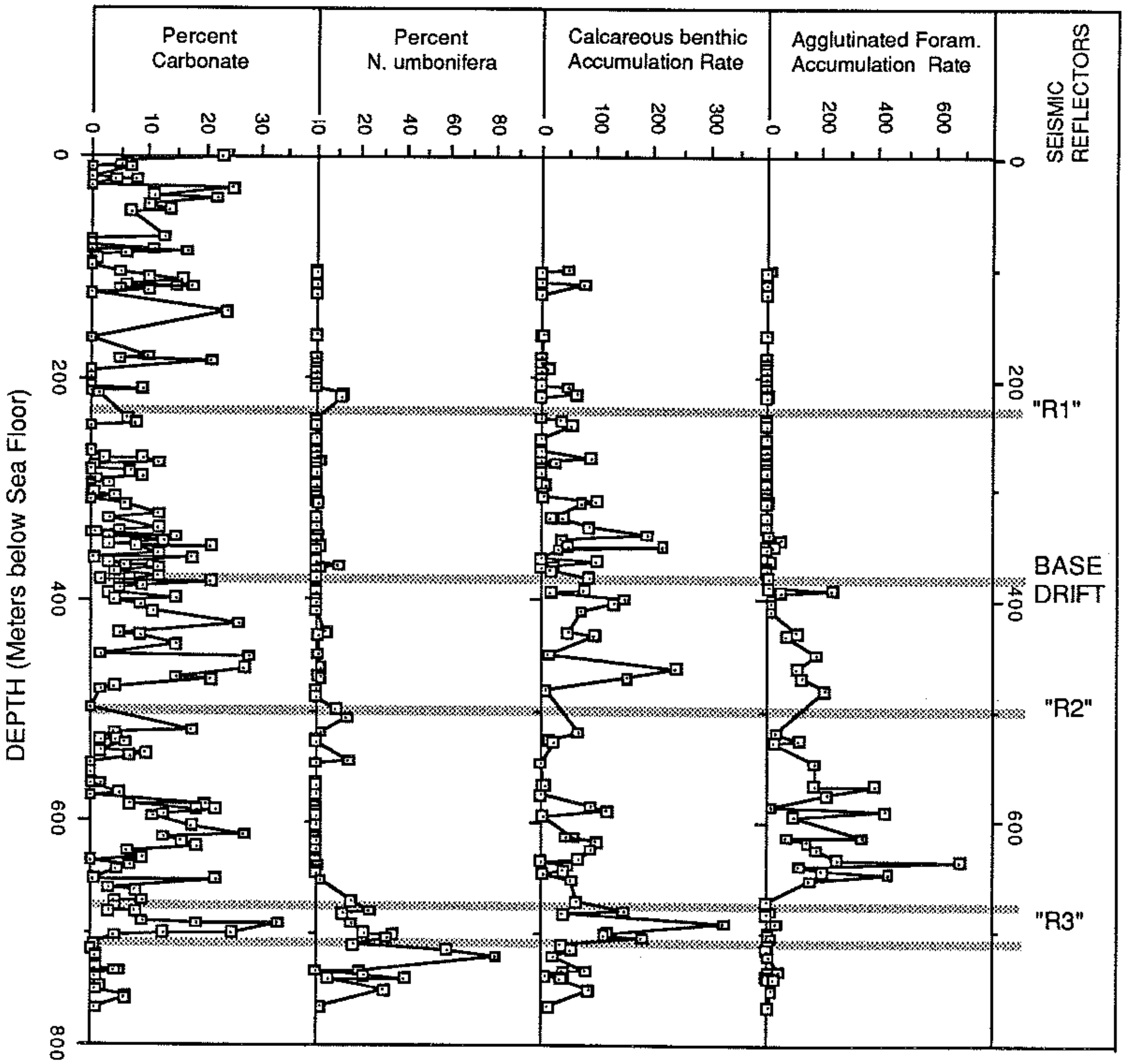
A. Site 646 Biostratigraphy --

A total of 140 samples from Holes 646A and 646B were examined for benthic foraminifera; faunal abundance data was given in Kaminski *et al*. (in press, c). The planktonic foraminiferal biochronology of this site is discussed by Aksu and Kaminski (in press). For this study, foraminiferal accumulation rates were calculated and plotted with respect to the carbonate record and the regional seismic reflectors (figure 2-12). The record of important first and last benthic foraminiferal occurrences is presented in figure 2-13. In Hole 646B, major changes in the benthic foraminiferal assemblages occur in close proximity to several of the seismic reflectors identified from shipboard seismic and downhole logging studies. The composition of each assemblage is discussed below.

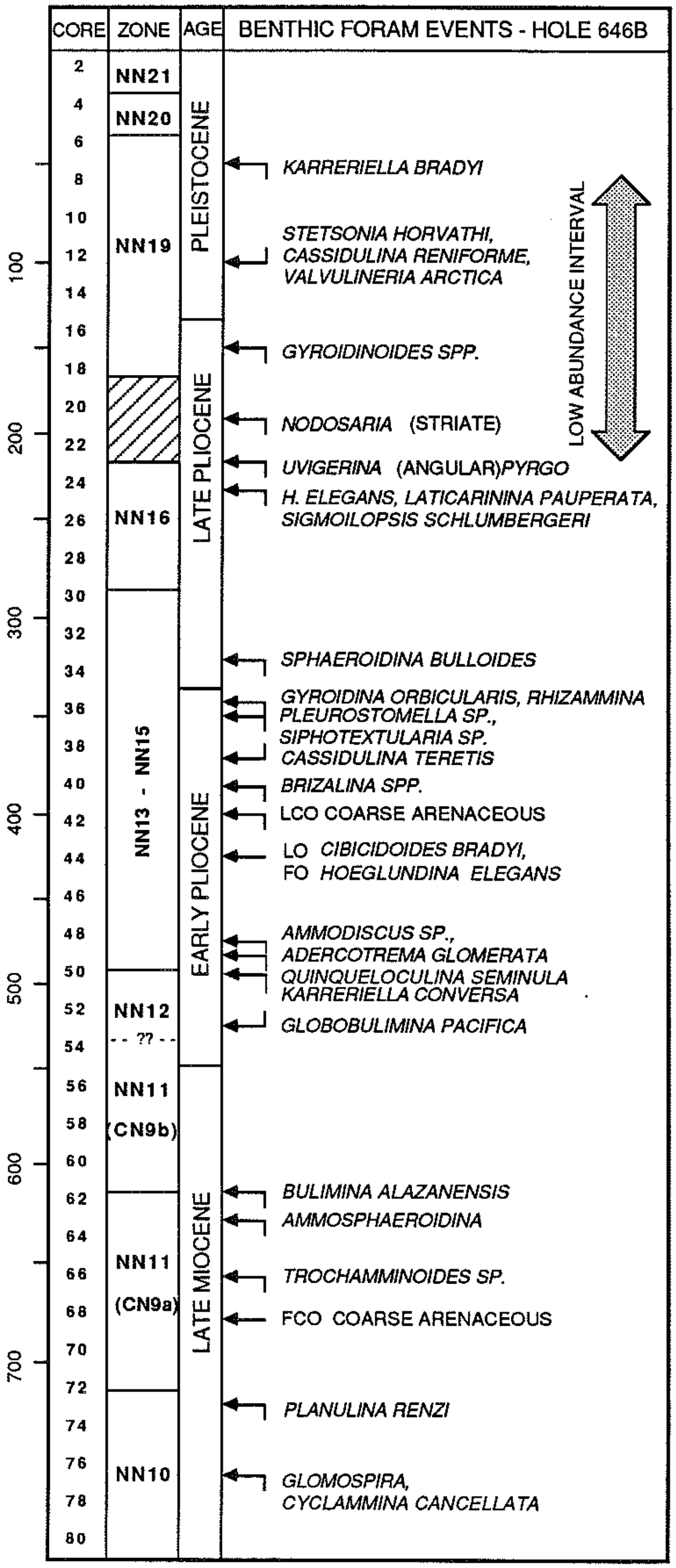
The upper interval of Seismic Unit 1 between 0 and 45.0 mbsf (Samples 105-646B-1H-2, 33-35 cm to -6H-2, 13-15 cm) contains an abundant fauna dominated by *Stetsonia horvathi*, with common occurrences of *F. fusiformis* and *Pullenia subcarinata*. The species *Epistominella exigua*, *Melonis barleeanum*,



2-11. Lithostratigraphic and Seismic Units of Site 646, correlated to regional seismic reflectors on a single-channel seismic line crossing the Eirik Ridge.



2-12. Accumulation rates of benthic foraminifera (# specimens/cm^2/k.y.), calcium carbonate content and percent *Nuttallides umbonifera* in Hole 646B. Also shown are the depths of important regional seismic reflectors.



2-13. Record of first and last occurrences of benthic foraminifera in Hole 646B, plotted against shipboard nannofossil stratigraphy. FO = first occurrence, FCO = first common occurrence, LO = last occurrence.

Planulina wuellerstorfi, *Cassidulina* spp. and *Pullenia bulloides* are present throughout this interval in lower but significant percentages. The uppermost sample (105-646B-1H-2, 33-35 cm) is co-dominated by *Pullenia subcarinata*, *M. barleeanum*, *F. fusiformis* and *Uvigerina* sp. The assemblages in the upper part of Unit 1 generally display good preservation.

Between 53.1 and 101.4 mbsf (Cores 105-646B-6H and -11H) the sediments are essentially barren of foraminifera, except for Sample 105-646B-9H-5, 138-140 cm which contains abundant *Fursenkoina fusiformis* and *Bolivina arctica*, and Sample -8H-3, 108-110 cm which contains a few specimens of *Oridorsalis*. A major turnover in the benthic assemblage occurs near the base of Seismic Unit 1, which overlies the sediment drift. Between 206 and 236 mbsf (Samples 105-646B-23X-5, 122-124 cm to -25X, CC), the last occurrence of *Laticarinina pauperata*, *Hoeglundina elegans*, and *Sigmoilopsis schlumbergeri* is encountered. In the Norwegian-Greenland Sea, *Laticarinina* and *Hoeglundina* also disappear before the onset of glacial conditions (Talwani, Udintsev, *et al.*, 1976). At Rockall Margin Site 552A, the LO of *Laticarinina* was recorded in the late Pliocene by Murray (1984). The lower part of Seismic Unit 1 contains a low abundance *Melonis barleeanum* assemblage. Assemblages with common *M. barleeanum* are typical of glacial sediments in lower bathyal DSDP Sites in the Northern North Atlantic (Murray, 1984) and in the Norwegian-Greenland Sea (Talwani, Udintsev, *et al.*, 1976).

Within the sediment drift (Seismic Unit 2), the abundance of benthic foraminiifers is still low, and the assemblage is numerically dominated by *Melonis barleanum*, *Pullenia bulloides*, *Cibicidoides* spp, and unilocular forms (*Lagena*, *Oolina* and *Fissurina*) and entosolenians. This assemblage also contains a greater proportion of species which are typical of modern North Atlantic Deep Water (*Oridorsalis* spp., *Planulina wuellerstorfi*, *Globocassidulina subglobosa*) than assemblages in other seismic units. The first occurrence of *Islandiella teretis* was found in Sample 105-646B-39X-2, 15-17 cm. This species first appears in the upper Pliocene of Rockall Margin sites (Murray, 1984).

The base of the drift sequence was placed at 377 mbsf from the seismic record. A major benthic faunal break occurs between 387.4 and 391.0 mbsf (between Samples 105-646B-41X-5, 10-12 cm and -41X, CC). Below the seismic reflector delineating the base of the drift, the upper Miocene to basal Pliocene benthic foraminiferal assemblages of Seismic Unit 3 are numerically dominated by coarse Rhizammina and associated agglutinated taxa (Cyclammina pusilla, Haplophragmoides, Psammosphaera, Recurvoides, Reophax, Trochammina, Lagenammina, and Ammobaculites). Calcareous benthic foraminifera are numerically subordinate, and are represented by Oridorsalis, Melonis barleeanum, M. pompilioides, Pullenia bulloides, and Cibicidoides spp. Near the middle of Seismic Unit 3, (between Samples 646B-47X, CC and -53, CC) Nuttallides umbonifera occurs sporadically and in low numbers. There is a smaller percentage of unilocular species in Seismic Unit 3 than in the overlying unit.

The upper reflector of the "R3" couplet was originally placed at 680 mbsf (Shipboard Scientific Party, 1987a). Between 671 and 651 mbsf another distinct change in the benthic foraminiferal assemblage occurs: coarse agglutinated taxa become sporadic and rare downhole. The calcareous assemblages within the seismic couplet (Cores 646B-72X and -73X) are transitional between assemblages from Seismic Units 3 and 4. In the six samples examined from Cores 646B-72X and -73X, the proportion of N. umbonifera is approximately equal to the proportion of "NADW species". The calcareous species Planulina renzi was found in samples 646B-73X-2, 58-60 cm and -73X, CC. In the Gulf of Mexico, the last occurrence of this species is reported in Zone N17 (Van Morkhoven et al., 1986).

In Seismic Unit 4 (710 - 766 mbsf), the benthic foraminiferal assemblage is dominated by Nuttallides umbonifera (Fig. 2-12). The abundance of this species is positively correlated with the degree of undersaturation of bottom waters with respect to calcium carbonate (Bremer and Lohmann, 1982). Characteristic accessory species in this assemblage are agglutinated foraminifera with smooth, finely finished tests, such as Bathysiphon, Ammodiscus and Glomospira. Isolated specimens of Cyclammina cancellata also occur near the base of Hole 646B.

PALEOECOLOGY OF NEOGENE AGGLUTINATED FORAMINIFERA:

Neogene agglutinated foraminiferal assemblages are known from silled high-latitude basins such as the Norwegian-Greenland Sea and Baffin Bay, but until now, Neogene agglutinated assemblages have not been reported from any DSDP site in the deep North Atlantic. Agglutinated assemblages are present in Paleogene sediments of the Labrador Sea (Gradstein and Berggren, 1981) as well as in the modern North Atlantic (Schroder 1986a), but are usually not preserved in Neogene sediments. Until now the only link in time between these occurrences has been the Pliocene agglutinated assemblages in cutting samples from the Texaco Blue H-28 well on the northern Grand Banks. Therefore, the microfossil record from Hole 646B is unique in containing cores with well-preserved agglutinated foraminifera.

The presence of agglutinated foraminifera in Cenozoic sediments is usually associated with sediment parameters allowing the preservation of organic matter. The ecology of early Cenozoic "flysch-type" agglutinated assemblages was discussed by Gradstein and Berggren (1981) and Miller et al. (1982). These authors noted the occurrence of these assemblages in areas of rapid sedimentation and in sedimentary basins containing corrosive bottom water. The set of environmental conditions associated with flysch-type assemblages has become known as the "old bottom water model". The disappearance of these assemblages from the deep Labrador Sea near the Eocene/Oligocene boundary was correlated with the onset of vigorous deep circulation and more oxygenated conditions (Miller et al. 1982, Miller and Tucholke, 1983). After this event in the North Atlantic, agglutinated assemblages persisted only in the high-latitude basins. In accordance with the old bottom water model, in order for agglutinated assemblages to be preserved in the upper Miocene to lower Pliocene of the Labrador Sea, sediment parameters or bottom water properties must have surpassed a certain threshhold. But which parameter or combination of parameters is unique to Site 646?

A compilation of sediment properties (Table 2-10) reveals that Site 646 has little in common with most Atlantic sites. With the exception of Site 114 on the east flank of the Reykjanes Ridge, lower Pliocene sediments in the Eastern Altlantic are nannofossil oozes with high calcium carbonate contents. Hole 114 penetrated drift sediments with a carbonate content of about 26% and a higher sedimentation rate than in Hole 646B, but no agglutinated assemblages were recovered.

The Miocene to early Pliocene deep water in the Norwegian-Greeland Sea and Arctic was apparently corrosive, since carbonate contents at deep sites are less than 1 percent (Talwani, Udintsev, et al., 1976). Agglutinated foraminiferal assemblages are present in pre-glacial Pliocene sediments of Hole 344 on the Knipovich Ridge and Hole 345 in the Lofoten Basin. In Cores 26-33 of Hole 344, the generic composition of the foraminiferal assemblage is remarkably similar to the assemblages in the Eirik Ridge. The assemblage consists mainly of *Bathysiphon*, *Haplophragmoides*, *Reophax*, *Hormosina* and *Saccammina*, but at some levels *Melonis barleeanum* and *I. teretis* occur with the planktonic species *Neogloboquadrina atlantica*. The last occurrence of coarse agglutinated species is associated with the appearance of ice-rafted sediments in Hole 345. The pre-glacial assemblage at this site is more diverse than the underlying Miocene assemblage and contains *Cyclammina*, *Haplophragmoides* and *Martinotiella* (Talwani, Udintsev, *et al*., 1976).

I speculate that the coarse agglutinated assemblages at Site 646 indicate the presence of old, corrosive bottom water derived from the Norwegian-Greenland Sea. Labrador Sea Hole 113 recovered a thick sequence of turbidite sediments in a local topographic depression. Calcium carbonate content is low, and sedimentation rate is higher than in Hole 646B. However, Hole 113 is not in the pathway of Denmark Straits Overflow water.

The trophic structure of the agglutinated foraminiferal assemblage is another clue to the nature of the depositional environment at Site 646. The assemblage in Seismic Unit 3 is strongly dominated by coarsely agglutinated specimens of *Rhizammina*, which is reported to be an epibenthic suspension-feeder (Jones and Charnock, 1985). Benthic communities dominated by suspension-feeders are rare in the deep sea (Jumars and Gallagher, 1982), since the proportion of suspension-feeders to deposit-feeders normally declines with depth and distance from shore (Levinton, 1982). Suspension-feeding communities in the deep sea have only been found near hydrothermal vents (Lonsdale, 1977) or in areas where there is a lateral advection of food particles (L. Mullineaux, personal communication, 1987). In Alvin dives, H. Sanders (personal communication, 1987) has observed concentrations of suspension-feeding animals atop local topographic elevations, while local depressions are occupied by deposit-feeders. In the modern North Atlantic, there is an increased proportion of the coarse tubular agglutinated species beneath the Western Boundary Undercurrent (Schroder 1986a). A *Rhizammina* community, therefore, presumably requires moving bottom currents to supply it with food. However, the genus is sessile and probably cannot escape the effects of strong bottom currents. The change from agglutinated asssemblages below the sediment drift to calcareous assemblages in the drift may reflect higher bottom current intensities, which would have inhibited *Rhizammina* and resulted in increased ventilation of the deep environment.

Table 2-10. A compilation of sediment parameters from DSDP and ODP sites in the North Atlantic with the occurrence of agglutinated assemblages noted.

Location	SITE	CORES	Latitude	Depth	WBD	TOC	%CARB	%Clay	%Sand	Silica?	Drift?	Sed Rate	Aggl?
LAB SEA	646	26-33	58*13'N	3455	2	0.4	0-20	90	5	no	yes	90 m/my	yes
	113	7-12	56*47'N	3615	2	0.4	1-12	62	37	no	no	160 m/my	no
	112A	5	54*47'N	3615	1.7	NA	NA	NA	NA	no	no	20 m/my	no
	111A	5-6	50*25'N	1797	1.7	0.1	72	21	54	no	no	0.4 m/my	no
E.N.ATL	114	4-6	59*56'N	1927	1.5	0.1	26	23	20	yes	yes	120 m/my	no
	116	2	57*30'N	1151	1.7	0.1	90	44	5	yes	no	30 m/my	no
	611	22-33	52*50'N	3200	1.8	NA	70	NA	NA	no	yes	58 m/my	no
	610	8-10	53*13'N	2417	1.8	NA	95	NA	NA	no	yes	51 m/my	no
	609	26-31	49*52'N	3883	1.8	NA	90	NA	NA	no	no	89 m/my	no
	608	13-15	42*50'N	3541	1.7	NA	95	NA	NA	no	no	19 m/my	no
	552A	14-23	56*03'N	2311	1.7	0.1	93	80	5	yes	yes	25 m/my	no
	553A	3	56*06'N	2339	1.7	0.1	92	90	5	yes	yes	30 m/my	no
	554	5-6	56*18'N	2584	1.7	0.1	97	85	10	yes	no	7 m/my	no
	555	3	56*34'N	1669	1.8	0.1	94	70	15	yes	no	16 m/my	no
G-S Ridge	407	8-14	63*56'N	2492	1.6	NA	85	NA	NA	no	no	45 m/my	no
	408	11-13	63*23'N	1634	1.6	NA	35	NA	NA	yes	no	35 m/my	no
N-G SEA	337	4-5	64*53'N	2657	1.5	0.2	NA	40	8	no	no	2 m/my	no
	344	26-33	76*09'N	2201	2.1	0.8	1	45	5	no	no	76 m/my	yes
	345	5,cc-6	69*50'N	3216	1.7	0.4	1	NA	NA	no	no	NA	yes
	348	6-7	68*30'N	1777	1.4	0.3	1	50	5	yes	no	22 m/my	no

WBD = Wet Bulk Density, TOC = Total Organic Carbon
Silica? = Presence of biogenic silica, Drift? = Site located on sediment drift
Aggl? = Presence of agglutinated foraminifers

Table 2-11. Summary of important benthic foraminiferal species and species groups in Hole 646B. Numbers represent the mean values of census data from each seismic unit. Seismic Unit 3/4 samples are from the calcareous interval within the reflector "R3" couplet. "NADW species" include the combined relative abundance of *P. wuellerstorfi*, *Oridorsalis*, *G. subglobosa* and *E. exigua*.

TAXA	Seismic Unit 2	Seismic Unit 3	Seismic Unit 3/4	Seismic Unit 4
Melonis spp	18.1%	5.2%	12.1%	3.2%
Smooth Agglutinated spp.	0.0	0.0	0.7	7.0
Coarse Agglutinated spp.	7.0	65.6	8.0	13.9
Nuttallides umbonifera	0.9	0.9	18.4	25.0
NADW species	10.3	4.9	19.4	11.5
Other	63.7	23.3	41.3	39.4
n	32	40	6	12

In contrast, the assemblage in Seismic Unit 4 of Site 646 contains a greater proportion of species with finely agglutinated tests (Table 2-11). Species restricted to this assemblage, Ammodiscus and Glomospira, have been identified as epifaunal detrital feeders (Jones and Charnock, 1985) and presumably have a low tolerance for disturbed environments. In the modern North Atlantic, these organisms are present in greater proportion in environments that are relatively undisturbed by bottom currents (Kaminski, 1985).

The agglutinated assemblages from the Texaco Blue H-28 well are remarkably similar to those from Seismic Unit 3 in Hole 646B. Each species found by us in the Pliocene of the Blue H-28 well also occurs in Hole 646B, and specimens of Rhizammina are about the same size. This well site is located under the current axis of the Western Boundary Undercurrent. The predominant lithology is hemipelagic clay, and sedimentation rates increase dramatically from 100 m/my in the late Miocene to ~300 m/my in the Pliocene and Pleistocene. In the Miocene interval of the well, the occurrence of agglutinated taxa is fairly continuous, but in the Pliocene, agglutinated taxa cluster at discrete levels. I tentatively interpret the preservation of this fauna as an indication of periods of slower deposition. The highest level with agglutinated taxa at 2610 mbsf may coincide with an increase in local WBUC circulation near the onset of ice rafting at 2.5 Ma. However, the exact chronology cannot be resolved.

One of the key environmental factors controlling the presence of Neogene flysch-type faunas in the high-latitude North Atlantic basins appears to be the local formation of bottom waters. The change from a predominantly agglutinated assemblage to a calcareous assemblage in the Pliocene is associated with the onset of drift sedimentation at Site 646. This change may reflect a change in deep-water properties and current intensities which may be ultimately linked to the initiation of convective overturn of deep waters and the onset of vigorous circulation in the Norwegian-Greenland Sea. Agglutinated assemblages are present in the Miocene to lower Pliocene of Norwegian-Greenland Sea sites, but the present microfossil chronology of the area does not provide the resolution to determine if the last occurrence of flysch-type taxa is isochronous in both regions. However, I speculate that the events are closely linked. Agglutinated assemblages persisted to younger stratigraphic levels in the deep Arctic Ocean. In some of the longer cores obtained by the Arctic Ocean CESAR Expedition, the Pliocene/Pleistocene boundary is marked by the LCO of agglutinated foraminifera. This event appears to be correlated with the onset of perennial sea ice formation in the Arctic Ocean (Scott et al., 1987). The formation of dense waters through brine release from sea ice formation apparently ventilates the deep basins. Therefore, the observed pattern of LCO of flysch-type assemblages in the high-latitude North Atlantic basins appears to be consistent with the old bottom water model of Gradstein and Berggren. I believe that the increase in bottom water formation by thermohaline processes resulted in the loss of agglutinated foraminifera from the high-latitude fossil record.

B. BOTTOM WATER HISTORY OF THE EIRIK RIDGE -

1. Modern Hydrographic Setting --

At present, the deep-water masses in the northern Atlantic are derived from both northern and southern sources. Dilute Antarctic Bottom Water (AABW) is present below 2500 m in the Rockall Trough and Iceland basins and is presumed to flow along the eastern Atlantic margin in a weak cyclonic gyre (McCave and Tucholke, 1986). In the Rockall region, this water is joined by Norwegian Sea Deep Water (NSDW) which flows southward through the Faeroe-Shetland Channel and across the Wyville-Thompson Ridge and then turns northwestwards following bathymetric contours around Rockall Bank. Additional amounts of NSDW flow across the Iceland-Scotland Ridge south of Iceland (Worthington and Volkmann, 1965). This flow travels along the eastern flank of the Reykjanes Ridge at a depth of 1300-2200m and passes over the Garder Drift. The flow then descends and passes through the Charlie-Gibbs Fracture Zone into the Labrador Sea.

In the present-day Labrador Sea and Irminger Basin, the deep-water mass consists entirely of northern-source water. The Iceland-Scotland Overflow water flows in a cyclonic loop along the western flank of the Reykjanes Ridge at a depth of around 3200m (Worthington, 1976). Southwest of Iceland, ISOW is joined by cooler, denser Denmark Straits Overflow Water (DSOW) which descends beneath it. The DSOW is derived mainly from Arctic Intermediate Water which forms by winter convection north of Iceland and overlies NSDW (Swift, 1986). This combined flow of ISOW and DSOW forms the Western Boundary Undercurrent which flows southwestward along the eastern margin of Greenland and around the Eirik Ridge (McCave and Tucholke, 1986).

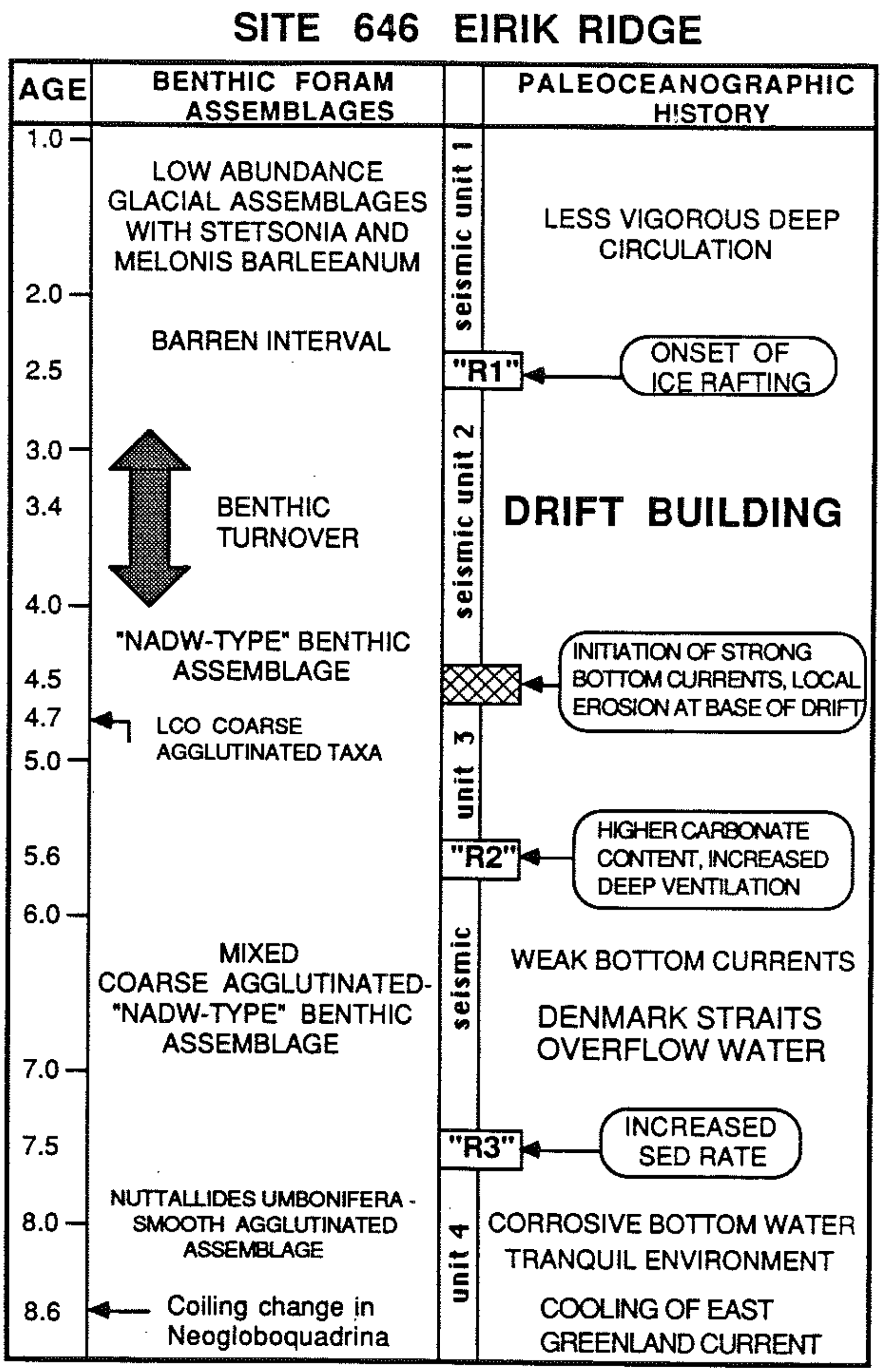
2. History of Deep Circulation --

The dating of regional seismic reflectors at Site 646 reveals a much younger age for the Eirik Ridge than previously predicted. The Eirik Ridge was originally thought to be coeval with the Gloria Drift in the southern Labrador Sea, which is of Oligocene age (Tucholke and Mountain, 1986). Instead, the major period of drift sedimentation at Site 646 occurred in the Pliocene, although there is evidence of weaker currents occurring earlier. The seismic horizon marking the onset of drift deposition at this site is dated at approximately 4.5 Ma, based on the age-depth model for Hole 646B. Although there is no obvious hiatus in Hole 646B, a prominent seismic horizon observed within the drift sequence to the east of Site 646 is interpreted as indicating erosion. This horizon occurs between Reflecctor "R1" and the base of the drift, and by correlation with the reflectors in Hole 646B I interpret the age of this erosional pulse as occurring between 4.5 and 2.5 Ma. This compares well with an age of 3 - 2 Ma for the "Blue" erosional event in the western North Atlantic reported by Tucholke and Mountain (1986).

The history of the deep circulation over the Eirik Ridge can be reconstructed by comparing benthic foraminiferal assemblages at Site 646 with those recovered on Leg 38 (Norwegian-Greenland Sea) and Leg 94 (Eastern Atlantic). Benthic assemblages in Hole 646B display turnovers which may be interpreted as reflecting changes in water mass properties. The occurrence of N. umbonifera with smooth agglutinated taxa in Hole 646B and N. umbonifera assemblages in nannofossil Zones NN10 to NN11 and in Holes 608, 609 and 611C in the eastern Atlantic (Murray, 1987; Thomas, 1987) point to the presence of a sluggish, corrosive deep-water mass in the northern Atlantic basins in the Tortonian. This finding is supported by benthic carbon isotope studies of Miller et al. (1987), which indicate that at ~8 Ma deep water in the North Atlantic did not differ greatly isotopically from deep water in the Pacific. Murray (1987) interpreted the presence of N. umbonifera assemblages in Leg 94 DSDP holes as an indicator of "AABW-type" water in the North Atlantic in the late Miocene. The influence of corrosive deep water persisted into the early Pliocene at Site 611 on the Gardar Drift where assemblages containing both N. umbonifera and modern NADW species were recovered. If ISOW were the predominant water mass over the Eirik Ridge in the early Pliocene, one might expect to find evidence of this entrained corrosive water reflected by assemblages in Hole 646B. However the lack of any assemblages with abundant

N. umbonifera above Seismic Unit 4 (Fig. 2-12, Table 2-11) argues against the influence of this water mass. The assemblages of Seismic Unit 3 are comprised of mainly coarse agglutinated species and Melonis, and are unlike Miocene assemblages at other North Atlantic sites. Instead, the assemblages from Unit 3 bear closest resemblance to pre-glacial assemblages from intermediate and deep depths in the Norwegian-Greenland Sea. A likely cause of this pattern is that Denmark Straits Overflow Water was the dominant deep-water mass over the Eirik Ridge since the late Miocene, displacing the corrosive bottom water in the Irminger Basin at approximately 7.5 Ma (Fig. 2-14). This interpretation is supported by both carbon isotopic evidence and the presence of displaced microfossils. Miller et al. (1987) noted that the benthic carbon isotope record at Site 608 diverged from the Pacific record between 8 and 6 Ma. At ~6 Ma, deep water in the North Atlantic was isotopically enriched with respect to Pacific water, indicating the production of "younger" deep waters analogous to modern NADW. Also, the reworked palynomorph Aquilapollenites was found above reflector "R3" in Hole 646B, but not below (Martin Head, personal communication to MAK, 1987). Aquilapollenites is a high-latitude form known from the Cretaceous sediments of the northern North Sea, Greenland and Svalbard (Batten, 1984). Sedimentologic evidence at Site 646 indicate increased bottom currents and increased sediment accumulation rate above the "R3" seismic reflector (Shipboard Scientific Party, 1987a).

The benthic foraminiferal and seismic data indicate the period of maximum DSOW current velocities occurred between ~4.5 and 2.5 Ma. The disappearance of Rhizammina and coarse grain size of sediments within the drift sequence is evidence of deposition of drift sediments under conditions of increased current velocities. This is in contrast with the model of Miller and Tucholke (1983) who interpret the onset of drift sedimentation to reflect a decrease and stabilization of abyssal circulation. The approximately coeval occurrence of hiatuses in the western North Atlantic and Norwegian-Greenland Sea also suggests increased current velocities at this time. At Sites 338, 342, 348, 350, and 647 glacial Plio-Pleistocene sediments rest on the Miocene, indicating a period of strong current activity possibly associated with the breakdown of a stable, stratified water column. The change from a coarse agglutinated assemblage in Seismic Unit 3 of Hole 646B to a calcareous



2-14. Summary of benthic foraminiferal assemblages and the deep-water history of the Eirik Ridge.

assemblage in Seismic Unit 2 probably reflects the increased ventilation of deep water associated with this current activity.

My observation of DSOW at Site 646 since ~7.5 Ma agrees with findings of Keigwin et al. (1987), who presented isotopic evidence for the continued production of NADW during the Messinian Salinity Crisis. Their results contradict earlier suggestions that the cutoff of Mediterranean Outflow Water during the Messinian would result in a cessation of NADW production in the Norwegian-Greenland Sea (Blanc and Duplessy, 1982). In the basal Pliocene to Messinian sediments beneath the sediment drift, Nuttallides umbonifera is present, but in lower proportions than before 7.5 Ma. The assemblage is still dominated by agglutinated taxa and species typical of modern NADW. The "R2" reflector reflects a change from carbonate-poor sediments (below) to more carbonate-rich sediments (above). This change is interpreted as reflecting increased ventilation of the deep water at ~5.6 Ma. At Site 609 in the eastern Atlantic, an analogous change from poor carbonate preservation (below) to increased carbonate preservation (above) began at ~5.8 Ma and reached a maximum at ~5.3 Ma (Hooper and Weaver, 1987), which suggests that this may be a basin-wide event. Hooper and Weaver interpreted the latest Miocene peak in carbonate preservation as indicating increased contribution of northern-source deep water to the basin at this time.

An increase in the production of NADW may have been caused by a number of oceanographic and climatic factors. Cooler late Miocene sea surface temperatures at high latitudes, culminating in the proposed 5.2 to 4.8 Ma glacial events reported by Keigwin et al. (1987) and Keigwin (in press), may have contributed to greater NADW production. Indeed, the appearance of DSOW at Site 646 is preceeded by a coiling change in Neogloboquadrina atlantica (at ~8.6 Ma) which indicates cooling of the surface waters in the East Greenland Current (Aksu and Kaminski, this volume). With the reopening of the Mediterranean at 4.83 Ma (Zijderveld et al., 1986), the northward advection of saline water to the Norwegian-Greenland Sea combined with cool sea surface temperatures, may have resulted in the production of denser, more oxygenated intermediate and deep waters. This raises the possibility that Mediterranean water may have been a contributing factor to the presence of hiatuses, the onset of drift sedimentation at Site 646 and the LCO of agglutinated taxa. The period of drift formation also correlates with the maximum northward penetration of "AABW" observed in the eastern Atlantic in the early Pliocene by Murray (1987). This correlation suggests that a feedback mechanism or "teleconnection" between NADW and AABW may have been operative in the early Pliocene analogous to the present day (see Johnson, 1982).

CONCLUSIONS:

Information on the trophic structure and life position of agglutinated benthic foraminiferal assemblages can be used to help interpret the depositional environment and water mass history of the Eirik Ridge (Fig. 2-14). Before ~7.5 Ma, an assemblage dominated by Nuttallides umbonifera and smooth agglutinated species point to a tranquil environment with southern-source deep water. After ~7.5 Ma northern-source deep water is present over the Eirik Ridge. Above the "R3" seismic reflector, the benthic assemblage consists mainly of coarse agglutinated taxa with affinities to the Norwegian-Greenland Sea. The predominance of Rhizammina in this assemblage is interpreted as indicating weak bottom currents. The onset of drift sedimentation at the Eirik Ridge at ~4.5 Ma is accompanied by a change to a predominantly calcareous assemblage. This faunal turnover is interpreted as indicating increased ventilation of the deep Labrador Sea owing to a more vigorous flow of Denmark Straits Overflow Water. Drift sedimentation at the Eirik Ridge ceased at ~2.5 Ma, concomitant with the onset of ice-rafting in the North Atlantic.

APPENDIX 2-1. Benthic foraminifera from ODP Hole 646B.

CORE	INTER	DEPTH	Ebrd	SIPH	MART	Kbrd	Ssch	LAGM	RHIZ	PSAM	AMMB	ASCH	TROC	RECV	Cpus	HAPL	REOP	Khor	AMMS	TROI	ADER	AMMD	GLOM	Ccan	PYRG	Qsem	Qang	Qrnd	Tarc	Ttri	OPTH	ORID	Mpom	Psub	CIB	STIL	DENT	FISS	OOLN
12-2	11-13	103.06	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	1	1	2	1	0	0	0
12-5	22-24	104.62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13-2	61-63	113.21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13-5	88-80	114.98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	4	4	0	1	1	1
14-5	81-83	124.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18-1	144-146	160.45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18-2	44-46	161.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20-2	7-9	180.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20-5	108-110	185.59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21-2	118-120	190.92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21-4	118-120	193.89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-2	7-9	199.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22-6	84-86	206.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-2	8-10	209.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	2	0	0	0	1	2
23-5	122-124	214.72	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	1	3	1
23,CC		217.10	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	5	4	2	0	2	0
25,CC		236.10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26-2	20-22	237.80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	1	0
26-5	125-127	243.35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
27,CC		255.70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29-2	14-16	266.94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29-5	88-90	272.18	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	3	0	1	0
29,CC		275.00	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	1	1	0
30-2	73-75	277.23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
30-5	63-65	281.63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31-2	10-12	286.30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31-6	76-78	292.97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31,CC		294.40	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3	0
32-2	58-60	296.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
32-6	98-100	302.88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
33-2	4-6	305.64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
33-5	129-131	311.39	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	2	0	0	4	0	0	0	1	1
33.CC		313.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	5	0	0	3	0	1	2	1
35-2	9-11	324.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
35-3	8-10	326.48	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	2	0	0	0	0
36-2	5-7	334.66	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	1	0	0
36-6	138-140	341.99	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	1	5	2	2	5	2
37-2	16-18	344.47	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	1	0
37-7	16-18	351.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1
37,CC		352.40	12	4	5	0	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	8	1	0	0	0	9	10	4	35	0	6	5	13
38-2	14-16	354.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	5	1	0	0	0	2	0	0	1	0	0	0	1
38-7	28-30	361.69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39-2	15-17	363.66	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	1	7	0	0	1	3
39-5	11-13	368.12	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	5	0	0	0	1
39,CC		371.70	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	2	3	0	0	4	3
40-2	14-16	373.35	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0	1
40-5	127-129	378.98	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2	4	7	0	2	0	3
41-5	10-12	387.41	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	1	0	0	0	4	0	1	7	0	2	1	4
41,CC		391.00	13	2	0	2	1	3	350	6	0	0	5	6	12	0	1	0	0	0	0	0	0	0	1	0	2	0	0	0	0	13	8	0	4	0	2	12	4
42-1	64-66	391.65	0	0	2	0	0	0	30	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3
42-5	89-91	397.90	11	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	3	17	0	0	1	4
43-3	53-55	404.24	8	1	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	4	1	9	0	1	4	2
43,CC		410.40	13	0	1	0	2	0	7	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	14	14	0	6	0	2	2	2
45,CC		429.80	9	0	0	0	0	2	95	15	0	0	2	3	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	7	6	2	2	0	1	0	1

APPENDIX 2-1 (Continued).

46-2	42-44	431.73	3	1	1	0	0	0	35	3	0	0	1	2	3	0	0	0	0	0	0	0	0	0	2	0	0	5	0	0	3	12	1	0	0	0	2	1	2
47,CC		449.10	0	0	0	0	0	4	90	27	3	0	3	4	13	0	1	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	4	1	0	0	1	0	0
49-2	54-56	460.85	11	2	0	0	0	0	64	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	25	7	0	2	0	0	4	3
49,CC		468.50	3	0	3	0	1	2	151	9	2	0	1	2	4	0	0	2	0	0	0	0	0	0	1	0	2	2	0	0	2	7	4	1	1	0	4	1	2
50-2	10-12	470.11	8	0	1	0	0	0	92	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	3	2	0	5	0	0	0	4
51-2	60-62	480.21	0	0	0	0	0	1	126	2	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0
51,CC		487.40	0	0	0	0	0	1	97	8	0	0	1	11	8	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	1	0	0	0	0	0	0	0
52,CC		497.10	5	1	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	4	7	16	0	8	0	6	0	2
53,CC		506.90	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	1	4	0	0	0	1
55-3	33-35	519.84	0	0	0	0	0	0	28	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	0	5	5	0	0	0	3	7	0	0	0	4	1	0
55,CC		526.20	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	2	0	0	0	1
56-1	40-42	526.61	0	0	0	0	0	0	51	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5
56-2	4-6	527.75	1	0	0	0	0	0	9	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2	2	0	0	0	3
57,CC		545.50	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
58-1	59-61	546.10	0	0	0	0	0	1	76	2	0	0	1	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
59,CC		564.40	0	0	0	0	0	1	121	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	2	3	0	4	0	0	0	1
60-1	77-79	565.18	0	0	0	0	0	2	130	8	0	0	0	1	20	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1
60-2	59-61	566.50	0	0	0	0	0	3	184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1
61-2	16-18	575.67	0	0	0	0	0	0	95	9	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61,CC		583.60	2	0	2	0	0	0	24	5	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	8	0	5	2	0	0	0
62-2	2-4	585.13	7	0	0	0	0	0	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	6	3	0	0	1	4	5
62-5	54-56	590.15	24	4	1	0	1	1	300	10	0	0	1	7	4	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	27	3	0	2	0	0	1	8
63-2	14-16	594.85	0	0	0	1	0	4	58	4	3	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
63,CC		602.90	0	0	0	0	0	0	60	2	0	0	0	4	1	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	2	1	0	1	0	0	0	1
64,CC		612.5	4	1	0	0	1	0	330	0	25	0	0	0	6	2	0	0	0	0	2	1	0	0	0	0	2	0	0	0	1	6	5	1	2	2	2	1	3
65-2	3-5	614.04	1	0	0	1	1	0	34	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	3	0	0	0	2	2	1	0	0	0	1	3
65-4	103-105	618.04	2	1	0	0	1	0	52	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0	0	1	4
66-2	34-36	624.05	3	0	1	0	0	0	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	23	2	0	2	0	1	1
66,CC		631.8	3	0	0	0	0	6	205	0	10	2	0	0	0	5	0	0	1	0	1	0	0	0	0	0	1	0	0	0	1	6	3	0	0	0	0	0	2
67-2	111-113	634.42	0	0	0	0	0	7	290	17	3	0	14	5	20	0	2	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67-5	106-108	638.87	4	0	0	0	0	0	78	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	7	0	0	0	3	1	1	1	0	0	1	3
68-2	11-13	642.92	4	1	0	0	0	1	117	2	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	0	2	3	0	0	0	1	7	0	0	0	0	0	3
68-3	47-49	644.78	0	0	0	0	0	0	164	20	2	0	7	0	62	0	4	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
69-1	33-35	651.24	1	0	0	2	0	6	79	4	2	0	2	2	5	0	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2	3	1	0	0	0	1	1
71-2	9-11	671.80	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	1	1	0	2	1
72-1	60-62	680.31	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	5	7	0	6	0	0	3	1
72-2	127-129	682.48	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1
73-2	58-60	691.39	21	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	1	0	0	0	0	40	4	14	8	0	0	6	4
73,CC		699.00	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	2	0	0	0	0	26	3	1	4	0	1	2	2
74-2	0-2	700.51	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	9	2	0	0	0	3	1	3	0	0	1	3	4
74-4	10-12	703.61	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	5	1	15	0	0	1	2	3
75-2	88-90	710.99	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3
75-4	87-89	713.98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	0	0
76-2	17-19	719.98	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
77-4	37-39	732.78	4	0	0	0	0	0	15	1	0	0	0	2	4	0	0	0	0	0	0	5	3	4	0	0	1	0	0	0	3	2	9	1	0	0	0	4	4
77-5	25-27	734.16	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	4	0	3	4	0	0	0	0	3	0	5	0	1	0	3
77,CC		737.70	0	0	0	0	0	0	8	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	2	0	0	1	0	0	0
78-2	8-10	739.29	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	1	3	1	1	0	0	1	3
78-2	40-42	739.61	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	3	1	0	0	4	0	0	0	0	1	0	0	0	2	1	0
79-2	140-142	750.31	5	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	2	0	0	0	1	7	4	0	0	0	1	0	1
80,CC		766.1	1	0	0	0	0	0	6	0	0	0	0	2	2	0	0	0	0	0	0	4	9	0	0	0	4	0	0	0	0	2	2	1	5	0	1	0	3

APPENDIX 2-1 (Continued).

LAGN	Gaur	Gpac	Pwue	ELPH	?ENT	Mbar	GOID	NODO	Nstr	SARA	UVIG	Usma	Numb	PSPL	Pbul	LENT	POLY	Hele	LATI	Eexi	Gsub	EPON	TOSA	FURS	Iter	Bfri	GYRO	Clob	PLEU	SPHA	FRON	BRIZ	Npyr	Cbrd	CIBs	Bala	Prnz	NONI	SUM	H'	DEPTH
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	1.48	103.06
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104.62
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113.21
0	1	1	1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	2.38	114.98
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	124.61
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	160.45
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	161.04
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	180.08
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	185.59
0	0	0	0	0	0	0	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0.95	190.92
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	199.38
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	206.14
0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	1.97	209.00
4	0	0	0	0	0	2	0	0	0	0	0	0	3	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25	2.37	214.72
4	0	0	0	11	0	6	0	0	0	0	0	0	7	0	5	1	3	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	2.58	217.10
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	236.10
0	0	2	0	0	1	1	0	0	5	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	1.89	237.80
2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	1.07	243.35
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	255.70
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	266.94
2	0	2	0	0	1	4	0	0	0	0	0	0	0	0	3	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	2.18	272.18
4	2	3	1	2	1	15	0	0	0	0	0	0	1	0	10	2	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56	2.45	275.00
2	0	1	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	1.54	277.23
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	281.63
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	286.30
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	292.97
0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	20	1.84	294.40
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1.09	296.48
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	302.88
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.69	305.64
1	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	6	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	43	2.25	311.39
1	0	0	0	1	2	21	0	0	0	0	0	1	1	0	8	1	0	4	0	1	8	2	0	0	17	0	0	0	0	1	0	0	0	0	0	0	0	0	84	2.43	313.8
1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	7	1.94	324.99
2	0	0	1	0	0	7	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	24	2.29	326.48
0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	1	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	21	1.89	334.66
3	0	0	2	0	0	15	0	3	0	0	20	2	1	0	8	0	0	1	0	0	1	0	1	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	86	2.66	341.99
2	0	0	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	1.46	344.47
3	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	14	2.10	351.96
7	0	0	8	0	0	71	0	0	0	0	0	3	5	0	9	0	0	4	8	0	0	0	0	0	0	0	0	1	7	2	0	0	1	0	0	0	0	0	251	2.70	352.40
1	0	0	0	0	0	5	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	28	2.11	354.05
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	361.69
3	0	0	7	0	0	23	0	0	0	0	2	2	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0	0	0	0	70	2.35	363.66
2	0	0	0	0	0	4	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	2.10	368.12
3	0	0	4	0	0	10	0	0	0	0	1	0	1	0	5	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	2.57	371.70
0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	11	2.01	373.35
0	0	0	0	0	0	21	1	2	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53	2.11	378.98
0	0	0	0	0	2	12	0	1	4	0	0	0	0	0	2	0	0	1	2	0	0	0	0	0	0	0	0	0	3	0	1	0	7	0	0	0	0	0	64	2.69	387.41
3	0	0	2	0	0	43	2	0	0	0	0	0	0	6	22	3	0	1	1	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	4	0	0	0	538	1.63	391.00
0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	1.16	391.65
3	0	0	5	0	0	21	0	0	0	0	0	1	0	0	4	1	0	15	0	4	0	0	0	0	0	0	0	0	3	1	1	0	0	0	0	0	0	0	112	2.46	397.90
3	0	0	2	3	0	27	0	0	0	0	0	2	0	0	4	0	0	16	1	0	4	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	113	2.56	404.24
1	0	0	5	8	0	14	0	0	0	0	2	4	0	0	13	0	0	9	1	2	0	0	0	0	0	0	7	0	4	1	0	1	0	5	0	0	0	0	147	3.00	410.40
1	0	0	5	1	1	4	2	0	0	0	2	0	9	0	4	0	1	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	183	2.08	429.80

APPENDIX 2-1 (Continued).

1	0	0	0	1	3	0	15	0	0	0	0	3	0	1	0	3	2	0	0	1	0	0	0	0	0	0	0	5	0	0	0	0	0	2	1	0	0	0	0	114	2.61	431.73
1	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	160	1.57	449.10
1	6	0	21	9	9	2	30	2	0	0	0	0	1	6	0	27	0	0	0	9	1	1	0	0	0	0	0	3	0	1	3	0	0	0	5	3	0	0	0	263	2.69	460.85
1	2	0	4	8	6	1	38	1	0	0	0	0	0	3	0	10	0	0	0	1	0	6	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	289	2.08	468.50
1	3	0	44	1	3	0	11	0	0	0	0	14	0	4	0	14	0	0	0	2	0	4	0	0	0	0	0	3	0	0	0	1	0	0	0	1	0	0	0	228	2.14	470.11
1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	139	0.50	480.21
1	0	0	0	0	0	0	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	138	1.21	487.40
1	5	0	3	8	0	0	25	0	0	0	0	80	6	23	0	16	0	0	0	0	0	6	0	0	0	0	0	0	0	1	0	0	0	0	9	0	0	0	0	241	2.45	497.10
1	0	0	0	0	0	0	9	0	0	0	0	9	0	6	0	4	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	45	2.26	506.90
1	0	0	0	0	9	0	0	0	3	0	0	0	4	2	0	3	1	0	0	0	0	2	0	0	0	0	0	1	1	0	0	0	0	0	3	0	0	0	0	89	2.48	519.84
1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	4	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	1.35	526.20
1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62	0.76	526.61
1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	1.99	527.75
1	0	0	0	0	0	0	4	1	0	0	0	0	0	2	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	14	2.04	545.50
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87	0.56	546.10
1	0	0	0	1	0	0	6	0	0	0	0	0	0	0	0	4	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	153	1.01	564.40
1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	166	0.83	565.18
1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	192	0.24	566.50
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	108	0.46	575.67
1	1	0	0	2	0	0	6	0	0	0	0	0	0	0	0	8	0	0	0	1	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	2.42	583.60
1	9	0	0	0	0	0	14	1	0	0	0	3	0	0	0	17	1	2	0	2	0	2	0	1	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	94	2.67	585.13
1	0	0	0	2	0	0	17	0	0	0	0	10	3	0	0	15	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	453	1.52	590.15
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	1.15	594.85
1	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79	1.09	602.90
1	0	0	0	0	6	0	11	1	0	0	0	0	5	0	0	4	1	0	0	1	1	1	2	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	433	1.23	612.5
1	0	0	0	0	0	0	2	1	2	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	61	1.89	614.04
1	2	0	0	1	1	0	9	0	0	0	0	0	1	0	0	6	0	2	0	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	97	1.89	618.04
1	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	5	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	143	1.33	624.05
1	0	0	0	3	0	0	17	1	17	1	0	1	0	1	0	5	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	296	1.42	631.8
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	366	0.91	634.42
1	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	7	0	0	0	1	3	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	120	1.57	638.87
1	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	4	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	156	1.22	642.92
1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	266	1.17	644.78
1	2	0	0	0	0	0	13	0	0	0	0	0	0	3	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	1	2	0	0	0	0	143	1.97	651.24
1	1	0	0	1	2	0	4	0	1	0	0	1	1	6	0	6	0	0	0	1	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	38	2.70	671.80
1	1	0	0	1	0	0	5	0	0	0	0	0	0	19	1	9	0	0	0	3	0	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	79	2.46	680.31
1	1	0	0	0	0	0	2	0	10	0	0	0	0	4	0	7	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	33	2.13	682.48
1	5	0	0	9	0	0	39	0	0	0	0	5	5	45	0	35	0	2	0	3	0	4	5	2	0	0	0	4	1	0	0	0	0	0	2	0	2	1	1	277	2.70	691.39
1	3	0	0	5	0	0	23	1	0	0	0	14	0	37	0	21	0	0	0	3	0	10	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0	175	2.51	699.00
1	2	0	0	5	0	0	2	0	0	0	0	4	0	33	0	16	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99	2.29	700.51
1	4	0	0	0	0	0	3	0	0	0	0	6	2	30	0	9	0	0	0	1	0	3	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	95	2.36	703.61
1	0	0	0	0	0	0	5	0	0	0	0	0	0	3	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	18	1.92	710.99
1	0	0	0	0	0	0	0	0	1	0	0	0	0	14	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	24	1.30	713.98
1	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0.62	719.98
1	1	0	0	0	1	0	6	0	6	0	0	1	0	21	0	6	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	107	2.77	732.78
1	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	2	0	2	0	0	46	2.72	734.16
1	1	0	0	1	1	0	0	0	0	0	0	0	0	10	0	4	0	0	0	0	3	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	46	2.46	737.70
1	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	1.94	739.29
1	0	0	0	0	0	0	3	0	0	0	0	0	1	2	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	2.41	739.61
1	1	0	0	0	0	0	0	0	0	0	0	0	0	17	0	2	1	0	0	4	0	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	57	2.41	750.31
1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	3	0	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	51	2.65	766.1

APPENDIX 2-1 (Continued).

ABBREVIATIONS OF SPECIES NAMES:

Ebrd = Eggerella bradyi (Cushman)
SIPH = Siphotextularia spp.
MART = Martinotiella spp.
Kbrd = Karreriella bradyi (Cushman)
Ssch = Sigmiolopsis schlumbergeri (Silvestri)
LAGM = Lagenammina sp.
RHIZ = Rhizammina spp.
PSAM = Psammosphaera fusca Schultze
AMMB = Ammobaculites spp.
ASCH = Aschemonella spp.
TROC = Trochammina spp.
RECV = Recurvoides spp.
Cpus = Cyclammina pusilla (Brady)
HAPL = Haplophragmoides sp.
REOP = Reophax pilulifer Brady
Khor = Karreriella horrida Mjatliuk
AMMS = Ammosphaeroidina sp.
TROI = Trochamminoides sp.
ADER = Adercotrema glomerata (Brady)
AMMD = Ammodiscus spp.
GLOM = Glomospira gordialis (Jones and Parker)
Ccan = Cyclammina cancellata Brady
PYRG = Pyrgo murrhina (Schwager)
Qsem = Quinquiloculina seminula (Linne)
Qang = Quinqueloculina sp (angular)
Qrnd = Quinqueloculina sp (rounded)
Tarc = Triloculina arctica (Cushman)
Ttri = Triloculina trihedra Loeblich and Tappan
OPTH = Opthalmidium sp.
ORID = Oridorsalis umbonatus (Reuss)
Mpom = Melonis pompilioides (Fichtel and Moll)
Psub = Pullenia subcarinata (d'Orbigny)
CIB = Cibicidoides sp. (transitional between
C. bradyi and P. wuellerstorfi)
STIL = Stilostomella spp.
DENT = Dentalina spp.
FISS = Fissurina spp.
OOLN = Oolina spp.
LAGN = Lagena spp.
Gaur = Globobulimina auriculata (Bailey)
Gpac = Globobulimina pacifica Cushman
Pwue = Planulina wuellerstorfi (Schwager)
ELPH = Elphidium spp.
?ENT = entosolenian, possibly Glandulina sp.
Mbar = Melonis barleeanum (Williamson)
GOID = Gyroidinoides spp.
NODO = Nodosaria spp.
Nstr = Nodosaria sp. (striate)
SARA = Saracenaria spp.
UVIG = Uvigerina peregrina Cushman
Usma = Uvigerina sp. (small)
Numb = Nuttallides umbonifera (Cushman)
PSPL = Pseudopolymorphina sp.
Pbul = Pullenia bulloides (d'Orbigny)
LENT = Lenticulina spp.
POLY = polymorphinids
Hele = Hoeglundina elegans (d'Orbigny)
LATI = Laticarinina pauperata (Parker and Jones)
Eexi = Epistominella exigua (Brayd)
Gsub = Globocassidulina subglobosa (Brady)
EPON = Eponides spp.
TOSA = Tosaia hanzawai Takayanagi
FURS = Fursenkoina fusiformis (Williamson)
Iter = Islandiella teretis (Tappan)
Bfri = Buccella frigida (Cushman)
GYRO = Gyroidina orbicularis d'Orbigny
Clob = Cibicidoides lobatulus (Walter and Jacob)
PLEU = Pleurostomella spp.
SPHA = Sphaeroidina bulloides d'Orbigny
FRON = Frondicularia spp.
BRIZ = Brizalina spp.
Npyr = Nodosaria pyrula d'Orbigny
Cbrd = Cibicidoides bradyi (Trauth)
CIBs = Cibicidoides spp ind.
Bala = Bulimina alazanensis Cushman
Prnz = Planulina renzi Cushman and Stainforth
NONI = Nonion spp.
H' = Shannon-Wiener Diversity

CHAPTER 3.

BIOSTRATIGRAPHY OF CENOZOIC FLYSCH-TYPE AGGLUTINATED FORAMINIFERA IN THE NORTH ATLANTIC.

INTRODUCTION:

Stratigraphic information on upper Cretaceous to Paleogene flysch-type foraminiferal assemblages have now been collected from a number of sedimentary basins and ODP Sites in the North Atlantic. Initial studies by Gradstein and Berggren (1981) in the North Sea and Labrador Margin and by Kaminski et al. (in press, a) in Trinidad have demonstrated that a unified approach to taxonomy and stratigraphy yields excellent stratigraphic and paleoecologic information. In this study, I use this approach to compare microfossil assemblages from Trinidad, Zumaya Spain, the Labrador and northern Newfoundland margins, Baffin Bay, West Greenland, the Labrador and North Seas and the Norwegian-Greenland Sea to establish a standard taxonomic and biostratigraphic framework for Cenozoic flysch-type assemblages.

The North Sea and the Labrador Margin are the classic areas for flysch-type assemblages in the North Atlantic region (Gradstein and Berggren, 1981). The initial work on agglutinated assemblages from the North Sea was expanded upon by King (1983), and Gradstein et al. (in press). Subsequent studies on the Labrador Margin were carried out by Gradstein and Agterberg (1982), Gradstein et al., 1985, D'Iorio (1986), and Kaminski et al. (in press, d). Deep-water equivalents of the flysch-type assemblages have been studied at ODP Sites 112 and 647 in the Labrador Sea (Miller et al., 1982; Kaminski et al., in press, d). The stratigraphy of Paleogene flysch-type foraminifera has also been described from other localities, including the Norwegian-Greenland Sea (Verdenius and Van Hinte, 1983), the Beaufort Sea (Young and McNeil, 1984), the Swiss Alps (Winkler, 1984), Polish Carpathians (Morgiel and Olszewska, 1981; Geroch and Nowak, 1984), the Rif Flysch of Morocco (Morgiel et al., 1980, Morgiel and Olszewska, 1982; Kuhnt, 1987), Trinidad (Kaminski and Geroch, 1987; Kaminski et al., in press, a).

Neogene agglutinated assemblages have only been reported from high-latitude DSDP sites in the North Atlantic, and thus far have found limited usefulness for biostratigraphy. Berggren and Schnitker (1983) reported a relatively diverse Miocene assemblage from Site 348 in the Norwegian-Greenland Sea, and Kaminski et al. (in press, c) reported Miocene assemblages from Baffin Bay Site 645 and Labrador Sea Site 646.

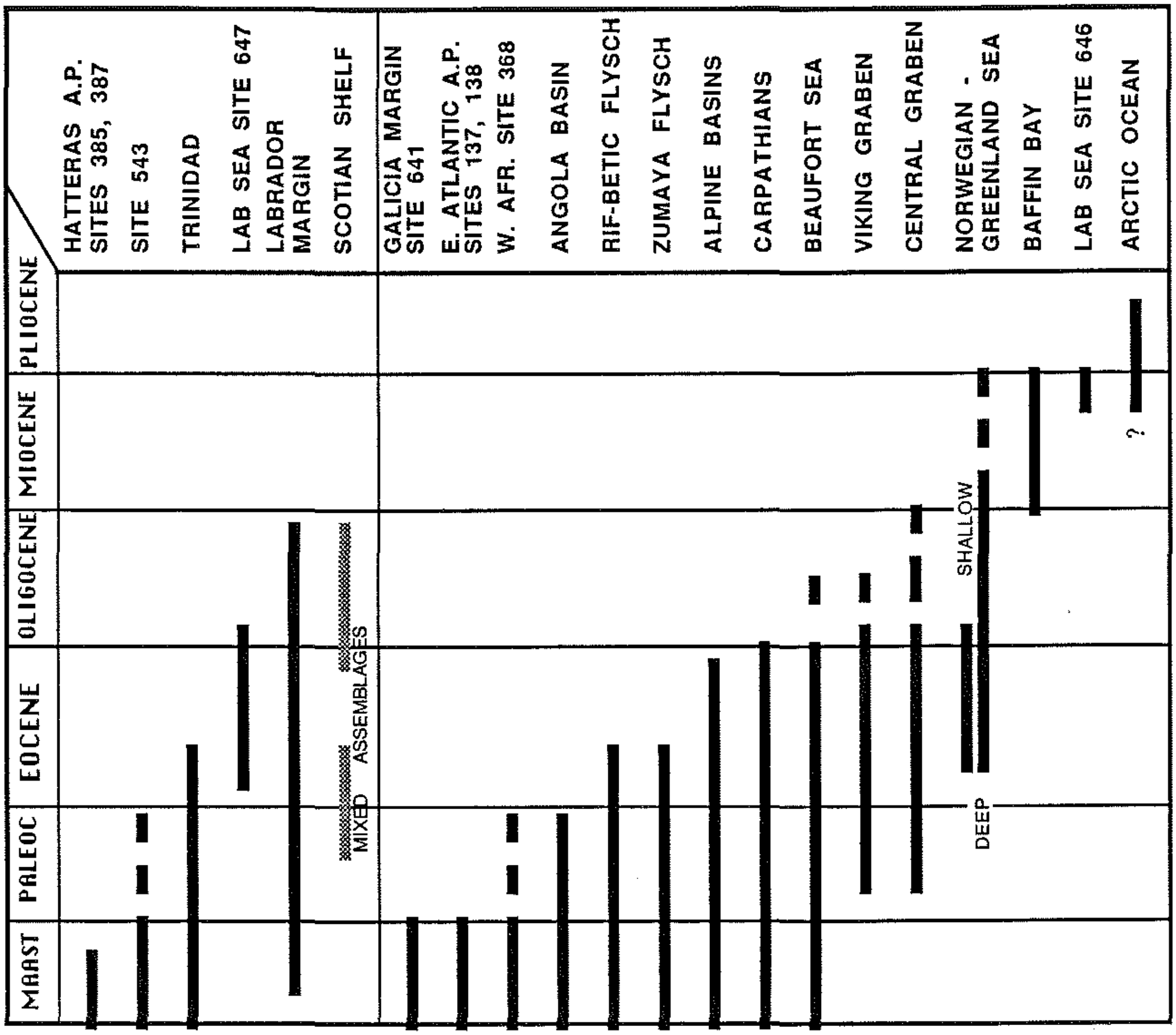
The purpose of this chapter is to summarize recent work on the stratigraphic distribution of flysch-type agglutinated foraminifera from North Atlantic and Tethyan localities and present new data from the Zumaya Flysch in Northern Spain, and ODP Site 643A in the Norwegian-Greenland Sea. I have used the geomagnetic polarity time scale (GPTS) of Berggren et al. (1985a,b) for the age of stage boundaries and planktonic foraminiferal and nannofossil zones. Whenever possible, the stratigraphic ranges of agglutinated formainifera were calibrated to the GPTS via second-order correlations using planktonic microfossil zonations. In one case (ODP Site 647), the biostratigraphy was calibrated to the GPTS by means of magnetic reversal stratigraphy. An overview of the stratigraphic distribution of flysch-type agglutinated foraminiferal assemblages from these localities is shown in figure 3-1. A detailed discussion of each locality follows below.

TAXONOMY:

The taxonomic framework for Paleogene bathyal agglutinated assemblages in the North Atlantic follows the systematics established for Trinidad. In Trinidad, 105 species of agglutinated foraminifera were reported from the Maastrichtian to lower Eocene Guayaguayare and Lizard Springs Formations. Specimens from the Trinidad formations were compared with type specimens of species described by Cushman and co-workers housed at the Natural History Museum, Washington D.C. Material from Trinidad was also compared with specimens in the White Collection (American Museum of Natural History, New York), and the Grzybowski Collection (Jagiellonian University, Krakow Poland). The results of these comparisons can be found in Kaminski et al. (in press, a) and need not be repeated here.

Eocene to Oligocene agglutinated species were illustrated from ODP Site 647 in the southern Labrador Sea by Kaminski et al. (in press, d). The taxonomic scheme for ODP Site 643A (Norwegian-Greenland Sea) used in this study is based on that established by Verdenius and Van Hinte (1983) with modifications based on work by Gradstein et al. (in press) and Kaminski et al. (in press, d). Checklists of the species found in each section are given in the tables and in the faunal appendixes. A full list of agglutinated taxa found at each locality studied is given in Chapter 4.

STRATIGRAPHIC DISTRIBUTION OF NORTH ATLANTIC FLYSCH-TYPE ASSEMBLAGES



3-1. Stratigraphic distribution of agglutinated assemblages in the western (left) and eastern (right) Atlantic. The last common occurrence of flysch-type taxa occurs first in the deep western basin, and later in the eastern Atlantic and at bathyal localities.

PALEOGENE BIOSTRATIGRAPHY:

1. TRINIDAD -

Foraminifera from the Lizard Springs Formation of Trinidad were initially studied by Cushman and Jarvis (1928, 1932) and Cushman and Renz (1946, 1947), who subdivided the formation into a lower and upper unit based on benthic foraminifera. These authors regarded the assemblages from Lizard Springs as representing open-marine, deep-water conditions. Samples with Rzehakina epigona were designated as lower Lizard Springs. Both zones were originally regarded as Cretaceous (upper Maastrichtian to Danian) in age, but were later assigned a Paleocene age by Bolli (1952) and Bronnimann (1952) based on studies of planktonic foraminifera. Beckmann (1960) tabulated the ranges of benthic foraminifera from the Guayaguayare and Lizard Springs Formations and was able to show that at least some of Cushman's samples from the upper Lizard Springs contain a mixture of Paleocene species and reworked elements from the Cretaceous. Ranges of some additional species of benthic foraminifera from the Guayaguayare and Naparima Hill Formations were given by Beckmann (in Kugler and Bolli, 1967).

The planktonic foraminiferal zonation of southeast Trinidad was developed by Bolli (1957a,b, 1959, 1966) and Kugler and Bolli (1967), who divided the Guayaguayare Formation into 3 zones, and the Lizard Springs Formation into 9 zones. Bolli (1957b) assigned a Paleocene to early Eocene age to the Lizard Springs Formation. The wholly agglutinated Rzehakina epigona facies of the basal Lizard Springs was given zonule rank, although this facies may also occur higher in the formation if only agglutinated foraminifera constitute the assemblage (Bolli, 1957b). The "Rzehakina epigona zonule" is approximately equivalent to the Subbotina pseudobulloides zone.

STRATIGRAPHY:

The Guayaguayare Formation has been described from exploration wells in southern Trinidad and from isolated slump blocks in Tertiary strata in the Central Range (Bolli, 1950; 1957a; Kugler and Bolli, 1967). It overlies the Turonian-Campanian Naparima Formation, and consists of mottled grey calcareous shale. The type locality of the Guayaguayare Formation is in the Texaco Trinidad G-163 well (Guayaguayare field) between 5588 and 6000 ft. This well is the type locality for the Maastrichtian Abathomphalus mayaroensis, Globotruncana gansseri, and G. lapparenti tricarinata zones of Bolli (1957a).

