Miocene-Pliocene bathyal benthic foraminifera and the uplift of Buff Bay, Jamaica

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ABSTRACT

We sampled lowermost middle Miocene to Pliocene sections exposed in roadcuts east of Buff Bay, Jamaica, for quantitative benthic foraminiferal studies. Our analyses document paleobathymetric changes and sediment sources. The Spring Garden Member of the Montpelier Formation and the Buff Bay Formation (middle to upper Miocene) were deposited at lower bathyal paleodepths (1,000 to 2,000 m) that probably exceeded 1,300 m, while the overlying Bowden Formation (Pliocene) was deposited within the upper bathyal zone (200 to 500 m). A significant portion of the benthic foraminifera found in Buff Bay sections consists of transported shallow-water reefal elements (Amphistegina spp./Asterigerina spp.) occurring in otherwise in situ deep-water bathyal biofacies.

The lower part of the Spring Garden Member (middle Miocene) contains a typical cosmopolitan lower bathyal biofacies dominated by Globocassidulina subglobosa, Cibicidoides mundulus, Stilostomella aculeata, and Oridorsalis spp. A biofacies change that occurs within the Spring Garden Member may reflect the well-documented global benthic foraminiferal taxonomic turnover that occurred throughout the deep sea from early to middle Miocene Biochrons N8 to N11. The upper Spring Garden Member and portions of the Buff Bay Formation (middle Miocene) faunas are characterized by the apparently endemic species Compressigerina coarata and Siphouvierina porrecta; we interpret this as an in situ lower bathyal biofacies. Much of the Buff Bay Formation (middle-upper Miocene) is dominated by Reussella spinulosa var. pulchra, Uvigerina proboscidea, Rosalina sp. 1, and Siphouvierina porrecta; although this assemblage may be an in situ lower bathyal biofacies, there is evidence to suggest that it may be a transported thanatofacies. The Bowden Formation (Pliocene) is characterized by an upper bathyal (200 to 600 m) biofacies dominated by Bulimina aculeata, Globobuliminina spp., Planulina foveolata (lower depth limit is 500 m), and Uvigerina sp. 1. The change in benthic foraminiferal biofacies between the Buff Bay and Bowden Formations reflects the tectonic uplift of the north coast of Jamaica. We estimate that at least 800 m of shallowing occurred between the late Miocene (ca. 8 Ma) and Pliocene (ca. 4 to 3 Ma) during the hiatus that separated deposition of the Buff Bay and Bowden Formations. A subsequent shallowing occurred from the Pliocene (bathyal paleodepths >200 m) to the Pleistocene (neritic depths <60 m; Robinson, 1969).

BACKGROUND

Regional and local setting

Hill (1899) described strata that are exposed east of the town of Buff Bay, Jamaica (Fig. 1), in surveys that he made for Alexander Agassiz. He designated over 30 m (100 ft) of "... bluish white, earthy, semi-indurated marl..." as the Buff Bay Beds, and reported that these beds rest directly on a "... pure, white chalky marl which in its lower part grades into the Montpelier beds..." (Hill, 1899, p. 84). The latter were believed to be lower Oligocene. Hill (1899) suggested that...
the previously reported Bowden Beds correlate with the Buff Bay Beds.

Robinson (1969) proposed formal names for Jamaican sections, including those east of the town of Buff Bay. He refined Hill's (1899) designations, assigning only part of the original beds near Buff Bay to the Montpelier and Bowden Formations. He named Hill's white marl the Spring Garden Member of the uppermost Montpelier Formation and used Bolli's (1957) zones to determine that it is Miocene rather than Oligocene, as previously believed. A conformable contact separates the Spring Garden Member from the overlying semi-indurated marl of the Buff Bay Formation. As formally designated, the Buff Bay Formation includes those strata that Hill referred to as the Buff Bay Beds (Robinson, 1969). An unconformable contact separates the Buff Bay Formation from the overlying unit, which Robinson (1969) described as a series of calcareous foraminiferal clays irregularly interbedded with clayey bioclastic limestones with a rich coral fauna. Hill (1899) assigned the upper beds near Buff Bay to the Bowden Marls, although his Figure 23 and Plate 17 indicate that he included the Buff Bay Beds as part of the Bowden. Robinson (1969) correlated the strata overlying the Buff Bay Formation at its type section to the Bowden Formation, which has its type locality near Bowden on the southeast coast (Fig. 1).

Caribbean foraminiferal studies

Uplifted exposures of deep-water sediments provided the only available pre-Pleistocene deep-sea record until the advent of the Deep Sea Drilling Project in 1967. The Caribbean region contains many of these classic uplifted deep-water sections. The sedimentary sequence exposed east of the town of Buff Bay on the north coast of Jamaica (Fig. 1) contains one of the most complete middle Miocene deep-water sequences in the Caribbean and has been the focus of several micropaleontological studies.

Vaughan (1928) pioneered benthic foraminiferal research in Jamaica. Cushman and Jarvis (1930, 1936) conducted preliminary studies of species from the Buff Bay outcrops. Cushman and Todd (1945) studied the benthic foraminiferal taxonomy of the Buff Bay faunas in greater detail, although most of their samples were from the Pliocene Bowden Formation (Robinson, 1969). The diverse assemblages described by Cushman and Todd (1945) include twenty-four new species and eight new varieties. Parker (1945) addressed foraminiferal taxonomy from the Bowden Formation of Jamaica, although her samples were not from the Buff Bay section. Steineck (1974) used benthic foraminifera to estimate the paleobathymetry of the Cenozoic Jamaican sections. He later (1981) modified his benthic foraminiferal estimates based on ostracods (see "Paleobathymetry" section).

Other publications on Caribbean Cenozoic benthic foraminifera describe faunas similar to those found at Buff Bay. Coryell and Rivero (1940) focused on the Miocene microfauna of Haiti. Cuban Miocene assemblages were the subject of several papers (Palmer and Bermúdez, 1936a, b; Palmer, 1940, 1941). Renz (1948) studied the Agua Salada Group of Venezuela. Bermúdez (1949) reported on the Tertiary smaller foraminifera of the Dominican Republic. McLaughlin and Sen Gupta (1989a, b, in preparation) discussed basin evolution and the paleoenvironment-
tal significance of Neogene benthic foraminifera from the Dominican Republic. Deep-water calcareous benthic foraminiferal faunas were described from Miocene sections in Costa Rica by Cassel and Sen Gupta (1989a, b).

Robinson (summary in 1969) supplied samples (designated ER21 through ER44) from the Buff Bay region to micropaleontologists throughout the world. These samples provided the basis for the construction of much of the Cenozoic biostratigraphic framework. The sections exposed near Buff Bay were used as type localities for many of Blow's (1969, 1979) planktonic foraminiferal zones (Berggren, this volume). Bolli (1970) studied ER samples and identified the index planktonic foraminiferal species from the upper Montpelier and Buff Bay Formations (Liska, 1985). Although these studies are critical to global biostratigraphy, the previous sample coverage of the sections exposed near Buff Bay was broad (e.g., the ER21 to ER44 samples were taken at an average of ~1.2 m [4 ft] apart, representing three samples/planktonic foraminiferal zone).

The previous foraminiferal studies of the sections exposed near Buff Bay concentrated on taxonomy (e.g., Cushman and Jarvis, 1930, 1936; Cushman and Todd, 1945) or biostratigraphy (e.g., Blow, 1969, 1979; Bolli, 1970; Liska, 1985). The foraminiferal biostratigraphy of these sections is not straightforward because of the wide sample spacing, problems in the local sections (reworking of older material and downslope contamination), and lack of independent stratigraphic control (e.g., magnetostratigraphy, stable isotope stratigraphy). These problems were discussed by Liska (1985), and are addressed in studies by our joint field party (Berggren, this volume; Aubry, this volume; Kent and van Fossen, unpublished data of 1992; Miller, unpublished data of 1992).

The sections exposed in Jamaica provide a record of a critical interval of deep-water benthic foraminiferal evolution. The early to middle Miocene was a period of change in benthic foraminiferal faunas worldwide (Berggren, 1972; Schnitker, 1979). Schnitker (1986), Thomas (1986a, b), and Miller and Katz (1987a) reported that a late early to middle Miocene taxonomic turnover occurred in the North Atlantic, and Thomas (1985, 1986b), Woodruff (1985), Boersma (1986), and Thomas and Vincent (1987) documented this event in the Pacific. Comparison of Caribbean deep-water sections with Miocene open-ocean sites shows that greater diversity is found in the Caribbean benthic foraminiferal faunas. Despite the differences in assemblages, the well-documented global late early to middle Miocene benthic foraminiferal taxonomic turnover event (Thomas, 1985, 1986a, b; Boersma, 1986; Miller and Katz, 1987a; for a different view see Bolotovskiy, 1978) may be reflected in the Buff Bay faunas.

Our field party sampled the sections exposed near Buff Bay, Jamaica, in 1987. These samples provide an opportunity to: (1) revise the biostratigraphy of the section; (2) evaluate the global correlations of these strata; (3) quantitatively describe middle Miocene to Pliocene benthic foraminiferal distributions; and (4) relate paleoenvironmental changes in Jamaica to global faunal changes and regional or local tectonic changes. This con-

tribution focuses on the paleobathymetric changes within the Spring Garden Member of the Montpelier Formation, the Buff Bay Formation, and the Bowden Formation primarily based on evidence from benthic foraminifera.

METHODS

Field sampling and lithologic description

A joint field party from Unocal (G. Jones, R. C. Tjalsma, C. Stuart), Woods Hole Oceanographic Institution (W. A. Berggren, M.-P. Aubry), and Lamont-Doherty Earth Observatory (D. V. Kent, K. G. Miller, M. van Fossen) sampled the sections exposed by roadcuts near Buff Bay (Fig. 1) in April 1987. E. Robinson (Florida International University) estimated where his ER samples were located in the new roadcut, which was modified by road construction since his (1969) samples were obtained. The roadcut exposed six sections: Lower (Pots and Pans), Middle, Main, Slide, Dead Goat Gully, and West (Fig. 2). The Pots and Pans Section is the lower Spring Garden Member of the Montpelier Formation and the Middle Section represents the upper Spring Garden Member as defined by Robinson (1969). The Main, Slide, and Dead Goat Gully Roadcuts represent the Buff Bay Formation as originally defined by Robinson (1969). The West Roadcut exposes sections correlated by Robinson (1969) to the Bowden Formation.

We collected samples from all six sections and oriented magnetostratigraphic samples from the Pots and Pans, Middle, Main, and Slide Sections. The Dead Goat Gully and West Sections were not suitable for paleomagnetic analyses because of poor exposure. Samples from the Main and Slide Roadcuts were numbered upsection BB1 through BB64, while samples from Dead Goat Gully and West Sections were numbered upsection 242 through 252 (Fig. 2). Samples from the Middle and Pots and Pans Roadcuts were numbered downsection SG1 through SG32. The sections were measured and described by C. Stuart (personal communication, 1987; Fig. 2).

The general lithologies were similar to those previously described (e.g., Hill, 1899; Robinson, 1969), although closer examination of the lithology of the Main Section resulted in the relocation of the formational boundary. The Spring Garden Member is a pure, white indurated chalk with characteristic black lichen overgrowths. In contrast, the Buff Bay Formation is a sandy, yellow-tan carbonate sediment that is only moderately indurated; lichens are not present on most of the Buff Bay Formation. Exposure of the unweathered Buff Bay Formation shows it to be slightly bluish, while the Spring Garden Member is consistently white. The contact between the underlying Spring Garden Formation and the Buff Bay Formation is gradational, with the dark lichens extending upsection into the lower one-third of the Main Section. C. Stuart (personal communication, 1987) considers the formational boundary to be at the top of this level in the Main Section; we follow this placement (Fig. 2).

