FORAMINIFERAL AND LITHOLOGIC INDICATORS OF DEPOSITIONAL PROCESSES IN WILMINGTON AND SOUTH HEYES SUBMARINE CANYONS, U.S. ATLANTIC CONTINENTAL SLOPE

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ABSTRACT

Foraminiferal and lithologic characteristics of sediments from 14 Deep Sea Research Vessel Alvin push cores have been used to investigate modern sedimentary processes in Wilmington and South Hayes submarine canyons. A nearly ubiquitous occurrence of abundant foraminiferal species is attributed to erosion of material from slump blocks of neritic origin which now comprise the steep and undercut walls of Wilmington Canyon.

In Wilmington Canyon, the consistent distribution of foraminifera contrasts with marked variations in lithologic characteristics observed at channel meanders. These variations are attributed to relatively minor mass-wasting processes and to effects of bottom (perhaps tidal) and/or low density current action, more active at constrictions and along the steep walls of meanders. These processes are less prevalent in South Hayes Canyon as indicated by markedly lower compositional variations, a low percent of clastic material, and a lower rate of sediment accumulation. This is, in part, a function of the linear morphology and less varied relief of South Hayes Canyon. There is no firm evidence for prevalent high energy downslope transportation events (i.e., erosive high-density turbidity currents) in either Wilmington and South Hayes Canyons during the past 200-400 years represented by the cored material.

INTRODUCTION

In this study, foraminiferal assemblages and quantitative lithologic data from short cores are used to investigate the mode and pattern of Recent sediment transport in Wilmington and South Hayes canyons off the coast of New Jersey, U.S.A. (Figs. 1, 2). South Hayes Canyon is a linear chute-like canyon confined to the continental slope. Wilmington Canyon is a larger feature that heads at a depth of approximately 90 m (Stanley and others, 1986) some 125 km from the Cape May shore (Uchupi, 1965), and from there sinusously traverses the shelf, slope and rise nearly to the Hat teras Abyssal Plain. Its meandering "fluvial-like" shape (McGregor and others, 1982; Stubblefield and others, 1982), with relatively steep walls and low gradient, contrasts with less steep walls and a gradient that approximates the regional slope in South Hayes Canyon (Fig. 2).

Stanley and others (1986) suggested that downslope sediment transport occurs in Wilmington Canyon via a "stop-and-go" mechanism, incorporating deep-water and shallow-water foraminifera into sediments being moved down the slope. This idea, that gravity flow, bottom currents, and/or turbidity currents displaced material down the continental margin, was based on foraminiferal and lithologic variation in the hemipelagic cover observed in several 20-35 cm short cores collected by the Deep Sea Research Vessel (DSRV) Alvin, along a meandering part of the Wilmington Canyon. The cores were inferred to record recent sedimentation based on rates of deposition >40 cm per 1,000 years (Stanley and others, 1984) for cores nearby on the upper rise.

The stop-and-go downslope transport mechanism is based on the supposition that foraminiferal assemblages were not transported by a single event from the shelf to lower reaches. Rather, the foraminiferal data indicate a mixing of assemblages via step-wise downslope transport, allowing autochthonous deeper water benthic foraminifera and planktic foraminifera to be incorporated into the sediment at each pause. In contrast, sediment transported by one major event generally would be dominated by a shallow water assemblage, with only minor additions of deeper water benthics and planktics (see Brummer and Culver, 1992). Sediment transported by the stop-and-go mechanism would have a mixture of several depth assemblages and a preponderance of planktics. Material moved down-canyon in this manner could incorporate material eroded from the canyon walls during its journey.

This study utilizes a greater number of cores, also collected during a series of Alvin dives, which allow for a wider physiographic and geographic coverage (i.e., from meanders along the length of Wilmington Canyon and from the nearby, morphologically distinct South Hayes Canyon). To aid comparison, the approach adopted here is the same as that in Stanley and others (1986), and the new data are evaluated in light of several other studies of currently active processes in the Wilmington Canyon area.

METHODS

Between 22 September and 2 October 1986, push-cores were collected during the course of six dives taken by the DSRV Alvin within Wilmington and South Hayes submarine canyons (Fig. 1). Sample locations were mapped on a SeaBEAM survey map (Fig. 2). Locations were determined using on-board sonar, depth, direction, and visual observation, and they were verified by coordinates determined by the triangulation of sonar buoys transmitted to the Alvin by the mother-ship Atlantis II.

Fourteen short cores containing 78 samples were ex-
amined. For most of the push-cores, every other 2-cm downcore segment was available for study; for some push-cores contiguous 2-cm samples were available. Table 1 summarizes the depth and location of each of the cores collected from this study, as well as the sampled intervals from each core. Sediment accumulation rates determined using $^{210}$Pb/$^{137}$Cs geochronology (Nittouer and others, 1979) vary within the canyons from 22 to >500 mg/cm$^2$/yr (Sanford and others, 1990) dependent on local processes, but background rates indicate that the ~25-cm cores of this study represent approximately 200 to 400 years of sediment accumulation.

Approximately five grams of material were disaggregated for each sample and sieved on a 63 μm mesh to remove silt and clay. The residue was dried, weighed, and the sand to silt plus clay ratio was calculated. Split fractions of each sample were spread evenly over a gridded picking tray. Every particle within randomly selected squares was counted and assigned to one of several compositional categories. Counting of benthic vs. planktic foraminifera continued until more than 300 planktics were recognized. Picking then continued until 300 benthic specimens had been counted, after which the relative proportions of species categories were determined. Following picking, the weight of sediment containing 300 benthic foraminifera was estimated by multiplying the weight of the split by the proportion of squares picked to obtain 300 individuals.

Species were identified initially using published figures and descriptions and by comparison to material previously identified by Brunner and Culver (1992). Identiﬁcations were checked by examination of material in the Cushman Collection of foraminifera in the Smithsonian Institution, Washington, D.C. and in the collection in The Natural History Museum, London.

RESULTS

LITHOLOGIC DATA

The relative abundance of different grain types composing the sand-sized fraction of each sample, as calculated directly from grain counts, is shown in Table 2. Grain count data have been organized into three groups: clastic grains (quartz, mica, glauconite, heavy minerals, sponge spicules, echinoderm spines), planktic microfossils (planktic foraminifera, radiolaria, diatoms), and benthic foraminifera. Also given in Table 2 is weight percent of sand-sized material in each sample, calculated number of benthic foraminifera in one gram of unsieved sediment, and ratio of planktic to benthic foraminifera (P/B, given as percent planktics).