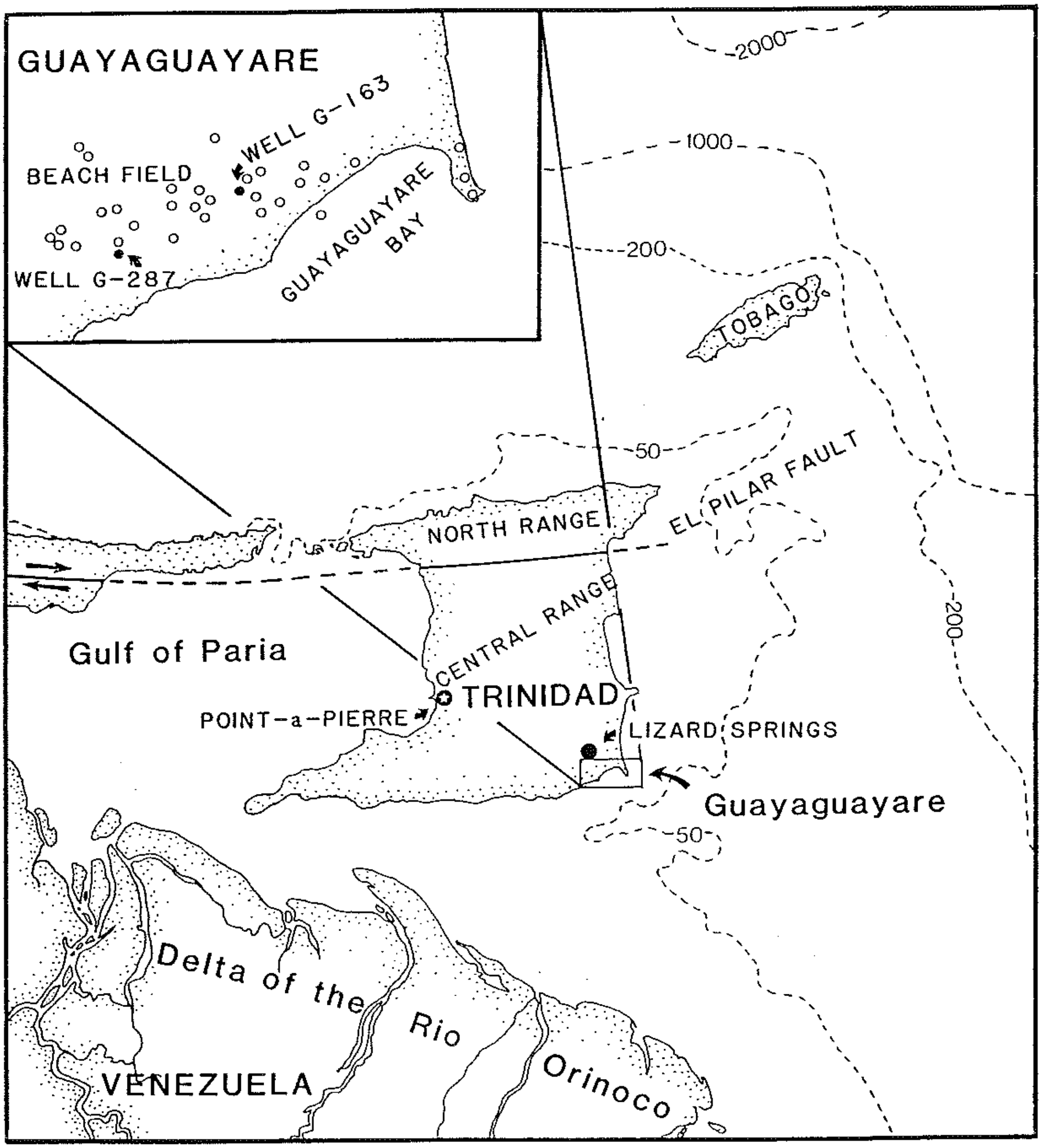
The Paleocene to lower Eocene Lizard Springs Formation is best developed in the subsurface of the Guayaguayare field where it lies unconformably on the Guayaguayare Formation and attains a thickness of 400 m (Kugler, 1956; Bolli, 1957b). It consists of dark grey calcareous or noncalcareous foraminiferal shales. Gamma ray and Sp logs from wells G-163 and G-287 suggest a predominantly argillaceous facies. In surface outcrops, the Lizard Springs Formation is strongly disturbed and incomplete. Very dark grey claystones of the Morozovella uncinata to Planorotalites pseudomenardii zones crop out in the Lizard Springs area. The type locality described by Cushman and Renz (1946), which is the type locality of the Morozovella velascoensis zone, consists of a slip mass within a clay boulder bed of Miocene age (Bolli, 1957a). The lowermost Eocene Morozovella edgari zone has not been recognized in Trinidad (Stainforth et al., 1975), indicating a possible hiatus of at least 1 m.y. duration. The upper Lizard Springs Formation differs lithologically from underlying sediments and consists of light tan to cream-colored slightly siliceous marly clay (R.D. Liska, personal communication, 1986). Bolli (1959) placed the contact of the Lizard Springs Formation with the overlying Navet Formation at the top of the Morozovella aragonensis zone.

MATERIALS and METHODS:

The biostratigraphy of flysch-type agglutinated foraminifera from Trinidad is based on examination of 63 samples from the Lizard Springs and Guayaguarare Formations that were gathered by a variety of sources (Table 3-1). The majority of the samples were provided by R.D. Liska, Texaco Trinidad, and consist of 34 washed residues and petrographic slides from three-inch diameter conventional core samples from Guayaguare wells 163 and 287 (Fig. 3-2), and washed residue from two outcrop samples collected by James Terry Christian from the "Tank Site Olistostrome" at Pointe-a-Pierre (Christian, 1979). An outcrop sample from the type locality of the Lizard Springs Formation in Ravine Ampelu, and three samples from the Guayaguayare Formation in the G-163 well were provided by Dr. J. Van Couvering from archived material deposited in the American Museum of Natural History by H.M. Bolli, H.H. Renz, and B. Stone. I also examined the original samples from the Lizard Springs Formation collected by P.W. Jarvis and H.H. Renz. These samples consist of picked assemblage slides sent to Joseph A. Cushman for taxonomic purposes and are

Table 3-1. Samples from the Lizard Springs and Guayaguayare Formations of Trinidad examined in this study

SAMPLE NUMBER	TYPE	AGE	COMMENTS
SAMPLES COLLECTED BY P.W. JARVIS:			
BON ACCORD 2	1 SLIDE	?	
LS CALEX 116'	2 SLIDES	?	← "MARL LENS IN VELASCO BEDS"
LS PIT 70	1 SLIDE	?	
LS PIT 82	1 SLIDE	?	← "NEAR TRINIDAD CENTRAL OILFIELDS WELL # 1.
LS PIT 96	1 SLIDE	?	
LS PIT 102	MISC. SLIDES	?	
TCO WELL #1, 720'	1 SLIDE	?	
RAVINE AMPELU	MISC. SLIDES	?	
SAMPLES COLLECTED BY H.H. RENZ:			
RENZ 378	SEDIMENT	P8	TYPE LOCALITY OF LIZARD SPRINGS FM.
RENZ 283; 286-291	5 SLIDES	?	MIXED PLANKTON ASSEMBLAGES
HGK 3463	2 SLIDES	?	NO PLANKTON
HGK 3465	2 SLIDES	P3b	
MAERKY 102A	3 SLIDES	M. velascoensis Zone	
HGK 4006	1 SLIDE	P7 or P8	
HGK 3460B	1 SLIDE	M. subbotinae Zone	
MAERKY 102B, I	2 SLIDES	P8	
MAERKY 102B, II	2 SLIDES	P8	
MAERKY 102B, III	2 SLIDES	M. subbotinae Zone	
MAERKY 102B, IV	2 SLIDES	P6	
SAMPLES SUPPLIED BY R.D. LISKA:			
GUAYAGUAYARE WELL G-287, 3205' TO 3364'	30 WASHED RESIDUES & PETROGRAPHIC SLIDES	P1b-P1c	CORE SAMPLES
GUAYAGUAYARE WELL G-163, 4452', 4456', 4566', 4569'	4 WASHED RESIDUES & PETROGRAPHIC SLIDES	"Rzehakina epigona Zonule"	CORE SAMPLES
SAMPLES COLLECTED BY J.T. CHRISTIAN:			
TC-145	WASHED RESIDUE	P4	Tank Site at Point-a-Pierre
TC-174	WASHED RESIDUE	Upper P2	
SAMPLES COLLECTED BY H.M. BOLLI:			
Sample 1006	WASHED RESIDUE	P. pseudomenardii Zone	Well G-163
Sample 1007	WASHED RESIDUE	P2	"South of Point-a-Pierre Railroad Station"
Sample 1008	WASHED RESIDUE	A. mayaroensis Zone	Well G-163, 5588-5598'
Sample 1110	WASHED RESIDUE	G. tricarinata Zone	Well G-163, 5882-5902'



3-2. Location of samples from the Lizard Springs Formation of Trinidad and surrounding areas. Base map adopted from DMA Chart 2408, bathymetry in fathoms. Insert map courtesy of R.D. Liska.

housed at the U.S. Natural History Museum in Washington, D.C.. Renz's samples from the upper Lizard Springs Formation contain planktonic foraminifera which allow zonal age assignments (Table 3-1), but none of Jarvis' eight samples in the Cushman collection contain enough planktonic foraminifera to make precise age determinations. The stratigraphic range chart (Fig. 3-3a,b) is based on the material mentioned above and is supplemented by information contained in unpublished reports on Trinidad type localities (see Bolli 1957a,b).

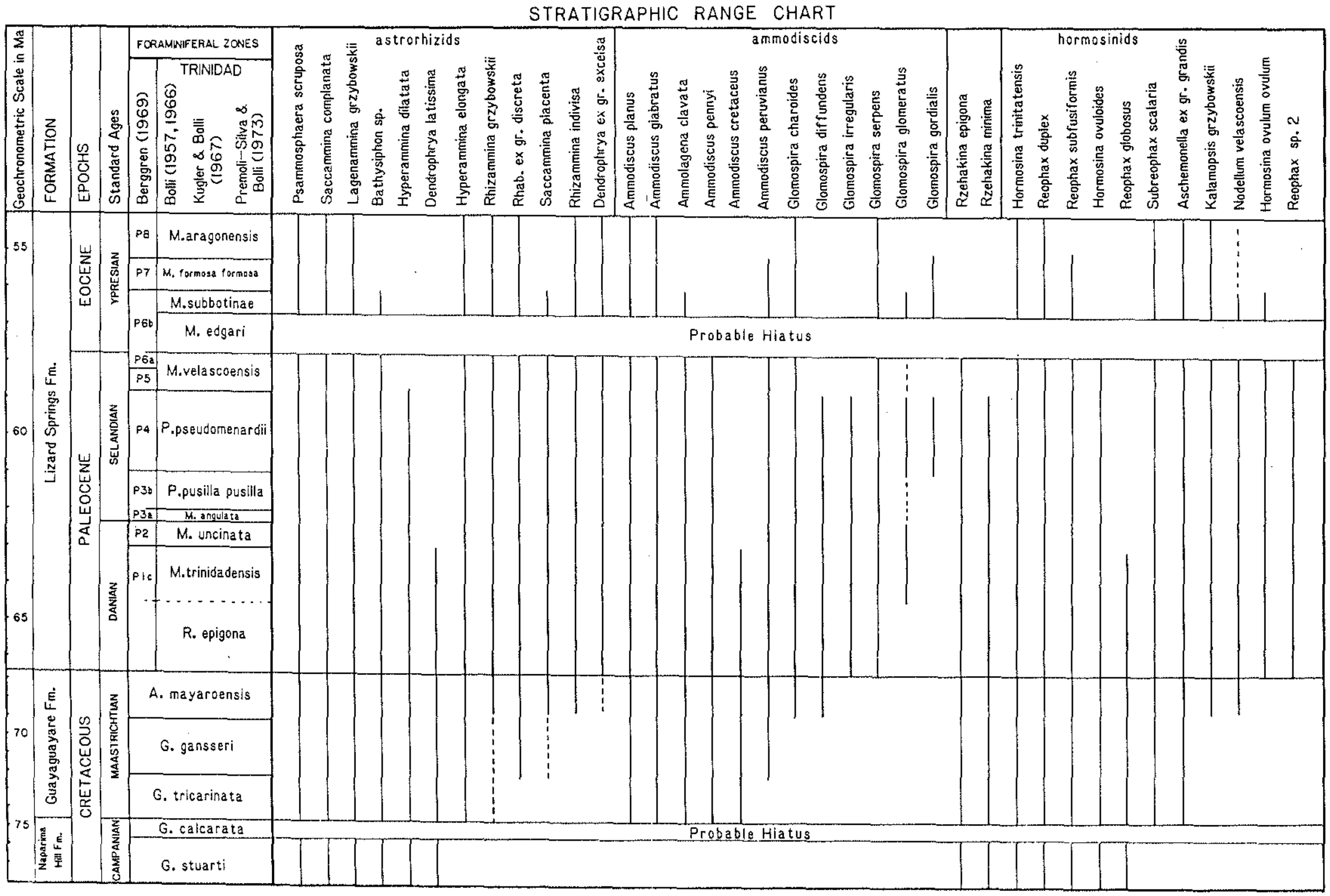
Faunal Composition -

Benthic foraminiferal assemblages of the Lizard Springs Formation are more diverse than in the underlying Guayaguayare Formation, display generally poorer preservation of calcareous forms, and are not as diluted by nonbiogenic sand particles. Table 3-2 presents a taxonomic checklist of species found in this study with a key to our modifications of the taxonomy of Cushman and Renz (1946). The stratigraphic ranges of agglutinated species from the Lizard Springs and Guayaguayare Formations are presented in figure 3-3a,b.

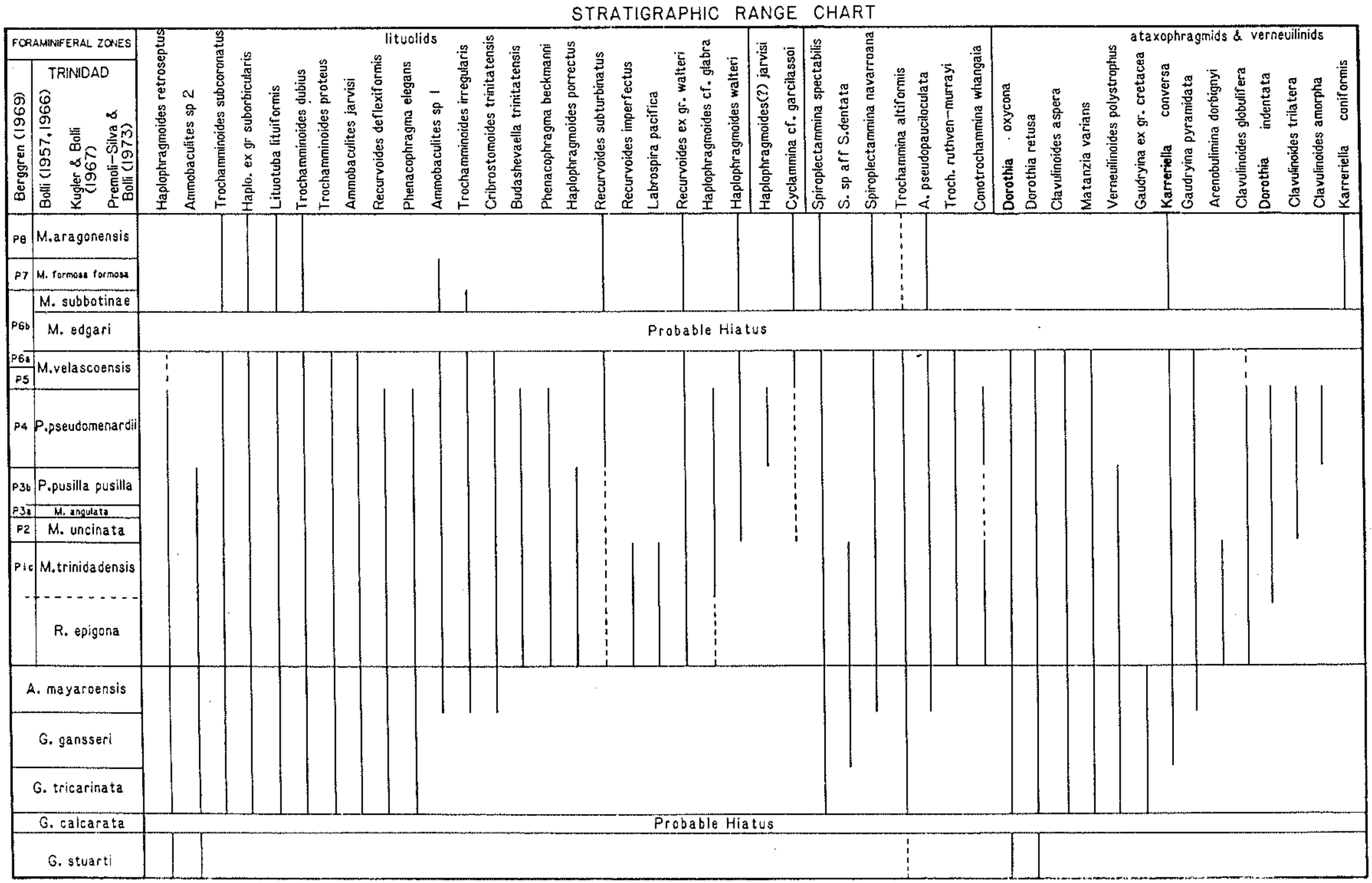
A. Guayaguayare Formation -

In the lower part of the Guayaguayare Formation (the *Globotruncana tricarinata* Zone of Bolli, 1957a), the agglutinated assemblage is dominated by simple, coarse grained species of astrorhizids, saccamminids and hormosinids. The most common species are *Dendrophrya* ex gr. *excelsa*, *Rzehakina epigona*, *Saccammina complanata*, *Hormosina trinitatensis*, *Karreriella conversa*, *Ammobaculites* sp. 2, and *Spiroplectammina spectabilis*. Species unique to this zone are *Rhizammina grzybowskii* and *Gaudryina* ex gr. *cretacea*.

Higher in the Guayaguayare Formation the agglutinated assemblage is more similar in composition to assemblages from the overlying Lizard Springs Formation. Sample G-163-1108, which is the type sample of the *Abathomphalus mayaroensis* zone of Bolli (1957a) contains diverse agglutinated and calcareous foraminifera. The agglutinated assemblage is dominated by astrorhizids. *D.* ex gr. *excelsa*, *Rhizammina indivisa*, *Bathysiphon* sp., *S. complanata* and *H. trinitatensis* are the most abundant species. A variety of *R. indivisa* which agglutinates small planktonic foraminifera is common in this sample, and there are numerous ataxophragmiids which are usually associated with calcareous facies, such as *Gaudryina pyramidata* and *Matanzia varians*. Compared with the



3-3a,b. Campanian to lower Eocene stratigraphic distribution of agglutinated foraminifera in Trinidad. Inferred occurrences are marked by a dashed line. Time scales used are from Berggren et al. (1985) and Kent and Gradstein (1985). Note change of scale across the Cretaceous/Tertiary boundary.



3-3b. Biostratigraphy of agglutinated foraminifera in Trinidad (cont.). The type locality of the "Rzehakina epigona Zonule" is approximately equivalent to zones P1a-P1b of Berggren (1969). The absence of the Globotruncana calcarata Zone between the Naparima Hill and Guayaguayare Formations may indicate a hiatus of at least 0.5 m.y. duration.

Table 3-2. Agglutinated species from the Guayaguayare and Lizard Springs Formations with modifications of the taxonomy of Cushman and Renz (1946).

THIS STUDY	CUSHMAN & RENZ (1946)
ASTRORHIZACEA BRADY, 1881	
Bathysiphon microrhaphidus Samuel	--
Bathysiphon sp.	*Bathysiphon? dubia* (White) pars
Dendrophrya ex gr. *excelsa* Grzybowski	--
Dendrophrya latissima Grzybowski	--
Lagenammina grzybowskii (Schubert)	--
Rhabdammina ex gr. *discreta* Brady	*Rhabdammina discreta* Brady *Rhabdammina discreta* Brady, var.
Rhizammina indivisa Brady	--
Rhizammina grzybowskii Liszka & Liszkowa	--
Psammosphaera scruposa (Berthelin)	--
Psammosphaera testacea Flint	--
Saccammina complanata (Franke)	*Pelosina complanata* Franke
Saccammina placenta (Grzybowski)	*Saccammina rhumbleri* (Franke)
Thurammina sp.	--
HYPERAMMINACEA Eimer & Fickert, 1899	
Hyperammina dilatata Grzybowski	--
Hyperammina elongata Brady	*Hyperammina elongata* Brady
Hyperammina ex gr. *subnodosiformis* Grzybowski	*Hyperammina?* sp.
AMMODISCACEA Reuss, 1862	
Ammodiscus cretaceus (Reuss)	--
Ammodiscus glabratus Cushman & Jarvis	*Ammodiscus glabratus* Cushman & Jarvis
Ammodiscus pennyi Cushman & Jarvis	*Ammodiscus pennyi* Cushman & Jarvis
Ammodiscus peruvianus Berry	--
Ammodiscus planus Loeblich	--
Ammolagena clavata (Jones & Parker)	*Ammolagena clavata* (Jones & Parker)
Glomospira charoides (Jones & Parker)	*G. charoides* var. *corona* Cushman & Jarvis
Glomospira diffundens (Cushman & Renz)	*G. gordialis* var. *diffundens* Cushman & Renz
Glomospira glomerata (Grzybowski)	--
Glomospira gordialis (Jones & Parker)	*Glomospira gordialis* (Jones & Parker) [1]
Glomospira irregularis (Grzybowski)	--
Glomospira serpens (Grzybowski)	*Glomospira* sp. A [2]
RZEHAKINACEA Cushman, 1933	
Rzehakina epigona (Rzehak)	*R. epigona* var. *lata* Cushman & Jarvis
Rzehakina minima Cushman & Renz	*R. epigona* var. *minima* Cushman & Renz
HORMOSINACEA Haeckel, 1894	
Aschemonella ex gr. *grandis* (Grzybowski)	--
Hormosina ovuloides (Grzybowski)	--
Hormosina ovulum ovulum (Grzybowski)	--
Hormosina trinitatensis Cushman & Renz	*H. globulifera* var. *trinitatensis* Cushman & Renz
Kalamopsis grzybowskii (Dylazanka)	*Bathysiphon dubia* White (pars)
Nodellum velascoensis (Cushman)	*Nodellum velascoense* (Cushman)
Reophax duplex Grzybowski	--
Reophax globosus Sliter	--
Reophax subfusiformis Earland emend. Höglund	--
Reophax sp. 2	--
Subreophax pseudoscalaria (Samuel)	--
Subreophax scalaria (Grzybowski)	*Reophax?* sp
LITUOLACEA de Blainville, 1827	
Ammobaculites jarvisi Cushman & Renz	*Ammobaculites jarvisi* Cushman & Renz
Ammobaculites sp. 1	--
Ammobaculites sp. 2	*Ammobaculites coprolithiformis* (Schwager)
Ammobaculites sp. 3	
Budashevaella cf. *multicameratus* (Voloshinova & Budasheva)	--
Budashevaella trinitatensis (Cushman & Renz)	*Haplophragmoides flagleri* var. *trinitatensis*
Cribrostomoides trinitatensis Cushman & Jarvis	*Cribrostomoides trinitatensis* Cushman & Jarvis (pars)
Haphragmoides cf. *glabra* Cushman & Waters	*Haplophragmoides glabra* Cushman & Waters [1]
Haplophragmoides horridus (Grzybowski)	--
Haplophragmoides lamella (Grzybowski)	--
Haplophragmoides porrectus Maslakova	--
Haplophragmoides retroseptus (Grzybowski)	--

Table 3-2 (continued).

THIS STUDY	CUSHMAN & RENZ (1946)
Haplophragmoides ex gr. *suborbicularis* (Grzybowski)	*Cribrostomoides trinitatensis* Cushman & Jarvis (pars)
Haplophragmoides walteri (Grzybowski)	*Haplophragmoides excavata* Cushman
Haplophragmoides(?) jarvisi (Thalmann)	*Nonion jarvisi* Thalmann
Labrospira pacifica Krashenninikov	--
Lituotuba lituiformis (Brady)	*Lituotuba lituiformis* (Brady)
Phenacophragma beckmanni Kaminski & Geroch	*Ammomarginulina* sp. A
Phenacophragma elegans Kaminski	--
Recurvoides deflexiformis (Noth)	--
Recurvoides gerochi Pflaumann	--
Recurvoides imperfectus Hanzliková	--
Recurvoides cf. *subturbinatus* (Grzybowski)	--
Recurvoides sp. 1	--
Recurvoides sp. 2	*Cribrostomoides trinitatensis* (pars)
Sphaerammina gerochi Hanzliková	--
Trochamminoides dubius (Grzybowski)	--
Trochamminoides irregularis White	*Haplophragmoides coronata* (Brady)
Trochamminoides proteus (Karrer)	--
Trochamminoides subcoronatus (Grzybowski)	-
LOFTUSIACEA Brady, 1884	
Reticulophragmium cf. *garcilassoi* (Frizzel)	*Cyclammina* cf. *garcilassoi* Frizzel
SPIROPLECTAMMINACEA Cushman, 1927	
Spiroplectammina aff. *S. dentata* (Alth)	*S. dentata* (Alth), *S. anceps* (Reuss) var., *S. jarvisi* Cushman.
Spiroplectammina excolata (Cushman)	*Spiroplectammina excolata* (Cushman)
Spiroplectammina navarroana Cushman	*Gaudryina foeda* (Reuss)
Spiroplectammina spectabilis (Grzybowski)	*Spiroplectammina grzybowskii* Frizzel
TROCHAMMINACEA Schwager, 1877	
Ammosphaeroidina pseudopauciloculata (Mjatliuk)	*Trochammina globigeriniformis* var. *altiformis* (pars)
Conotrochammina whangaia Finley	--
Trochammina altiformis Cushman & Renz	*T. globigeriniformis* var. *altiformis* Cushman & Renz
Trochammina ruthven-murrayi Cushman & Renz	*Trochammina ruthven-murrayi* Cushman & Renz
VERNEUILINACEA Cushman, 1911	
Gaudryina ex gr. *cretacea* (Karrer)	--
Gaudryina pyramidata Cushman	*Gaudryina (Pseudogaudryina) pyramidata* Cushman
Verneuilinoides polystrophus (Reuss)	*Verneuilina polystropha* (Reuss)
ATAXOPHRAGMIACEA Schwager, 1877	
Arenobulimina dorbignyi (Reuss)	--
Arenobulimina truncata (Reuss)	--
Clavulinoides amorpha (Cushman)	*Pseudoclavulina amorpha* (Cushman)
Clavulinoides aspera (Cushman)	*Clavulinoides aspera* (Cushman)
Clavulinoides globulifera (ten Dam & Sigal)	*Clavulinoides aspera* var. *whitei* (Cushman & Jarvis)
Clavulinoides paleocenica (Tjalsma & Lohmann)	--
Clavulinoides trilatera (Cushman)	*Clavulinoides trilatera* (Cushman)
Dorothia beloides Hillebrandt	--
Dorothia indentata (Cushman & Jarvis)	*Marssonella indentata* Cushman & Jarvis
Dorothia oxycona (Reuss)	*M. oxycona* var. *trinitatensis* Cushman & Renz
Dorothia retusa (Cushman)	*Gaudryina retusa* Cushman [1]
Dorothia cf. *trochoides* (Reuss)	--
Eggerella trochoides (Reuss)	*Eggerella trochoides* (Reuss)
Karreriella coniformis (Grzybowski)	--
Karreriella conversa	*Gaudryina filiformis* Berthelin; *G. bentonensis* (Carmen)
Karreriella horrida Mjatliuk	--
Karreriella tenuis (Grzybowski)	--
Karreriella sp. 2	--
Matanzia varians (Glaessner)	*Textulariella trinitatensis* Cushman & Renz *T. trinitatensis* var. *subcylindrica* Cushman & Renz
TEXTULARACEA Eherenberg, 1839	
Textularia sp.	*Textularia* sp.

-- not reported [1] from Cushman & Jarvis (1932) [2] from Beckmann (1960) underlying assemblage, there is a greater abundance of species with finely agglutinated tests, such as Ammodiscus spp., Trochamminoides spp., Bathysiphon sp. and Ammosphaeroidina.

B. Lizard Springs Formation -

Agglutinated assemblages in Danian Zones P1c and P1d are more diverse than Maastrichtian assemblages, and are characterized by the appearance of a number of species typical of deeper paleodepths, such as Glomospira serpens, Glomospira irregularis, Hormosina ovulum, Haplophragmoides porrectus, Recurvoides imperfectus, and Labrospira pacifica. However, other species also have their FO's in the Danian that are not necessarily indicative of deeper water. These include Arenobulimina d'orbignyi, Trochammina ruthven-murrayi, Conotrochammina whangaia and Clavulinoides globulifera. The Danian assemblages in samples from Well G-287 are numerically dominated by astrorhizids. Ataxophragmiids are common in the basal interval of the well, whereas spiroplectamminids, rzehakinids, ammodiscids and hormosinids increase in abundance in the upper section. One interval between 3309' and 3320' contains assemblages wholly comprised of agglutinated foraminifera.

Benthic foraminiferal assemblages from Zone P2 and younger contain a mixture of calcareous and agglutinated species. Samples from the Morozovella uncinata zone contain markedly fewer astrorhizids than lower Danian assemblages, and many specimens are green in color. The assemblage is dominated by Saccammina placenta, Rzehakina epigona, Haplophragmoides spp., Clavulinoides aspera, Dorothia retusa, Trochammina altiformis, and Conotrochammina whangaia (with closed umbilicus). The first probable occurrence of Reticulophragmium has been found in the upper part of Zone P2.

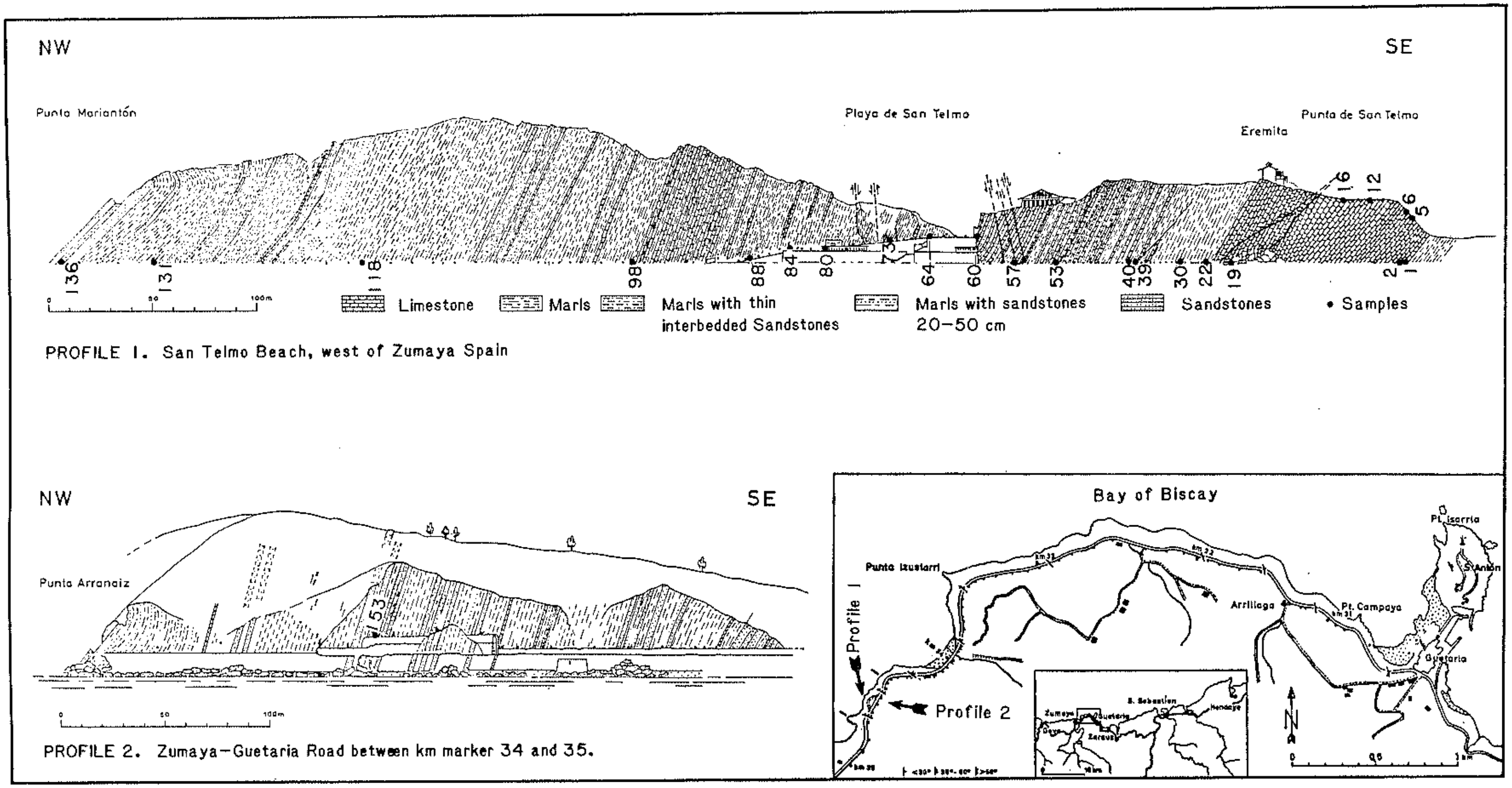
Samples from the Selandian similarly contain few astrorhizids, and are dominated by Saccammina placenta, Dendrophrya ex gr. excelsa, Karreriella conversa, Trochammina altiformis, and Glomospira spp. (G. charoides, G. diffundens, G. glomeratus, G. gordialis, G. irregularis). The ataxophragmiids are well represented, and include Dorothia beloides, Karreriella horrida, and five species of Clavulinoides (C. amorpha, C. aspera, C. globulifera, C. paleocenica, and C. trilatera). Stratigraphically restricted forms include Haplophragmoides(?) jarvisi, large typical specimens of H. walteri and Recurvoides subturbinatus (in contrast with small Danian specimens), C.

whangaia with an open umbilicus, and the first primitive variety of Reticulophragmium (R. cf garcilassoi s.l.).

The interval from Zones P5 to P6b encompassing the Paleocene/Eocene Boundary contains the LO's of at least 40 species of agglutinated foraminifera (Fig. 3a,b). The agglutinated assemblage from the type locality of the Lizard Springs Formation in Ravine Ampelu is less diverse, as noted by Cushman and Renz (1946), and is dominated by astrorhizids and lituolids. The most abundant genera in lower Eocene assemblages are Dendrophrya, Rhizammina, Rhabdammina, Saccammina, Hormosina, Trochamminoides, Haplophragmoides and Spiroplectammina. The dominent lituolids are Haplophragmiodes ex gr. suborbicularis, Trochamminoides dubius, T. irregularis, and T. subcoronatus. The most distinctive forms in this assemblage are Hyperammina ex gr. subnodosiformis, Ammodiscus planus, Ammobaculites sp. 1, and two species which utilize small planktonic foraminifera in the construction of the test wall: Rhizammina indivisa (identical to specimens from the Guayaguayare Formation), and Psammosphaera testacea, a species described from the recent Gulf of Mexico (Flint, 1899), but hitherto unreported from fossil material. Two species which have FO's in the upper Lizard Springs Formation are Karreriella coniformis and the more inflated morphotype of Reticulophragmium cf. garcilassoi with 12 or more chambers in the last whorl which displays affinity to Reticulophragmium amplectens.

2. ZUMAYA, SPAIN -

The samples analyzed in this study were collected from coastal exposures at Playa de San Telmo, near the town of Zumaya in northern Spain collected by A. von Hillebrandt in 1962 (Fig. 3-4). The section consists of interbedded marls, claystones, and sandy claystones that are part of a thick upper Cretaceous to Paleogene section that was deposited in a flysch trough of the Basque-Cantabric Basin (Lamolda et al. 1981). Paleocene sediments are mostly marls and claystones, whereas lower Eocene sediments contain more sandy layers. The sediments at Zumaya are a result of hemipelagic and turbidite sedimentation in a deep shelf or slope basinal setting below the photic zone and wave base, but above the local lysocline (Mount et al., 1986). Planktonic foraminiferal stratigraphy (Hillebrandt, 1965) indicates continuous sedimentation in this section from the Maastrichtian to the middle Eocene.



PROFILE 1. San Telmo Beach, west of Zumaya Spain

PROFILE 2. Zumaya–Guetaria Road between km marker 34 and 35.

3-4. Map of Zumaya, Spain showing location of outcrop samples investigated in this study (redrawn after Von Hillebrandt, 1965).

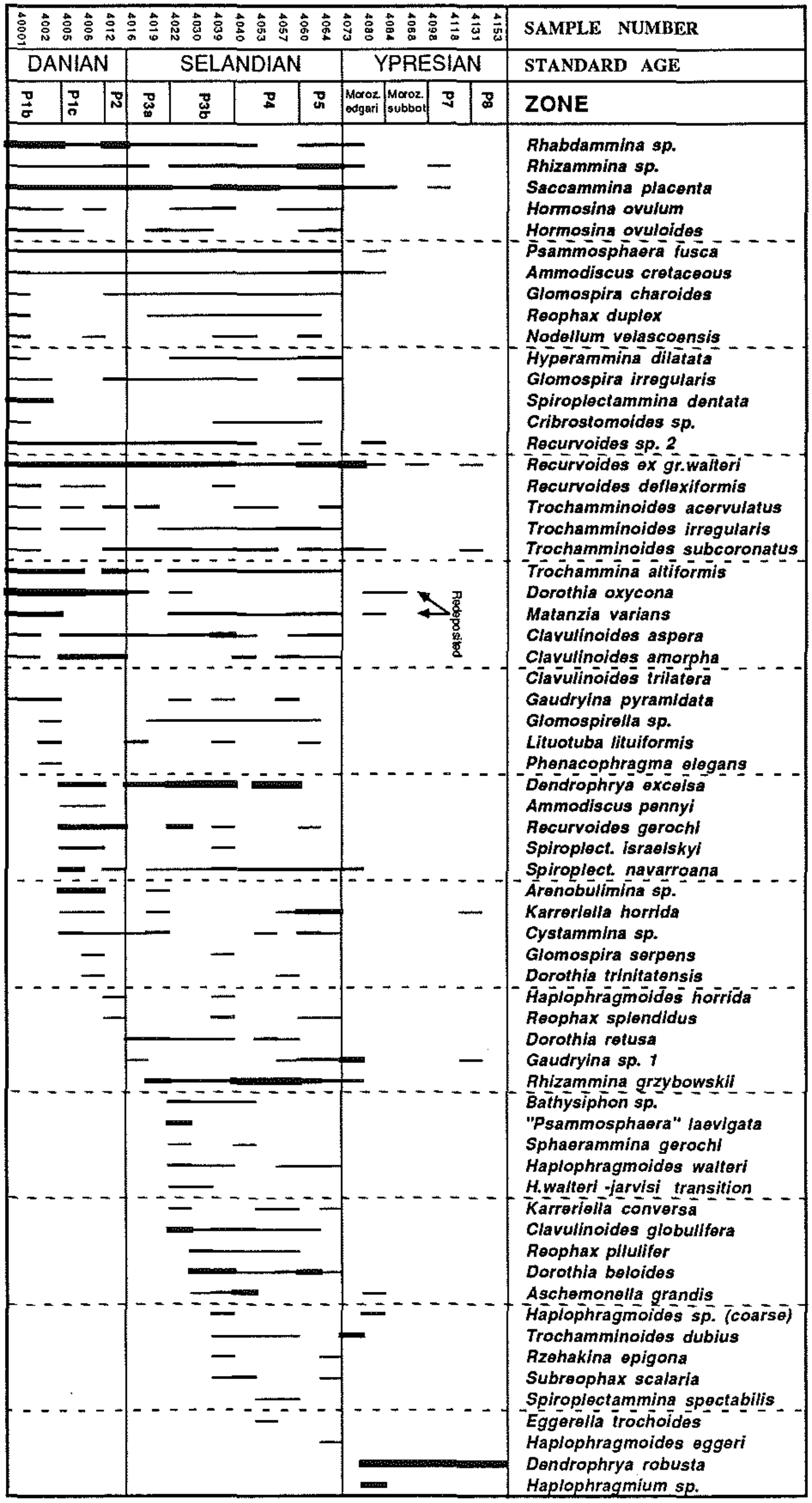
Agglutinated foraminifera have been reported by Hillebrandt to occur throughout the Paleocene in this section, but no special study of this group was made at the time. Because each planktonic foraminiferal zone is present, this section provides a unique opportunity to calibrate the stratigraphic ranges of agglutinated taxa to the standard time scale in a mid-latitude paleogeographic setting. This section is also important because it is the geographically closest section to the North Sea that contains both agglutinated and planktonic foraminifera.

The stratigraphy of agglutinated taxa (Fig. 3-5) is based on examination of 23 samples ranging from Danian Zone P1b to lower Eocene Zone P8. One to three samples were examined from each zone, and the relative abundance data is given in Appendix 3-1. Although there is noticeable reworking of Cretaceous plankton in the Paleogene strata, color changes between the Cretaceous and Danian, and between the Danian and Selandian allow us to determine whether benthic foraminifera are reworked from older strata.

Faunal composition -

Assemblages from the Playa de San Telmo section can be sudivided into Danian, Selandian and Ypresian assemblages, based on the ranges and relative abundance of distinctive taxa. Danian samples contain large numbers of calcareous taxa and agglutinated foraminifera which utilize calcareous material in the construction of their tests. The genera *Arenobulimina*, *Dorothia* and *Clavulinoides* are more abundant in Danian samples than in overlying assemblages. The species *Trochammina altiformis*, *Recurvoides gerochi*, *Recurvoides deflexiformis*, *Spiroplectammina israelskyi* and *Hormosina ovulum* are also common in the Danian. One species, *Spiroplectammina dentata*, is restricted to Zone P1b.

Selandian assemblages are more diverse than the underlying Danian assemblages and contain more taxa that are typical of greater water depths, such as *Bathysiphon*, *Sphaerammina*, *Glomospira* and *Trochamminoides*. The Selandian assemblages are numerically dominated by tubular forms such as *Dendrophrya* ex gr. *excelsa*, *Rhizammina grzybowskii*, and *Rhabdammina*. Other common forms include *Saccammina placenta*, *Recurvoides* ex gr. *walteri*, *Clavulinoides globulifera*, *Dorothia beloides*, *Karreriella horrida*, and *Spiroplectammina navarroana*.



3-5. Range chart of agglutinated species in the Zumaya section.

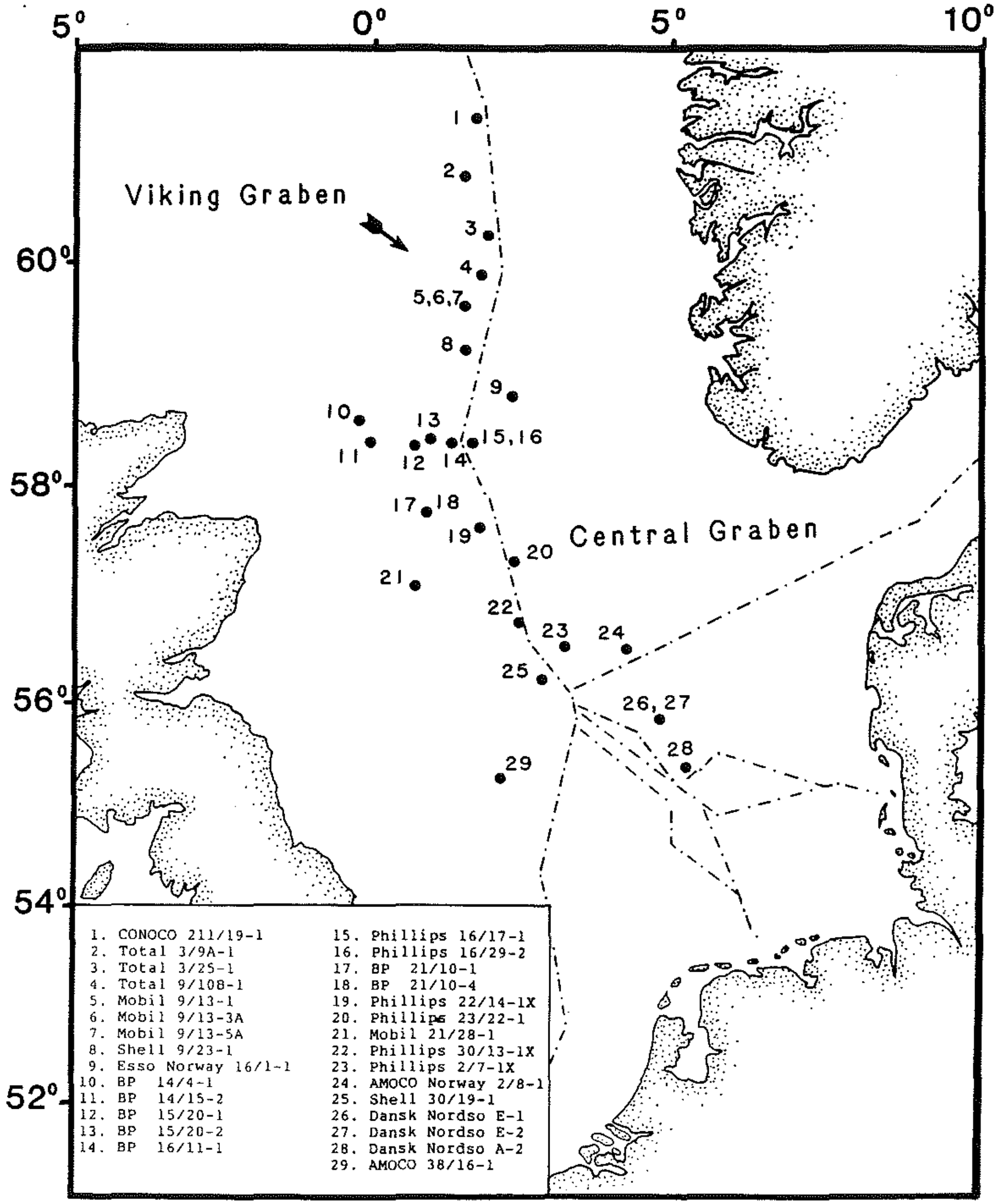
There are two notable occurrences in the Selandian which may have time-stratigraphic significance in the Atlantic. A morphotype of Haplophragmoides which is transitional between H. walteri and ?H. jarvisi first appears in Zone P3b. This H. walteri/jarvisi transitional form was also observed in Zone P4 of the Lizard Springs Formation. Another microfossil, "Cenosphaera" lenticularis (=Psammosphaera laevigata White) occurs in Zone P3b. This species, which is actually a spongodiscid radiolarian infilling, was described by White (1928) from the Velasco Shale. White's type sample, which was made available to me for comparison, is also from Zone P3b.

The Paleocene/Eocene boundary in the Playa de San Telmo section is marked by the local disappearance of the majority of the agglutinated taxa. Lower Eocene sediments are markedly more terrigenous and contain mostly Dendrophrya robusta. About 14 species range up into the lower Eocene section, including Rhabdammina, Rhizammina, Saccammina placenta, Ammodiscus cretaceus, Recurvoides ex gr. walteri, Trochamminoides subcoronatus, T. dubius, Spiroplectammina navarroana, but the majority of these are not found above the M. subbotinae Zone.

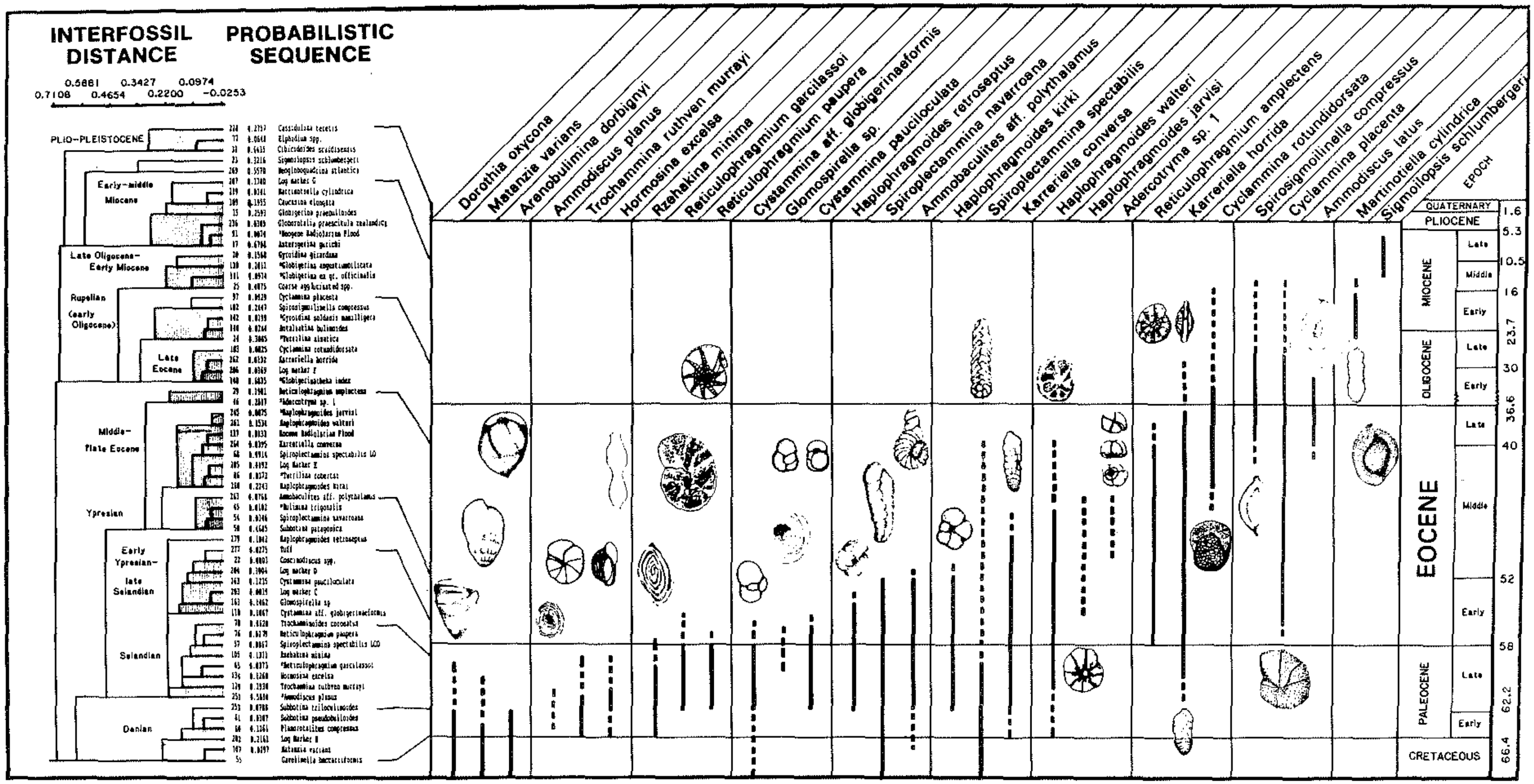
3. NORTH SEA -

Agglutinated assemblages are well-developed in the central part of the North Sea where they appear abruptly in shaly intervals of a thick Selandian to Eocene deltaic clastic complex immediately overlying Maastrichtian to Danian carbonates (Gradstein and Berggren, 1981). The stratigraphy of these assemblages is based on upper range limits of microfossils in exploration wells, and has been discussed by Gradstein and Berggren (1981), Miller et al. (1982), King (1983) and Gradstein et al. (in press). The paleoecology and paleobathymetry of Paleocene assemblages is discussed by Jones (in press). For this study, 9 wells were examined for foraminifera (Total 3/9A-1, Total 3/25-1, Total 9/10B-1, Total 14/30-1, Mobil 9/13-3a, Mobil 9/13-5a, Mobil 21/28-1, Phillips 16/29-2x, Phillips 16/17-1). These data were incorporated in the Central North Sea data base of Gradstein et al. (in press) consisting of 29 wells (Fig. 3-6).

The stratigraphic ranges of selected taxa in the 29 well data base are shown in figure 3-7. These stratigraphic ranges are plotted against the RASC optimum microfossil sequence determined in these wells, which in turn, has been scaled in linear time by means of chronostratigraphically important



3-6. Location of 29 exploration wells in the Central North Sea (after Gradstein, et al., in press).



3-7. Average stratigraphic distribution of 29 agglutinated species in the central North Sea. Isolated first or last occurrences are shown with dashed lines. The zonation to the left is the scaled optimum sequence of microfossil events and log markers in 29 wells. Unique events (those occurring in fewer than 8 wells) are marked with an asterisk (after Gradstein, et al., in press).

paleontologic and lithologic "tie-points" (Gradstein et al., in press). This probabilistic zonation divides the Paleogene sequence of the central North Sea into 7 microfossil interval zones (figure 3-8) and is discussed in the next section.

Faunal Composition -

The Paleocene assemblages of the central North Sea beneath the Paleocene/Eocene ash sequence can be divided into two assemblages that reflect regional differences in lithofacies.

Carbonate-rich Danian sediments were placed in the Subbotina pseudobulloides zone by Gradstein et al. (in press). The agglutinated assemblage of this zone displays low diversity, and contains two species that utilize calcareous material in the construction of their tests and may be restricted to carbonate facies, Arenobulimina dorbignyi and Matanzia varians. The upper range limits of Hormosina ovulum ovulum and Reophax duplex are also associated with this zone.

The overlying carbonate-poor clastic section contains an assemblage of Selandian age dominated by morphologically simple astrorhizids, ammodiscids and coarsely agglutinated lituolids. This assemblage was designated the Trochammina ruthven-murrayi - Reticulophragmium paupera zone by Gradstein et al., based on the characteristic occurrence of the nominate taxa. Other immortant upper range limits in the Selandian of the North Sea are those of Trochamminoides coronatus, Rzehakina minima and Hormosina excelsa. Less commonly, the LO's of Hyperammina sp. "supercoarse", Nodellum velascoensis, Labrospira pacifica, Ammodiscus planus, Sphaerammina gerochi, Trochammina subvesicularis and Reticulophragmium garcilassoi are observed in the T. ruthven-murrayi - R. paupera zone. An acme of spongodiscid radiolarians ("Cenosphaera" lenticularis) was observed in the middle Selandian of well 16/29-2x. This occurrence is isochronous with the spongodiscid radiolarian event in Zumaya, which suggests that this event may become a useful chronostratigraphic tie-point.

Ataxophragmiids and rzehakinids are rare in the Selandian of the North Sea in comparison to Lizard Springs, and are largely represented by Karreriella, Matanzia and less frequently Gaudryina. It is interesting that the Selandian of the North Sea also contains primitive Reticulophragmium, a genus known from Trinidad and coeval strata in Spitsbergen (J. Nagy, personal communication

EPOCH		BLOW 1979	GRADSTEIN ET AL. (IN PRESS)	KING 1983
PLEISTOC. PLIOCENE		N21- N19	*Cassidulina teretis*	
MIOCENE	L		▨	NSP11
	M	?N11- N6	*Globorotalia praescitula* – *G. zealandica*	
	E			
OLIGOCENE	L	?N5- P21	*Globigerina ex gr. officinalis*	
	E		*Rotaliatina buliminoides*	NSB7
EOCENE	L	P17- P15	*Globigerinatheka index*	NSP8
	M		*Reticulophragmium amplectens*	NSB5 NSB4
	E	P6b-P8	*Subbotina patagonica*	NSP5-NSB3
		P5-P6b	*Coscinodiscus spp.*	NSP4
PALEOCENE	L	P3-P4	*Trochammina ruthven murrayi* *Reticulophragmium paupera*	NSP1-NSB2
	E	P1-P2	*Subbotina pseudobulloides*	NSP1

3-8. Correlation of the foraminiferal zonation of Gradstein, et al. with the standard planktonic biostratigraphy and the neritic zonation of King (1983).

1986), but absent in the Paleocene of the Labrador Sea and Polish Carpathians. The North Sea Selandian fauna differs from contemporaneous assemblages in Trinidad and Labrador by its high diversity of tubular forms. Although all tubular varieties were initially placed in only three taxonomic designations (Gradstein and Berggren, 1981), morphotypes can be found corresponding to species described from the Carpathians and Greenland-Norwegian Sea. The coarse, agglutinated astrorhizids common in the North Sea, such as Hyperammina rugosa, Rhizammina grzybowskii, and Psammosphaera fusca, may be facies-dependent. Their absence at Lizard Springs may be due to the paucity of large sand grains. A number of important species in the Paleocene of the North Sea, such as Hormosina excelsa and Ammobaculites aff. polythalamus are not present in Trinidad or Zumaya.

The microfossil assemblage associated with the North Sea tuffs contain abundant pyritized Coscinodiscus infillings, and was named the Coscinodiscus spp. zone by Gradstein et al. (in press). This zone straddles the Paleocene/Eocene boundary and is characterized by the transition from the Selandian "greenbug" fauna to a less diverse Ypresian assemblage above.

Foraminifera in the Coscinodiscus spp. zone are often stained a brownish color. Near the base of the zone many of the typical Paleocene forms such as Saccammina placenta, Glomospira diffundens, Glomospirella spp., Trochammina subvesicularis, and Kalamopsis grzybowskii have their last occurrences. Last occurrences associated with this zone include Glomospirella spp., Cystammina pauciloculata and Coscinodiscus spp. Benthic foraminifera which seem to be associated with this interval are Trochamminoides spp., and Reticulophragmium garcilassoi.

The upper Ypresian of the North Sea was placed in the Subbotina patagonica zone, and often contains sediments stained a reddish color. In the RASC scaled optimum sequence of Gradstein et al. (Fig. 3-7) the species S. navarroana occurs directly above S. patagonica but the interfossil distance between the two events is small, which indicates that the highest occurrences of these species cross over from well to well.

The benthic foraminiferal assemblages of the Subbotina patagonica zone are characterized by Ammobaculites aff. polythalamus, Spiroplectammina navarroana, Haplophragmoides "kirki", Haplophragmoides retroseptus, and Haplophragmoides(?) jarvisi, a species displaying morphological affinity to Reticulophragmium that was first found in the Paleocene of Trinidad.

Middle Eocene assemblages were placed in the Reticulophragmium amplectens zone and display a continued trend towards decreased diversity with time. In the optimum sequence the average LO of S. spectabilis occurrs below that of the Eocene Radiolarian Flood. This may be due to the diachronous LO of this species in different sectors of the North Sea. Important last occurrences in the R. amplectens zone include Karreriella conversa, S. spectabilis, Haplophragmoides walteri and R. amplectens. An event in this zone which may have wider chronostratigraphic value is the Eocene radiolarian flood.

Upper Eocene to lower Oligocene assemblages mostly contain robust, coarsely agglutinated taxa such as Dendrophrya robusta, Rhabdammina discreta, Cyclammina placenta/cancellata, Cyclammina rotundidorsata, and Ammodiscus latus. However, smaller and more finely agglutinated species such as Karreriella horrida, Spirosigmoilinella, Dorothia sp. 6, and Ammodiscus cretaceus also occur. These assemblages comprise the Globigerinatheka index and Rotaliatina bulimoides zones, named after these calcareous species particularly found in several of the more southern wells in the central North Sea. In several of the wells studied, the robust tubular forms are among the last agglutinated forms to disappear in the lower Oligocene. This pattern has also been observed in the Playa de San Telmo section and in the Labrador Sea site discussed below.

4. NORWEGIAN-GREENLAND SEA:

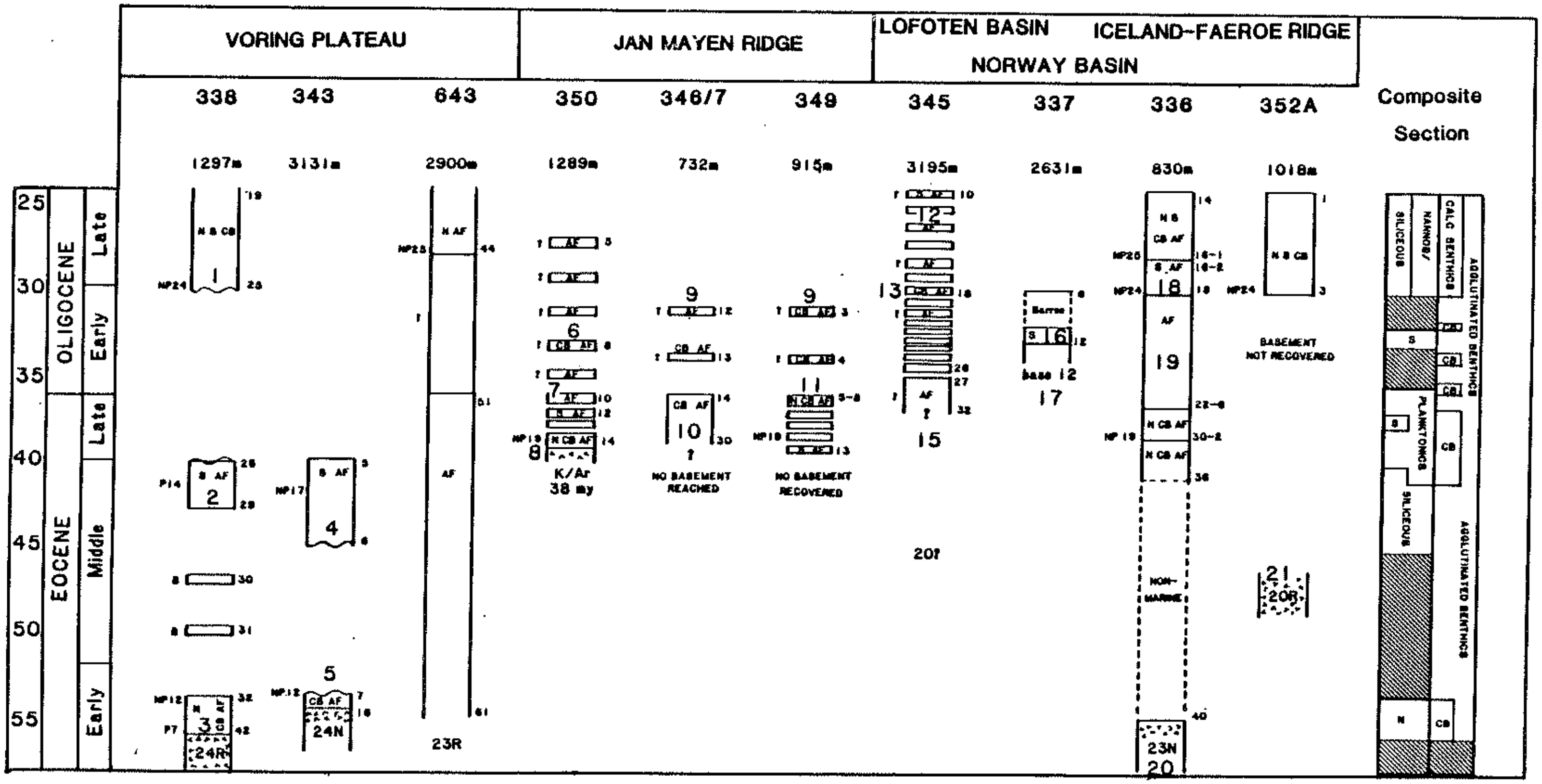
Sixteen sites were cored in the Norwegian-Greenland Sea during DSDP Leg 38 and three sites were drilled during ODP Leg 104. In total, 10 sites recovered sediments of Paleogene age, resulting in a relatively complete composite Eocene to Oligocene section (Fig. 3-9). The Leg 38 sites unfortunately contain 9.5 m to 28.5 m coring gaps in some of the intervals of interest, therefore the biostratigraphic resolution is limited. Gaps exist in the record of planktonic microfossils, which likewise limited the ability of Leg 38 scientists to correlate these sites to the standard geochronology. Nevertheless, these sites are important for constraining the paleobiogeographic and paleobathymetric distribution of microfossil groups in the Norwegian-Greenland Sea. The record of benthic foraminifera is more complete than that of planktonic microfossil groups, and the chronostratigraphy of this region can be constrained by comparison with our benthic foraminiferal zonation in the North Sea.

The most complete continuously cored section available for benthic foraminiferal analysis is ODP Site 643 on the Vøring slope (Fig. 3-10). This site is located at 67°42.9′N; 01°02.0′E at a present water depth of 2768 m, on anomaly 23/24, which is the oldest oceanic crust in the region. This site constitutes the deep end of a transect of ODP Leg 104 sites drilled on the Vøring Plateau. Drilling in Hole 643A penetrated 565.2 m of sediment, including approximately 165 m of Eocene sediments and 125 m of Oligocene to lower Miocene sediments. These sediments provide a record of depositional environments in a deep basinal setting under the western boundary of the Norwegian Current.

The sediments in Hole 643A were subdivided into 5 lithologic units by the shipboard scientific party. For this study, I sampled Lithologic Unit 5, which occurs between 400.7 and 565.2 mbsf, and the lowermost part of Lithologic Unit 4, occurring between 274.05 and 400.7 mbsf. The sediments of Unit 5 consist of predominantly dark greenish gray to dark reddish brown zeolitic mudstones, most of which are compacted and laminated. The base of the unit contains pebble sized basaltic fragments, indicating a close proximity to oceanic basement. Significant quantities of volcanic ash are found in the lower 100 m of this unit. Unit 4 is comprised of monotonous, compaction-laminated mudstones and minor amounts of chalk and siliceous

3-9. Stratigraphic summary of Paleogene sediments in Leg 38 and Leg 104 Holes. The presence of microfossils in each site is indicated by the following letters: N= nannofossils and/or planktonic foraminifera; S= siliceous microfossils; CB= calcareous benthic foraminifera, AF= agglutinated foraminifera. Large numbers refer to footnotes:

1 - After Muller (1976). **2** - Following Fenner's (1985) correlation of the Norwegian-Greenland Sea *C. oblongus* and *T. inconspicuum triloba* zones of Schrader and Fenner (1976) to the low latitude *Brightwellia imperfecta* zone and lower part of the *Asterolampa marylandica* zone; which according to Bolli *et al*. (1985) correlates to P14. This contrasts with the late Eocene age assigned by Manum (1976) for his Dinoflagellate Zones IV and V described from the same interval. M.J. Head interprets this dinocyst assemblage as middle-upper Eocene, rather than strictly upper Eocene (written communication, 1986).
3 - After Muller (1976). **4** - Cores 5-6 were reported to be lower middle Eocene (*Naviculopsis minor* Zone) by Martini and Muller (1976), but may be as young as the *D. hexacantha* Zone of Bukry (1977) based on the occurrence of *Dictyocha frenquelli*, which is reported to be restricted to that zone in tropical and subtropical regions by Bukry (1981). This zone was correlated to NP16-NP17 by Bolli *et al*. (1985). Manum (1976) reports Cores 5-6 to correlate best with dinocyst Zone V of Site 338, which supports our reassignment of that zone to P14 via the diatom zonation (see footnote 2). **5** - Muller (1976) assigned this interval to NP12 and Berggren and Schnitker (1983) assigned this to P7, based on the occurrence of *Subbotina patagonica* (=*G. linaperta* reported by Van Hinte in the Site reports). **6** - Dinocysts are present. Manum (1976) places Cores 8-9 in dinocyst Zone IV, but I tentatively assign a younger age based on the occurrence of an agglutinated foraminiferal assemblage without *Spiroplectammina spectabilis* (see Verdenius and Van Hinte, 1983). **7** - An Eocene age is based on the presence of *S. spectabilis* in Core 10 (Verdenius and Van Hinte, 1983). **8** - NP19 or younger based on the presence of *Isthmolithus recurvus* in Core 19. **9** - An Oligocene age is suggested by Manum (1976). **10** - Agglutinated foraminifera are the only indigenous fossils present. A rich assemblage implys an Eocene age. Basement was not reached, and the magnetic anomaly is not known. Rare calcareous benthics are redeposited. **11** - Sample 349-5-6, 148 cm contains nannofossils suggesting a late Eocene age. Core 12 contains *I. recurvus* (=NP19 or younger). Cores 4-6 contain only tubular agglutinated foraminifera, so may be Oligocene in age. **12** - Cores 10-15 were assigned a late Oligocene age based on agglutinated foraminifera (Verdenius and Van Hinte, 1983) and were assigned to dinocyst Zone III (Oligocene) by Manum (1976). **13** - Cores 15-21 were assigned to dinocyst Zone IV or lower by Manum (1976), but agglutinated foraminifera suggest an Oligocene age. **14** - Verdenius and Van Hinte (1983) assigned an Eocene age to Cores 30-32 based on *R. amplectens*; *S. spectabilis* was not found. **15** - Age of crust was reported by Talwani and Udentsev (1976) to be between anomalies 13 and 20, but the site is probably closer to Anomaly 20 based on the Leg 104 map. **16** - Silicoflagellates give conflicting ages, e.g. co-occurrence of *Corbisema apiculata* (Eocene - lower Oligocene) and *Naviculopsis ponticula* (Miocene). The top of the *C. apiculata* Zone of Bukry (1978) is correlated to CP17 by Bukry (1981), which suggests that Core 9 is no younger that 34 Ma. **17** - Age of crust at this site is anomaly 12, according to Nunns *et al*. (1983). The site was drilled 20 km E of the extinct axis on the steep slope of the magnetic anomaly (?= base 12N). **18** - Silicoflagellates give conflicting ages (*Naviculopsis lata* Zone = lower Miocene). **19** - Sedimentation in this interval was assumed continuous by Leg 38 scientists (Site 338 Report). Fossils were undiagnostic. **20** - Our best estimate from the magnetic anomaly map of Nunns *et al*. (1983). **21** - Basement was not reached. My estimate of the magnetic anomaly is from the map of Nunns *et al*. (1983).