There are coarse sandy layers in the Main and Slide Sec-
Figure 2. Benthic foraminiferal range chart with stratigraphic section, sampling intervals, and biostratigraphy. Planktonic foraminiferal biostratigraphy after Berggren (this volume).
Biostratigraphy and magnetostratigraphy

Paleontological samples were examined for planktonic foraminiferal (W. A. Berggren) and calcareous nanoplanckton (M.-P. Aubry) biostratigraphy. The planktonic foraminiferal results (Berggren, this volume) are included on Figure 2 (note that a greater number of samples were examined by Berggren for qualitative planktonic foraminiferal biostratigraphy than were examined here). Magnetostratigraphic data have been generated and will be published elsewhere (D. V. Kent and M. van Fossen, unpublished data of 1992). The integration of the biostratigraphic and magnetostratigraphic results will be published elsewhere.

We rely on a hybrid planktonic foraminiferal biostratigraphic zonation (Berggren, this volume; Fig. 2) for our correlations that use criteria of Blow (1969, 1979) and Bolli (1957) because neither of these standard zonations is entirely suitable for correlation of the Jamaican samples (see Berggren, this volume for discussion). The magnetostratigraphic relationships observed in Jamaica differ somewhat from those in our previous studies (e.g., Miller, Aubry et al., 1985), and correlations to the Geomagnetic Polarity Time Scale are uncertain. Because of these difficulties, the Jamaican data are presented versus thickness of section (e.g., Figs. 2 to 12).

Benthic foraminiferal taxonomic and quantitative studies

Samples examined for benthic foraminifera were disaggregated in a rock crusher and then soaked in Alconox (an industrial detergent) for two days. Spring Garden Member samples were boiled subsequently in Quaternary-O for one hour. All samples were washed with an Alconox spray through a 63-μm sieve and air-dried. Benthic foraminifera were picked from aliquots of the greater than 150-μm-size fraction and mounted on reference slides to be used for qualitative and quantitative analyses. In general, 300 to 500 specimens were picked per sample, although several samples contained 500 to 550 specimens while others contained 240 to 300 specimens.

Our identifications of cosmopolitan deep-water taxa are based on literature and museum studies by W. A. Berggren and K. G. Miller (summarized in van Morkhoven et al., 1986). We identified taxa that were previously described from the Caribbean primarily using the species concepts of Cushman and Todd (1945) and Bermúdez (1949). Our taxonomic base for most of the uvigerinids follows Boersma (1984). Brief descriptions of some of the lesser known taxa are included in the "Taxonomic Notes" section. Not all species present were identified; for example, species of Lagenina, Fissurina, and Oolina were not differentiated.

We performed Q-mode Principal Components and Varimax Factor Analyses and R-mode Principal Components Analysis on the relative abundance (percentage) data using modifications of programs provided by Lohmann (1980). The Q-mode Principal Component and Varimax Factor programs utilize a Cosine-theta matrix, standardizing each sample to unit length. R-mode Principal Components Analysis uses a correlation coefficient matrix with zero mean and unit variance. All species contribute equally in this analysis, and as a result, it explains less of the total variation in the faunal data. These programs were modified to run on a Macintosh microcomputer. These multivariate analyses objectively identify natural associations of taxa in the relative percentage data. Four Q-mode Principal Components and Factors and five R-mode Principal Components adequately describe the variance observed in the Jamaican benthic foraminiferal faunas (68 and 43% of the total faunal variance, respectively). Species that constitute greater than 1% in at least one sample were included in these multivariate analyses.

The benthic foraminiferal and percent planktonic foraminiferal (Table 1) data from the Jamaican samples were compared with faunas from three Gulf of Mexico Eureka boreholes that were drilled near the De Soto Canyon (Table 2; van Morkhoven, et al., 1986). The Eureka borehole paleodepth estimates were calculated assuming simple thermal subsidence and empirical age-subidence curves ("backtracking"; Sclater et al., 1971; Berger and Winterer, 1974; see Miller et al., 1989, for examples). The backtracking of the Eureka boreholes will be presented elsewhere (Katz and Miller, in preparation). These De Soto Canyon sites lie on transitional or continental crust with a Jurassic rifting age; because of this, thermal subsidence has been minor since the Miocene, and sediment loading corrections make up most of the minor differences between the present water depths and paleodepths of these locations. We estimate the paleodepths at E68-126, E66-73, and E68-151A to be 600, 900, and 1,300 m, respectively.

RESULTS AND DISCUSSION

Paleobathymetry

Paleobathymetric estimates for the Jamaican sections were made by: (1) examining the Jamaican sections for depth-diagnostic taxa (depth ranges after van Morkhoven et al., 1986); and (2) calculating the percentages of planktonic foraminifera relative to total foraminifera (greater than 150-μm size fraction; Fig. 3, Table 1). We use the bathymetric terminology described by van Morkhoven et al. (1986) and Berggren and Miller (1989) in subdividing the bathyal zone into upper (200 to 600 m), middle (600 to 1,000 m), and lower (1,000 to 2,000 m) bathyal.

Benthic foraminiferal faunas indicate that both the Spring Garden Member and the Buffalo Bay Formation were deposited at lower bathyal depths. Comparison of the Jamaican benthic foram-
TABLE 1. PERCENT PLANKTONIC FORAMINIFERA RELATIVE TO TOTAL FORAMINIFERA AT BUFF BAY

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TABLE 2. DEPTH-DIAGNOSTIC BENTHIC FORAMINIFERAL TAXA COMPARED AMONG THE BUFF BAY SECTION AND THE EUREKA BOREHOLES

Upper to middle bathyal taxa absent from the Spring Garden Member and the Buff Bay Formation which are present in the Eureka boreholes:
- *Cibicidoides alazonensis*
- *Cibicidoides crebbsi* (only at E68-136 and E66-73)
- *Rectувигерина nodifera* (only at E68-136)
- *Rectувигерина transversa*
- *Planulina ariminensis* (only at E68-136 and Bowden Formation)
- *Planulina dohertyi*

Middle to lower bathyal taxa found in the Spring Garden Member and the Buff Bay Formation which are absent from the Eureka boreholes:
- *Anomalinoidea globulosa*
- *Cibicidoides robertsonianus* (also present at lower bathyal E66-151A)
- *Cibicidoides havanensis*
- *Planulina rugosa*
- *Anomalinoidea pseudogrosserugosus*

*Paleobathymetric ranges after van Morkhoven and others, 1986.

in the Buff Bay Formation. The presence or absence of these depth-diagnostic species implies that the paleodepths were 1,300 to 2,000 m during the deposition of the Spring Garden Member and the Buff Bay Formation.

Several first and last occurrences of benthic foraminiferal species suggest that there was a shallowing within the lower bathyal zone from the uppermost Spring Garden Member to the lowermost Buff Bay Formation. There is a transition from the deeper-water *Melonis spheeroides* to the shallower-water morphotype *Melonis pomplioides* in this interval. In addition, several species first occur in the uppermost Spring Garden Member or lower Buff Bay Formation that are generally rare at lower bathyal depths and increase in abundance at shallower depths (van Morkhoven et al., 1986; Katz and Miller, in preparation): *Cancriis nuttali*, *Cibicidoides pachyderma*, *Plectofrondicularia parri*, *Plectofrondicularia vaughani*, and *Rectувигерина striata*. Although the presence or absence of a few key benthic foraminiferal taxa suggests that a shallowing occurred, attempting to subdivide the lower bathyal zone into finer depth increments may not be warranted at this time. Nevertheless, this gradual shallowing is consistent with the gradual nature of the lithologic change from the upper Spring Garden Member to the Buff Bay Formation.

Benthic foraminiferal faunas indicate that the Bowden Formation was deposited in the upper bathyal zone. *Planulina foveolata* and *Buliminia marginata* occur only in the Bowden Formation samples at Buff Bay. These taxa are recognized as generally restricted to upper bathyal and shallower depths (van Morkhoven et al., 1986), and they are found throughout the Bowden Formation. In fact, *P. foveolata* has a lower depth limit of 500 m (van Morkhoven et al., 1986). Benthic foraminiferal faunal abundance changes indicate that there may have been a
slight deepening during the deposition of the Bowden Formation (see "In Situ Assemblages"). In addition, several depth-diagnostic benthic foraminiferal species found in the deeper-water Spring Garden Member and Buff Bay Formation are absent from the Bowden Formation, including Anomalainoides globulus, C. robertsonianus, P. rugosa, and P. wuellerstorfi. The benthic foraminiferal faunas indicate that a shallowing of at least 800 m occurred at Buff Bay between the early late Miocene (ca. 8 Ma) and the Pliocene (ca. 4 to 3 Ma). Additional shallowing occurred between the deposition of the upper bathyal Pliocene Bowden Formation (this study) and the Pleistocene upper Coastal Group (Robinson, 1969). The Coastal Group contains neritic reeval foraminifera (Robinson, 1969) that lived in the photic zone (<60 m), implying that between ~140 and 500 m of shallowing occurred from the Pliocene to the Pleistocene at Buff Bay.

The relative abundances of planktonic foraminifera are consistent with the inferred paleobathymetry. Planktonic foraminifera constitute about 94 to 99% of the total foraminifera both in the Spring Garden Member and in the Buff Bay Formation (Fig. 3, Table 1), consistent with deposition at lower bathyal paleodepths (1,000 to 2,000 m; Grimsdale and van Morkhoven, 1955). Planktonic foraminiferal percentages were lower in the Eureka samples (Katz and Miller, in preparation) than in the Spring Garden Member and the Buff Bay Formation, reflecting the shallower paleodepths at the Eureka locations.

There is a marked decrease in the planktonic foraminiferal percentages (to 55 to 70%) across the unconformity separating the Buff Bay Formation from the overlying Bowden Formation (Fig. 3). This decrease in the percentage of planktonic foraminifera is consistent with the inferred decrease in water depth. The lower planktonic foraminiferal percentages observed in the Bowden Formation samples are consistent with deposition in the upper bathyal zone (200 to 600 m; Grimsdale and van Morkhoven, 1955).

The paleodepth estimates made here compare well with those based on benthic foraminifera and ostracod faunas (Steinbeck, 1974, 1981). Steinbeck (1974) initially estimated that the Spring Garden Member of the Montpelier Formation and the basal Buff Bay Formation were deposited at paleodepths of approximately 1,500 m. He noted that there was a shallowing within the Buff Bay Formation; our paleobathymetric estimates agree with this. Steinbeck (1974) estimated that the middle and upper Buff Bay Formation was slightly shallower than the section below, with an upper depth limit of 1,000 m. He later (1981) recalculated these paleobathymetric estimates using ostracods. The lowermost Spring Garden Member section that we sampled (Zone N8) corresponds to the upper portion of Steinbeck’s (1981) ostracod Biofacies 3. He interpreted this ostracod biofacies to represent depths of 1,500 to 2,000 m. Above this, the remaining section of the Spring Garden Member and the entire Buff Bay Formation is characterized by Steinbeck’s (1981) ostracod Biofacies 4, representing paleodepths of 1,000 to 1,500 m. This corroborates our paleobathymetric estimates and our suggestion that shallowing (and inferred uplift; see also Steinbeck, 1974, 1981) began in the middle Miocene.

**Biofacies**

**Downslope contamination.** Q-mode Principal Components Analysis of the combined faunal datasets from the Spring Garden Member of the Montpelier Formation, the Buff Bay Formation, and the Bowden Formation reveals two primary benthic foraminiferal associations (Fig. 4, Table 3). High negative loadings on Q-mode Principal Component II represent relatively deep-water assemblages. Dominant deep-water benthic foraminifera include Globocassidulina subglobosa, Bulimina aculeata, Gyroidinoides spp., and Cibicidoides mundulus.

Approximately 5 to 45% of the benthic foraminifera identified in the Jamaican samples consists of shallow-water (neritic) species that were transported downslope and mixed with an in situ deep-water fauna (Fig. 4). These shallow-water species include Amphiostegina spp., Asterigerina spp., and Cibicidoides lobatu-
lus. *Amphistegina* spp. and *Asterigerina* spp. are typical of reefs, lagoons, outer shelf areas, guyots, and atolls (Todd, 1976). *Cibicides lobatulus* is typical of shallow-water and reeval environments (Brasier, 1975; Sen Gupta and Schaefer, 1973; McLaughlin, 1989). These are the three most abundant transported taxa in our samples, although other species may also have been transported downslope (see “In Situ Assemblages”). High positive loadings on Q-mode Principal Component II (Fig. 4) represents these shallow-water benthic foraminiferal assemblages that are dominated by the taxa *Amphistegina* spp./*Asterigerina* spp. and *Cibicides lobatulus*. These high loadings characterize the Buff Bay Formation and the upper Spring Garden Member, which contain the highest abundances of transported material.