Examination of lithologic characteristics reveals little significant downcore variation (Table 2). Thus, values are summarized as averages for each core (Fig. 3). However, in samples from core 1739-1, one of the few marked downcore changes is seen with variation between the top half and lower half of the core (Table 2). The 2-4 cm and 6-8 cm intervals have low percent benthic foraminifera, comparatively low percent planktic microfossils, and a high sand fraction. The 10-12 cm and 14-16 cm intervals have approximately seven times greater percent benthic foraminifera, double the percent planktic microfossils (with a corresponding decrease in proportion of clastic material), and a diminution of the sand fraction by ~10%. An increase in clastic and sand-sized input in the upper core corresponds with a decrease in number of benthic foraminifera per gram, suggesting a higher rate of sediment accumulation. Notwithstanding this downcore variation, the generally high sand fraction in this core is unusual, from three to four times greater than any other sample in our study (Fig. 3). This is of interest because this core comes from a water depth of 2,483 m and its sand content contrasts with core 1739-5.
Relatively nearby on the opposite side of the canyon. Samples from core 1739-5 are generally high in planktic microfossils and benthic foraminifera (relatively low in clastic material) and have a moderate percent sand fraction relative to other locations in Wilmington Canyon. Upcore variations include only a slightly decreased sand fraction. In core 1739-5 the percentage of planktic microfossils is high relative to all other samples in this study.

Three cores from location 1745 show an overall pattern in which cores 1745-6 and 1745-7 are quite similar, yet distinct from core 1745-9 (Table 2; Fig. 3). The percent sand-sized material in cores 1745-6 and 1745-7 varies little, with a slight decrease in values about mid-core. The percent planktic microfossil and benthic foraminifera also vary about similar values. Percentages of benthic foraminifera tend to be relatively low (Table 2). Samples from core 1745-9 record planktic microfossil values that vary little about the mean of ~34%. Values for percent benthic foraminifera are slightly higher than in other cores and one interval (4-6 cm) has a high value of 6.8% benthic foraminifera. The sand fraction in core 1745-9 varies little throughout, but decreases slightly upcore with a comparatively low mean of approximately 5%. Composition at location 1745 shows a clear but modest drop in sand fraction and an increase in benthic foraminifera and planktic microfossils (a decrease of clastic material) between the center to the outside of a meander.

The two cores on opposite sides of a meander at location 1741 also display modest between-core variation (Table 2; Fig. 3). The sand fraction in core 1741-7 along the outside
of the meander is relatively high, with values averaging ~12%. Other than extremely high values in core 1739-1, such proportions are consistently higher than at any other locations in this study. The percentage of planktic microfossils is nearly uniform, with values averaging ~7%. This, and a low percent benthic foraminifera, indicate a high clastic input. Samples from core 1741-8 are also fairly high for the sand fraction (averaging ~9%) but are notably lower than those across the canyon in core 1741-7. The percent contribution of planktic microfossils, benthic foraminifera and clastic material in core 1741-8 is similar to that in 1741-7. Core 1743-8 from the gully in Wilmington Canyon's south wall has sand fraction percents that are similar (~9%) to values in locations nearby and down-canyon (cores 1741-8, 1745-6, and 1745-7). The clastic content in 1743-8 is also similar to that of location 1741 (Fig. 3).

The two cores from opposite sides of the canyon at site 1748 are located where the channel takes on a north-south trend. Core 1748-5 is located high on the canyon wall. The shipboard description noted 3 to 4 cm, sharp-edged "outcrop blocks" down to 6 cm, with "greenish hemipelagic material in between blocks." Also noted were burrows with a blackish sandy infilling in samples from 6-8 cm and 8-10 cm. The 14-15 cm interval was described as having a small burrow entering from the side filled with "wetter material" (S. J. Culver, field notes). However, during the course of sample preparation no obvious blocks of consolidated outcrop material were noted.

Samples from core 1748-5 record an extremely high percent of clastic material (~99%) with very low values of planktic microfossils and benthic foraminifera (Table 2). The top intervals (2-4 cm and 6-8 cm) have a slightly higher percent planktic microfossils, and percent benthic foraminifera three times that of the lower intervals (8-10 cm, 10-12 cm, 12-14 cm, and 14-15 cm). Values for the sand fraction show a trend of lessening values downcore from 9.4% to 2.6% with an average of 5.1% (Table 2).

Core 1748-1 did not encounter any similar consolidated outcrop material. The sand fraction percent is internally consistent, showing a rather low average of 2.6%. Percentages of planktic microfossils and benthic foraminifera are variable.

Samples from South Heyes Canyon cores show a striking consistency, and differ in composition from those in Wilmington Canyon (Table 2). Percentages of sand, clastics, planktic microfossils and benthic foraminifera vary slightly throughout the cores. Average values for the sand fraction in these cores (Fig. 3) are: 1.7% (1749-2), 2.4% (1749-4), 2.9% (1749-5), and 2.3% (1749-13). This demonstrates cross-canyon consistency not seen in Wilmington Canyon, but does resemble values in core 1748-1 (at a similar depth). Percentages of benthics are also consistent and high. With one exception (core 1749-4, 18-20 cm), benthic percentages are higher than in Wilmington Canyon, and the average percent from South Heyes (8.5%) is much higher than anywhere in Wilmington Canyon. Planktic microfossil percentages are also noticeably higher (average ~20.5%) than in most cores from Wilmington Canyon, with the exception of cores 1739-5 and 1749-5. High planktic microfossil and benthic percentages are inversely proportional to the generally low values of clastic material.

The number of benthic foraminifera occurring in one
gram of the total weight of sediment (Fig. 3) can be roughly related to the rate of deposition (although this number must also be a function of food supply and other variables). A low number of benthic foraminifera per gram of sediment suggests that the sediment accumulation rate has been relatively rapid. For example, the number of benthic foraminifera in core 1739-1 is low (Table 2). There is substantial reduction (by half) between the lower intervals and top two intervals, suggesting an increase in sedimentation rate in this area.

Numbers of benthic foraminifera from core 1739-5 tend to be somewhat higher than in other cores from Wilming Canyon (except cores 1745-9 and 1748-1), and there is a slight upcore increase that is the inverse of the sand fraction trend. The average number of benthic foraminifera present in core 1739-5 is 201,500 per gram (Fig. 3), suggesting a lower sedimentation rate than in most canyon locations, and, perhaps, many times lower than in samples across the canyon in core 1739-1.

Numbers of benthic foraminifera of per gram of sediment in samples from location 1745 are inversely related to the percentage of the sand-sized fraction. The average number present from core 1745-6 is 180,800 and that from core 1745-7 is 142,900 (relatively low because of uncharacteristically low numbers in the top two intervals and in the lowest interval; Table 2). These two cores are similar to each other and distinctly different from samples that are nearby but on the outside of the meander. Core 1745-9 has higher values, with an average of 472,400 foraminifera per gram. These values increase to some degree up the core, reflecting the decrease in sand fraction there. The substantially greater number of benthic per gram of sediment along the outside of the meander at location 1745 suggests that the sedimentation rate may have been considerably less on the outside of this meander.

The two cores at location 1741 show a small but noticeable cross-canyon change. Numbers of benthic foraminifera in core 1741-7 do not vary greatly, and average 73,300. In core 1741-8 the sedimentation rate is lower, with an average of 136,800 benthic foraminifera per gram of sediment. This value is similar to those in the middle of the canyon, at location 1745.