VORING PLATEAU
JAN MAYEN RIDGE
LOFOTEN BASIN
ICELAND-FAEROE RIDGE
NORWAY BASIN
Composite Section
338
343
643
350
346/7
349
345
337
336
352A
1297m
3131m
2900m
1289m
732m
915m
3195m
2631m
830m
1018m
25
30
35
40
45
50
55
OLIGOCENE
EOCENE
Late
Early
Late
Middle
Early
K/Ar 38 my
NO BASEMENT REACHED
NO BASEMENT RECOVERED
BASEMENT NOT RECOVERED
NON-MARINE
24R
24N
23R
23N
20R
20?
base 12
SILICEOUS
NANNOS/
CALC BENTHICS
AGGLUTINATED BENTHICS
PLANKTONICS
SILICEOUS
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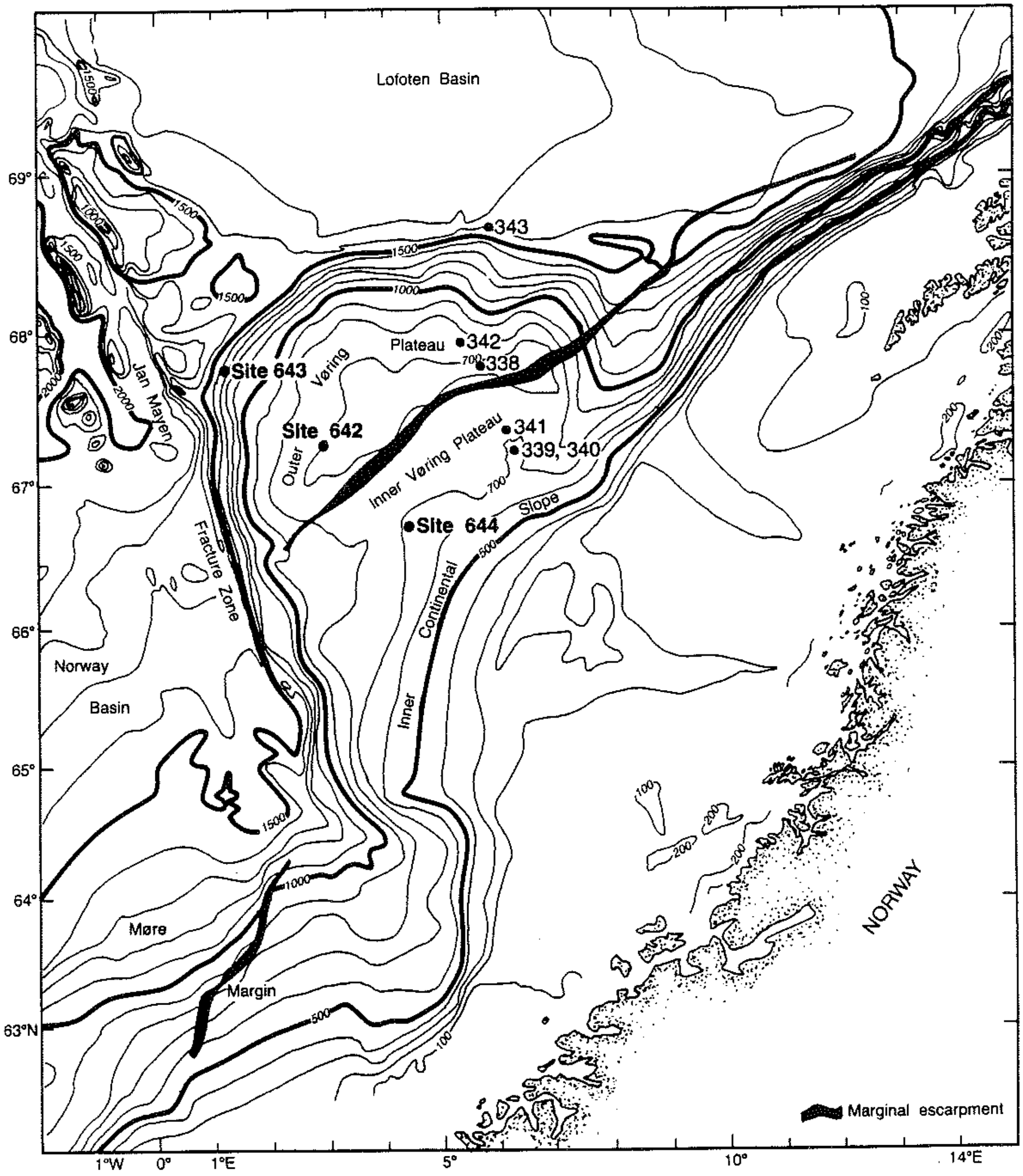


3-10. Map of the Vøring Plateau showing the location of ODP Site 643 and other DSDP and ODP sites (after Shipboard Scientific Party, 1987b).

mudstone. The amount of biogenic silica increases upcore from the upper Eocene to the lower Miocene.

The age assignments of Paleogene sediments from Hole 643A is based primarily on shipboard analyses of nannofossils, dinoflagellates, and foraminifera (Shipboard Scientific Party, 1987b), which at times yielded conflicting ages. Samples from Core 43X yielded Discolithina enormis, and were assigned to Zone NP25. The boundary between the upper Eocene and Oligocene was placed within Core 50X, based on palynomorph assemblages. The lower Eocene was recognized by the occurrence of Subbotina patagonica in Cores 53X-56X (reported as G. linaperta in the Site 643 Chapter) and upper-lower Eocene palynomorph assemblages in Cores 57X and 59X.

For this study, a total of 55 samples from Cores 41X to 63X were processed for benthic foraminifera, dinocysts and radiolarians following the methodology outlined in Kaminski et al. (in press, d). The taxonomy of benthic foraminifera from the Leg 38 sites in the Norwegian-Greenland Sea was originally developed by Verdenius and Van Hinte (1983). For this study, I have followed their taxonomic scheme with some modifications. The nomenclatorial changes and the complete list of species found in Hole 643A is given in Table 3-3. The relative abundance of benthic foraminiferal taxa was estimated for each sample (Appendix 3-3), and the stratigraphic ranges of common species were compiled into a range chart (Fig. 3-11). Examination of the biostratigraphic data yields 5 major assemblages of benthic foraminifera, based on the ranges of characteristic taxa (Fig. 3-12). These assemblages are discussed below in order of their stratigraphic occurrence.

Foraminiferal Assemblages:

1. Rhabdammina-Cyclammina Assemblage (Sample 643A-62X-1, 77-81 cm to -56X-1, 77-82 cm). Lower Eocene.

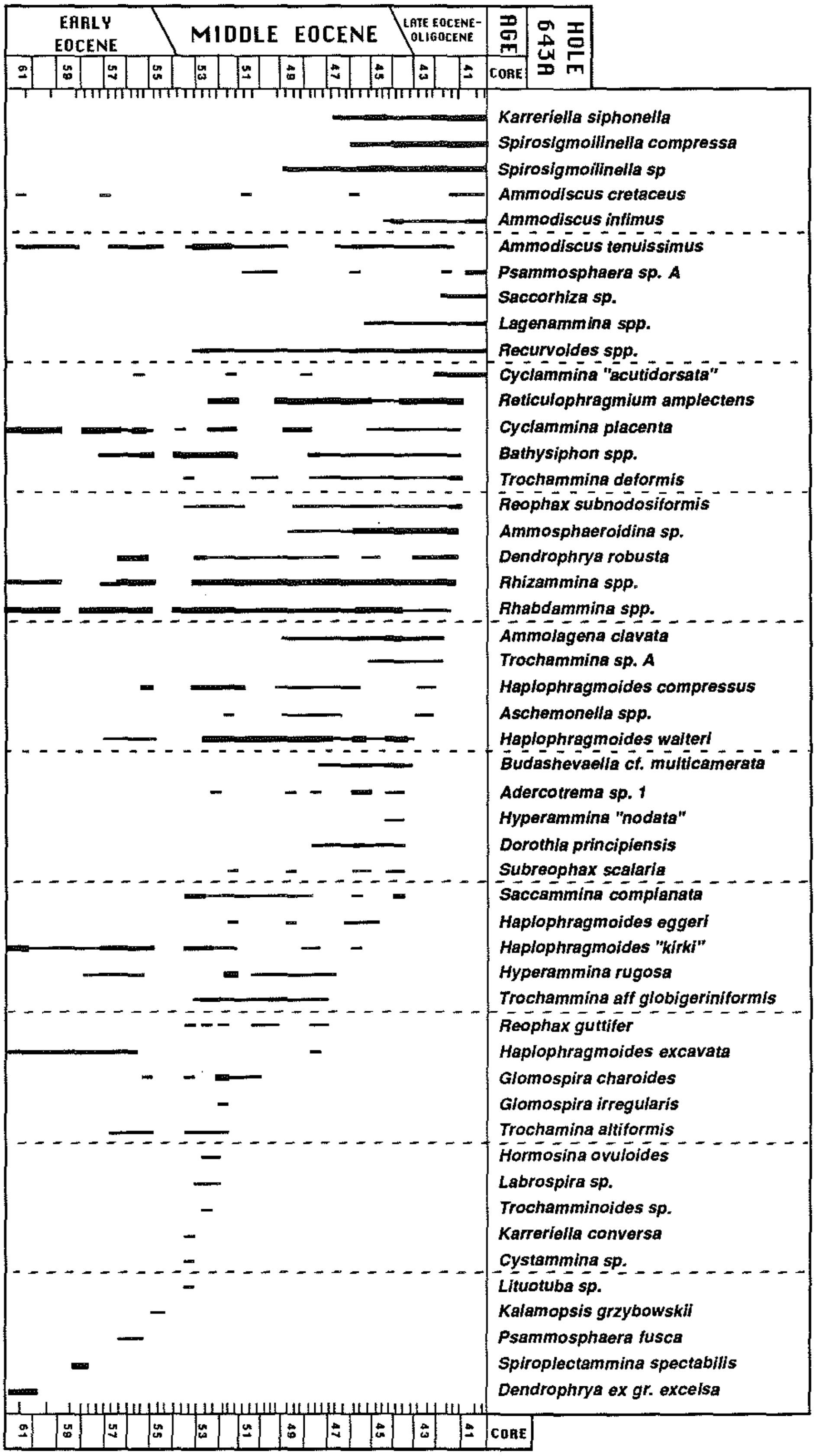
The lowermost 70 m of Hole 643A beneath the barren interval in Core 55X contains a benthic assemblage dominated by tubular agglutinated forms. The diversity of the assemblage is low (typically 5 or 6 species per sample) reflecting deposition at relatively shallow paleodepth. The most abundant non-tubular species is Cyclammina placenta, which is accompanied by Haplophragmoides "kirki", and H. excavata. The latter species may be an evolute morphotype of H. walteri that typically occurs at outer neritic to

Table 3-3. Agglutinated taxa recovered in ODP Hole 643A, with nomenclatoral changes to the taxonomy of Verdenius and Van Hinte (1983).

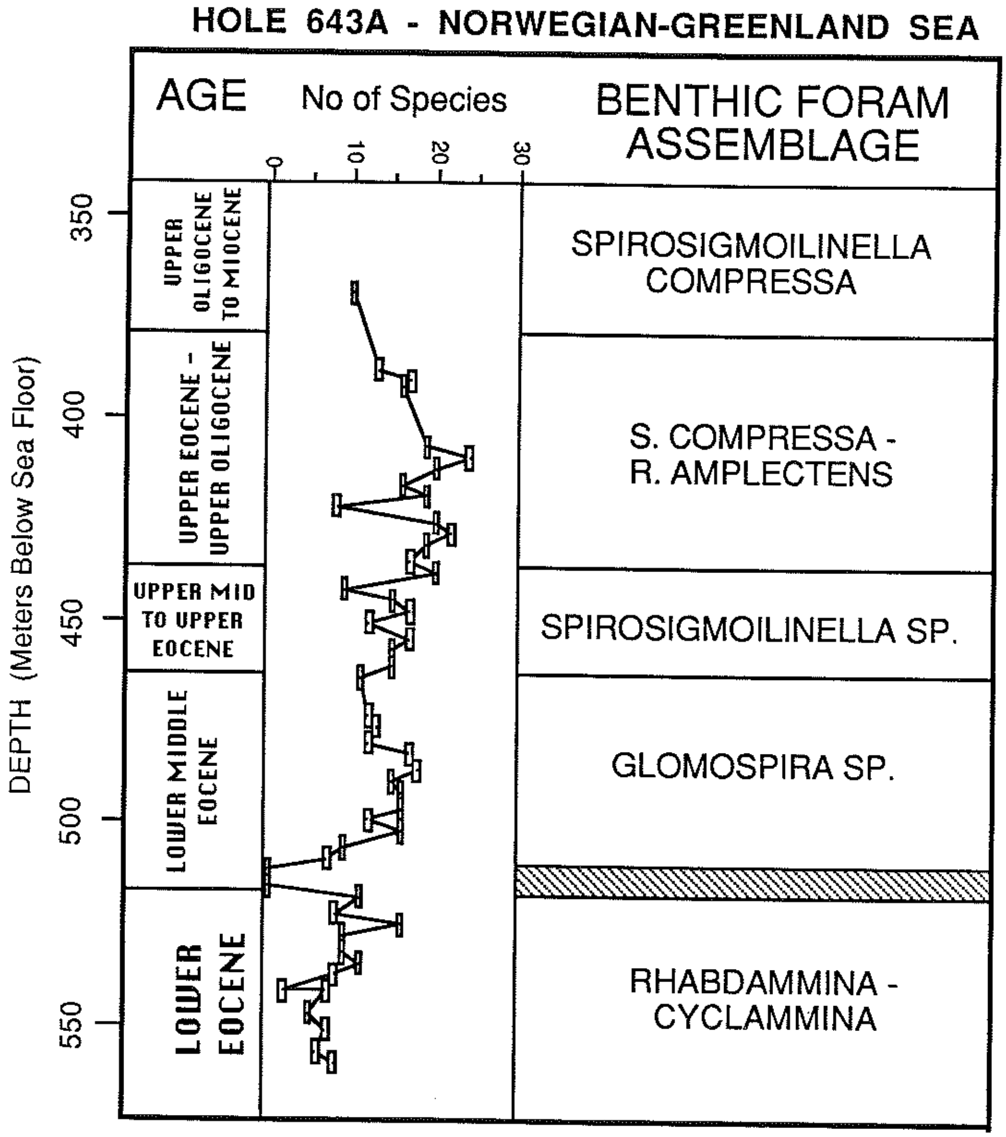
VERDENIUS AND VAN HINTE (1983)	THIS STUDY
ASTRORHIZACEA and HYPERAMMINACEA:	
Bathysiphon filiformis M. Sars	Bathysiphon sp.
Bathysiphon eocenica Cushman & Hanna	Dendrophrya robusta Grzybowski
Dendrophrya excelsa Grzybowski	Dendrophrya excelsa
-- not found --	Dendrophrya latissima Grzybowski
Hippocrepina sp. cf. H. depressa Vasicek	Hippocrepina sp.
Jacuella sp.	-- not found --
-- not found --	Lagenammina sp.
Marsipella elongata Norman	Aschemonella crassatina
Protobotellina (?) lofotensis Verdenius & Van Hinte	Rhizammina indivisa Brady
Psammosphaera fusca Schultze	Psammosphaera fusca
Psammosphaera sp. cf. P. bowmani Heron-Allen & Earland	Psammosphaera sp. A.
Rhabdammina sp. cf. R. eocenica Cushman & Hanna	Rhabdammina discreta Brady
Rhabdammina cylindrica Glaessner	Rhabdammina discreta Brady
Saccammina placenta Grzybowski	Saccammina complanata (Franke)
Saccorhiza ramosa (Brady)	Saccorhiza ramosa
Hyperammina nodata Grzybowski	Hyperammina ex gr. subnodosiformis Grzyb.
Hyperammina cylindrica Parr	Rhabdammina cylindrica Glaessner
Hyperammina rugosa Verdenius & Van Hinte	Hyperammina rugosa
-- not found --	Aschemonella spp. ind.
AMMODISCACEA	
Ammodiscus siliceus (Terquem)	Ammodiscus cretaceus (Reuss)
Ammodiscus infimus Bornemann	Ammodiscus infimus
-- not found --	Ammodiscus tenuissimus Grzybowski
-- not found --	Glomospira gordialis (Jones & Parker)
-- not found --	Glomospira charoides (Jones & Parker)
-- not found --	Glomospira irregularis (Grzybowski)
Lituotuba sp.	
Ammolagena clavata (Jones & Parker)	Ammolagena clavata
RZEHAKINACEA	
Miliammina earlandi Loeblich & Tappan	
Silicosigmoilina californica Cushman & Church	Sigmoilopsis schlumbergeri (Silvestri)
Spirolocammina lamposa (Hussey)	Spirosigmoilinella compressa
Spirolocammina sp.	
Spirosigmoilinella sp.	Spirosigmoilinella sp.
HORMOSINACEA	
Hormosina excelsa (Dylazanka)	Reophax guttifer Brady
Reophax trinitatensis (Cushman & Renz)	Reophax pilulifer Brady
Reophax subfusiformis Earland	Reophax subfusiformis
-- not found --	Subreophax scalaria (Grzybowski)
-- not found --	Reophax subnodosiformis Grzybowski
LITUOLACEA	
-- not found --	Adercotrema sp 1. Gradstein et al. (in press)
Ammobaculites strathaernensis Cushman & LeRoy	
-- not found --	Ammobaculites aff. polythalamus Loeblich
-- not found --	Cribrostomoides spp. ind.

Table 3-3 (continued).

VERDENIUS AND VAN HINTE (1983)	THIS STUDY
Haplophragmoides compressa LeRoy	Haplophragmoides compressa
-- not found --	Haplophragmoides eggeri Cushman
Haplophragmoides excavata Cushman	Haplophragmoides excavata
Haplophragmoides walteri Grzybowski	Haplophragmoides walteri
Haplophragmoides kirki Wickenden	Haplophragmoides "kirki"
Recurvoides contortus Earland	Recurvoides spp. ind.
Recurvoides deflexiformis (Noth)	Recurvoides spp. ind.
Recurvoides sp. sff. R. deflexiformis (Noth)	Recurvoides spp. ind.
LOFTUSIACEA	
Cyclammina placenta (Reuss)	Cyclammina placenta
Cyclammina acutidorsata (Hantken)	Cyclammina acutidorsata
Cyclammina rotundidorsata (Hantken)	Cyclammina rotundidorsata
Cyclammina amplectens Grzybowski	Reticulophragmium amplectens
Reticulophragmium sp.	Reticulophragmium sp.
SPIROPLECTAMMINACEA	
Spiroplectammina spectabilis (Grzybowski)	Spiroplectammina spectabilis
Spiroplectammina navarroana Cushman	Spiroplectammina navarroana
TROCHAMMINACEA	
-- not found --	Ammosphaeroidina sp.
-- not found --	Cystammina aff. pauciloculata (Brady)
Trochammina globigeriniformis (Parker & Jones)	Trochammina aff. globigeriniformis
-- not found --	Trochammina altiformis Cushman and Jarvis
-- not found --	Trochammina deformis Grzybowski
-- not found --	Trochammina sp. (6-chambered)
Budashevaella sp. aff. B. multicamerata (Budasheva)	Budashevaella cf. multicamerata
ATAXOPHRAGMIACEA	
Dorothia principiensis Cushman & Bermudez	Dorothia principiensis
Karreriella conversa (Grzybowski)	Karreriella conversa
Karreriella siphonella (Reuss)	Karreriella siphonella
-- not found --	Karreriella horrida Mjatliuk
Martinotiella communis (d"Orbigny)	Martinotiella communis



3-11. Biostratigraphy of agglutinated foraminifera in Hole 643A.



3-12. Age of sediments, diversity of benthic foraminifera and characteristic assemblages defined in ODP Hole 643A.

upper bathyal paleodepths. Also present in this assemblage are Ammolagena clavata, Ammodiscus tenuissimus and Psammosphaera fusca. An unusual occurrence is an almost monospecific acme of Spiroplectammina spectabilis in Sample 59X-1, 77-81. The age of the Rhabdammina-Cyclammina assemblage is constrained by the basement below and the Eocene Radiolarian Flood in Core 55X. Assuming isochrony of the Eocene Radiolarian Flood with the North Sea, I place Core 55X in the basal Lutetian.

2. Glomospira Assemblage (Sample 643A-54X-5, 64-69 cm to -50X-1, 79-84 cm). Lower Middle Eocene.

Above the barren interval represented by Samples 55X-3, 73-78 cm and 55X-1, 73-78 cm, the benthic foraminiferal assemblage becomes more diversified. The basal samples in this interval (54X-5, 64-69 cm and 54X-3, 75-79 cm) still contain abundant radiolarians and the benthic assemblage is dominated by astrorhizids. However, the benthic foraminiferal assemblage in the overlying cores contain a diversified, deep-water assemblage. A number of forms make their first appearance in this interval, including Recurvoides spp., Saccammina complanata, Reophax subnodulosus, Glomospira charoides, G. irregularis, Hormosina ovuloides, Buzasina sp., Trochamminoides, Karreriella conversa, and Cystammina sp. The species Haplophragmoides walteri, Trochammina altiformis and Bathysiphon are more abundant in this assemblage compared with the underlying Rhabdammina-Cyclammina assemblage. Most notable is the acme of Glomospira in Samples 53X-3, 73-78 cm and 53X-1, 83-88 cm. The chronostratigraphic and paleoecological significance of the Glomospira facies is discussed in Chapters 4 and 5.

3. Spirosigmoilinella sp. Assemblage (Sample 643A-49X-5, 79-84 cm to -47X-1, 79-84 cm). Upper Middle - Upper Eocene ?.

This interval in Hole 643A is characterized by the partial range of Spirosigmoilinella sp. (of Verdenius and Van Hinte, 1983), which has its first occurrence in Sample 49X-5, 79-84 cm. Two stratigraphically important taxa have their first occurrences within this interval. These are Budashevaella cf. multicamerata in Sample 48X-3, 65-69 cm and Dorothia principiensis in Sample 48X-5, 65-69 cm. Near the top of the Spirosigmoilinella sp.

assemblage, the last occurrences of *Hyperammina rugosa* (in Sample 47X-3, 79-84) and *Trochammina* aff. *globigeriniformis* (in Sample 47X-1, 79-84) were observed.

The *Spirosigmoilinella* assemblage is still numerically dominated by tubular forms, but the species *R. amplectens* and *H. walteri* are also common in this interval. Interestingly, most of the specimens of *R. amplectens* present in this assemblage are juvenile specimens or belong to the smaller morphotype with fewer chambers and less-well developed alveoles than the typical form. This morphotype is similar to the assumed ancestral species *R. intermedia* (Mjatliuk) and appears to be morphologically intermediate between *H. walteri* and *R. amplectens*. The common occurrence of the smaller morphotype of *R. amplectens* in this interval of Hole 643A is usually thought to have stratigraphic significance, since *R. intermedia* was reported by Mjatliuk (1970) to occur in the lower Eocene. However, shipboard palynomorph work yields a conflicting, younger (late Oligocene) age for this interval (Shipboard Scientific Party, 1987b).

4. ***Spirosigmoilinella compressa*** - ***Reticulophragmium amplectens*** **Assemblage**

(Sample 643A-46X-5, 65-69 cm to -42X-1, 74-77 cm). ?Upper Eocene - ?Lower Miocene.

This interval in Hole 643A is defined by the concurrent stratigraphic ranges of the nominate taxa. The co-occurrence of *Spirosigmoilinella compressa* and *R. amplectens* in the Norwegian-Greenland Sea was unexpected, since Verdenius and Van Hinte (1983) reported that these species possess disjunct stratigraphic ranges in the Leg 38 sites. *S. compressa* differs from the larger and thicker *Spirosigmoilinella* sp., and was first found in Sample 47X-3, 79-84 cm. The morphotype of *R. amplectens* occurring in this interval is the larger, typical form with many chambers. The assignment of the base of this zone to the upper Eocene is based upon correlation with the North Sea benthic foraminiferal zonations (Fig. 3-7). The age of the upper portion of this interval was determined by the presence of calcareous nannofossils indicative of Zone NP25 (upper Oligocene) in Sample 43X, CC (Shipboard Scientific Party, 1987b). Nannofossil samples from Core 42X did not contain Oligocene marker species, and this core was assigned to the lower Miocene.

The 40 m interval represented by the *S. compressa-R. amplectens* assemblage is characterized by a gradual decline in diversity culminating near the top of the assemblage, which is determined by the LO of R. amplectens. A total of 27 species have their last occurrences in this assemblage, 22 of which occur in the upper 20 m of the interval. The S. compressa-R. amplectens assemblage contains one important first occurrence - the FO of Ammodiscus infimus in Sample 45X-1, 79-84 cm. Ammodiscus infimus is a large, coarse variety with unknown affinity to Ammodiscus latus.

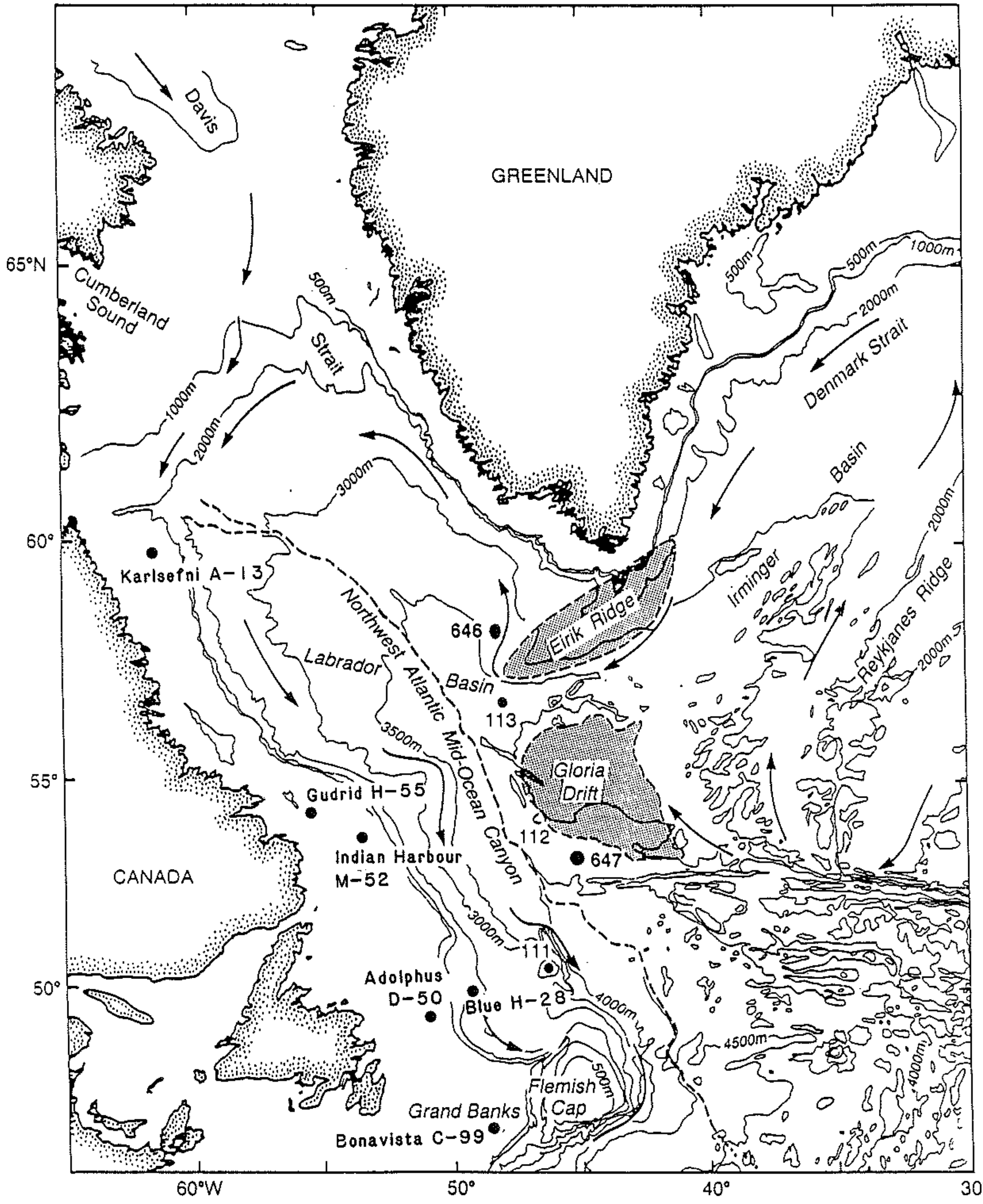
In addition to the ubiquitous tubular species, the S. compressa-R. amplectens assemblage is dominated by Karreriella siphonella, Spirosigmoilina sp., S. compressa and Ammosphaeroidina sp. In comparison with the underlying assemblages, A. tenuissimus, Ammosphaeroidina sp., and Budashevaella cf. multicamerata display increased abundance, whereas R. amplectens occurs in lower numbers.

5. **Spirosigmoilinella compressa Assemblage** (Samples 41X-1, 105-107 and 41X-1, 73-76 cm). Lower Miocene ?.

The Spirosigmoilinella Zone as defined by Verdenius and Van Hinte (1983) corresponds to the total range of the nominate taxon. For the purpose of this study, the S. compressa assemblage in Hole 643A is defined by the common occurrence of the nominate taxon above the last occurrence of R. amplectens, and therefore does not correspond to the Spirosigmoilinella Zone. Only two samples examined in this study contains this assemblage, since samples from overlying Core 40X were cherty and did not break down. Sample 41X-1, 73-76 cm contains 10 species of benthic foraminifera, and is dominated by Psammosphaera sp. A, Saccorhiza sp., S. compressa, K. siphonella, Spirosigmoilinella sp., Lagenammina sp., and A. infimus. The species Ammodiscus cretaceus, Cyclammina acutidorsata and Recurvoides are present in lesser numbers.

5. LABRADOR SEA -

Site 647 was drilled at a water depth of 3869 m in the Southern Labrador Sea (53°19.8′N, 46°15.7′W) on oceanic crust of Anomaly 24 age. The site is located approximately 90 km southeast of DSDP Site 112 (Fig. 3-13) on the southeast flank of the Gloria Drift, a depositional feature formed by bottom currents that originate in the Norwegian-Greenland Sea and flow through the Charlie-Gibbs Fracture Zone. Two holes were drilled at Site 647. Hole 647A



3-13. Location of DSDP and ODP Sites in the Labrador Sea and exploration wells on the Labrador Margin penetrated 580 m of Paleogene sediments which have been subdivided into 4 lithologic units (Fig. 3-14). Hole 647B recovered only Neogene sediments, and was not examined in this study.

The biochronology of Hole 647A is constrained by calcareous nannofossils, planktonic foraminifera, diatoms, radiolarians, and palynomorphs. In addition, the identification of Chron C17 to C19 magnetic reversals allows us to calibrate the age-depth curve to a standard geochronology (Berggren _et_ _al_. 1985). A list of microfossil datums used to establish the chronology of Hole 647A is reproduced in Table 3-4. This chronology has been refined by Firth (in press), and I use his biochronology across the lower/middle Eocene boundary. By interpolation from the sedimentation rate curve, the Eocene/Oligocene boundary was placed at 290 mbsf and the middle/upper Eocene boundary at 410 mbsf. A hiatus or condensed section separating lower Eocene and middle Eocene sediments is present between 610 and 640 mbsf. This hiatus or condensed interval corresponds approximately to the position of the lowermost intra-Eocene seismic reflector apparent in multichannel seismic records across the Gloria Drift (Fig. 3-14). Core recovery between the intra-Eocene seismic reflectors was incomplete, and only core-catcher samples from Cores 647A-55R to -61R were available for study.

The lower Eocene to lower Oligocene of Hole 647A can be subdivided into seven assemblages, based on the partial ranges of characteristic benthic taxa. The assemblages were chosen to reflect a subdivision of the sedimentary section at a stage level, and are named after taxa that are cosmopolitan and have correlative value in the North Atlantic. These assemblages are shown in figure 3-14, and are discussed below in order from oldest to youngest. The relative proportions of important taxa in the Paleogene section are shown in figures 3-15 and 3-16. The biostratigraphy of agglutinated taxa is presented in figure 3-17, and the chronology of benthic foraminiferal FO's and LO's in given in Table 3-5.

Foraminiferal Assemblages:

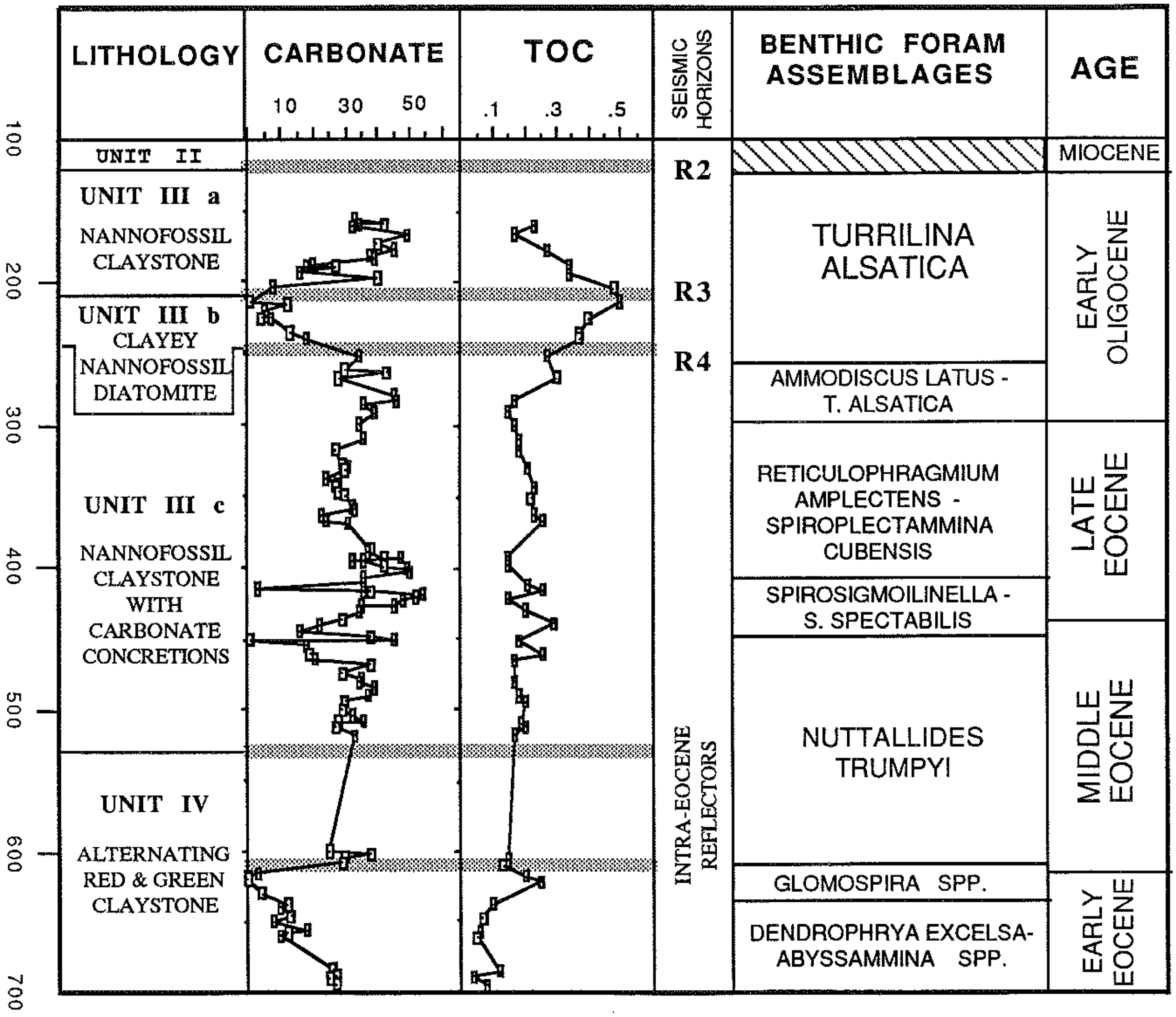
1. Dendrophrya ex gr. excelsa - Abyssammina Assemblage (Samples 647A-71R-2, 43-45 cm to -66R-2, 24-27 cm). Lower Eocene:

This assemblage is characterized by the presence of the nominate taxa and contains a mixture of agglutinated and calcareous benthics in a _Subbotina_

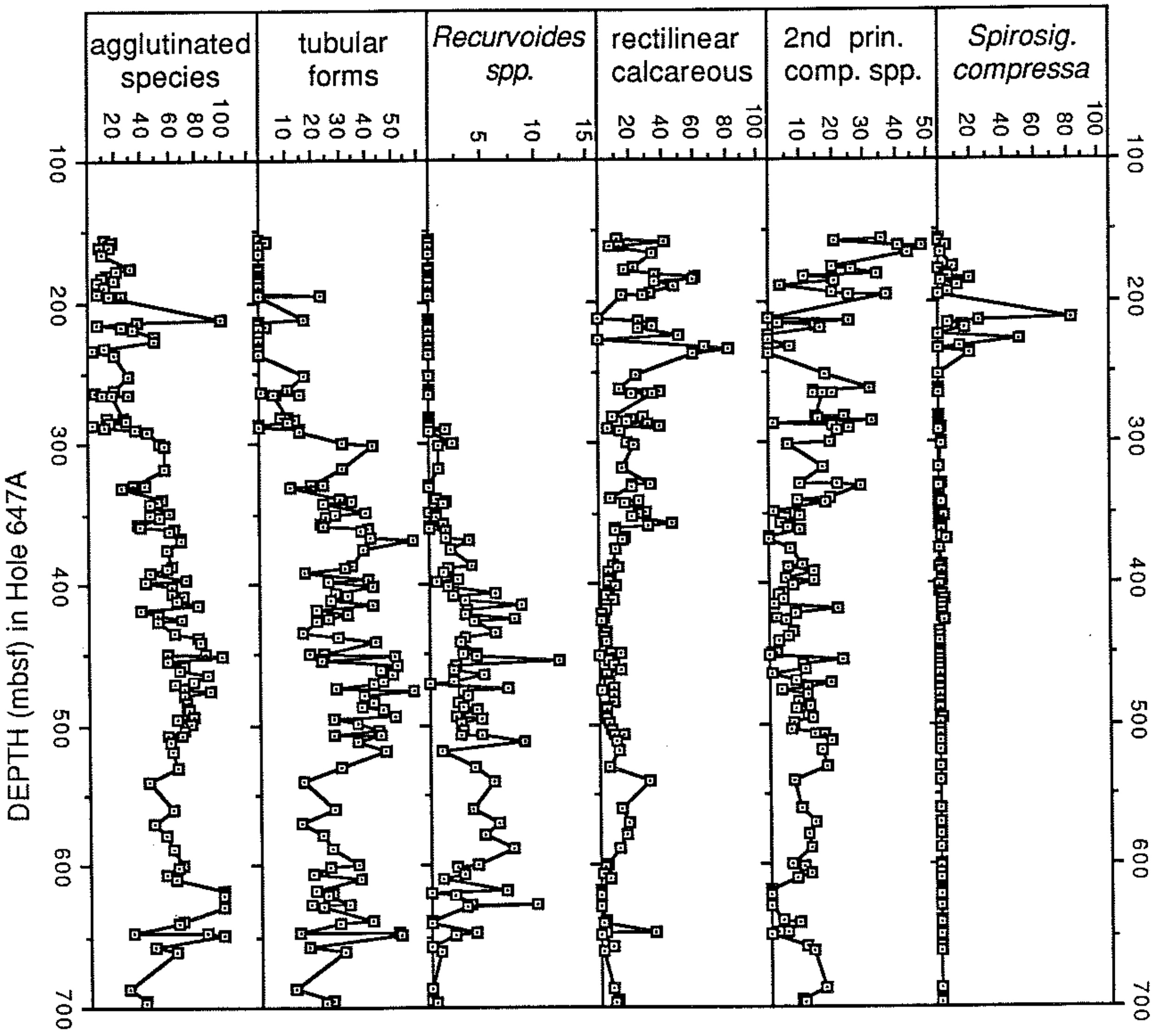
TABLE 3-4.

Sub-bottom depths of biostratigraphic and magnetostratigraphic age picks used to construct the age-depth curve for Hole 647A (after Shipboard Scientific Party, 1987, c).

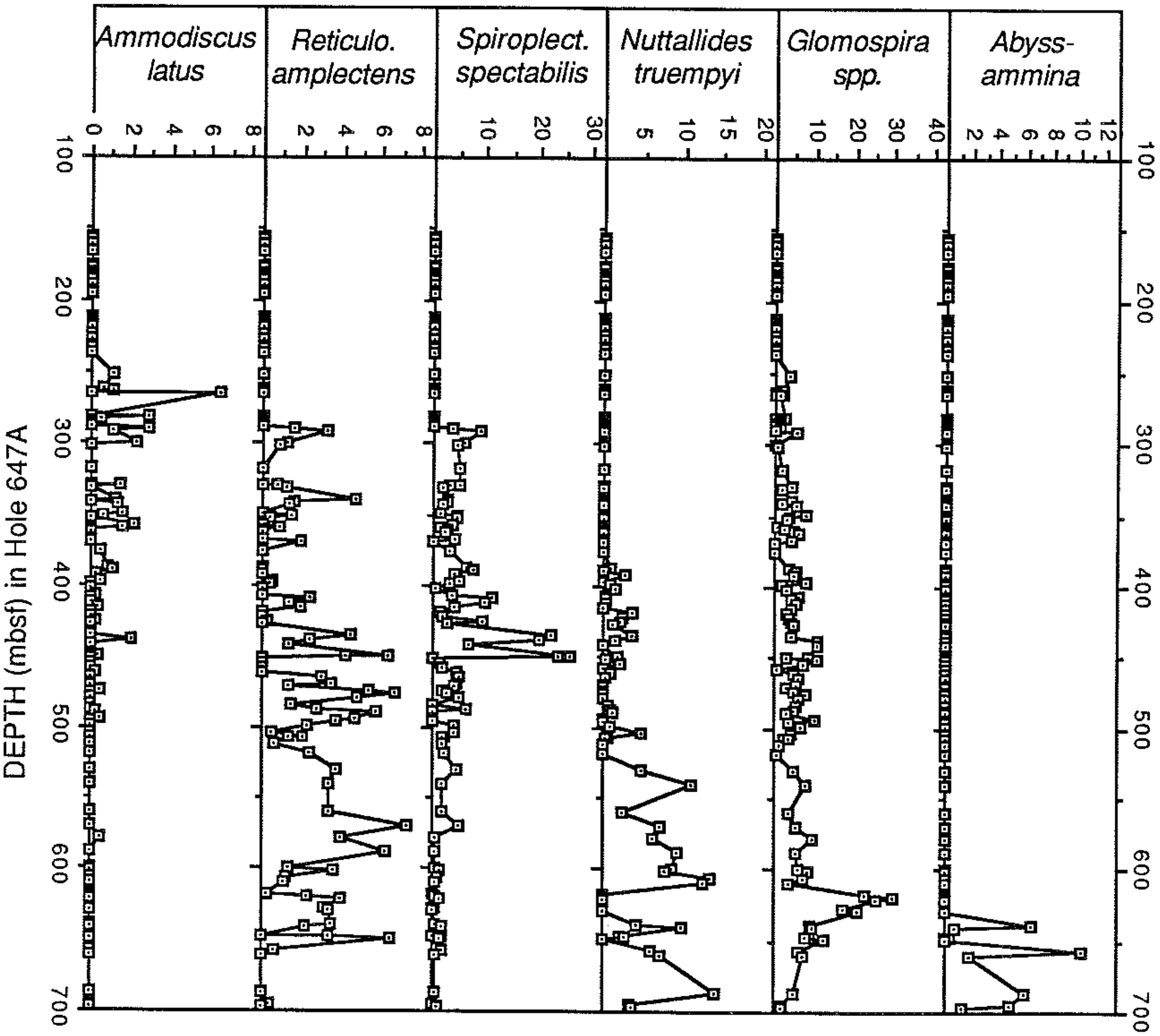
Name of Datum	AGE	DEPTH
LCO Dictyococcites bisectus	>23.7	135.4-136.1
Occ Pentadinium imaginatum	>23.7	145.1
FAD Sphenolithus ciperoensis	<30.3	147.5
LAD Globigerina angiporoides	>32.0	190.0
LAD Reticulofenestra umbilica	34.6	214.0-215.5
Occ Cyclamperium pegetrum	<33.0	221.9
LO Cestodiscus reticulatus	34.0	221.9
FO Cestodiscus reticulatus	36.2	239.0
LAD Ericsonia formosa	35.1	250.5-251
LAD Chiloguembelina	30.0	260.1
Occ Coscinodiscus excavatus	36.8	260.1
Occ Globigerina ampliapertura	>32.8	262.0
LAD Pseudohastigerina	34.0	269.7
LAD Discoaster barbadiensis	36.7	288.8
LO Subbotina linaperta	36.7	291.0
LAD Turborotalia cerroazulensis	36.7	298.6
LAD Globigerinatheka	37.0	335.0-337.2
LAD Nuttallides truempyi	38.5	385.4-395.1
FAD Chiasmolithus oamaruensis	39.7	443.5-435.0
LAD Truncorotaloides	40.6	443.5-453.2
LAD Chiasmolithus solitus	42.3	453.2-454.0
LAD Acarinina	40.6	463.5-472.5
FAD Globigerinatheka index	45.0	578.8
LO Pseudohastigerina wilcoxensis	44.5	588.4
FAD Reticulofenestra umbilica	<45.5	608
Occ Tribrachiatus orthostylus and Discoaster lodoensis	>55.3	638.5
FO Homotryblium oceanicum	<53.6	648.0
Occ Morozovella lensiformis	>53.4	659.0
FAD Discoaster lodoensis	55.3	675.5-685.0
FO ?Dracodinium condylos	56.0	675.5
Occ Tribrachiatus orthostylus	<56.6	696.6
FO Dracodinium	<56.6	696.6
Base Chron C17	41.11	450.75-453.25
Top N2 event, Chron C18	41.80	481.45-482.15
Base N2 event, Chron C18	42.23	490.15-490.25



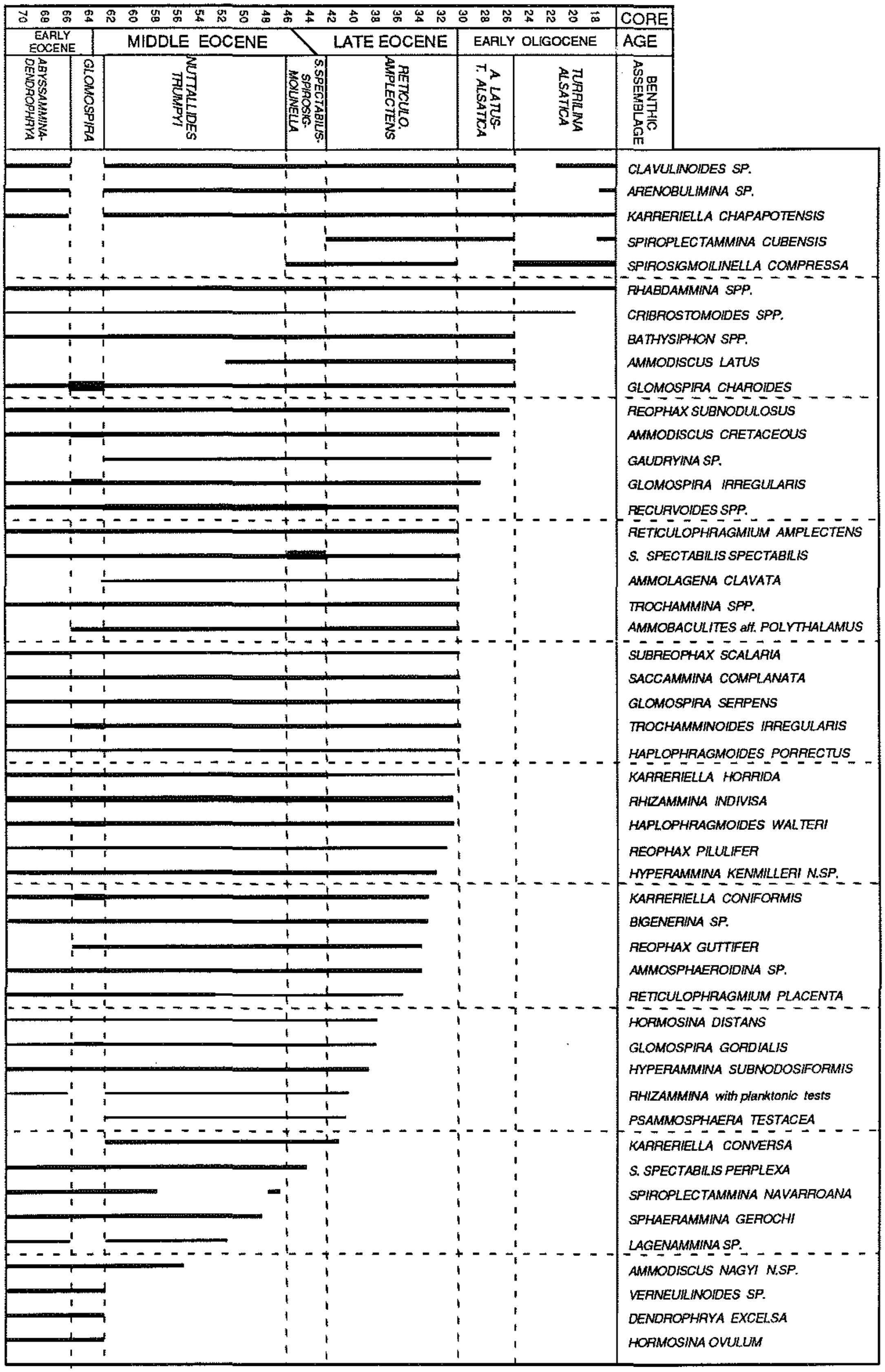
3-14. Comparison of lithostratigraphy, seismic reflectors, percent carbonate and Total Organic Content with benthic foraminiferal biochronology in the Paleogene of Hole 647A. Depth to reflectors and lithologic data are from the Site 647 Chapter (Shipboard Scientific Party, 1987c).



3-15. Relative abundance of common benthic foraminiferal species and species groups in Hole 647A.



3-16. Relative abundance of stratigraphically important benthic foraminiferal species and in Hole 647B.



3-17. Biostratigraphy of common agglutinated species in Hole 647A.

Table 3-5. Chronology of benthic foraminiferal first and last occurrence events in ODP Hole 647A.

	Taxon	depth (mbsf)	Age
LO	Turrilina alsatica	155.9m	31 Ma
LO	Bathysiphon sp.	251.2m	35.5 Ma
LO	Glomospira charoides	251.1m	35.5 Ma
LO	Ammodiscus latus	251.1m	35.5 Ma
LO	Nuttallides umbonifera	262.7m	35.8 Ma
LO	Ammodiscus cretaceus	280.5m	36.3 Ma
LO	Osangularia mexicana	"	"
LO	Gavelinella micra	"	"
LO	Bolivina huneri	281.4m	36.4 Ma
LO	Glomospira irregularis	285.0m	36.5 Ma
LO	Recurvoides spp.	290.3m	36.6 Ma
LO	Reticulophragmium amplectens	"	"
LO	Spiroplectammina spectabilis	"	"
LO	Ammolagena clavata	"	"
LO	Trochammina deformis	"	"
LO	Ammobaculites aff. polythalamus	"	"
LO	Subreophax scalaria	"	"
LO	Saccammina complanata	290.8m	36.6
LO	Glomospira serpens	"	"
LO	Trochamminoides irregularis	"	"
LO	Rhizammina spp.	300.3m	36.9 Ma
LO	Haplophragmoides walteri	"	"
LO	Reophax pilulifer	318.0m	37.4 Ma
LO	Gavelinella capitata	"	"
LO	Cibicidoides grimsdalei	328.4m	37.6 Ma
LO	Hyperammina kenmilleri n.sp.	329.9m	37.7 Ma
LO	Bulimina macilenta	"	"
LO	Karreriella coniformis	331.4m	37.7 Ma
LO	Bigenerina sp.	"	"
LO	Reophax guttifer	339.2m	38.0 Ma
LO	Ammosphaeroidina sp.	340.7m	38.0 Ma
LO	Reticulophragmium placenta	350.6m	38.3 Ma
LO	Hormosina distans	360.3m	38.6 Ma
LO	Glomospira gordialis	"	"
LO	Nuttallides truempyi	386.0m	39.2 Ma
LO	Karreriella conversa	405.8m	39.8 Ma
FO	Spiroplectammina cubensis	408.8m	39.9 Ma
FO	Spirosigmoilinella compressa	425.8m	40.4 Ma
LO	Spiroplectammina spectabilis perplexa	434.4m	40.6 Ma
LO	Spiroplectammina navarroana	460.3m	41.3 Ma
FO	Ammodiscus nagyi n.sp.	498.3m	42.4 Ma
LO	Aragonia spp.	540.0m	43.5 Ma
LO	Cibicidoides subspiratus	569.1m	44.3 Ma
FO	Ammodiscus latus	578.8m	44.6 Ma
LO	Verneuilinoides polystrophus	578.8m	44.6 Ma
LO	Dendrophrya ex gr. excelsa	620.7m	48.8-52.6 Ma
LO	Hormosina ovulum	627.2m	"
LO	Abyssammina spp.	638.6m	52.6-53.6 Ma
LO	Quadrimorphina profunda	657.5m	54.2 Ma

patagonica planktonic ooze typical of Zones P8 to P9 (Berggren and Schnitker, 1983). Calcareous foraminifera are silicified to some degree, probably owing to the proximity of basement. The sediments overlying basement were deposited in 1700-2000 m water depth, based on estimates using the backtracking method of Sclater et al. (1985). The benthic assemblage displays evidence of a lower bathyal setting, for example, the relative proportion of Lenticulina spp. and Bulimina spp. is higher than in any of the overlying assemblages. The Abyssammina - Dendrophrya assemblage corresponds to nannofossil zones NP11 - NP13 (J.V. Firth, personal communication 1987).

The nominate taxa are common to abundant in some samples (Fig. 3-16). Abyssammina comprises 10% of the assemblage in Sample 68R-1, 129-132 cm, and Dendrophrya ex gr. excelsa makes up 37% of the assemblage in Sample 67-1, 40-43 cm. Abyssammina spp, Quadrimorphina profunda, Bulimina trinitatensis and Bulimina cf semicostata of Tjalsma and Lohmann (1983) are restricted to this assemblage. The latter species is transitional between Bulimina semicostata and Bulimina glomarchallengeri. An interesting agglutinated species tentatively identified as Hormosina ovulum was found in Samples 70R, CC and 64R, CC. This occurrence was unexpected in that H. ovulum is not known to occur above the Paleocene in bathyal assemblages, and there is no other evidence for reworking.

2. Glomospira Assemblage (Samples 65R-2, 31-34 cm to 63R, CC). Lower to middle Eocene:

Samples from the 20m interval represented by Cores 64R and 65R are barren of calcareous microfossils, and the benthic foraminifera are present in a "Glomospira facies". The most common species in this interval are Glomospira irregularis, Glomospira charoides, Ammodiscus cretaceous, Karreriella coniformis, Trochamminoides spp. and Haplophragmoides walteri. Depending upon where the base of the Glomospira Assemblage lies in Zone NP13, the assemblage may be as old as 53.6 to 52.8 Ma. A Glomospira-facies also occurs in "lower Eocene" sediments in the Carpathian Mountain Belt, and is usually interpreted as reflecting a pelagic environment at bathyal to abyssal paleodepths (Geroch et al., 1967, Olszewska, 1984). At Site 647 the presence of a Glomospira facies is likely due to a rise in the lysocline to a level above 2500m.

3. Nutallides truempyi Assemblage (Samples 63R-1, 139-142 cm to 47R-4, 74-77 cm), Middle Eocene:

This is the interval in Hole 647A between the last occurrence of the carbonate-free claystones containing abundant Glomospira and the first occurrence of Spirosigmoilinella. This assemblage is characterized by the common occurrence of the nominate taxon (Fig. 3-16). The lower portion of the assemblage corresponds to an interval of poor recovery between Samples 54R, CC and 61R, CC. This interval was placed in the middle of Zone NP15 (Zones CP13b - CP13C of Okada and Bukry, 1980) by Firth (in press), which corresponds to an age between 48.7 and 47.0 Ma. The N. truempyi Assemblage therefore overlies a condensed section and/or hiatus encompassing the uppermost lower Eocene and the lower middle Eocene. The species Cibicidoides subspiratus (Nuttall) was found in Samples 61R, CC, 60R, CC and 59R, CC. This is a distinctive taxon in the Atlantic owing to its restricted stratigraphic range (P9 to P13; Van Morkhoven et al., 1986). The last occurrence of Aragonia spp. occurs between Samples 55R, CC and 56R, CC. This event was placed at the top of Zone P14 by Tjalsma and Lohmann (1983), but it apparently occurs earlier in the Labrador Sea. Above Core 55R, recovery was more or less continuous, and Nuttallides truempyi decreases in relative abundance. Core 54R was placed in nannofossil Zone NP16 by Firth (in press), and interpolation from the sedimentation rate curve yields an age of 45.5 Ma.

The agglutinated component comprises approximately 80% of the benthic assemblage between Cores 55R and 46R. Tubular species are dominant, but Reticulophragmium amplectens and Recurvoides spp. attain their maximum relative abundance in this interval. A number of important stratigraphic events also occur (Fig. 3-17). These are the first occurrence of Ammodiscus latus in Sample 52R-2, 45-48 cm; the last occurrence of Ammodiscus nagyi in Sample 52R-5, 54-57 cm, and the last occurrence of Spiroplectammina navarroana in Sample 49R-6, 117-120 cm. In the North Sea, the last occurrence of S. navarroana usually occurs lower in the section, in the lower Eocene (Gradstein et al., in press).

4. Spiroplectammina spectabilis - Spirosigmoilinella Assemblage (Samples 46R-5, 60-63 cm to 43R-5, 97-100 cm), Middle - Upper Eocene:

This interval in Hole 647A is defined by the partial range of Spirosigmoilinella compressa, from its first occurrence to the first occurrence of Spiroplectammina cubensis. The assemblage is characterized by the acme of the Spiroplectammina spectabilis plexus (Fig. 3-16). This interval corresponds the uppermost part of middle Eocene nannofossil zone NP17, and the lowermost upper Eocene. The exact position of the middle/upper Eocene boundary, however has not been determined exactly. Nannofossil stratigraphy (Firth, in press) place the boundary within Core 46R, but interpolation from the sedimentation rate curve places the boundary in Core 43R. Our age model yields an age for this assemblage between 40.4 and 39.9 Ma.

Two important stratigraphic events are associated with the S. spectabilis - Spirosigmoilinella Assemblage (Fig. 3-17). The last occurrence of the small, compressed variety of Spiroplectammina spectabilis (S. spectabilis perplexa of Kaminski, 1984) occurs in Sample 46R-1, 60-63 cm. The last common occurrence of S. spectabilis spectabilis occurs in Sample 43R-3, 104-107 cm. This event occurs approximately 1 meter above the middle/upper Eocene boundary as determined from the sedimentation rate curve. Above this level, the relative abundance of S. spectabilis in our samples never exceeds 10%.

5. **Reticulophragmium amplectens - Spiroplectammina cubensis Assemblage** (Sample 43R-3, 104-107 cm to 31R-1, 133-135 cm), Upper Eocene:

Within the accuracy of our microfossil and magnetic chronology, the interval represented by this assemblage encompasses the entire upper Eocene. The assemblage is defined by the concurrent range of R. amplectens and S. cubensis. The first occurrence of S. cubensis (in Sample 43R-3, 104-107 cm) occurs at about the same level as the LCO of S. spectabilis, so the latter event can also be used to determine the base of the interval. The last occurrence of R. amplectens in Sample 31R-1, 133-135 cm occurs within 1 meter of the Eocene/Oligocene boundary, which was placed at 290 mbsf according to our age-depth model.

Within this interval, there is a gradual transition from an agglutinated assemblage to a predominantly calcareous assemblage in the Oligocene. A number of typical Eocene taxa such as Nuttallides truempyi, Cibicidoides grimsdalei, and many of the "flysch-type" agglutinated taxa have their last occurrences in this assemblage. This is particularly apparent in Cores 32R and 31R, which contain the last occurrences of 10 agglutinated taxa (Fig. 3-17). The interval can be further subdivided into a lower and upper portion based on the last occurrances of *Ammosphaeroidina*, *Bulimina macilenta*, *C. grimsdalei*, and *Karreriella coniformis* between Cores 35R and 37R. The last occurrence of *N. truempyi* in Sample 41R-1, 58-61 cm, is an important extinction event, and corresponds to an approximate age of 39 Ma.

Throughout the interval, the assemblage is still numerically dominated by tubular agglutinated species. In the upper portion of the assemblage, the rectilinear calcareous group (*Stilostomella*, *Dentalina*, nodosariids), *Pullenia* spp, and the "2nd Principal Component" of Tjalsma and Lohmann (*Cibicidoides*, *Oridorsalis*, *Gyroidinoides*, and *Globocassidulina*) become more important.

6. *Ammodiscus latus* - *Turrilina alsatica* Assemblage (Samples 31R-1, 133-135 cm to 27R-1, 78-83 cm.), Basal Oligocene:

This interval is defined by the concurrent range of the nominate taxa. The first occurrence of *Turrilina alsatica* coincides with the last occurrence of *R. amplectens* in Sample 31R-1, 133-135 cm. The last occurrence of *Ammodiscus latus* was observed in Sample 27-1, 78-83 cm, but its true last occurrance may be as much as 14 m higher, because Core 26R recovered only drilling slurry and was not sampled for benthic foraminifera. This assemblage corresponds to the basal Oligocene, and represents the time interval between 36.6 ± 0.05 and 35.3 ± 0.2 Ma.

The species *Ammodiscus latus* attains its maximum relative abundance in the basal Oligocene (Fig. 3-16), and *Turrilina alsatica* is also a common species in many samples. A "flood" of *Nuttallides umbonifera* is observed in Sample 30R-5, 10-13 cm (36.5 ± 0.05 Ma), where it comprises 56% of the total assemblage. The increased abundance of *N. umbonifera* has also been observed in the basal Oligocene of Southern Pacific Site 277 (Corliss, 1979) and Eastern Atlantic Site 119 (Miller, 1983), which suggests that this event may be useful for inter-basinal correlation. Within this interval the agglutinated foraminifera display a noticeable reduction in size, and most of the remaining flysch-type taxa (*Glomospira charoides*, *Bathysiphon* sp, *Reophax* spp, *Ammodiscus cretaceous*, and *Glomospira irregularis*) have their last occurrences. Throughout much of the interval, the benthic assemblage is numerically dominated by rectilinear calcareous taxa, the "2nd Principal Component" taxa, and *Pullenia* spp. This assemblage corresponds to the "*Stilostomella* assemblage" of Miller *et al.* (1982) at Site 112.

7. **Turrilina alsatica Assemblage** (Sample 25R-4, 107-110 cm to 17R-1, 107-110 cm), Lower Oligocene:

This is the interval between the last occurrence of Ammodiscus latus and the top of the Paleogene section in Hole 647A. The upper limit of the Turrilina alsatica assemblage is truncated by a barren interval and one or more hiatuses above Core 17R. In exploration wells drilled on the Labrador Margin, the last occurrence of T. alsatica is used to identify the Paleogene/Neogene boundary, but a hiatus encompassing much of the upper Oligocene is also present in the area (Gradstein, 1987).

Throughout the interval, the abundance and diversity of benthic taxa is low, and washed residues contain mainly siliceous debris. Many samples in Lithologic Unit IIIb contain only rectilinear and unilocular calcareous species, Karreriella, and Spirosigmoilinella. The most characteristic taxa is Spirosigmoilinella compressa, which displays its greatest relative abundance in this relatively depauperate assemblage. However, its absolute abundance in the lower Oligocene does not differ noticeably from its abundance in the upper Eocene. Uvigerina are common in samples from Core 20R. This occurrence corresponds to a peak in the TOC content of the sediment (Fig. 3-14), indicating high paleoproductivity. Among flysch-type agglutinated taxa, only Cribrostomoides subglobosus and Rhabdammina persist into this assemblage.

NEOGENE BIOSTRATIGRAPHY

1. BAFFIN BAY SITE 645 -

Site 645 lies on the continental slope off southern Baffin Island at a water depth of 2,020 m. Drilling at Site 645 penetrated 1,147.1 m of sediment, providing a continuous lower Miocene to Recent stratigraphic record. The entire lithologic sequence in Holes 645B, 645D and 645E has a pronounced terrigenous character and was subdivided into 3 lithologic units:

Lithologic unit 1 consists of alternating beds of light tan to gray calcareous gravel-bearing muddy sand and dark gray silty mud with scattered dropstones. This unit occurs from 0 to 168.1 mbsf and its age was determined as early Pleistocene to Recent based on dinoflagellates.

Lithologic unit 2 extends from 168.1 to 330.7 mbsf, and consists of noncalcareous silty mud with dropstones. Its age was determined as late Pliocene to early Pleistocene based on dinoflagellates.

Lithologic Unit 3 extends from 330.7 to 1147.1 mbsf and is lower Miocene to upper Pliocene, based on dinoflagellates and occasional calcareous planktonic microfossils. Subunit 3a consists mainly of poorly sorted olive-gray silty mudstone and muddy sandstone. Scattered pebbles occur to a depth of 605m. Subunit 3b contains calcareous silty claystones with organic carbon content to ca. 3% interbedded with muddy sandstones. Subunit 3c consists of fine to medium grained muddy sandstone and silty mudstones.

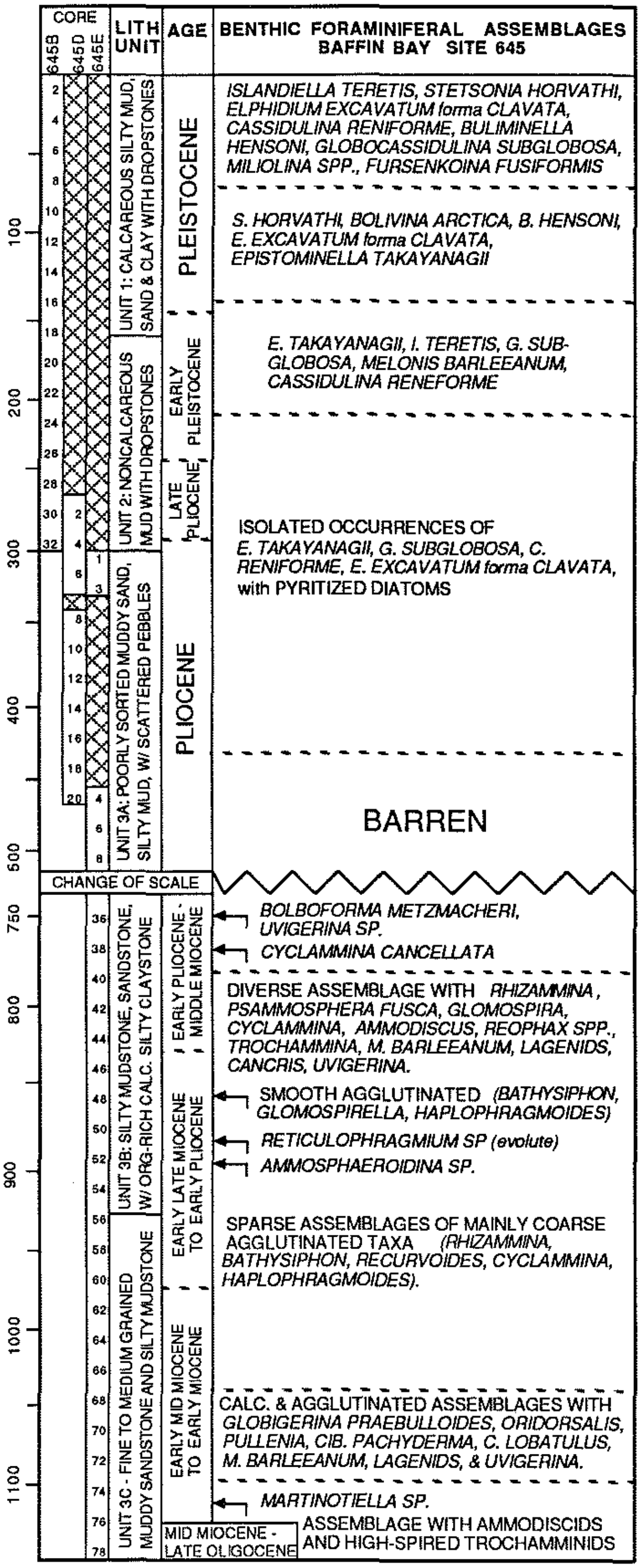
Faunal Composition:

Fifty-five samples from lithologic units 1 and 2 were studied for benthic foraminifera. The upper 220 meters of Hole 645B contain benthic foraminiferal assemblages dominated by calcareous species (Fig. 3-18), and were discussed in detail by Kaminski et al. (in press, c). Hole 645D recovered sediments belonging to lithologic units 2 and 3a. Twenty core-catcher samples were examined from this hole, of which only two (Samples 645D-6R, CC and -13R, CC) contain rare specimens of calcareous foraminifera.

Hole 645E penetrated Lithostratigraphic Units 2 - 3 between 301 and 1147 mbsf. A total of 180 samples were examined for foraminifera and associated microfossils. Samples from Unit 2 and the upper portion of lithologic unit 3 are barren. Microfossils are again encountered in subunit 3b below approximately 750 mbsf. These consist mainly of fragments of agglutinated foraminifera. Less commonly, calcareous benthic foraminifera, pyritized diatoms and specimens of bolboforma are present. Planktonic foraminifera were only found in two samples. Because of the sparse and fragmentary nature of the assemblages, the microfossil data from this hole are not treated quantitatively.

The presence of Bolboforma metzmacheri in sample 645E-36R,CC constrains the age of this sample as no younger than nannofossil Zone NN16 (lower Pliocene). This species is known from the North Atlantic (Murray, 1987) and the North Sea (King, 1983). In the North Sea, B. metzmacheri occurs together with the dextral form of Neogloboquadrina atlantica and defines King's upper Miocene Zone NSP14.

The last occurrence of coarse agglutinated species occurs between samples 38R-3,44-47cm and 38R-6,127-129 cm, at approximately 770 mbsf. This event occurs in the lower Pliocene in the Beaufort Sea (Young and McNeil, 1984) and



3-18. Lithostratigraphy and summary of the benthic foraminiferal assemblages and associated microfossils at Site 645, Baffin Bay. The age interpretation of the composite section of Holes 645B, 645D, and 645E is based on the multiple microfossil and paleomagnetic records given in the Site 645 Chapter (Shipboard Scientific Party, 1987d).

at some DSDP sites in the Norwegian-Greenland Sea (Leg 38 Site reports; Berggren and Schnitker, 1983). Agglutinated foraminifera are locally abundant to the base of Hole 645E. The assemblages consist mainly of coarse species of *Rhizammina*, *Hyperammina*, *Cyclammina*, *Reophax*, *Lagenammina*, *Ammodiscus*, *Haplophragmoides*, *Glomospira*, and *Trochammina*. Less frequently, specimens of *Glomospirella*, *Ammosphaeroidina* and *Martinotiella* are found, but many samples contain little more than unidentifiable fragments. Miocene assemblages of this type have only been reported previously from DSDP Site 348 in the Norwegian-Greenland Sea (Berggren and Schnitker, 1983).

The agglutinated assemblages between approximately 790 and 850 mbsf (from Sample 40R,CC to 46R-3, 95-97 cm) are dominated by coarse astrorhizids and hormosinids, mainly *Rhizammina*, *Lagenammina* and *Reophax*. Species with finely agglutinated tests become common in sample 49R, CC. Samples between 49R, CC, and 51R-1, 41-43 cm are dominated by finely agglutinated *Bathysiphon* fragments. Below this interval, the assemblages contain common specimens of *Cyclammina cancellata*, *Recurvoides* spp. and *Haplophragmoides carinata*. Also present is a compressed species of *Reticulophragmium* similar to a variety described from the Beaufort Sea (Young and McNeil, 1984) that I tentatively identify as *R.* cf. *arctica*. Near the base of Hole 645E, a change in the composition of the agglutinated assemblage is observed. The assemblage in sample 78R, CC is dominated by small species of *Ammodiscus* and *Trochammina*.

Calcareous benthic foraminifera were also found in samples 38R, CC to 46R-3, 95-97 cm. The dominant calcareous species in this interval is *Melonis barleeanum*. Unilocular species (*Lagena*, *Oolina* & *Fissurina*) are common, and accessory forms include *Globocassidulina subglobosa* and species of *Nodosaria*, *Quinqueloculina* and *Uvigerina*. In the majority of samples, however, preservation of calcareous benthics is poor and only relatively robust specimens are present. Smaller individuals are presumably dissolved. Samples 48R-2, 84-86 cm to 60R, CC are barren of calcareous foraminifera.