*Amphistegina* spp. and *Asterigerina* spp. are morphologically similar genera with controversial taxonomic histories (see Todd, 1976, for discussion). Todd (1976) concludes that *Amphistegina* spp. and *Asterigerina* spp. should be maintained as distinct genera, even though the separation may be more an artificial than a natural one. These two taxa are combined in this study for the multivariate analyses because they represent similar paleoenvironmental and paleobathymetric settings.

There are numerous discrete, coarse, relatively thin, dark layers that are irregularly spaced in the Main Section (Fig. 2). Quantitative analysis reveals a difference between the benthic foraminiferal assemblages contained in these layers and the faunas yielded by the remaining sections. These dark layers contain fragments of corals and bivalves in addition to many benthic foraminiferal specimens greater than 1,000 μm. This large size fraction primarily contains *Amphistegina* spp., *Asterigerina* spp., and *Gypsina* spp., along with a few *Lenticulina* spp. Two]

*Amphistegina* spp./*Asterigerina* spp.—rich layers that we examined are composed of 11 and 12% benthic foraminifera in the greater than 1,000 μm size fraction and 33 and 40% benthic foraminifera in the 355 to 1,000 μm size fraction, respectively. Shallow-water benthic foraminiferal specimens (*Amphistegina* spp., *Asterigerina* spp., and *Gypsina* spp.) constitute 65 and 58% of the assemblages, respectively. The planktonic foraminiferal percentages (80 and 75%) were lower than those in the remaining Buff Bay Formation and Spring Garden Member samples.

The coarse nature of the dark layers, the high percentages of the shallow-water taxa *Amphistegina* spp., *Asterigerina* spp., and *Gypsina* spp., the fragments of corals and bivalves, and the lower percentages of planktonic foraminifera suggest that the discrete layers formed by downslope transport. High percentages of *Amphistegina* spp. and *Asterigerina* spp. were observed throughout the rest of the section (Fig. 4), although the large size fractions and large *Gypsina* spp. were not observed outside of the discrete layers. We suggest that the contamination by *Amphistegina* spp./*Asterigerina* spp. outside of the layers occurred either as a result of the steady downslope transport of reeval elements during storms or as a result of the mixing of these discrete layers after deposition.

In situ assemblages. We deleted the major shallow-water components (*Amphistegina* spp., *Asterigerina* spp., and *Cibicides lobatulus*) from the faunal dataset and conducted a Q-mode Factor Analysis on the remaining deep-water assemblages in order to examine the changes in the in situ benthic foraminiferal faunas. While there are other probable shallow-water taxa present in the Buff Bay samples (e.g., *Discorbis* spp., *Planorbulina* spp.), they are very rare and do not significantly affect the outcome of the multivariate analyses. The Q-mode Factor Analysis of the deep-water taxa delineated four major benthic foraminiferal biofacies, which will be discussed in ascending stratigraphic order.

Q-mode Factor 3 has the highest negative loadings in the lower part of the Spring Garden Member, and explains 13% of the faunal variation (Fig. 5). It is dominated by *Globocassidulina subglobosa*, *Cibicidoides mundulus*, *Silicostomella aculeata*, and *Oridorotalis* (Fig. 6). An abundance change reflected by the transition from the high negative values of Q-mode Factor 3 (the *G. subglobosa-C. mundulus-S. aculeata-Oridorotalis* biofacies) to high negative values of Factor 4 (a *Compressigenera coaratae-Siphouvgenera porrecta* biofacies, see below) occurs within the Spring Garden Member (between 100 and 150 m). Steineck (1981) found a change in ostracod biofacies near this level. The relative abundance change in benthic foraminifera may reflect the well-documented global benthic foraminiferal taxonomic turnover from planktonic foraminiferal Zones N8 to N11 (e.g., Thomas, 1985, 1986a, b; Woodruff, 1985; Boersma, 1986; Miller and Katz, 1987a). One point in favor of the global nature of the faunal abundance change is that a coeval decrease occurred in the percentages of *Globocassidulina subglobosa* and *Cibicidoides mundulus* at western North Atlantic Deep Sea Drilling Project (DSDP) Site 563 (paleodepth >3 km; Miller and Katz, 1987a).
TABLE 3. BUFF BAY BENTHIC FORAMINIFERAL TAXA USED IN MULTIVARIATE ANALYSES

<table>
<thead>
<tr>
<th>Taxa</th>
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<tbody>
<tr>
<td>Alabamina wilcoxensis</td>
</tr>
<tr>
<td>Amphistegina spp./Asteroegina spp.</td>
</tr>
<tr>
<td>Anomalinae globulosus</td>
</tr>
<tr>
<td>Anomalinae seminifibratus</td>
</tr>
<tr>
<td>Anomalinae spp.</td>
</tr>
<tr>
<td>Astronomon pusillum</td>
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<tr>
<td>Bolivina antesialisiformis</td>
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<tr>
<td>Bolivina atae</td>
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<tr>
<td>Bolivina elazanensis</td>
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<tr>
<td>Bolivina integressa</td>
</tr>
<tr>
<td>Bolivina thalmanni</td>
</tr>
<tr>
<td>Bolivina fortese</td>
</tr>
<tr>
<td>Bolivina floridana and pseudoplicata</td>
</tr>
<tr>
<td>Bolivina elazanensis</td>
</tr>
<tr>
<td>Bolivina mexicana and maclintia</td>
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<tr>
<td>Bolivina marginita</td>
</tr>
<tr>
<td>Bolivina tuxpanensis</td>
</tr>
<tr>
<td>Bolivina impendens</td>
</tr>
<tr>
<td>Bolivina aculeata</td>
</tr>
<tr>
<td>Cancris nutalli</td>
</tr>
<tr>
<td>Cancris oblongus</td>
</tr>
<tr>
<td>Cancris scindilans</td>
</tr>
<tr>
<td>Cancris spp.</td>
</tr>
<tr>
<td>Cassidulina cressa</td>
</tr>
<tr>
<td>Cassidulina carpatena</td>
</tr>
<tr>
<td>Cassidulina laevigata</td>
</tr>
<tr>
<td>Cassidulina reflexa</td>
</tr>
<tr>
<td>Cassidulina spinifera</td>
</tr>
<tr>
<td>Cassidulinaeides spp.</td>
</tr>
<tr>
<td>Chilostomella sp.</td>
</tr>
<tr>
<td>Cibididoides bradyi</td>
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<tr>
<td>Cibididoides cicatricosus</td>
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<tr>
<td>Cibididoides havanensis</td>
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<tr>
<td>Cibididoides increassatus</td>
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<tr>
<td>Cibididoides metanzasensis</td>
</tr>
<tr>
<td>Cibididoides mundialis</td>
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<tr>
<td>Cibididoides pachyderma</td>
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<tr>
<td>Cibididoides coryeli</td>
</tr>
<tr>
<td>Cibididoides dominicus</td>
</tr>
<tr>
<td>Cibididoides sp. 33</td>
</tr>
<tr>
<td>Cibididoides cockel</td>
</tr>
<tr>
<td>Cibididoides lobatus</td>
</tr>
<tr>
<td>Compressigera coarata</td>
</tr>
<tr>
<td>Dentatina spp.</td>
</tr>
<tr>
<td>Discorbis spp.</td>
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<tr>
<td>Eggerella braudyi</td>
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<tr>
<td>Ehrenbergina caribaea</td>
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<tr>
<td>Ehrenbergina siniae</td>
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<tr>
<td>Ehrenbergina spinosissima</td>
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<tr>
<td>Elphidium spp.</td>
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<tr>
<td>Eponides spp.</td>
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<tr>
<td>Fissurinae spp.</td>
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<tr>
<td>Fusshockinae spp.</td>
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<tr>
<td>Globobulimina spp.</td>
</tr>
<tr>
<td>Globocassidulina subglobosa</td>
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<tr>
<td>Globocassidulina paleracea</td>
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<tr>
<td>Globocassidulina ceudrissae</td>
</tr>
<tr>
<td>Gyrocoelinaeides spp.</td>
</tr>
<tr>
<td>Hanzawaia mantaensis</td>
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<tr>
<td>Hanzawaia ammophila</td>
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<tr>
<td>Hanzawaia sp. 3</td>
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<tr>
<td>Hanzawaia spp.</td>
</tr>
<tr>
<td>Hoagulinida elegans</td>
</tr>
<tr>
<td>Kamerella subglabre</td>
</tr>
<tr>
<td>Legensia and Ocellina spp.</td>
</tr>
<tr>
<td>Leticammina pauperata</td>
</tr>
<tr>
<td>Lentulinaeides spp.</td>
</tr>
<tr>
<td>Loxostomum leidicensis</td>
</tr>
<tr>
<td>Loxostomum spp.</td>
</tr>
<tr>
<td>Melonis barreanum</td>
</tr>
<tr>
<td>Melonis pomplioides and sphaeroides</td>
</tr>
<tr>
<td>Neopomponiella spp.</td>
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<tr>
<td>Nonion spp.</td>
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<tr>
<td>Nothionelinea sp.</td>
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<tr>
<td>Nuttalliades umbonifera</td>
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<tr>
<td>Oridorsalis spp.</td>
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<tr>
<td>Osangularia spp.</td>
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<tr>
<td>Orthomorphinae spp.</td>
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<tr>
<td>Pararotaliae sp.</td>
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<tr>
<td>Planorbulinae sp.</td>
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<tr>
<td>Planulina arminensis</td>
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<tr>
<td>Planulina ambigua</td>
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<tr>
<td>Planulina foedatalis</td>
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<tr>
<td>Planulina renzi</td>
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<tr>
<td>Planulina rugosa</td>
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<tr>
<td>Planulina wuelsterfori</td>
</tr>
<tr>
<td>Planulina sp.</td>
</tr>
<tr>
<td>Pleurotendinaria perla</td>
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<tr>
<td>Praeotendinulare vaughani</td>
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<tr>
<td>Pleurotomelina sp.</td>
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<tr>
<td>plectostomellaeiks</td>
</tr>
<tr>
<td>polymorphinids</td>
</tr>
<tr>
<td>Pseudonionia spp.</td>
</tr>
<tr>
<td>Pullenella bulloides</td>
</tr>
<tr>
<td>Pullenella malvinae</td>
</tr>
<tr>
<td>Pullenella quadriornis</td>
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<tr>
<td>Pullenella quinqueloba</td>
</tr>
<tr>
<td>Pyrgo murnhins</td>
</tr>
<tr>
<td>Quinquelocalinae spp.</td>
</tr>
<tr>
<td>Reduvigerina multifaceta</td>
</tr>
<tr>
<td>Reduvigerina striata</td>
</tr>
<tr>
<td>Reussella spinulosa var. pulchra</td>
</tr>
<tr>
<td>Rosalinia sp. 1</td>
</tr>
<tr>
<td>Sigmoilopsis schlumbergeri</td>
</tr>
<tr>
<td>Siphonolina salufa</td>
</tr>
<tr>
<td>Siphotextulinae spp.</td>
</tr>
<tr>
<td>Siphonovigerina porrecta</td>
</tr>
<tr>
<td>Sphaeroidina bulloides</td>
</tr>
<tr>
<td>Spiroshigollinella sp.</td>
</tr>
<tr>
<td>Stilostomella aculeata</td>
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<tr>
<td>Stilostomella curvature</td>
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<tr>
<td>Stilostomella modesta</td>
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<tr>
<td>Stilostomella subspinoso</td>
</tr>
<tr>
<td>Stilostomella spp.</td>
</tr>
<tr>
<td>Textularia spp.</td>
</tr>
<tr>
<td>Trifarina bradyi</td>
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<tr>
<td>Uvigerina lavoiculate</td>
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<tr>
<td>Uvigerina carpatena</td>
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<tr>
<td>Uvigerina hispida</td>
</tr>
<tr>
<td>Uvigerina pipema</td>
</tr>
<tr>
<td>Uvigerina sp. 1</td>
</tr>
<tr>
<td>Uvigerina coijamarenae</td>
</tr>
<tr>
<td>Uvigerina procubideae</td>
</tr>
<tr>
<td>Uvigerina hispido-costata</td>
</tr>
<tr>
<td>Uvigerina jamaicansis</td>
</tr>
<tr>
<td>Uvigerina sp. 7</td>
</tr>
<tr>
<td>Uvigerina sp. 9</td>
</tr>
<tr>
<td>Uvigerina sp. 53</td>
</tr>
<tr>
<td>Anguligerina illugi</td>
</tr>
<tr>
<td>Anguligerina aximia</td>
</tr>
<tr>
<td>Vulvulina sp.</td>
</tr>
<tr>
<td>Vermeulina spp.</td>
</tr>
<tr>
<td>Siphonina spp.</td>
</tr>
</tbody>
</table>

Alternatively, the faunal abundance change may have resulted from a local change. This is supported by the nature of the change from a cosmopolitan lower bathyal biofacies (the G. subglobosa—C. mundulus—S. aculeata—Oridorsalis biofacies) to an apparently endemic biofacies (Compressigera coarata—Siphonovigerina porrecta biofacies; see below) that also contains cosmopolitan elements. This local change may have been caused by: (1) regional tectonic basin isolation; (2) increased downslope transport that caused dilution of the in situ, deeper-water biofacies; or (3) progressive shallowing of this part of the Jamaican section within the lower bathyal zone. We find that the faunal changes (see “Paleobathymetry”) indicate that there was a shallowing from the deeper part of the lower bathyal zone during the deposition of the Spring Garden Member to the upper part of the lower bathyal zone during the deposition of the Buff Bay Formation.