Number of benthic foraminifera in samples from the gully site (core 1743-8) show little variation (Table 2). The average number present (161,300) is intermediate between values in cores from the inside of the meander at location 1741 and the middle of the canyon at location 1745 (Fig. 3). Similar numbers of benthic foraminifera suggest comparable rates of deposition in these morphologically dissimilar areas.

The two cores from location 1748 show marked differences. Samples from 1748-1 exhibit high numbers of benthic foraminifera per gram (average of 1,368,400 and a low value of 1,200,900). This would suggest a substantially lower rate of sediment accumulation than at other Wilming Canyon core locations. The relatively low values at core 1748-5 indicate that benthic foraminifera make up an uncontrollably low proportion of these sediments compared to other samples at similar depths (Fig. 3).
yon. Except for core 1748-1, values in South Heyes Canyon are an order of magnitude greater than those in Wilmington Canyon. The average value for core 1749-2 is 3,589,100 with a high of 5,145,800 and a low of 1,682,400. Cores 1749-4 and 1749-5 have comparable averages (1,689,800 and 1,713,500, respectively) but exhibit considerable between-sample variability. Values in cores 1749-1 and 1749-2 tend to be higher than in cores 1749-4 and 1749-5, with an average value of 2,419,000. This may indicate a slightly decreased sedimentation rate along the east side of South Heyes Canyon. Based on number of benthic foraminifera per gram of sediment (Fig. 3), we suggest that South Heyes Canyon is characterized by much lower sedimentation rates than Wilmington Canyon.

**FORAMINIFERAL DATA**

**Planktic to Benthic Ratios**

The ratio of planktic to benthic foraminifera (P/B, often expressed at percent planktics as in this study) can be used as an indicator of water depth and as a measure of distance from shore (cf. Murray, 1976; Douglas, 1979; Gibson, 1989). This relationship was first described by Grimsdale and Morkhoven (1955), who observed an increase in the abundance of planktic foraminifera beyond the outer shelf in the Gulf of Mexico. Samples from deep water with a low percentage of planktic foraminifera are thus suggestive of transport from shallower waters.

Percent planktic foraminifera (P/B) in Wilmington Canyon are generally high (P/B data in Table 2 and Fig. 3). At the deepest location (1739, at ~2,500 m depth), two cores show uniformly high values (average of 88%). There is no cross-canyon variation and values do not reflect the considerable lithologic variation between cores (Table 2, Fig. 3). Samples from cores taken at location 1745 (~2,080 m) show minor variation within and between cores. Values (average of 84%) are slightly less than those at location 1739 (Fig. 3).

Further up canyon (location 1741, at ~1,900 m), the value for percent planktics is lower than at location 1745. Cores 1741-7 and 1741-8 show a slight decrease in values upcore, and show average values of 74% and 76% respectively. Here, at location 1739, no significant cross-canyon variation is recorded.

In slightly shallower water (~1,700 m), core 1743-8 has average values of percent planktics (73%) similar to those in cores from location 1741. This core also exhibits a trend toward lower values higher in the core.

Cores from location 1748 (~1,570 m), which show marked variations in lithologic characteristics (Fig. 3), show...
remarkably similar values of percent planktics (50% for core 1748-1, and 49% for core 1748-5). Both cores display the same slight trend toward decreased values upcore.

Within South Heyes Canyon (location 1749), several trends are recorded: consistent values within cores, increasing values with increasing water depth, and low values relative to Wilmington Canyon. Values of percent planktics are fairly consistent, and are somewhat higher than those of cores at similar depth in Wilmington Canyon (location 1748, 1,570 m).

The consistent increase in percent planktics (P/B) with increased water depths (Fig. 3) is in accordance with what would be expected in relatively undisturbed pelagic sediments. Accordingly, the absence of anomalously low percent planktic values indicates either that material transported to the study area arrived in amounts small enough such that values of percent planktics were not affected, or that the material was displaced from a location of similar depth characterized by comparable values.

Species Diversity and Equitability

Species diversity \( H(S) \) values (Table 2, Fig. 3) are slightly higher than values recorded at similar depths along the North Atlantic continental margin (Buzas and Gibson, 1969; Gibson and Buzas, 1973). These authors showed that diversity increases with depth in the North Atlantic and that it is generally the greatest in more stable deep-sea environments (Douglas, 1979).

Diversity values (Table 2) are generally consistent with expected trends, except for higher values recorded in cores 1739-1 and 1743-8 (Fig. 3). At location 1739 this results in a marked contrast between the high values in core 1739-1 (\(-3.5\) in the upper core, and \(-3.7\) in the lower core), and lower values in core 1739-5 (\(-3.0\)).

Samples in core 1743-8, recovered in a gully off Wilmington Canyon, record a relatively diverse fauna (\(-3.5\)). Core 1748-5 is characterized by distinctly different upcore values as compared to other cores (Table 2). The top two samples (2–4 cm and 6–8 cm) have distinctly higher \( H(S) \) values (\(-3.4\)) than lower samples (8–10 cm, 10–12 cm, 12–14 cm, and 14–15 cm, \( H(S) = -2.8 \)). Indeed, the four lower samples record lower diversity than the majority of samples in this study (Fig. 3). Diversity values reveal no distinct water depth-related pattern in Wilmington Canyon.

Diversity values in South Heyes Canyon (location 1749) show considerable cross-canyon and upcore consistency. Average values are slightly higher than most Wilmington Canyon sample sites, but, nevertheless, are lower than the two areas of high diversity (cores 1739-1, 1743-8) in Wilmington Canyon.

Values of equitability (E of Gibson and Buzas, 1969) indicate the degree to which species abundances are evenly distributed. Basic relationships observed for diversity values are similar to those of equitability (Fig. 3). Most cores from Wilmington Canyon are similar, with high values for cores 1739-1 and 1743-8, and with low values in the lower portion of core 1748-5. Values from South Heyes Canyon are consistently higher than those of most samples from Wilmington Canyon.

Taxonomic Data

Two hundred and forty-six species of benthic foraminifera have been recognized in Wilmington and South Heyes Canyon cores. Of these, 145 species were identified to the species level (Appendix 1), 30 were closely related to known species, 66 could not be assigned specific names, and five species were of uncertain generic placement. Census data (relative proportions of taxa in each sample) are given in Appendix 2.

Several cluster analyses were conducted to determine the relationship between samples based on taxa within each sample. Results were similar, and thus we present here only the analysis (unweighted pair group, Q-mode analysis, average distance method) using the 45 taxa composing at least 2% of the assemblage in any one sample (Fig. 4).