Calcareous foraminifera are again encountered in isolated samples below about 975 mbsf (60R, CC to 77R-1, 107-109 cm). In this interal *B. metzmacheri* is absent, and the most common genus is *Cibicidoides*. The most diverse assemblage was found in sample 67R-2, 89-91 cm, which contains *Oridorsalis umbonatus*, *Pullenia bulloides*, *Cibicidoides pachyderma*, *C. lobatulus*, *Uvigerina* sp. (smooth), and four specimens of *Globigerina praebulloides*. Although the total range of *G. praebulloides* is from P22 to N18 (Kennett and

Srinivasan, 1983), this species is restricted to lower to lower middle Miocene sediments in the North Sea (Zone NSP11 of King, 1983) and lower Miocene sediments on the Labrador Margin (Gradstein and Agterberg, 1982).

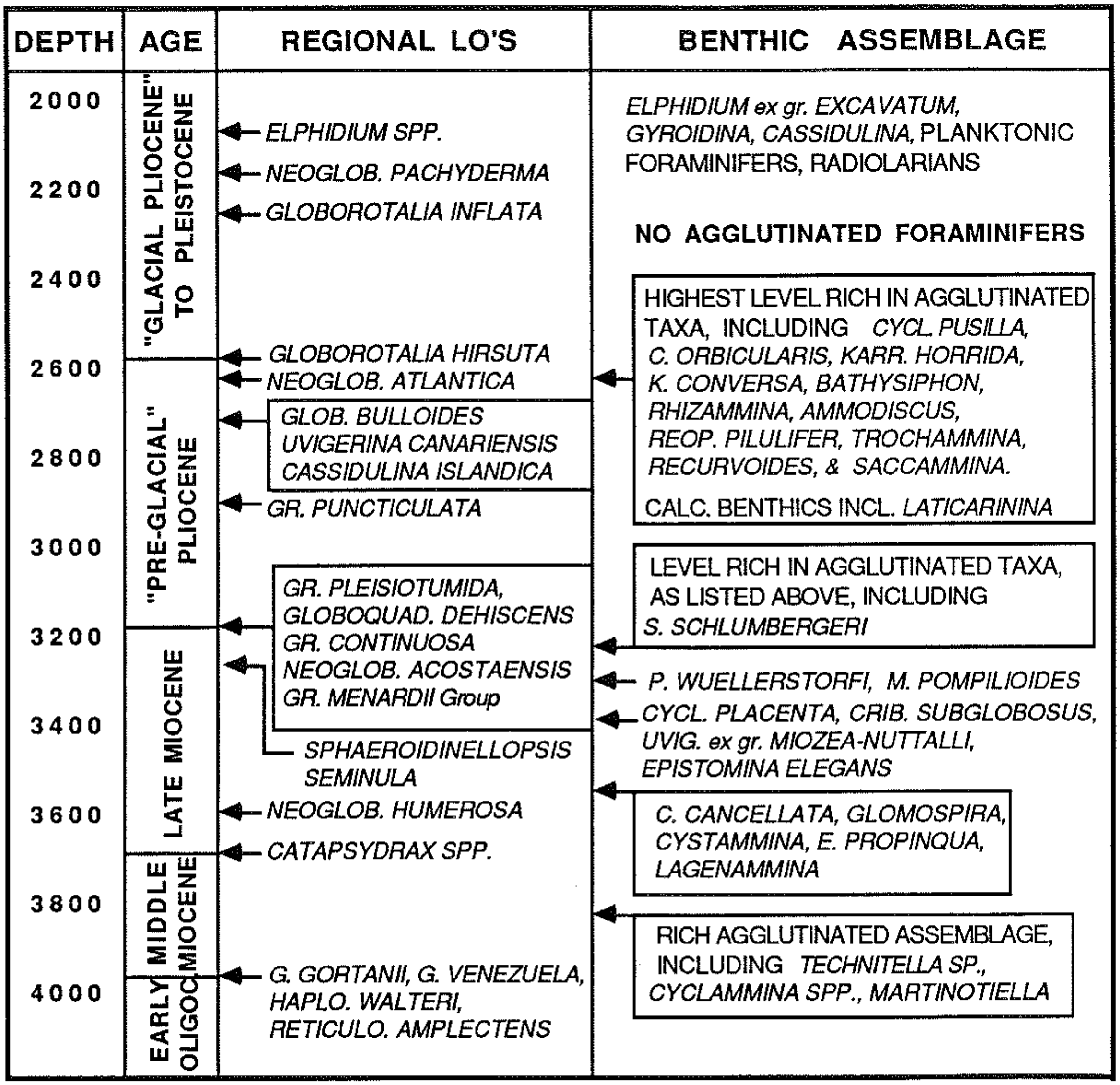
2. TEXACO BLUE H-28 WELL (Labrador Margin):

The Texaco Blue H-28 well was drilled in 1486 m of water on the northeastern Grand Banks near Orphan Knoll, and is one of the few commercial wells along the Canadian Atlantic Margin with a deep marine Miocene to Pliocene stratigraphic record. The well is situated near the present axis of the Western Boundary Undercurrent and was a site of rapid sedimentation in the late Neogene. The Cenozoic microfossil record reflects deposition in mid-bathyal water depths which this well has probably occupied since the late Cretaceous. The Neogene biostratigraphic record displays a four-fold division based on planktonic foraminiferal stratigraphy (Fig. 3-19). The foraminiferal assemblages are discussed from from oldest to youngest:

Middle Miocene sediments with *Sphaeroidinella seminulina* and *Catapsydrax dissimilis* occur between 3810 and 3640 m, and immediately overly lower Oligocene and older sediments. The middle Miocene benthic assemblage is rich in agglutinated species, including *Bathysiphon*, *Rhizammina*, *Saccammina*, *Cystammina*, *Cyclammina placenta*, *Cyclammina pusilla*, *Cyclammina orbicularis*, *Cribrostomoides subglobosus*, *Karreriella conversa*, and *Sigmoilopsis schlumbergeri*. This assemblage is remarkably similar to the assemblage from the upper Miocene to lower Pliocene Seismic Unit 3 of Hole 646B. Calcareous foraminifera that testify to the lower - middle bathyal environment are *Laticarinina*, *Melonis pompilioides* and *Cibicidoides wuellerstorfi*.

The upper Miocene (N16-N18) occurs between 3640 and 3160 m. This interval contains the last ocurrences of *Sigmoilopsis schlumbergeri*, *Neogloboquadrina humerosa-atlantica*, *N. acostaensis*, *N. continuosa*, *Globoquadrina dehiscens*, and the *G. menardii* group. A diverse agglutinated assemblage similar to the one mentioned above occurs between 3200 and 3500m.

The lower/upper Pliocene boundary in this well was originally determined by the last occurrences of *Neogloboquadrina atlantica* and *Globorotalia hirsuta* near 2550 m. However, Aksu and Kaminski (in press) report the LAD of *N. atlantica* at ~2.4 Ma in the Labrador Sea. Therefore, the LO of this species in exploration wells along the Labrador Margin may be a useful indicator of


TEXACO BLUE H-28 WELL

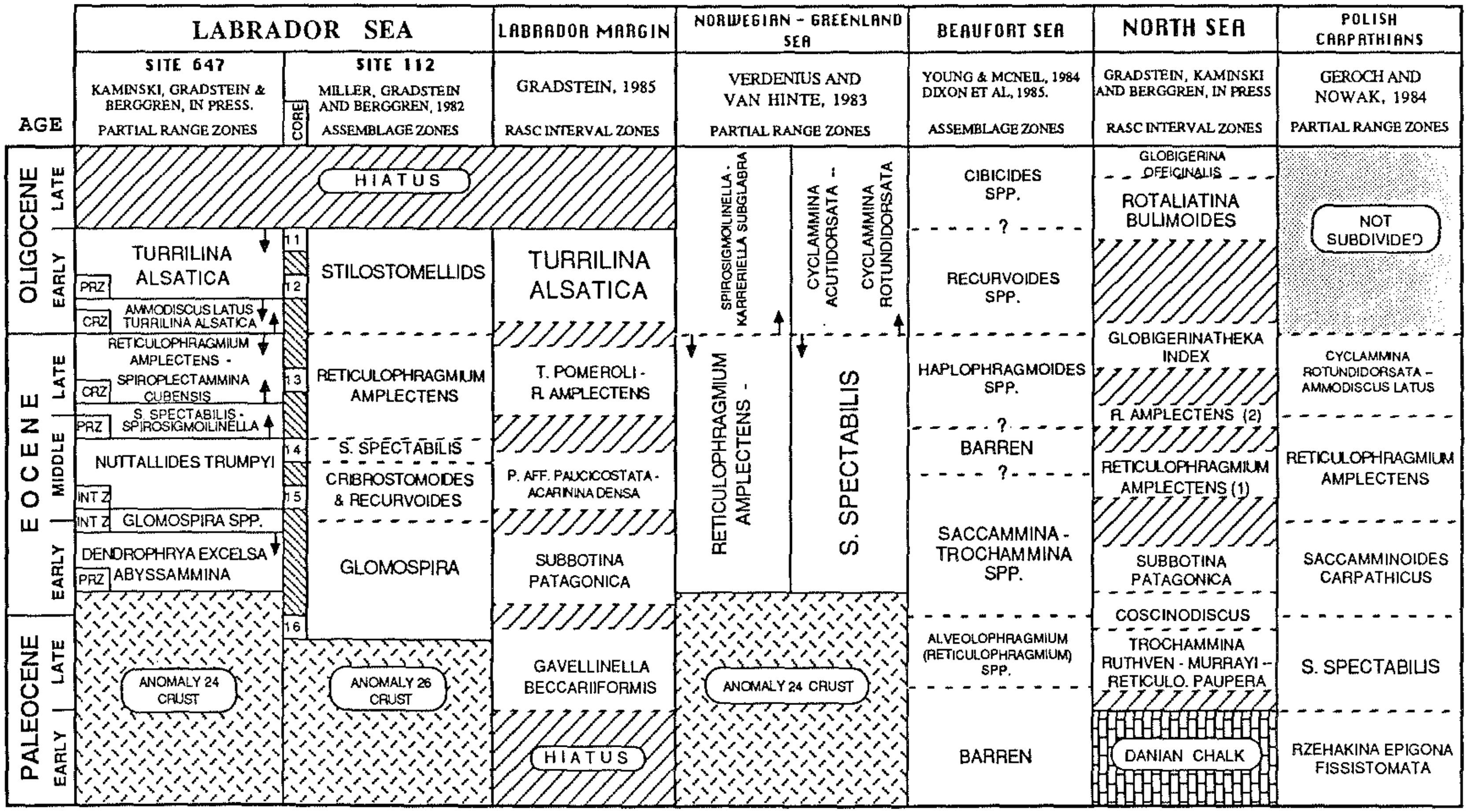
3-19. Biostratigraphic record of the Texaco Blue H-28 well, Labrador Margin.

the pre-glacial Pliocene. Another useful LO in this well is *Gr. puncticulata*, which has a LAD at 3.8 Ma in Hole 646B (Aksu and Kaminski, in press). Through much of the Pliocene, the benthic foraminifera are represented by calcareous taxa such as *Elphidium*, *Gyroidina*, *Cassidulina*, *Uvigerina*, and *Laticarinina*. However, an assemblage rich in coarse agglutinated species similar to those mentioned above occurs at 2600m.

ZONATIONS BASED ON AGGLUTINATED FORAMINIFERA:

Agglutinated foraminifera have now been used to define regional zonations for the lower Tertiary in the North Sea, Norwegian-Greenland Sea, Beaufort Sea, on the Labrador Margin, as well as in the Polish Flysch Carpathians (Verdenius and Van Hinte, 1983; Gradstein and Agterberg, 1982; Geroch and Nowak, 1984; Gradstein *et al*., in press; Mjatliuk, 1970; Miller *et al*., 1982; King (1983); Young and McNeil, 1984; Kaminski *et al*., in press, d). A compilation of regional zonations based primarily on agglutinated foraminifera is presented in Figure 3-20. To date, only the zonation of Geroch and Nowak (1984) has been used on a wider scale. This zonation, based on Carpathian material, can be successfully applied in other areas of the Tethys such as the Austrian Alps and the Rif-Betic Flysch (W. Kuhnt, personal communication 1986). This demonstrates the usefulness of agglutinated foraminifera for interregional, or at least intra-tethyan correlation. Correlative extinction events among agglutinated benthic foraminifera have been identified in the North Sea, Labrador Sea and Trinidad (Gradstein, 1983; Kaminski *et al*., in press, a). However in all the regions mentioned above, the task of correlating these zonations to a standard geochronology has been a problem owing to the paucity of calcareous microfossils and lack of magnetic reversal information. The biochronology of Hole 647A, therefore, may serve as a key for correlating the benthic foraminiferal stratigraphy of the Labrador Margin to the Norwegian-Greenland Sea and North Sea.

The Paleogene Norwegian-Greenland Sea zonation of Verdenius and Van Hinte (1983) was based upon DSDP Samples collected aboard Leg 38. The Eocene/Oligocene boundary in the Leg 38 sites was recognized using the last occurrences of *Spiroplectammina spectabilis* and/or *Reticulophragmium amplectens*. Their use of these taxa as Eocene marker species was based on analogies with the Polish Carpathians (Grzybowski, 1898) and the Eocene of



3-20. Comparison of Paleogene zonal classifications in areas containing flysch-type assemblages. Correlation of Sites 112 and 647 is from Kaminski *et al.*, in press, d. Zonal boundaries that have not been tied to a standard geochronology (Berggren *et al.*, 1985) are indicated by dashed lines. The Labrador Margin and North Sea RASC zonations have been scaled against linear time (after Gradstein, 1987) to show the position of stratigraphic breaks.

Belgium (Kaaschieter, 1961). However in the Leg 38 samples, calibration of ranges of these taxa to a standard planktonic microfossil chronology was tentative. In Hole 647A, the last occurrence of both taxa was found just 30 cm below the position of the Eocene/Oligocene boundary predicted by the age-depth model.

The biostratigraphy of agglutinated foraminifera in 29 wells from the Central and Viking Grabens was studied by Gradstein et al. (in press). This zonation based on RASC is very robust and precise in a relative sense, but the chronostratigraphy of benthic foraminiferal datums in the North Sea is still not well established because of the paucity of planktonic foraminifera in most wells. The presence of ash layers and three incursions of planktonic foraminifera provide tie points in the zonation, but it is not possible to recognize or assign standard "P Zones" in the North Sea. This problem can be circumvented, however, by the use of local palynomorph zones.

Both the North Sea zonation and the Labrador Margin zonation are made up of RASC interval "zones" based on clusters of last occurrences of taxa in exploration wells. The RASC biozones are named after characteristic species which most likely have their last occurrences in the interval, but not necessarily at the top of that interval. Therefore, RASC "zones" reflect the average ranges of taxa, and may differ conceptually from traditional zonations based on maximum ranges of taxa in a given interval. When a RASC optimum sequence is scaled in linear time by the identification of microfossil datum events, "missing intervals" of time become apparent. In the Paleogene Labrador Margin and North Sea zonations, the missing intervals correspond to hiatuses caused by basinward shifts in shoreline (Gradstein, 1987). Reviews of the methodology used in constructing and interpreting RASC zonations can be found in Gradstein et al. (1985), D'Iorio (1986), Gradstein (1987) and Williamson (1987).

1. Correlation of Holes 647A and 112 -

Site 112 is located approximately 90 km northwest of Site 647, and until now constituted the only reference section for the abyssal Paleogene in the Labrador Sea. A total of 6 cores containing Paleogene sediments were recovered from this site, and preliminary stratigraphic analysis was carried out by Berggren (1972), Perch-Nielsen (1972) and Bukry (1972). Unfortunately, the Eocene/Oligocene boundary and the position of subsurface seismic reflectors at this site are represented by coring gaps. The foraminiferal and nannofossil stratigraphy of Hole 112 was restudied by Miller, Gradstein, Berggren and Aubry (in Miller et al., 1982), who were able to correlate Cores 12R to 15R with standard planktonic microfossil zonations (Table 3-5).

Table 3-5. Age of Paleogene cores from Hole 112 (from Miller et al., 1982):

Core	Nannofossil zone	Planktonic zone
12R	NP22	not diagnostic
13R	NP19	P15 - P16
14R	NP17	not older than P14
15R	NP14	P10
16R	barren	barren

For this study, I examined benthic foraminiferal assemblages from Hole 112 to correlate the position of individual cores from this site with Hole 647A (Fig. 3-20).

Core 112-11R contains a calcareous benthic assemblage belonging to the Turrilina alsatica Assemblage in Hole 647A. The diverse nature of the fauna and good preservation present in 112-11R-2, 103-106 cm is comparable only to the assemblages above the siliceous sediments of Lithologic Unit IIIb in Hole 647A. The composition of the assemblage compares best with assemblages from Core 17R of Hole 647A.

Sample 112-12R-1, 44-46 cm contains a planktonic assemblage with Chiloguembelina, Pseudohastigerina, and Bolboforma irregularis. In Hole 647A, the last occurrences of Chiloguembelina and B. irregularis were found in Sample 27R-1, 78-85 cm. However, the only flysch-type agglutinated species present in Sample 112-12R-1, 44-46 cm is Rhabdammina sp. The lack of Ammodiscus latus and Glomospira charoides in this sample indicates that it belongs in the Turrilina alsatica Assemblage. The assemblage in this sample probably correlates with the unsampled interval between Cores 25R and 27R in Hole 647A.

Two samples from Core 112-13R were examined for benthic foraminifera (Samples 112-13R-3, 118-122 cm and 13R-5, 120-124 cm). Both samples contain

Ammosphaeroidina and *Karreriella coniformis*, which suggests that Core 13R correlates with the lower half of our *R. amplectens* Assemblage. The position of the assemblage with regard to Hole 647A can be further constrained by the absence of *N. truempyi*, and the low abundance of *Spiroplectammina spectabilis*. This assemblage compares well with assemblages from Cores 36R to 40R of Hole 647A.

Cores 112-14R and -15R correlate with our *Nuttallides truempyi* Assemblage. In Core 112-14R, I did not find any specimens of *Spirosigmoilinella compressa* in the two samples examined in this study (Samples 112-14R-2, 100-104 cm and 112-14R-3, 113-114 cm) but its presence is reported by Miller *et al.*, (1982) from a single sample. In the *Spirosigmoilinella* - *S. spectabilis* Assemblage of Hole 647A, however, the occurrence of *Spirosigmoilinella* is continuous (see Appendix). The assemblage from Core 112-14R contains *S. spectabilis perplexa*, *Reticulophragmium* sp. (evolute), and abundant *N. truempyi*. In addition, the abundance of *S. spectabilis* s.l. in our samples from Core 14R does not exceed 6 percent. This suggests a better correlation with our *N. truempyi* Assemblage. Although Miller *et al*. (1982) refer the agglutinated component of this core to a "*Spiroplectammina spectabilis* assemblage", this assemblage does not correlate with our *Spirosigmoilinella* - *S. spectabilis* Assemblage (Fig. 3-20). Core 112-15R belongs in nannofossil Zone NP14 (Miller *et al*., 1982), and contains poorly preserved calcareous benthics that are overgrown with pyrite in a manner analogous to assemblages from Samples 647A-56R, CC and -58R, CC. The assemblage in Core 112-15R contains *Ammodiscus nagyi*, but none of the other species typical of the lower Eocene of Hole 647A (see Fig. 3-17).

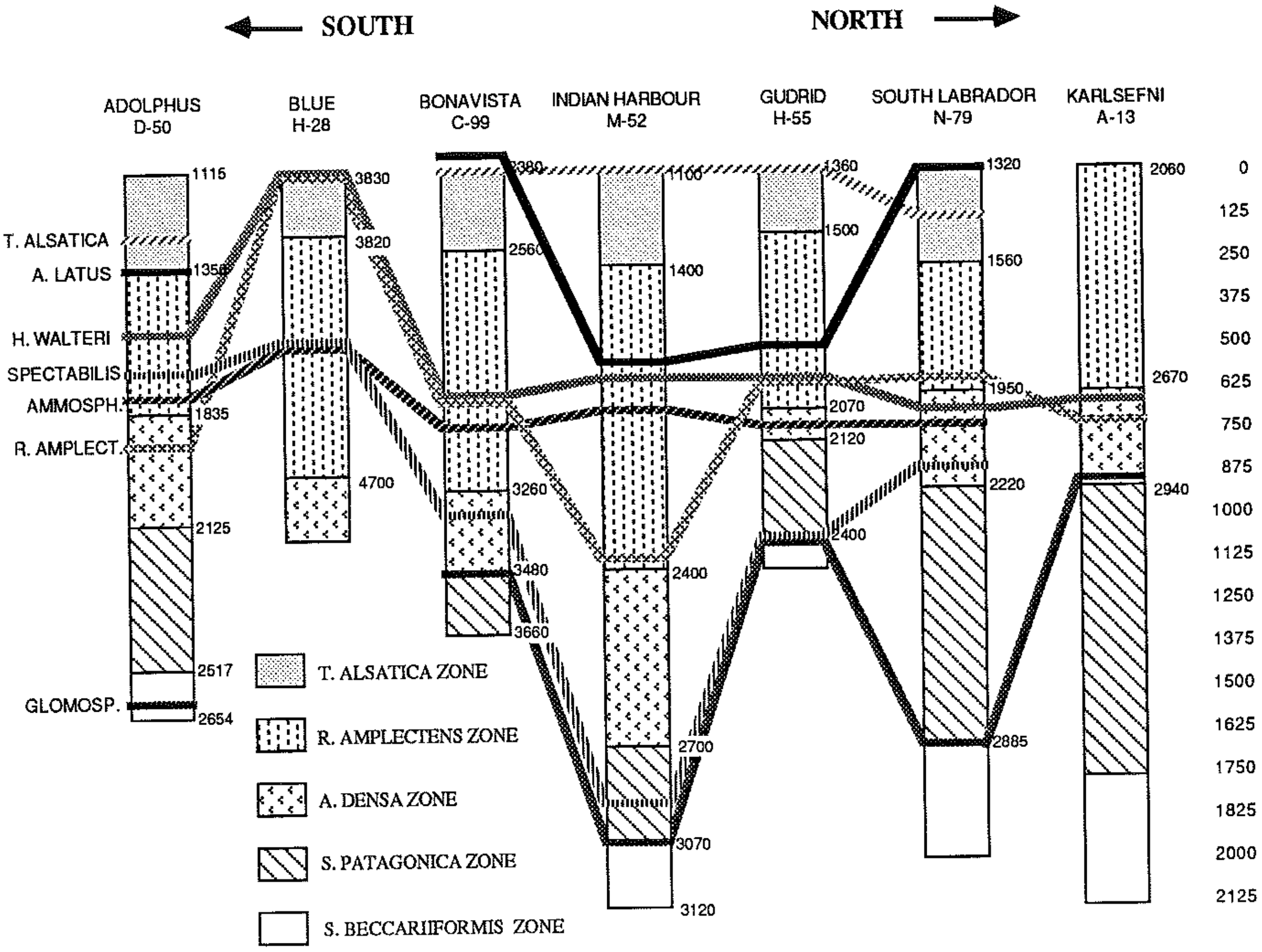
The basal core of Hole 112 was cut approximately 10 m above basement, which at this site was formed near the boundary between the reversed and normal interval of Chron 26. The indurated red claystones overlying basement are barren of calcareous microfossils. On the Labrador Margin, the Paleocene/Eocene boundary is determined by the last occurrences of *Stensioina beccariiformis*, *Rzehakina epigona*, and rare *Planorotalites chapmani*. However, *R. epigona* persists into the lower Eocene in the abyssal western North Atlantic (Tjalsma and Lohmann, 1983). Other species restricted to the Paleocene on the Labrador Margin are *Hormosina ovulum*, *Hormosina excelsa*, *Saccammina placenta*, *Tappanina selmensis*, and rare Danian planktonics (*Subbotina pseudobulloides*, *S. triloculinoides*, *Planorotalites compressus*).

In Sample 112-16R-1, 85-87 cm, I found specimens of Hormosina, but these persist into the lower Eocene of Hole 647A. This sample also contains R. epigona, Labrospira pacifica and S. placenta, species which do not occur in Hole 647A. In Trinidad and in the North Sea, Labrospira does not occur above the Paleocene. I therefore favor a Paleocene age assignment for Core 112-16R.

2. Correlation of Hole 647A with the Labrador Margin -

The benthic foraminiferal assemblages from Hole 647A and the Labrador Margin display differences related to paleobathymetry and depositional setting. The Eocene-Oligocene Labrador Margin sequences were deposited in an outer neritic to upper bathyal clastic environment, and abyssal taxa are absent from the benthic foraminiferal assemblages. Faunal diversity in exploration well samples from the Labrador Margin is noticeably lower than at Site 647, but a number of important benthic foraminifera occur in both regions, including Turrilina alsatica, Rhabdammina spp., Ammodiscus latus, A. cretaceus, Reticulophragmium amplectens, R. placenta, Haplophragmoides walteri, Ammosphaeroidina sp., Reophax pilulifer, Karreriella conversa, K. horrida, Spiroplectammina spectabilis, S. navarroana, Ammobaculites aff. polythalamus, Glomospira charoides, Trochamminoides spp., and Hormosina ovulum. Relatively few species of calcareous foraminifera are present in the Labrador Margin assemblages, and these are represented mainly by neritic to upper bathyal species of Nodosaria, Lenticulina, Plectofrondicularia, Cibicidoides, and uvigerinids. With the exception of T. alsatica, none of the middle Eocene - Oligocene calcareous species typical of the Labrador Margin were found in Hole 647A. In the lower Eocene, a few of the more offshore wells contain deep-water calcareous species, including Nuttallides truempyi.

Figure 3-21 presents Paleogene RASC benthic foraminiferal zones and important benthic taxa in 7 wells aligned from south (Adolphus D-50) to north (Karlsefni A-13) on the Labrador Margin. In these wells, several benthic foraminifera possess the same relative order of last occurrence events. The LO's of T. alsatica, H. walteri, Ammosphaeroidina, and S. navarroana do not cross over one another. The LO of Ammodiscus latus, however appears to be variable with respect to T. alsatica. In the Bonavista C-99 and South Labrador N-79 wells A.latus was found above T. alsatica, but this may be an

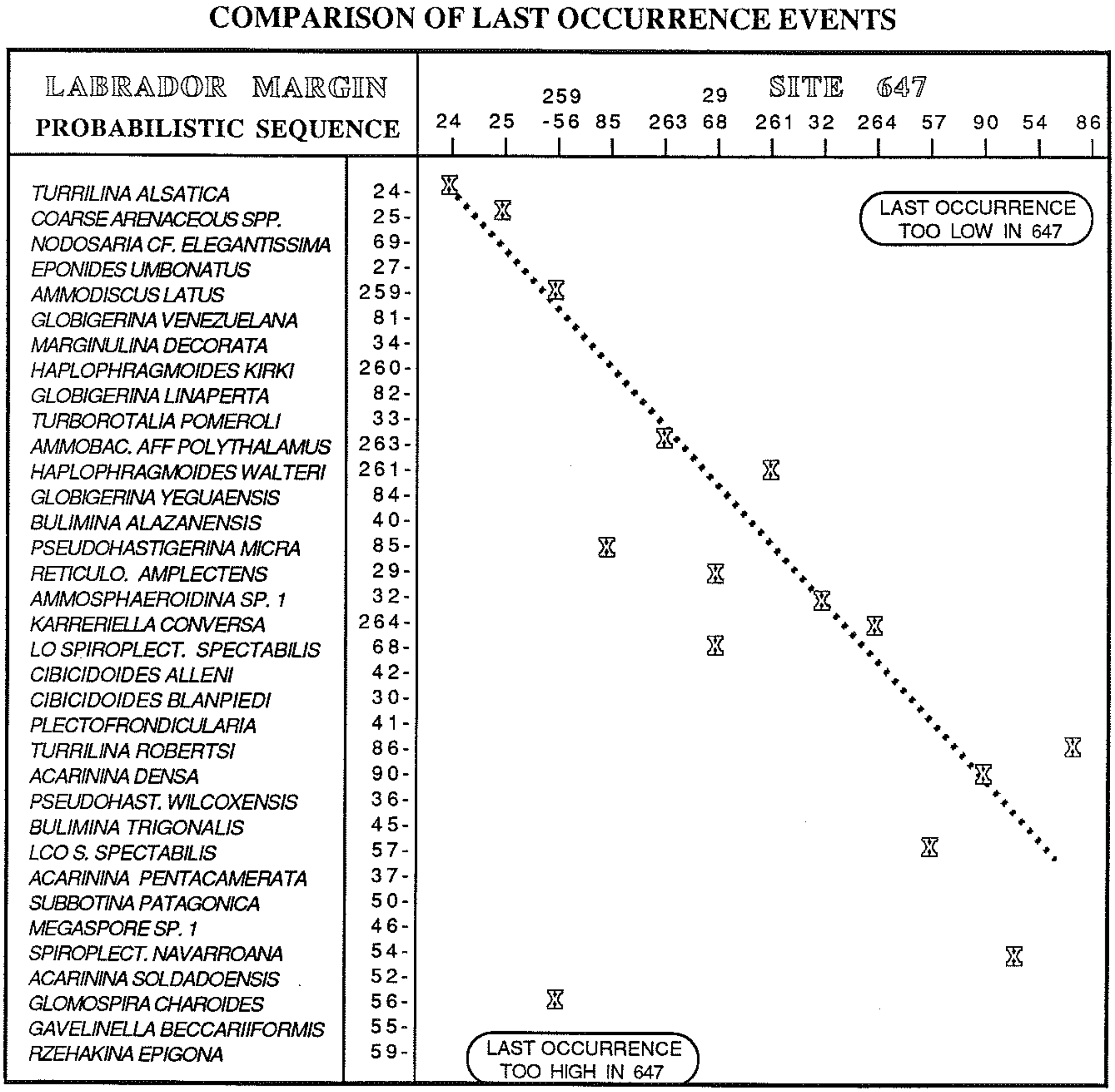


3-21. Important benthic foraminiferal last occurrences in 7 exploration wells on the Labrador Margin. Depth scale on right is thickness of Paleogene sediments (in meters).

artifact of sampling. *T. alsatica* is often a rare species on the Labrador Margin. *Reticulophragmiumm amplectens* displays a high cross-over frequency with respect to *H. walteri* and *Ammosphaeroidina*, which suggests a small interfossil distance between them. However, this species appears to intergrade with *R. placenta* in the younger portion of its stratigraphic range, so determining its true LO is sometimes subjective. The LO's of *S. spectabilis* and *Glomospira* extend to youngest levels in the southern Adolphus D-50 and Blue H-28 wells, but this may be due to the deeper paleobathymetry of these wells. These species are present at younger levels in deeper assemblages.

The probabilistic optimum sequence of microfossil last occurrences on the Labrador Margin and northern Grand Banks is shown in figure 3-22. This is an ordering based on the average position of last occurrences occurring in at least 7 of the 23 wells studied. Of the 35 Paleogene last occurrences recorded on the Labrador Margin, 15 were also present in Hole 647A. These last occurrences are listed across the top of figure 3-22, in a manner analogous to a bivariate scatter plot. The probabilistic last occurrence of *Turrilina alsatica* is used to identify the top of the Paleogene sequence on the Labrador Margin. However, the true upper range limit of this event in Hole 647A is most likely truncated by the barren interval and hiatus above Core 17R. Microfossil events that extend to younger stratigraphic levels in Hole 647A than on the Labrador Margin plot below a best-fit line between the points.

The most noticeable difference between the Labrador Margin and deep Labrador Sea last occurrences is the stratigraphic range of *Glomospira charoides* (number 56 in Fig. 3-22). This is a long ranging taxon that is present in the modern North Atlantic. Its local last occurrence is usually associated with the Paleocene/Eocene boundary on the Labrador Margin and in the southern North Sea, but the taxon extends to the top of the *Ammodiscus latus* - *Turrilina alsatica* Assemblage (lower Oligocene) in Hole 647A. *Spiroplectammina spectabilis* has its last occurrence earlier on the Labrador Margin than in Hole 647A, as mentioned above. The planktonic species *Pseudohastigerina micra* also extends to younger levels in Hole 647A, but this may be a function of poorer preservation of calcareous microfossils or the larger sieve size used to process samples from exploration wells. The



3-22. Comparison of microfossil last occurrences in common between the probabilistic Labrador Margin optimum sequence and Site 647. Numbers across the top of the scatterplot are the dictionary numbers assigned to each taxon. Dashed line is the best-fit line between the points.

extinction of P. micra, nevertheless occurs about 2 m.y. earlier in the Labrador Sea than in low-latitude sites, and therefore cannot be used as a reliable planktonic datum event in high latitudes.

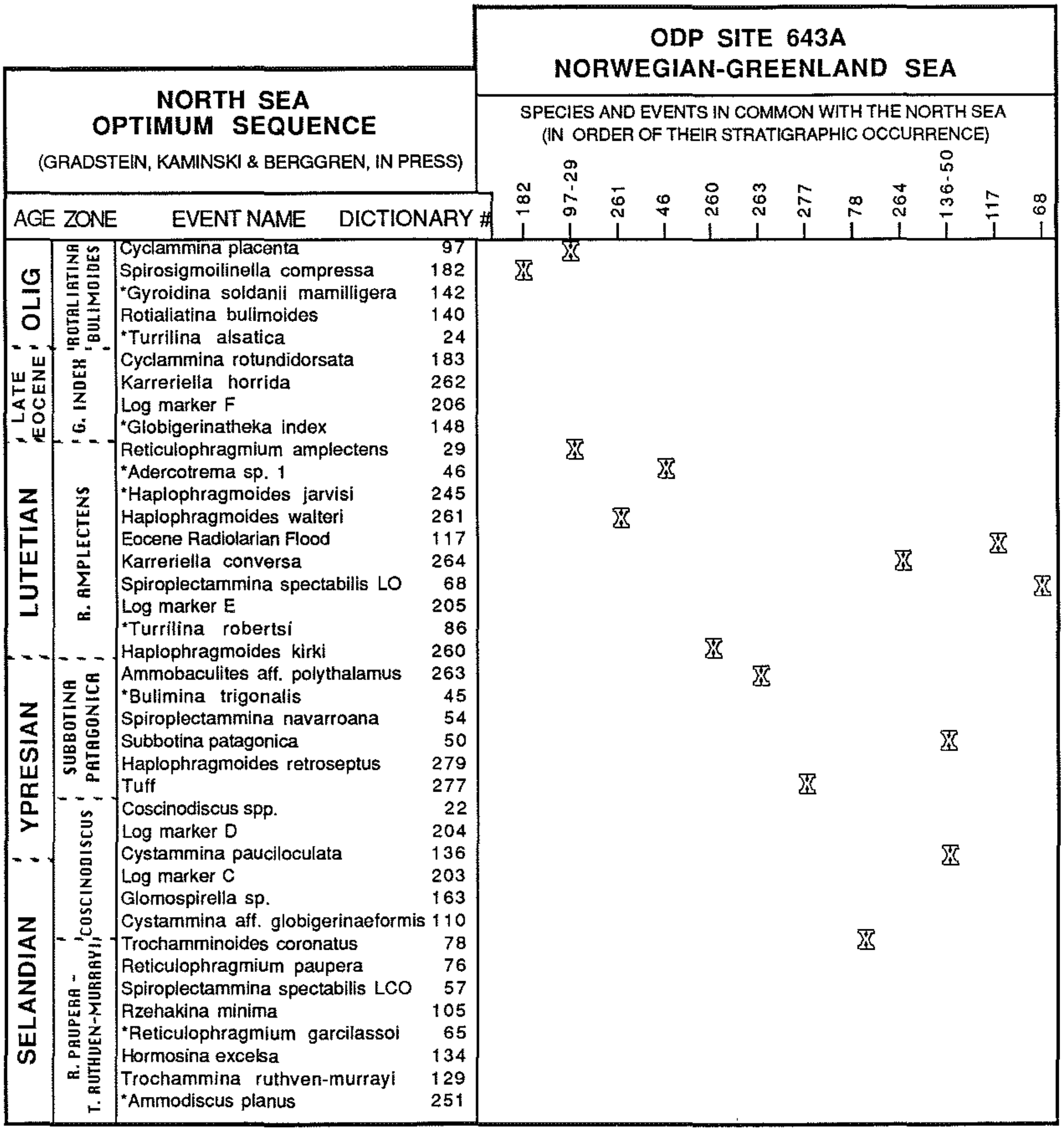
Of the benthic microfossil last occurrences in figure 3-22, only A. latus, Ammobaculites aff. polythalamus, Ammosphaeroidina sp 1, and Karreriella conversa plot close to a best-fit line. This suggests that these taxa are isobathyal and that their last occurrences can be used for correlation at different paleodepths.

3. Correlation of Hole 643A with the North Sea Probabilistic Zonation:

The probabilistic sequence of Gradstein, et al. (in press) was based on the local disappearance levels of 60 agglutinated taxa in 29 wells in the central North Sea. The RASC zonation (using a threshold value $K_c \geq 8$) identified 25 species of agglutinated foraminifera as possessing regional stratigraphic value. Twelve of these 25 potentially useful species were found in the Paleogene section of Norwegian-Greenland Sea Site 643A. A graphic comparison of the microfossil events in common between Hole 643A and the North Sea microfossil optimum sequence is given in figure 3-23.

Although a line can be drawn through the majority of points, there are two notable outliers. The LO's of Karreriella conversa and Spiroplectammina spectabilis occur earlier in Hole 643A than their average position in the North Sea. In Hole 634A, the LO's of both species are in the lower Eocene. On the Vøring Plateau, S. spectabilis is found in what Verdenius and Van Hinte termed a "poor association" characterized by low diversity. At Sites 338 and 643A this species occurs in nearly monospecific assemblages which may have been deposited in a relatively shallow paleobathymetric setting.

The calibration of the Hole 643A microfossil sequence to a standard chronology is still tentative. The benthic foraminiferal events and lithologic tie-points cannot be assumed to be isochronous between the North Sea and Norwegian-Greenland Sea. Lithologic markers, such as the occurrence of reddish sediments and tuff may likewise be diachronous. The highest occurrence of abundant tuff was observed in Core 643A-51X. This event correlates with Anomaly 24 in the North Sea, but since volcanic activity continued to younger levels in the Norwegian-Greenland Sea the occurrence of tuff at Site 643A may be diachronous. A late Ypresian age for Core 57X in



AGE	ZONE	EVENT NAME	DICTIONARY #	182	97-29	261	46	260	263	277	78	264	136-50	117	68
OLIG	ROTALIATINA BULIMOIDES	Cyclammina placenta	97		☒										
		Spirosigmoilinella compressa	182	☒											
		*Gyroidina soldanii mamilligera	142												
		Rotialiatina bulimoides	140												
		*Turrilina alsatica	24												
LATE EOCENE	G. INDEX	Cyclammina rotundidorsata	183												
		Karreriella horrida	262												
		Log marker F	206												
		*Globigerinatheka index	148												
LUTETIAN	R. AMPLECTENS	Reticulophragmium amplectens	29		☒										
		*Adercotrema sp. 1	46				☒								
		*Haplophragmoides jarvisi	245												
		Haplophragmoides walteri	261			☒									
		Eocene Radiolarian Flood	117											☒	
		Karreriella conversa	264									☒			
		Spiroplectammina spectabilis LO	68												☒
		Log marker E	205												
		*Turrilina robertsi	86												
		Haplophragmoides kirki	260					☒							
YPRESIAN	SUBBOTINA PATAGONICA	Ammobaculites aff. polythalamus	263						☒						
		*Bulimina trigonalis	45												
		Spiroplectammina navarroana	54												
		Subbotina patagonica	50										☒		
		Haplophragmoides retroseptus	279												
		Tuff	277							☒					
	COSCINODISCUS	Coscinodiscus spp.	22												
		Log marker D	204												
SELANDIAN		Cystammina pauciloculata	136										☒		
		Log marker C	203												
		Glomospirella sp.	163												
		Cystammina aff. globigerinaeformis	110												
	R. PAUPERA - T. RUTHVEN-MURRAYI	Trochamminoides coronatus	78								☒				
		Reticulophragmium paupera	76												
		Spiroplectammina spectabilis LCO	57												
		Rzehakina minima	105												
		*Reticulophragmium garcilassoi	65												
		Hormosina excelsa	134												
		Trochammina ruthven-murrayi	129												
		*Ammodiscus planus	251												

3-23. Comparison of microfossil last occurrences in common between the probabilistic North Sea optimum sequence of Gradstein _et_ _al_. (in press) and Site 647. Numbers across the top of the scatterplot are the dictionary numbers assigned to each taxon.

indicated by a dinocyst assemblage containing Wetzeliella hormeomorpha and Homotryblium spp. (Shipboard Scientific Party, 1987b).

A planktonic microfossil event which may have correlative value between the Vøring Plateau and North Sea is the "Eocene Radiolarian Flood", which corresponds to the lower Lutetian in the North Sea. In Hole 643A, the top of the interval containing abundant radiolarians occurs in Core 53R. The occurrence of common Glomospira in Core 52R gives supporting evidence for this age assignment.

The sediments in Core 46X are no older than upper Eocene, based on the FO of Spirosigmoilinella compressa which is assumed to be isochronous with the North Sea. The most significant turnover in benthic foraminifera occurs in Core 44X, where the LO's of 7 species were found. Since the LO's of H. walteri and Adercotrema sp. 1 occur in the upper Eocene in the North Sea, Core 44X may still be of Eocene age. Shipboard nannofossil stratigraphy places Core 43X in upper Oligocene zone NP25, which suggests a hiatus or condensed section may be present. If this is the case, the LO of R. amplectens in Core 42X is anomalously young in comparison to the North Sea biostratigraphy.

STRATIGRAPHIC UTILITY OF AGGLUTINATED FORAMINIFERA:

A. Paleocene:

Several species of agglutinated foraminifera appear to be stratigraphically useful and have correlative first or last occurrence levels in different basins in the North Atlantic or Tethys. Taxa with similar stratigraphic ranges have now been observed in Trinidad, Zumaya, the Labrador Margin, North Sea and the Polish Carpathians. The Paleocene/Eocene boundary in most areas is noted by the extinction of a number of agglutinated taxa, but there are fewer distinctive evolutionary events within the Paleocene.

Several species have their LO's near the top of the Paleocene in the areas studied. These are Glomospira diffundens, Hormosina ovulum ovulum, Rzehakina epigona epigona, Rzehakina minima, and Trochammina ruthven-murrayi. The distinctive conical form, Trochammina ruthven-murrayi appears to be a Paleocene index species in all regions except Zumaya, where it was not found. It has a probabilistic last occurrence beneath the Paleocene/Eocene tuff marker in the North Sea (Gradstein et al., in press). In Trinidad this species ranges into Zone P5, and it has now been found in the Paleocene interval of wells along the Labrador Margin.

The species Hormosina excelsa is restricted to the Paleocene in the North Sea and on the Labrador Margin. However, Morgiel and Olszewska (1982) found this species ranging into the lower Eocene in the Tanger Unit of the Rif Mountains in Morocco. A smaller but morphologically similar form identified as Hormosina cf. excelsa was found in the lower Eocene of Hole 647A. The highest reported occurrence of H. excelsa in the Polish Carpathians is from Zone NP12 of the lower Hieroglyphic Beds in the Dukla Unit (Olszewska and Smagowicz, 1977). The report of this species from the Eocene of the Norwegian-Greenland Sea (Verdenius and Van Hinte, 1983) is based on a misidentification.

In the probabilistic zonation of the Labrador Shelf (Gradstein and Agterberg, 1982), the last occurrences of R. epigona and H. ovulum ovulum are closely associated with the last occurrence of S. beccariiformis, which in Atlantic DSDP Sites occurs near the P5/P6 boundary (Tjalsma and Lohmann, 1983). H. ovulum ovulum is therefore useful for determining the Paleocene/Eocene boundary in bathyal assemblages, but this species ranges into younger levels at abyssal depths. Its last occurrence is in lower Eocene Zone NP12 at Site 647 (Kaminski et al., in press, d). A morphologically related species, Hormosina ovuloides, was found in the lower middle Eocene of Norwegian-Greenland Sea Site 643A.

Another example of coeval (at the resolution provided by planktonic foraminiferal zonations) benthic foraminiferal events is in the equatorial eastern Atlantic. A number of agglutinated species typical of the upper Paleocene in the Lizard Springs Formation of Trinidad, such as Trochammina ruthven-murrayi, Rzehakina epigona and Haplophragmoides jarvisi, possess extinction levels at equivalent stratigraphic positions in the Angola Basin (Serge Gofas, personal communication 1986).

One of the most prominent Paleocene lineages is the evolution of the first primitive Reticulophragmium from Haplophragmoides. Although the genus Reticulophragmium is probably polyphyletic, one particular lineage can be traced in the North Atlantic which may be useful for stratigraphy. The first occurrence of Haplophragmoides walteri (sensu stricto) is noted near the base of the Selandian in Trinidad and Poland. This species may have evolved from a species such as Haplophragmoides cf. glabra (from the Danian of Trinidad) by the addition of more chambers in the last whorl. In Zone P4, a morphotype of H. walteri began to acquire features which are transitional to

Reticulophragmium. The transitional form between *H. walteri* and *H*(?). *jarvisi* is found in Zone P4 in Trinidad and Zumaya. The first occurrence of *H*(?). *jarvisi* is noted in Zone P5 in Trinidad. Near the top of the Paleocene in the Angola Basin, this species developed alveoles near its sutures.

The first primitive *Reticulophragmium* (*R*. cf. *garcilassoi*), appeared in Zone P4 in Trinidad, but the phylogeny of this species is still uncertain. Related forms such as *R. paupera* and *R. garcilassoi*, also occur below the tuff marker in the North Sea.

B. Eocene --

The species *Reticulophragmium amplectens* is perhaps the most distinctive Eocene species in North Atlantic and Tethyan flysch-type assemblages, and is used as a stratigraphic marker species in every zonal scheme (Fig. 3-20). Its total range is given as middle to upper Eocene in the Outer Carpathians (Geroch and Nowak, 1984). Its partial range and optimum occurrence characterizes the middle Eocene *Cyclammina amplectens* Zone of Geroch and Nowak (1984). In the North Sea, Gradstein *et al*. (in press) define a middle to upper Eocene *R. amplectens* RASC interval zone based on the partial range of this species. In this region, it is reported to range from the lower Eocene to the Eocene/Oligocene boundary, with possible occurrences in the lower Oligocene. On the Labrador Margin, Gradstein (1985) defines an upper Eocene *Turborotalia pomeroli* - *R. amplectens* RASC interval zone. The total range of this species was given as lower to upper Eocene by Miller *et al*. (1982).

The relative abundance record of *R. amplectens* in Hole 647A is shown in figure 3-16. The first occurrence of this taxon was found in the upper part of Zone NP11. The greatest abundance of *R. amplectens* in Hole 647A occurs in the middle Eocene. In this respect its occurrence displays similarities with the Carpathian assemblages. The last occurrence of this species at 36.6 Ma indicates that it is a reliable indicator of the Eocene/Oligocene boundary in the deep Labrador Sea.

The *Karreriella horrida-conversa-coniformis* group may also have regional stratigraphic importance in the Eocene, but more detailed taxonomic work is required on these species. The species *Karreriella coniformis* has a first occurrence near the base of the Eocene in both Trinidad and Poland. This species is also present at the base of Hole 647A (Zone NN11), but does not occur in the Paleocene in Labrador Margin wells. The last occurrence of *K.*

conversa is a useful middle Eocene event in the North Sea and Labrador Sea, but this species ranges to the Eocene/Oligocene boundary in the Carpathians and is found living today in the North Atlantic.

The utility of Spiroplectammina spectabilis as an indicator of the Eocene/Oligocene boundary is probably restricted to abyssal assemblages in the open North Atlantic, but this species also occurs at anomalously shallow paleodepths on the Vøring Plateau. In the North Sea and Labrador Margin, the Eocene sequences display a series of last occurrences of flysch-type taxa which mainly refect the shallowing of the basins as sediment supply exceeded tectonic subsidence. Spiroplectammina spectabilis disappears from the Labrador Margin in the lower Eocene, but persists at Site 647 and the deep Norwegian-Greenland Sea until the Eocene/Oligocene boundary. Interestingly enough, in the North Sea S. spectabilis has a diachronous last occurrence in wells aligned from south to north along the axis of the basin (Gradstein et al., in press).

Upper Eocene assemblages in the North Sea, Poland, and on the Labrador Margin contain the species Ammodiscus latus and Cyclammina rotundidorsata. In the Carpathians, the partial range of the former and the total range of the latter are used to define an upper Eocene zone (Fig. 3-20). Neither of these species, however, is present in the deep Norwegian-Greenland Sea. Cyclammina rotundidorsata was reported by Verdenius and Van Hinte (1983) from the Oligocene of Site 345 and the Miocene of Site 348, but the specimen illustrated by them is not typical of the species, and may have been misidentified. Ammodiscus latus (sensu lato) occurs in both bathyal and abyssal assemblages in the Labrador Sea. The abyssal variety is noticeably smaller than the bathyal variety, and because of this Miller et al. (1982) recorded its occurrence at Site 112 as Ammodiscus rugosus Schijfsma, following Krasheninnikov and Pflaumann (1977). However, A. rugosus is an upper Cretaceous species known from the epicontinental deposits of Europe (Schijfsma, 1946) and possibly from Site 367 off Morocco (Krasheninnikov and Pflaumann, 1977). Because of the restricted stratigraphic occurrence of the "rugose" Ammodiscus in Hole 647A, I believe that this species is a deep-water ecophenotype of A. latus. The FO of A. latus was determined at 44.6 Ma in Hole 647A. This agrees with the findings of Morgiel and Olszewska (1981), who report its FO in the upper middle Eocene in the Polish Carpathians.

C. Oligocene --

The Oligocene of Norwegian-Greenland Sea sites contains *Spirosigmoilinella*, which was used by Verdenius and Van Hinte (1983) as a zonal indicator. At Site 338 on the Vøring Plateau, *Spirosigmoilinella* is not observed below the last occurrence of *S. spectabilis*, or below the last occurrence of *R. amplectens* at Site 345 in the Lofoten Basin. These species were used to determine the Eocene/Oligocene boundary in the Leg 38 Norwegian-Greenland Sea Sites (Verdenius and Van Hinte, 1983), and both range to the top of the Eocene at Site 647. The data from Site 643, however, indicate that the ranges of *R. amplectens* and *Spirosigmoilinella* sp. overlap. This suggests that the zonation of Verdenius and Van Hinte (1983) may only be applicable to bathymetrically shallower sites, such as Site 338.

Another event which serves as a correlation horizon in the Labrador Sea is the LO of *Ammodiscus latus*. In the Polish Carpathians, type area of this species, its stratigraphic range is truncated by the latest Eocene Globigerina Marls. However in Hole 647A, its LO was determined to occur at 35.5 Ma. The finding of the LO of *A. latus* above the last occurrence of *R. amplectens* in Hole 647A agrees with the relative position of these taxa on the Labrador and northern Grand Banks margins (Fig. 3-21).

CONCLUSIONS:

The biostratigraphy of agglutinated foraminifera in the North Atlantic region is based upon examination of core samples from Trinidad, the North Sea, ODP Sites 643A, 645, 646 and 647 and from outcrop sections near Zumaya, Spain. Stratigraphic ranges of 81 agglutinated taxa are reported from the upper Campanian to lower Eocene of Trinidad; 64 taxa are reported in the Danian to Ypresian sediments of Zumaya Spain; 26 agglutinated taxa are reported from the 29 well data base of Gradstein *et al*. (in press) from the Cenozoic of the North Sea; 50 taxa are given from the lower Eocene to upper Oligocene of ODP Site 643, and 49 agglutinated taxa are reported from the lower Eocene to lower Oligocene of Site 647.

In the Guayaguayare and Lizard Springs Formations of Trinidad, faunal turnovers are observed near the Cretaceous/Tertiary boundary and near the Paleocene/Eocene boundary. The FO's of species such as *Glomospira irregularis*, *Glomospira serpens*, *Kalamopsis grzybowskii*, *Hormosina ovulum*, Recurvoides imperfectus, Labrospira pacifica near the base of the Danian in Trinidad probably reflects increasing paleo-water depths owing to subsidence of the basin. The Paleocene/Eocene faunal turnover observed in Trinidad and Zumaya is characterized by the LO's of calcareous ataxophragmiids and many of the typically deep-water taxa. This turnover is a result of both evolutionary turnover and shoaling paleodepths in both basins.

In the high-latitude slope basins such as the Labrador Margin and North Sea, faunal turnovers are associated with the Paleocene/Eocene and Eocene/Oligocene boundaries. The species Glomospira diffundens, Rzehakina epigona, Trochammina ruthven-murrayi, Matanzia varians and Hormosina ovulum are restricted to the Paleocene in the areas studied. Distinctive taxa with Eocene FO's are Reticulophragmium amplectens, Karreriella coniformis, Ammodiscus latus and Cyclammina rotundidorsata. The Eocene/Oligocene turnover is ascribed to shoaling paleodepths as sedimentation exceeded subsidence in these basins, a trend which is accentuated by lowered sealevel in the basal Oligocene.

The recovery of a continuous section of lower Eocene to lower Oligocene sediments at Site 647 and the establishment of a multiple planktonic microfossil biochronology allows us to correlate the benthic foraminiferal biostratigraphy to a standard time scale. Seven assemblages of benthic foraminifera were defined in Hole 647A based on the stratigraphic ranges of important taxa. This subdivision can also be recognized at DSDP Site 112, allowing a precise correlation of the two sites. Four of the assemblages (Abyssammina-Dendrophrya, Nuttallides truempyi, Reticulophragmium amplectens, and Turrilina alsatica assemblages) correlate with standard epoch subdivisions (lower, middle, and upper Eocene, and lower Oligocene). Periods of increased faunal turnover and opportunistic increases in dominance of individual taxa correlate with stage boundaries, and accordingly, the remaining three assemblages (Glomospira, Spirosigmoilinella - S. spectabilis, and Ammodiscus latus - T. alsatica assemblages) are of shorter duration. The lower/middle Eocene boundary is contained within a 20 m interval of noncalcareous claystones containing a Glomospira facies comprised of only agglutinated taxa. The middle/upper Eocene boundary is characterized by an acme of Spiroplectammina spectabilis and the first occurrence of S. cubensis and Spirosigmoilinella. The largest cluster of last occurrences occurs near the Eocene/Oligocene boundary, which is delineated by the disappearance of about 12 species of flysch-type taxa and an acme of Nuttallides umbonifera. The faunal change from an Eocene agglutinated assemblage to an Oligocene calcareous assemblage is gradual, having taken place over a period of about 4 m.y..

Comparison of benthic foraminiferal last occurrences from Site 647 with the Labrador Margin reveals a number of similarities. The last occurrences of Turrilina alsatica, Ammodiscus latus, Haplophragmoides walteri, and Ammosphaeroidina sp., Spiroplectammina navarroana occur in the same relative order on the Labrador Margin and in the deep Labrador Sea, which confirms the utility of these taxa for regional stratigraphy. However, some forms display diachronous last occurrences with depth. Glomospira disappears in the lower Eocene in most Labrador Margin wells, but continues into the lower Oligocene at Site 647. The species R. amplectens and S. spectabilis disappeared at the Eocene/Oligocene boundary at Site 647, but their last occurrences occurred earlier on the Labrador Margin.

The Paleogene sequence of Hole 643A in the Norwegian-Greenland Sea is subdivided into 5 major assemblages based on the stratigraphic occurrence of important taxa. The basal Rhabdammina-Cyclammina assemblage displays low diversity and reflects shallow paleodepths at this site during the intial sea-floor spreading phase near the Vøring Plateau. The overlying Glomospira assemblage is correlated with the basal Lutetian and may be the temporal equivalent of the Glomospira facies observed in Hole 647A. The Spirosigmoilinella sp. assemblage is correlated with the upper Eocene, based on comparison with the North Sea biostratigraphy. A hiatus or condensed interval is indicated near the base of the S. compressa-R. amplectens assemblage, which extends to the upper Oligocene. The overlying upper Oligocene to Miocene assemblage is characterized by S. compressa.

Comparison of the upper range limits of taxa from Site 643A with the North Sea probabilistic zonation of Gradstein et al. reveals 13 biostratigraphic events in common. Many benthic foraminiferal LO's appear to be diachronous between the two regions, with species such as Trochamminoides subcoronatus, Cystammina sp., Reticulophragmium amplectens, and Spirosigmoilinella compressa extending to younger levels in the Norwegian-Greenland Sea. The LO's of Karreriella conversa and Spiroplectammina spectabilis, however, may occur earlier in Hole 643A than their average position in the North Sea.

A comparison of the biostratigraphy of flysch-type agglutinated foraminifera in the Atlantic basins reveals a number of evolutionary first and last occurrences that serve as important regional stratigraphic marker horizons. The LO's of *Glomospira diffundens*, *Hormosina ovulum*, *Rzehakina epigona*, *Rzehakina minima*, *Trochammina ruthven-murrayi*, and calcareous ataxophragmiids occur near the Paleocene/Eocene boundary in bathyal assemblages. The first occurrence of the intermediate forms in the *Haplophragmoides* cf. *glabra* - *H. walteri* - *H*?. *jarvisi* lineage may be usful stratigraphic events in the North Atlantic region. Important marker horizons which probably reflect evolutionary events in the Eocene are the FO's of *Karreriella coniformis*, *Reticulophragmium amplectens*, *Ammodiscus latus*, *Spirosigmoilinella compressa*, and *Cyclammina rotundidorsata*. The Eocene/Oligocene boundary is characterized by a decline in species diversity or local disappearance of flysch-type agglutinated taxa in the areas studied. In abyssal assemblages in the Labrador Sea, the boundary can be recognized by the LO of *R. amplectens* and *S. spectabilis*. An important Oligocene event in the Labrador Sea is the LO of *Ammodiscus latus*.

Appendix 3-1. Relative abundance of taxa in samples from Zumaya, Spain.

Sample	Zone	RHAB	RHIZ	Spla	Hovm	Hovl	PSAM	Acre	Gcha	Rdup	NODL	Hdil	Girr	Sden	CRIB	Rano	Rwal	Rdef	Tace	Tirr	Tsub	Talt	Doxy	Mvar	Casp	Camo	Ctri	Gpyr	GSLA	LITU	Pele	Dexc	Apen	Rger	Sisr	Snav	AREN	Khor	CYST	Gser	Dtrn	Hhor	Hspl
4153	P8																																										
4138	P8																R				R																						
4118	P7																																										
4098	P7																R																										
4088	M.subbotinae																R																										
4084	M.subbotinae																																										
4080	M.edgari			R			R	R									R				R																						
4073	M.edgari	F	F	F				F									A				F															F							
4064	P5	C	C	C	R	F	F	F				F	F				C		F	R	R	F		F	F	R										F		C	R				R
4060	P5	F	C	F		R	F	R	R	R	F	F	R		R	R	C			F	F	F		F	R	R			R	R				R		F		C	F				R
4057	P4		F	F	R		F		R			R					F			F		R				F		F	R			A				F		R			R		
4053	P4		F	C			R	R	R	R		R			R		F		R	R	F	F		R					R			A				F			R				
4040	P4	F	F	C			F	R		R	R	R	R		R	R	F		R	R	F	F		F	R	R			R							R							
4039	P3b	R	C	C	F		F	R	R		R	F	R		F	F	C	R		F	R	C		F	C			R	R	R		A		R	R	F				R		R	F
4030	P3b	R	F	F	R	R	F	R	R			R	R			F	C			R	R	R		F	F				R							R							
4022	P3b	F	F	F	R	R	F	R	R				F			F	C			R	F	C	R	F	C		F	R				A		C		R							
4019	P3a			C		F	R		R	R			R			F	C		F		F				C		R		R			C				R	R	R	F				
4016	P3a	F	F	C				R	R								C				R	R	F		F		F			F		C							R				
4012	P2	A	C	C			F		R				F			F	C		F		F	C	C			F	F							F		F			R			R	R
4006	P1c	F	R	C	R						R						C	R		F			C		C	C	C					C	R	C	F		C	R	R	R	R		
4005	P1c	F	R	C		R	R	R								R	C	R	R	R		C	A		C	C	F					C	R	C	F	C	C	R	R				
4002	P1b	C	F	C	R	F	F	R					R	C			C					C	C	C				F	R	F	R												
40001	P1b	A	R	C	F	F	F	F	R	R	F	R	R	C	R	F	C	F	R	R	R	C	C	A	A	F	F	F															

Appendix 3-1 (Continued).

Sample	Dret	Gspl	Rgrz	BATH	RADs	Ggor	SPHR	Hwal	Kcnv	Cglo	Hw/j	Rpil	Dbel	Repi	Hcor	Tdub	ASCH	SUBR	Ajar	Etro	Sspe	Hegg	Drob	HAPL	Gsp2
4153																									
4138																							A		
4118																							A		
4098																							A		
4088																							A		R
4084																							A		R
4080															F		R						A	C	F
4073		C	F													C									
4064		F	F					R	R				R	R				R				R			
4060		F	C					R		R			C								R				
4057	R	R	A					R	R	R		R	F			R				R	R				
4053	F		A						R	R		R	R			R	C	R							
4040			A	R			R			F		R	R			R	R		R						
4039	R		F	R				R		F	R	R	C	R	F	R	R	R							
4030	R		F	R				R		R	R	F	C												
4022	R		F	F	C	R	R	F	R	C															
4019	F		C																						
4016	F	R																							
4012																									
4006																									
4005																									
4002																									
40001																									

ABBREVIATIONS:

RHAB = Rhabdammina
RHIZ = Rhizammina
Spla = Saccammina placenta
Hovm = Hormosina ovulum
Hovl = Hormosina ovuloides
PSAM = Psammosphaera scruposa
Acre = Ammodiscus cretaceus
Gcha = Glomospira charoides
Rdup = Reophax duplex
NODL = Nodellum velascoense
Hdil = Hyperammina dilatata
Girr = Glomospira irregularis
Sden = Spiroplectammina dentata
CRIB = Cribrostomoides spp.
Rano = Recurvoides sp. aff. R. anormis
Rwal = Recurvoides ex gr. walteri
Rdef = Recurvoides deflexiformis
Tace = Trochamminoides acervulatus
Tirr = Trochamminoides irregularis
Tsub = Trochamminoides subcoronatus
Talt = Trochammina altiformis
Doxy = Dorothia oxycona
Mvar = Matanzia varians
Casp = Clavulinoides aspera
Camo = Clavulinoides amorpha
Ctri = Clavulinoides trilatera
Gpyr = Gaudryina pyramidata
GSLA = Glomospirella spp.
LITU = Lituotuba lituiformis
Pele = Phenacophragma elegans
Doxy = Dorothia oxycona
Apen = Ammodiscus pennyi
Rger = Recurvoides gerochi
Sisr = Spiroplectammina israelskyi

Snav = Spiroplectammina navarroana
ARNB = Arenobulimina dorbignyi
Khor = Karreriella horrida
CYST = Cystammina sp.
Gser = Glomospira serpens
Dtrn = Dorothia trinitatensis
Hhor = Haplophragmoides horrida
Rspl = Reophax splendidus
Dret = Dorothia retusa
Gspl = Gaudryina sp. 1
Rgrz = Rhizammina grzybowskii
BATH = Bathysiphon spp.
RADs = "Cenosphaera" lenticularis
Ggor = Glomospira gordialis
SPHR = Sphaerammina gerochi
Hwal = Haplophragmoides walteri
Kcnv = Karreriella conversa
Cglo = Clavulinoides globulifera
Hw/j = H. walteri - H(?) jarvisi transitional form
Rpil = Reophax pilulifer
Dbel = Dorothia beloides
Repi = Reophax epigona
Hcor = Haplophragmoides sp. (coarse)
Tdub = Trochamminoides dubius
ASCH = Aschemonella spp.
SUBR = Subreophax scalaria
Ajar = Ammobaculites jarvisi
Etro = Eggerella trochoides
Sspe = Spiroplectammina spectabilis
Hegg = Haplophragmoides eggeri
Drob = Dendrophrya robusta
HAPL = Haplophragmium sp.
Gsp2 = Gaudryina sp. 2

Appendix 3-2 Relative abundance of taxa in samples from ODP Hole 643A.

Core	Inter	Depth	Ksip	Scom	SPIR	Ainf	Acre	Aten	PSAM	SRIZ	LAGN	RECV	Cacu	Ramp	Cpla	CRIB	AMMS	BATH	Tdef	Rsub	Drob	AHIZ	RHAB	Acla	Diat	TROC	Hcom	ASCH	Hwal	Bmul	ADER	Hnod	Dpri	SUBR	SACC	Hcyl	Hegg	Ggor	Hkir	Hrug	RETC	Apol	Apil
41X-1	72-76	372.1	F	C	F	F	R		C	A	F	R	R																														
42X-1	74-77	391.4	F	R	C	R	R			A		F	F	F	R			R	C	C																							
42X-3	71-74	394.4	C	C	F	R		F		C		R		C	R		F		R	R	R	C	R	F	R																		
42X-4	30-34	395.5	F	C	C			R				R	R	F	R		F		R		R	C	R			R	R	F															
44X-1	79-84	410.8	R	R	F	R			R	C	R	F		F			C	R	R	R	F	A	R					R	R	R													
44X-3	79-84	413.8	R	C	R	R		R			R	F		R			C	R	R			A	R	R		R	R	R	C	F	R	R	R	R	F								
44X-5	79-84	416.8	R	A	F	F		R			R	C			R		C			R		C	C	R		R			C	F	R	R	R	R									
45X-1	79-84	420.5	R	R	F	R		R				R		R			F	R	R	R		C	F			R			R	R													
45X-3	79-84	423.5	F	C	F			R				F		R		R	F	R	R		R	C	F	R					R	R			R			R	R						
45X-5	77-84	426.5	R		F			R							R			R				R	R							R													
46X-1	79-84	430.2	C	F	C			F			R	F		C			F	R			F	F	C	R					R	F	R		R	R			R	R					
46X-3	65-69	433	F	A	F			F				F		C			F		R	R		C	C	R		R	R		F	C	F		F	R	R		F		R				
46X-5	65-69	436	R	R	R		R	R	R			F		F			C	R		R		C	R				R		C	F			R		R		R						
47X-1	79-84	439.9	R					R				R		C			A		R	R		F	C	R		R	R	R	R	R			R				R						
47X-3	79-84	442.9	R		R									F			R	R	R	R	R	F	F	R		R	R	R	R				R							R	R	R	R
47X-5	72-77	445.9												C					R	R		F	F	R			R		R														
48X-1	79-84	449.5			R							R		C			R	R				C	F	R			R	R	F	R													
48X-3	65-69	452.4			R									F	F	R		F		R	R	C	F				R		C	R	R				R					R			
48X-5	65-69	455.4										R	R		F		R					F	F				R		C				R		R				R				
49X-1	79-84	459.2			R							R		C	R		R			F	R	A	F		R		R	R	C						R				R	R			
49X-3	79-84	462.2			F									F	F		R			R		C	C	R			R	R	F								R			R			
49X-5	79-84	465.2	R		F			R				R		C	R		R			R		F	F	R			F		C		R			R									
50X-1	79-84	468.9							R					C					R			C	C	R			R		R						R								
51X-1	84-87	478.5						R				R							R		R	A	C	R					A						R					R			
51X-3	79-84	481.5					R	R	R							R					R	C	F	F					C						R	R				R			
51X-5	79-84	484.5						R				R				R				R	F	F	F	F			R	R	F						R								
52X-1	83-88	488.1						R				R	R	C				R		R	R	C	C	F											R		R		R				
52X-3	73-78	491.1						R				R			R			C			R	A	A	F				R	A					R	R				R	C			
52X-5	73-78	494.1						F				R		R	R			C		R		C	C	F			F		C						R				R				
53X-1	75-79	497.8						C				F		C	F	R		F		R		C	A	C			R		C		R												
53X-3	73-78	500.8						R				F			R			C			R	C	C	F			R		C						R				F				
53X-5	79-84	503.8						R				R						C				C	A	C			R	R	C										R				
54X-1	62-65	507.4						C										F	R	R	C	C	C						F						C				F				
54X-3	75-81	510.5						A										C			R	C	A						R						C				R				
54X-5	64-69	513.4						R							R			C			R	C	A																				
55X-1	72-78	517.1																																									
55X-3	72-78	520.1																																									
55X-5	77-82	523.1						F							R			C				C	A				F		R										F				
56X-1	77-82	526.8						C										R			C	C	A	F															F				
56X-3	56-61	529.6						C							C			R			C	C	A	F					R										F	F			
56X-5	72-77	532.7						F							R			R			R	C	C	R															R	R			
57X-1	77-82	536.4						F							R			F			C	C	C	C																			
57X-3	83-88	539.4						F							C							F	A	C					F										R	C			
57X-5	79-83	542.4					R	R							C							F	A	R																R			
58X-1	80-84	546													R			R				F	A						R										F				
58X-5	88-91	552													R								C	R															R	R			
59X-1	77-81	545.9																																					R				
60X-1	72-75	555.6						F							A							F	C	R															R				
61X-1	72-75	561.9						R							R							F	A																R				
62X-1	77-81	564.5						R							C								C	F															C				

Appendix 3-2 (Continued).

Core	Tglo	Rgut	Hexc	Gcha	Girr	Talt	Vpol	Hovu	BUZA	TOID	Kcnv	CYST	LITU
41X-1													
42X-1													
42X-3													
42X-4													
44X-1													
44X-3													
44X-5													
45X-1													
45X-3													
45X-5													
46X-1													
46X-3													
46X-5													
47X-1													
47X-3													
47X-5	R	R	R										
48X-1	R	R											
48X-3	R												
48X-5	F												
49X-1	R												
49X-3	R												
49X-5	F												
50X-1	F	R		R									
51X-1		R											
51X-3	R												
51X-5	R												
52X-1	R			F	R	R							
52X-3	R	R		C			R						
52X-5						R		F					
53X-1	F							R	R	R			
53X-3	C	R				R			F				
53X-5	R								R				
54X-1	R			R		R					R	R	R
54X-3						R							
54X-5		R											
55X-1													
55X-3													
55X-5	R					R							
56X-1													
56X-3			R			R						R	
56X-5													
57X-1	R		F										
57X-3			F			R							
57X-5			F										
58X-1			F										
58X-5													
59X-1													
60X-1			R										
61X-1			R										
62X-1			R										

ABBREVIATIONS:
Ksip = Karreriella siphonella
Scom = Spirosigmoilinella compressa
SPIR = Spirosigmoilinella sp. of Verdenius & Van Hinte
Ainf = Ammodiscus infimus
Acre = Ammodiscus cretaceus
Aten = Ammodiscus tenuissimus
PSAM = Psammosphaera sp. A
SRIZ = Saccorhiza sp.
LAGN = Lagenammina sp.
RECV = Recurvoides spp.
Cacu = Cyclammina acutidorsata
Ramp = Reticulophragmium amplectens
Cpla = Cyclammina placenta
CRIB = Cribrostomoides
AMMS = Ammosphaeroidina sp.
BATH = Bathysiphon sp.
Tdef = Trochammina deformis
Rsub = Reophax subnodulosus
Drob = Dendrophrya robusta
RHIZ = Rhizammina
RHAB = Rhabdammina
Acla = Ammolagena clavata
Dlat = Dendrophrya latissima
TROC = Trochammina sp. (6-chambers)
Hcom = Haplophragmoides compressus
ASCH = Aschemonella spp.
Hwal = Haplophragmoides walteri
Bmul = Budashevaella cf. multicamerata
ADER = Adercotrema sp 1
Hnod = Hyperammina "nodata"
Dpri = Dorothia principiensis
SUBR = Subreophax scalaria
SACC = Saccammina complanata
Hcyl = Hyperammina cylindrica
Hegg = Haplophragmoides eggeri
Ggor = Glomospira gordialis
Hkir = Haplophragmoides "kirki"
Hrug = Hyperammina rugosa
RETC = Reticulophragmium sp.
Apol = Ammobaculites aff. polythalamus
Rpil = Reophax pilulifer
Tglo = Trochammina aff. globigeriniformis
Rgut = Reophax guttifer
Hexc = Haplophragmoides excavata
Gcha = Glomospira charoides
Girr = Glomospira irregularis
Talt = Trochammina altiformis
Vpol = Verneuilinoides polystrophus
Hovu = Hormosina ovuloides
BUZA = Buzasina sp.
TOID = Trochamminoides sp
Kcnv = Karreriella conversa
CYST = Cystammina sp.
LITU = Lituotuba sp.