Q-mode Factor 4 explains 22% of the faunal trend and it characterizes the upper part of the Spring Garden Member and a portion of the Buff Bay Formation (Fig. 5). Dominant taxa in the Q-mode Factor 4 biofacies are Compressigera coarata and Siphonovigerina porrecta (Fig. 7). Interpreting the paleoenvironmental significance of these two species is difficult. Neither has been reported in studies of North Atlantic, South Atlantic, and Pacific deep-water Miocene sections recovered by the Deep Sea Drilling Project (e.g., Thomas, 1985, 1986a; b; Woodruff, 1985; Boersma, 1986; Miller and Katz, 1987a), or observed in the
Figure 5. Q-mode Factors 1 to 4 calculated from the deep-water benthic foraminiferal dataset at Buff Bay. Refer to Figure 2 for the positions of unconformities.

Figure 6. Percentages plots of the taxa that characterize Q-mode Factor 3. Refer to Figure 2 for the positions of unconformities.
coeval Eureka bathyal boreholes (Katz and Miller, in preparation), the Miocene of Haiti (Coryell and Rivero, 1940), the Tertiary Aquasala group of Venezuela (Renz, 1948), or Tertiary sections from Cuba (Palmer and Bermúdez, 1936bb; Palmer, 1940). Bermúdez (1949) reported that Compressigera coarctata and Siphouviergera porrecta are present in samples from the Dominican Republic. Since the abundances of these two taxa do not co-vary with the abundances of the transported shallow-water taxa, they are interpreted as being in situ deep-water forms. In fact, the interval of high negative Q-mode Factor 4 scores of the deep-water dataset (the C. coarctata and S. porrecta biofacies) alternates with the Amphistegina spp./Asterigerina spp. thanatofacies.

R-mode Principal Component Analyses of the complete Buff Bay section dataset (including the shallow-water taxa) support the in situ nature of the Q-mode Factor 4 biofacies. Negative loadings on R-mode Principal Component III are characterized by Compressigera coarctata, Cassidulina reflexa, and Siphouviergera porrecta, while Amphistegina spp./Asterigerina spp. does not load onto this component. Shallow-water taxa dominate the negative loadings on R-mode Principal Component II and characterize the upper Spring Garden Member and the Buff Bay Formation with Cibicides lobatus and Amphistegina spp./Asterigerina spp., in addition to Rosalina sp. 1, Uvigerina pigmea, and Reussella spinulosa var. pulchra (Fig. 8). Negative loadings on R-mode Principal Component III and negative loadings on R-mode Principal Component II do not co-vary.

Q-mode Factor 1 accounts for 31% of the faunal variation and is found in the upper Spring Garden Member and most of the Buff Bay Formation (Fig. 5). It is dominated by Reussella spinulosa var. pulchra, Uvigerina proboscidea, Rosalina sp. 1, and Siphouviergera porrecta (Fig. 9). Reussella spinulosa has been reported as being abundant in neritic biofacies (e.g., McLaughlin, 1989). In addition, R. spinulosa is common in faunas that contain both in situ deep-water species and transported species off the northeastern Australian margin (Katz and Miller, 1993). With the available data, we cannot say for certain if Q-mode Factor 1 represents an in situ biofacies or a transported thanatofacies. This factor does not consistently coincide with the high positive loadings on Q-mode Principal Component II that represent the highest abundances of the Amphistegina spp./Asterigerina spp. thanatofacies, suggesting that it may be an in situ biofacies. However, percentage plots comparing Cibicides lobatus and Reussella spinulosa var. pulchra (Fig. 10) show three distinct common peaks. In addition, two of the dominant Q-mode Factor I species, Reussella spinulosa var. pulchra and Rosalina sp. 1, load onto R-mode Principal Component II, which is characterized by the shallow-water forms Cibicides lobatus and Amphistegina spp./Asterigerina spp. (Fig. 8). This may indicate that Reussella spinulosa var. pulchra and Rosalina sp. 1 are shallow-water taxa that were transported downslope with Cibicides lobatus and Amphistegina spp./Asterigerina spp.; alternatively, this simply may reflect high abundances of Reussella spinulosa var. pulchra and Rosalina sp. 1, along with Uvigerina proboscidea, in the Buff Bay Formation (Fig. 9). R-mode Principal Components and Factor Analyses on the Buff Bay Formation dataset without the Spring Garden Member and Bowden Formation samples help to clarify this issue. The results of the analyses show that neither Reussella spinulosa var. pulchra nor Rosalina sp. 1 load onto the same principal component or factor as the shallow-water taxa Amphistegina spp./Asterigerina spp. and Cibicides lobatus. While the limited evidence cited above suggests that the Reussella spinulosa var. pulchra-dominated assemblage may be a transported thanatofacies, Q-mode Factor 1 may represent an in situ biofacies primarily based on results of the R-mode Principal Components and Factor Analyses on the Buff Bay Formation dataset.

Q-mode Factor 2 characterizes the Bowden Formation with 12% of the faunal variation explained (Fig. 5). It is dominated by Bulimina aculeata, Globobulimina spp., Planulina foveolata, and Uvigerina sp. 1 (Fig. 11). Separate factor analysis of the Bowden Formation dataset yields two important factors (Fig. 12). Q-mode Factor 1 of the isolated Bowden Formation dataset represents 52% of the faunal variation and is most pronounced in the lower three samples. This biofacies is dominated by Bulimina aculeata, Globobulimina spp., Lenticulina spp., Melonis barleei-num, and Planulina foveolata. The upper two samples have higher loadings on Q-mode Factor 2, explaining 37% of the faunal variation. Q-mode Factor II is dominated by Globocassidinaplanulina subglobosa, Melonis pompilioides, Sphaeroidina bulbiloides, Uvigerina sp. 1, Gyroidinoides spp., and Cibicidoides mundulus.

Both of the Bowden Formation biofacies delineated by the factor analysis were deposited in the upper bathyal zone (200 to 600 m; see “Paleobathymetry”). The presence of Planulina foveolata in this section indicates that the paleodepth estimate can be...
R-MODE PRINCIPAL COMPONENT II

Figure 8. R-mode Principal Component II. Refer to Figure 2 for the positions of unconformities.

Figure 9. Percentages plots of the taxa that characterize Q-mode Factor 1. Refer to Figure 2 for the positions of unconformities.
further refined to 200 to 500 m. The higher abundances of Planulina foveolata in the lower of the two Bowden Formation biofacies and the higher abundances of typically deeper-water taxa in the upper Bowden Formation biofacies indicate that there may actually have been a slight deepening from the upper part of the upper bathyal zone to the lower part during the Pliocene. However, subdividing the upper bathyal zone with this precision may not be warranted.

**Stratigraphic ranges**

We compiled a benthic foraminiferal range chart for the entire Buff Bay section (Fig. 2). Because of space limitations, about 90 continuously ranging or very rare taxa were omitted from Figure 2. Thirty-six of the 64 taxa shown here last occur within this section; 19 of these last occur near the top of the Main Section within the Buff Bay Formation immediately below the unconformity. Many of these last occurrences are local; for example, Melonis sphaeroidea, Rectuvigerina striata, Anomalinooides globulosus, and Uvigerina carapiana are all known to range above this interval elsewhere (van Morkhoven et al., 1986).

The calibration of the first and last occurrences at Buff Bay to planktonic foraminiferal biostratigraphy (Fig. 2) shows that a few may be biostratigraphically useful. For example, Anomalinooides globulosus first occurs in Zone N12 both in Jamaica and at Deep Sea Drilling Site 563, although van Morkhoven et al., 1986) reported that this species first occurred in Biochron N15 (see "Taxonomic Notes"). The first occurrence of Planulina wuellerstorfi is in Zone N8 in Jamaica; Thomas (1985, 1986b) also reported the first occurrence of this taxon in Zone N8 in the

Figure 11. Percentages plots of the taxa that characterize Q-mode Factor 2. Refer to Figure 2 for the positions of unconformities.
Pacific. These are among the earliest reported occurrences of *P. wuellerstorfi*, although an older occurrence (Zones N6 to N7) has been reported from Costa Rica (Cassel and Sen Gupta, 1989a, b).

Some of the first and last occurrences found in this section resulted from paleobathymetric changes. The ranges of the following taxa reflect the shallowing from the late Miocene to Pliocene:

1. *Nuttallides umbonifera* has been reported as abundant at abyssal depths and as scattered through the bathyal zone in Miocene sections from the Pacific (Woodruff, 1985), and it is present only in the Spring Garden Member and the Buff Bay Formation at Jamaica.

2. *Planulina wuellerstorfi* is present only in the Spring Garden Member and the Buff Bay Formation; van Morkhoven et al. (1986) report that it is primarily a lower bathyal to abyssal taxon, while Katz and Miller (in preparation) have found that it occurs as shallow as 500 m in the Gulf of Mexico and increases in abundance with depth.

3. *Planulina ariminensis* extends from outer neritic depths to approximately 800 m (van Morkhoven et al., 1986); it is present in the Bowden Formation, yet is absent from the rest of the section.

4. *Bulimina marginata* is present only in the Bowden Formation and is generally restricted to upper bathyal and shallower depths (van Morkhoven et al., 1986).

5. *Planulina foveolata* is useful as both an age and a depth indicator in the Bowden Formation, as it is known to first occur in the early Pliocene (Zone N18) and it is regarded as a useful guide fossil for Pliocene-Pleistocene outer neritic-upper bathyal environments (van Morkhoven et al., 1986) with a lower depth limit of 500 m.

The ranges of the following taxa indicate that a shallowing may have occurred during the middle-late Miocene deposition of the Spring Garden Member and Buff Bay Formation:

1. The transition from the deeper-water morphotype *Melonis sphaeroides* to the shallower-water form *M. pompilioides* occurs in the lower part of the Main Section (Fig. 2; see van Morkhoven et al., 1986, for discussion of these morphotypes).

2. Van Morkhoven et al. (1986) report that *Plectofrondicularia parri* and *P. vaughani* are commonly associated with outer neritic to middle bathyal environments, while Katz and Miller (in preparation) found rare specimens of *P. vaughani* in the upper lower bathyal zone; these two species are absent from the Spring Garden samples, yet they are found in the Buff Bay and Bowden Formation samples.

3. *Cancris nutalli* is reported primarily from upper and
middle bathyal deposits (van Morkhoven et al., 1986), although it may extend into the upper lower bathyal zone (Katz and Miller, in preparation); it is present only in one Spring Garden Member sample and several Buff Bay Formation samples, but is absent from most of the deeper Spring Garden section.