Five major clusters were identified, with three divided into subclusters (Fig. 4). Location 1739 (Cluster 1) is clearly distinguished from any other location, and the cores from the opposite sides of the canyon (1739-1 and 1739-5) are clearly separated. Cores from the two locations midway down the canyon (1741 and 1745) form Cluster 2, which is composed of three subclusters. At location 1741 the two cores (1741-7 and 1741-8) on either side of the meander are distinguished, samples from core 1741-8 are similar to the samples at location 1745. Samples from the gully of Wilmington Canyon (location 1743) form a distinct group (Cluster 3), but show similarity to samples from locations 1748 and 1749 (Cluster 4). Samples from South Heyes Canyon (location 1749) cluster with one another and show similarity to core 1748-1. The top two intervals (2–4 cm and 6–8 cm) in 1748-5 are grouped with samples from location 1749 and core 1748-1 at a lower level of similarity. However, bottom samples from core 1748-5 (Cluster 5) are the most distinctive samples in the entire data set.

A relationship of foraminiferal assemblages to water depth appears evident. Location 1739, which does not show a close relationship to other clusters, contains samples from a depth of \(-2,500\) m, considerably deeper than any other samples. Locations 1741 and 1745, at water depths of approximately 1,900–2,100 m, are distinguished from each other but are related (Fig. 4). Location 1743, from a depth of \(-1,700\) m, shows a closer relation to samples from sites 1748 and 1749 (depths from \(-1,500–1,600\) m) than to samples from 1741 and 1745 (depths from 1,900–2,100 m). Samples from depths of \(-1,500–1,600\) m in South Heyes Canyon (location 1749) are similar to those of core 1748-1, a core from a similar depth in Wilmington Canyon. The top of core 1748-5 is also similar to samples from comparable depths in South Heyes Canyon.

To better understand which species contribute to the observed clusters, biofacies fidelity (BF) and constancy (C) (Hazel, 1977; Culver, 1988) have been calculated for each species within each subcluster depicted in Figure 4. Constancy is a measure of the relative contribution a particular species makes to a bioassociation. This value is given by a number from zero through ten representing the percentage of samples in a group in which a given species occurs. Biofacies fidelity is, in essence, the chance that an investigator, having randomly sampled an individual of a particular species, would be sampling a particular biofacies. Thus, it is a
Biofacies fidelity values in Table 3 illustrate the rather homogeneous nature of species distributions in this study. For example, *Uvigerina peregrina*, with all its values equal to one, occurs in every subcluster and so is not particularly characteristic of any one site. The great dominance of values ranging from 1 to 2 shows that most species are widely distributed. The few slightly higher values are highlighted in Table 3.

Only 8 of the 45 most abundant species in this study have biofacies fidelity values of 3 or more. *Ammoglobigerina globigeriniformis, Cassidulina subcalifornica, Cibicides sp. A, and Eggerella bradyi* have values of 3. However, each of these species does not particularly characterize any one group of samples. The four species having values of biofacies fidelity >4 each show fidelity to particular locations. *Eoeponidella pulchella* is found almost exclusively in the bottom samples of core 1748-5. Location 1739 is characterized by *Hoeglundina elegans* and *Oridorsalis umbonatus*. *Cibicidoides kullenbergi* is characteristic of cores 1743-8 and 1748-1. Only these few species contribute to the outcome of the cluster analysis based on occurrence alone. Obviously, abundance variation of taxa helps to define discrete clusters.

Most species occur in many samples from each cluster, and thus notable variations in constancy are seen in only a few species. Of the species with the highest biofacies fidelity values, *Ammoglobigerina globigeriniformis* occurs in both samples from the top of core 1748-5, with greater persistence than elsewhere except South Heyes Canyon (location 1749). *Cibicides sp. A* is present in every sample from the two locations (cores 1739-1 and 1748-5) for which it demonstrates a relatively high biofacies fidelity. *Cibicidoides kullenbergi* occurs in many, but not all, samples from cores 1743-8 and 1748-1, and in only a few other samples. *Eggerella bradyi* occurs in nearly all samples from core 1743-8. *Eoeponidella pulchella* is present in all samples from the bottom section of core 1748-5 and is scarce elsewhere. *Hoeglundina elegans* and *Oridorsalis umbonatus* characterize location 1739, but have few occurrences elsewhere. Of the remaining species, *Valvulineria laevigata, Buliminia exilis, Bolivina subspinescens, Globobulimina pacifica* and *Gyroidina quinqueloba* are absent in the bot-
tom section of core 1748-5, the most distinct cluster. Clustering of samples from location 1743 can be related to low constancy values (compared to other cluster groups) for Bolivina subspinescens, Nonionella turgida, Nuttallides umbofera and Rosalina squamata.

In summary, cluster analysis indicates that: (1) major groups of samples show a depth-related pattern; (2) nearly all abundant species are ubiquitous throughout both canyons; (3) species distributions are relatively constant upcore (the only exception being core 1748-5); and (4) depth-related patterns are primarily a result of variation in relative abundances of the most abundant species, and are only secondarily related to variation in the occurrence of less abundant species.

Foraminiferal Depth Distribution

The cluster analysis distinguished sample sites on the basis of their depth below sea level. However, all sites, with the exception of the abyssal site 1739, are located in the lower bathyal (1,000–2,000 m) depth zone recognized by previous workers on the North American Atlantic continental margin (e.g., Berggren and Miller, 1989; Brunner and Culver, 1992). Hence, samples are discriminated by variation in abundance of species rather than by their presence or absence. In agreement with published depth zonation, abyssal site 1739 clustered separately from lower bathyal sites.

The depth distributions of abundant species were compared with the published record (e.g., Brady, 1884; Cushman, 1920, 1922b, 1923, 1930, 1931; Uchio, 1960; Barker, 1960; Culver and Buzas, 1980 and included sources, 1981b, 1983a, 1983b; Poag and others, 1980; Sejrup and Guibault, 1980; Cole, 1981; Miller and Lohmann, 1982; Hermelin and Scott, 1985; Mead, 1985; Stanley and others, 1986; Hermelin, 1989; Berggren and Miller 1989; Corliss 1991; Brunner and Culver, 1992), and several significant bathymetric extensions of presence or high abundance were identified.

_Tritifarina fluens_ has been reported infrequently from the North American Atlantic continental margin but is present in all but two samples (core 1748-5, 10–12 cm and 12–14 cm). It occurs in considerable numbers at every location with the exception of the abyssal site 1739, where it is less abundant. Because of its high abundance, not only in Wilmington and South Heyes canyons but also in a gully shielded from downslope transport, the known depth range of _Tritifarina fluens_ can now be extended through the lower bathyal zone into the abyssal zone where it begins to become less abundant around 2,500 m. Similarly, _Bolivina ordinaria_ occurs consistently and with a relatively high abundance in nearly all samples. It has been recorded previously in the lower bathyal zone, but in low abundance (Brunner and Culver, 1992). _Bolivina ordinaria_ also occurs at the abyssal location 1739, but in low abundances. _Epistominella sandiegoensis_ has a published depth range like that of _Bolivina ordinaria_ and has been infrequently reported from the North American Atlantic continental margin (Brunner and Culver, 1992). It has a similar distribution in both canyons but is found in slightly higher abundances in core 1739-1 and in great abundance in core 1748-5 (10–15 cm, together with characteristically neritic forms) making up ~19–25% of the assemblage in the four samples. This form is identified as _Epistominella takayangii_ Iwasa by D. B. Scott (personal
communication, 1990), who has recorded it in Recent sediments in the Arctic from outer shelf to middle bathyal depths (Schröder-Adams and others, 1990), and from Pleistocene DSDP core material off New Jersey (Scott, 1987). *Bolivina marginata* has been recorded previously at lower bathyal depths, but normally in lower abundances than on the upper to mid-slope (although Cushman [1922] reported *B. marginata* as “common” at a station ~2,000 m deep). In this study it was abundant in South Heyses Canyon (location 1749), and in both the deepest (core 1739-1) and the shallowest (core 1748-1) locations in Wilmington Canyon.