Appendix 3-3 Benthic foraminifera in samples from ODP Hole 647A

CORE	INTERV	DEPTH	CLAV	ARNB	Kchp	Scub	SFSG	RHAB	CRIB	BATH	Alat	Gchr	REOP	Acrt	GAUD	Girr	RECV	Ramp	Sspt	AMML	Tdef	Apol	SUBR	SACC	Gser	Tirr	Hpor	Khor	Aten	RHIZ	Hwal	LITU	Rpil	Hken	Kcon	BIGN	Rgut	AMMS	Cpla	Hdis	Ggor	Hsub	Helg
17-1	107-110	155.9	6	1	32	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-2	116-119	157.5	0	0	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-4	88-91	160.2	0	0	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17-5	99-102	161.8	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18-2	78-81	166.4	4	0	9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19-2	105-108	176.4	2	0	4	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19-3	112-115	177.9	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19-5	126-129	181.1	0	0	5	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19-6	117-120	182.5	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20-1	91-94	184.4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20-2	93-96	185.9	0	0	7	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20-4	84-87	188.9	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21-1		193.3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21-2	13-17	194.8	0	0	0	0	0	9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21-3	13-17	196.3	3	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22,CC		212.3	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-1		213.1	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-2	95-98	214.8	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-4	75-78	217.6	3	0	0	0	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-5	23-26	218.5	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24-2	31-33	223.7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24-4	31-33	226.7	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25-1	107-110	232.6	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25-2	107-110	234.1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25-4	107-110	237.1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27-1	78-83	251.2	0	7	3	26	0	34	0	31	4	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28-1	108-113	261.2	0	3	4	5	0	18	0	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28-2	105-108	262.7	1	0	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28-3	102-107	264.1	1	0	11	0	0	10	0	6	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28-4	91-94	265.5	0	0	1	5	0	9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28-4	105-108	265.6	2	0	0	2	0	2	0	2	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-1	107-110	280.5	3	0	17	7	0	16	0	5	0	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-2	25-28	281.2	0	0	0	4	0	5	0	9	5	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-3	110-113	283.5	1	0	9	13	0	28	0	3	1	3	1	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-4	107-110	285	3	2	2	4	0	17	0	9	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-5	10-13	285.5	0	0	4	5	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-7	33-36	287.2	1	0	15	8	0	0	0	1	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31-1	132-135	290.3	4	0	5	8	2	33	0	5	7	0	1	0	0	0	4	4	9	1	5	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31-2	34-37	290.8	2	0	6	5	1	16	0	12	2	8	0	1	0	1	0	6	17	0	0	0	1	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32-1	89-92	299.5	0	0	0	0	1	23	0	4	2	0	1	2	1	0	2	1	5	1	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32-2	20-23	300.3	2	0	0	1	1	16	0	6	0	1	1	0	0	0	1	1	5	0	0	0	0	0	0	0	0	0	1	27	1	0	0	0	0	0	0	0	0	0	0	0	0
33,CC		318	1	0	1	3	0	3	0	34	0	4	0	1	2	0	2	0	11	0	10	0	1	12	0	2	0	0	0	35	4	1	4	0	0	0	0	0	0	0	0	0	0
35-1	77-80	328.4	0	0	1	0	1	13	0	1	0	4	1	3	0	1	0	0	7	0	0	0	0	0	1	0	0	0	0	14	1	0	0	0	0	0	0	0	0	0	0	0	0
35-2	77-80	329.9	1	0	3	0	3	12	0	1	2	6	0	0	0	0	0	1	4	0	0	0	3	0	0	0	0	0	0	12	1	0	0	0	0	0	0	0	0	0	0	0	0
35-3	77-80	331.4	0	1	10	0	0	22	0	8	0	4	2	2	2	0	0	3	4	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	2	1	0	0	0	0	0	0	0
36-2	49-52	339.2	0	0	8	0	0	33	0	5	2	7	3	4	0	0	1	8	5	0	0	0	0	0	0	1	0	0	0	15	2	0	0	0	0	0	3	0	0	0	0	0	0
36-3	49-52	340.7	0	1	7	0	0	5	0	5	0	3	2	1	0	1	3	3	5	0	1	0	1	1	0	0	0	0	0	60	0	0	0	0	0	2	0	1	0	0	0	0	0
36-4	49-52	342.2	4	0	2	0	2	6	0	7	2	7	4	0	1	1	2	2	3	0	0	0	0	3	0	1	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0
37-2	90-93	349.1	0	0	0	0	0	9	0	5	1	2	0	0	0	1	0	0	1	0	0	0	0	0	2	0	0	0	0	12	3	0	0	0	0	0	3	0	0	0	0	0	0
37-3	90-93	350.6	0	2	5	0	3	38	0	3	2	4	0	0	0	8	2	5	16	0	1	2	0	0	0	1	0	0	0	55	3	0	4	5	1	0	2	0	1	0	0	0	0
37-4	90-93	352.1	13	1	14	0	7	22	3	11	0	0	0	1	0	8	2	1	12	0	0	0	1	0	0	8	0	0	0	30	0	0	1	6	0	0	0	0	4	0	0	0	0
38-1	83-86	357.2	1	0	5	0	0	20	0	20	5	0	0	0	0	0	3	0	9	0	0	0	0	0	1	2	0	0	0	16	2	2	0	0	0	0	1	1	0	0	0	0	0
38-2	84-97	358.8	2	0	4	0	0	3	0	17	2	2	2	1	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	11	3	0	0	0	0	0	0	0	0	0	0	0	0
38-3	84-87	360.3	12	0	14	0	4	11	0	11	0	2	0	2	0	11	0	0	8	0	0	0	1	0	1	5	2	0	0	77	5	0	0	28	3	0	0	3	0	2	1	0	0

Appendix 3-3 (Continued).

38-4	86-89	361.8	0	0	5	0	1	38	0	3	0	3	1	2	0	3	2	0	3	0	0	3	0	0	0	1	0	0	0	16	1	0	0	0	1	0	0	1	0	0	2	0	0
39-1	80-83	366.9	1	0	4	0	1	2	0	27	0	3	5	0	0	1	2	0	5	0	0	2	0	1	1	0	2	0	0	25	0	0	0	0	0	0	0	3	3	0	0	0	0
39-2	77-80	368.4	0	0	0	0	2	0	1	2	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	6	0
39,CC		375.7	0	0	3	0	0	13	5	20	1	0	0	0	0	0	5	0	7	0	1	2	0	6	0	6	0	0	0	38	5	0	0	9	3	0	1	1	0	0	0	0	14
41-1	58-61	386	0	0	3	6	2	46	0	8	2	1	4	1	0	5	10	0	15	1	0	0	0	1	2	6	0	0	0	16	5	0	0	13	3	0	0	3	0	0	1	3	0
41-3	58-61	389	0	3	14	2	1	36	0	5	5	6	7	5	0	12	8	0	35	1	0	0	2	4	1	0	0	0	0	58	4	0	0	0	4	1	2	1	0	0	5	0	8
41-5	58-61	392	0	0	16	10	5	0	2	3	1	9	13	3	0	9	5	0	15	0	0	0	0	0	0	2	0	0	0	59	1	0	0	1	12	0	2	0	0	1	1	1	1
42-1	98-101	396.1	0	0	6	2	4	18	0	14	1	6	3	2	0	9	5	1	9	0	2	0	0	1	0	0	0	0	0	36	5	0	0	5	2	0	0	2	0	0	0	3	1
42-3	32-35	398.4	0	0	8	4	3	20	0	0	0	3	4	4	0	3	2	1	9	1	0	0	0	0	0	1	0	0	0	41	3	0	0	10	4	2	0	0	0	0	0	0	3
42-5	96-99	402.1	0	0	4	10	0	47	0	4	0	2	0	0	1	6	5	0	1	0	0	2	0	0	0	6	0	0	0	47	2	0	1	12	8	0	1	0	0	1	0	0	4
43-1	95-98	405.8	2	0	14	2	2	25	3	10	1	13	6	11	0	10	24	0	14	4	0	0	0	0	0	5	0	0	0	53	7	0	0	18	5	0	4	2	0	0	1	0	4
43-3	104-107	408.8	7	1	15	1	7	56	4	9	0	8	2	1	0	3	9	9	44	0	0	0	0	2	0	4	0	0	2	50	8	0	0	5	3	2	4	6	0	0	5	7	1
43-5	97-100	411.8	0	1	6	0	10	24	0	5	0	11	4	6	0	2	10	4	29	0	2	2	4	7	2	0	0	0	0	36	6	0	0	9	7	0	0	1	0	0	0	0	5
44-1	45-48	415	1	0	8	0	6	23	2	0	1	9	1	10	0	5	28	6	13	0	0	1	0	0	0	13	0	0	0	99	6	3	2	16	8	0	1	2	0	0	0	0	0
44-3	42-45	417.9	0	0	7	0	3	19	2	6	0	3	0	1	0	6	12	0	5	0	0	1	0	0	1	0	5	2	0	28	0	0	0	15	1	2	0	1	0	0	0	0	2
44-5	45-48	421	0	0	10	0	4	16	0	4	0	4	3	1	1	6	11	0	6	0	0	0	0	0	0	0	3	3	0	44	0	0	0	41	3	3	0	2	0	0	1	0	0
45-1	14-17	424.3	1	3	23	0	8	32	0	12	1	11	4	8	1	5	30	1	35	1	0	0	1	0	0	1	0	2	0	54	0	0	0	0	20	0	1	4	0	0	0	0	0
45-2	20-23	425.8	0	2	20	0	10	8	2	12	0	9	5	5	0	7	16	0	10	1	4	0	0	1	1	4	0	3	0	58	1	2	0	5	5	1	0	4	0	0	2	0	0
46-1	60-63	434.4	0	4	5	0	1	21	0	5	0	9	4	7	0	4	20	14	70	0	1	0	0	0	0	0	0	1	2	23	1	0	0	0	7	0	0	1	0	0	0	1	0
46-3	60-63	437.4	0	4	6	0	2	76	2	9	10	39	10	17	0	9	17	12	99	1	0	0	0	0	1	4	0	1	3	43	4	0	0	17	14	0	3	4	0	0	3	0	0
46-5	60-63	440.4	1	0	1	0	2	42	6	10	0	19	0	3	1	12	9	4	20	0	2	1	0	3	2	8	0	0	0	64	0	0	0	16	2	2	6	15	0	0	0	0	0
47-4	74-77	448.8	0	2	3	0	0	22	2	16	1	20	0	5	0	6	15	21	86	0	0	0	0	2	2	8	0	0	0	26	1	0	6	14	18	0	0	8	1	0	0	2	0
47-5	55-58	450.1	0	0	3	0	0	17	0	7	0	7	1	0	0	1	8	11	62	0	0	0	0	3	0	0	0	0	1	19	0	0	0	7	1	0	0	3	1	0	0	0	0
47-6	52-55	451.6	0	0	1	0	0	54	0	7	0	12	0	8	0	29	17	0	0	1	11	3	0	31	0	11	7	0	0	99	18	0	14	32	0	0	0	18	0	0	0	0	0
48-1	106-109	454.3	4	0	15	0	0	32	1	12	0	7	8	0	0	13	39	0	4	0	0	0	2	0	2	0	0	0	0	26	3	0	0	5	7	0	0	4	0	0	1	0	0
48-3	107-110	457.3	0	1	0	0	0	7	0	22	0	1	0	2	0	0	3	0	2	0	2	0	0	2	0	2	0	0	0	20	3	3	1	13	0	0	1	0	0	0	0	0	0
48-5	104-107	460.3	0	0	13	0	0	52	0	24	1	5	2	2	0	7	8	0	16	0	1	0	0	5	0	1	0	0	0	66	5	0	3	22	0	0	3	3	0	0	5	0	0
49-1	118-121	464	9	0	3	0	0	32	1	23	0	10	1	3	0	12	19	11	19	0	0	0	2	19	0	0	0	0	4	90	2	6	1	42	5	1	1	9	0	0	0	0	0
49-5	117-120	470	2	0	3	0	0	24	2	21	0	0	0	1	0	14	7	11	14	0	4	0	0	5	3	0	0	2	1	99	9	1	1	0	6	1	8	3	0	0	0	0	5
49-6	117-120	471.5	1	1	1	0	0	20	0	1	0	4	3	1	2	2	0	3	9	0	1	0	0	3	0	1	0	1	0	50	10	0	0	22	1	0	0	1	0	0	0	2	0
50-1	91-94	473.4	0	0	2	0	0	20	0	2	1	0	0	1	0	8	15	11	4	0	2	0	0	7	2	12	0	2	0	23	1	0	0	14	3	0	2	2	5	0	0	0	0
50-3	91-94	476.4	2	0	0	0	0	44	2	9	0	4	0	0	0	12	7	15	6	0	0	0	0	3	1	0	0	2	1	56	4	0	0	4	1	0	0	4	3	0	0	5	12
50-5	44-47	479	0	0	3	0	0	8	0	4	0	3	3	2	0	13	11	15	15	0	4	0	5	12	3	2	0	0	2	82	2	1	0	28	0	0	0	2	1	0	0	0	0
51-2		484.6	8	0	11	0	0	12	0	3	0	4	0	2	0	9	8	4	0	0	4	0	6	5	2	0	0	4	3	94	2	0	0	15	0	0	4	4	3	1	0	0	0
51-4	96-99	487.6	1	0	3	0	0	19	0	7	0	4	0	2	0	12	10	9	2	0	0	3	7	10	0	1	1	3	4	68	20	1	11	30	0	0	0	5	0	0	0	0	0
51-5	94-97	489.1	0	0	1	0	0	20	0	36	1	2	5	3	1	9	16	21	0	0	9	0	0	10	0	3	0	0	2	99	6	1	0	13	0	0	0	3	4	0	0	1	0
52-2	45-48	493.8	0	1	1	0	0	9	1	1	1	6	1	0	0	18	6	11	0	0	1	0	1	6	0	1	0	0	0	99	2	0	0	11	0	0	4	2	0	0	0	0	0
52-3	45-48	495.3	0	0	1	0	1	4	0	0	0	0	0	0	0	3	4	3	0	0	1	0	0	0	0	5	0	2	1	14	4	4	0	3	0	0	0	0	0	0	0	0	2
52-5	54-57	498.3	0	0	3	0	0	17	0	3	0	12	0	8	0	9	9	7	12	0	3	1	5	9	0	0	4	3	13	67	7	0	0	25	4	0	0	4	7	0	0	0	2
53-2	40-43	503.3	1	0	3	0	0	15	0	4	0	5	2	0	0	4	7	1	9	0	2	0	0	11	0	3	0	0	4	65	3	0	2	18	0	1	1	2	0	1	0	0	0
53-4	84-87	506.8	2	0	8	0	0	0	0	2	0	2	3	6	0	4	10	7	8	0	4	6	0	3	3	0	0	3	7	68	6	0	0	23	0	0	0	2	11	0	0	0	0
53-5	24-27	507.7	4	0	6	0	0	49	0	20	0	4	0	5	0	9	18	5	6	0	5	2	5	7	1	3	0	0	2	62	2	0	0	35	0	0	0	1	3	0	0	1	0
54-2	32-35	512.9	0	0	4	0	0	7	0	1	0	0	2	1	1	2	15	1	3	0	0	0	0	2	0	0	0	0	0	36	7	0	0	18	0	0	0	0	0	0	0	0	0
54-6	23-26	518.8	4	0	4	0	0	10	0	20	0	1	0	2	0	0	3	7	6	0	1	1	0	5	1	2	0	2	1	99	4	0	0	11	0	0	1	0	0	0	0	0	0
55,CC		530.3	2	1	7	0	0	8	0	16	0	10	4	6	0	3	13	11	14	0	0	0	0	2	2	0	0	2	2	61	8	0	0	3	2	0	0	0	1	0	0	0	2
56,CC		540	0	0	0	0	0	2	0	12	0	8	1	7	0	6	11	6	3	0	1	1	0	0	0	1	0	0	1	16	1	0	0	0	2	0	0	0	1	0	0	0	0
58,CC		559.4	0	0	4	0	0	3	0	11	0	1	3	1	0	3	5	4	2	0	0	0	0	0	0	9	0	0	1	18	0	0	0	0	1	0	0	3	1	0	0	2	0
59,CC		569.1	0	0	1	0	0	2	0	2	0	7	0	5	0	0	9	10	7	0	0	0	0	0	0	0	0	0	5	12	0	0	1	0	0	0	0	0	0	0	0	0	5
60,CC		578.9	0	0	4	0	0	11	4	15	2	18	7	13	2	19	22	17	2	0	0	0	0	5	1	1	0	0	9	76	7	0	0	0	0	0	0	1	6	0	2	0	0
61,CC		588.4	0	5	1	0	0	19	2	36	0	16	4	10	0	10	38	30	3	1	1	2	0	8	1	4	0	5	16	70	3	0	0	0	0	0	0	6	4	0	0	2	0
62-1	112-115	599.2	1	4	7	0	0	30	2	20	0	13	8	4	0	7	16	5	1	1	2	1	2	1	1	4	0	0	14	68	7	0	0	16	0	0	0	0	3	3	0	0	0
62-3	60-63	601.7	7	3	12	0	0	27	0	0	0	12	4	6	0	7	6	9	3	1	0	1	0	0	0	0	0	2	8	36	6	0	0	0	0	0	0	1	0	0	2	2	0
62-6	22-25	605.8	2	0	5	0	0	5	0	8	0	16	7	4	0	10	13	5	3	0	2	1	3	2	2	2	0	4	10	62	12	0	2	0	0	2	0	3	6	1	2	3	0
63-1	139-142	609.2	2	0	2	0	0	9	1	3	0	2	2	7	0	9	4	4	1	0	2	1	1	6	2	4	0	6	17	99	13	0	0	27	0	0	0	5	5	0	0	0	0
63,CC		617.5	0	0	0	0	0	24	2	0	0	43	7	13	0	33	25	1	0	0	5	1	3	9	0	4	0	7	25	33	5	0	1	12	28	0	0	15	19	3	3	1	0
64-2	58-61	619.6	0	0	0	0	0	0	0	41	0	28	8	50	0	15	0	4	1	0	0	0	0	0	0	7	0	0	1	7	2	0	0	0	0	0	1	0	1	0	11	0	0

Appendix 3-3 (Continued).

64-3	18-21	620.7	0	0	0	0	0	1	0	8	0	10	0	21	0	40	5	9	3	0	1	0	1	4	5	13	0	0	0	27	20	0	0	20	8	0	0	7	0	0	4	0	0
64,CC		627.2	0	0	0	0	0	32	0	9	0	12	4	2	0	40	12	10	1	0	16	1	0	6	2	12	0	1	17	49	30	0	0	11	10	0	0	15	0	0	0	2	0
65-1	31-34	627.5	0	0	0	0	0	3	0	11	0	19	1	4	0	31	35	11	0	0	10	1	0	3	2	20	3	0	23	46	40	0	0	7	30	0	8	8	0	0	8	0	0
65-2	31-34	629	0	0	0	0	0	0	0	8	0	5	2	7	0	22	7	7	0	0	0	0	0	2	6	20	6	0	23	38	0	0	0	3	13	0	0	2	11	0	12	0	0
66-2	24-27	638.6	0	1	2	0	0	6	0	4	0	1	4	3	0	27	0	12	2	0	5	0	2	3	2	8	0	2	1	23	3	0	0	13	0	0	0	1	5	0	0	0	0
66-3	57-60	640.4	0	0	5	0	0	0	0	2	0	5	4	5	0	21	0	6	5	0	3	0	5	2	2	5	0	0	11	31	0	1	1	13	4	0	0	6	2	0	0	2	0
66,CC		646.5	0	0	0	0	0	0	0	3	0	6	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	3	10	2	0	0	0	0	0	0	0	0	0	1	0	0
67-1	40-43	646.9	1	0	2	0	0	0	0	3	0	2	1	11	0	18	11	9	2	0	1	0	4	0	1	15	0	0	0	12	0	0	0	23	6	0	0	3	4	0	0	1	0
67-3	36-39	649.9	0	0	0	0	0	0	0	2	0	3	1	4	0	24	5	14	3	0	0	0	13	1	0	9	0	0	6	15	0	0	0	37	2	0	0	0	14	0	0	0	0
68-1	129-132	657.5	0	2	0	0	0	2	0	7	0	1	2	2	0	16	0	2	6	0	1	0	12	1	3	3	1	2	20	16	2	3	0	16	3	0	0	0	7	1	0	0	0
68-3	74-77	660	3	0	0	0	0	1	1	15	0	9	6	1	0	25	4	0	3	0	7	0	10	0	1	7	0	0	18	78	5	0	0	17	7	1	0	5	26	0	0	0	0
70-2		687.5	0	0	0	0	0	0	0	7	0	3	5	2	0	7	0	0	1	0	0	0	0	0	1	1	0	1	0	14	0	0	0	0	0	0	0	0	7	0	0	0	0
70,CC		694.8	0	1	0	0	0	4	0	10	0	3	0	0	0	2	0	1	0	0	0	0	9	0	0	2	1	1	0	53	2	0	0	0	0	0	0	1	1	0	0	0	0
71-2	42-45	696.7	1	3	0	0	0	0	0	8	0	2	0	0	0	0	1	0	2	0	3	0	6	0	0	0	0	4	2	46	0	0	0	0	0	0	0	0	5	0	2	0	0

Appendix 3-3 (Continued).

CORE	INTERV	Rtes	Ptes	Tpro	Gs45	Kcnv	SPHR	STEX	Snav	LAGN	Hexc	VERN	Dexc	Hovl	STIL	DENT	NODO	LENT	PLEU	ENTO	OOLN	LAGN	FISS	ANGL	UVIG	Aspi	Asem	Cbrd	Cspp	Cpra	Ceoc	Csmo	Gmic	Csub	Chav	Cgrm	Cldgo	Peoc	Pqui	ORID	Gsub	GOID	Nhav
17-1	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	24	13	3	0	6	2	14	5	12	12	1	4	3	11	12	4	6	2	0	0	0	0	0	38	5	34	25	35	7
17-2	116-119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	2	0	0	0	0	1	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	3	1	3	3	3	0
17-4	88-91	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	2	4	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	1	1	7	5	4	0
17-5	99-102	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	1	2	1	0	0	1	1	0	1	0	0	1	2	0	0	0	0	0	3	1	12	6	2	0
18-2	78-81	0	0	0	0	0	0	0	0	0	0	0	0	0	19	23	0	0	3	2	1	0	1	0	0	1	0	3	4	0	0	0	0	0	0	0	0	0	2	27	19	5	0
19-2	105-108	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	1	0	0	0	3	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	4	2	1	0
19-3	112-115	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	2	3	0	0
19-5	126-129	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	2	0	1	0	2	0	0	0	2	1	0	0	0	0	0	0	0	0	1	0	0	0	1	9	5	1	0
19-6	117-120	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	2	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
20-1	91-94	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
20-2	93-96	0	0	0	0	0	0	0	0	0	0	0	0	0	10	34	0	1	4	4	6	0	0	0	12	8	0	2	0	0	0	1	0	0	2	0	0	1	1	13	5	6	0
20-4	84-87	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	0	0	0	3	1	1	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
21-1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	1	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	0
21-2	13-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	4	1	0	1	0	0	3	0	2	0	0	0	0	0	3	0	0	0	1	0	0	0	0	7	0	0	0
21-3	13-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	1	0	0	0	2	1	2	0	0	1	0	0	0	0	0	2	0	0	0	0	0	2	1	4	13	4	0
22,CC		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-1		0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2	0	0	0
23-2	95-98	0	0	0	0	0	0	0	0	0	0	0	0	0	7	14	2	1	0	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
23-4	75-78	0	0	0	0	0	0	0	0	0	0	0	0	0	3	6	5	0	2	1	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2	4	0	2	0
23-5	23-26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
24-2	31-33	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24-4	31-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25-1	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
25-2	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	6	13	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25-4	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27-1	78-83	0	0	0	0	0	0	0	0	0	0	0	0	0	40	35	17	0	13	0	24	8	3	0	0	12	1	8	1	0	1	3	0	0	0	0	0	21	2	49	9	8	4
28-1	108-113	0	0	0	0	0	0	0	0	0	0	0	0	0	2	19	3	2	6	0	5	4	4	0	1	6	0	2	0	1	0	5	0	0	0	0	0	0	20	10	27	17	0
28-2	105-108	0	0	0	0	0	0	0	0	0	0	0	0	0	4	29	3	0	5	2	3	3	4	0	0	4	0	7	0	6	0	5	0	0	0	0	0	4	0	4	0	2	0
28-3	102-107	0	0	0	0	0	0	0	0	0	0	0	0	0	8	12	2	0	0	6	3	1	4	0	0	2	0	2	0	0	0	5	0	0	0	0	0	1	0	14	0	7	4
28-4	91-94	0	0	0	0	0	0	0	0	0	0	0	0	0	13	26	9	0	0	0	4	3	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	9	5	13	0	9	3
28-4	105-108	0	0	0	0	0	0	0	0	0	0	0	0	0	13	10	3	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	8	0	5	1
30-1	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	13	4	0	0	7	2	1	2	12	0	5	0	0	13	0	0	0	9	1	0	0	0	0	9	7	25	1	4	23
30-2	25-28	0	0	0	0	0	0	0	0	0	0	0	0	0	37	11	1	0	4	3	4	0	4	0	1	0	0	4	0	0	0	1	0	0	0	0	0	8	8	37	0	5	13
30-3	110-113	0	0	0	0	0	0	0	0	0	0	0	0	0	26	21	0	1	4	2	2	2	2	0	1	0	0	9	0	0	0	4	0	0	0	0	0	4	9	19	12	5	10
30-4	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	34	9	0	1	4	4	2	2	2	0	1	0	0	6	0	0	0	15	0	0	0	0	0	17	1	42	33	6	17
30-5	10-13	0	0	0	0	0	0	0	0	0	0	0	0	0	52	56	0	1	0	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	4	0	2	2
30-7	33-36	0	0	0	0	0	0	0	0	0	0	0	0	0	60	28	0	2	2	1	7	3	0	0	0	0	0	0	1	0	6	1	0	0	0	0	0	0	1	32	5	1	6
31-1	132-135	0	0	0	0	0	0	0	0	0	0	0	0	0	10	1	3	1	4	6	7	7	7	0	2	0	0	1	0	0	5	8	0	0	0	0	0	11	2	27	22	8	0
31-2	34-37	0	0	0	0	0	0	0	0	0	0	0	0	0	19	7	0	0	1	0	3	2	1	0	0	0	0	1	0	0	3	3	0	0	0	0	0	16	1	18	8	10	10
32-1	89-92	0	0	0	0	0	0	0	0	0	0	0	0	0	5	11	0	0	0	0	0	1	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0	3	0	11	2	1	0
32-2	20-23	0	0	0	0	0	0	0	0	0	0	0	0	0	6	19	0	1	0	2	0	2	0	0	1	0	0	1	0	0	0	1	0	0	0	0	0	4	0	4	0	3	2
33,CC		0	0	0	0	0	0	0	0	0	0	0	0	0	16	19	0	0	0	1	1	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	0	11	2	19	12	8	0
35-1	77-80	0	0	0	0	0	0	0	0	0	0	0	0	0	28	17	0	0	2	4	2	0	6	0	5	0	0	0	0	0	0	0	3	0	0	2	0	3	0	5	0	6	8
35-2	77-80	0	0	0	0	0	0	0	0	0	0	0	0	0	14	12	2	1	0	0	0	0	1	0	2	0	0	1	0	0	0	1	0	0	0	0	0	5	4	24	0	4	2
35-3	77-80	0	0	0	0	0	0	0	0	0	0	0	0	0	40	10	2	2	6	0	3	0	5	0	2	0	0	4	2	0	8	6	1	0	0	0	0	18	0	53	2	7	6
36-2	49-52	0	0	0	0	0	0	0	0	0	0	0	0	0	4	8	0	0	5	0	2	1	2	0	0	2	0	1	1	0	1	2	0	0	0	0	0	11	1	31	0	2	0
36-3	49-52	0	0	0	0	0	0	0	0	0	0	0	0	0	26	21	4	1	1	5	3	0	1	0	0	0	0	5	0	2	0	2	0	0	0	0	0	5	0	14	0	2	0
36-4	49-52	0	0	0	0	0	0	0	0	0	0	0	0	0	14	11	0	1	0	4	0	1	2	0	0	0	0	5	0	8	1	0	0	0	0	1	0	7	2	15	1	0	1
37-2	90-93	0	0	0	0	0	0	0	0	0	0	0	0	0	4	15	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0
37-3	90-93	0	0	0	0	0	0	0	0	0	0	0	0	0	38	51	1	0	0	3	4	4	1	0	0	0	0	9	0	0	6	3	2	0	0	1	0	37	2	12	1	7	4
37-4	90-93	0	0	0	0	0	0	0	0	0	0	0	0	0	27	30	0	0	3	2	4	3	2	0	0	0	0	1	0	4	6	2	0	0	0	0	0	15	0	9	0	7	9
38-1	83-86	0	0	0	0	0	0	0	0	0	0	0	0	0	72	37	0	0	3	1	3	1	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	11	0	8	0	4	0
38-2	84-97	0	0	0	0	0	0	0	0	0	0	0	0	0	19	18	4	1	0	0	0	0	0	0	0	0	0	4	0	0	1	4	0	0	0	0	0	10	0	11	0	2	0
38-3	84-87	0	0	0	0	0	0	0	0	0	0	0	0	0	25	8	0	0	4	1	0	7	2	0	0	0	0	12	0	0	0	6	1	0	0	0	0	6	0	19	5	3	6

Appendix 3-3 (Continued).

38-4	86-89	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	1	0	0	3	0	0	2	0	0	0	0	1	0	1	0	1	0	0	0	0	0	8	2	3	1	5	2
39-1	80-83	0	0	0	0	0	0	0	0	0	0	0	0	0	7	13	0	1	0	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	5	0	0	2
39-2	77-80	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	4	0	0	0
39,CC		0	0	0	0	0	0	0	0	0	0	0	0	0	9	11	3	0	1	3	1	0	2	0	4	0	0	0	4	1	1	2	6	0	0	0	0	13	0	10	6	4	0
41-1	58-61	0	0	0	0	0	0	0	0	0	0	0	0	0	16	7	0	0	0	0	3	0	3	0	0	0	0	0	0	5	4	3	0	0	0	1	0	3	0	11	14	6	4
41-3	58-61	0	0	0	0	0	0	0	0	0	0	0	0	0	31	21	2	1	0	0	0	0	2	0	6	0	0	2	9	0	5	0	6	0	1	0	0	36	0	27	17	5	8
41-5	58-61	4	1	1	1	0	0	0	0	0	0	0	0	0	7	9	5	0	7	0	2	4	1	0	1	0	0	8	13	8	1	8	6	0	0	0	0	41	5	19	26	11	5
42-1	98-101	0	0	0	0	0	0	0	0	0	0	0	0	0	12	3	0	1	0	0	2	2	0	0	0	0	0	1	3	0	0	1	3	0	0	0	0	2	1	6	7	1	3
42-3	32-35	0	0	0	0	0	0	0	0	0	0	0	0	0	13	3	2	1	2	4	1	1	0	0	5	0	0	5	7	2	0	4	5	0	0	2	0	16	4	32	25	6	10
42-5	96-99	1	0	0	0	0	0	0	0	0	0	0	0	0	3	23	0	0	0	3	2	2	1	0	0	0	0	5	0	0	6	0	2	0	0	0	0	7	1	7	16	2	7
43-1	95-98	4	0	0	0	1	0	0	0	0	0	0	0	0	16	9	0	1	1	0	6	0	1	0	0	0	0	1	12	0	0	3	2	0	0	2	0	16	2	44	1	6	6
43-3	104-107	4	0	0	0	0	0	0	0	0	0	0	0	0	9	6	2	0	2	4	1	3	0	0	6	0	0	9	0	0	9	4	2	0	0	0	0	24	0	13	4	2	0
43-5	97-100	0	0	0	0	0	0	0	0	0	0	0	0	0	13	13	0	0	1	4	2	0	0	0	1	0	0	1	0	1	8	3	0	0	0	0	0	5	2	31	6	2	3
44-1	45-48	0	0	0	1	0	0	0	0	0	0	0	0	0	4	12	0	0	2	2	1	4	1	0	0	0	0	0	0	0	4	0	1	0	0	0	0	3	1	12	1	2	6
44-3	42-45	9	0	0	0	0	0	0	0	0	0	0	0	0	2	12	2	2	5	2	6	5	3	0	4	0	0	10	3	5	8	12	0	0	0	0	0	16	6	20	35	11	0
44-5	45-48	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	0	1	3	1	5	3	1	0	0	0	0	4	2	10	2	5	0	0	0	0	6	22	7	28	1	9	7
45-1	14-17	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	2	0	0	3	1	0	0	0	1	0	0	2	0	6	30	1	1	0	0	0	0	7	5	28	1	3	4
45-2	20-23	1	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	2	2	4	7	1	0	0	0	0	0	2	10	7	5	2	2	0	0	2	5	5	2	82	0	6	8
46-1	60-63	0	0	0	0	0	0	0	0	0	0	0	0	0	12	3	0	0	0	0	2	0	0	0	0	0	0	2	6	0	0	0	0	0	0	2	0	10	0	31	6	9	0
46-3	60-63	0	0	0	0	0	0	0	0	0	0	0	0	0	11	7	0	0	0	0	1	0	0	0	0	0	0	2	4	0	0	6	0	0	0	4	0	5	0	14	9	7	1
46-5	60-63	0	0	0	0	0	0	0	0	0	0	0	0	0	8	6	1	0	2	0	0	4	2	0	0	0	1	0	0	0	0	3	0	0	0	0	0	8	0	9	3	2	1
47-4	74-77	2	0	0	0	0	0	0	0	0	0	0	0	0	23	0	0	0	1	0	2	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2	0	4	0	1	0
47-5	55-58	3	0	0	0	0	0	0	0	0	0	0	0	0	16	20	0	0	2	0	4	0	1	0	0	0	2	1	0	0	0	1	1	0	0	0	0	1	0	36	1	2	9
47-6	52-55	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48-1	106-109	0	0	0	0	1	0	1	0	0	0	0	0	0	7	11	0	0	4	2	3	0	4	0	0	0	0	3	1	0	0	1	6	0	0	0	0	13	0	48	0	19	1
48-3	107-110	1	0	0	0	0	0	0	0	0	0	0	0	0	7	2	1	0	4	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	3	8	0
48-5	104-107	0	0	1	0	1	0	0	1	0	0	0	0	0	13	33	0	0	6	0	3	2	4	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	32	0	9	2
49-1	118-121	7	0	0	0	0	0	1	0	0	0	0	0	0	5	10	0	2	2	3	4	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0
49-5	117-120	4	2	0	0	0	0	0	0	0	0	0	0	0	3	16	0	0	4	5	0	0	3	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	1	21	0	5	0
49-6	117-120	0	0	0	0	1	0	0	0	1	0	0	0	0	3	10	0	0	4	0	5	0	0	0	0	0	0	3	0	0	0	2	0	0	0	0	0	0	2	38	0	5	5
50-1	91-94	1	6	0	0	1	0	0	0	0	0	0	0	0	3	16	0	0	1	3	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3	18	0	6	0
50-3	91-94	5	0	0	0	0	0	1	0	0	2	0	0	0	0	5	0	1	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	8	0	1	0
50-5	44-47	0	2	0	0	0	0	0	0	0	0	0	0	0	3	24	0	1	1	1	4	2	0	0	0	0	1	3	1	0	0	0	7	0	0	0	0	0	2	25	0	4	0
51-2		0	0	0	0	0	0	0	0	1	1	0	0	0	2	22	0	0	3	0	1	0	2	0	0	0	0	0	1	0	0	0	5	0	0	2	0	0	1	18	0	2	3
51-4	96-99	0	0	0	0	0	0	0	0	0	2	0	0	0	0	14	0	1	2	2	8	0	2	0	0	0	0	7	0	0	0	3	1	0	0	0	0	1	1	28	9	3	1
51-5	94-97	5	1	1	0	2	1	0	0	0	0	0	0	0	2	17	0	0	3	0	8	0	1	0	0	0	0	7	2	0	0	0	0	0	0	0	0	2	4	24	1	3	8
52-2	45-48	0	0	0	0	2	0	0	0	0	1	0	0	0	0	8	0	1	3	1	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	20	1	5	3
52-3	45-48	1	1	0	0	0	0	0	0	0	0	0	0	0	1	3	0	1	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	10	0	1	2
52-5	54-57	1	0	0	0	1	0	0	0	1	1	0	0	0	8	12	0	0	4	0	4	0	3	0	0	0	0	3	2	0	0	0	3	0	0	0	0	6	0	12	7	0	1
53-2	40-43	0	0	0	0	0	0	0	0	0	0	0	0	0	6	12	0	2	1	4	4	0	2	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	7	1	5	2
53-4	84-87	4	0	0	0	6	0	0	0	0	0	0	0	0	20	28	0	0	2	3	3	0	1	0	0	0	0	6	1	0	0	0	0	0	0	0	2	1	0	40	8	6	10
53-5	24-27	1	0	0	0	0	0	0	0	0	0	0	0	0	19	13	0	1	1	1	3	3	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	4	3	43	2	4	8
54-2	32-35	1	0	0	0	0	0	0	0	0	0	0	0	0	5	12	0	2	0	4	2	2	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	24	5	2	5
54-6	23-26	2	0	0	0	0	0	0	0	0	0	0	0	0	18	16	0	2	0	0	5	0	3	0	0	0	0	11	0	0	14	0	3	0	0	0	0	0	0	15	8	10	2
55,CC		2	0	0	0	0	0	0	0	0	0	0	0	0	15	5	0	3	3	2	2	0	3	0	0	0	0	3	4	0	0	0	2	0	0	1	0	0	5	28	10	8	7
56,CC		0	0	0	0	0	0	0	0	0	2	0	0	0	43	14	0	2	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	9	1	1	1
58,CC		0	0	0	0	0	0	0	0	0	0	0	0	0	6	11	0	1	0	1	1	1	0	0	0	0	1	0	2	0	0	3	0	0	0	0	0	0	0	3	2	5	3
59,CC		0	0	0	0	0	0	0	0	0	0	0	0	0	10	13	1	0	0	1	2	0	1	0	0	0	0	0	2	0	0	0	0	1	0	0	0	4	0	3	7	6	7
60,CC		2	1	0	0	1	0	0	0	0	0	1	0	0	26	44	0	0	0	0	2	0	2	0	0	0	0	3	16	0	0	2	0	2	0	0	0	10	0	22	10	3	9
61,CC		4	0	0	0	0	0	0	0	0	0	0	0	0	45	10	0	0	3	0	1	0	1	0	0	0	0	2	19	0	0	0	1	2	0	0	0	6	2	29	7	3	1
62-1	112-115	5	0	0	0	10	0	0	0	0	1	0	0	0	7	7	1	1	3	0	0	3	0	0	0	2	0	5	1	0	0	7	0	0	0	0	0	6	2	12	7	5	3
62-3	60-63	7	0	0	0	7	0	0	0	0	0	0	0	0	5	3	1	1	4	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	7	0	10	0	17	4
62-6	22-25	12	0	0	0	22	0	0	0	0	2	0	0	0	6	3	0	5	10	0	12	0	2	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	19	24	9	12
63-1	139-142	3	2	0	0	0	0	0	0	0	1	0	0	0	9	14	0	5	7	1	5	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	17	10	3	7
63,CC		18	0	2	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64-2	58-61	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 3-3 (Continued).

64-3	18-21	21	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64,CC		10	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65-1	31-34	16	0	0	0	0	3	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65-2	31-34	12	0	0	0	0	1	0	1	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66-2	24-27	4	0	0	0	0	0	0	2	0	0	1	99	0	7	0	1	0	4	0	0	0	0	0	0	0	1	0	9	0	0	10	1	0	1	0	0	0	1	0	0	2	14
66-3	57-60	8	0	0	1	0	1	0	1	0	0	3	39	0	1	2	0	1	6	0	0	0	0	0	0	0	0	0	8	0	0	4	0	0	0	0	0	0	0	14	0	4	9
66,CC		0	0	0	0	0	0	0	0	0	0	0	0	0	24	7	1	0	0	17	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	2	2
67-1	40-43	3	0	0	0	0	0	0	0	0	0	1	99	0	7	1	1	0	2	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0	1
67-3	36-39	2	0	0	0	0	0	0	1	0	0	1	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68-1	129-132	16	0	0	0	0	0	0	0	0	0	0	22	0	16	8	0	1	3	0	0	0	0	0	0	0	2	7	2	0	0	0	0	0	0	0	0	2	6	15	15	7	8
68-3	74-77	16	0	0	0	0	1	0	0	0	2	0	43	0	1	1	2	9	7	0	0	1	0	0	0	0	1	0	21	0	0	0	0	0	0	0	0	0	3	22	16	6	27
70-2		5	0	0	1	0	0	3	0	0	0	0	7	0	0	18	0	17	1	4	0	2	0	0	0	0	2	0	19	0	0	0	0	0	0	0	0	0	0	14	0	5	15
70,CC		2	3	0	0	0	1	0	0	2	0	0	0	3	9	18	0	10	4	0	0	2	0	0	0	1	1	0	11	0	0	0	0	0	0	0	0	0	0	12	0	0	25
71-2	42-45	7	0	0	0	0	0	0	0	0	0	0	0	0	6	14	1	17	0	0	0	3	0	0	0	9	0	0	10	0	0	0	1	0	0	0	0	30	0	12	0	0	5

CORE	INTERV	TURR	FRON	QUIN	Numb	Eexg	Bcos	OSAN	Bhun	CASS	Usmo	GAVL	Bmac	Ntrm	Uhis	Bsem	ARAG	Prnz	ABYS	QUAD	NONI	CLIN	Bglm	Btrn	SUM
17-1	107-110	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	321
17-2	116-119	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
17-4	88-91	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39
17-5	99-102	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43
18-2	78-81	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	125
19-2	105-108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35
19-3	112-115	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
19-5	126-129	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47
19-6	117-120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
20-1	91-94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
20-2	93-96	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	123
20-4	84-87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
21-1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
21-2	13-17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39
21-3	13-17	2	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56
22,CC		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
23-1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
23-2	95-98	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67
23-4	75-78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
23-5	23-26	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
24-2	31-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
24-4	31-33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
25-1	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
25-2	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23
25-4	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
27-1	78-83	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	381
28-1	108-113	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	171
28-2	105-108	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93
28-3	102-107	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105
28-4	91-94	9	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	154
28-4	105-108	3	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77
30-1	107-110	6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	199
30-2	25-28	1	0	8	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	177
30-3	110-113	4	0	16	2	1	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	226
30-4	107-110	2	0	0	3	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	244
30-5	10-13	0	0	4	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	346
30-7	33-36	11	0	19	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	224
31-1	132-135	20	0	5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	248
31-2	34-37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	187
32-1	89-92	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	87
32-2	20-23	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	113
33,CC		0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	228
35-1	77-80	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	140
35-2	77-80	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	133
35-3	77-80	0	0	2	6	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	252
36-2	49-52	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	174
36-3	49-52	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	198
36-4	49-52	0	0	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	149
37-2	90-93	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64
37-3	90-93	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	351
37-4	90-93	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	271
38-1	83-86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	234
38-2	84-97	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	126
38-3	84-87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	308

ABBREVIATIONS OF SPECIES NAMES, HOLE 647A:

CLAV = Clavulinoides sp.
ARNB = Arenobulimina sp.
Kchp = Karreriella chapapotensis (Cole)
Scub = Spiroplectammina cubensis (Cushman and Bermudez)
SPSG = Spirosigmoilinella compressa Matsunaga
RHAB = Rhabdammina spp.
CRIB = Cribrostomoides subglobosus (Brady)
BATH = Bathysiphon spp.
Alat = Ammodiscus latus Grzybowski
Gchr = Glomospira charoides (Jones and Parker)
REOP = Reophax subnodulosus Grzybowski
Acrt = Ammodiscus cretaceus (Reuss)
GAUD = Gaudryina sp.
Girr = Glomospira irregularis (Grzybowski)
RECV = Recurvoides spp.
Ramp = Reticulophragmium amplectens (Grzybowski)
Sspt = Spiroplectammina spectabilis (Grzybowski)
AMML = Ammolagena clavata (Jones & Parker)
Tdef = Trochammina deformis Grzybowski
Apol = Ammobaculites aff. polythalamus Loeblich
SUBR = Subreophax scalaria (Grzybowski)
SACC = Saccammina complanata (Franke)
Gser = Glomospira serpens (Grzybowski)
Tirr = Trochamminoides irregularis White
Hpor = Haplophragmoides porrectus Maslakova
Khor = Karreriella horrida Mjatliuk
Aten = Ammodiscus nagyi n.sp.
RHIZ = Rhizammina spp.
Hwal = Haplophragmoides walteri (Grzybowski)
LITU = Lituotuba lituiformis (Brady)
Rpil = Reophax pilulifer Brady
Hken = Hyperammina kenmilleri n.sp.
Kcon = Karreriella coniformis (Grzybowski)
BIGN = Bigenerina sp.
Rgut = Reophax guttifer Brady
AMMS = Ammosphaeroidina pseudopauciloculata (Mjatliuk)
Cpla = Cyclammina placenta (Reuss)
Hdis = Hormosina distans (Brady)
Ggor = Glomospira gordialis (Jones and Parker)
Hsub = Hyperammina ex gr. subnodosiformis Grzybowski
Helg = Hyperammina elongata Brady
Rtes = Rhizammina sp. (with planktonic tests)
Ptes = Psammosphaera testacea Flint
Tpro = Trochamminoides proteus (Karrer)
Gs45 = Gaudryina sp. 45
Kcnv = Karreriella conversa (Grzybowski)
SPHR = Sphaerammina gerochi Hanzlikova
STEX = Siphotextularia sp.
Snav = Spiroplectammina navarroana Cushman
LAGN = Lagenammina sp.
Hexc = Hormosina cf. excelsa Dylazanka
VERN = Verneuilinoides polystrophus (Reuss)
Dexc = Dendrophrya excelsa Grzybowski
Hovl = Hormosina ovulum ovulum (Grzybowski)

Appendix 3-3 (Continued).

38-4	86-89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121
39-1	80-83	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	127
39-2	77-80	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52
39,CC		0	0	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	229
41-1	58-61	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	240
41-3	58-61	0	0	1	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	454
41-5	58-61	0	0	0	0	0	0	3	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	379
42-1	98-101	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	186
42-3	32-35	0	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	282
42-5	96-99	0	0	0	1	0	0	5	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	262
43-1	95-98	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	375
43-3	104-107	0	0	1	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	383
43-5	97-100	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	291
44-1	45-48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	321
44-3	42-45	0	0	5	0	0	2	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	319
44-5	45-48	0	0	4	0	0	6	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	307
45-1	14-17	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	369
45-2	20-23	0	0	2	0	0	1	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	368
46-1	60-63	0	0	0	0	0	0	0	0	0	0	0	0	11	11	0	0	0	0	0	0	0	0	0	306
46-3	60-63	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	489
46-5	60-63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	301
47-4	74-77	2	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	332
47-5	55-58	0	0	0	0	0	0	0	0	0	0	0	2	5	0	0	0	0	0	0	0	0	0	0	259
47-6	52-55	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	377
48-1	106-109	0	0	0	0	0	0	2	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	319
48-3	107-110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	119
48-5	104-107	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	359
49-1	118-121	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	370
49-5	117-120	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	318
49-6	117-120	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	220
50-1	91-94	0	0	3	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	204
50-3	91-94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	224
50-5	44-47	0	0	0	0	0	0	7	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	312
51-2		0	0	1	0	0	0	14	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	289
51-4	96-99	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	321
51-5	94-97	0	0	3	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	366
52-2	45-48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	231
52-3	45-48	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	82
52-5	54-57	0	0	0	0	0	0	4	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	310
53-2	40-43	0	0	2	0	0	1	0	0	0	0	0	0	11	0	2	0	0	0	0	0	0	0	0	230
53-4	84-87	0	0	0	0	0	0	4	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	335
53-5	24-27	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	367
54-2	32-35	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	167
54-6	23-26	0	0	2	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	299
55,CC		0	0	2	0	0	0	1	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	300
56,CC		0	0	0	0	0	0	0	0	0	0	0	1	20	0	0	4	0	0	0	0	0	0	0	182
58,CC		0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	115
59,CC		0	0	1	0	0	0	0	0	0	0	0	2	10	0	0	0	0	0	0	0	0	0	0	137
60,CC		0	0	0	0	0	0	0	0	0	0	0	0	27	0	0	4	0	0	0	1	0	0	0	432
61,CC		0	0	1	0	0	0	0	0	0	0	0	0	45	0	0	0	0	0	0	0	0	0	0	479
62-1	112-115	0	0	0	0	0	0	1	0	0	0	0	0	31	0	2	1	1	0	0	0	0	0	0	365
62-3	60-63	0	0	0	0	0	0	0	0	0	0	0	5	20	0	4	0	1	0	0	0	0	0	0	254
62-6	22-25	3	0	0	0	0	0	5	0	0	0	0	2	54	0	2	1	0	0	0	0	0	0	0	405
63-1	139-142	0	0	0	0	0	0	1	0	0	0	0	1	46	0	0	0	0	0	0	0	0	0	0	370
63,CC		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	345
64-2	58-61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	180

STIL = Stilostomella spp.
DENT = Dentalina spp.
NODO = Nodosaria spp.
LENT = Lenticulina spp.
PLEU = Pleurostomella spp.
ENTO = entosolenians
DOLN = Dolina spp.
LAGN = Lagena spp.
FISS = Fissurina spp.
ANGL = Angulogerina sp.
UVIG = Uvigerina spp.
Aspi = Anomalinoides spissiformis (Cushman and Stainforth)
Asem = Anomalinoides semicribratus (Beckmann)
Cbrd = Cibicidoides bradyi (Trauth)
Cspp = Cibicidoides spp. ind.
Cpra = Cibicidoides praemundulus Berggren and Miller
Ceoc = Cibicidoides eocaenus (Guembel)
Csmo = Cibicidoides sp. (smooth)
Gmic = Gavelinella micra (Bermudez)
Csub = Cibicidoides subspiratus (Nuttall)
Chav = Cibicidoides havanensis (Cushman and Bermudez)
Cgrm = Cibicidoides grimsdalei (Nuttall)
Cldgo = Cibicidoides lamontdohertyi Miller and Katz
Peoc = Pullenia eocenica Cushman and Seigfus
Pqui = Pullenia quinqueloba (Reuss)
ORID = Oridorsalia spp.
Gsub = Globocassidulina subglobosa (Brady)
GOID = Gyroidinoides spp.
Nhav = Nonion havanense Cushman and Bermudez
TURR = Turrilina alsatica
FRON = Frondicularia spp.
QUIN = Quinqueloculina spp.
Numb = Nuttallides umbonifera (Cushman)
Eexg = Epistominella exigua (Brady)
Bcos = Bulimina sp. (costate)
OSAN = Osangularia mexicana (Cole)
Bhun = Bolivina huneri Howe
CASS = Cassidulina spp.
Usmo = Uvigerina sp. (smooth)
GAVL = Gavelinella capitata (Guembel)
Bmac = Bulimina macilenta Cushman and Parker
Ntrm = Nuttallides trumpyi (Nuttall)
Uhis = Uvigerina sp. (hispid)
Bsem = Bulimina semicostata
ARAG = Aragonia spp.
Prnz = Planulina renzi Cushman and Stainforth
ABYS = Abyssammina spp.
QUAD = Quadrimorphina profunda Schnitker and Tjalsma
NONI = Nonion sp.
CLIN = Clinapertina spp.
Bglm = Bulimina aff. glomarchallengeri Tjalsma and Lohmann
Btrn = Bulimina trinitatensis Cushman and Jarvis

Appendix 3-3 (Continued).

64-3	18-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	230
64,CC		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	307
65-1	31-34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	349
65-2	31-34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	213
66-2	24-27	2	0	0	0	0	0	2	0	0	0	0	5	14	0	10	0	0	22	0	0	0	0	3	345
66-3	57-60	0	0	0	0	0	0	5	0	0	0	0	3	29	0	10	4	0	2	0	0	0	0	1	297
66,CC		0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	2	0	0	0	92
67-1	40-43	0	0	0	0	0	0	0	0	0	0	0	0	7	0	7	0	0	1	0	0	0	0	0	265
67-3	36-39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	219
68-1	129-132	0	0	0	0	0	0	1	0	0	0	0	7	21	0	10	5	0	26	7	0	6	4	0	348
68-3	74-77	0	0	0	0	0	0	1	0	0	0	0	0	35	0	3	0	0	6	3	4	3	2	0	486
70-2		7	0	0	0	0	0	0	0	0	0	0	9	31	0	0	0	0	13	0	0	0	0	0	222
70,CC		0	0	0	0	0	0	1	0	0	0	0	1	8	0	11	17	0	11	3	1	0	0	0	248
71-2	42-45	12	0	0	0	0	0	2	0	0	0	0	0	8	0	0	0	0	3	0	0	0	0	0	225

TOTAL 26775

CHAPTER 4

PALEOBIOGEOGRAPHY OF AGGLUTINATED FORAMINIFERA:

INTRODUCTION:

The late Cretaceous to Paleogene was a period of transition between a circum-equatorial circulation in the Mesozoic to a more meridional circulation pattern in the Atlantic in the middle to late Cenozoic (Berggren & Hollister, 1974). In comparison with the present day North Atlantic, the late Cretaceous to Paleocene ocean was characterized by milder climates and a lower temperature contrast between the tropics and high latitudes (Haq, 1981). Equatorial circulation in the Tethyan seaway was directed from east to west, and may have moderated polar influences resulting in the early Paleogene oceans being less stratified than the present day (Johnson, 1984). The paleobiogeography of benthic foraminifera at this time was probably affected by many factors, including global climate and paleocirculation patterns. For example, low-latitude calcareous benthic foraminiferal faunas in the Atlantic reflect Tethyan influence, which affected the composition of Midway faunas (Berggren and Aubert, 1975). In the deep ocean basin, calcareous benthic assemblages can be subdivided into a middle bathyal Stensioina beccariiformis assemblage and a lower bathyal to abyssal Nuttallides truempyi assemblage (Tjalsma and Lohmann, 1983), but superimposed on the bathymetric pattern is a latitudinal differentiation of Nuttallides species.

In addition to paleoclimatic factors, the paleobiogeography of benthic foraminifera in the North Atlantic basins was influenced by regional tectonic effects, such as the relationship between depocenters and continental breakup, and opening and closing of oceanic gateways which at times prevented the migration of species. For example, in the Maastrichtian to Paleocene, the North Sea and Norwegian-Greenland Seas were isolated from the North Atlantic region by the Greenland-Scotland Ridge, which at times formed a barrier to the exchange of surface and deep waters at least until the early Eocene (Eldholm and Thiede, 1980; McKenna, 1983; Miller and Tucholke, 1983; Berggren and Schnitker, 1983). Intermittent shallow marine connections between the North Sea and the northern margin of the Tethys seaway existed across central Europe via the Danish-Polish Trough (Pozaryska, 1981; Ziegler, 1982; McKenna, 1983), but this passageway served as a filter for deeper dwelling species. With the closing of deep-water passageways in the eastern Tethys in the late Eocene

(Pomerol and Premoli-Silva, 1986), Mediterranean deep-water faunas became isolated from the Indo-Pacific region.

Compared with planktonic and calcareous benthic foraminifera, relatively little is known about the paleobiogeography of flysch-type agglutinated foraminifera or their response to environmental changes in the Paleogene. The revision of the taxonomy of flysch-type agglutinated species from Trinidad now enables an interregional comparison of agglutinated species from circum-North Atlantic and Tethyan regions (Table 4-1). For comparative purposes, I have examined agglutinated assemblages from the Labrador Sea, North Sea, Norwegian-Greenland Sea, West Greenland, Trinidad, Jamaica, Poland, Spain, and Morocco in order to conduct a survey of species based on a standardized taxonomy. Many of the 200+ species found at the Paleogene localities listed in table 4-1 are cosmopolitan, but some faunal provinciality is evident among deep-water agglutinated assemblages from the North Atlantic and Tethys. Provinciality is manifested by differences in species diversity, the presence of endemic species or disjunct stratigraphic ranges in different areas and in the relative proportions of certain genera or species groups. A comparison of the assemblages of these regions follows below.

SAMPLE LOCALITIES:

The sample base for the Paleocene consists of exploration well samples from the Guayaguayare Beach Field of Southern Trinidad, the Labrador Margin, the central Viking Graben, and the Zumaya Flysch in Northern Spain (von Hillebrandt, 1965; this study). Spot samples were examined from the Blatt Arba Ayocha section in the external Tangier Unit of the Rif Mountains of eastern Morocco provided by Wolfgang Kuhnt (Tubingen). These samples are from the noncalcareous claystones of Pelitic Series III of Kuhnt (1987), which was deposited in a basin plain environment. Spot samples were also examined from Paleocene flysch sediments in Jamaica, collected by Garry D. Jones (UNOCAL). Microfossil data were compiled from the Schlieren flysch of the Swiss Alps (Winkler, 1984), the Wienerwald flysch in the Austrian Alps (Grun et al., 1964) and the Polish Carpathians (Jurkiewicz, 1967; Jednorowska, 1975; Kaminski et al., in press, a). In the abyssal equatorial Atlantic, data were compiled from DSDP Sites 368 (Krasheninnikov and Pflaumann, 1977) and 543A (Hemleben and Troester, 1984). Spot samples from Sites 543A and 368 were

Table 4-1. A checklist of Paleogene species from Atlantic and Tethyan localities studied.

SPECIES	TR	PL	RF	ZU	LA	647	NS	WG	NGS
ASTRORHIZACEA Brady, 1881									
Bathysiphon gerochi Mjatliuk		XX							
Bathysiphon microrhaphidus Samuel	XX	XX			XX		XX		
Bathysiphon sp [1]	XX	XX	XX	XX	XX	XX	XX	XX	XX
Dendrophrya ex gr. *excelsa* Grzybowski	XX	XX	XX	XX		XX	XX		XX
Dendrophrya latissima Grzybowski	XX	XX					XX		XX
Dendrophrya robusta Grzybowski		XX		XX	XX		XX	XX	XX
Lagenammina grzybowskii (Schubert)	XX	XX	XX		XX	XX			XX
Rhabdammina cylindrica Glaessner [2]		XX							
Rhabdammina ex gr. *discreta* Brady	XX	XX	XX	XX	XX	XX	XX	XX	XX
Rhabdammina subdiscreta Grzybowski [3]		XX							
Rhizammina grzybowskii Liszka & Liszkowa	XX	XX	XX	XX			XX		
Rhizammina indivisa Brady [4]	XX	XX	XX	XX	XX	XX	XX	XX	XX
Psammosphaera fusca Schultze		XX		XX	XX		XX		XX
Psammosphaera scruposa (Berthelin)	XX	XX	XX		XX		XX		XX
Psammosphaera testacea Flint	XX					XX			
Saccammina complanata (Franke)	XX	XX	XX		XX	XX	XX	XX	XX
Saccammina placenta (Grzybowski) [5]	XX	XX	XX	XX	XX	XX	XX		
Saccammina sphaerica Brady		XX							
Saccamminoides carpathicus Geroch		XX							
Thurammina sp.	XX					XX	XX		
HYPERAMMINACEA Eimer and Fickert, 1899									
Hyperammina cylindrica Parr									XX
Hyperammina dilatata Grzybowski	XX	XX	XX	XX	XX		XX		
Hyperammina elongata Brady	XX	XX	XX			XX			
Hyperammina kenmilleri Kaminski						XX			
Hyperammina nodata Grzybowski		XX					XX		XX
Hyperammina rugosa Verdenius & Van Hinte					XX		XX		XX
Hyperammina ex gr. *subnodosiformis* Grzybowski	XX	XX			XX	XX			XX
AMMODISCACEA Reuss, 1862									
Ammodiscus bornemanni (Reuss)		XX							
Ammodiscus cretaceus (Reuss) [6]	XX	XX	XX	XX	XX	XX	XX	XX	XX
Ammodiscus glabratus Cushman & Jarvis	XX				XX		XX		
Ammodiscus incertus (d'Orbigny)		XX							
Ammodiscus infimus Bornemann									XX
Ammodiscus latus Grzybowski		XX			XX	XX	XX		
Ammodiscus nagyi Kaminski						XX			
Ammodiscus pennyi Cushman & Jarvis	XX	XX	XX	XX					
Ammodiscus peruvianus Berry [7]	XX	XX	XX		XX		XX	XX	
Ammodiscus planus Loeblich	XX	XX			XX		XX	XX	
Ammodiscus tenuissimus Grzybowski		XX	XX						
Ammolagena clavata (Jones & Parker)	XX	XX	XX		XX	XX	XX		XX
Ammovertella sp.		XX	XX			XX			
Glomospira charoides (Jones & Parker)	XX	XX	XX	XX	XX	XX	XX	XX	XX
Glomospira diffundens (Cushman & Renz)	XX	XX	XX		XX	XX			
Glomospira glomerata (Grzybowski)	XX	XX			XX		XX		
Glomospira gordialis (Jones & Parker)	XX	XX	XX		XX	XX	XX	XX	XX
Glomospira irregularis (Grzybowski)	XX	XX	XX	XX	XX	XX	XX	XX	XX
Glomospira serpens (Grzybowski)	XX	XX	XX	XX		XX	XX		
Glomospirella grzybowskii (Jurkiewicz)		XX	XX	XX	XX				
Tolypammina sp.		XX					XX		
RZEHAKINACEA Cushman, 1933									
Rzehakina complanata (Grzybowski)		XX							
Rzehakina epigona (Rzehak)	XX	XX	XX	XX	XX	XX		XX	
Rzehakina fissistomata (Grzybowski)		XX							
Rzehakina inclusa (Grzybowski)		XX							
Rzehakina minima Cushman & Renz	XX	XX	XX				XX		
Spirosigmoilinella sp. (of Verdenius & Van Hinte)									XX
Spirosigmoilinella compressa Matsunaga [9]						XX	XX		XX

Table 4-1 (Continued).

SPECIES	TR	PL	RF	ZU	LA	647	NS	WG	NGS
HORMOSINACAE Haeckel, 1894									
Aschemonella ex gr. *grandis* (Grzybowski)	XX	XX	XX	XX	XX	XX	XX		XX
Aschemonella carpathica Neagu		XX							
Hormosina excelsa Dylazanka		XX			XX	XX	XX		
Hormosina ovuloides (Grzybowski)	XX	XX	XX	XX					XX
Hormosina ovulum ovulum (Grzybowski)	XX	XX	XX	XX	XX	XX	XX		
Hormosina ovulum gigantea Geroch	XX	XX			XX				
Hormosina trinitatensis Cushman & Renz	XX	XX							
Hormosina sp. Gradstein & Berggren				XX					
Kalamopsis grzybowskii (Dylazanka)	XX	XX	XX	XX		XX		XX	
Nodellum velascoensis (Cushman)	XX	XX	XX	XX	XX		XX		
aff. *Reophax bacillaris* Brady					XX		XX		
Reophax distans Brady			XX			XX			
Reophax duplex Grzybowski	XX	XX	XX	XX	XX		XX		
Reophax elongatus Grzybowski		XX	cf						
Reophax globosus Sliter	XX		XX		XX				
Reophax guttifer Brady		XX				XX			XX
Reophax pilulifer Brady		XX	XX	XX	XX		XX	XX	XX
Reophax splendidus Grzybowski		XX	XX	XX					
Reophax subfusiformis Earland emend Hoglund	XX		XX		XX		XX	XX	XX
Reophax subnodulosus Grzybowski		XX				XX			XX
Reophax sp. 2	XX								
Reophax sp. Gradstein & Berggren								XX	
Subreophax pseudoscalaria (Samuel)	XX	XX	XX						
Subreophax scalaria (Grzybowski)	XX	XX	XX	XX	XX	XX	XX		XX
LITUOLACEA de Blainville, 1827									
Adercotryma sp. 1							XX		XX
Ammobaculites agglutinans (d'Orbigny)		XX			XX				
Ammobaculites deflexus (Grzybowski)		XX	XX		XX				
Ammobaculites fontinensis (Terquem)		XX							
Ammobaculites jarvisi Cushman & Renz	XX	XX							
Ammobaculites problematicus Neagu		XX			XX				
Ammobaculites wazaczi (Grzybowski)		XX							
Ammobaculites aff. *polythalamus* Loeblich					XX	XX	XX		XX
Ammobaculites sp. 1	XX						XX		
Ammobaculites sp. 2	XX		XX						
Ammobaculites sp. 3	XX				XX				
Ammomarginulina sp. G		XX			XX				
Ammoscalaria spp. ind.			XX				XX		
Budashevaella cf. *multicameratus* (Voloshinova & Budasheva)	XX				XX		XX	XX	XX
Budashevaella trinitatensis (Cushman & Renz)	XX				XX		XX		
Cribrostomoides scitulus (Brady)		XX	XX				XX	XX	
Cribrostomoides trinitatensis Cushman & Jarvis	XX	XX	XX						
Cribrostomoides sp. 1 Gradstein & Berggren							XX		
Cribrostomoides spp. ind.			XX	XX	XX	XX			XX
Haplophragmoides compressa LeRoy									XX
Haplophragmoides eggeri Cushman		XX		XX	XX		XX	XX	XX
Haplophragmoides excavatus Cushman					XX				XX
Haplophragmoides cf. *glabra* Cushman & Waters	XX				XX		XX		
Haplophragmoides horridus (Grzybowski)	XX	XX	XX	XX					
Haplophragmoides "kirki" Wickenden		XX			XX		XX		XX
Haplophragmoides lamella (Grzybowski)	XX	XX					XX		
Haplophragmoides mjatliukae Maslakova		XX							
Haplophragmoides porrectus Maslakova	XX	XX				XX			
Haplophragmoides retroseptus (Grzybowski)	XX	XX	XX		XX				
Haplophragmoides stomatus (Grzybowski)		XX							
Haplophragmoides subglobulosus (Grzybowski)		XX							
Haplophragmoides ex gr. *suborbicularis* (Grzybowski)	XX	XX			XX		XX		
Haplophragmoides walteri (Grzybowski)	XX	XX	XX	XX	XX	XX	XX	XX	XX
Haplophragmoides sp. (coarse)				XX					

Table 4-1 (Continued).

SPECIES	TR	PL	RF	ZU	LA	647	NS	WG	NGS
Haplophragmoides (?) jarvisi (Thalmann)	XX						XX		
H. walteri/H(?). jarvisi transitional form	XX		XX	XX					
Haplophragmium sp. Gradstein & Berggren				XX	XX		XX	XX	
Labrospira pacifica Krashenninikov	XX	XX			XX	XX	XX		
Lituotuba lituiformis (Brady)	XX	XX	XX	XX	XX	XX	XX		XX
Phenacophragma beckmanni Kaminski & Geroch	XX	XX							
Phenacophragma elegans Kaminski	XX			XX					
Recurvoides contortus Earland									XX
Recurvoides deflexiformis (Noth)	XX	XX		XX	XX		XX	XX	XX
Recurvoides gerochi Pflaumann	XX	XX		XX	XX		XX		
Recurvoides globulosus Jednorowska		XX							
Recurvoides imperfectus Hanzlikova	XX	XX							
Recurvoides pseudoregularis Mjatliuk		XX							
Recurvoides cf. subturbinatus (Grzybowski)	XX	XX							
Recurvoides ex gr. walteri (Grzybowski)		XX	XX	XX	XX	XX	XX		
Recurvoides varius Mjatliuk		XX							
Recurvoides sp, 1.	XX								
Recurvoides sp, 2	XX			XX					
Recurvoides spp. ind.			XX			XX			XX
Sphaerammina gerochi Hanzlikova	XX	XX		XX		XX			
Sphaerammina subgaleata (Vasicek)		XX			XX				
Trochamminoides acervulatus (Grzybowski)		XX		XX		XX			
Trochamminoides dubius (Grzybowski)	XX	XX		XX					
Trochamminoides elegans (Rzehak)		XX							
Trochamminoides heteromorphus (Grzybowski)		XX							
Trochamminoides intermedius (Grzybowski)		XX							
Trochamminoides irregularis White	XX	XX	XX	XX	XX	XX			
Trochamminoides mitratus (Grzybowski)		XX							
Trochamminoides proteus (Karrer)	XX	XX				XX			
Trochamminoides subcoronatus (Grzybowski)	XX	XX	XX	XX	XX	XX	XX		
Trochamminoides subtrullisatus (Grzybowski)		XX			XX		XX		
Trochamminoides vermetiformis (Grzybowski)		XX							
LOFTUSIACEA Brady, 1884									
Reticulophragmium amplectens (Grzybowski)		XX	XX		XX	XX	XX		XX
Reticulophragmium garcilassoi sensu stricto (Frizzel)			XX						
Reticulophragmium cf. *garcilassoi* (Frizzel)	XX								
Reticulophragmium paupera Chapman							XX		
Reticulophragmium sp. (evolute)						XX			
Cyclammina sp aff *C. acutidorsata* (Hantken)									XX
Cyclammina placenta (Reuss)					XX	XX	XX		
Cyclammina rotundidorsata (Hantken)		XX			XX		XX		
SPIROPLECTAMMINACEA Cushman, 1927									
Spiroplectammina aff. *S. dentata* (Alth)	XX	XX		XX	XX		XX	XX	
Spiroplectammina excolata Cushman	XX	XX	XX						
Spiroplectammina isrealskyi Hillebrandt		XX	XX	XX					
Spiroplectammina navarroana (Cushman)	XX	XX		XX	XX	XX	XX	XX	XX
Spiroplectammina spectabilis s.l. (Grzybowski)	XX	XX	XX	XX	XX	XX	XX	XX	XX
Spiroplectammina cubensis (Cushman & Bermudez)						XX			
TROCHAMMINACEA Schwager, 1877									
Ammosphaeroidina pseudopauciloculata (Mjatliuk)	XX	XX	XX		XX	XX	XX		XX
Conotrochammina whangaia Finlay	XX								
Cystammina aff. pauciloculata (Brady)		XX		XX			XX		XX
Praecystammina globigerinaeformis Krashenninikov						XX	XX		
Trochammina altiformis Cushman & Renz	XX	XX	XX	XX	XX		XX		XX
Trochammina bulloidiformis Grzybowski		XX							
Trochammina deformis Grzybowski		XX	XX		XX	XX	XX	XX	
Trochammina aff globigeriniformis Parker & Jones		XX	XX		XX		XX	XX	XX
Trochammina quadriloba (Grzybowski)		XX					XX		
Trochammina ruthven murrayi Cushman & Renz	XX				XX		XX		
Trochammina subvesicularis Hanzlikova		XX					XX		

Table 4-1 (Continued).