4. Rectangularina striata is primarily an upper and middle bathyal taxon (van Morkhoven et al., 1986) that is sometimes rare in the lower bathyal zone (Katz and Miller, in preparation); it is present only in the Buff Bay Formation and the uppermost Spring Garden Member.

5. Cibicides oblongoides is primarily an upper bathyal species, although it has been found in shelf assemblages and at depths of 3,615 m (van Morkhoven et al., 1986); it is present in the Buff Bay and Bowden Formations, but is absent from the Spring Garden Member.

Two of the taxa discussed above (M. pompilioides and P. parrti) were reported previously to be middle bathyal or shallower (van Morkhoven et al., 1986). These taxa are found in the uppermost Spring Garden Member and the Buff Bay Formation, suggesting that these units may have been deposited at middle bathyal or shallower depths. However, based on the evidence presented here, we interpret the Spring Garden Member and the Buff Bay Formation as lower bathyal with estimated paleodepths of 1,300 to 2,000 m (below the depth of E68-151A). We suggest that the above two taxa have had wider depth ranges than suggested by van Morkhoven et al. (1986).

**SUMMARY AND CONCLUSIONS**

Sections exposed east of the town of Buff Bay, Jamaica, provide a record of earliest middle Miocene to Pliocene palaeoenvironmental and palaeoceanographic changes. Quantitative analyses of benthic foraminifera contained in these sections delineates a transported thanatofacies of shallow-water reefal elements and four deep-water (bathyal) biofacies. The transported elements are found in discrete layers that contain high percentages of large (>1 mm) Amphistegina spp., Asterigerina spp., and Gypsina spp. along with coral and bivalve fragments. In addition, high abundances (5 to 45%) of Amphistegina spp./Asterigerina spp. are scattered throughout the sections; these result either from the steady downslope transport of reefal elements by storms or from the mixing of the Amphistegina spp./Asterigerina spp.--rich layers after deposition.

The four biofacies in the Buff Bay sections record deposition in the bathyal zone and progressive upsection shallowing:

1. A typical lower bathyal biofacies (estimated paleodepth 1,300 to 2,000 m) dominates the lower part of the Spring Garden Member (lower middle Miocene).

2. An unusual Compressigera coarata and Siphowigerina porrecta biofacies is found in the middle Miocene upper Spring Garden Member and lower Buff Bay Formation. R-mode Principal Components Analysis supports the in situ lower bathyal nature of this biofacies, which is apparently unique to Jamaica and portions of the Dominican Republic.

3. A Reussella spinulosa var. palcura biofacies found in the Buff Bay Formation may represent either in situ lower bathyal deposition or transport from further upslope and mixing with in situ deeper-water species.

4. A typical upper bathyal (200 to 500 m estimated paleodepth) biofacies dominates the Bowden Formation (Bulimina aculeata, Globobulimina spp., Planulina joveolata, and Uvigerina sp. 1).

Benthic foraminiferal biofacies, key bathymetric marker species, and the relative abundances of planktonic foraminifera document that there was a distinct shallowing from the lower bathyal Miocene Spring Garden Member of the Montpelier Formation and the Buff Bay Formation (1,300 to 2,000 m estimated paleodepth) to the upper bathyal Pliocene Bowden Formation (200 to 500 m estimated paleodepth). This shallowing occurred during an approximately 4 to 5 m.y. hiatus between the late Miocene (ca. 8 Ma) and the Pliocene (ca. 4 to 3 Ma; Berggren, this volume; Aubry, this volume), and reflects the local tectonic uplift of the north coast of Jamaica. There may have been a gradual shallowing within the lower bathyal zone during the middle to early late Miocene, as is indicated by the benthic foraminiferal biofacies changes and the presence/absence of key bathymetric marker species. A biofacies change that occurred in the early middle Miocene (during the deposition of the Spring Garden Member) may reflect either this local paleobathymetric change or the well-documented global benthic foraminiferal taxonomic turnover from Zones N8 to N11. Changes in benthic foraminiferal faunas suggest that a slight deepening within the upper bathyal realm may have occurred during the deposition of the Pliocene Bowden Formation. Further uplift from the upper bathyal zone to the neritic zone occurred between the Pliocene Bowden Formation and the Pleistocene Upper Coastal Group.

**TAXONOMIC NOTES**

This section provides references for most of the benthic foraminiferal species included in this study. Brief descriptions of some of the lesser known taxa are included. We describe "rare" taxa as those with fewer than two to three specimens in a sample. Not all species present were identified; for example, species of Lagena, Fissurina, and Oolina were not differentiated (Table 3). Most identifications were based on literature studies, except for those taxa also considered by van Morkhoven et al. (1986), who made comparisons with type material.

**Alabama wilcoxensis** Toulmin

_Pulvinulinella exigua_ (H. B. Brady) var. _obusta_ (Burrows and Holland) - Cushman and Ponton, 1932, p. 71, Plate 9, Figs. 9a-c-Jennings, 1936, p. 192, Plate 31, Figs. 4a-b-Howe, 1939, p. 81, Plate 11, Figs. 4–6. _Pulvinulinella obusta_ (Burrows and Holland)-Cushman and Garrett, 1939, p. 57, Plate 15, Figs. 12-13. _Alabama wilcoxensis_ Toulmin, 1941, p. 603, Plate 81, Figs. 10–14; p. 605, fig. 4A–C.

We distinguish this species from the similar form _A. mississippiensis_ Todd on the basis of the plano-convex nature of the Buff Bay specimens.
Amphistegina spp.

Amphistegina spp. and Asterigerina spp. are morphologically similar genera with controversial taxonomic histories (see Todd, 1976, for discussion). Todd (1976) concludes that Amphistegina spp. and Asterigerina spp. should be maintained as distinct genera, even though the separation may be more an artificial than a natural one. These two taxa are combined in this study for statistical analyses because they represent the same pelagic environment and paleobathymetric settings.

Angulogerina cymbiformis Palmer

Figure 15, Photos 11–12

Angulogerina cymbiformis Palmer, 1941, p. 186, Plate 15, Fig. 8.-Bermúdez, 1949, p. 214, Plate 13, Figs. 49–50.

The test is irregularly triangular in cross section with blunt angles. The coiling tends to loosen in the upper portions.

Angulogerina eximia Cushman and Jarvis

Figure 18, Photos 9–10

Angulogerina eximia Cushman and Jarvis, 1936, p. 3, Plate 1, Figs. 11–12.-Coryell and Rivero, 1940, p. 342, Plate 44, Fig. 26.-Palmer, 1941, p. 186, Plate 15, Fig. 18.-Cushman and Todd, 1945, p. 52, Plate 8, Fig. 1.-Bermúdez, 1949, p. 214–215, Plate 13, Figs. 59–63.

Test is subtriangular in cross section with small, longitudinal costae.

Angulogerina illingi Cushman and Renz

Figure 18, Photos 5–6

Angulogerina illingi Cushman and Renz, 1941, p. 21, Plate 3, Figs. 19–20.-Cushman and Todd, 1945, p. 52, Plate 8, Fig. 2.-Renz, 1948, p. 114, Plate 7, Figs. 31–32.-Bermúdez, 1949, p. 216, Plate 13, Fig. 52.

Angulogerina yumuriana Palmer, 1941, p. 186, Plate 15, Fig. 8.

This form is strongly triangular in cross section. Three keels at the triangle apices run the length of the test in larger specimens. The three corners of each chamber tend to partially extend over the previous chamber.

Angulogerina selsevensis Heron-Allen and Earland

Uvigerina selsevensis Heron-Allen and Earland, 1909, p. 437, Plate 18, Figs. 1–3.-Cushman, 1913, p. 93, Plate 42, Figs. 5a–b.

Angulogerina selsevensis (Heron-Allen and Earland).-Bermúdez, 1949, p. 218, Plate 13, Fig. 53.

This rare form (generally less than 1%) resembled Siphonovigerina porrecta at Buff Bay and was combined with it for multivariate analyses.

Anomalinoidea globulosus (Chapman and Parr)

Figure 19, Photos 11–13

Anomalina globulosa Chapman and Parr, 1937, v. 1, pt. 2, p. 117, Plate 9, Fig. 27.

Anomalinoidea globulosus (Chapman and Parr).-van Morkhoven et al., 1986, p. 36–38, Plate 9, Figs. 1–3.

Anomalinoidea globulosus is very similar to Anomalinoidea semicribra tus. A. globulosus has a distinct lip, while A. semicribra tus is more coarsely perforate on the umbilical surface. Discrepancies in the reported stratigraphic ranges result from difficulties in differentiating Anomalinoi-
Cushman (1926) illustrated faint striae on his *B. tectiformis*. However, his type specimen shows a faint medial ridge with no striae. Therefore, we follow Miller and Katz (1987a) in adopting Subbotina’s taxon for this striae bolivinid.

*Bolivina thalmanni* Renz

Figure 17, Photos 1–2

*Bolivina thalmanni* Renz, 1948, p. 120, Plate 12, Fig. 13.

The most distinctive feature of this taxon is the prominent ornamentation of the test. Two sharp ridges run from the initial end roughly parallel to the periphery on either side of the median line. Two additional peripheral ridges may form on larger specimens. The ridges are connected by irregular, sharply raised lamellar ridges, forming irregular deep depressions. This ornamentation gives this distinctive test surface a strongly reticulate appearance.

*Bolivina tortuosa* Brady

Figure 15, Photo 5

*Bolivina tortuosa* Brady, 1884, v. 9, p. 420, Plate 52, Figs. 31–34.-Cushman and Todd, 1945, p. 44, Plate 7, Fig. 6.-Bermúdez, 1949, p. 195, Plate 12, Fig. 45.

This small *Bolivina* is easily recognized by the characteristic twist in the early portion of its test.

*Botulinovita quadrilatera* (Schwager)

*Textularia quadriangulata* Schwager

*Bolivinoida quadrilatera* (Schwager).-Cushman, 1927c, p. 90.

Rare specimens were scattered through the Buff Bay exposure.

*Bolivinoida sp.*

Rare specimens were scattered through the Buff Bay exposure.

*Bulimina aculeata* d’Orbigny

*Bulimina aculeata* d’Orbigny, 1826, p. 269, type figure not given.-Parker et al., 1871, Plate 11, Fig. 128.-Fornasini, 1902, p. 153, Fig. 4.-Bermúdez, 1949, p. 179, Plate 12, Fig. 10.-van Morkhoven et al., 1986, p. 31–33, Plate 7, Figs. 1–3.

*Bulimina alazanensis* Cushman

*Bulimina alazanensis* Cushman, 1927a, p. 161, Plate 25, Fig. 4.-Bermúdez, 1949, p. 180, Plate 12, Fig. 1.-Tjalsma and Lohmann, 1983, p. 24, Plate 14, Fig. 4.-Miller, Curry, et al., 1985, Plate 4, Fig. 6.-Miller and Katz, 1987a, p. 124, Plate 2, Fig. 7.

*Bulimina impendens* Parker and Bermúdez

*Bulimina impendens* Parker and Bermúdez, 1937, p. 514, Plate 58, Figs. 7–8.-Bermúdez, 1949, p. 181, Plate 12, Fig. 9.-Proto Decima and Bolli, 1978, p. 791, Plate 2, Figs. 11–12.-Tjalsma and Lohmann, 1983, p. 25, Plate 14, Figs. 2a–b.-van Morkhoven et al., 1986, p. 236–238, Plate 79, Figs. 1–2.-Miller and Katz, 1987a, p. 125, Plate 2, Fig. 3.

*Bulimina impendens* can be distinguished from *B. trinitatensis* Cushman and Jarvis by its squat test and absence of ribs.

*Bulimina marginata* d’Orbigny

*Bulimina marginata* d’Orbigny, 1826, p. 269, Plate 12, Figs. 10–12.-Bermúdez, 1949, p. 182, Plate 12, Fig. 11.-van Morkhoven et al., 1986, p. 18–21, Plate 2, Fig. 1.

*Bulimina mexicana* Cushman

Figure 17, Photo 14–15

*Bulimina inflata* Seguenza var. *mexicana* Cushman, 1922a, p. 95, Plate 21, Fig. 2.