*Bulimina mexicana*, *Cassidulina carinata*, *Cassidulina neocarinata*, and *Islandiella norcrossi* have been recorded with high abundance at middle bathyal depths. In this study, these species occur in many samples throughout Wilmington Canyon, the gully of Wilmington Canyon (location 1743), and South Heyses Canyon where it composes 3% of assemblages. The abyssal record of *Bulimina mexicana* is in accordance with Corliss’ (1991) record of living specimens in the northwest Atlantic Ocean off the Nova Scotian continental margin.

Several species previously recorded at neritic depths were recovered in this study. Thirty of a total of 34 specimens of *Eoeponiidella pulchella* are in the lower four samples of core 1748-5. One specimen is found in both cores 1749-4 and 1745-7, and two individuals occur in core 1743-8. *Rosalina squamata* is relatively common only in core 1743-8 (~1-2%) and the lower samples of core 1748-5 (~2-3%), occurrences at other localities being rare and scattered. *Bolivina pseudoplicata* has been considered as a neritic species along the Atlantic coast of North America (Brunner and Culver, 1992). However, Hermelin and Scott (1985) described this species as quite common to a depth of 2,760 m in the central North Atlantic, and its widespread distribution in this study suggests that this species inhabits lower bathyal depths along the North Atlantic continental margin. Specimens of *Hanzawaia strattoi* in this study are smaller, less robust, and more fresh in appearance than specimens of this species identified by Brunner and Culver (1992) that were interpreted as neritic in origin. Although few in number, they display a wide distribution, and may represent in situ specimens. A widespread distribution for the supposed neritic species *Cibicides fletcheri* may be similarly interpreted. It was, in fact, reported at a depth of 650 fathoms by Uchino (1960).

*Bulimina elegantissima* and *Eggerella advena*, two classically neritic species, occur in small numbers in Wilmington Canyon. *Bulimina elegantissima* occurs in core 1748-5, 11 specimens throughout the lower four samples and one specimen in each of the top two samples. One specimen also occurs in core 1745-5 at 2-4 cm. Only three individuals of *Eggerella advena* were found, two from core 1748-1 at 2-4 cm and one from core 1748-5 at 2-4 cm.

In summary, the great majority of species in this study occupy their previously recorded depth ranges. Nearly all of those species that had not been recorded previously from the lower bathyal zone have a widespread distribution, similar to that of the known lower bathyal species that occur with them. Hence the dominant component of foraminiferal assemblages recorded in this study is lower bathyal in nature. Some downslope displacement of these specimens from outer neritic or upper to middle bathyal depths is not ruled out, but the data suggest such transport is not the dominant process. Exceptions include the lower part of core 1748-5, which contains an unusual assemblage with definite neritic input.

**DISCUSSION**

**FORAMINIFERAL AND LITHOLOGIC DATA**

The lithologic and foraminiferal data are a function of sedimentary processes in Wilmington and South Heyses canyons. Lithologic data show variation across all canyon meanders, significant differences throughout Wilmington Canyon, and consistent values in South Heyses Canyon which differ from those in Wilmington Canyon. In contrast, foraminiferal data indicate general consistency (with few exceptions) between and throughout the canyons, but demonstrate clear variations with water depth (Table 4). This contrast between variability in lithologic characteristics in Wilmington Canyon and generally uniform lithologic attributes in South Heyses Canyon is shown in Figure 3. In locations 1739, 1745, and to a lesser degree at 1741, cross-canyon variability is recorded in clastic material, sand fraction, and number of benthic foraminifera per gram of sediment. In South Heyses Canyon, the lithology is less variable and, except for an increase along the south wall (core 1749-2), the number of benthic foraminifera per gram is generally uniform. Also notable at 1749 is the lower input of clastic material relative to a site at similar depth in Wilmington Canyon (1748), and the possibly lower rate of deposition indicated by the high number of benthic foraminifera per gram of sediment at 1749. The larger proportion of planktic foraminifera at similar depths in South Heyses than in Wilmington Canyon may suggest that there is an additional source of benthic foraminifera supplied to Wilmington Canyon (it is difficult to envisage the alternative, a greater source of planktic foraminifera to South Heyses Canyon).

Figure 3 and Table 4 show the general similarity in foraminiferal characteristics in Wilmington and South Heyses canyons. Planktic to benthic foraminiferal ratios (expressed as percent planktics) do not vary significantly across-canyon, and values increase at greater depths. Species diversity values show no similar depth-related pattern, but exhibit great uniformity throughout nearly all cores. The only cross-canyon variability is seen at location 1739. The values for biofacies fidelity and constancy (Table 3) also show a lack of variability in the distribution of benthic foraminifera. Only a few species are characteristic of any one location (abyssal location 1739 is the exception); distinctions made by cluster analysis are based on variations in species abundance.