SPECIES	TR	PL	ZU	LA	647	NS	WG	NGS
VERNEUILINACEA Cushman, 1911								
Gaudryina ex gr. *cretacea* (Karrer)	XX			XX				
Gaudryina ex gr. gigantea Subbotina						XX		
Gaudryina pyramidata Cushman	XX	XX	XX					
Gaudryina rugosa d'Orbigny		XX						
Gaudryina spp. ind.			XX		XX	XX	XX	
Verneuilinoides polystrophus (Reuss)	XX	XX			XX			
ATAXOPHRAGMIACEA Schwager, 1877								
Arenobulimina americana Cushman				XX	XX			
Arenobulimina dorbignyi (Reuss)	XX	XX	XX	XX		XX		
Arenobulimina truncata (Reuss)	XX	XX						
Bigenerina sp.					XX			
Clavulinoides amorpha (Cushman)	XX	XX	XX					
Clavulinoides aspera (Cushman)	XX	XX	XX					
Clavulinoides globulifera (ten Dam & Sigal)	XX		XX	XX				
Clavulinoides paleocenica (Tjalsma & Lohmann)	XX							
Clavulinoides trilatera (Cushman)	XX		XX					
Clavulinoides sp.					XX			
Dorothia beloides Hillebrandt	XX	XX	XX					
Dorothia indentata (Cushman & Jarvis)	XX	XX						
Dorothia oxycona (Reuss)	XX	XX	XX	XX				
Dorothia princeps Cushman & Bermudez								XX
Dorothia trinitatensis (Cushman and Jarvis)	XX		XX					
Dorothia trochoides (Marsson)		XX						
Dorothia cf. *trochoides* (Marsson)	XX							
Dorothia retusa (Cushman)	XX	XX	XX	XX				
"*Dorothia* sp. 6" Gradstein & Berggren				XX				
Eggerella palmerae (Cole)		XX						
Eggerella propinqua Brady		XX						
Eggerella trochoides (Reuss)	XX		XX					
Karreriella chapapotensis (Cole)					XX			
Karreriella coniformis (Grzybowski)	XX	XX			XX	XX		
Karreriella conversa (Grzybowski)	XX	XX	XX	XX	XX	XX	XX	XX
Karreriella horrida Mjatliuk	XX	XX	XX	XX	XX	XX	XX	
Karreriella lenis (Grzybowski)		XX						
Karreriella siphonella (Reuss)						XX		XX
Karreriella tenuis (Grzybowski)	XX	XX						
Karreriella sp. 2	XX							
Matanzia varians (Glaessner)	XX	XX	XX	XX		XX		
Uvigerinammina jankoi (Majzon)		XX		XX				
TEXTULARIACEA Ehrenberg, 1839								
Textularia sp. Cushman & Renz	XX							
Siphotextularia sp.					XX			

Trinidad data (TR) are from Kaminski *et al.* (in press, a). Data from Zumaya, Spain (ZU) are from this study. Data from Labrador Margin (LA) are from this study. Data from Labrador Sea Sites 112 and 647 are from Kaminski et al. (in press, d). Western Carpathian data (PL) are compiled from modern Polish and Czechoslovakian literature (Geroch, 1960; Jednorowska, 1968, 1975; Hanzlikova, 1972, 1973, 1983; Huss, 1966; Samuel, 1977; Morgiel and Olszewska, 1981; Geroch and Nowak, 1984; Liszkowa and Morgiel, 1984; Olszewska, 1985). West Greenland (WG) and North Sea (NS) data are from Gradstein and Berggren (1981), Gradstein *et al.* (in press), and Kaminski *et al.* (in press, d) supplemented by additional observations. Norwegian-Greenland Sea (NGS) species are from Verdenius and Van Hinte (1983) and this study.

Taxonomic notes: [1] includes *Bathysiphon filiformis*, *B. eocenica*, and *B. nodosariiformis*. [2] includes *Rhabdammina linearis* of Grzybowski and *Rhabdammina abyssorum* of Jurkiewicz (1967). [3] includes *Hyperammina subdiscretiformis* Mjatliuk. [4] includes forms with and without small planktonic tests incorporated in the wall, and *Protobotellina lofotensis* of Verdenius and Van Hinte (1983). [5] includes *Saccammina rhumbleri*. [6] includes *Ammodiscus siliceus* and *A. angustus*. [7] includes *Ammodiscus gorayskii*. [8] includes *Glomospirella biedai*. [9] includes *Rzehakina* sp. 1 of Gradstein and Berggren (1981). [10]. includes *Textularia plummerae* and *Spiroplectammina lanceolata*. [11] includes forms also designated as *Dorothia crassa* in Carpathian literature. [12] includes forms also described as *Karreriella apicularis* in Carpathian literature and in Gradstein and Berggren (1981).

collected to provide additional data on the occurrences of species and estimates of faunal abundance and diversity.

Eocene to Oligocene flysch-type assemblages are present in Leg 38 and Leg 104 sites in the Norwegian-Greenland Sea (Verdenius and Van Hinte, 1983; this study), the Beaufort Sea (Young and McNiel, 1984; Dixon et al., 1985), Sites 112 and 647 in the southern Labrador Sea (Kaminski et al., in press, d), the Eocene of the Rif-Betic Flysch (Morgiel and Olszewska, 1980; W. Kuhnt, personal communication), the upper Lizard Springs Formation of Trinidad (Kaminski et al., in press, a), and the Eocene of the Alpine Mountain Belt from Switzerland to Rumania. Assemblage data from Poland were compiled from Jurkiewicz (1967), supplemented by additional observations. Data from the Austria were compiled from Grun et al., (1964), and supplemented by sample material collected from the Buntmergelserie of the Helvetic Zone of the Alps in the Steinbauergraben of Upper Austria (Rogl, 1986). Data from the Schlieren flysch of the Swiss Alps were compiled from Winkler (1984). Assemblages from these localities were examined to determine biostratigraphic and geographic patterns in species diversity, the presence of endemic taxa, and the relative proportions of supra-generic groups.

Neogene agglutinated assemblages were recovered at ODP Site 645 in Baffin Bay, Site 646 in the Labrador Sea, and in the TEXACO Blue-H28 well on the Labrador Margin (Kaminski et al., in press, c). Additional data were compiled from Norwegian-Greenland Sea Sites 338, 344, 345 and 348 from Verdenius and Van Hinte (1983), Berggren and Schnitker (1983) and from Leg 38 site reports (Talwani, Udintsev et al., 1976).

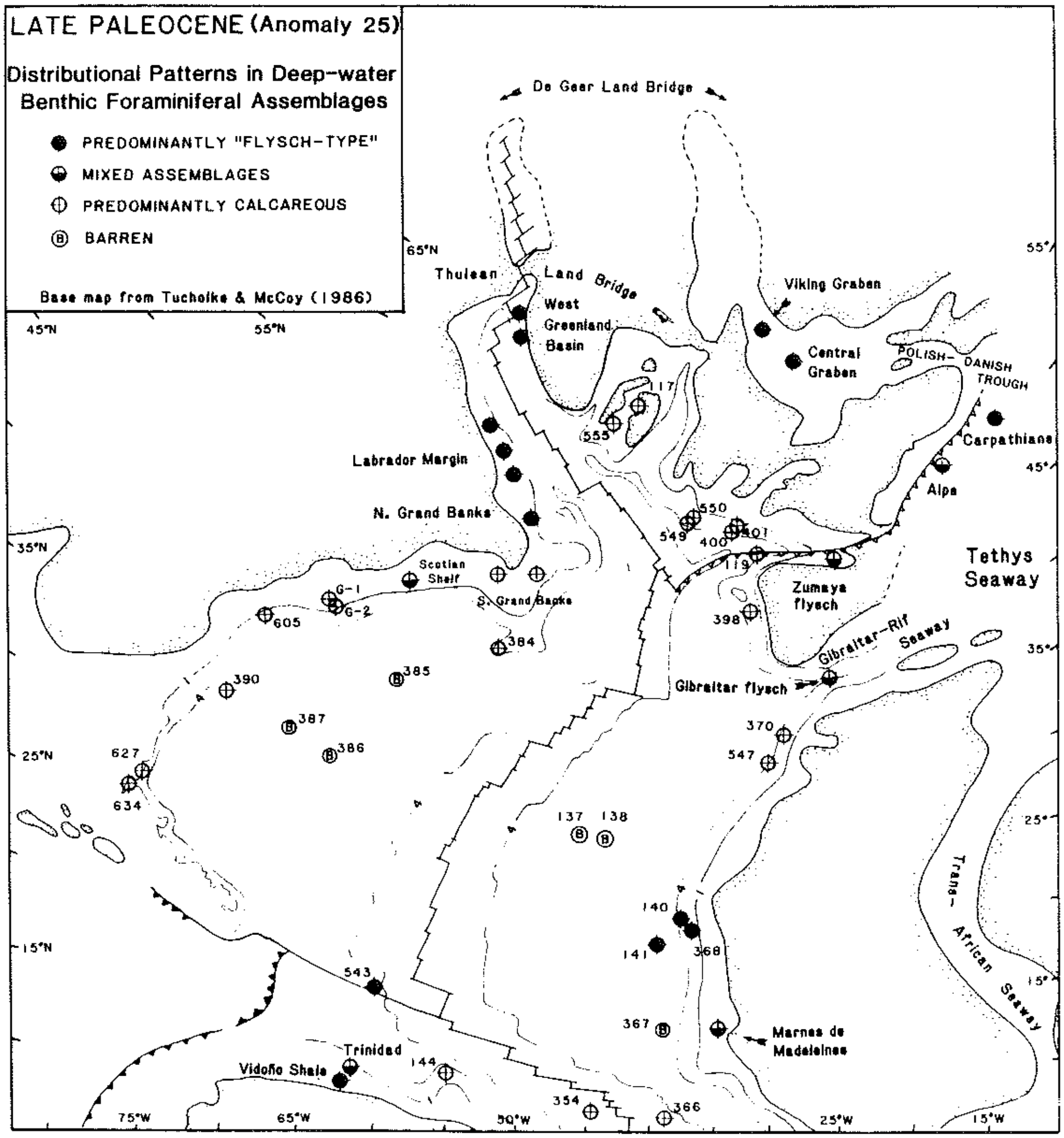
A. PALEOCENE PALEOBIOGEOGRAPHY:

In the late Maastrichtian and Danian, vertical and latitudinal temperature gradients were low, with surface water temperatures averaging 16°C and bottom water 10 - 12°C in the South Atlantic (Shackleton et al. 1984). Paleocene bottom water temperature from paleodepths of 1000-3500 m in the Atlantic varied by only 2-3°C through time and by about 2°C from the equator to 50°N (Boersma and Primoli-Silva, 1983). The homogeneous water mass resulting from comparatively low thermal gradients in the western North Atlantic has been suggested as a probable cause for the lack of discrete, paleobathymetrically confined benthic foraminiferal assemblages in the Danian (Tjalsma & Lohmann, 1983). By contrast, in the mid-Paleocene equatorial regions and their associated current systems underwent a pronounced warming, and warm water was carried to nearly 40°N (Boersma, 1984). Later in the Paleocene and early Eocene, surface water temperatures were higher than at any other time in the Cenozoic, and deep-water temperatures increased by as much as 4°C in the South Atlantic (Oberhansli et al., 1984) and 6°C in the Pacific (Miller et al., in press). The increase in thermal gradients and increased water column stratification may have led to the restriction in paleobathymetric patterns in deep-water benthic taxa observed by Tjalsma and Lohmann (1983).

In the Paleocene, flysch-type assemblages are widespread in slope basins along the Atlantic margins from Trinidad to the northern Labrador Sea. The distribution of flysch-type foraminiferal assemblages in the North Atlantic and adjacent seas is shown in figure 4-1. These faunas traverse a range of latitudes, and Tethyan and Boreal end member assemblages can be clearly recognized. A meridional diversity gradient is also observed, with 102 species occurring in the Lizard Springs Formation of Trinidad (Kaminski et al. 1987) and around 80 species occurring in Zumaya, Spain. In contrast, Paleocene assemblages from exploration wells in the Labrador and North Seas contain about 60 species. The lowest species diversity is found beneath the oceanic CCD. Paleocene assemblages at Sites 543A and 368 are depauperate, with only about 20 species. Main features of the agglutinated assemblages in each area studied are summarized in Table 4-2.

The availability of calcium carbonate appears to be a major factor controlling the diversity of generic groups with calcareous cement. The calcareous ataxophragmiids (Arenobulimina, Clavulinoides, Dorothia and Gaudryina) are more typical of low latitude assemblages in carbonate environments. These forms are locally abundant in Trinidad and Zumaya, and commonly occur in marly units in the Carpathians. However, the calcareous ataxophragmiids are rare above the Maastrichtian on the Labrador Margin, and in the North Sea their probabilistic last occurrence is near the top of the Danian chalk unit. It is not yet clear whether their paucity in the high-latitude basins reflects differences in temperature. No calcareous ataxophragmiids were found in the abyssal assemblages of Site 543A or in the noncalcareous shales from the Tangier Unit of Morocco.

Provinciality among noncalcareous agglutinated taxa is evident mainly among rzehakinids and loftusiids. The rzehakinids are profusely abundant in



4-1. Distribution of agglutinated, calcareous and mixed benthic foraminiferal assemblages in the North Atlantic in the late Paleocene. Data is compiled from Site reports, personal observations, and personal communication with J.P. Beckmann, W.A. Berggren, S. Gofas, W. Kuhnt, R.M. Leckie, H.P. Luterbacher, K.G. Miller, L.E. Ostermann, C.W. Poag, A. von Hillebrandt, and M.A. Williamson. Plate reconstruction is after Tucholke and McCoy (1986).

Table 4-2. Main features of Paleocene and lower Eocene assemblages. Numbers in boxes refer to numbers of species represented at each locality.

PALEOCENE FLYSCH-TYPE ASSEMBLAGES

TRINIDAD	ZUMAYA	NORTH SEA	LABRADOR MARGIN
100	83	~40	~40
This study	This study	This study	This study
Abundant calcareous ataxophragmiids, Rzehakina and Trochamminids	Abundant calcareous ataxophragmiids & lituolids. Few Rzehakina	Abundant tubular forms, lituolids, & ammodiscids. Common Spiroplectammina Few calcareous ataxophragmiids, Rzehakina	Abundant tubular forms & lituolids. Few ammodiscids, Rzehakina, spiroplectamminids and calcareous ataxophragmiids
Characteristic forms: H(?). jarvisi, P. elegans, T. ruthven-murrayi, L. pacifica, C. whangaia	Characteristic forms: P. elegans, H.walteri/H(?). jarvisi	Charact. forms: L. pacifica, A. aff. polythalamus, R. paupera, Praecystammina R. aff. garcilassoi, T. ruthven-murrayi	Characteristic forms: Ammob. aff. polythalamus, T. ruthven-murrayi
RIF MOUNTAINS (Tangier Unit)	**SWITZERLAND (Schlieren flysch)**	**AUSTRIA (Wienerwald flysch)**	**POLAND (Central Carpathian Depression)**
50	61	42	95
This study	(Winkler, 1984)	(Grün et al., 1964)	(Jurkiewicz, 1967; Jednorowska, 1975)
Abundant tubular forms, lituolids, & ammodiscids. Few calcareous ataxophragmiids, Rzehakina	Abundant tubular forms, lituolids, & ammodiscids. Few Rzehakina, no calcareous ataxophragmiids,	Abundant tubular forms, common Trochamminoides. Rare Ammodiscids and Rzehakina. No calcareous ataxophragmiids	Abundant tubular forms, common Ammodiscus, hormosinids, lituolids and Rzehakina. Few calcareous ataxophragmiids. No loftusiids
Characteristic species: R. garcilassoi (s.s.)	Characteristic forms: Rzehakina fissistomata	Characteristic species: Rzehakina fissistomata	Characteristic species: Rzehakina fissistomata

EARLY EOCENE FLYSCH-TYPE ASSEMBLAGES

TRINIDAD	NORTH SEA	LABRADOR MARGIN	LABRADOR SEA (ODP SITE 647)
50			45
This study	This study	This study	This study
Abundant tubular species and Trochamminoides No noticeable Glomospira facies	Sparse assemblages in tuff and underlying sands. Level with Trochamminoides above Tuff Horizon	Sparse assemblages in Gudrid Sands. Common lituolids and loftusiida above. Level with Glomospira in offshore wells	Level with common Dendrophrya & Trochammoides. in NP11-NP12 Glomospira facies in NP13-NP15. H.ovulum persists until Glomospira facies.
Characteristic species: P. testacea	Characteristic species: H(?). jarvisi, A. aff. polythalamus	Characteristic species: A. aff. polythalamus, C. placenta	Characteristic species: A. nagyi, H. kenmilleri
RIF MOUNTAINS (Tangier Unit)	**SWITZERLAND (Schlieren flysch)**	**AUSTRIA**	**POLAND**
~25	44	27	~55
(This study, Morgiel & Olszewska, 1982)	(Winkler, 1984)	(Grün et al., 1964)	(Jurkiewicz, 1967)
Glomospira facies	Glomospira facies (NP10-NP12) above the Guber Sandstone. Decrease in Rhabdammina & Rhizammina, increase in Dendrophrya and Trochamminoides above Glomospira horizon No Spiroplectammina, ataxophragmiids, Rzehakina	Barren interval in upper Paleocene-lower Eocene Greifenstein Sandstones. Glomospira facies in overlying pelitic layers. Less common unilocular & tubular spp, lituolids. No ataxophragmiids, loftusiids. Increase in Trochamminoides above max. Glomospira abundance.	Glomospira facies in all tectonic units. Increased Trochamminoides only in deeper (basinal) facies. Fewer Ammodiscus, Kalamopsis, Karreriella, and tubular spp. No calc. ataxophragmiids or loftusiids. Characteristic species: Sacc-oides carpathicus

Trinidad, where they are represented by two species (Rzehakina epigona and Rzehakina minima). These species occur only rarely at other Atlantic localities. Paleocene flysch sediments in the Carpathians (Geroch and Nowak, 1984) and Alps (Winkler, 1984) contain R. fissistomata, which may be a geographic (Tethyan) variant of R. epigona. This taxon has been given species or subspecies status by various authors, and has not been unequivocably identified outside the Carpathians. Another Paleocene species that appears to be restricted to Trinidad and Zumaya is Phenacophragma elegans.

The most restricted geographic patterns are exhibited by the primitive cyclamminids. The evolution of alveolar structures apparently occurred rapidly in the Paleocene among several lineages in different areas. Although the taxonomy of the early species of Reticulophragmium is still poorly understood, it appears that the North Sea contained two or more species (Reticulophragmium paupera and R. cf garcilassoi) which are not found at low-latitude localities. Deltaic assemblages from the Paleocene Moose Channel Formation of the Mackenzie Delta (Young and McNeil, 1984, Dixon et al., 1985) and from the Selandian of Spitsbergen (J. Nagy, personal communication 1986) contain additional species with alveolar wall structure. In the Atlantic, Reticulophragmium-type features began to appear in the Haplophragmoides walteri lineage in the early Selandian, giving rise to ?Haplophragmoides jarvisi in Zone P5. By the end of the Paleocene, specimens of ?H. jarvisi from exploration wells on the Angola Margin displayed true alveoles, but this species is not found above the Paleocene/Eocene Boundary in low latitudes. The low latitude assemblages contain at least two different species of Reticulophragmium in the Paleocene of Trinidad, Venezuela, and Morocco but their taxonomic affinities are still poorly understood. One of these species, R. garcilassoi (sensu stricto) displays "advanced" morphological features already in the mid-Paleocene in Morocco. For unknown reasons, primitive cyclamminids and H(?). jarvisi do not occur in the Carpathians and are rare on the Labrador Margin.

The Paleocene/Eocene Boundary:

A major turnover in the composition of North Atlantic benthic foraminiferal assemblages occured in Zone P6a. Tjalsma and Lohmann (1983) noted extinctions and depth migrations of calcareous benthics in DSDP sites in the western Atlantic near the Paleocene/Eocene boundary. This turnover was no doubt due to a combination of factors, including a lowering of sea level, reduced oceanic primary productivity, and decreased thermal gradients due to warming of deep waters. Carbon isotopic evidence points to increased oxygenation of deep water across the boundary (Shackleton, 1986). The development of more oligotrophic conditions and loss of niche space may have contributed to disappearances of flysch-type taxa in low-latitude assemblages. In Trinidad and Zumaya, about 80% of Paleocene species disappeared at the end of Zone P5, and early Eocene assemblages were dominated by calcareous benthic taxa. Agglutunated foraminifera disappear entirely from abyssal DSDP sites in the equatorial Atlantic.

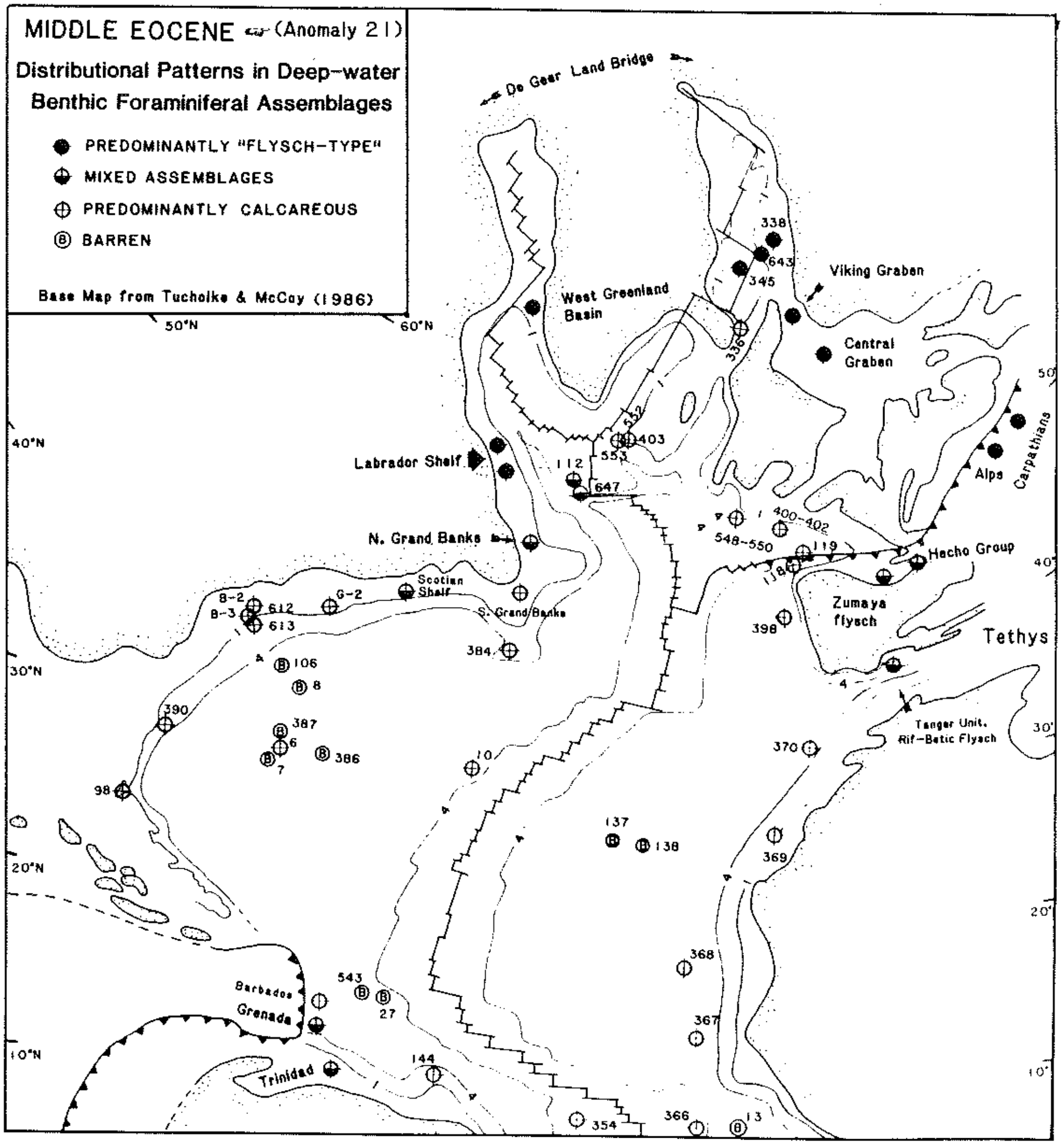
The Paleocene/Eocene turnover among agglutinated foraminifera is not as pronounced in the high-latitude basins, but is still easily recognized by the loss of a number of species. In the North Sea, the Paleocene/Eocene transition is represented by a zone of low foraminiferal abundance in the North Sea tuff sequence. In Labrador Margin wells, the lower Ypresian Gudrid Sands produce a similar effect. In these sections, the Paleocene/Eocene boundary is characterized by the loss of the remaining calcareous ataxophragmiids (Clavulinoides, Gaudryina, Matanzia) and the genera Hormosina, Glomospirella, and Rzehakina.

EOCENE PALEOBIOGEOGRAPHY:

The Eocene period witnessed the change from a sluggish, salinity-driven deep circulation pattern to vigorous, thermohaline circulation driven by cooling at high latitudes. After the early Eocene temperature maximum, deep waters underwent a series of stepwise coolings culminating in the ice growth/cooling event of the basal Oligocene, when deep waters were probably as cool as they are today (Miller et al., 1987). At the same time, changes in global sea level, surface water productivity, the carbonate lysocline, and oceanic circulation patterns affected the sedimentologic record in the North Atlantic to a much greater extent in the Eocene than in preceding times when sediments at abyssal sites consisted predominantly of variegated clays. In the Eocene of the equatorial Atlantic, abyssal agglutinated assemblages were no longer preserved beneath the oceanic CCD. In Hole 543A, the disappearance of agglutinated assemblages coincides with the change from Paleocene variegated claystones to Eocene biosiliceous sediments (Hemleben and Troester, 1985; this study). Eocene radiolarites in the western North Atlantic basin are barren of all foraminifera. During the Eocene, bathyal flysch-type assemblages became restricted mainly to high latitudes and areas of the continental margins of the North Atlantic and Tethys which experienced clastic sedimentation. The persistance of bathyal flysch-type assemblages in high-latitude basins may reflect the northward "unzippering effect" of atlantic sea-floor spreading, since rapid subsidence and clastic deposition in sedimentary basins took place during the rifting and early spreading stages. Figure 4-2 shows the distribution of flysch-type assemblages in the Eocene, and main features of these assemblages are summarized in Tables 4-2 and 4-3.

The lowermost Eocene sediments in Austria, Switzerland, Poland, Zumaya and on the Labrador Margin are often represented by sands which are either barren or have sparse agglutinated assemblages. Similarly, North Sea wells contain both sands and ash layers with poor assemblages. Above the ubiquitous sparse interval, certain similarities between lower Eocene agglutinated assemblages are observed throughout the Atlantic and Mediterranean Tethys. Although faunas vary in diversity and species composition from region to region, two basic faunas are observed: one with common Trochamminoides, and a second with abundant Glomospira.

The low-latitude end member of the lower Eocene faunas is represented in the upper Lizard Springs Formation of Trinidad, where the total diversity of agglutinated taxa is about 50 species. These assemblages are characterized by large numbers of the genus Trochamminoides. This genus was presumably well adapted to the more oxygenated deep-water conditions reflected by the widespread development of red clay facies throughout the Atlantic and by the carbon isotope record of Shackelton (1986). The upper Lizard Springs Formation contains several species of this group as well as a number of astrorhizids which build their wall out of small planktonic tests. In the Zumaya section, Trochamminoides is one of the few forms to survive the Paleocene/Eocene boundary event. The lower Eocene red clays in the Magura Flysch of Poland contain assemblages that are numerically dominated by this genus (Morgiel and Olszewska, 1981). In the North Sea, red sediments with Trochamminoides occur near the top of the ash unit deposited during the Anomaly 23-24 rifting phase in the Norwegian-Greenland Sea, but this genus is not as common in the North Sea as in low latitudes. Trochamminoides does not occur in lower Eocene assemblages on the Labrador Margin. The Trochammininoides assemblage in the North Sea may reflect the early Eocene



4-2. Paleobiogeography of Eocene benthic foraminiferal biofacies. Data sources are the same used for figure 4-1.

Table 4-3. Main features of Middle Eocene and Oligocene assemblages. Numbers in boxes are numbers of species recognized at each locality.

MIDDLE EOCENE FLYSCH-TYPE ASSEMBLAGES

NORTH SEA	LABRADOR MARGIN	LABRADOR SEA	VØRING SLOPE
~25 This Study	30 This Study	51 This Study	38 This Study
Common D. robusta, Rhabdammina, Ammodiscus, H. walteri, R. amplectens, K. horrida, C. placenta Few S. spectabilis. Characteristic spp: C. placenta, Dorothia sp. 6, H?. jarvisi, Adercotryma sp. 1.	Abundant R. walteri, C. placenta, H. walteri/excavatus, and R. amplectens. Common Cribrostomoides, Budashevaella, K. horrida, Ammosphaeroidina, Trochammina. Few ammodiscids, hormosinids & tubular spp. S. spectabilis disappears from Labrador Margin. Charact. spp: Dorothia sp 6, C. placenta, B. trinitatensis, Ammomarginulina sp. G.	Mixed calc.-aggl. faunas. Abundant tubular spp. Common Recurvoides, S. spectabilis, R. amplectens, Ammosphaeroidina, K. coniformis. Few Trochammina. Acme of S. spectabilis near mid/late Eocene boundary Charact. spp: P. testacea, H. distans, H. kenmilleri	Diverse lower mid Eocene fauna w/ Glomospira and deep-water benthics (Buzasina, Hormosina). Mid-upper Eocene faunas w/ common tubular spp., H. walteri, R. amplectens, Recurvoides, Spirosigmoilinella sp. 1. Few ammodiscids, Trochammina. No S. spectabilis. Charact. spp D. principiensis, Adercotryma sp. 1, Spirosigmoilinella sp. 1.
RIF MOUNTAINS	**SWITZERLAND** (upper Schlieren Sandstones)	**AUSTRIA** (Variegated Marl Series)	**POLAND**
~25	~14 (Winkler, 1984)	~20 This study	~55 (Jurkiewicz, 1967)
Common tubular spp., Recurvoides and R. amplectens	Impoverished assemblage w/ abundant Dendrophrya. Less common ammodiscids & Haplophragmoides spp. No Spiroplectammina, hormosinids or ataxophragmiids.	Impoverished assemblages with tubular spp., Recurvoides and R. amplectens	Common Dendrophrya, R. amplectens, S. spectabilis, R. walteri, R. deflexiformis, K. coniformis in basinal facies (Skole, Silesian). Fewer Recurvoides & K. coniformis in shallower facies. Characteristic spp.: P. beckmanni, Ammomarginulina sp. G

LATE EOCENE - OLIGOCENE FLYSCH-TYPE ASSEMBLAGES

NORTH SEA	LABRADOR MARGIN	LABRADOR SEA	POLAND
Late Eocene-early Oligocene assemblages with common C. placenta, Rhabdammina, D. robusta, C. rotundidorsata A. latus, Spirosigmoilinella, H. walteri, R. pilulifer. LCO flysch-type species due to mid Oligocene shallowing and calcareous sedimentation.	Late Eocene-early Oligocene assemblages with common C. placenta, A. latus, H. walteri/excavatus, D. robusta, C. rotundidorsata LCO flysch-type species due to mid Oligocene shallowing and hiatus.	Eocene assemblages with S. compressus & A. latus. Reduction in size and LO's of 32 spp. from late Eocene to early Oligocene. LO's of S. spectabilis and R. amplectens at boundary. Max. abundance of A. latus in basal Oligocene. LCO flysch-type taxa NP22	Late Eocene assemblages with common Rhabdammina A. latus, C. rotundidorsata, & R. pilulifer. S. spectabilis common in deeper (Silesian) basin. Flysch-type spp disappear within Globigerina Marls (NP19-20), owing to calc. sedimentation & shallowing of the basin.
JAN MAYEN RIDGE	**LOFOTEN BASIN**	**VØRING PLATEAU**	**VØRING SLOPE**
(Verdenius & Van Hinte, 1983; Berggren & Schnitker, 1983)			
Low diversity Eocene assemblages w/ common tubular spp. and less common R. amplectens, H. excavatus, S. spectabilis, C. placenta. Oligocene assemblages contain only tubular and unilocular spp,	Eocene assemblage w/ C. placenta, R. amplectens, and common tubular spp, P. fusca & Recurvoides Diverse Oligocene assemblage w/ Spirosigmoilinella spp., C. acutidorsata, H. walteri & K siphonella	Low diversity late Eocene assemblage w/ S. spectabilis, R. amplectens and calc. benthics (Ceratobulimina). Sparse assemblage in Oligocene w/ S. compressa and Rupelian calcareous spp.	Late Eocene assemblage w/ Rhizammina, S.compressa, Ammosphaeroidina, H. walteri, Adercotryma sp 1, Ammodiscus infimus, Karreriella siphonella, Budashevaella. LO's of 21 species near mid-Oligocene hiatus. Late Oligocene assemblage w/ R. amplectens/acutidorsata, Recurvoides, Spirosigmoilinella spp., K. siphonella. Characteristic spp: A. infimus, K. siphonella

temperature maximum, or the influx of warm waters from the Atlantic. However, for other species the North Sea served as a refuge. The persistence of ?*H. jarvisi* in the lower and middle Eocene sediments of the North Sea is evidence that faunal connections with the Atlantic were still restricted.

After early Eocene Zone NP12, bottom waters in the North Atlantic cooled approximately 2°C, (Boersma *et al*., 1987) and the CCD in the Labrador Sea shoaled to a level above 2500 m, possibly in response to a change in sea level. Condensed noncalcareous clays in Hole 647A contain a *Glomospira* assemblage. Similar glomospirid assemblages are widespread in the Alpine mountain belt (Grun *et al*., 1964, Winkler, 1984), Carpathian basins (Jurkiewicz, 1967; Morgiel and Olszewska, 1981) and in the Tangier Unit of Morocco (Morgiel and Olszewska, 1982). These assemblages are reported from the lower Eocene, and may be coeval with this event. However, the presence of endemic species such as *Saccamminoides carpathicus* in the Carpathians, and *Ammobaculites* aff. *polythalamus* and *Cyclammina placenta* in the Labrador and North Seas is evidence of continued provinciality between the Atlantic and Tethys. Marine connections via the Polish-Danish Trough probably did not allow the exchange of deep water between the North Sea and Tethyan basins in Poland.

By middle Eocene time, flysch-type assemblages disappeared from Trinidad and Zumaya, and there is only one report of an isolated occurrence of agglutinated assemblages in western North Atlantic DSDP Holes. In Hole 612, Miller and Katz (1987) found one level with abundant *S. spectabilis* in the lower Lutetian. DSDP Holes in the eastern Atlantic and bathyal assemblages from Rockall Bank contain only calcareous assemblages. Middle Eocene agglutinated assemblages in the Labrador Sea and in the northern Atlantic basins typically contain 20-50 species of agglutinated forminifera, and a north-south diversity gradient is maintained. Assemblages from Site 647 are most diverse, with about 50 agglutinated species. An intermediate number of species (~35) occur in the North Sea and in ODP Hole 643A in the Norwegian-Greenland Sea, which contains about 38 species. The least diverse assemblages are reported in the Austrian and Swiss Alps, where flysch basins probably experienced shallowing owing to continuing orogeny. Middle Eocene assemblages continue to display higher diversity in Poland, where the basins were not yet affected by orogeny.

Perhaps the most typical Eocene species in the North Atlantic is *Reticulophragmium amplectens*. This species is isobathyal and has a cosmopolitan distribution. In the Carpathians, *R. amplectens* has been found in sediments as old as Zone NP12 (Olszewska and Smagowicz, 1977). In the Atlantic, this species is found in the lower Eocene Tangier Unit of Morocco, in Zone P8 on the Labrador Margin and it occurs as early as Zone NP11 in the deep Labrador Sea. A closely related form which may be synonymous (*Cyclammina* cf. *garcilassoi* of Cushman and Renz, 1946) occurs in Zone P8 in Trinidad.

In the North Sea and Labrador Margin, the Eocene sequences display a series of last occurrences of flysch-type taxa which mainly refect the shallowing of the basins as sediment supply exceeded tectonic subsidence. Middle Eocene assemblages in the Labrador Margin wells are typically dominated by lituolids and loftusiids, with lower numbers of astrorhizids, ammodiscids and hormosinids. The most common species are *R. amplectens*, *Recurvoides* ex gr. *walteri*, and *Cyclammina placenta* along with subdominant *Ammosphaeroidina*, *Haplophragmoides walteri*, *H. kirki*, *H. excavatus*, *Karreriella horrida*, *K. conversa*, *Ammodiscus latus*, *Budashevaella* cf. *multicamerata*, *Ammobaculites* aff. *polythalamus* and *Dorothia* sp. 6. The genera *Spiroplectammina* and *Glomospira* disappear from the Labrador Margin on average in the lower Eocene, but these persist at Site 647 and in the Norwegian-Greenland Sea until the Eocene/Oligocene boundary. In the North Sea, an interesting pattern is observed in *S. spectabilis*, which extends into younger strata in northern wells. This species persists into the upper Eocene on the Vøring Plateau.

The transition from the middle to late Eocene is associated with a decrease in bottom water temperature of around ~3°C, and increased oxygenation of intermediate and deep waters (Boersma *et al*., 1987). Extinctions of warm surface-dwelling as well as cool deeper-dwelling planktonic foraminifera during the late Eocene has been interpreted as an indication of steeper latitudinal and vertical temperature gradients (Corliss *et al*. 1984; Snyder *et al*. 1984; Keller, 1985). By the late Eocene, agglutinated assemblages are restricted to Poland, Labrador, and the North Sea - Norwegian Greenland Sea area. All three regions contain the species *Ammodiscus latus* and *Cyclammina rotundidorsata*. There is evidence of endemic species particularly in the North Sea and Norwegian-Greenland Sea in the late Eocene. The Norwegian-Greenland Sea assemblages contain *Spirosigmoilinella* sp. 1 of Verdenius and Van Hinte (1983), *Karreriella siphonella*, *Dorothia* principiensis, and Adercotryma sp. 1, which are unknown in Labrador and the Carpathians. The only other reported occurrence of a robust Spirosigmoilinella species in the northern hemisphere is in the upper Eocene to Oligocene Kugmallit Formation of the Mackenzie Delta (Dixon et al., 1985).

Spirosigmoilinella compressa is found in the New Jersey Transect Sites as well as in Holes 647A, 643A and in the North Sea wells, but this species is not found in the Carpathians. For other species, though, the Carpathian basins served as a refuge. Phenacophragma beckmanni is found in the middle Eocene of the Silesian Unit in Poland, whereas it was not found above the Paleocene in Trinidad. Similarly, Glomospira, S.spectabilis and S. navarroana are common in the region until the latest Eocene, whereas they disappear much earlier from the North Sea and from bathyal assemblages on the Labrador Margin.

OLIGOCENE PALEOBIOGEOGRAPHY:

A number of paleoceanographic and paleobiogeographic changes occurred near the end of the Eocene which are known collectively as the "Terminal Eocene Event" (Wolfe, 1978; Van Couvering et al., 1981). These changes have been attributed to cool meridional circulation replacing warmer Eocene water masses (Steineck et al., 1984). An increase in benthic foraminiferal oxygen isotope values across the Eocene-Oligocene transition has been interpreted as evidence for increased ice volume and a decrease in bottom water temperature of at least 1 - 2°C (Keigwin and Corliss, 1986). The covariance between planktonic and benthic delta 18-0 records in the lower Oligocene (36, 31 and 25 Ma) led Miller and Fairbanks (1985) to suggest three periods of continental glaciation as a causual mechanism. A change in deep-water mass properties also occurred at this time. In both the Atlantic and Pacific, a major faunal abundance change among abyssal foraminifera is observed in the upper Eocene (Tjalsma and Lohmann, 1983; Miller, 1983; Miller et al., 1985; Wood et al., 1985; Thomas, 1985). Lower Oligocene benthic carbon isotope records in the western North Atlantic are enriched relative to the Pacific, suggesting a supply of nutrient-depleted deep water in the North Atlantic analogous to modern NADW (Miller and Fairbanks, 1985). The timing of the delta 13-C difference correlates with a period of increased bottom water erosion in the North Atlantic (Miller and Tucholke, 1983).

Flysch-type assemblages disappeared from the deep Labrador Sea and the Carpathian basins within one or two million years of the Eocene/Oligocene boundary. In Poland, this disappearance was abrupt and takes place within a few meters of the base of the *Globigerina* marls, which mark the sudden transition from terrigenous sedimentation to calcareous sedimentation in Zone NP19-20 (Van Couvering *et al*., 1981). About 40 species of agglutinated foraminifera occur directly beneath the marls, whereas only a few rare species of lituolids, *Rhabdammina* and *Ammodiscus* are found within the marls. Only isolated occurrences of agglutinated foraminifera are reported from the overlying lower Oligocene organic-rich siliceous sediments (Olszewska, 1985). These consist mainly of rare specimens of *Glomospira*, *Trochammina*, *Ammodiscus* and *Hyperammina* in a predominantly calcareous benthic assemblage.

In contrast to the Carpathians, the disappearance of agglutinated species in the continuous hemipelagic section recovered at Site 647 is by no means abrupt, and the last occurrences of individual taxa apparently took place over a period of several million years. At Site 647, there was a clustering of last occurrences between 36 and 37 Ma, but this did not correspond to any obvious change in sedimentation. This suggests that a change in bottom water properties was the likely cause of this faunal turnover, as suggested by Miller *et al*. (1982). The basal Oligocene assemblage in Hole 647A contains only 7 flysch-type species, characterized by small-sized specimens of *Glomospira* and *Bathysiphon*. The maximum abundance of *Ammodiscus latus* occurs in this interval. The final disappearance of the remaining flysch-type species is associated with the lithologic change from siliceous hemipelagic clays to diatomites in Zone NP22. Only three species of agglutinated foraminifera (*Rhabdammina* sp., *Spirosigmoilinella compressa*, and *Cribrostomoides* sp.) were encountered in the biosiliceous interval in Hole 647A.

Flysch-type assemblages persisted on the Labrador Margin and in the central North Sea into the lower Oligocene, but these assemblages consist of less than ten species. The assemblages in both regions were dominated by lituolids, loftusiids (*Cyclammina placenta-cancellata*, *C. rotundidorsata*) and robust tubular species (*Dendrophrya robusta* and *Rhabdammina*). In the early Oligocene in both regions there was a regional trend from slope to shelf environments, accompanied by a transition to calcareous benthic assemblages.

This trend was accentuated by the "mid"-Oligocene sealevel lowstand which resulted in hiatuses in many sections.

North of the Greenland-Scotland Ridge, more diverse assemblages (about 20 species) were present in the deep Norwegian-Greenland Sea. This area again served as a refuge for some of the "typical Eocene" species such as Ammosphaeroidina, and the R. amplectens lineage. Advanced forms of R. amplectens with numerous lobate chambers and Cyclammina acutidorsata occur as high as Zone NP25 (upper Oligocene) in Hole 643A. In this Hole, the LCO of agglutinated taxa is associated with the transition to ?upper Oligocene - lower Miocene siliceous sediments, but in other holes agglutinated assemblages persisted into the Neogene. Similarly, the Mackenzie Delta area harbours a diverse lower Oligocene assemblage containing R. amplectens (see Dixon et al., 1985, pl. 2, fig. 4) in bathyal facies of the Kugmallit Formation. In this area, the agglutinated facies was replaced by a calcareous fauna with Cibicidoides and Turrilina in the mid-Oligocene (Dixon et al., 1985).

NEOGENE PALEOBIOGEOGRAPHY:

Miocene agglutinated assemblages are known only from the Norwegian-Greenland Sea, Baffin Bay, and from two wells in the Labrador Sea (ODP Hole 646B on the Eirik Ridge and the TEXACO Blue H-28 well near Orphan Knoll). The main features of these assemblages are shown in Table 4-4. In all areas, the assemblages are numerically dominated by simple, coarse-walled species (Rhizammina, Rhabdammina, Lagenammina, Saccammina, and Psammosphaera). Only a few stratigraphically distinctive forms are present, the most important of which being the genus Martinotiella, which occurs in all three regions.

In the Norwegian-Greenland Sea, assemblages have been reported from Sites 348 (Berggren and Schnitker, 1983). A lower Miocene assemblage at this site contains a diverse assemblage comprised of Ammodiscus, Bathysiphon, Cribrostomoides, Cyclammina, Haplophragmoides, Reophax, Psammosphaera and Tolypammina. Above this assemblage, however, a depauperate middle to upper Miocene assemblage consists mainly of Spirosigmoilinella, Eggerella and Martinotiella. This type of depauperate Spirosigmoilinella assemblage traverses a wide depth range, since it is also reported in Holes 338 and 643 on the Vøring Plateau and Slope and in Hole 345 in the Lofoten Basin. Middle to upper Miocene assemblages in Holes 338, 345 and 348 consist of only 3 to 5 species. In Holes 338 and 348, the first occurrence of Martinotiella was used

Table 4-4. Main features of Miocene assemblages.

MAIN FEATURES OF MIOCENE FLYSCH-TYPE ASSEMBLAGES

BAFFIN BAY	LABRADOR SEA	NORWEGIAN-GREENLAND SEA
MIDDLE-UPPER MIOCENE ASSEMBLAGES CONTAINING COARSE SPECIES OF RHIZAMMINA, RHABDAMMINA, PSAMMOSPHAERA, LAGENAMMINA, RECURVOIDES AND CYCLAMMINA CANCELLATA.	LATE MIOCENE - EARLY PLIOCENE COARSE ASSEMBLAGES CONSISTING MAINLY OF TUBULAR SPECIES IN HOLE 646B, AND TEXACO BLUE H-28 WELL. ASSOCIATED SPECIES ARE AMMOSPHAEROIDINA, HAPLOPHRAGMOIDES, C. PUSILLA, K. CONVERSA.	PRE-GLACIAL PLIOCENE ASSEMBLAGE IN HOLES 345 MORE DIVERSE THAN MIOCENE, WITH HAPLOPHRAGMOIDES, CYCLAMMINA. PREGLACIAL PLIOCENE ASSEMBLAGES IN HOLE 344 CONSIST OF DIVERSE COARSE AGGLUTINATED SPECIES (HAPLOPHRAGMOIDES, REOPHAX, SACCAMMINA, BATHYSIPHON, CRIBROSTOMOIDES).
MIDDLE MIOCENE INTERVAL WITH SMOOTH AGGLUTINATED SPECIES (BATHYSIPHON, HAPLOPHRAGMOIDES, GLOMOSPIRELLA) IN A CLAY-RICH INTERVAL WITH HIGHER TOC.	TORTONIAN ASSEMBLAGES WITH SMOOTH SPECIES (BATHYSIPHON, AMMODISCUS, GLOMOSPIRA) WITH A NUTTALLIDES UMBONIFERA FAUNA IN HOLE 646B.	MIOCENE BIOSILICEOUS SEDIMENTS CONTAIN LOW DIVERSITY ASSEMBLAGES WITH SPIROSIGMOILINELLA, MARTINOTIELLA IN HOLES 338 & 345, AND IN MIDDLE-UPPER MIOCENE OF HOLE 348.
LOWER MIOCENE ASSEMBLAGES WITH TROCHAMMINA, AMMODISCUS AND HAPLOPHRAGMOIDES.	MIDDLE MIOCENE ASSEMBLAGES WITH S. SCHLUMBERGERI IN BLUE H-28 WELL.	DIVERSE (~20 SPP) LOWER MIOCENE ASSEMBLAGE IN HOLE 348 WITH SPIROSIGMOILINELLA, RECURVOIDES, BATHYSIPHON, PSAMMOSPHAERA, HAPLOPHRAGMOIDES, CYCLAMMINA, BUDASHEVAELLA, REOPHAX.
ENDEMIC SPECIES: CYCLAMMINA PLACENTA-CANCELLATA RETICULOPHRAGMIUM (EVOLUTE),	ENDEMIC SPECIES: CYCLAMMINA? PUSILLA, KARRERIELLA CONVERSA, ADERCOTRYMA GLOMERATA	ENDEMIC SPECIES: SPIROSIGMOILINELLA

by Verdenius and Van Hinte (1983) to determine the base of the middle Miocene.

The Miocene to early Pliocene deep water in the Arctic and Norwegian-Greenland Sea was apparently corrosive, since carbonate contents at deep sites are less than 1 percent. Agglutinated foraminiferal assemblages are present in pre-glacial Pliocene sediments of Hole 344 on the Knipovich Ridge and Hole 345 in the Lofoten Basin. In Cores 26-33 of Hole 344, the assemblageconsists mainly of *Bathysiphon*, *Haplophragmoides*, *Reophax*, *Hormosina* and *Saccammina*, but at some levels *Melonis barleeanum* and *Islandiella teretis* occur together with the planktonic species *Neogloboquadrina atlantica*. The last occurrence of coarse agglutinated taxa was coincident with the onset of ice-rafting in Hole 345. The pre-glacial assemblage at this site is more diverse than the underlying Miocene assemblage and contains calcareous benthics and species of *Cyclammina*, *Haplophragmoides* and *Martinotiella* (Talwani, Udintsev, *et al.*, 1976).

Spillover from the Norwegian-Greenland Sea through Denmark Straits was a likely factor resulting in the presence of agglutinated assemblages at Site 646 on the Eirik Ridge. In Hole 646B, primitive agglutinated species occur as a component of mixed calcareous-agglutinated assemblages. The agglutinated assemblages are late Miocene to early Pliocene in age and are strongly dominated by tubular species, with subdominant unilocular species (*Psammosphaera*) and *Haplophragmoides*, and less common *Ammosphaeroidina*, *Cyclammina*, *Glomospira*, *Glomospirella*, *Martinotiella* and *Recurvoides*. Several distinctive forms occurring in these assemblages impart a decidedly modern aspect to these faunas. The species *Adercotryma glomerata*, *Cyclammina(?) pusilla*, and *Ammomarginulina foliacea*, are known to live in the present-day North Atlantic. However, several forms bear marked resemblance to some Paleogene species. *Cyclammina(?) pusilla* resembles *R. amplectens* in outline, and *Haplophragmoides* sp. of Kaminski *et al.* (in press, c) recalls *H. walteri/excavatus*. Also present in this assemblage is a species of *Ammodiscus* which resembles the upper Eocene - Oligocene species *A. latus*. The composition and diversity of upper Miocene to lower Pliocene species (17 total) in Hole 646B is similar to the middle - upper Miocene assemblages in the TEXACO Blue H-28 well, although cyclamminids of the *C. placanta-cancellata* type are more abundant on the Labrador Margin. The generic composition of the foraminiferal assemblage is remarkably similar to the assemblages in the pre-glacial Pliocene of the Norwegian-Greenland Sea sites. The Miocene assemblages in Holes 348 and 345 in the Norwegian-Greenland Sea differ in containing species of Spirosigmoilinella, which was not found in the Miocene of the Labrador Sea wells.

In the Miocene of Baffin Bay Site 645, agglutinated foraminifera are the only forms present in most samples, since the preservation of calcareous species is discontinuous and generally poor. These agglutinated assemblages contain mainly the ubiquitous complement of tubular and unilocular species (Rhizammina, Rhabdammina, Bathysiphon, Psammosphaera, Lagenammina), but differ from Norwegian-Greenland Sea and Labrador Sea assemblages in the species of loftusiids present. In samples from Hole 645E, the most common species of Cyclammina is C. placenta-cancellata, which is morphologically similar to the Oligocene species known from bathyal sediments in the North Sea and on the Labrador Margin. Cyclammina(?) pusilla was not observed, nor were any other forms with acute peripheries ("C. acutidorsata" from the Norwegian-Greenland Sea). However, a second species of Cyclammina which is more evolute and laterally compressed was observed in Hole 645E. This species resembles the early Paleogene species R. arctica (Petracca) from the Mackenzie Delta.

SUMMARY:

In the early Paleogene, flysch-type foraminifera were widely distributed in areas of clastic sedimentation, at high latitudes and beneath the oceanic lysocline. As is true with modern deep-sea organisms (Thompson, 1877), the majority of flysch-type agglutinated foraminiferal species are cosmopolitan. However, lower Paleogene assemblages display some latitudinal differentiation in diversity, species composition and in the proportions of species groups. A general decrease in diversity is observed from low to high latitudes and from the continental slope to the deep ocean basins. Tropical Paleocene faunas contained abundant calcareous ataxophragmiids and rzehakinids. Boreal and Tethyan faunas contained endemic elements in the Paleocene and early Eocene. An early Eocene to early middle Eocene maximum in Glomospira was apparently an oceanwide phenomenon.

The diversity of these microfossils declined with time in most studied sections throughout the Paleogene. The last common occurrence of flysch-type foraminifera in the North Atlantic exhibits a pattern of diachrony with latitude and depth. There were three main periods of faunal turnover among

agglutinated foraminifera in the Cenozoic. The first turnover, near the Paleocene/Eocene boundary, is characterized by the loss of agglutinated assemblages in the deep ocean basin and the extinction of many species and some genera in bathyal assemblages. However, some species persisted to younger levels in high-latitude basins. The Eocene/Oligocene transition in marked by disappearance of the last deep sea faunas in the Labrador Sea and Poland, and throughout most parts of the Labrador Margin and the North Sea. The early Oligocene witnessed a reduction in diversity on the Labrador Margin and in the Norwegian-Greenland Sea and the disappearance of agglutinated taxa in the Mackenzie Delta. The approximately coeval disappearance of agglutinated assemblages in these areas was caused by a regional trends from slope to shelf environments, accentuated by the "mid"-Oligocene sealevel lowstand.

The early/middle Miocene turnover in the Norwegian-Greenland Sea resulted in a reduction in diversity to around 5 species in the overlying biosiliceous sediments. Pre-glacial Pliocene assemblages display higher diversity until the onset of ice-rafting, when agglutinated species were replaced by calcareous benthic assemblages. In the Neogene, the only DSDP Site in the Atlantic where agglutinated assemblages were preserved is Site 646 in the Labrador Sea. At this site on near the Eirik Ridge, the presence of upper Miocene to lower Pliocene agglutinated assemblages reflects the overflow of dense water from the Norwegian-Greenland Sea over Denmark Straits. Upper Miocene assemblages recovered from Hole 646 contain elements of modern Atlantic faunas. Throughout their respective histories, both Baffin Bay and the Norwegian-Greenland Sea possessed endemic faunal elements.

CHAPTER 5 - PALEOECOLOGY AND PALEOCEANOGRAPHY

A. PALEOBATHYMETRY OF AGGLUTINATED FORAMINIFERA

INTRODUCTION:

Since flysch-type foraminifera are significant components of assemblages in economically important sedimentary basins, it is important to assess the paleobathymetric distribution of biofacies in order to improve their usefulness for interpreting regional geohistory. Unfortunately, few studies have been published that relate the abundance and composition of Paleogene flysch-type agglutinated taxa to paleobathymetry. Brouwer (1965) searched for a recent analogue to alpine flysch-type (Rhabdammina) faunas and concluded they are indicative of abyssal depths based on his analogies to recent faunas. Ksiazkiewicz (1975) likewise reviewed the published data on recent deep-sea agglutinated faunas (mainly the works of Brady and Bandy), and assigned bathyal paleodepths to upper Cretaceous and Paleogene assemblages from the Polish Carpathians. The occurrence of agglutinated assemblages in alpine regions and the ocean basins was synthesized by Gradstein and Berggren (1981), who proposed a generalized model for the occurrence of upper Cretaceous to Paleogene flysch-type agglutinated faunas. They related the occurrence of flysch-type assemblages to hydrographic and sediment properties associated with restricted bottom water circulation or the rapid deposition of fine grained clastic sediments (low oxygen low pH, high CO_2 low positive or intermittently negative Eh, corrosive bottom water) which lead to reducing substrates and high organic content. Tjalsma and Lohmann (1983) have illustrated depth variations in lower Paleogene calcareous foraminifera, but flysch-type faunas are often found in regions where independent depth control is lacking. This makes the task of assigning paleodepths to agglutinated assemblages all the more difficult.

Although the occurrence of flysch-type agglutinated assemblages is not controlled by bathymetry *per se* (Gradstein and Berggren, 1981), bathymetric patterns in species composition are apparent from bathyal to abyssal depths. Gradstein and Berggren (1981) recognized two main types of flysch-type assemblages, probably reflecting faunistic trends. A "Type-A" assemblage is comprised primarily of large, coarsely agglutinated taxa which corresponds to the *Rhabdammina*-fauna of Brouwer (1965). This assemblage is found in slope basins on the continental margins and in DSDP sites with shallow (2.5-3.5 km) paleodepths. A different, "Type-B" assemblage consisting of minute, smooth-walled varieties has been found in deeper (>4 km) sites such as Sites 196, 198A, 260, 261, 263 (Krasheninnikov, 1973, 1974) and probably lived beneath the oceanic lysocline. This assemblage is generally restricted to upper Cretaceous zeolitic clays, and is characterized by diverse species of *Bathysiphon*, *Haplophragmoides*, small ammodiscids, *Hormosina*, *Recurvoides*, *Praecystammina*, *Pseudobolivina* and *Uvigerinammina*. Elements of the upper Cretaceous "Type-B" fauna have been reported from Atlantic DSDP Sites 543A (Hemleben and Troester, 1985), 603 and 641 (Moullade *et al*., in press).

A similar paleobathymetric pattern persists to the present in recent agglutinated foraminifera from the western North Atlantic (Kaminski, 1985; Schroder, 1986), where assemblages along the continental slope and rise consist mainly of large coarse grained astrorhizids and hormosinids, whereas the abyssal plain assemblage consists of small, finely agglutinated lituolids. There is evidence that some representatives of the genera *Hormosina*, *Reophax*, *Trochammina*, *Thurammina*, *Rhizammina*, *Psammosphaera*, *Hyperammina*, and *Ammomarginulina* are non-selective in the material used in the construction of the test wall (Schroder, 1986). As a result, their morphology may change dramatically with depth and the grain size of the substrate. On the Newfoundland continental slope and rise, the distribution of some modern agglutinated genera has been correlated with bathymetric patterns in the mean grain size of the sediment, total organic content and the occurrence of water masses (Schafer *et al*., 1983). Upper to middle slope environments contain a biofacies consisting of *Trochammina*, *Textularia*, *Hemisphaerammina* and *Bathysiphon*. The tranquil middle slope biofacies is characterized by the tubular genera *Rhizammina*, *Bottellina*, and *Hyperammina*. The abundance of *Cyclammina* is positively correlated with fine, organic-rich substrates on the middle slope. Lower slope to rise biofacies contain increased proportions of *Ammobaculites*, *Glomospira*, *Karreriella*, *Recurvoides*, *Reophax* and *Sigmoilopsis*. The abundance of *Haplophragmoides*, *Saccammina* and *Spiroplectammina* correlates with coarse substrates on the rise beneath the Western Boundary Undercurrent.

The primary purpose of this study is to develop a generalized paleoslope model for the North Atlantic which relates the species composition and relative abundance of agglutinated foraminiferal species to paleobathymetry. This model is based on observations carried out in Trinidad, Zumaya, the Labrador Sea and the Norwegian-Greenland Sea and encompasses the Maastrichtian to middle Eocene. Several methodological approaches are utilized to construct this model, including backtracking, paleoslope reconstructions, microfossil facies changes in a deepening-upward sequence and identification of autochthonous vs redeposited assemblages in a basinal setting. Another aspect of this study is to compare the paleobathymetric distribution of assemblages from the North Atlantic with contemporaneous flysch-type agglutinated faunas from the Carpathian basins to determine whether consistent paleobathymetric patterns exist in these regions. Finally, the paleobathymetry of Paleogene agglutinated foraminifera in the North Atlantic is compared with a simple, generalized, mid-Cretaceous paleobathymetric model of Haig (1979) to determine whether this model adequately describes Maastrichtian to Paleogene patterns observed in the North Atlantic basins.

A. TRINIDAD:

The Lizard Springs formation of Trinidad was deposited on continental crust which has subsequently been deformed and uplifted; therefore paleobathymetric estimates based on thermal subsidence models cannot be used. The approach to studying the paleobathymetry of agglutinated taxa in Trinidad rests upon two assumptions: (1) that the assemblages in the turbidite sediments of the Lizard Springs Formation are made up of a mixture of basin-plain assemblages in autochthonous sediments and faunal elements redeposited from shallower paleodepths in turbidite muds, and (2) that end-member assemblages can be identified whose paleobathymetric significance can be determined by means of cross-correlation with calcareous benthic assemblages, whose paleobathymetry has been calibrated in DSDP Sites (Tjalsma and Lohmann, 1983).

Sedimentary structures observed in thin section were used to provide supporting evidence for interpreting sedimentary environments. Thin sections from each core sample in well G-287 were examined to distinguish hemipelagic silts and clays from those of turbiditic origin. Studies of alpine flysch (Hesse, 1975) have revealed differences in bioturbation, grain size, microfossil content, color, bed thickness, and carbonate content between the two facies. Hemipelagic sediments are generally mottled owing to bioturbation, whereas parallel laminae are preserved in turbidites. Turbidite muds are often darker in color due to a greater amount of organic matter present (Piper, 1973; Hesse, 1977; O'Brian <u>et</u> <u>al</u>. 1980). Despite the discontinuous sampling, inferences can be made about the depositional environment of the intervals studied in well G-287. A brief description of the sediments encountered follows, and is summarized in figure 5-1.

A. Sedimentology of TEXACO Trinidad Well G-287:

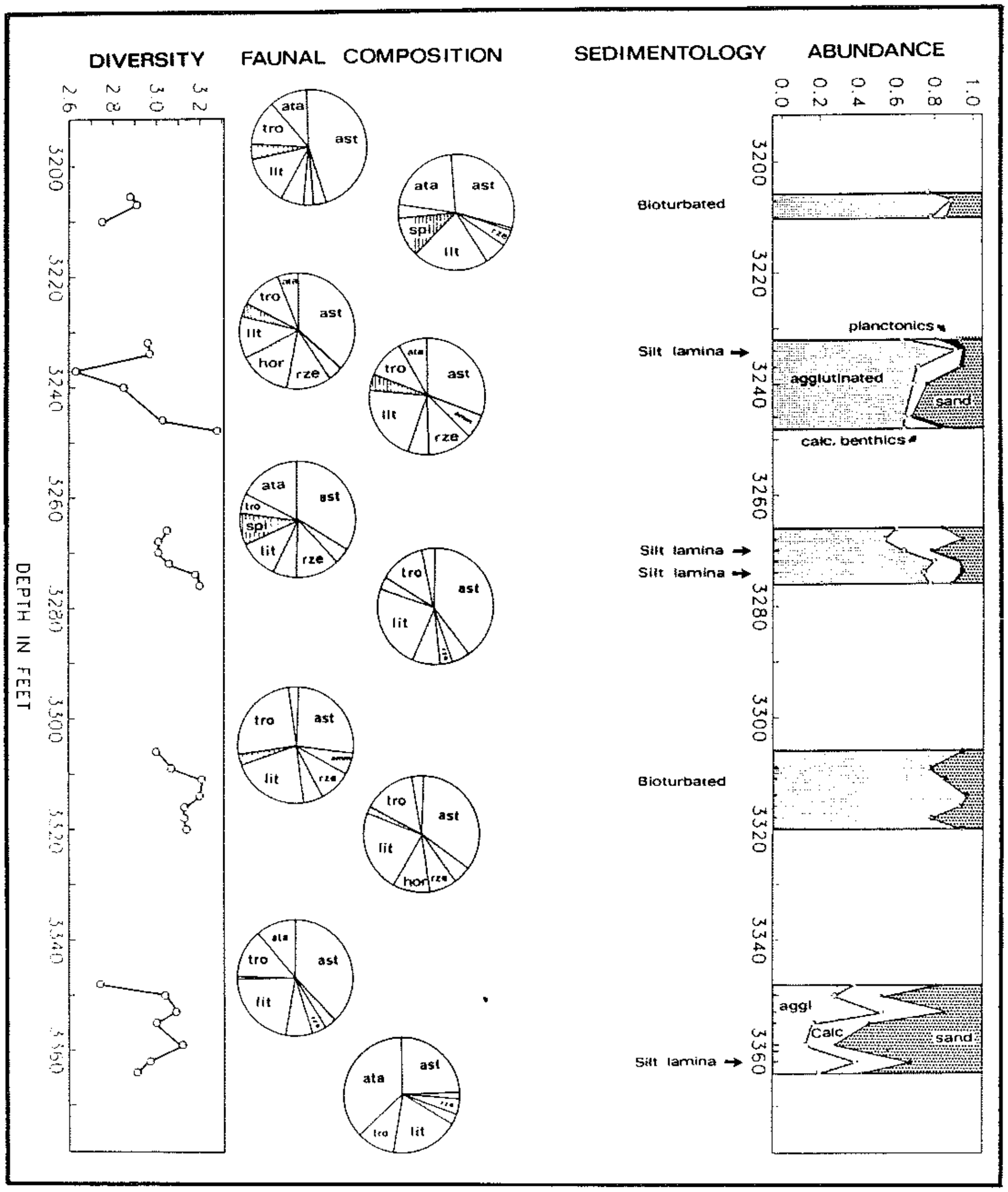
The uppermost interval (3205-3210 ft) consists of a uniform, noncalcareous clay with discontinuous organic-rich laminae. The next lower interval (3232-3248 ft) also contains a uniform clay with organic-rich burrows and streaks, but calcareous particles are present. A single lamina containing silt-sized calcareous grains was found at 3237 ft. The interval from 3266 to 3276 ft again contains calcareous mottled clay with organic-rich burrows. Silt laminae containing calcareous particles were encountered at 3270 and 3274 ft. The presence of these sedimentary structures implies deposition by traction currents.

Uniform bioturbated noncalcareous clay was found from 3306-3320 ft. No sedimentary laminations were observed in this interval, suggesting hemipelagic deposition beneath the local lysocline.

The basal interval from 3348 to 3364 ft contains rather coarse silty shales that are darker in color due to the presence of pyrite and siderite. Calcareous particles are common, and silt laminae were found at 3362 ft, suggesting redeposition. Organic-rich burrows were found at 3351, 3362, and 3364 ft.

B. Composition of the Sand Fraction:

The relative proportion of calcareous benthic, agglutinated, planktonic foraminifera, and nonbiogenic constituents (quartz, siderite and pyrite) was estimated for each washed sample (fig. 5-1). Of the five intervals studied, the basal interval displays the largest proportion of nonbiogenic sand and the largest ratio of calcareous/agglutinated foraminifera. Quartz and siderite predominate, and echinoderm fragments are common, supporting the sedimentological evidence suggesting redeposition. The bioturbated noncalcareous interval from 3306-3320 ft contains exclusively agglutinated foraminifera and quartz grains, with only minor authigenic minerals. Laminated sediments higher in the well contain greater proportions of



5-1. Shannon-Wiener diversity, faunal composition, sedimentology, and composition of the sand fraction in well G-287. Pie diagrams show faunal composition by superfamily for the top and bottom sample of each interval. ast= astrorhizids, amm= ammodiscids, rze= rzehakinids, hor= hormosinids, lit= lituolids, spi= spiroplectamminids, tro= trochamminids, ata= ataxophragmiids.

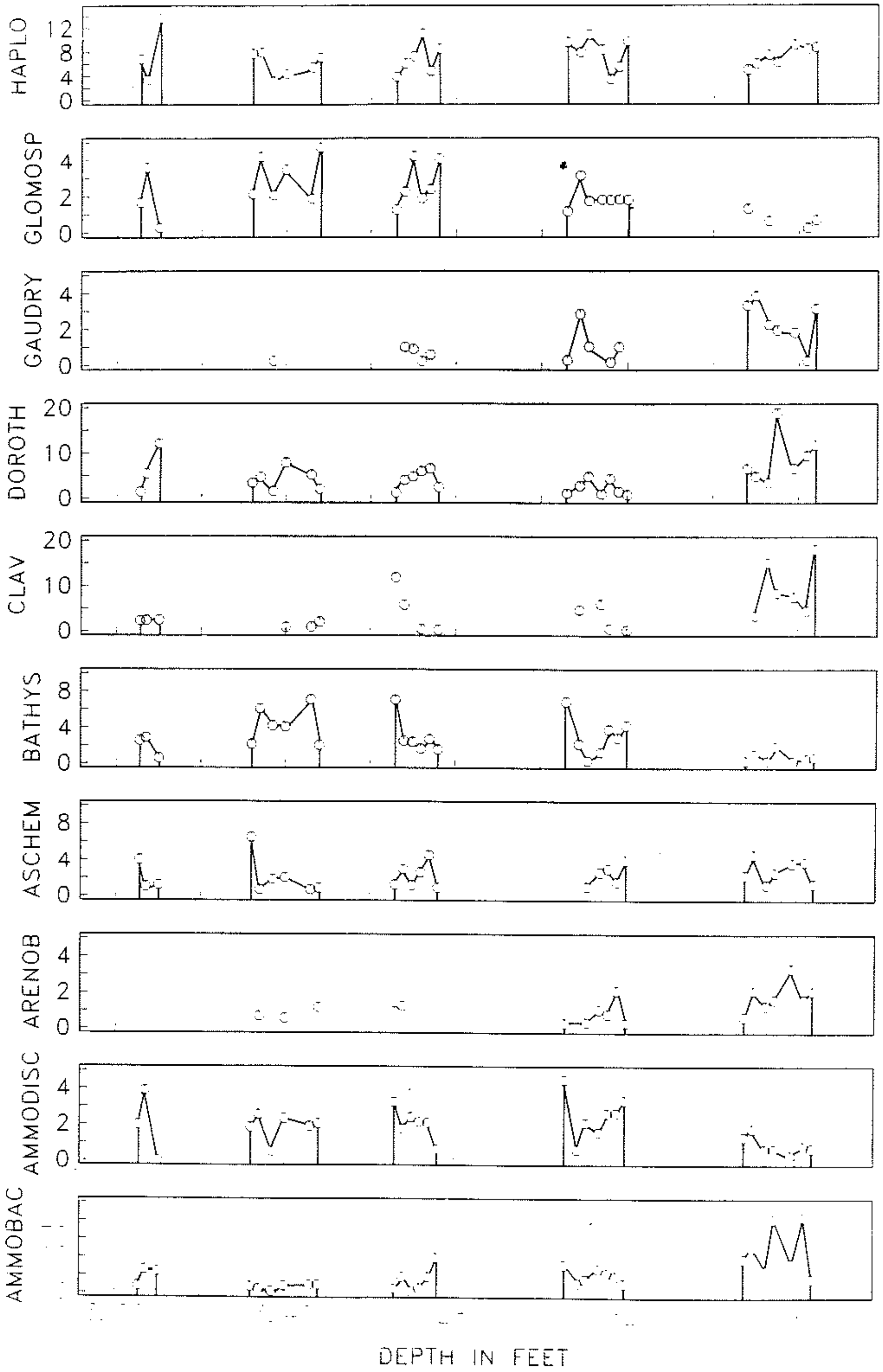
calcareous benthics, but the amount of nonbiogenic grains does not differ greatly from the noncalcareous interval.