*Bulimina mexicana* Cushman.-Bermúdez, 1949, p. 182, Plate 12, Fig. 2.-van Morkhoven et al., 1986, p. 59–62, Plate 19, Figs. 1–4.

*Bulimina tuxpanensis* Cole

*Bulimina tuxpanensis* Cole, 1928, p. 212, Plate 32, Fig. 23.-Parker and Bermúdez, 1937, p. 513, Plate 58, Figs. 1a–c.-Tjalsma and Lohmann, 1983, p. 26, Plate 12, Figs. 1a–c.-van Morkhoven et al., 1986, p. 155–158, Plate 51A, Figs. 1–4; Plate 51B, Figs. 3–4.

*Cancris nutalli* (Palmer and Bermúdez)

*Valvulineria nutalli* Palmer and Bermúdez, 1936a, p. 300, Plate 19, Figs. 3–5.-Bermúdez, 1949, Plate 18, Figs. 25–27.

*Cancris nutalli* (Palmer and Bermúdez)-van Morkhoven et al., 1986, p. 120–122, Plate 38, Figs. 1–3.

*Cancris sagra* Nutall (not d’Orbigny), 1932, p. 27, Plate 6, Figs. 6, 7.

The type locality of *Cancris nutalli* is in Cuba, and it has been reported from other Caribbean localities (e.g., the Ponce Formation of Puerto Rico; Galloway and Hemingway, 1941; and the Sombrero Formation of the Dominican Republic; Bermúdez, 1949). van Morkhoven et al. (1986) suggest that *Cancris sagra* (a species commonly identified in Caribbean faunas) is a synonym of *Cancris nutalli*, which would establish C. *sagra* as the senior synonym.

*Cancris oblongus* (Williamson)

*Palvulinula oblonga* (Williamson).-Barker, 1960, Plate 106, Figs. 4–5.

*Cancris scintillans* (Coryell and Mossman)

Figure 19, Photos 3–4


We combined *Cancris scintillans* and *Cancris scintillans var. sinecarina* for multivariate analyses.

*Cancris scintillans var. sinecarina* (Coryell and Mossman)

Figure 21, Photos 1–4

*Valvulineria scintillans* Coryell and Mossman var. *sinecarina* Coryell and Mossman, 1942, p. 236, Plate 36, Figs. 16–18.

*Cancris scintillans var. sinecarina* is most common in the Bowden Formation. This taxon has prominent knobs surrounding the umbilical region.

*Cassidulina carapitana* Hedberg

*Cassidulina carapitana* Hedberg, 1937, p. 680, Plate 52, Fig. 8.-Renz, 1948, p. 124, Plate 9, Fig. 8.-Bermúdez, 1949, p. 267, Plate 20, Figs. 7–9.
This form has about ten chambers visible in the final whorl. These chambers are sharply curved at the inner ends, forming hooks at the center of the test. *Cassidulina carapitana* can be distinguished from *C. reflexa* by its blunt, subrounded periphery, more robust test, and consistently hooked chambers, while *C. reflexa* has an acute periphery and hooked chambers only in the first few visible chambers.

**Cassidulina crassa** d’Orbigny

*Cassidulina crassa* d’Orbigny, 1839, p. 56, Plate 7, Figs. 18–20.-Renz, 1948, p. 124, Plate 9, Figs. 13a–b; Plate 12, Fig. 23.-Miller and Katz, 1987a, p. 125, Plate 3, Figs. 1a–b.

This small *Cassidulina* has a rounded periphery and broad chambers.

**Cassidulina laevigata** d’Orbigny

*Cassidulina laevigata* d’Orbigny, 1826, p. 282, Plate 15, Figs. 4–5.-Cushman and Todd, 1945, p. 62, Plate 10, Fig. 10–11.-Renz, 1948, p. 125, Plate 9, Fig. 9.-Bermúdez, 1949, p. 268, Plate 20, Figs. 16–21.

*Cassidulina laevigata* has a relatively flat test with a very sharp periphery. It is distinguished from the other *Cassidulina* spp. at Buff Bay by its straighter sutures and broader chambers.

**Cassidulina reflexa** Galloway and Wissler

*C. reflexa* Galloway and Wissler, 1927, p. 80, Plate 12, Fig. 13.

See discussion of *Cassidulina carapitana*.

**Cassidulina spinifera** Cushman and Jarvis

Figure 14, Photos 10–11

*Cassidulina spinifera* Cushman and Jarvis, 1929, p. 17, Plate 3, Fig. 1

This distinctive taxon is easily recognized by the spines extending from each chamber.

**Cibicides lobatus** (Walker and Jacob) d’Orbigny

Figure 13, Photos 1–3

*Nautilus lobatus* Walker and Jacob, 1798, p. 642, Plate 14, Fig. 36.

*Nautilus spirals lobatus anfractus supra rotundatis subius depressoribus* Walker and Boys, 1784, p. 20, Plate 3, Fig. 71.

*Nautilus farrusi* Fitchell and Moll, 1798, p. 64, tab. 9, Figs. g.h.i.

*Serpula lobata* Montagu, 1803, p. 515.

*Polyxenes cribratus* Montfourn, 1808, p. 139, tab. 9, Figs. g.h.i.

*Truncatulina tuberculata* d’Orbigny, 1826, p. 279.

*Truncatulina lobata* d’Orbigny, in Barker et al., 1839, p. 134, Plate 2, Figs. 22–24.

*Truncatulina lobata* d’Orbigny, 1846, p. 168, Plate 9, Figs. 18–23.-Brady, 1884, Plate 95, Figs. 4–5.-Cushman, 1918, p. 16, 60, Plate 1, Fig. 10.

*Truncatulina lobata* (Walker and Jacob).-Nuttall, 1928, p. 98.

**Cibicides lobatus** (Walker and Jacob).-Cole, 1931, Plate 56.-Cushman, 1931, p. 118, Plate 21, Fig. 3.

**Cibicides lobatus** (d’Orbigny).-Galloway and Heminway, 1941, p. 393, Plate 24, Fig. 4.

**Cibicides bradyi** (Trauth)

*Truncatulina duremeli* Brady (not d’Orbigny), 1884, p. 665, Plate 95, Fig. 5 (type figure).

*Truncatulina bradyi* Trauth, 1918, p. 235 (type reference).

**Cibicides haitienis** (Coryell and Rivero).-Tjalma and Lohmann, 1983, p. 26, Plate 17, Figs. 6a–b.-Miller, 1983, p. 433, Plate 2, Fig. 5.

**Cibicides bradyi** (Trauth).-Pflum and Frierichs, 1976, Plate 3, Figs. 6, 7.-van Morkhoven et al., 1986, p. 100–102, Plate 30, Figs. 1–2.-Miller and Katz, 1987a, p. 126, Plate 7, Figs. 2a–c.

**Cibicides caticricosus** (Schwager)

*Anomalina caticricosa* Schwager, 1866, p. 260, Plate 7, Figs. 4, 108.

**Cibicides caticricosus** (Schwager).-van Morkhoven et al., 1986, p. 53–55, Plate 16, Figs. 1a–c.

**Cibicides compressus** (Cushman and Renz)

*Cibicides floridanus* (Cushman) var. *compressus* Cushman and Renz, 1941, p. 26, Plate 4, Fig. 9.-Renz, 1948, p. 127, Plate 10, Figs. 9a–c.

**Cibicides compressus** (Cushman and Renz).-van Morkhoven et al., 1986, p. 137–139, Plate 44, Figs. 1–2.

**Cibicides cookei** (Cushman and Garrett)

*Cibicides cookei* Cushman and Garrett, 1938, p. 65, Plate 11, Fig. 3.

This species is reminiscent of *C. bradyi*, but the test is larger, the spiral side sutures are limbate, the chambers are not inflated, and the periphery is subacute.

**Cibicides coryelli** (Bermúdez)

Figure 14, Photos 4–6

**Cibicides coryelli** Bermúdez, 1949, p. 296, Plate 25, Figs. 7–9.

This small, strongly biconvex test has a subacute periphery. The contact between the whorls on the spiral side is very distinct. The umbilical side, while strongly convex, tends to be flattened at the end.

**Cibicides dominicus** (Bermúdez)

Figure 14, Photos 1–3

**Cibicides dominicus** Bermúdez, 1949, p. 298, Plate 25, Figs. 25–27.

This taxon is similar to *Cibicides coryelli* in that the contact between whorls on the spiral side is very distinct; however, it is not as strongly biconvex and the end of the umbilical side is not flattened. The early chambers tend to be obscured and are frequently perforate.

**Cibicides havanensis** (Cushman and Bermúdez)

*Cibicides havanensis* Cushman and Bermúdez, 1937, p. 28, Plate 3, Figs. 1–3.

**Cibicides havanensis** (Cushman and Bermúdez).-Tjalma and Lohmann, 1983, p. 27, Plate 22, Figs. 4a–c.-Miller, 1983, p. 433, Plate 2, Figs. 9–10.-van Morkhoven et al., 1986, p. 189–193, Plate 64A, Figs. 1–4; Plate 64B, Figs. 1–2.-Miller and Katz, 1987a, p. 128, Plate 7, Figs. 5a–c.
**Cibicidoides incrassatus** (Fichtel and Moll)

*Nautilus incrassatus* Fichtel and Moll, 1798, p. 38, Plate 4, Figs. a–c.
*Cibicidoides incrassatus* (Fichtel and Moll).-Rogel and Hansen, 1984, p. 36, Plate 8, Figs. 4–6.
*Cibicidoides incrassatus* (Fichtel and Moll).-van Morkhoven et al., 1986, p. 83–89, Plate 25A, Figs. 1–2; Plate 25B, Figs. 1–4; Plate 25C, Figs. 1–4.

**Cibicidoides matanzensis** (Hadley)

Figure 20, Photos 1–3

*Planulina matanzensis* Hadley, 1934, p. 27, Plate 4, Figs. 1–3.
*Cibicidoides matanzensis* (Hadley).-van Morkhoven et al., 1986, p. 158–161, Plate 52, Figs. 1–5.

**Cibicidoides mundulus** (Brady, Parker, and Jones)

*Truncatulina mundula* Brady, Parker, and Jones, 1888, p. 228, Plate 45, Fig. 25a–c.
*Cibicidoides mundulus* (Brady, Parker, and Jones).-Loeblich and Tappan, 1955, Plate 25, Figs. 4a–c.-van Morkhoven et al., 1986, p. 65–67, Plate 21, Figs. 1a–c.-Miller and Katz, 1987a, p. 130, Plate 7, Figs. 3a–c.
*Cibicidoides kullenbergi* Parker (in Phleger et al., 1953), p. 49, Plate 11, Figs. 7–8.

**Cibicidoides pachyderma** (Rzebak)

*Truncatulina pachyderma* Rzebak, 1886, p. 87, Plate 1, Figs. 5a–c.
*Cibicidoides pachyderma* (Rzebak).-van Morkhoven et al., 1986, p. 68–71, Plates 22, Figs. 1a–c.

**Cibicidoides robertsonianus** (Brady)

*Planorbulina robertsoniana* Brady, 1881, p. 65 (type reference).
*Truncatulina robertsoniana* Brady, 1884, p. 664, Plate 95, Figs. 4a–c (type figure).
*Cibicidoides robertsonianus* (Brady).-Pflum and Frerichs, 1976, Plate 3, Figs. 3–5.
*Cibicidoides robertsonianus* (Brady) van Morkhoven et al., 1986, p. 41–43, Plate 11, Figs. 1a–c.-Miller and Katz, 1987a, p. 132, Plate 7, Figs. 1a–c.

**Cibicidoides sp. 33**

This plano-convex test has ten chambers in the rapidly inflating final whorl. The initial whorl on the spiral side is obscured by a perforate covering. It has limbate sutures, a small umbilical knob, and a narrow keel.

**Compressigerina coartata** (Palmer)

Figure 18, Photos 3–4

*Uvigerina compressa* Palmer, 1941, p. 182, Plate 15, Figs. 10–11.
*Uvigerina coartata* Palmer (new name), 1945, p. 51.

This form is strongly compressed with only the earliest portion triserial. Most of the test appears to be biserial. There is a characteristic twist in the test. The aperture is on a short neck.