Disparity between lithologic and foraminiferal patterns indicate that, within a background of hemipelagic rain, the canyons experience sedimentary processes in addition to turbidity currents. Processes such as small scale slumping and other mass wasting processes (including creep), tidal currents, down-canyon low-density current flows (some perhaps triggered by storms), and bioerosion (as evidenced by direct observation from Alvin of the steep walls of South Wilmington Canyon) need also to be considered.
<table>
<thead>
<tr>
<th>Core</th>
<th>Depth (m)</th>
<th>% Clastic material</th>
<th>% Sand fraction</th>
<th>No. benthic foraminifera per gram</th>
<th>% Plastics (P/B)</th>
<th>Species diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilmington Canyon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1739-1-3P</td>
<td>2.483</td>
<td>86%</td>
<td>39%</td>
<td>5,881</td>
<td>88%</td>
<td>Cross-canyon variation; high values at outside of meander, low values on inside of meander.</td>
</tr>
<tr>
<td>1739-5-8P</td>
<td>2.503</td>
<td>54%</td>
<td>7%</td>
<td>201,500</td>
<td>88%</td>
<td></td>
</tr>
<tr>
<td>Outside meander with significantly higher clastic input.</td>
<td>Outside of meander markedly sandier.</td>
<td>Marked variation; much more rapid deposition on outside of meander.</td>
<td>No variation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1741-7-8P</td>
<td>1.898</td>
<td>91%</td>
<td>12%</td>
<td>73,300</td>
<td>74%</td>
<td></td>
</tr>
<tr>
<td>1741-8-11P</td>
<td>1.897</td>
<td>89%</td>
<td>9%</td>
<td>136,800</td>
<td>76%</td>
<td></td>
</tr>
<tr>
<td>Very minor variation.</td>
<td>Slightly sandier on outside of meander.</td>
<td>Significant variation; more rapid deposition of outside of meander.</td>
<td>Insignificant variation.</td>
<td>No variation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1743-8-11P</td>
<td>1.703</td>
<td>88%</td>
<td>9%</td>
<td>161,300</td>
<td>73%</td>
<td></td>
</tr>
<tr>
<td>Similar to values at location 1741.</td>
<td>Similar to values at location 1741 and in channel at location 1745.</td>
<td>Similar to values in 1741 and in channel at location 1745.</td>
<td>High values</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1745-6-9P</td>
<td>2.076</td>
<td>80%</td>
<td>8%</td>
<td>180,800</td>
<td>82%</td>
<td></td>
</tr>
<tr>
<td>1745-7-11P</td>
<td>2.080</td>
<td>82%</td>
<td>8%</td>
<td>142,900</td>
<td>84%</td>
<td></td>
</tr>
<tr>
<td>1745-9-13P</td>
<td>2.080</td>
<td>62%</td>
<td>5%</td>
<td>472,400</td>
<td>87%</td>
<td></td>
</tr>
<tr>
<td>Much lower clastic input on outside of meander than middle of channel.</td>
<td>Less sandy on outside of meander than middle of channel.</td>
<td>Marked variation between middle and outside of channel.</td>
<td>Insignificant variation.</td>
<td>No variation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1748-1-1P</td>
<td>1.600</td>
<td>85%</td>
<td>2.6%</td>
<td>1,368,400</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>1748-5-8P</td>
<td>1.540</td>
<td>99%</td>
<td>5% (8% upper, 4% lower)</td>
<td>3,800 (5,800 upper, 2,800 lower)</td>
<td>49% (41% upper, 53% lower)</td>
<td>3.2 (upper), 2.7 (lower).</td>
</tr>
<tr>
<td>Material with extremely high clastic input in burrowed core.</td>
<td>Material in burrowed core low in sand.</td>
<td>1748-1-1P—Very high values, slow deposition.</td>
<td>1748-1-1P—Low values.</td>
<td>1748-5-8P—Burrowed material has similar values.</td>
<td>1748-1-1P—Similar to location 1749.</td>
<td></td>
</tr>
<tr>
<td>1749-2-2P</td>
<td>1.589</td>
<td>70%</td>
<td>1.7%</td>
<td>3,599,100</td>
<td>57%</td>
<td></td>
</tr>
<tr>
<td>1749-4-4P</td>
<td>1.585</td>
<td>69%</td>
<td>2.4%</td>
<td>1,689,800</td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td>1749-5-5P</td>
<td>1.560</td>
<td>73%</td>
<td>2.9%</td>
<td>1,713,500</td>
<td>59%</td>
<td></td>
</tr>
<tr>
<td>1749-13-13P</td>
<td>1.501</td>
<td>74%</td>
<td>2.3%</td>
<td>2,419,100</td>
<td>56%</td>
<td></td>
</tr>
<tr>
<td>Consistent, comparatively low, clastic input.</td>
<td>Consistently low values.</td>
<td>Very high values, some cross channel variation.</td>
<td>Insignificant variation.</td>
<td>Insignificant variation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Heyes Canyon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1749-2-2P</td>
<td>1.589</td>
<td>70%</td>
<td>1.7%</td>
<td>3,599,100</td>
<td>57%</td>
<td>3.2</td>
</tr>
<tr>
<td>1749-4-4P</td>
<td>1.585</td>
<td>69%</td>
<td>2.4%</td>
<td>1,689,800</td>
<td>60%</td>
<td>3.3</td>
</tr>
<tr>
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<td>1,713,500</td>
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<td>3.3</td>
</tr>
<tr>
<td>1749-13-13P</td>
<td>1.501</td>
<td>74%</td>
<td>2.3%</td>
<td>2,419,100</td>
<td>56%</td>
<td>3.2</td>
</tr>
</tbody>
</table>
Tidal currents, with velocities usually <50 cm/sec, have been recorded in some submarine canyons along the United States Atlantic continental margin (Shepard, 1979). A few measurements have recorded currents of slightly greater velocity (50 to 75 cm/s) occurring during storms (Shepard and others, 1977). Direct measurements of tidal currents in Wilmington Canyon collected at a maximum depth of 915 m (3 m above the canyon floor) during nineteen days of observation indicated a maximum velocity of 22 cm/sec, with a mean of 8 cm/sec (Keller and Shepard, 1978). The currents at this station varied up- and down-canyon and showed a slight trend toward up-canyon flow.

Currents generated by tides and density flow in submarine canyons have been known to stir silts and fine sands on canyon floors, and in some instances generate ripple marks (Shepard, 1979). Within Wilmington Canyon, at a location a short distance up-canyon from core 1739-1 and along the same bend in the canyon, ripple marks were observed (S. J. Culver, field notes; Sanford and others, 1990). The orientation of these ripple marks may indicate the presence of active tidal currents flowing up-canyon at this location.

Weak up-canyon, down-canyon, or bidirectional tidal currents, intensified at constrictions and the outside of meander bends, could gently but continuously winnow sediment on the canyon floor, and also disturb sediment along the canyon walls. Silt- and clay-sized material would be preferentially removed from these areas, leaving a sand-enriched lag and a correspondingly decreased sand-sized fraction in nearby less energetic areas (e.g., location 1739). The lower proportion of silt- and clay-sized material in Wilmington Canyon compared to South Heyes Canyon (Fig. 3) suggests that fines are being winnowed in Wilmington Canyon. The depth-related ratios of planktic to benthic foraminifera, and the generally uniform distribution of benthic foraminifera in Wilmington Canyon demonstrate that the main constituents of foraminiferal assemblages present in this canyon have been relatively unaffected by this process.

Segall and others (1989) and Sanford and others (1990) have suggested that the dominant recently active sedimentary process in Wilmington and South Heyes canyons is mass wasting. Sanford and others (1990) found substantially higher rates of deposition at location 1745 than in most samples throughout Wilmington Canyon. They attributed this, and other areas of high deposition, to extensive bioclastic input (observed from DSRV Alvin; S. J. Culver, field notes) of canyon walls (steeper along the outside of meanders) and attendant redeposition at the base of walls.

The variations in sedimentary data observed across meanders in Wilmington Canyon may result in part from slumping of canyon walls. The consistency observed in foraminiferal data may be explained in part by movement of material down canyon walls by mass wasting and redeposition at only slightly greater depths in the nearby canyon. Subsequent transport of material somewhat farther down-canyon would not conspicuously alter foraminiferal assemblages.

Cross-canyon variations in lithologic characteristics in Wilmington Canyon are not evident in South Heyes Canyon. The low average gradient of the walls and the absence of steep walls in South Heyes Canyon help explain differences in sediment content of the two canyons. Steep canyon walls, such as those found at the outside of meander bends, would be more susceptible to sediment failure, slumping and bioclastic erosion. In comparison, the relative homogeneity in lithologic attributes across South Heyes Canyon is largely a function of its morphology.