C. Benthic Foraminiferal Assemblages:

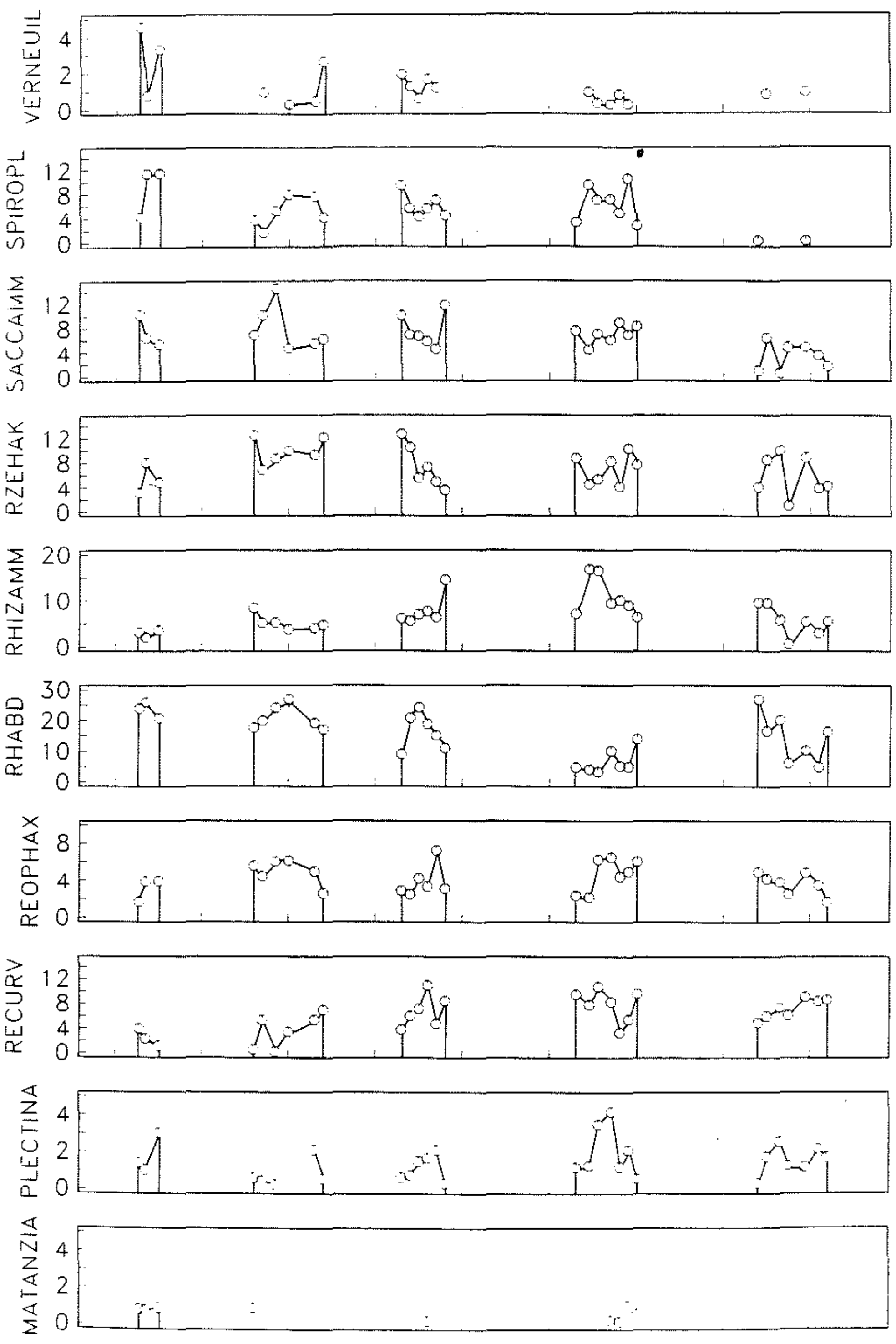
The agglutinated foraminiferal component of well G-287 is dominated by astrorhizids. Ataxophragmiids are common in the basal interval, whereas spiroplectamminids, rzehakinids, ammodiscids and hormosinids increase in abundance in the upper section of the well. Figure 5-1 presents the faunal composition by superfamily of Loeblich and Tappan (1984) for the top and bottom sample in each interval. The relative abundance of agglutinated genera in the three intervals in well G-287 is shown in figure 5-2. To provide additional information on the main sources of variation in the data set, the faunal matrix (Kaminski et al., in press, a) was subjected to Q-mode Varimax factor analysis. Three faunal factors were associated with eigenvalues greater than unity, explaining 87% of the variance. A plot of factor scores showing the composition of each faunal factor is given in figure 5-3.

The first factor, which reflects the "average" fauna, explains 40% of the variance and consists primarily of Dendrophrya ex gr. excelsa, with Rzehakina epigona, Spiroplectammina spectabilis, Saccammina placenta, and Bathysiphon sp. of lesser importance. Shannon-Wiener faunal diversity is variable in this interval. Faunal factor 2, which describes the principal axis of variation about the "average" explains 28% of the variance. This factor is made up of forms with finely agglutinated tests such as Ammosphaeroidina pseudopauciloculata, Rhizammina indivisa, Recurvoides gerochi, and Rzehakina epigona, and has highest loadings in the noncalcareous interval from 3306-3318 ft. The third significant faunal factor accounts for 18% of the variance and is strongly associated with the basal interval. This assemblage exhibits a relatively low diversity of agglutinated taxa, and species awarded highest factor scores are robust coarse forms such as Clavulinoides globulifera, Dorothia retusa, Phenacophragma beckmanni, and Haplophragmoides ex gr. suborbicularis.

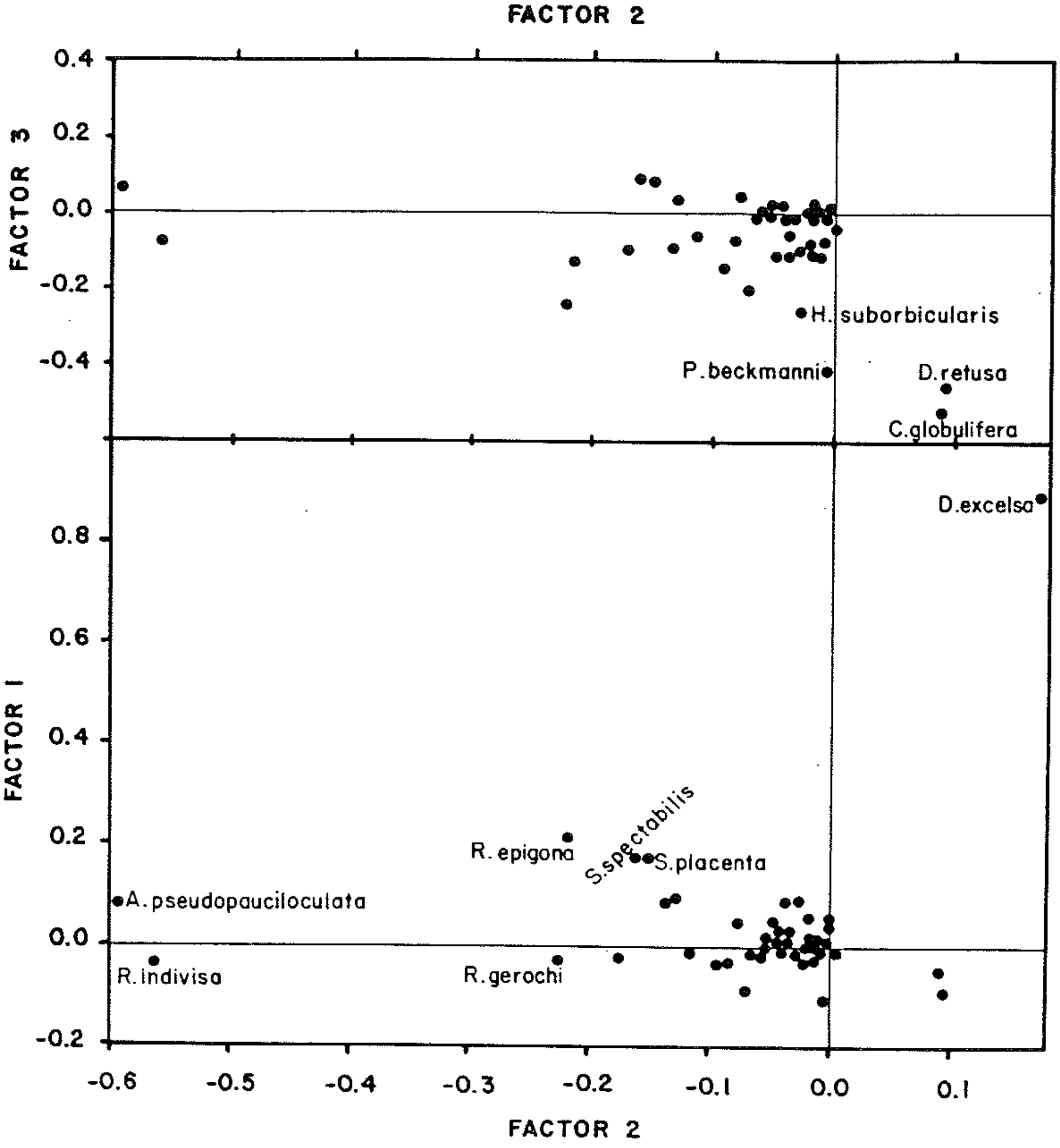
The relative abundance of Nuttallides spp. (mostly N. truempyi) is greatest in redeposited intervals between 3232 and 3248 ft (Figure 5-4). Tjalsma and Lohmann (1983) have shown that the Nuttallides fauna was the important abyssal assemblage during the Paleocene. Stensioeina



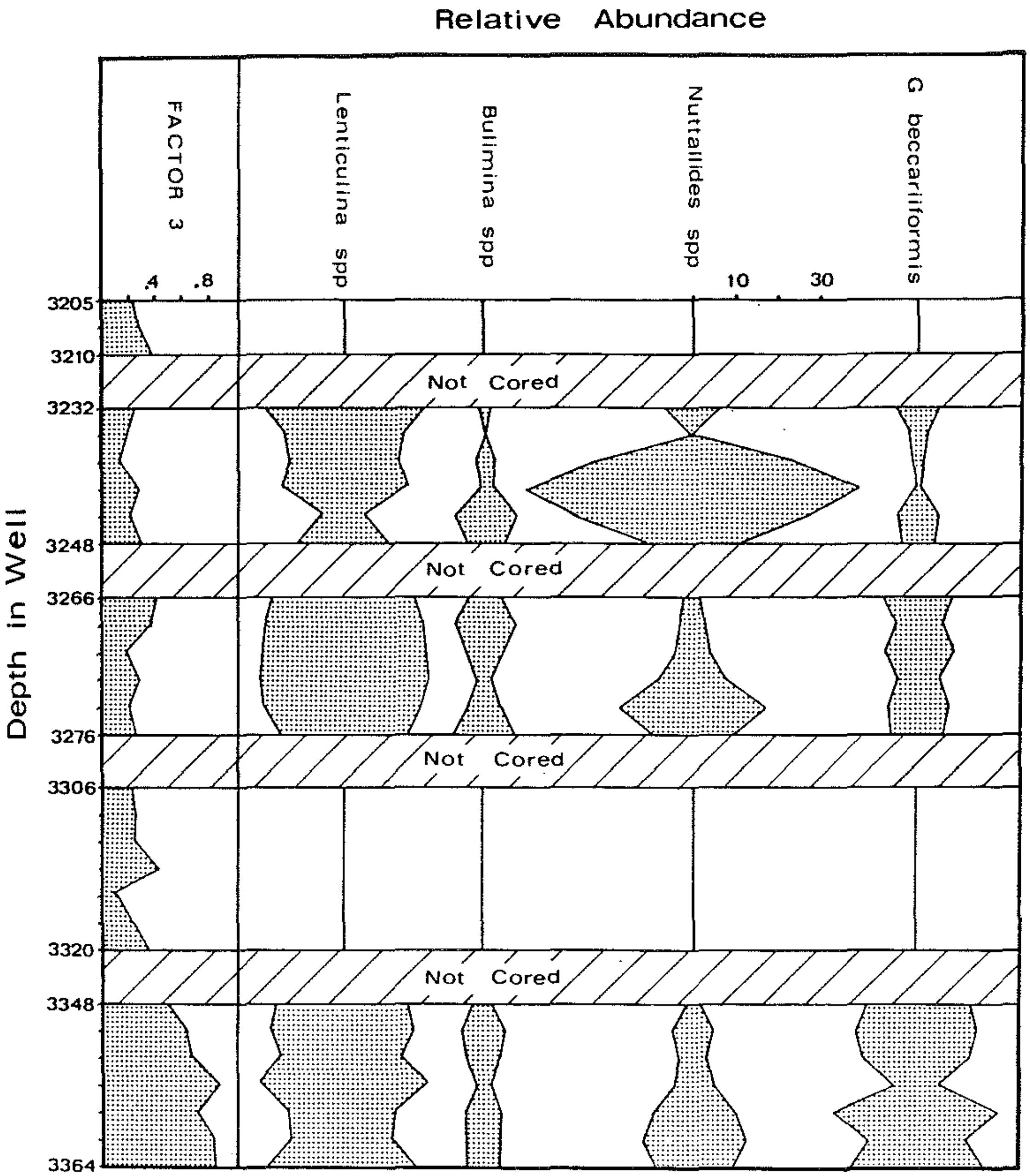
5-2a. Relative abundance (in percent) of agglutinated genera in well G-287. Data for Phenacophragma is included in Ammobaculites. Data for Dendrophrya are included in Rhabdammina.



5-2,b. Relative abundance of agglutinated genera in well G-287 (continued). Data for Subreophax are included in Reophax.



5-3. Distribution of benthic foraminiferal species on first three Q-mode varimax factors.



5-4. Relative abundance of important calcareous benthic taxa compared with the importance of faunal factor 3 in well 287.

beccariiformis, which characterizes a shallower facies in the Paleocene than the *Nuttalides* fauna, displays greatest relative abundance in the basal interval.

PALEOBATHYMETRY

Sedimentological and faunal evidence enables the construction of a relative paleobathymetric model for Paleocene agglutinated foraminifera from southeast Trinidad (Fig. 5-5), but assigning well-constrained paleodepths to the assemblages is difficult due to the lack of independent depth control. Tjalsma and Lohmann (1983) assigned a paleodepth of 900 m to the Lizard Springs Formation but did not specify how they derived this estimate. Since most late Cretaceous species of agglutinated foraminifera range up into the Paleocene, it is possible to compare the generic composition of the Danian Lizard Springs assemblages with existing Cretaceous paleobathymetric schemes.

The bathymetric distribution of late Cretaceous benthic foraminiferal genera in continental margin deposits of southern California was studied by Sliter and Baker (1972), who recognized inner and outer shelf, and upper, middle and lower slope assemblages. Upper slope assemblages in California were found to be dominated by calcareous genera, with *Gaudryina*, *Dorothia*, *Cribrostomoides*, *Bathysiphon* and *Spiroplectammina* the most common agglutinated genera. Middle slope assemblages were dominated by agglutinated species and turrilinids, osangulariids, and anomalinids. Agglutinated genera were similar to the upper slope assemblage, with increased importance of *Ammodiscus*, *Hyperammina*, *Bathysiphon*, and *Cribrostomoides*. Haig (1979) divided mid-Cretaceous agglutinated assemblages into a shallow water Ammobaculites association, an abyssal *Recurvoides* association, and a bathyal *Marssonella* association that can be further subdivided with the aid of calcareous taxa.

In the basal interval of well G-287, the composition of the agglutinated assemblage resembles the upper to middle slope assemblages of Sliter and Baker (1972) and the mid slope facies of the "*Marssonella* association" of Haig. In Cretaceous sediments of the western North Atlantic margin, Nyong and Olsson (1984) used downdip distance as an independent estimate of paleobathymetry. The greatest abundance of *Marssonella* and *Arenobulimina* were found at depths of 200-500 m.

5-5. Paleobathymetry of agglutinated taxa in equatorial Atlantic.

LIZARD SPRINGS FORMATION - WELL G-287			HOLE 543A, Core 5-6
Upper Bathyal	Middle Bathyal	Basin Plain	Abyssal
Dendrophrya excelsa	*Dendrophrya excelsa*	*Ammosphaeroidina*	*Kalamopsis grzybowskii*
Clavulinoides globulifera	*Rzehakina epigona*	*Rhizammina indivisa*	*Haplophragmoides cf walteri*
Phenacophragma beckmanni	*Ammosphaeroidina*	*Rzehakina epigona*	*Ammodiscus cretaceous*
Rzehakina epigona	*Rhizammina indivisa*	*Recurvoides gerochi*	*Glomospira irregularis*
Rhizammina indivisa	*Spiroplectammina spectabilis*	*Dendrophrya excelsa*	*Glomospira charoides*
Recurvoides gerochi	*Saccammina placenta*	*Spiroplectammina spectabilis*	*Hormosina ovulum*
Ammosphaeroidina	*Hormosina trinitatensis*	*Hormosina trinitatensis*	*Bathysiphon sp.*
Haplophragmoides retroseptus	*Bathysiphon spp.*	*Saccammina placenta*	*Hyperammina dilatata*
Hormosina trinitatensis	*Recurvoides gerochi*	*Saccammina complanata*	*Paratrochamminoides*
Conotrochammina whangaia	*Haplophragmoides retroseptus*	*Haplophragmoides retroseptus*	
Trochammina altiformis	*Saccammina complanata*	*Bathysiphon spp.*	
Rhabdammina discreta	*Aschemonella ex gr. grandis*	*Trochammina altiformis*	
Aschemonella ex gr. grandis	*Clavulinoides globulifera*	*Conotrochammina whangaia*	
Saccammina complanata	*Ammobaculites sp. 2*	*Ammobaculites sp. 2*	
Recurvoides sp. 2	*Glomospira charoides*	*Aschemonella grandis*	

(LISTED IN ORDER OF DECREASING RELATIVE ABUNDANCE)

The Paleocene bathymetric distribution of several species of calcareous ataxophragmiids are reported by Tjalsma and Lohmann (1983). Clavulinoides globulifera was found to be restricted to sites with backtracking paleodepths above 1800 m, and Gaudryina pyramidata possesses a maximum abundance centered about 2000 m in Zone P1 time. Two species of Clavulinoides occurring in the outcrop samples possess limited depth ranges. Tjalsma and Lohmann show that Clavulinoides trilatera is restricted to paleodepths between 1000 and 2000 m in Zone P3/P4, and C. paleocenica, which occurs only rarely in the samples, was reported to occur most commonly below 2,000 m.

Based on the literature analysis above, the shallowest assemblage in well G-287 is represented by factor assemblage 3. This assemblage is dominated by calcareous ataxophragmiids, occurs in redeposited sediments, and is positively correlated with the relative abundance of Stensioeina beccariiformis (Fig. 5-4). Sediments in this interval were probably derived from a relatively shallow (more proximal) source area. Factor assemblage 1, from the upper intervals of well G-287, contains fewer calcareous elements and a greater proportion of deeper dwelling Nuttallides truempyi than factor 3, and probably represents a mixture of autochthonous species and specimens redeposited from a more distal source than the basal interval. Spiroplectammina sp. aff. S. dentata, which displays maximum abundance in factor assemblage 1, was found by Nyong and Olsson (1984) to be most common in their lower slope (1500-2500 m) assemblage.

The presumably deepest assemblage in well G-287, represented by factor assemblage 2, is probably in situ judging from the sedimentological evidence. This assemblage contains more elements of a "Type-B" fauna reported from abyssal DSDP sites, but these are not the dominant forms. The species composition compares well with the lower slope assemblages of Sliter and Baker (1972), which are dominated by the agglutinated genera Glomospira, Hyperammina, Pelosina, Hormosina, Saccammina, Haplophragmoides, and Bathysiphon. Haig defines an abyssal assemblage characterised by Recurvoides, Plectorecurvoides, Uvigerinammina, Hormosina, Dendrophrya and Kalamopsis. At Lizard Springs, Kalamopsis and Hormosina ovulum ovulum are most abundant in factor 2, but the genus Recurvoides was not found to increase in abundance from shallow to deep assemblages. In fact, Recurvoides can be among the most abundant taxa in neritic deposits from high latitudes (see discussion of

Labrador Margin below). Nyong and Olsson (1984) find abundant Glomospira, Rhizammina, Uvgerinammina, Saccammina, and Trochammina below 2500 m.

A true "Type-B" agglutinated fauna of probable Paleocene or early Eocene age was recovered from noncalcareous pelagic claystones from Cores 5 and 6 of Site 543A (Hemleben & Troester, 1984). This site is located 600 km NNE of Trinidad and has a backtracked Paleocene paleodepth of about 5000 m. The fauna displays low diversity and consists mainly of Glomospira charoides, Kalamopsis grzybowskii, and Hormosina ovulum, with less frequent Ammodiscus cretaceus, Glomospira irregularis, G. diffundens, Reophax scalaris, Paratrochamminoides spp., Hyperammina spp., Nodellum velascoensis, Saccammina spp., Praecystammina globigerinaeformis, and Tolypammina sp. All but two of the above species are more abundant in the deeper assemblage from noncalcareous intervals of the Lizard Springs Formation. The sole exceptions are P. globigerinaeformis, and Tolypammina spp., which were not found in the samples.

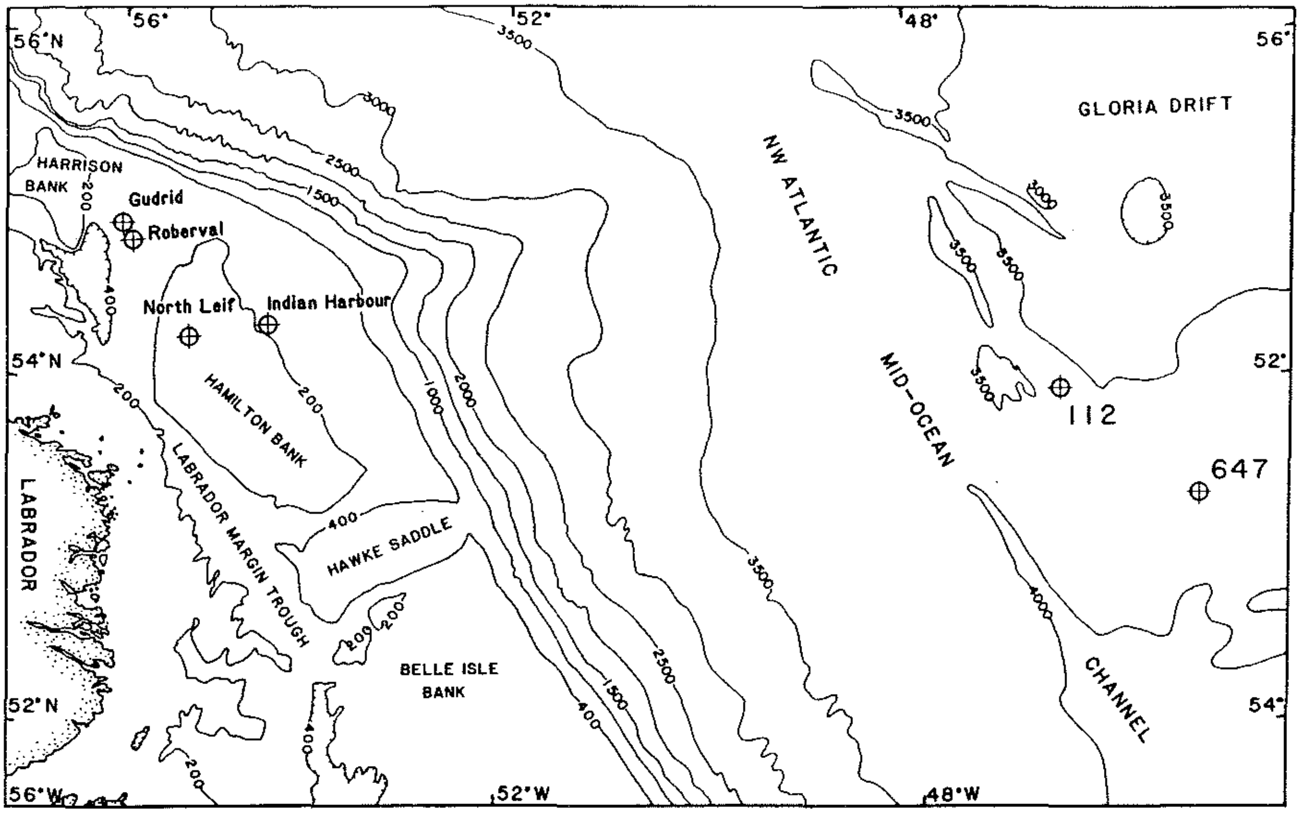
In summary, the Guayaguayare and Lizard Springs assemblages reflect deposition in a basin plain environment at lower bathyal depths. Generally shallower paleodepths are evident in the lower Maastrichtian and lower Eocene, with the deeper paleodepths recorded in the Danian. Redeposited assemblages present in turbidites are derived from upper bathyal and middle bathyal sources. However, it should be borne in mind that upper depth limits of agglutinated taxa are often elevated in areas of thick clastic sedimentation such as the Mississippi Delta (Pflum and Frerichs, 1976); therefore this estimate represents a lower limit.

LABRADOR MARGIN

The passive margin setting of the Labrador Margin is structurally less complex than Trinidad and Zumaya where sediments have been uplifted and deformed by Cenozoic tectonic movements. As a result, paleobathymetric patterns exhibited by benthic foraminiferal assemblages in the Labrador Sea reflect the present position of offshore wells. Subsidence in this region was greatest during the late Campanian to late Eocene phase of sea floor spreading in the Labrador Sea (Srivastava, 1978) when a thick wedge of clastic sediment was deposited. The regional geology and stratigraphy of the Labrador Sea area has been discussed by Gradstein and Williams (1976), Umpleby (1979), McWhae et al. (1980), Gradstein and Srivastava (1980) and Gradstein and Berggren (1981).

Since all well sites on the Labrador Margin are on continental crust, the wells cannot be backtracked using the seafloor subsidence equations. The approach used here to determine paleobathymetric trends in foraminiferal biofacies is similar to that taken by Olsson and Nyong (1984), who use distance downdip as a measure of increasing paleodepth in Atlantic passive margin settings. The sample base for this study consists of a bathymetric transect of four exploration wells on the Labrador Margin and two DSDP/ODP sites in the Labrador Sea (Table 5-1). The North Lief I-05 well was drilled on a structural high on Hamilton Bank (Fig. 5-6). This well recovered the thinnest Cenozoic section of the Labrador Margin wells studied (Fig. 5-7) and serves as the updip reference site for benthic foraminiferal biofacies. A downslope position on the Labrador Margin is occupied by the Indian Harbour M-52 well, which contains a well preserved, deep-water microfauna, especially near the base of the hole. The relative abundance of planktonics and the diversified calcareous and agglutinated benthic assemblages together with the more distal setting of the well site point to a bathyal depositional environment, probably upper to middle bathyal. The Gudrid H-55 and Roberval K-92 wells occupy an intermediate position between the North Leif and Indian Harbour wells. The abyssal end member of Maastrichtian assemblages in the North Atlantic is present in ODP Hole 641A, drilled off the Galicia Margin. This is the geographically closest DSDP/ODP site to the Labrador Margin with well-preserved upper Cretaceous agglutinated assemblages. Paleocene abyssal assemblages were recovered from Core 16R of DSDP Hole 112, whereas ODP Hole 647A provides the abyssal reference section for the Eocene.

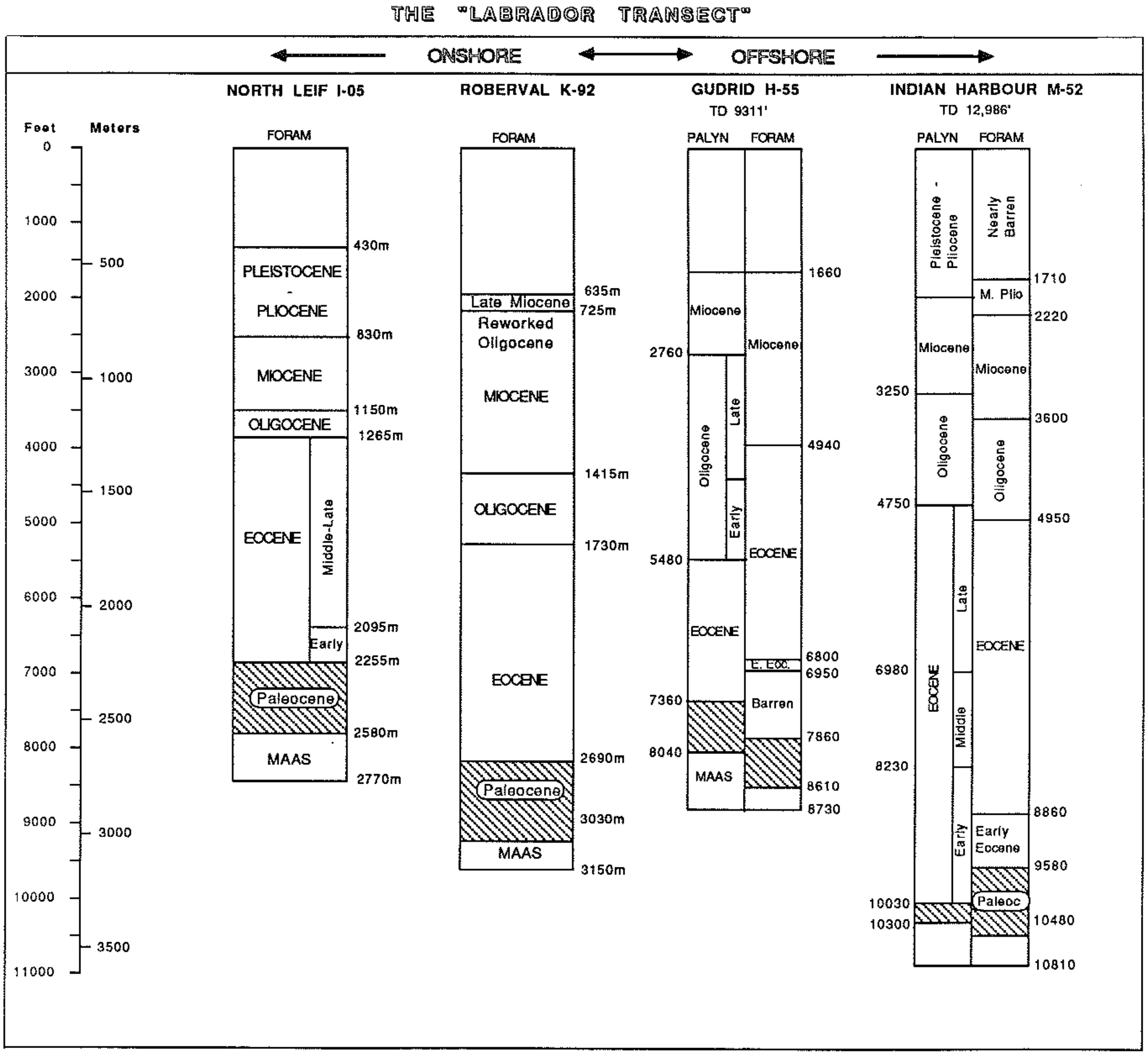
Maastrichtian to Paleocene flysch-type assemblages on the Labrador Margin are best developed in the Uniform Shale of the Cartwright Formation, a dark green pyritic and micaceous shale unit. The most abundant species in the Cartwright Formation in the North Leif, Gudrid and Indian Harbour wells are listed in figure 5-8 and a full census of species are given in Appendixes 5-1 to 5-4. The Cretacous/Tertiary boundary in these wells was determined by the last occurrences of Maastrichtian planktonics, or in the case of the Gudrid well, by the last common occurrence of reddish-stained calcareous benthic foraminifera. Agglutinated species that are generally restricted to the Maastrichtian portion of the Uniform Shale are Ammobaculites sp. 4, Arenobulimina dorbignyi, Dorothia oxycona, and Uvigerinammina jankoi. The age



5-6. Location of well sites in the Labrador Sea. Base map redrawn after Srivastava (1986), bathymetry in meters.

TABLE 4-1. Exploration wells and DSDP/ODP Sites in the northern Atlantic examined in this study.

WELL:	LATITUDE	LONGITUDE	WATER DEPTH:	INTERVAL STUDIED	AGE:
NORTH LEIF				2465 - 2700 m	Maast - Eocene
ROBERVAL K-92	54° 51' 35.53"	55° 44' 35.76"	268 m	2220 - 3070 m	Maast - Eocene
GUDRID H-55	54° 54' 30.02"	55° 52' 32.22"	299 m	8070-8730 ft	Maast - Paleoc
INDIAN HARBOUR M-52	54° 21' 51.34"	54° 23' 51.81"	198 m	10060-10810 ft	Maast - Paleoc
DSDP HOLE 112	54° 01.00'	46° 36.24'	3657 m	653 mbsf	Paleocene
ODP HOLE 647	53° 19.876'	45° 15.717'	3862 m	290-699 mbsf	Eocene
ODP HOLE 641A	42° 09.3'	12° 10.9'	4646 m	0-54.1 mbsf	Coniac-Maast



5-7. Cenozoic stratigraphy of four Labrador Margin wells comprising the "Labrador Transect". Stratigraphy of the Indian Harbour and Gudrid wells is after Srivastava (1986). Stratigraphy of North Leif and Roberval wells is based on new observations by Gradstein (personal communication, 1987).

of sediments in the Gudrid, Roberval and Indian Harbour wells based on foraminifera and palynomorphs was recently summarized by Gradstein (in Srivastava, 1986).

A. Maastrichtian -

The shallowest Maastrichtian assemblage in the transect occurs in the North Lief I-05 well (Fig. 5-8, Appendix 5-1). This assemblage is dominated by large, coarsely agglutinated astrorhizids and lituolids. In contrast with shallow assemblages from Trinidad, the calcareous ataxophragmiids and rzehakinids are rare on the Labrador Margin. Only three of the 12 most common species (Glomospira charoides, Ammodiscus cretaceus and Hormosina ovulum) possess finely agglutinated wall structure. Calcareous benthics are rare in this well and indicate an outer neritic to upper bathyal setting. Agglutinated species which are associated with "Type-B" assemblages, such as Labrospira, Subreophax, Ammosphaeroidina and Uvigerinammina, are represented by few specimens. Planktonic foraminifera are likewise rare and consist mainly of small species of Hedbergella.

The Roberval K-92 well is situated between the North Leif and Gudrid wells. Only one Maastrichtian sample (Appendix 5-2) was examined quantitatively. Although still dominated by coarse tubular forms, this assemblage contains increased proportions of Glomospira and Uvigerinammina in comparison to the North Leif well.

In the Gudrid and Indian Harbour wells, calcareous benthic and planktonic foraminifera are more abundant and more diverse than in the updip wells, and the most abundant agglutinated species is Glomospira charoides. The species Karreriella horrida, Hormosina ovulum, Cribrostomoides sp. (smooth) also display increased relative abundance in both wells relative to the updip wells. Samples from the Gudrid well (Appendix 5-3) also contain increased abundances of species with finely agglutinated tests such as Haplophragmoides glabra, Saccammina placenta and Trochamminoides spp.

The planktonic assemblage in the Indian Harbour well is most diverse and consists of Rugoglobigerina, Globigerinelloides, Heterohelix, and rare Abathomphalus mayaroensis, but still reflects a marginal (as opposed to open ocean) setting. Calcareous benthic foraminifera are more abundant than in other wells which attests to deposition further offshore. The agglutinated

AGE	CARTWRIGHT FORMATION - LABRADOR MARGIN			Abyssal
	NORTH LEIF 2465-2505 m	GUDRID H-55 8070-8550 ft.	INDIAN HARBOUR M-52 10060-10450 ft.	DSDP HOLE 112 Core 16
PALEOCENE	S=41	S=53	S=54	S=22
	Trochammina deformis	*Karreriella horrida*	*Rhabdammina spp.*	*Rhizammina spp.*
	Recurvoides walteri	*Recurvoides walteri*	*Glomospira charoides*	*Rhabdammina spp.*
	Bathysiphon spp.	*Rhizammina spp.*	*Trochammina deformis*	*Glomospira irregularis*
	Rhabdammina spp.	*Rhabdammina spp.*	*Haplophragmoides walteri*	*Ammodiscus glabratus*
	Haplophrag. walteri	*Trochammina deformis*	*Bathysiphon spp*	*Praecystammina spp.*
	Saccammina complanata	*Saccammina complanata*	*Recurvoides walteri*	*Recurvoides spp.*
	Saccammina placenta	*Haplophragmoides glabra*	*Recurvoides gerochi*	*Haplophragmoides eggeri*
	Karreriella horrida	*Bathysiphon spp.*	*Rhizammina spp.*	*Glomospira charoides*
	Glomospira charoides	*A. aff. polythalamus*	*Saccammina complanata*	*Saccammina complanata*
	Haplo. retroseptus	*Glomospira charoides*	*Ammosphaeroidina*	*Hyperammina spp.*
	Ammodiscus planus	*Cribrostomoides (smooth)*	*Karreriella horrida*	*S. spectabilis*
	Haplophragmoides eggeri	*Cribrostomoides (coarse)*	*Ammodiscus cretaceus*	*S. scalaria*
	NORTH LEIF I-05 2580-2700 m	GUDRID H-55 8640-8730 ft.	INDIAN HARBOUR M-52 10510-10810 ft	HOLE 641A, Cores 1-3* (Hormosina gigantea Zone)
MAASTRICHTIAN	S=48	S=50	S=57	S=21
	Rhabdammina spp.	*Glomospira charoides*	*Glomospira charoides*	*Rhabdammina sp.*
	Bathysiphon spp.	*Bathysiphon spp.*	*Recurvoides walteri*	*Hormosina ovulum*
	Rhizammina spp	*Karreriella horrida*	*Rhabdammina spp.*	*Glomospira charoides*
	Glomospira charoides	*Rhabdammina spp.*	*Bathysiphon spp.*	*Paratrochamminoides*
	Recurvoides walteri	*Recurvoides walteri*	*Uvigerinammina jankoi*	*Hormosina crassa*
	Ammodiscus cretaceous	*Ammodiscus cretaceus*	*Karreriella horrida*	*Recurvoides spp.*
	Haplo. suborbicularis	*Haplophragmoides glabra*	*Ammodiscus cretaceus*	*Glomospira irregularis*
	Karreriella horrida	*Hormosina ovulum*	*Hormosina ovulum*	*Karreriella spp.*
	Haplo. retroseptus	*Cribrostomoides (smooth)*	*Glomospira gordialis*	*Haplo. perexplicatus*
	Saccammina complanata	*Rhizammina spp.*	*Cribrostomoides (smooth)*	*Labrospira*
	Trochammina deformis	*Saccammina complanata*	*Rhizammina spp.*	*Haplo. multicamerus*
	Hormosina ovulum	*Saccammina placenta*	*Haplophragmoides eggeri*	*Ammodiscus cretaceus*

* Data from this study, supplemented with observations by Moullade et al. (in press).

S = Number of species present in assemblage, depths in meters or feet indicate depth in the well.

5-8. Paleobathymetry of agglutinated taxa in the northern Atlantic. Taxa are listed in order of decreasing relative abundance.

assemblage (Appendix 5-4) displays the highest diversity observed in the Labrador Margin wells (~57 species). The uppermost Maastrichtian assemblage strongly dominated by Glomospira charoides, and the species Uvigerinammina jankoi and Ammosphaeroidina pseudopauciloculata display increased abundance relative to the Gudrid Well. In comparison with the updip wells, this assemblage displays a greater proportion of ammodiscids, hormosinids and lituolids with finely agglutinated wall structure. A paleobathymetric pattern is observed in the smooth, carinate species of Haplophragmoides. Specimens in the Indian Harbour well are small with ~6 chambers and are assigned to H. glabra. However, specimens from the North Leif and Roberval wells are somewhat larger and possess more chambers. These specimens are placed in H. walteri.

Paleobathymetric patterns from shallow to deeper assemblages can be verified by examining changing benthic assemblages with depth in the Indian Harbour Well. The Maastrichtian sediments in this well are only about 100 m thick, and the well site apparently experienced rapid thermal subsidence after the Anomaly 30 rifting phase in the Labrador Sea. The assemblages in the well display a distinct changes indicating a deepening-upward pattern. Basal assemblages (10720′ to 10810′) consist mostly of large tubular species. However, above 10720 ft samples contain increased proportions of calcareous benthics as well as Glomospira, Uvigerinammina, Karrieriella horrida, Cribrostomoides sp. (smooth), and Hormosina ovulum. In addition, the genera Trochamminoides, Glomospirella and Labrospira were only found in the upper interval.

Abyssal agglutinated assemblages of Maastrichtian age are well-represented in ODP Hole 641A, drilled at a water depth of 4639 m off the Galicia Margin. These assemblages occur in a 40 m thick unit of red, noncalcareous clays which were deposited in a fault-bordered basin on thin continental crust. Although situated on continental crust, Site 641 had subsided to a depth beneath the oceanic lysocline by the late Cretaceous. The benthic assemblages in the upper 3 cores of Hole 641A are less diverse (~21 species) than assemblages from the Labrador Margin wells and are dominated by three forms: Rhizammina spp., Hormosina ovulum, and Glomospira charoides. Other less common taxa incude Karreriella lenis/conversa, Hormosina crassa, Glomospira irregularis, Recurvoides spp., and Paratrochamminoides spp. In addition, the species H. crassa, Haplophragmoides perexplicatus and

Pseudobolivina cf. *P. munda* are not recorded on the Labrador Margin, but are known from abyssal DSDP Sites in the equatorial Atlantic (Hemleben and Troester, 1985), in the Indian Ocean (Krasheninnikov, 1974) and Pacific (Krasheninnikov, 1973). One important difference is the stratigraphic position of *Uvigerinammina jankoi* in Hole 641A. This species is absent from the upper portion of the red clay unit (Cores 1-3), but is abundant in underlying Cores 5-6. Its local extinction in Hole 641A was correlated with the top of the lower Campanian by Moullade *et al*., (in press) based on comparison with the Gubbio Section in Italy. If this chronology for Hole 641A is correct, than the LO of *U. jankoi* is diachronous between the abyssal site and the Labrador Margin. Nevertheless, the finding of this species dominating the ?lower Campanian assemblage in Hole 641A is consistent with its paleobathymetry on the Labrador Margin.

B. Paleocene:

Paleobathymetric patterns in the Paleocene portion of the Cartwright Formation recovered in the four wells are not as distinct as in the Maastrichtian and their interpretation is complicated by the presence of the prodeltaic Gudrid Sands (McWhae *et al*., 1980) in the upper Paleocene section in some wells. In both the Gudrid and Indian Harbor wells, a shallowing and coarsening upward trend is detected in the foraminiferal assemblages. There is an uphole decrease in the proportions of *Ammodiscus*, *Glomospira*, *Saccammina placenta* in both wells. However, uphole trends in the abundance of other species appear contradictory. *Karreriella horrida*, which occurs in deeper facies in the Maastrichtian, decreases in abundance upsection in the Indian Harbour well but increases in the Gudrid well. The abundance of *Ammobaculites* aff. *polythalamus* increases upwell in the Gudrid well, but not in the Indian Harbour well. Sonic and gamma ray logs from the Indian Harbour well indicate a change from shales to more sandy sediments above ~10,300 ft (Srivastava 1986, fig. 2). At approximately this level, the benthic foraminiferal assemblage also displays a major turnover, with the last occurrences of *H. ovulum*, *H. excelsa*, *H. dilatata*, *R. duplex*, *Subreophax*, *G. gordialis*, *G. irregularis*, *H. glabra*, and *T. subcoronatus* between 10240 and 10360 ft. The overlying assemblage contains more calcareous benthics and ~35 species of agglutinated foraminifera, including *D. robusta*, *B*. cf. *multicamerata*, *H.*

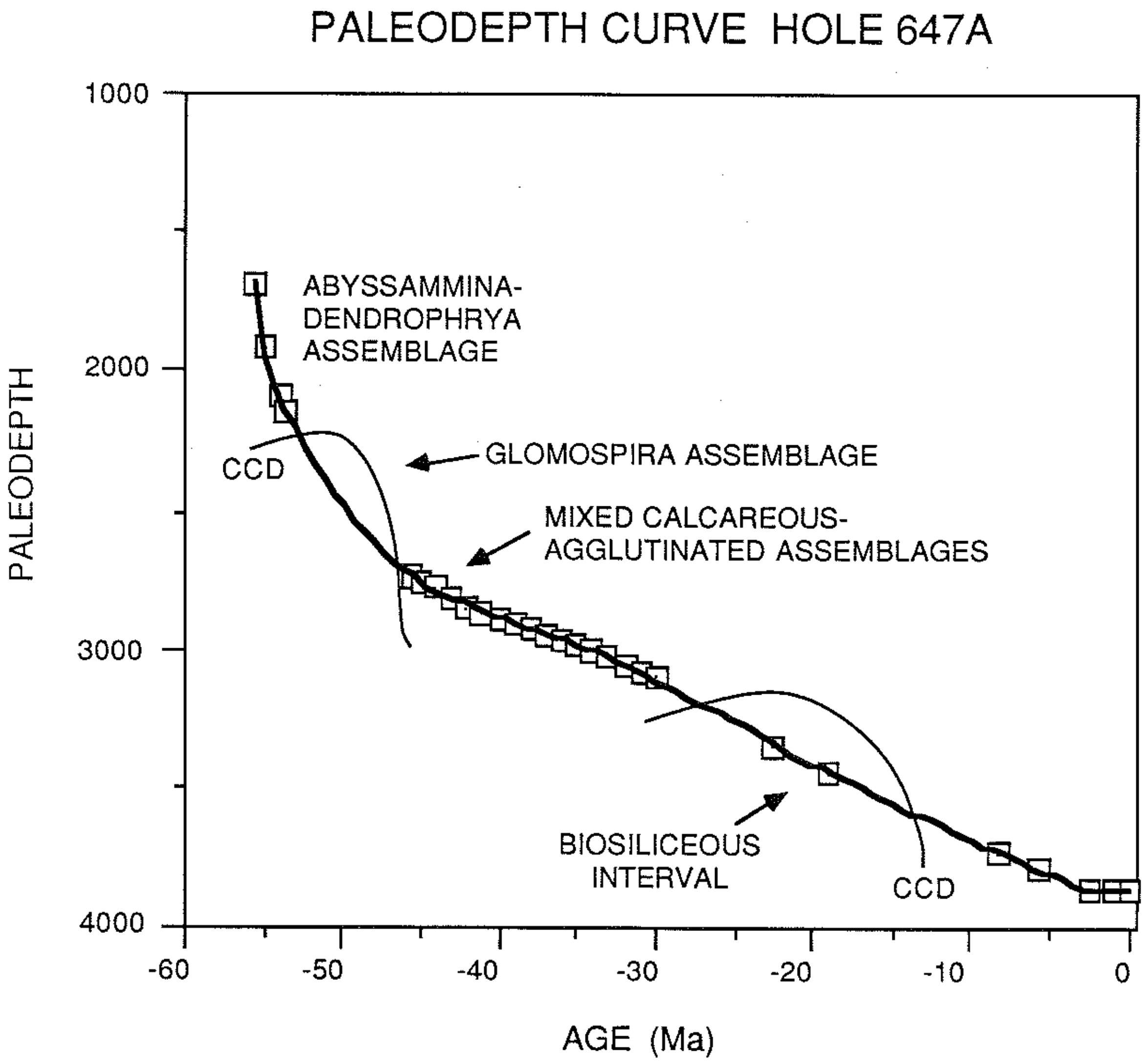
walteri, T. ruthven-murrayi, and two species of Reticulophragmium. This assemblage appears to be more typical of a clastic (deltaic) environmnent.

The greatest difference among benthic foraminiferal assemblages is observed between the Labrador Margin wells and DSDP Site 112, which has a backtracked paleodepth of ~1,700 m for the late Paleocene. The assemblage in Core 112-16R (Appendix 5-5) contains about 22 species dominated by finely agglutinated tubes, Glomospira irregularis, small ammodiscids, Praecystammina, Spiroplectammina spectabilis, and Subreophax. Of the four Labrador Margin wells studied, the greatest numbers of these forms were found in the lower Paleocene assemblage of the Indian Harbour well.

Eocene:

The benthic foraminiferal assemblages from Hole 647A and the Labrador Margin display differences related to paleobathymetry and the composition of the substrate. The Eocene Labrador Margin sequences were deposited in an outer neritic to upper bathyal clastic (deltaic) environment, while Site 647 experienced pelagic deposition in a ridge-crest setting at lower bathyal to abyssal depths. As a result, coarse grained forms such as Psammosphaera fusca, Dendrophrya robusta and Haplophragmoides (coarse) are absent from this hole. Other taxa, such as Rhizammina, Rhabdammina and Trochammina spp. are noticably smaller and more finely agglutinated. The subsidence history of Site 647 based on backtracking calculations is shown in figure 5-9.

Faunal diversity in exploration well samples from the Labrador Margin is noticeably lower than at Site 647, and abyssal calcareous benthic foraminiferal taxa are absent from these assemblages. Relatively few species of calcareous foraminifera are present in the Labrador Margin assemblages, and these are represented mainly by neritic to upper bathyal species of Nodosaria, Lenticulina, Plectofrondicularia, Cibicidoides, and uvigerinids. In contrast, the proportion of calcareous benthics in the Eocene of Hole 647A ranges from 0 to ~60% (Kaminski et al., in press, d). With the exception of T. alsatica in the Oligocene, and Nuttallides truempyi in the lower Eocene, none of the calcareous benthic species typical of the Labrador Margin were found in Hole 647A. A number of agglutinated taxa occur in both regions, including Rhabdammina spp., Ammodiscus latus, A. cretaceus, Reticulophragmium amplectens, R. placenta, Haplophragmoides walteri, Ammosphaeroidina sp.,



5-9. Paleodepth curve at Site 647 and the history of the lysocline. Thermal subsidence calculations are after Sclater _et_ _al_., 1985.

Reophax pilulifer, *Karreriella conversa*, *K. horrida*, *Spiroplectammina spectabilis*, *S. navarroana*, *Ammobaculites* aff. *polythalamus*, *Glomospira charoides*, *Trochamminoides* spp., and *Hormosina ovulum*. However, the species *Ammodiscus planus*, *Dorothia* sp. 6, *Ammomarginulina* sp. G, and the evolute morphotype of *Haplophragmoides* (*H. excavata*) occur only on the margin. Abyssal taxa found only in Hole 647A are *Ammodiscus nagyi*, *Hyperammina kenmilleri*, *Spiroplectammina cubensis* and species which utilize calcareous material in the construction of their tests (*Psammosphaera testacea*, *Arenobulimina*, *Clavulinoides*, and the morphotype of *Rhizammina indivisa* with planktonic tests).

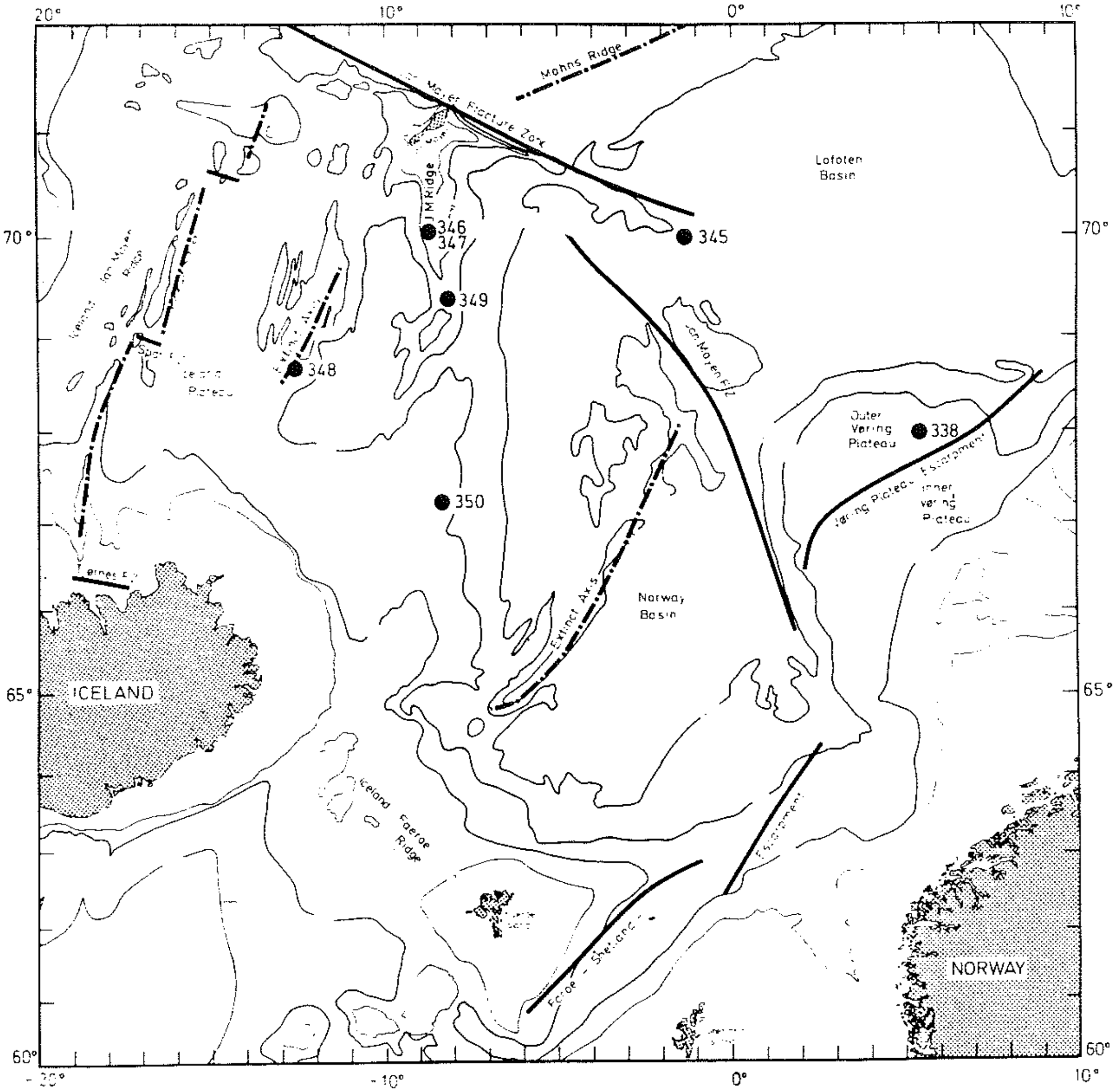
Important differences between assemblages can be found in the proportions of species and species groups and in disjunct stratigraphic ranges between the Labrador Margin and the abyssal site. A major difference in abundance between the margin and Hole 647A is observed in the relative proportions of tubular species and cyclamminids. In the North Leif well, the middle Eocene assemblage is dominated by *R. amplectens* and *C. placenta*, contains common *Budashevaella* and only rare tubular forms. In Hole 647, tubular forms are numerically dominant, and the relative abundance of *R. amplectens* is usually not greater than ~5%. A noticeable difference is also observed between the timing of extinction events in the Labrador Margin and deep Labrador Sea. The stratigraphic ranges of "deep" taxa determined above, such as *Glomospira charoides*, *Spiroplectammina spectabilis*, and *Hormosina ovulum* are diachronous from bathyal to abyssal depths. *Glomospira charoides* is a long ranging taxon that is present in the modern North Atlantic. Its local last occurrence is usually associated with the Paleocene/Eocene boundary on the Labrador Margin and in the southern North Sea, but the taxon extends to the top of the *Ammodiscus latus* - *Turrilina alsatica* Assemblage (lower Oligocene) in Hole 647A. *Hormosina ovulum* and *Hormosina excelsa* disappear near the Paleocene/Eocene boundary on the margin but are present (albeit in low numbers) in the lower Eocene of Hole 647A. *Spiroplectammina spectabilis* has its LO in the lower Eocene on the Labrador Margin, but it persists until the Eocene/Oligocene boundary in Hole 647A, as mentioned above. Other species, such as *A. latus*, *Ammobaculites* aff. *polythalamus*, *Ammosphaeroidina* sp 1, and *Karreriella conversa* possess more isochronous last occurrences (see Chapter 2). This suggests that these taxa have a more isobathyal distribution.

NORWEGIAN-GREENLAND SEA

Quantitative data on Paleogene agglutinated foraminiferal assemblages from the Norwegian-Greenland Sea have been reported by Verdenius and Van Hinte (1983) and in Chapter 3 of this study. The new microfossil data from ODP Site 643, combined with the data of Verdenius and Van Hinte (1983) now enables the construction of a paleobathymetric transect consisting of three sites: Sites 338 and 643 on the Vøring Plateau and Site 345 in the Lofoten Basin (Fig 5-10).

Site 338 is located on the crest of the Outer Vøring Plateau, and was drilled on a basement high on the seaward side of the Vøring escarpment. Hole 338 penetrated 400 m of sediment overlying basaltic basement of early Eocene age (Talwani, Udintsev et al., 1976). The basement at this site may actually be transitional between oceanic and continental, since landward of the Vøring escarpment, sediments are underlain by continental crust (Eldholm et al., 1987). As a result of the transitional nature of the basement, backtracking calculations (Sclater et al., 1985) at the site yield less reliable results. Early Eocene sedimentation at Site 338 was shallow-water and terrigenous, with predominant lithologies consisting of limey sandstones, glauconitic sandstones, mudstones and basalt breccias. Late Eocene to Oligocene sedimentation was more pelagic, reflecting the waning influence of local terrigeous sources as the Vøring Plateau subsided (Talwani, Udintsev et al., 1976).

Sites 643 and 345 are situated on oceanic basement, and can be backtracked to estimate paleodepth (Table 5-2). Hole 643A is located near the base of the Vøring Slope and was drilled on ocean crust between magnetic anomalies 23 and 24A. The age/depth estimates used for Hole 634A follow those of the shipboard scientific party (Eldholm, Thiede, Taylor et al., 1987) and those determined in Chapter 3. Hole 345 was drilled at a depth of 3195 m in the Lofoten Basin, but its precise position in relation to the magnetic anomaly pattern was not determined during Leg 38. By plotting the position of Site 345 on the magnetic anomaly map in Eldholm et al. (1987), a late Eocene (Anonaly 15 correlative) age is inferred for the basement. This estimate is in agreement with the age of sediments overlying basement reported by Verdenius and Van Hinte (1983). Although there may be some error associated with the estimate of the age of the crust used in Table 5-2, paleodepth calculations indicate that the depth of Site 345 in the late Eocene and



5-10. DSDP and ODP Sites in the Norwegian-Greenland Sea containing Paleogene agglutinated assemblages. Base map is after Gronlie and Talwani (1977), bathymetry in fathoms.

Table 5-2. Paleodepth of Norwegian-Greenland Sea sites.

Input the following values:

SITE	Water Depth	Sedim thick	Sedim Density	Age of Crust	time (my)	Sedthick for time	unsedim present depth	offset from curve	PALEODEPTH: unsedim paleod	sedim paleod
643	2764	565	1.7	55	23.5	165	3164.41	-1931.2	2533.11	2416.17
643	2764	565	1.7	55	28.2	155	3164.41	-1931.2	2380.64	2270.80
643	2764	565	1.7	55	36.6	155	3164.41	-1931.2	2070.07	1960.22
643	2764	565	1.7	55	52	55	3164.41	-1931.2	1174.96	1135.98
643	2764	565	1.7	55	55	0	3164.41	-1931.2	568.743	568.743
345	3195	762	1.8	38	23.5	602	3701.89	-955.64	2877.11	2476.65
345	3195	762	1.8	38	36.6	72	3701.89	-955.64	1958.47	1910.58
345	3195	762	1.8	38	38	0	3701.89	-955.64	1544.35	1544.35

Oligocene did not differ greatly from the depth of Site 643. However, the sediment lithology (turbidites in Hole 345 vs hemipelagic claystones in Hole 643A) suggests that Site 345 was the deeper site.

On the western side of the Lofoten Basin, upper Eocene to Oligocene benthic foraminiferal assemblages are present at DSDP Sites 346, 349, and 350 on the Jan Mayen Ridge. At present, the sites are located at depths of 732 m to 1289 m. Unfortunately, backtracking paleodepth estimates at these sites are meaningless.

Benthic Foraminiferal Paleobathymetry:

A. Late Eocene:

The major paleobathymetric patterns for the upper Eocene and Oligocene are summarized in figure 5-11. The shallowest assemblages (Hole 338) display the lowest diversity of agglutinated foraminifera observed in the Norwegian-Greenland Sea. Upper Eocene assemblages in this site consist solely of *Spiroplectammina spectabilis* and *Rhabdammina*. Oligocene assemblages contain only *S. compressa* (Verdenius and Van Hinte, 1983). Although *S. spectabilis* in usually found at deeper paleodepths in the Eocene (see discussion above on Labrador Margin), in some instances and for unknown reasons, this species appears in large numbers in relatively shallow (bathyal) environments such as in Hole 612 on the New Jersey Margin (Miller and Katz, 1987) or in Hole 338. The finding of a *S. spectabilis* assemblage in the lower Eocene of Hole 643A (see chapter 3) may be attributable to redeposition from a shallow source.

Hole 643A contains a considerably more diverse upper Eocene assemblage (~30 species) than Hole 338. The most common forms in the *S. compressa*-*R. amplectens* assemblage of Hole 643A (Fig. 5-11) are finely agglutinated tubular varieties, *Ammospheroidina* and *Spirosigmoilinella* spp. In contrast with Hole 643A, the most common upper Eocene forms in Hole 345 are coarse species of *Hyperammina* and *Psammosphaera*. This is no doubt attributable to the predominance of turbidite sediments near the base of this hole. Verdenius and Van Hinte report 22 species from the upper Eocene of Hole 345. One important difference between the assemblages from Holes 345 and 643A is the absence of the species *S. compressa*, *Ammosphaeroidina*, *Ammodiscus infimus*, *Dorothia principiensis*, and *K. siphonella* in the upper Eocene of Hole 345.

The upper Eocene of DSDP sites 346, 349 and 350 on the Jan Mayen Ridge

	JAN MAYEN RIDGE			LOFOTEN BASIN	VØRING SLOPE	VØRING PLATEAU
	SITE 346 (732 m)*	SITE 349 (915 m)	SITE 350 (1289 m)	SITE 345 (3216 m)	SITE 643 (2764 m)	SITE 338 (1297 m)
OLIGOCENE	Spirosigmoilinella	Hiatus Spirosigmoilinella sp Eggerella sp. Bathysiphon sp. *(Calc. benthics include* *Angulogerina gracilis* *Turrilina alsatica* *Sphaeroidina bulloides* *Cibicides spp., lagenids)*	Hiatus Bathysiphon sp. Rhabdammina sp. Psammosphaera fusca Dendrophrya sp.	Hyperammina rugosa Hyperammina nodata Haplo. compressa Haplo. walteri Saccorhiza ramosa C. rotundidorsata T. globigeriniformis Ammolagena clavata R. deflexiformis R. contortus Bathysiphon sp. P. fusca Spirosigmoilinella	Saccorhiza sp. S. compressa Spirosigmoilinella sp 1 Karreriella siphonella Recurvoides R. amplectens Rhizammina Troch. deformis Ammosphaeroidina Ammodiscus infimus	Spirosigmoilinella *(Calcareous benthics* *represented by* *Angulogerina gracilis* *Turrilina alsatica* *Sphaeroidina bulloides* *Cibicides spp., Melonis,* *and lagenids*
UPPER EOCENE	Bathysiphon sp. Rhabdammina sp. C. placenta C. acutidorsata P. fusca B. multicamerata S. spectabilis R. amplectens	Bathysiphon sp. Rhabdammina sp. R. deflexiformis P. fusca C. acutidorsata R. amplectens C. placenta H. cylindrica	Dendrophrya sp. R. amplectens Haplo. excavata S. spectabilis C. placanta Bathysiphon B. multicamerata	Hyperammina rugosa P. fusca Bathysiphon sp. R. amplectens C. placenta H. cylindrica R. deflexiformis	Rhizammina Ammosphaeroidina S. compressa Rhabdammina Spirosigmoilinella sp 1 Recurvoides H. walteri B. multicamerata R. amplectens	S. spectabilis Rhabdammina

*DEPTHS INDICATE PRESENT WATER DEPTH OF SITE

5-11. Paleobathymetry of agglutinated taxa in the Norwegian-Greenland Sea, compiled from Verdenius and Van Hinte (1983) and this study. Taxa are listed in order of decreasing relative abundance.

provides examples of shallow (probably upper bathyal) benthic foraminiferal assemblages. Hole 349 contains the shallowest upper Eocene assemblages of the three sites, which consist of a mixture of calcareous benthic and agglutinated species. The predominant sediments at all three sites consist of massive turbidites, which raises the possibility that calcareous components are redeposited. Verdenius and Van Hinte report ~23 species from Holes 346 and 349, and ~10 species from Hole 350. Most importantly, these authors report S. spectabilis from all three sites. Hole 350 also contains common specimens of H. excavata, which occurs in shallow facies in Spitsbergen (J. Nagy, personal communication 1986) and on the Labrador Margin.

Oligocene:

Oligocene paleobathymetric patterns in the Norwegian-Greenland Sea reveal a dramatic difference between shallow and deep sites. At Sites 338, 346 and 349, the only agglutinated species reported by Verdenius and Van Hinte is Spirosigmoilinella compressa. At Site 349, the Oligocene sediments contain a relatively diverse assemblage of calcareous benthics with Turrilina alsatica, Angulogerina, Sphaeroidina, Melonis, Gyroidina, Pullenia, Eponides, Cibicidoides and lagenids (Talwani, Udintsev, et al., 1976) which displays affinity to the type Rupelian of northwest Europe. In Hole 350, calcareous benthics are absent, and the Oligocene assemblage consists of four species of agglutinated foraminifera (Fig. 5-11).

More diversified assemblages (~25 spp) are present in Holes 345 and 643A. Both sites contain only agglutinated foraminifera. Hole 643A contains hemipelagic claystones with abundant Saccorhiza and Spirosigmoilinella spp. Hole 345, which recovered turbidite sediments, contains an assemblage dominated by the coarse tubular species Hyperammina rugosa and lituloids (Haplophragmoides spp.).

DISCUSSION:

A. Comparison of North Atlantic and Tethyan (Carpathian) Benthic foraminiferal Paleobathymetry:

The tectonic setting of the Outer Flysch Belt of the Carpathians in the Cretaceous and Paleogene has been variously interpreted as a marginal basin which underwent rifting without sea-floor spreading (Unrug, 1982) or that of a series of submarine trenches (Koszarski and Zytko, 1965) which underwent subduction in Tertiary time (Pescatore and Slaczka, 1984; Koszarski, 1985). Lithologic and microfaunal facies displayed maximum diversity in the late Senonian to early Paleogene, when thick turbidite sequences were deposited in rapidly subsiding troughs. From north to south these were the Skole-Tarcau, Silesian, Cernogora-Audia, Dukla-Grybow, and Magura Basins (Unrug, 1979, Koszarski, 1985). The Skole and Silesian basins were separated by the Subsilesian submarine high, which experienced mainly pelagic sedimentation.

During the Paleocene, lithofacies in the Carpathian basins became less differentiated as late Cretaceous clastic sedimentation gave way to more pelagic deposition. In the deep Skole, Silesian, Dukla and Magura troughs, noncalcareous pelagic claystones occur among turbidite deposits and contain agglutinated assemblages with few calcareous elements, whereas pelagic claystones and marls from the Subsilesian Unit contain a (predominantly bathyal) Velasco-type fauna containing calcareous and agglutinated taxa. The diversity of agglutinated taxa is highest in the Subsilesian Unit, where Jednorowska (1975) records 94 species. Foraminiferal assemblages from the Subsilesian Unit most closely resemble the assemblages from Trinidad, with about 70 species in common (table 3-1). Therefore, I have focused comparisons on examples from the Subsilesian Unit and adjacent deeper basins.

In southeastern Poland, variegated claystones of the Subsilesian Unit display changes in lithology and microfossil assemblages along a paleobathymetric transect from the axis of the unit to the flysch basins on either side (Koszarski, 1985). Sediments from the slopes of the Subsilesian high are tectonically disturbed, but lateral lithofacies changes can be observed in places. The shallower sediments from the axial region consist mainly of variegated marls with foraminiferal assemblages dominated by planktonic and calcareous benthic taxa. The agglutinated genera are represented mainly by lituolids, ammodiscids, hormosinids and ataxophragmiids (especially Dorothia, Marssonella, Tritaxia and Matanzia).

On the slopes of the Subsilesian high, marly sediments are laterally replaced by reddish-brown noncalcareous pelagic shales which contain a foraminiferal assemblage consisting entirely of agglutinated forms. Further to the south these shales are replaced by thick flysch sediments of the Silesian basin which contain more depauperate agglutinated assemblages. In the deep facies of the Silesian and Magura basins Jednorowska (1975) records 65 species of agglutinated foraminifera. Assemblages from Trinidad compare well with those from greenish-grey marly shales of Paleocene age from the southern paleoslope of the Subsilesian Unit exposed in the area of Sanok in southeastern Poland (Koszarski and Liszkowa, 1963). The assemblage is characterized by Rhabdammina spp., Dendrophrya ex gr. excelsa, Ammodiscus spp., Glomospira spp., Hormosina ovulum ovulum, Nodellum velascoensis, Recurvoides spp., Saccammina placenta, Trochamminoides spp., Haplophragmoides walteri, Kalamopsis grzybowskii, Cystammina pauciloculata (=Ammosphaeroidina pseudopauciloculata auct.), Rzehakina epigona, R. fissistomata, Spiroplectammina spectabilis, Karreriella spp., Dorothia trochoides, and Matanzia varians. Planktonic foraminifera are absent in these sediments, and rare calcareous benthic taxa are represented mainly by Nuttalides spp., Stensioeina beccariiformis, Osangularia florealis and Aragonia spp. As pointed out by Koszarski and Zytko (1965) these sediments were deposited near the CCD, since nearby they grade into noncalcareous shales.

The most complete quantitative data available on agglutinated assemblages from Southeast Poland are given by Jurkiewicz (1967), and the general similarity between Carpathian and North Atlantic assemblages allows us to distinguish consistent paleobathymetric patterns in species composition. Species that occur in greater abundance in the basin plain facies of the Lizard Springs formation and the Carpathian basins in southeastern Poland (Table 5-3) include Saccammina placenta, Ammodiscus spp., Glomospira spp., Hormosina ovulum, Reophax duplex, Recurvoides deflexiformis, and Trochamminoides spp. The genus Karreriella generally occurs in deeper facies in both Trinidad and Poland. Labrospira pacifica was not recognized at the time of Jurkiewicz's study but occurs in the upper Cretaceous of the Silesian Basin (Geroch and Nowak, 1984). Its occurrence in Table 5-3 is marked by question marks.