**Eggerella bradyi** (Cushman)

*Verneuilina bradyi* Cushman, 1911, pt. 2, p. 67, Figs. 107a–c.
*Eggerella bradyi* (Cushman).-Pflum and Parker, 1951, p. 6, Plate 3, Figs. 1–2.-Miller, 1983, p. 435, Plate 5, Fig. 5.-Miller and Katz, 1987a, p. 132, Plate 1, Figs. 9a–b.

**Ehrenbergina caribbica** Galloway and Heminway

Figure 17, Photos 10–11

**Ehrenbergina caribbica** Galloway and Heminway, 1941, p. 342, Plate 44, Fig. 22.-Renz, 1948, p. 131, Plate 9, Figs. 17a–b.

We include in our species concept forms that have two rows of knobs along with less common specimens in which the knobs appear to fuse into a single row of knobs or even disappear in rare instances.

**Ehrenbergina spinosa** Cushman

Figure 15, Photos 6–8

**Ehrenbergina spinosa** Cushman, 1935, p. 8, Plate 3, Figs. 10–11.-Cushman and Todd, 1945, p. 63, Plate 11, Fig. 2.

This very tightly enrolled species of *Ehrenbergina* has one spine on each of the final two chambers, one on either side of the test.

**Ehrenbergina spinosissima** Cushman and Jarvis

Figure 21, Photos 13–14

**Ehrenbergina spinosissima** Cushman and Jarvis, 1936, p. 5, Plate 1, Figs. 15–16.-Cushman and Todd, 1945, p. 63, Plate 11, Figs. 1a–b.-Bermúdez, 1949, p. 272, Plate 20, Figs. 32–34.

This distinctively characterized by its prominently raised plate-like chamber margins which extend into spines on the end of each chamber.

**Globocassidulina caudrae** (Cushman and Stainforth)

*Cassidulina caudrae* Cushman and Stainforth, 1945, p. 64, Plate 12, Figs. 2–3.

This species possesses chambers which tend to be more inflated than *Cassidulina*; therefore, we assign it to *Globocassidulina*.

**Globocassidulina palmerae** (Bermúdez and Acosta)

Figure 16, Photos 4–7

*Cassidulina palmerae* Bermúdez and Acosta, 1940, p. 57, Plate 9, Figs. 6–8.-Bermúdez, 1949, p. 269, Plate 20, Figs. 25–28.

This taxon similar in size and overall shape to *Globocassidulina subglobosa* and displays the same inflated test. It is characterized by irregular, sharply raised lamellar ridges, forming irregular, deep depressions. This ornamentation gives this distinctive test surface a strongly reticulate appearance.
**Globocassidulina subglobosa** (Brady)

_Cassidulina subglobosa_ Brady, 1881, p. 60 (type reference).
_Cassidulina subglobosa_ Brady-Brady, 1884, p. 430. Plate 54, Figs. 17a-c (type figure).
_Globocassidulina subglobosa_ (Brady).-Lohmann, 1978, p. 26. Plate 2, Figs. 8-9.-Tjalsma and Lohmann, 1983, p. 31. Plate 16, Fig. 9.-Miller and Katz, 1987a, p. 134. Plate 3, Fig. 4.

**Gypsina sp.**

We found this shallow-water taxon only in the _Amphistegina/Asterigerina_-rich layers. They tend to be concentrated in the >1,000 µm size fraction.

**Hanzawaia ammophila** (Guelbel)

_Rotalia ammophila_ Guembel, 1868, p. 652. Plate 2, Figs. 90a-b.
_Hanzawaia cushmani_ (Nuttall).-Tjalsma and Lohmann, 1983, p. 32. Plate 17, Figs. 1a-c.-Miller, 1983, p. 437. Plate 1, Fig. 12.

**Hanzawaia mantaensis** Galloway and Morrey

_Figure 19, Photos 8-10_

_Anomalina mantaensis_ Galloway and Morrey, 1929, p. 28. Plate 4, Figs. 5a-c.

This plano-convex test has strongly curved sutures, a clear umbilical boss, and an acute periphery.

**Hanzawaia sp. 3**

_Figure 19, Photos 5-7_

This species is very similar to the Eocene form _Hanzawaia carboeae_ (Cushman and Bermudez) with its thick, circular test that is quadratic to subquadrate in peripheral view. The spiral side is planar to slightly convex with broad, limbate sutures. There is a peripheral thickening of shell material with a keel-like appearance.

**Hoeglundina elegans** (d’Orbigny)

_Rotalia (Turbinilina) elegans_ d’Orbigny, 1826, p. 276 (type reference).
_Rotalia (Turbinilina) elegans_ d’Orbigny.-Parker et al., 1965, Plate 12, Fig. 142 (type figure).

**Karreriella subglobula** (Guembel)

_Gaudryina subglobula_ Guembel, 1868, p. 602. Plate 1, Figs. 4a-b.
_Gaudryina bradyi_ Cushman, 1911, p. 67. Fig. 107.

_Karreriella bradyi_ (Cushman).-Cushman, 1937, p. 135. Plate 16, Figs. 6-11.-Cushman and Todd, 1945, p. 8. Plate 1, Fig. 20.-Barker, 1960, Plate. 46, Figs. 1-4.
_Karreriella subglobula_ (Guembel).-Tjalsma and Lohmann, 1983, p. 34. Plate 9, Figs. 1a-b.-Miller and Katz, 1987a, p. 134. Plate 1, Figs. 3a-b.

**Laticarinina pauperata** (Parker and Jones)

_Pulvinula repanda_ Fichtel and Moll, var. _menardii_ d’Orbigny, subvar. _pauperata_ Parker and Jones, 1865, p. 295. Plate 16, Figs. 50-51b.

**Laxostomum isidroensis** (Cushman and Rentz)

_Figure 17, Photos 8-9_

_Bolivina isidroensis_ Cushman and Rentz, 1941, p. 17. Plate 3, Fig. 8.-Cushman and Todd, 1945, p. 43. Plate 6, Fig. 30.-Rentz, 1948, p. 118. Plate 7, Figs. 5a-b.

**Melonis barleeanum** (Williamson)

_Nonion barleanum_ Williamson, 1858, p. 32. Plate 3, Figs. 68-69.
_Nonion barleanum_ (Williamson).-Phleger et al., 1953, p. 30. Plate 6, Fig. 4.
_Melonis barleanum_ (Williamson).-Pflum and Frerichs, 1976, Plate 7, Figs. 5-6.-Miller and Katz, 1987a, p. 136. Plate 4, Figs. 5a-b.

**Melonis pompilioides** (Fichtel and Moll)

_Figure 15, Photos 1-2_

_Nautilus pompilioides_ Fichtel and Moll. 1798, p. 31. Plate 2, Figs. a-c (above).
_Nonion solidanii_ d’Orbigny, 1846, p. 109. Plate 5, Figs. 15-16.
_Nonion solidanii_ (d’Orbigny).-Cushman and Todd, 1945, p. 36. Plate 5, Fig. 25.
_Melonis pompilioides_ (Fichtel and Moll).-van Morkhoven et al., 1986, p. 72-77. Plate 23A, Figs. 1a-2c; Plate 23B, Figs. 1a-2b; Plate 23C, Figs. 1a-d.

_Melonis pompilioides_ and _Melonis sphaeroides_ are morphologically similar, bathymetrically segregated species. We follow _van Morkhoven et al_. (1986) in distinguishing between these species. _Melonis sphaeroides_ is the more inflated, deeper-water form that is restricted to middle bathyal to abyssal depths. _Melonis pompilioides_ is usually larger and has more chambers in the final whorl (10 to 11) and increases in width less rapidly, resulting in a different outline in aperture view. _Melonis pompilioides_ has more finely perforate test and a larger umbilicus. Its sutures are broad, imperforate bands, rather than the thinner, straight, and slightly depressed sutures of _M. sphaeroides_.

**Melonis sphaeroides** Voloshinova

_Figure 15, Photos 3-4_

_Melonis pompilioides_ (Fichtel and Moll), forma _sphaeroides_ Volo-
Miocene-Pliocene bathyal benthic foraminifera

Planulina wuellerstorfi (Schwager)

Anomalina wuellerstorfi Schwager, 1866, p. 258, Plate 7, Figs. 105, 107.

Cibicides wuellerstorfi (Schwager)-Pflum and Freichs, 1976, p. 116, Plate 4, Figs. 2–4.


Planulina sp. 1

Figure 20, Photos 7–9

This small planuliloid is reminiscent of Planulina foveolata, but it lacks surface ornamentation.

Plectofrondicularia parri Finlay

Plectofrondicularia parri Finlay, 1939, p. 516, Plate 68, Figs. 4a–b.-van Morkhoven et al., 1986, p. 128–130, Plate 41, Figs. 1–2.

Plectofrondicularia diversiscostata Cushman and Todd, 1945, non Fronndicularia diversiscostata Neugeboren, 1980, p. 37, Plate 6, Fig. 3.

Cushman and Todd's (1945) illustration of Plectofrondicularia diversiscostata is indistinguishable from our specimens of Plectofrondicularia parri. However, Neugeboren’s (1980) type figure of Plectofrondicularia diversiscostata illustrates distinct, continuous longitudinal costae that cover the entire test. Cushman and Todd (1945) note that while a number of their Buff Bay specimens fit this description, they show considerable variation in the length of the intermediate costae. Cushman and Todd’s (1945) illustration of Plectofrondicularia diversiscostata lacks these pronounced, continuous longitudinal costae. van Morkhoven et al. (1986) report that Plectofrondicularia parri last occurred in the late Miocene (Zone N17); however, we found this species throughout the Pliocene Bowden Formation.

Plectofrondicularia vaughani Cushman

Plectofrondicularia vaughani Cushman and Todd, 1945, p. 38, Plate 6, Fig. 5.

Plectofrondicularia vaughani Cushman 1927b, p. 112, Plate 23, Fig. 3.-van Morkhoven et al., 1986, p. 130–133, Plate 42, Figs. 1–2.

Our specimens of Plectofrondicularia vaughani tend to be broken. Despite this, we see little difference between Plectofrondicularia jarvisi illustrated by Cushman and Todd (1945) and Plectofrondicularia vaughani. Therefore, we tentatively consider Plectofrondicularia jarvisi to be a junior synonym of Plectofrondicularia vaughani. Comparison of type specimens would clarify this issue. As with Plectofrondicularia parri, van Morkhoven et al. (1986) report that Plectofrondicularia vaughani last occurred in the late Miocene (Zone N17); however, we found this species throughout the Pliocene Bowden Formation.

Pullenia bulboides (d’Orbigny)

Nonionina bulboides d’Orbigny, 1826, p. 293.

Pullenia bulboides (d’Orbigny) - Cushman and Todd, 1945, p. 64, Plate 11, Fig. 5.-Bermúdez, 1949, p. 276, Plate 21, Figs. 28–29.-Lohmann, 1978, p. 26, Plate 1, Figs. 10–11.-Miller and Katz, 1987a, p. 136, 138, Plate 4, Figs. 4a–b.
Pullenia malikinae Coryell and Mossman

Pullenia malikinae Coryell and Mossman, 1942, p. 234, Plate 36, Figs. 3-4.-Cushman and Todd, 1945, p. 65, Plate 11, Fig. 8.

Pullenia malikinae has a circular outline and a compressed test in axial view.

Pullenia quadrilobata Reuss

Pullenia compressiscula Reuss var. quadriloba Reuss, 1867, p. 87, Plate 3, Fig. 8.

Pullenia quadriloba (Reuss).-Cushman and Todd, 1945, p. 65, Plate 11, Fig. 7.

This species differs from Pullenia quinquelooba in having four chambers in the final whorl rather than five.

Pullenia quinquelooba (Reuss)

Noioniina quinquelooba Reuss, 1851, p. 71, Plate 5, Figs. 31a-b.

Pullenia quinquelooba (Reuss).-Bermúdez, 1949, p. 276, Plate 21, Figs. 32-33.-Tjalsma and Lohmann, 1983, p. 36, Plate 16, Fig. 2.-Miller and Kaz, 1987, p. 138, Plate 4, Figs. 2a-b.

Pyrgo murrhina (Schwager)

Biloculina murrhina Schwager, 1866, p. 203, Plate 4, Figs. 15a-c.