In summary, sediment failure along steep and undercut canyon walls and the observation of rare ripple-marks apparently generated by bottom currents (perhaps tidal) indicate that several processes are currently active in Wilmington Canyon. The lower rate of deposition and low percent clastic input in South Heyes Canyon suggest that mass wasting, bottom current action and/or low-density flows are currently less important, in terms of sediment displacement, than in Wilmington Canyon.

FORAMINIFERAL IMPLICATIONS FOR SEDIMENT TRANSPORT

Mass wasting, bottom current processes and low-density flows best explain the observed patterns of lithologic and foraminiferal data within Wilmington and South Heyes canyons. This allows for a modification of the model of recent sediment transport in Wilmington Canyon that involves erosive gravity flows or turbidity currents, as proposed by Stanley and others (1986). These denser currents were believed responsible for the differences observed downcore and between cores, and a discontinuous stop-and-go transport process was invoked. The basis for their model was observation of marked increases in "shallow" benthic foraminifera across-canyon and downcore in two cores along the steep walls of meanders, accompanied by marked discontinuities in sedimentary characteristics in the canyon sections. Sedimentary variations observed by Stanley and others (1986) correspond to variations attributed in the present study to a combination of mass-wasting, low-density and perhaps tidal current action. Documentation of benthic foraminifera in this study indicates that some "shallow" species that Stanley and others (1986) considered to have been actively transported down-canyon either lived and accumulated at lower bathyal depths or resulted from bioclastic erosion and downslope failure of exposed canyon wall sections, including sections of slump blocks of nemic origin emplaced during a Pleistocene lowstand of sea-level (Brunner and Culver, 1992).

Some of the abundant species observed in Wilmington Canyon were previously considered native to shallower water, and were thus interpreted as evidence of downslope transport (Stanley and others, 1986). It is of note, however, that these species are also found in similar abundances in South Heyes Canyon where turbidity currents do not prevail (Farre and others, 1983), where there is no direct connection with the outer shelf, and where the recent dominant active process is small-scale mass and down-wall wasting of hemipelagic material (Sanford and others, 1990). This indicates that many species within South Heyes Canyon (and, by comparison, the same species in Wilmington Canyon) lived and accumulated at lower bathyal depths where they were sampled. This is supported by samples from core 1743-8, taken from the hemipelagic drape high on the southeastern wall of a gully feeding into Wilmington Canyon (Fig. 2). This gully is orthogonal to the trend of the slope in this location and is directly downslope of another gully
of the same orientation. This location is, therefore, well-
shielded from downslope transport of material in the chan-
nel by bottom currents and density currents. Species found
in this location likely live at lower bathyal depth. Forty-
three of the 45 most abundant species in this study are found
in this core, and nearly all are abundant.

Evidence for bioerosion of Wilmington Canyon walls are
recorded by differences in lithologic and foraminiferal char-
acter between the top and bottom of core 1748-5. These
three burrowed samples have low diversity and equitability
values relative to other samples in this study (Fig. 3), cluster
distinctly from all other samples (Fig. 4), and contain a few
dominant species which are dominant nowhere else in Re-
cent sediments in Wilmington Canyon but which are dom-
inant in Pleistocene slump blocks of neritic origin that, in
places, comprise the steep walls of Wilmington Canyon
(Brunner and Culver, 1992). Epistominella sandiegoensis
and Elphidium excavatum are very abundant. Cassidulina
reniforme has greater abundance here than in other samples.
Rosalina squamata is present in moderate numbers and there
are occurrences of Balaminella elegansissima. Elphi-
dium subarcticum, Elphidium sp. A and Elphidium sp. B.

Most of these species have been used previously as shallow
water indicators, although live specimens of Elphidium ex-
cavatum have been recovered from lower bathyal and abyss-
al depths (e.g., Miller and Lohmann, 1982; Corliss, 1991;
see Brunner and Culver, 1992 for discussion). The occur-
rence of E. excavatum in moderate abundances throughout
this study also suggests a natural occurrence at these depths.
However, high abundance of E. excavatum in the lower part
of 1748-5, together with other anomalously abundant spe-
cies, is suggestive of shallow water, and probably indicative
of an allochthonous fauna derived from a Pleistocene slump
block of neritic origin (Brunner and Culver, 1992).

The presence in core 1739-1 of anomalously large num-
ers of the species that dominate the lower portion of core
1748-5 indicate that bioerosion may have contributed ma-
terial to core 1739-1. This is supported by the high diversity
observed and by evidence for increased sand fraction and
clastic deposition, as well as the possible higher rate of de-
position in this location relative to samples across canyon,
as indicated by benthic foraminifera per gram of sediment
(Fig. 3). Core 1739-1 was collected along the outside of a
meander beneath a nearly vertical wall, a location similar to
those where Stanley and others (1986) observed downcore
differences that they inferred to result from downslope trans-
port. In this core, Epistominella sandiegoensis and El-
phidium excavatum occur with slightly higher abundances
than in most samples in this study. Relatively large numbers
of Rosalina squamata occur in one sample. Proportions of
these species, which are widespread in the cores of this
study, are augmented by additional material derived via
bioerosion and downslope transport from the canyon walls
at this location.

The action of gravity on downslope sediment transport
cannot be discounted. Moreover, the scattered occurrences
of neritic species within Wilmington Canyon indicate that
some downslope transport is occurring. However, it appears
from study of samples herein that gravity-driven transport
is occurring at fairly low rates, and that high rates of fora-
miniferal production in situ tend to overprint this displace-
ment signal.

Thus, only modest evidence for large-scale sediment
transport has been recognized in this study; while clearly
able to mold the surficial sediment drape, these processes
cannot completely account for the gross morphology of the
modern canyons. Major mass wasting and headward erosion
in straight canyons and active scouring by major turbidity
currents in meandering canyons have not been the major
processes during the past 200–600-year period (cf. Sanford
and others, 1990) represented by cores in this study.

CONCLUSIONS

Marked variations in lithologic characteristics observed
across meanders throughout Wilmington Canyon contrast
with the ubiquitous distribution of the abundant foraminif-
era, which vary almost exclusively in relative abundance
(not occurrence) and show a clear depth-related pattern. This
indicates that relatively minor mass-wasting processes (in-
cluding creep) and bottom low-density and/or tidal current
action are altering the lithologic characteristics, particularly
along the outside of meanders, while leaving the overall
distribution of foraminifera relatively unaffected. South
Heyes Canyon is more quiescent, with minor mass wasting
interpreted to be the only process recently active. Samples
from this canyon exhibit striking uniformity in nearly all
foraminiferal and lithologic attributes measured. Thus, this
contrast with Wilmington Canyon is most likely related to
marked morphologic differences and slope settings of the
two canyons.