By synthesizing microfaunal, sedimentological and ichnofaunal evidence, Ksiazkiewicz (1975) interpreted the paleobathymetry of the subsilesian sediments as outer neritic to upper bathyal, and assigned upper bathyal paleodepths to sediments in the Skole and Silesian Basins. However, Koszarski and Zytko (1963) and Olszewska (1984) favor a deeper (bathyal to upper abyssal) interpretation based on the assumption of oceanic depths of the CCD in the Carpathian troughs. By comparing the taxonomic composition of the assemblages from SE Poland with DSDP Holes 543A and 641A, abyssal depths can

Table 5-3.

Agglutinated foraminifera with greater relative abundance in deeper facies of Trinidad and the Polish Carpathians. Carpathian data are compiled from Jurkiewicz (1967). Species listed in column 2 occur in greater abundance in both the Silesian and Skole Basins relative to the paleobathymetrically shallower Subsilesian Unit. Column 3 lists species with greater abundance in the Magura Basin relative to the paleobathymetrically shallower Dukla Unit.

TRINIDAD	POLISH CARPATHIANS	
LIZARD SPRINGS	SKOLE-SUBSILESIAN-SILESIAN	DUKLA-MAGURA
Bathysiphon sp.		
Rhizammina indivisa	*Dendrophrya* ex gr. *excelsa*	
Saccammina placenta	*Saccammina placenta*	*Saccammina placenta*
Hyperammina dilatata		
Ammodiscus spp	*Ammodiscus* spp	*Ammodiscus* spp
Glomospira spp	*Glomospira* spp	*Glomospira* spp
Rzehakina epigona		*Rzehakina epigona*
Hormosina ovuloides	*Aschemonella* spp	
Hormosina ovulum ovulum	*Hormosina ovulum ovulum*	*Hormosina ovulum ovulum*
Kalamopsis grzybowskii		*Kalamopsis grzybowskii*
Nodellum velascoensis		*Nodellum velascoensis*
Reophax duplex	*Reophax duplex*	*Reophax duplex*
	Ammobaculites deflexus	*Ammobaculites deflexus*
Haplophragmoides horridus	*Haplophragmoides horridus*	
Haplophragmoides lamella	*Haplophragmoides lamella*	
Haplophragmoides porrectus		
H. ex gr. *suborbicularis*	*H.* ex gr. *suborbicularis*	
Labrospira pacifica	??	??
Recurvoides deflexiformis	*Recurvoides deflexiformis*	*Recurvoides deflexiformis*
Recurvoides cf. subturbinatus	*Recurvoides cf. subturbinatus*	*Recurvoides cf. subturbinatus*
	Recurvoides walteri	*Recurvoides walteri*
Trochamminoides irregularis	*Trochamminoides coronatus*	*Trochamminoides coronatus*
Trochamminoides subcoronatus	*Trochamminoides subcoronatus*	*Trochamminoides subcoronatus*
Ammosphaeroidina pseudopauciloculata		*A. pseudopauciloculata*
	Trochammina altiformis	*Trochammina altiformis*
Spiroplectammina spectabilis		
Spiroplectammina navarroana		
Karreriella tenuis	*Karreriella tenuis*	
Karreriella sp. 2	*Karreriella conversa*	*Karreriella coniformis*

be ruled out because of the lack of diverse, smooth Haplophragmoides spp and other "Type-B" faunal elements in the Carpathian basins. Comparisons with the Lizard Springs Formation constrain the lower depth limit of the Carpathian basins to lower bathyal depths.

B. Comparison of Paleogene paleobathymetric patterns with existing models:

Paleobathymetric models of benthic foraminiferal distribution patterns have been established for sediments as old as mid-Cretaceous. For example, Sliter and Baker (1972) compiled a model of the bathymetric distribution of modern species on the Pacific Margin, and used this information to interpret the depositional environment of upper Cretaceous deposits in Southern California. A more generalized model was compiled by Haig (1979), who used both modern and fossil data to interpret global distribution patterns for mid-Cretaceous foraminiferids. Haig divided benthic assemblages into three general paleobathymetric associations. His classification of benthic assemblages into an epicontinetal neritic "Ammobaculites association", a neritic to bathyal "Marssonella association" and an abyssal "Recurvoides association" has been adopted for the alpine basins and these terms have become widely used in the literature (Geroch and Nowak, 1984; Slaczka and Gasinski, 1984; Olszewska, 1984; Pescatore and Slaczka, 1985). But what exactly are these associations and does this classification adequately describe the faunal patterns observed in the Paleogene North Atlantic and Alpine basins?

Haig based his subdivision of Cretaceous assemblages to a large extent on the work of Sliter and Baker (1972) from the California borderland as well as on a compilation of microfossil data from sedimentary basins in the Carribean, alpine Europe, India and New Guinea. Unfortunately, these localities are mostly in tectonically active regions where deep-water sediments have been obducted and uplifted, and reconstruction of the original bathymetry is not unequivocal. The use of this classification in the Paleogene North Atlantic and Tethyan flysch basins requires a number of assumptions. Firstly, it is necessary to assume that Haig's fossil data was based on samples with good paleobathymetric control. With the lack of an independent means of estimating paleobathymetry there is a possibility of introducing systematic errors into any paleoenvironmental interpretations. Secondly, there is the problem of evolutionary turnover between the Cretaceous and Paleogene. One must also

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Hyperammina dilatata		
Ammodiscus spp	*Ammodiscus* spp	*Ammodiscus* spp
Glomospira spp	*Glomospira* spp	*Glomospira* spp
Rzehakina epigona		*Rzehakina epigona*
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Haplophragmoides horridus	*Haplophragmoides horridus*	
Haplophragmoides lamella	*Haplophragmoides lamella*	
Haplophragmoides porrectus		
H. ex gr. *suborbicularis*	*H.* ex gr. *suborbicularis*	
Labrospira pacifica	??	??
Recurvoides deflexiformis	*Recurvoides deflexiformis*	*Recurvoides deflexiformis*
Recurvoides cf. subturbinatus	*Recurvoides cf. subturbinatus*	*Recurvoides cf. subturbinatus*
	Recurvoides walteri	*Recurvoides walteri*
Trochamminoides irregularis	*Trochamminoides coronatus*	*Trochamminoides coronatus*
Trochamminoides subcoronatus	*Trochamminoides subcoronatus*	*Trochamminoides subcoronatus*
Ammosphaeroidina pseudopauciloculata		*A. pseudopauciloculata*
	Trochammina altiformis	*Trochammina altiformis*
Spiroplectammina spectabilis		
Spiroplectammina navarroana		
Karreriella tenuis	*Karreriella tenuis*	
Karreriella sp. 2	*Karreriella conversa*	*Karreriella coniformis*

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The Cretaceous Model:

Shelf and Slope Assemblages: Sliter and Baker (1972) compiled the upper depth limits and characteristic occurrences of modern foraminiferal genera along the eastern Pacific margin. Using modern patterns as a key to the past, they constructed a paleobathymetric model of Cretaceous genera by identifying genera or homeomorphs in common with the modern bathymetric succession. Cretaceous assemblages were assumed to indicate water depths analogous to their modern counterparts living in similar clastic environments. They recognized five generalized assemblages indicative of slope and shelf environments (Fig. 5-12). Haig (1979) named the slope assemblages the "Marssonella association" which was further subdivided according to the paleobathymetric model of Sliter and Baker.

Sliter and Baker used their model to interpret the paleobathymetric environment of the upper Cretaceous Point Loma Formation at La Jolla Bay, California. These flysch sediments were interpreted as being deposited in a setting similar to the modern slope basins off Southern California in water depths of up to 1000 m. The assemblages recorded by Sliter and Baker from La Jolla can be regarded as the type locality of the "Marssonella association" of Haig.

The paleodepth of base of the Point Loma Formation at La Jolla was interpreted by Sliter and Baker as 900-1000 m. This is the deepest part of the sequence, and the benthic assemblage is dominated by Bathysiphon, Cribrostomoides, Dorothia, Gaudryina, Gyroidinoides, Lenticulina, Osangularia, Praebulimina, Pullenia, Reussella, Saracenaria, Reussella, Spiroplectammina, and Stilostomella. This assemblage corresponds to middle bathyal depths as determined from the model. Lower bathyal assemblages were not reported from the Point Loma Formation, but were discussed in the paleobathymetric model. Haig noted that these assemblages are dominated by agglutinated species (mainly Glomospira, Hyperammina, Pelosina, Hormosina, Saccammina, Haplophragmoides and Bathysiphon), and regarded these as transitional to abyssal assemblages.

Abyssal Assemblages: The abyssal realm was not included in the model of

PALEO-DEPTH	CRETACEOUS PALEOBATHYMETRY Sliter & Baker, (1972) Haig (1979)			NORTH ATLANTIC PALEOCENE PALEOBATHYMETRY	
				Low-Latitude	Boreal
200 UPPER SLOPE 600	"MARSSONELLA ASSOCIATION"	Osangularia Gavelinella Gyroidinoides Hoeglundina Silicosigmoilina Bathysiphon Gaudryina Cribrostomoides Praebulimina	Dorothia Spiroplectammina Ammodiscus Trochammina Colomia nodosariids Tappanina Pyramidina Globulina	Clavulinoides Dorothia Phenacophragma coarse Haplophrag. Ammobaculites Arenobulimina Gaudryina Rhabdammina	cyclamminids D. robusta Rhabdammina coarse Haplophrag. coarse Trochammina Recurvoides walteri Budashevaella H. excavata Ammodiscus planus Dorothia sp. 6
MIDDLE SLOPE 1200		Praebulimina Dorothia Osangularia Hoeglundina Gaudryina Chilostomella Allomorphina Pullenia Planulina	Bathysiphon Silicosigmoilina Hyperammina Cribrostomoides Spiroplectammina Gavelinella Ammodiscus Ammodiscoides Stilostomella	Ammosphaeroidina Rhizammina Rzehakina Rec. gerochi S. spectabilis Sacc. placenta Bathysiphon Glomospira Hormosina Kalamopsis smooth Haplophrag. Labrospira Nodellum Trochamminoides Karreriella	Glomospira (G. charoides, G. irregularis) Hormosina (H. ovulum, H. excelsa) S. placenta Ammosphaeroidina Cribrostomoides Trochamminoides S. spectabilis Reophax duplex Subreophax Glomospirella Labrospira
LOWER SLOPE 2000		Glomospira Bathysiphon Hyperammina Ammodiscus Gaudryina Cribrostomoides Silicosigmoilina Osangularia Pullenia	Praebulimina Saccammina Pelosina Hormosina Allomorphina Gavelinella Haplophragmoides Spiroplectammina		
ABYSSAL	"RECURVOIDES ASSOCIATION"	RECURVOIDES PLECTORECURVOIDES THALMANNAMMINA UVIGERINAMMINA HORMOSINA DENDROPHRYA KALAMOPSIS		fine tubular species HORMOSINA GLOMOSPIRA minute AMMODISCUS S. SPECTABILIS TROCHAMMINOIDES KALAMOPSIS RECURVOIDES PRAECYSTAMMINA SUBREOPHAX	

5-12. Comparison of upper Cretaceous and Paleocene paleobathymetric models for agglutinated foraminiferal assemblages. Cretaceous data compiled from Sliter and Baker (1972) and Haig (1979).

Sliter and Baker, and Haig referred all abyssal assemblages to a "*Recurvoides* association" characterized by agglutinated foraminifera. Typical genera in this assemblage were listed as *Recurvoides*, *Plectorecurvoides*, *Thalmannammina*, *Uvigerinammina*, *Hormosina*, *Dendrophrya*, and *Kalamopsis*. Haig noted the similarity of the mid-Cretaceous assemblage with the fauna reported by Bandy and Rodolfo (1964) from depths below 3400m in the Peru-Chile Trench. Haig listed three localities that contain the "*Recurvoides* association". The first two are from upper Cretaceous red clays in DSDP Sites from the western Pacific and Argo Abyssal Plain recovered on Legs 20 and 27. The benthic foraminiferal assemblages from these sites were first described by Krasheninnikov (1973, 1974) who regarded them as unique and created about 40 new species. Many of the remaining species at these sites not regarded as new by Krasheninnikov are also known from the Alpine Mountain Belt. Krasheninnikov (1974) noted that although similar genera are present in both regions, upper Cretaceous assemblages from the Carpathians differ from Indian Ocean assemblages in morphology and the types of species present. He remarked that Carpathian specimens are larger and possess coarsely agglutinated tests. This led Krasheninnikov to speculate that true abyssal sediments may be absent on the continents. Despite this fact, Haig included mid-Cretaceous assemblages from Alpine and Carpathian area as the third type locality of the "*Recurvoides* association", and subsequent authors have followed this usage.

A comparison of Paleogene paleobathymetric patterns with the Cretaceous model (Fig. 5-12) reveals that Haig's threefold paleobathymetric subdivision of agglutinated faunas cannot be applied to Paleogene assemblages without qualification. An important difference is that the "*Marssonella* association" as defined by Haig cannot be recognized in boreal areas or in sediments younger than Paleocene in the Tethyan region. Assemblages containing meaningful proportions of calcareous ataxophragmiids (*Arenobulimina*, *Clavulinoides*, *Dorothia*, *Gaudryina*, *Matanzia*) are present in upper bathyal assemblages in Trinidad, Zumaya and the Subsilesian Unit of the Polish Carpathians, but these genera are rare in the North Sea and Labrador.

If Carpathian localities are excluded from the definition of the "*Recurvoides* association", this association now corresponds to the "Type-B" fauna, However, there is no strict Paleogene analog of this fauna. The majority of the typical upper Cretaceous "Type-B" species described by Krasheninnikov have their last occurrences in the Maastrichtian and Paleocene.

Eocene sediments in deep abyssal (>4 km) sites in the Atlantic are barren of foraminifera. The closest example of an abyssal fauna in the Eocene is found in Hole 647A, but with the exception of the *Glomospira* facies the site was situated above the oceanic lysocline and therefore the analogy with upper Cretaceous abyssal assemblages is not exact. Moreover, even in bathyal faunas the relative abundance of *Recurvoides* does not change appreciably from the shallow to deep assemblages. In Trinidad and the Labrador transect, its relative abundance shows no meaningful pattern. A comparison of paleobathymetry of flysch-type agglutinated assemblages allow us to identify other species which display interregional depth-related patterns. Agglutinated taxa which consistently occur in greater abundance in deeper facies in the Paleogene include the genera *Bathysiphon*, *Rhizammina*, *Ammodiscus*, *Glomospira*, *Nodellum*, *Subreophax*, *Trochamminoides*, *Ammosphaeroidina*, small, finely agglutinated species of *Haplophragmoides*, and the species *Saccammina placenta*, *Reophax duplex*, *Hormosina ovulum*, *Recurvoides deflexiformis*, and *R. subturbinatus*. In Tethyan areas, *Rzehakina* and non-calcareous species of *Karreriella* can be added to the list of deeper taxa.

SUMMARY:

The lower Lizard Springs Formation of Trinidad contains both *in situ* and penecontemporaneously redeposited assemblages. Sedimentological and calcareous microfossil evidence enable the construction of a paleobathymetric microfossil facies model for the lower Lizard Springs Formation. Three faunas were delineated by Q-mode factor analysis which explain most of the variance.

The deepest assemblage in the material studied is dominated by small, finely agglutinated species such as *Ammosphaeroidina pseudopauciloculata*, *Rhizammina indivisa*, and *Recurvoides gerochi*, with a lesser contribution by *Rzehakina epigona*, *Spiroplectammina spectabilis* and *Saccammina placenta*. This assemblage occurs in bioturbated, noncalcareous clays and probably represents an *in situ* fauna in pelagic sediments deposited below a local CCD. An assemblage strongly dominated by *Dendrophrya* ex gr. *excelsa* is found in redeposited sediments containing calcareous benthics dominated by *Nuttallides truempyi*. This fauna was probably redeposited from a deep, distal source. A third faunal assemblage occurs in the basal interval of well G-287. This fauna is dominated by species associated with a calcareous facies, such as *Clavulinoides globulifera*, *Dorothia retusa*, *Phenacophragma beckmanni*, and *Haplophragmoides* ex. gr. *suborbicularis*. This assemblage occurs with a calcareous benthic fauna containing an increased abundance of *Stensioeina beccariiformis*, and is interpreted as being redeposited from a shallower, more proximal source.

The paleobathymetry of agglutinated foraminifera in the northern Atlantic can be reconstructed from a transect of wells on the Labrador Margin and DSDP/ODP sites in the Labrador Sea, Norwegian-Greenland Sea and Galicia Margin. Paleobathymetric patterns in northern assemblages differ from low-latitude assemblages by the lack of a shallow "*Marssonella* association" of calcareous ataxophragmiids. Shallow Maastrichtian and Paleogene assemblages contain abundant coarse tubular species and lituolids with only very rare calcareous ataxophragmiids. Shallow Eocene assemblages on the Labrador Margin contain few tubular species and are dominated by cyclamminids. However, shallow assemblages on the Vøring Plateau and Slope contain abundant tubular forms, cyclamminids, and acmes of *S. spectabilis*. Deeper assemblages contain more abundant *Glomospira*, *Hormosina*, *Trochamminoides*, *Ammosphaeroidina*, *Praecystammina*, and finely agglutinated lituolids (*Cribrostomoides*, *Haplophragmoides*, *Labrospira*). Cretaceous deep assemblages contain abundant

Uvigerinammina, and Paleocene deep assemblages contain more abundant *S. spectabilis*. *Hormosina ovulum* was common in deep assemblages before the early Eocene.

The paleobathymetric subdivision of Cretaceous agglutinated assemblages of Haig (1979) cannot be used in the Paleogene. The relative abundance of *Recurvoides*, the nominate taxon of Haig's deep assemblage, does not display meaningful depth-related patterns in the North Atlantic. The "*Marssonella* association" does not occur at high latitudes, or above the Paleocene in low latitudes. It is therefore neccessary to use other species as paleobathymetric indicators in the Paleocene. A comparison of paleobathymetry of agglutinated assemblages from Trinidad, Poland, Labrador and the Norwegian-Greenland Sea enables the recognition of interregional depth-related patterns. Agglutinated taxa which generally occur in greater abundance in deeper facies include the genera *Bathysiphon*, *Rhizammina*, *Ammodiscus*, *Glomospira*, *Rzehakina*, *Karreriella*, *Nodellum*, *Trochamminoides*, *Ammosphaeroidina*, small, finely agglutinated *Haplophragmoides*, and the species *Saccammina placenta*, *Reophax duplex*, *Hormosina ovulum*, *Recurvoides deflexiformis*, and *R. subturbinatus*. The Carpathian basins do not contain "type-B" elements typical of abyssal DSDP sites, and therefore the basinal facies were probably deposited at shallower (bathyal) paleodepths.

The paleobathymetry of some deep-water species may have been influenced by latitudinal effects. Most noteably, the Eocene distribution of *S. spectabilis* displays tropical submergence, since it occurs at relatively shallow paleodepths at high latitudes. This finding is consistent with the observation of Thompson (1877) that the modern abyssal fauna of the ocean resembles the shallow-water faunas of high northern and southern latitudes.

B. PALEOCEANOGRAPHIC SIGNIFICANCE OF AGGLUTINATED FORAMINIFERAL ASSEMBLAGES.

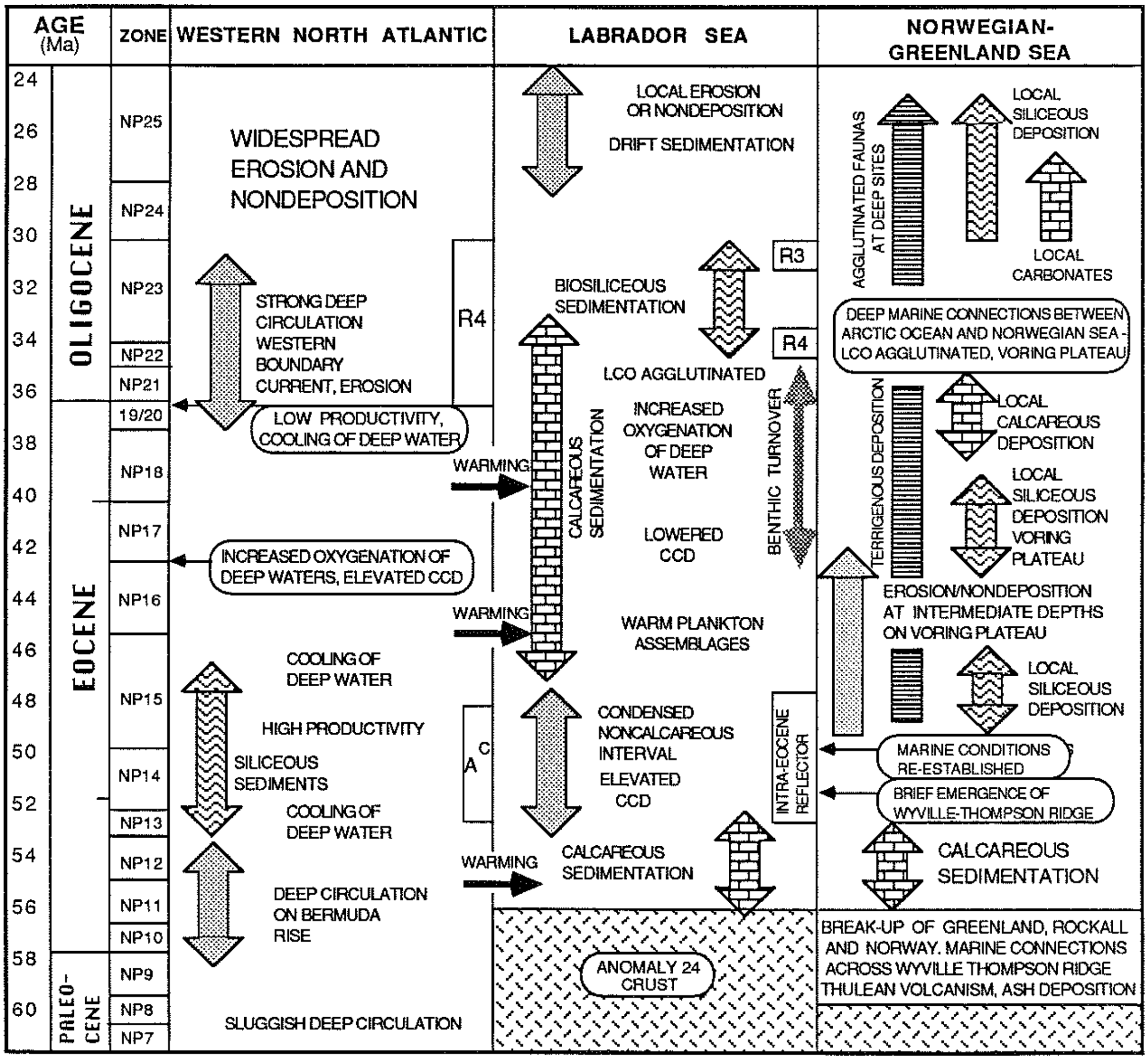
1. The *Glomospira* Facies and the NP14 Sealevel Event -

In Chapter 2, I noted the occurrence of agglutinated assemblages with abundant Glomospira associated with organic carbon-rich substrates in the Gulf of Mexico. In Chapter 3, I reported assemblages of exclusively agglutinated foraminifera characterized by *Glomospira* spp. in lower Eocene and lower middle Eocene sediments from the Labrador Sea and Norwegian-Greenland Sea. Similar *Glomospira* facies have been found in the Austrian Alps (Grun *et al*., 1964), the Swiss Alps (Winkler, 1984), in the Carpathian basins in Poland (Geroch *et al*., 1967; Morgiel and Olszewska, 1981), and in the Tanger Unit of the Moroccan Rif Zone (Morgiel and Olszewska, 1982). In the Dulka Unit of the Polish Carpathians, the age of the *Glomospira* facies was constrained by nannofossil-bearing sediments above and below as NP12 to NP14 (Olszewska and Smagowicz, 1977). As in the Labrador Sea and Norwegian-Greenland Sea holes, in both Poland and Morocco the *Glomospira* facies is associated with reddish or variegated (red and green) shales. Morgiel and Olszewska (1982) noted the remarkable similarity in species composition of this assemblage on both the northern and southern margins of the Mediterranean Tethys. Kaminski *et al*. (in press, d) were the first to report Eocene *Glomospira* assemblages outside of Tethyan alpine areas.

In Hole 647, a *Glomospira* facies was found in a 20 m interval of noncalcareous claystones and is coincident with an increase in TOC (Fig. 2-14). The carbonate-free interval is evidence of a rise in the lysocline in the Labrador Sea to a level above 2500 m (Fig. 5-9). The age of the *Glomospira* assemblage in Hole 647A is constrained by nannofossils occurring above and below as NP13 to the lower portion of Zone NP15 (CP13b) (Firth, in press). The lithologic change from the carbonate-free interval with *Glomospira* (below) to calcareous sediments above also corresponds to a mid-sediment seismic reflector which can be traced regionally in the Labrador Sea (S.R. Srivastava, personal communication, 1987). An assemblage with common *Glomospira* also occurs at the top of the lower Eocene in the Bonavista C-99 well on the Labrador Margin (Fig. 2-21). In Hole 643A, in the Norwegian-Greenland Sea, an acme of *Glomospira* was found in a ~10 m interval directly overlying an interval with abundant radiolarians. Although the relative abundance of *Glomospira* in Hole 643A is not as high as in Hole 647A, the assemblage is neveretheless distinctive since Glomospira is absent from overlying and underlying assemblages. The temporal coincidence of Glomospira facies in both the Atlantic and Tethys suggests a common ecologic cause.

In the modern Gulf of Mexico, Glomospira assemblages have been reported in areas of low sedimentation rates, such as on submarine highs (Poag, 1981). The Glomospira facies in Hole 647A also represents a period of lowered sedimentation rate (~5 m/my, assuming continuous sedimentation, compared with 37 m/my in the middle to late Eocene). A number of important oceanographic events occur near the early/middle Eocene Boundary (Fig. 5-13). The earliest middle Eocene (Zone NP14) was a time of lowered global sealevel (Haq et al., 1987), and much increased paleoproductivity as shown by the presence of biosiliceous sediments in the equatorial Atlantic. Berggren and Hollister (1974) cited volcanism in the Carribean and Norwegian-Greenland Sea as a possible source of nutrients to the North Atlantic. Planktonic and benthic carbon isotope ratios display increased surface to bottom gradients from the early Eocene to the early middle Eocene (Boersma et al., 1987), compared with the late Eocene. These increased carbon gradients suggest higher nutrient contents and paleoproductivity. The highest surface water δ13 C values in the Atlantic were recorded from the lower middle Eocene. In Hole 643A, the Glomospira facies is associated with an interval containing radiolarians, which suggests increased productivity. In Hole 647A, although radiolarians are not present, the findiing of increased TOC contents despite lower sedimentation rates in the Glomospira facies is in aggreement with the scenario of increased nutrients, and (presumably) decreased oxygenation of bottom water. The synecology of the assemblage is consistent with the idea of high productivity. Glomospira and Ammodiscus are assumed to be epifaunal detritus feeders (Haynes, written communication to Jones and Charnock, 1985), and presumably are well-adapted to take advantage of an increased amount of food particles derived from the surface layer of the ocean.

Climatic and paleoceanographic changes were coincident with the eustatic sealevel lowering in the basal Lutetian. In the Atlantic, surface waters cooled approximately 1°C and deep water cooled about 2°C across the early/middle Eocene boundary (Boersma et al., 1987). At the same time, the proto-Gulf Stream flow intensified, possibly due to restriction of the circum-global current in the Carribean (Tucholke and Mountain, 1986), and an east -



5-13. A synopsis of Paleogene depositional environments, paleoceanography and important faunal events in the high-latitude North Atlantic, compiled from Berggren and Olsson (1986), Tucholke and Mountain (1986), Boersma et al. (1987) and this study.

west gradient is established among planktonic foraminiferal faunas (Boersma *et al.*, 1987), indicating intensification of the Atlantic subtropical gyres. The increased circulation and eustatic sealevel drop is a likely cause of numerous hiatuses encompassing the early/middle Eocene boundary at DSDP Sites in the western North Atlantic (Poag, 1987; Miller and Hart, 1987) and at bathyal depths on the Goban Spur (Poag *et al.*, 1985), Rockall Margin (Tucholke and Mountain, 1986), and Labrador Margin - Northern Grand Banks (Gradstein, 1987). Among benthic foraminifera, there appears to be a reduction in numbers of *Bulimina* and an increase in *Nuttallides truempyi* across the Ypresian/Lutetian Boundary in the western North Atlantic (Poag and Low, 1987) as well as in the Labrador Sea. Miller *et al.* (1987) ascribed the sealevel fluctuations in the early and middle Eocene to global tectonic and sea-floor spreading rate changes. In the North Atlantic, sea floor spreading rate changed from ~21 mm/yr to ~9 mm/yr between Anomaly 21 and 22 (Srivastava, 1978), and in the Labrador Sea a spreading rate decrease from 7.5 mm/yr to ~2 mm/yr occurred between Anomaly 20 and 21 (S.R. Srivastava, personal communication, 1987).

Carbon isotopic evidence at Walvis Ridge Site 357 (Boersma *et al.*, 1987), points to some nutrient-poor deep-water production in the early middle Eocene. Benthic foraminifera record δC-13 ratios of ~0.5 ^{o}/oo in Zone P10, compared with values of around -0.1 ^{o}/oo in the lower Eocene (Boersma *et al.*, 1987). The source of the deep water, however, is still a matter of debate. During the earliest Lutetian sea-level lowstand, marine connections between the Atlantic and the Norwegian-Greenland Sea were temporarily interrupted allowing the trans-Atlantic migration of terrestrial faunas (McKenna, 1983). Berggren and Olsson (1986) noted that the opening of surface connections between the Arctic and the Norwegian-Greenland Sea in the early middle Eocene may have been a source of proto-NADW. However, the presence of warm temperate early Eocene floras and faunas in northern high latitudes (Schweitzer, 1980; Wolfe, 1980; Estes and Hutchison, 1980) would argue against outflow from the Norwegian-Greenland Sea being very cold. Annual mean early Eocene temperature in Spitsbergen has been estimated as between 15 and 18°C (Schweitzer, 1980). Winter temperatures must have been mild, since the fossil flora contains species which do not tolerate frosts (Schweitzer, 1980; M.J. Head, unpublished data).

Berggren and Schnitker (1983) postulated a northward flow of cool water from the South Atlantic, based on a comparison of oxygen isotopic evidence.

Carbon isotopic evidence from Hole 647A lend support to the idea of a southern source of nutrient-depleted deep water. Benthic δC-13 ratios at Site 647A average about -0.5 ^{o}/oo (Arthur et al., in prep). These values are about 1 ^{o}/oo lighter than the values recorded at Site 367. Poag (1987) placed the onset of significant thermohaline circulation in the North Atlantic as early as the Paleocene/Eocene boundary, before the opening of the Norwegian-Greenland Sea. Recent oxygen isotopic evidence, however, indicates that cooling near Antarctica may have resulted in deep-water production as early as the late Cretaceous (Barrera et al. 1987).

2. Agglutinated foraminifera and the Eocene/Oligocene Boundary -

Site 647 is unique because no other DSDP Site in the North Atlantic contains assemblages of flysch-type agglutinated foraminifera in an Eocene-Oligocene section. From the middle Eocene to the lower Oligocene, agglutinated foraminifera in Hole 647A display a reduction in abundance, a reduction in size, and a decrease in diversity as the flysch-type taxa underwent a series of extinctions and local pseudoextinctions over a period of 5 m.y.. There is a cluster of last occurrence events near the Eocene/Oligocene boundary, when about 10 species disappeared within a span of 0.5 m.y. With the exception of two species, the flysch-type taxa disappeared from the deep Labrador Sea by the end of Zone NP21. The disappearance of flysch-type taxa was essentially completed before the onset of major biogenic silica deposition, denoted by the R4 seismic reflector at 240 mbsf in Hole 647A.

Unlike at other DSDP sites in the North Atlantic, the Eocene/Oligocene boundary at Site 647 is not delineated by a hiatus or any obvious lithologic change. The abundance of biosiliceous components and TOC increased from the upper Eocene to the lower Oligocene of Hole 647A, therefore there is no evidence of oligotrophic conditions observed in other areas of the North Atlantic (Boersma et al., 1987). The earliest Oligocene acme of Nuttallides umbonifera at Site 647 apparently correlates with coeval assemblages from the Bay of Biscay (Miller, 1983) and the equatorial Pacific (Corliss, 1979).

The sequence of last occurrences of taxa in Hole 647A is shown in figure 3-17. Among agglutinated foraminifera, last occurrences began at an increased rate near the middle/late Eocene boundary. The first group of species to disappear were agglutinated taxa with walls comprised of small planktonic foraminiferal tests, such as Psammosphaera testacea and a species of Rhizammina. Small elongate forms such as Karreriella conversa, Bigenerina sp., Reophax guttifer, and Karreriella coniformis, and the delicate species such as Hormosina distans, Hyperammina subnodosiformis, and Hyperammina kenmilleri were also among the first forms to disappear in the late Eocene. However, some of these last occurrences were local extinctions, since K. conversa, P. testacea and R. guttifer, and H. distans are all found in the modern North Atlantic. Near the Eocene/Oligocene boundary, the species which disappeared were mainly lituolids and species which presumably shared an epifaunal habitat, such as Glomospira serpens, Trochammina and Saccammina.

About 10 species of "flysch-type" taxa survived the Eocene/Oligocene boundary at Site 647. These were either robust forms, such as Rhabdammina, Ammodiscus latus and Cribrostomoides, or species with smooth, well-cemented tests, such as Ammodiscus cretaceous, Bathysiphon, or Glomospira charoides. Interestingly, over half the surviving species were ammodiscids or similarly coiled forms (Spirosigmoilinella). Such species are epibenthic detritus feeders, according to Jones and Charnock (1985), but the assemblage in Hole 647A still contains a mix of infaunal species (Reophax subnodulosus) and suspension feeders (Rhabdammina and Bathysiphon). Therefore, there was no obvious change in the synecologic structure of the assemblage, as observed in the Miocene drift sediments at Site 646 (see Chapter 2).

The disappearance of agglutinated taxa near the Eocene/Oligocene boundary in Hole 647A suggests a change in water mass properties as a primary cause. Delicate species disappeared first, indicating that the faunal turnover may be at least partly attributed to preservational factors. This observation is therefore consistent with the "old bottom water model" of Gradstein and Berggren (1981). Although carbon δC-13 values in Hole 647A show no trend with depth, the Eocene Cibicidoides values are relatively light (mean = -0.55 ^{o}/oo) which suggests the presence of comparatively "old" nutrient-rich bottom water (Zachos et al., in press). Although there is no benthic isotopic data for the Oligocene of Hole 647A, data from Sites 558 and 563 (Miller and Fairbanks, 1985) indicate the presence of "young" nutrient-poor water in the North Atlantic between 36 and 33 Ma. I suspect that increased oxygenation of deep water resulted in increasingly poorer preservation of agglutinated foraminifera observed in Hole 647A.

3. Paleoceanographic Significance of Flysch-Type Assemblages

The disappearance of agglutinated foraminifera in the deep Labrador Sea near the Eocene/Oligocene boundary has been attributed to changes in water mass properties associated with the onset of vigorous thermohaline circulation in the North Atlantic (Miller et al., 1982). Typical bottom water temperatures cooled from about 6-10 °C in the late Eocene to temperatures similar to modern bottom water in the earliest Oligocene (Miller et al., 1987). At the same time, the Atlantic carbon isotope values began to diverge from mean ocean water near the Eocene/Oligocene boundary. A comparison of Atlantic benthic carbon isotope records with the Pacific indicates a maximum supply of nutrient-depleted bottom water between 36 and 34 Ma (Miller and Fairbanks, 1985; Miller and Katz, 1987a). The source of the cool, nutrient-depleted deep water in the early Oligocene was reported by Miller and Tucholke (1983) as Greenland-Scotland Ridge Overflow Water, analogous to the present-day North Atlantic. Therefore, one needs to look to the Norwegian-Greenland Sea for the ultimate cause of the Eocene-Oligocene faunal turnover at Site 647.

Berggren and Schnitker (1983) and Miller and Tucholke (1983) noted that the opening of a deep channel through the Fram Strait between Greenland and Spitsbergen during Chron 13 probably allowed cold water from the Arctic to enter the Norwegian-Greenland Sea, and from there, to enter the North Atlantic. However, this Arctic water was as dense as the deep water already present in the deep Norwegian-Greenland Sea. At deep sites in the Lofoten Basin and at the base of the Vøring Plateau agglutinated foraminiferal assemblages were preserved throughout the Oligocene, indicating a stable, stratified water column. Shallow sites on the Vøring Plateau, however, display a faunal turnover from agglutinated assemblages in the Eocene to predominantly calcareous assemblages in the Oligocene. Agglutinated foraminifera also disappeared near the Eocene/Oligocene boundary in exploration wells from the Beaufort Sea (Young and McNiel, 1983). Therefore, if Arctic water was the cause of this faunal turnover, the water mass may have been analogous to present-day Polar Water, which is present in the Norwegian-Greenland Sea to a depth of 150 m (Johannessen, 1986). Since there most likely was no connection with the Atlantic through the Denmark Straits until the mid Miocene (Thiede and Eldholm, 1983), Polar Water flowing south along the east coast of Greenland would have turned east at the Greenland-Scotland Ridge to recirculate through the Norwegian-Greenland Sea.

An alternative scenario exists which may account for the disappearance of agglutinated foraminifera in the shallow Norwegian-Greenland Sea. Agglutinated foraminifera also disappear near the Eocene/Oligocene boundary in exploration wells from the Viking Graben (Kaminski and Gradstein, 1987). The outflow of water through the Faeroe-Shetland Channel must be volumetrically balanced by the inflow of Eastern Atlantic surface water, as it is today (Worthington, 1970). Return flow to the Norwegian-Greenland Sea would have existed through the Faeroe-Shetland Channel and through the North Sea via the English Channel. Therefore, Atlantic water may have been present over the Vøring Plateau in the early Oligocene, analogous to the present-day Norwegian Current. This Atlantic water would have circulated along the eastern margin of the basin through the Greenland-Spitsbergen Channel and into the Arctic Ocean. The first possible evidence for the advection of Atlantic water into the Norwegian-Greenland Sea was the finding of Muller (1976) of an abundant and diverse "mid" Oligocene nannoflora on the Vøring Plateau. Unfortunately, microfossil data near the Eocene/Oligocene boundary is still tenuous. The addition of warm saline water into the Arctic realm may have affected the density structure of the surface layer, thereby effecting faunal changes at neritic to upper bathyal depths. However, the Atlantic vs. Polar Water models of faunal change remain to be tested micropaleontologically using benthic and planktonic microfossils at the Vøring Plateau and in the Beaufort Sea.

The disappearance of flysch-type taxa near the Eocene/Oligocene boundary in the Labrador Sea and in shallow Vøring Plateau Sites at first glance suggests an oceanographic link between the regions. Miller et al. (1982), Berggren and Schnitker (1983) and Tucholke and Mountain (1986) favor the production of northern-source deep water as the cause of the faunal turnover in the deep Labrador Sea. However, northern-source deep water may not have been the universal cause of the disappearance of the flysch-type faunas in the Northern Hemisphere. The paleogeographic distribution of flysch-type assemblages in the North Atlantic suggests that a southern source of deep water may have contributed to the disappearance of the North Atlantic assemblages in the early Paleogene, since the last common occurrence of flysch-type assemblages displays a diachronous pattern with latitude and depth (Fig. 3-1). In the western basin, agglutinated foraminifera first disappear from deep, equatorial sites in the upper Maastrichtian, but continue into the Paleocene on the margins and in the eastern basin. Flysch-type assemblages disappear from Site 647 and the Carpathian flysch basins near the Eocene/Oligocene boundary, but persist at bathyal depths on the Labrador Margin and in the central North Sea into the Oligocene.

The approximately coeval disappearance of flysch-type assemblages in the North Atlantic and Carpathian flysch basins cannot be attributed to northern-source deep water in the latter region. The basal Oligocene sealevel lowstand interrupted connections between the North Sea and the northern Tethys through the Polish-Danish trough, allowing the immigration of Asian vertebrate faunas into western Europe (Cavelier *et al.*, 1981). Deep water in the eastern Tethys may have been derived from a southern source, judging from the distribution of hiatuses along the western margin of the Indian Ocean (Kennett, 1977; Davies and Kidd, 1977). Shackleton and Kennett (1975) attributed the Eocene/Oligocene cooling of deep waters and increased deep circulation throughout the southern oceans to sea ice formation near Antarctica. The increasing production of well-oxygenated, northern and southern sources of deep waters at the end of the Eocene, and the basal Oligocene sea-level lowering resulted in a deepening of the oceanic lysocline throughout most of the world ocean, including the Tethyan flysch basins (Van Couvering *et al.*, 1981). These events may have led to the extinction of flysch-type assemblages in the North Atlantic and Tethys. However, the shallow Greenland-Scotland Ridge prevented the exchange of deep Arctic and Atlantic water below sill depth in the Norwegian-Greenland Sea, and this area served as a refuge for flysch-type faunas until the late Neogene. This scenario for the disappearance of flysch-type faunas at the Eocene/Oligocene boundary still remains to be tested with microfossil paleobiogeographic data.

CONCLUSIONS:

The lower Eocene to lower middle Eocene *Glomospira* assemblages in the Labrador and Norwegian-Greenland Seas are apparently coeval with similar assemblages known from the Tethys. By analogy with modern fauna in the Gulf of Mexico, the presence of *Glomospira* facies in these areas is interpreted as being indicative of organic-rich substrates. Unlike the modern Gulf of Mexico, where *Glomospira* faunas occur in areas of hydrocarbon seepage, the Eocene *Glomospira* assemblages owe their presence to a period of increased paleoproductivity. This increased productivity is ascribed to paleoceanographic changes caused by the basal Lutetian sea-level lowstand.

The transition from a predominantly agglutinated assemblage in the Eocene to a calcareous assemblage in the Oligocene is attributed to the increasingly poorer preservation of agglutinated taxa. The temporal coincidence of this faunal turnover in Site 647, the shallow Vøring Plateau, the Viking Graben and the Beaufort Sea suggests a common oceanographic link between the regions. At Site 647, the turnover is attributed to the increasing influence of cool, nutrient-poor deep waters associated with the onset of thermohaline circulation. However, the possible oceanographic causes of this faunal change in the high-latitude basins and Carpathian flysch troughs remain to be investigated.

Appendix 5-1. Benthic foraminiferal data from the North Leif I-05 well.

	Middle Eocene				Lower Eocene				Paleocene						Maastrichtian		
SPECIES	1945	1985	2025	2065	2105	2145	2185	2225	2265	2305	2385	2425	2465	2505	2580	2620	2700
ASTRORHIZACEA																	
Bathysiphon		1		1	2	3		21	60	8	2	2	7	40	20	52	42
Rhabdammina	6		1		6			17	23	84	6	11	30	16	37	75	109
Rhizammina					1	10		1	2	4		2	8	30	28	36	20
P. fusca										2				1			4
P. scruposa		4	3	3	5					1							
S. complanata	2	1	1	3	3	2		4	2		4		6	35	6	9	2
S. placenta								1				3	16	12	2	3	2
D. robusta	2	12		1	18	13	1	3	2	1	1						
HYPERAMMINACEA																	
H. dilatata																2	1
AMMODISCACEA																	
A. cretaceus											3	1		6	4	16	33
A. glabratus																	
A. latus																	
A. peruvianus				3	1	1				3	1	1	1				
A. planus		1		8	3	1		3	3	6	2	3	1	15		11	
Al. clavata																	3
G. charoides									2	1		4	5	18	14	53	17
G. gordialis													4	4		5	2
G. irregularis										1					1		5
Glomospirella					1								2	4		1	1
RZEHAKINA																3	1
HORMOSINACEA																	
Aschemonella					1	1		1	2	1			2				
H. ovulum														7	5	11	
H. excelsa															5	6	
Kalamopsis																	
R. duplex													1	3	3	4	
R. pilulifer						1			2	4			2	1	2		4
R. subfusiformis						1			1	1			3	3		3	3
R. globosus																	1
R. splendidus															6		
S. pseudoscalaria																	2
S. scalaria																	1
LITUOLACEA																	
A. deflexus		1												1			
A. aff. polythalamus														12			
A. sp. 3															1	1	2
A. sp. 4																	6
A. agglutinans																	3
A. jarvisi													1				
Ammoscalaria	1																2
B. multicamerata	40	47	17	4	11	4	1	2	17	6	1		2				
B. trinitatensis	3	1	1	1	1				2				3	1			
Cribrostomoides	10	2	8	7	11	4		6	4	6	1	3	1				4

Appendix 5-1 (Continued).

H. eggeri		2		2	2	3		17	4	2	1	2	3	12	6	4	3
H. glabra																	
H. kirki													1				
H. retroseptus			7	2	12	4	1	2	8	4	3	1	13	7	18	12	
H. suborbicularis					1								1	12	19	16	4
H. walteri	37	24	14	22	8	6	2	1	8	12	6	3	8	34	1	10	
Haplo. coarse					6			3	3	2		1	3	6	1	1	
Labrospira																	1
Lituotuba											1			1			
R. deflexiformis					10	5	2	11	1	19			8	4			
R. gerochi		1	1	2								1	10	2			
R. walteri	15	60	23	40	45	17		21	25	9	7	7	26	28	21	18	35
T. irregularis																5	
T. subcoronatus								1						3			
T. subtrullisatus																	8
LOFTUSIACEA																	
C. placenta		12	15	55	22	3		12	19	20	3						
C. rotundidorsata									7				1				
R. amplectens	35	93	78	50	22	3	4	8	2		2						
R. paupera									1	2							
TROCHAMMINACEA																	
Ammosphaeroidina			1	1	9	1					2		1		1		
T. deformis		8	4	16	16	18	1	34	9	15	4	5	29	36	10	3	3
T. altiformis	49	25	8	5	4	2	3	3	1	1	1						3
T. globigeriniformis		25	13	24	21	6		57	16	8	3		4				
ATAXOPHRAGMIACEA																	
Arenobulimina																	
Dorothia sp. 6	2	10	4	4		3				1							
D. retusa															1		
Eggerella																	
K. horrida	14	20	1	4	22	4		3					8	18	16	8	10
K. conversa		4			4	1		1									
M. oxycona					1											3	3
M. varians																	
K. coniformis		1			1												
Gaudryina									3	1					1	1	1
Uvigerinammina																	6
SPIROPLECTAMMINACEA																	
S. spectabilis	1				4	5	1	1	1	1		9	3				
S. navarroana					2	2	1			1				13	6	6	1
S. aff. dentata															1		
IND FRAGMENTS	80	15	20	30	10			20	4	10	3	5	21	70			80
CALC BENTHICS	11													3	26	45	4

Appendix 5-2. Benthic foraminiferal data from the Roberval K-92 well.

	Mid Eocene			Paleocene				Maast.
SPECIES	2220	2280	2340	2950m	2920	2950	2980	3070
ASTRORHIZACEA								
Bathysiphon				5	11	14	28	54
Rhabdammina	4	2	1	9	23	18	33	92
Rhizammina				14	4	4	37	35
P. fusca					2		4	10
P. scruposa								
S. complanata	8	2	8	12	6	7	4	3
S. placenta				3	2		5	
D. robusta		1						
HYPERAMMINACEA								
H. dilatata								3
AMMODISCACEA								
A. cretaceus					4	2	7	20
A. glabratus								
A. peruvianus								
A. planus				3			8	
Al. clavata								1
G. charoides				4	5	4	13	46
G. diffundens								
G. gordialis							7	1
G. irregularis			1				2	2
Glomospirella							1	
RZEHAKINA					1	1	4	
HORMOSINACEA								
Aschemonella							1	
H. ovulum				2	1		3	4
H. excelsa				2	1		2	2
Kalamopsis						2	4	
Nodellum								
R. duplex				1	2	1	2	4
R. pilulifer	2	1		3	3	1		1
R. subfusiformis				2	2		6	4
R. globosus								
R. splendidus								
S. pseudoscalaria						1		
S. scalaria								
LITUOLACEA								
A. aff. polythalamus				16	5		9	
A. sp. 3					2		4	
A. sp. 4				4	1			6
A. agglutinans				2			2	1
A. jarvisi								
Ammomarginulina	3							
Ammoscalaria								4
B. multicamerata	25	19	13					
B. trinitatensis	6	2						

Appendix 5-2 (Continued).

Cribrostomoides	5		6					
H. eggeri					2		6	8
H. glabra								
H. kirki	2		1					
H. retroseptus			6		15	4	14	8
H. suborbicularis				7	9	9	10	
H. walteri	7	14	1	8	2	11	5	1
Haplo. coarse		3	1				1	1
Labrospira								2
Lituotuba								
R. deflexiformis			6	2	1	2		16
R. gerochi	2						1	
R. walteri	20	11	5	29	17	19	30	37
T. irregularis								
T. subcoronatus						1		
T. subtrulisatus								
LOFTUSIACEA								
C. placenta	15	9	6					
C. rotundidorsata								
R. amplectens	43	31	10					
Retic. acute								
Retic. robust								
Alveolophragmium	5							
TROCHAMMINACEA								
Ammosphaeroidina					1	2		1
T. deformis	24	14	9	7	5	3	9	1
T. altiformis								
T. globigeriniformis	7							5
T. ruthven-murrayi								
Conotrochammina								
ATAXOPHRAGMIACEA								
Arenobulimina								2
Clavulinoides								
Dorothia sp. 6								
D. retusa								
Eggerella								
K. horrida	5	3	2	12	11	9	32	18
K. conversa		12						
M. oxycona								
M. varians								
K. coniformis								
Gaudryina			1		1		2	3
Uvigerinammina								36
SPIROPLECTAMMINACEA								
S. spectabilis								
S. navarroana				8	1	1	8	4
S. aff. dentata				2	2			
S. carinata	2	1						
IND FRAGMENTS				70	60	70	110	170
CALC BENTHICS	31	12	6					

Appendix 5-3. Benthic foraminiferal data from the Gudrid H-55 well.

	Paleocene											Maastrichtian			
SPECIES	8070	8130	8160	8220	8280	8340	8400	8460	8490	8520	8550	8640	8670	8700	8730f
ASTRORHIZACEA															
Bathysiphon	13	5	30	11	16	14	13	19	6	8	4	32	10	111	68
Rhabdammina	15	4	54	6	20	18	13	19	7	12	3	23	11	49	66
Rhizammina	18	2	4	14	21	18	23	38	22	14	7	8	1	13	9
P. fusca	4	10	2	1	3	3	1	4	2			1		1	4
P. scruposa															
S. complanata	13	12	6	7	22	23	16	15	16	11	5	7	2	2	7
S. placenta	2	2	2	3	3	16	4	4	20	6	6	10	6		
D. robusta															
HYPERAMMINACEA															
H. dilatata															1
H. elongata												2		3	
AMMODISCACEA															
A. cretaceus	1	2	3			2	2	3	6	2	2	3	4	25	17
A. glabratus															5
A. peruvianus															
A. planus		1	6		1	7	1	2	2	5	5	6	2		3
Al. clavata															
G. charoides	12	9	7	1	6	9	10	5	16	9	12	46	48	59	102
G. diffundens															
G. gordialis	1	1	1				1					1	2	1	5
G. irregularis	1													3	
Glomospirella															
RZEHAKINA			5			1	2				1		2		
HORMOSINACEA															
Aschemonella		1		1	1		1								
H. ovulum		3	4			1	3			3	2	2	10	19	11
H. excelsa										2					
Kalamopsis						1									
Nodellum															2
R. duplex	2				6	1	1	3				2			
R. pilulifer	5		4	8	7	1	1	4	3	1		1			1
R. subfusiformis				2	7								1		1
R. globosus															
R. splendidus								2		1			1		
S. pseudoscalaria															
S. scalaria		1			3					3			1		2
LITUOLACEA															
A. aff. polythalamus	27	23	22	7	6	4	15	1	9	4	6	3	4		
A. sp. 3	2	1	3			2					3	3	2		
A. sp. 4	5	3	8				3			1					2
A. agglutinans				4					2	1	4		1		
A. jarvisi															
Ammoscalaria	6														
B. multicamerata															
B. trinitatensis										2			1		1

Appendix 5-3 (Continued).

Cribro. smooth	7	8	18	5	6	7	3	2	11	5	3	11	8	7	8
Cribrostomoides coarse		9	7	11	13	8	12	3	12						
H. eggeri	9	1						16				2	4		
H. glabra		19	16	5	16	3	35	1	26	13	6	15	20	7	5
H. kirki	2				2	1	2			1	3	2	1		1
H. retroseptus	1					8	6	2	1	4		10		1	
H. suborbicularis									9	1	2			1	
H. walteri	5	3													
H. walteri/jarvisi	4														
Haplo. coarse			2		4							1	1	8	
Labrospira														2	
Lituotuba															
R. deflexiformis	7	1		6	2	1	4	5	2				1	5	1
R. gerochi	1			1	3	11	1			2	3				13
R. walteri	36	30	39	27	37	23	12	38	15	30	29	47	32	45	16
T. irregularis				1									1	6	5
T. subcoronatus												1			
T. subtrullisatus															
LOFTUSIACEA															
C. placenta															
C. rotundidorsata															
R. amplectens															
Retic. acute															
Retic. robust				1		2									
TROCHAMMINACEA															
Ammosphaeroidina	2	4	15	1	5	10	8	3	3	5	3	7	3		2
T. deformis	11	18	18	7	14	14	15	13		18	40		4	3	
T. altiformis															
T. globigeriniformis			2	2	1	1	3	4	2	2	1	4	5	4	8
T. ruthven-murrayi			1												
Conotrochammina						1									
ATAXOPHRAGMIACEA															
Arenobulimina															
Clavulinoides															
Dorothia sp. 6															
D. retusa															
Eggerella															
K. horrida	39	45	66	33	36	26	22	14	44	25	29	38	32	25	57
K. conversa	4	1													1
M. oxycona				1	1										
M. varians							2		1				1		
K. coniformis															
Gaudryina				1	1	2	1		2			2			
Uvigerinammina												1			1
SPIROPLECTAMMINACEA															
S. spectabilis	5								1	1	3				
S. navarroana	6	3	21	5	5	6	3		7	4	3	5	1	2	7
S. aff. dentata						3	4	1	2	1			1		
IND FRAGMENTS	80	90	70							10	58		80		30
CALC BENTHICS	0	0	0	0	0	0	0	0	0	0	6	45	31	3	3

Appendix 5-4. Benthic foraminiferal data from the Indian Harbour M-52 well.

	Paleocene								Maastrichtian								
SPECIES	10060	10120	10180	10240	10300	10360	10390	10450	10510	10540	10600	10660	10690	10720	10750	10780	10810
ASTRORHIZACEA																	
Bathysiphon	5	17	18	62	27	29	33	30	59	32	25	22	48	66	65	38	60
Rhabdammina	32	46	60	84	40	48	76	25	159	48	87	28	149	46	51	42	56
Rhizammina		9	23	52	19	23	35	6	3	10	2		18	13	21	9	11
P. fusca														1	1		
P. scruposa																	
S. complanata	27	9	24	17	22	21	25	15	11	5		5	12	1		1	
S. placenta				2	1	8	13	8	20	8	6		2	1			1
D. robusta	18	26	7														
HYPERAMMINACEA																	
H. dilatata						2	4		4				5	1	2	1	1
AMMODISCACEA																	
A. cretaceus				2	5	11	36	12	29	22	24	28	35	13	10	13	14
A. glabratus														1			
A. peruvianus																	
A. planus	1	5	13	14	4	4	7	1	1	3		1	1		3		
Al. clavata											2	2		1		1	2
G. charoides	1	5	7	26	16	138	139	66	156	101	132	306	408	62	50	20	32
G. diffundens										2							
G. gordialis						9	16	6	21	13	15	62	47	3	5	1	4
G. irregularis				5	2	5	6	4	9	7	14	10	15	4	7	2	5
Glomospirella						1			3			3	7	3			
RZEHAKINA							2					1	2		1		1
HORMOSINACEA																	
Aschemonella			1							1							
H. ovulum						6	1	14	40	45	27	16	27	4	6	4	9
H. excelsa					1	5	10	7									
Kalamopsis					1	2	2	3									
Nodellum						1								1			
R. duplex						4		2	2	2			18		2	2	1
R. pilulifer	2	2		2			1						2	3			1
R. subfusiformis					1										1	1	
R. globosus																	
R. splendidus						3	5	2									
S. pseudoscalaria					2	1											
S. scalaria					1	6	10	4				1			5		
LITUOLACEA																	
A. aff. polythalamus	3			4	2	4	4		5	2	1						
A. sp. 3													1				
A. sp. 4												11	27	1	3	3	
A. agglutinans							1					2	1	4	2	3	
A. jarvisi																	
Ammoscalaria										1			6				
B. multicamerata	13	20	12	2	13												
B. trinitatensis	8	3	1			3	3		2			12	14				
Cribrostomoides									1		1	71	87	4			

Appendix 5-4 (Continued).

H. eggeri		2				4	2	11	17	7		7	26	11	4	7	8
H. glabra						9	4	12	9	12	6	3	1				
H. kirki									6	1		10	1		1		
H. retroseptus	5		5	2	13	11	15	10	9	2			2				
H. suborbicularis	10	5		5	4	7	11	6	5	5		7		1	6	2	2
H. walteri	8	17	65	94	49												
Haplo. coarse					1				1			4	3	1	1		1
Labrospira								1	4	2							
Lituotuba																	
R. deflexiformis	2				2	1	2	12	6				3	2	1		1
R. gerochi	24	25	21	22	23	11	28	21	19			5	13		1		
R. walteri	6			14	4	36	51	67	152	90	104	80	178	39	26	16	23
T. irregularis	1	1	1	4	3		2	5	14	5		6	2				
T. subcoronatus						2	3	2			7		2				
T. subtrullisatus																	
LOFTUSIACEA																	
C. placenta																	
C. rotundidorsata																	
R. amplectens																	
Retic. acute	4	10	12	7	3												
Retic. robust	27		5														
TROCHAMMINACEA																	
Ammosphaeroidina	19	7	29	38	22	26	14	2	7	14	3	2	6		3		
T. deformis	29	13	56	60	36	21	23	23	21	15	1	17	15	3	4	4	3
T. altiformis		2															
T. globigeriniformis	1							3	3			19	12	4	3	6	4
T. ruthven-murrayi	2	2	1		1												
Conotrochammina										2			1		1		
ATAXOPHRAGMIACEA																	
Arenobulimina												3	3	4		2	
Clavulinoides		2															
Dorothia sp. 6				1													
D. retusa									1								
Eggerella																	
K. horrida	2	6	3	3	5	42	38	14	22		12	52	192	4	19	13	6
K. conversa			1						1	1		1					
M. oxycona											2			1			
M. varians																	
K. coniformis																	
Gaudryina									1		6				1		1
Uvigerinammina									3	6	1	140	136	11	10	6	8
SPIROPLECTAMMINACEA																	
S. spectabilis				12		12	10	4					1				1
S. navarroana			2		4	13	7	9	2	1	3	1	12	1	3		
S. aff. dentata											3		1				
IND FRAGMENTS																	
CALC BENTHICS	48	42	110	62	35	0	3	0	118	275	480	23	12	4	11	5	4

CHAPTER 6.

GENERAL CONCLUSIONS:

Flysch-type agglutinated foraminifera are found in tectonically active areas of southern Europe, northwest Africa and the Carribean, in offshore wells in northern Atlantic basins, and at some North Atlantic DSDP and ODP sites. In these areas agglutinated foraminiferal facies are particularly well-developed in deep-water facies of late Cretaceous to early Paleogene age. The revised taxonomic data base[1] (over 200 species and species groups) used throughout this study has made possible the first regional synopsis of the biostratigraphic and paleobiogeographic distribution of these microfossils in the North Atlantic and western Tethys. A major result of this survey is that most flysch-type taxa are cosmopolitan, but regional differences in species composition, relative abundance and diversity are recognized that can be attributed to differences in latitude and paleodepth between sampled localities. A general decrease in diversity is observed from low to high latitudes and from the continental slope to the deep ocean basins. Tropical Paleocene assemblages contained abundant calcareous ataxophragmiids and rzehakinids. Boreal and Tethyan assemblages contained endemic elements in the Paleocene and early Eocene. An early Eocene to early middle Eocene maximum in Glomospira is apparently an oceanwide phenomenon.

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1. Illustrations of species can be found in the following pre-prints, which are available from the author upon request:

Kaminski, M.A., Gradstein, F.M., Berggren, W.A., Geroch, S., and Beckmann, J.P. (in press, a). Flysch-type agglutinated foraminiferal assemblages from Trinidad: Taxonomy, Stratigraphy and Paleobathymetry. Proceedings of the Second International Workshop on Agglutinated Foraminifera, Vienna Austria, June 23-28, 1986.

Kaminski, M.A., Gradstein, F.M., Scott, D.B., and MacKinnon K.D. (in press,c). Neogene benthic foraminiferal stratigraphy and deep water history of Sites 645, 646 and 647, Baffin Bay and Labrador Sea. in: Arthur, M.A., Srivastava, S., et al. Init. Repts. ODP Leg 105.

Kaminski, M.A., Gradstein, F.M., and Berggren, W.A. (in press, d). Paleogene benthic foraminiferal stratigraphy and paleoecology at Site 647, Southern Labrador Sea. in: Arthur, M.A., Srivastava, S., et al. Init. Repts. ODP Leg 105.

Investigation of well samples in different North Atlantic basins indicates that flysch-type agglutinated foraminifera are useful for biostratigraphy, particularly in areas where calcareous microfossils are absent or underrepresented. Biostratigraphic schemes have been developed for flysch-type taxa from Trinidad, Zumaya Spain, the North Sea, Labrador Sea, and Norwegian-Greenland Sea. In Trinidad, Zumaya and the deep Labrador Sea, the stratigraphic ranges of flysch-type taxa were correlated to the GPMS via second-order correlations using planktonic microfossil zonal schemes. Hole 647A in the Labrador sea is the only section recovered thus far where the chronology of flysch-type taxa can be directly tied to the GMPS by means of first-order correlation with magnetostratigraphy. The finding of disjunct stratigraphic ranges of certain taxa in silled basins is attributed to restricted deep-water connections with the North Atlantic.

A comparison of the biostratigraphy of flysch-type taxa in the basins studied reveals a number of evolutionary first and last occurrences that serve as important regional stratigraphic marker horizons. The LO's of Glomospira diffundens, Hormosina ovulum, Rzehakina epigona, Rzehakina minima, Trochammina ruthven-murrayi, and calcareous ataxophragmiids occur near the Paleocene/-Eocene boundary in bathyal assemblages. The first occurrence of the intermediate forms in the Haplophragmoides cf. glabra - H. walteri - H?. jarvisi lineage may be usful stratigraphic events in the North Atlantic. Important FO's which probably reflect evolutionary events in the Eocene are Karreriella coniformis, Reticulophragmium amplectens, Ammodiscus latus, Spirosigmoilinella compressa, and Cyclammina rotundidorsata.

The diversity of flysch-type foraminifera in the North Atlantic declined with time throughout the Paleogene, and the last common occurrence of these microfossils exhibits a pattern of diachrony with latitude and depth. The loss of flysch-type assemblages from the abyssal regions may be due to the appearance of younger bottom water in the deep basins. However, their presence in slope basins is related to rapid clastic deposition associated with the early phases of extensional tectonics along the margins of the Labrador and Norwegian-Greenland Sea.

There were four main periods of faunal turnover among agglutinated foraminifera in the Cenozoic. The first turnover, near the Paleocene/Eocene boundary, was characterized by the loss of agglutinated assemblages in the deep ocean basin and the extinction of many species and some genera in bathyal assemblages. However, some species persisted to younger levels in high-latitude basins. The lower/middle Eocene transition is marked by additional extinctions and the development of a widespread *Glomospira* facies. The Eocene/Oligocene transition in marked by disappearance of the last deep-sea faunas in the Labrador Sea and Poland, and throughout most parts of the Labrador Margin and the North Sea. The early Oligocene witnessed a reduction in diversity on the Labrador Margin and in the Norwegian-Greenland Sea and the disappearance of agglutinated taxa in the Mackenzie Delta. The disappearance of agglutinated assemblages in these areas was caused by regional changes from slope to shelf environments.

The early/middle Miocene turnover in the Norwegian-Greenland Sea resulted in a reduction in diversity to ~5 species in the overlying biosiliceous sediments. Pre-glacial Pliocene assemblages display higher diversity until the onset of ice-rafting, when agglutinated species are replaced by calcareous benthic assemblages. In the Neogene agglutinated assemblages were preserved under exceptional circumstances in the Labrador Sea. Upper Miocene assemblages recovered from Hole 646 contain elements of modern Atlantic faunas. Throughout their respective histories, both Baffin Bay and the Norwegian-Greenland Sea possessed endemic faunal elements.

The paleobathymetry of agglutinated foraminifera in the North Atlantic was studied in Trinidad, Labrador and the Norwegian-Greenland Sea. The presence of redeposited assemblages in the Lizard Springs Formation allows the recognition of shallow and deep assemblages. The shallowest assemblage of the Lizard Springs Formation is dominated by species associated with a calcareous facies, such as *Clavulinoides globulifera*, *Dorothia retusa*, *Phenacophragma beckmanni*, and *Haplophragmoides* ex. gr. *suborbicularis*. This assemblage occurs with a calcareous benthic assemblage containing a high abundance of *Stensioina beccariiformis*. An assemblage redeposited from a deeper source area is dominated by *Dendrophrya*, and occurs with a calcareous benthic assemblage containing a higher proportion of *Nuttallides truempyi*. The deepest assemblage of the Lizard Springs Formation is dominated by small, finely agglutinated species such as *Ammosphaeroidina pseudopauciloculata*, *Rhizammina indivisa*, and *Recurvoides gerochi*, with a lesser contribution by *Rzehakina epigona*, *Spiroplectammina spectabilis* and *Saccammina placenta*. In the northern Atlantic, paleobathymetric trends can be reconstructed from a transect of wells on the Labrador Margin and DSDP/ODP sites in the Labrador

Sea, Norwegian-Greenland Sea and Galicia Margin. Paleobathymetric patterns in northern assemblages differ from low-latitude assemblages by the lack of a shallow "Marssonella association" of calcareous ataxophragmiids. Shallow Maastrichtian and Paleogene assemblages contain abundant coarse tubular species and lituolids with only very rare calcareous ataxophragmiids. Shallow Eocene assemblages on the Labrador Margin contain few tubular species and are dominated by cyclamminids. However, shallow assemblages on the Vøring Plateau and Slope contain abundant tubular forms, cyclamminids, and acmes of S. spectabilis. Deeper assemblages contain more abundant Glomospira, Hormosina, Trochamminoides, Ammosphaeroidina, Praecystammina, and finely agglutinated lituolids (Cribrostomoides, Haplophragmoides, Labrospira). Cretaceous deep assemblages contain abundant Uvigerinammina, and Paleocene deep assemblages contain more abundant S. spectabilis. Hormosina ovulum was common in deep assemblages before the early Eocene.

The paleobathymetry of species in the North Atlantic compares well with patterns observed in the Carpathian flysch basins, and enables the constructon of an empirical paleobathymetric model for the Paleocene. This model differs from Cretaceous paleobathymetric patterns discussed by Haig (1979) in a number of details. The relative abundance of Recurvoides, the nominate taxon of Haig's deep assemblage, does not display consistent depth-related patterns in the North Atlantic. The "Marssonella association" of Haig can be recognized in the Paleocene at low latitudes, but does not occur at high latitudes or in Eocene or younger assemblages.

The modern analogs of flysch-type agglutinated foraminifera yield information about the autecology of species and the synecology of species associations which provide important constraints for paleoenvironmental analysis. Disequilibrium studies of living agglutinated foraminifera in the Panama Basin and on the Nova Scotian continental rise have documented their microhabitats, identified epifaunal and infaunal forms as well as opportunistic species, and assessed the preservation potential of some modern taxa. This information was used to construct a general model of the response of agglutinated foraminifera to substrate disturbance. Other major conclusions are as follows:

- Tubular forms (Dendrophrya and Rhizammina) are epifaunal and did not recolonize sediment trays. This implys that epifaunal forms are at risk in physically disturbed areas.

- The genus Reophax has a vagrant infaunal microhabitat and displays the best ability to recolonize sediment trays.
- Nine months is not sufficient time for a the deep-sea benthic foraminiferal community to recover to background abundance levels after a disturbance. This implys that substrate disturbance which occurs on a timescale of about a year is sufficient to produce a "physically-controlled" community consisting of more opportunistic species.

The substrate disturbance model can be used to assess the physical stability of deposional enviroments recorded by fossil assemblages. A study of the synecology of fossil assemblages in ODP Hole 646B on the Eirik Ridge is useful for determining the bottom water history of the area. Beneath a regional seismic horizon (reflector "R3"), the presence of smooth-walled agglutinated assemblages point to a tranquil environment. Above horizon "R3", coarse-walled assemblages dominated by large tubular species suggest a disturbed environment. This evidence, along with sedimentologic and isotopic evidence, suggests an intensification of the Western Boundary Undercurrent at the Eirik Ridge at ~7.5 Ma. The similarity of the agglutinated assemblages and other microfossils in Hole 646B to assemblages from the Norwegian-Greenland Sea indicates that Demark Straits Overflow was the dominant water mass over the Eirik Ridge in the late Miocene.

A study of the agglutinated foraminiferal fauna at areas of hydrocarbon seepage on the Lousiana slope has identified taxa which tolerate or prefer organic-rich substrates. This finding has potential use for petroleum exploration. In both study areas, the hydrocarbon seep assemblage is characterized by a decrease in the proportion of astrorhizids and a corresponding increase in the relative abundance of trochamminids and textulariids when compared with control samples. At the highly organic-rich substrate in Block 184 where a chemosynthetic macrofaunal community was recovered, infaunal foraminiferal morphotypes are absent and the predominant species are Trochammina glabra and Glomospira charoides. Similar types of assemblages have been reported from organic-rich sediments as old as Jurassic in age. In the course of this study, a Glomospira-dominated assemblage was observed in the upper lower Eocene to lower middle Eocene of ODP Holes 647A and 643A. This "Glomospira facies" is coeval with the well-known Glomospira beds in the Alpine areas, and is the first report of such an assemblage in the Atlantic. The presence of the Glomospira facies in the North Atlantic and western Tethys is ascribed to increased nutrients, and (presumably) decreased oxygenation of bottom water resulting from higher paleoproductivity in the surface waters and paleoceanographic changes caused by the basal Lutetian sea-level lowstand.

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During his time as a student at Rutgers, he worked at the Rutgers Geology Museum and as a Labratory Assistant in Richard K. Olsson's lab. While in Krakow, he also translated for the Journal of the Geological Society of Poland (Rocznik PTG), and lectured at the Academy of Mining and Metallurgy. In summer, 1984, he worked as an Assistant Geologist in the Biostratigraphy Group of the UNOCAL Science and Technology Division, under the supervision of Harry Leffingwell and Garry Jones. Between 1985 and 1987, he was a TA for W.A. Berggren's Short Course on Benthic Forams at Brown University.

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