Several foraminiferal species in both canyons, previously
considered to be characteristic of shallower waters, lived
and accumulated at lower bathyal or abyssal depths. Some,
if not most, species that Stanley and others (1986) inferred
to be indicative of downslope transport (i.e., neritic species)
were deposited in the Wilmington Canyon channel after be-
ing eroded from the slumped blocks of neritic origin that
now constitute the steep canyon walls.

The observations of recent relative inactivity in South
Heyes Canyon and of a moderately active Wilmington Can-
yon during the past 200–400 years indicate that the major
processes responsible for canyon erosion are not currently
active to any significant degree, and occur at time scales
much greater than those represented by the core material in
this study.

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APPENDIX I

Original references to benthic foraminifera taxa identified to the species level.

Abditodentrix asketocomptella Patterson
Abditodentrix asketocomptella Patterson, 1985, p. 140, pl. 1, figs. 1-9.

Alliata cf. A. primitiva (Cushman and McCulloch)
Cushmanella primitiva Cushman and McCulloch, 1940, p. 163, pl. 18, figs. 6-8, 10.

Anodontias cf. A. tenuis Brady
Anodontias tenuis Brady, 1881, p. 51.—Brady, 1884, p. 38, figs. 4-6.

Anomlogobirgina globigeriniformis (Parker and Jones)
Litulina nautiloides Lamark var. globigeriniformis Parker and Jones, 1865, p. 407, pl. 17, fig. 96.

Anomalinaeides cf. A. lankfordi (Uchio)
Nonion lankfordi Uchio, 1960, p. 60, pl. 4, figs. 5-8.

Anomalinaeides cf. A. mexicana Parker
Anomalinaeides mexicana Parker, 1954, p. 539, pl. 11, figs. 21-23.

Anomalinaeides phlegeri (Uchio)
Cibicides phlegeri Uchio, 1960, p. 69, pl. 10, figs. 7-10.

Astronomion gallowayi Loeblich and Tappan
Astronomion gallowayi Loeblich and Tappan, 1953, p. 90, pl. 17, figs. 4-7.
Bolivina lanceolata
Bolivina rostrata
Brady
Bolivina marginala Wickenden)
Bulimina glabra
Brady
Bulimina exilis
Brady
Bulimina aculeata
Andersen
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B. variabilis
Williamson
Borbulia translucens
Phleger and Parker
Bolivina subaenariensis
Cushman
B. pseudopunctata
Höglund
Heron-Allen and Earland
Bolivina pseudoplicata
Cushman
B. variabilis
Williamson, 1858, p. 76, pi. 6, figs. 36-40.
Bolivina pseudopunctata
Höglund, 1947, p. 273, pl. 24, fig. 5, pi.
32, figs. 23, 24.
Bolivina subnaenariensis
Cushman
B. pseudopunctata
Höglund
B. marginata
Brady
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B. translucens
Phleger and Parker
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Williamson, 1858, p. 69, pi. 6, figs. 143, 144.
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Williamson, 1858, p. 76, pi. 6, figs. 162.
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Williamson, 1858, p. 76, pl. 6, figs. 36-40.
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Pseudorochammina (Parker) atlántica Loeblich and Tappan
Nonionella fragilis Uchio
Nonionella (?) fragilis Uchio, 1960, p. 62, pl. 4, figs. 19–21.
Nonionella grateoupi (d’Orbigny)
Nonionina grateoupi d’Orbigny, 1826, p. 294
Parafissurina cf. N. iridea Heron-Allen and Earland
Parafissurina iridea Heron-Allen and Earland, 1932, p. 438, pl. 16, figs. 14–16.
Nonionella opima Cushman
Nonionella opima Cushman, 1947, p. 90, pl. 20, figs. 1–3.
Nonionella turgida (Williamson)
Rotalina turgida Williamson, 1858, p. 50, pl. 4, figs. 95–97.
Nonionellina labradorica (Dawson)
Nonionella labradorica Dawson, 1860, p. 191, fig. 4.
Nuttallides umbonifera (Cushman)
Nuttallides umbonifera Cushman, 1933, p. 90, pl. 9, figs. 9a–c.
Oolina apiculata (Reuss)
Oolina apiculata Reuss, 1850, p. 22, pl. 1, fig. 1.
Oolina globosa (Montagu)
Vermicidium globosum Montagu, 1803, p. 523.
Oolina hexagona (Williamson)
Entosolenia squamosa Montagu var. hexagona Williamson, 1848, p. 20, pl. 2, fig. 23.
Oolina laevigata d’Orbigny
Oolina laevigata d’Orbigny, 1839b, p. 19, pl. 5, fig. 3.
Oolina lineata (Williamson)
Entosolenia lineata Williamson, 1848, p. 18, pl. 2, fig. 18.
Oolina cf. O. lineata (Williamson)
Entosolenia lineata Williamson, 1848, p. 18, pl. 2, fig. 18.
Oridorsalis tener (Brady)
Truncatulinia tenera Brady, 1884, p. 665, pl. 95, figs. 11a–c.
Oridorsalis umbonatus (Reuss)
Rotalina umbonata Reuss, 1851, p. 75, pl. 5, fig. 35a–c.
Osangularia cultur (Parker and Jones)
Planorbulina forcato (Fichet and Moll) var. ungeriana (d’Orbigny) subvar. cultur Parker and Jones, 1865, p. 421, pl. 19, figs. 1a–c.
Paraffissurina arctica Green
Paraffissurina arctica Green, 1959, p. 76, pl. 1, figs. 2a, b, 14, figs. 17a–c.
Paraffissurina fusiformis Loeblich and Tappan
Paraffissurina fusiformis Loeblich and Tappan, 1953, p. 79, pl. 14, figs. 18, 19.
Paraffissurina cf. P. fusiformis Loeblich and Tappan
Paraffissurina fusiformis Loeblich and Tappan, 1953, p. 79, pl. 14, figs. 18, 19.
Paraffissurina inornata Bergen
Paraffissurina inornata Bergen and others, 1986, p. 266, pl. 10, figs. 27–29.
Paraffissurina tectulosostoma Loeblich and Tappan
Paraffissurina tectulosostoma Loeblich and Tappan, 1953, p. 81, pl. 17–19.
Pseudotrophammina atlantica (Parker)
Trocchaminella atlantica Parker, 1952, p. 409, pl. 4, figs. 17–19.
Pullenia bulboides (d’Orbigny)
Nonionina bulboides d’Orbigny, 1826, p. 293, model no. 2.—d’Orbigny, 1846, p. 107, pl. 5.
### APPENDIX 2—Relative proportions (expressed as percents) for each species in each of the 78 samples in this study.

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### Notes:
- Sample values are in percent.
- Column headers indicate species and depth intervals.
- Depth intervals are in meters.
- Species names are abbreviated for clarity.

### References:
- Foraminifera and Sedimentary Processes in Submarine Canyons.
- Modified from existing databases and literature reviews.

### Data Sources:
- University of California, Santa Barbara, Marine Geology Laboratory.
- Smithsonian Institution, National Museum of Natural History.
- Other relevant institutions and publications.