Pyrgo murrhina (Schwager).-Cushman and Todd, 1945, p. 12, Plate 2, Fig. 5.-van Morkhoven et al., 1986, p. 50-52, Plate 15, Figs. 1-2.

Rectuvigerina multicomata (Cushman and Jarvis)

Figure 16, Photo 9-11

Siphogenerina multicomata Cushman and Jarvis, 1929, p. 14, Plate 3, Fig. 6.


Rectuvigerina striata (Schwager)

Figure 16, Photo 8

Dimorphina striata Schwager, 1866, p. 251, Plate 7, Figs. 2, 99 (above left).


Reussella spinulosa (Reuss) var. pulchra (Cushman)

Figure 17, Photos 12-13

Verneulinia spinulosa Reuss, 1850, p. 374, Plate 47, Fig. 12a-c.

Reussella spinulosa (Reuss).-Renz, 1948, p. 156, Plate 7, Figs. 16-17.-Bermúdez, 1949, p. 196, Plate 12, Fig. 59.

Reussella pulchra Cushman, 1945, p. 34, Plate 6, Figs. 11-12.-Cushman and Todd, 1945, p. 49, Plate 7, Fig. 21.

Reussella simplex (Cushman).-Barker, 1960, p. 96, Plate 47, Fig. 1.

Reussella aculeata Cushman.-Barker, 1960, p. 96, Plate 47, Fig. 2-3.

This form has a carinate periphery with a spine at the base of each chamber. The chambers are distinct with limbate, slightly raised sutures and a finely spinose surface. Reussella pulchra Cushman appears to be a junior synonym of Reussella spinulosa (Reuss). We believe that it is separable as a subspecies on the basis of its finely spinose ornamentation and therefore we include it as a variety.

Rosalina sp. 1

Figure 19, Photos 1-2

This species has a highly perforate test and an open umbilicus.

Signiloopsis schlumbergeri (Silvestri)

Sigmoidina schlumbergeri Silvestri, 1904, p. 267, 269 (type reference).-Schlumberger, 1887, p. 481-482, Plate 7, Figs. 12-14 (type figure).-Cushman and Todd, 1945, p. 11, Plate 2, Fig. 3.

Signiloopsis schlumbergeri (Silvestri).-van Morkhoven et al., 1986, p. 57-59, Plate 18., Figs. 1a-e.

Siphogenerina advena var. ornata Cushman

Siphogenerina advena Cushman, 1922b, p. 35, Plate 5, Fig. 2.-Bermúdez, 1949, p. 221, Plate 13, Fig. 76.

Siphogenerina advena Cushman var. ornata Palmer and Bermúdez, 1936b, p. 249, Plate 22, Figs. 4, 7.-Cushman and Todd, 1945, p. 52, Plate 7, Fig. 32.

Siphonina tenuicarinata Cushman

Figure 16, Photos 1-3

Siphonina tenuicarinata Cushman, 1927a, p. 166, Plate 26, Figs. 11-12.-van Morkhoven et al., 1986, p. 206-209, Plate 70, Figs. 1-3.

The majority of our specimens are S. tenuicarinata; however, several specimens may be S. cf. pulchra (see Cushman and Todd, 1945, for illustrations and discussion).

Siphoninella soluta (Brady)

Figure 15, Photos 9-10

Truncatullina soluta Brady, 1884, in Barker, 1960, p. 198, Plate 96, Figs. 4a-c.

Siphoninella soluta (Brady).-Cushman, 1927c, p. 77, Plate 16, Fig. 13.

This species tends to have a broken keel and pustular ornamentation, particularly along the sutures.

Siphonovigerina porrecta (Brady)

Figure 18, Photos 1-2

Uvigerina porrecta Brady, 1884, in Barker 1960, p. 156, Plate 74, Figs. 21-23.

Neuvigerina porrecta (Brady).-Hofker, 1951, p. 213.

Angulogerina porrecta (Brady).-Bermúdez, 1949, p. 218, Plate 13, Fig. 56.
This distinctive taxon is common in the Buit Bury samples. It has discontinuous costae on its loosely coiled chambers.

*Sphaeroidina bulloides* d’Orbigny

*Sphaeroidina bulloides* d’Orbigny, 1826, p. 267.-Parker et al., 1865, Plate 2, Fig. 58.-Bermúdez, 1949, p. 277, Plate 21, Figs. 34–38.-van Morkhoven et al., 1986, p. 80–83, Plate 24, Figs. 1–2.

*Stilostomella aculeata* (Cushman and Renz)

*Ellipsonodosaria nutalli* Cushman and Jarvis var. *aculeata* Cushman and Renz, 1948, p. 32, Plate 6, Fig. 10.

*Stilostomella aculeata* (Cushman and Renz).-Miller, 1983, p. 439, Plate 4, Fig. 1.-Miller and Katz, 1987a, p. 138, Plate 1, Fig. 11.

*Stilostomella curvatura* (Cushman)

*Ellipsonodosaria curvatura* Cushman, 1939, p. 71, Plate 12, Fig. 6.


*Stilostomella modesta* (Bermudez)

*Ellipsonodosaria modesta* Bermúdez, 1937, p. 238, Plate 20, Fig. 3.

*Stilostomella modesta* (Bermúdez).-Beckmann, 1954, p. 371, Plate 21, Fig. 32.-Tjalsma, 1983, p. 743, Plate 1, Fig. 10.

*Siphonodosaria modesta* (Bermúdez).-Douglas, 1973, Plate 5, Fig. 4.

*Orthomorphina modesta* (Bermudez).-Boltovskoy, 1978, p. 163, Plate 5, Fig. 25.

*Stilostomella subspinosa* (Cushman)

*Ellipsonodosaria subspinosa* Cushman, 1943, p. 92, Plate 16, Figs. 6–7b.

*Stilostomella subspinosa* (Cushman).-Tjalsma and Lohmann, 1983, p. 36, Plate 14, Figs. 16–17.-Miller and Katz, 1987a, p. 138, Plate 1, Fig. 12.

*Trifarina Bradyi* Cushman

*Trifarina Bradyi* Cushman, 1923, p. 99, Plate 22, Figs. 3–9.-Phleger and Parker, 1951, p. 18, Plate 8, Figs. 10–11.-Renz, 1948, p. 172, Plate 7, Figs. 33.-Bermúdez, 1949, p. 225, Plate 13, Fig. 75.

*Uvigerina carapitana* Hedburg

*Uvigerina carapitana* Hedburg, 1937, p. 677, Plate 91, Figs. 1984, p. 202, Plate 13, Fig. 1.-Boersma, 1984, p. 28–30, Plate 1, Figs. 1–5.

*Uvigerina hispida* Schwager

*Uvigerina hispida* Schwager, 1866, p. 249, Plate 7, Fig. 95.-Boersma, 1984, p. 76–74, Plate 1, Figs. 1–4.-van Morkhoven et al., 1986, p. 62–64, Plate 20, Figs. 1–4.

*Uvigerina hispida-costa* Cushman and Todd

Figure 21, Photos 11–12


*Uvigerina jamaicensis* (Cushman and Todd)

Figure 21, Photos 9–10

*Angulogerina jamaicensis* Cushman and Todd, 1945, p. 53, Plate 8, Fig. 3.

*Uvigerina laviculata* Coryell and Rivero


*Uvigerina pigmea* d’Orbigny

Figure 18, Photos 7–8

*Uvigerina pigmea* d’Orbigny, 1826, p. 269.-Bermúdez, 1949, p. 209, Plate 13, Fig. 44.-Boersma, 1984, p. 127–130, Plate 1, Figs. 1–6; Plate 2, Figs. 1–5.

*Uvigerina proboscidea* Schwager

Figure 18, Photos 13–14

*Uvigerina proboscidea* Schwager, 1866, p. 250, Plate 7, Fig. 96.-Cushman and Todd, 1945, p. 50, Plate 7, Figs. 28–29.-Bermúdez, 1949, p. 209, Plate 13, Fig. 45.-Boersma, 1984, p. 131–134, Plate 1, Figs. 1–5.-van Morkhoven et al., 1986, p. 28–30, Plate 6, Figs. 1–4.

*Uvigerina sp. 1*

Uvigerina sp. 1 is primarily a costate form, although costae may break into hisps or short ridges on a few specimens. Costae are restricted to individual chambers. Coiling is generally triserial throughout, although rare specimens are elongate with a biserial final whorl. Although this species resembles *Uvigerina parastra* Cushman (see Boersma, 1984), we did not adopt this name because of its different stratigraphic and bathymetric ranges.

*Uvigerina sp. 7*

Figure 18, Photos 11–12

The final chambers of this costate uvigerinid tend to become angular.
Figure 13. Shallow-water taxa. Scale bar = 100 μm. 1–3, Cibicides lobatus (Walker and Jacob), sample BB64; 4–6, Asitterta sp., sample BB52; 7–8, Ephemedium sp., sample BB8; 9–10, Planorbulina sp., sample BB52.
Figure 14. Scale bar = 100 μm. 1-3, Cibicidoides dominicus (Bermúdez), sample SG1; 4-6, Cibicidoides coryelli (Bermúdez), sample SG1; 7-9, Planulina ambigua (Franzenau), sample SG28; 10-11, Cassidulina spinifera, Cushman and Jarvis, sample SG30.
Figure 15. Scale bar = 100 µm. 1-2, Melonis pomplioides (Fichtel and Moll), sample BW248; 3-4, Melonis sphaeroides Voloshinova, sample SG23A; 5, Bolivina tortuosa Brady, sample SG30; 6-8, Ehrenbergina spinosa Cushman, sample BB4; 9-10, Siphonodictya soluta (Brady), sample BB24; 11-12, Angulogerina caimarenensis Palmer, sample SG25.
Figure 16. Scale bar = 100 μm. 1–3, Siphonina temulatina Cushman, sample BB64. 4–7, Globocassidulina palmerae (Bermúdez and Acosta), sample BB8; 8, Rectuvigerina striata (Schwager), sample BB4; 9–11, Rectuvigerina multicostata (Cushman and Jarvis), sample BB4.
Figure 17. Scale bar = 100 μm. 1–2, Bolivina thalmani Renz, sample BB44; 3–4, Bolivina aenariensisformis Subbotina, sample BB48; 5–6, Bolivina alazanensis Cushman, sample BB28; 7, Bolivina aiosa (Seguenza), sample BB8; 8–9, Loxosomum isidroensis (Cushman and Renz), sample BB12; 10–11, Ehrenbergina caribbea Galloway and Hemingway, sample BB36; 12–13, Reussella spinulosa (Reuss) var. pulchra (Cushman), sample BB64; 14–15, Bulimina mexicana Cushman, sample BB20.
Figure 18. Scale bar = 100 µm. 1–2, Siphougerina porrecta (Brady), sample BB64; 3–4, Compressigerina coarctata (Palmer), sample BB64; 5–6, Angulogerina illungi Cushman and Renz, sample BB64; 7–8, Uvigerina pigmea d'Orbigny, sample BB44; 9–10, Angulogerina exigua Cushman and Jarvis, sample BB48; 11–12, Uvigerina sp. 7, sample BB48; 13–14, Uvigerina proboscidea Schwager, sample BB56.
Figure 19. Scale bar = 100 μm. 1–2, Rosalina sp. 1, sample BB64; 3–4, Cancris scintillans (Coryell and Mossman), sample BB60; 5–7, Hanzawaia sp. 3, sample BB1; 8–10, Hanzawaia mutaensis Galloway and Morrey, sample SG6; 11–13, Anomalinoidea globulosus (Chapman and Parr), sample BB64.
Figure 20. Scale bar = 100 μm. 1–3, *Cibicidoides matanzasensis* (Hadley), sample BB16; 4–6, *Planulina rugosa* (Phleger and Parker), sample BB20; 7–9, *Planulina* sp. 1, sample BB48; 10–12, *Cibicidoides* sp., sample BB4.
Figure 21. Scale bar = 100 μm. 1–4, Cancris scintillans var. sinecarina (Coryell) and Mossman, sample BW252; 5–8, Planulina foveolata (Brady), sample BW 245; 9–10, Uvigerina jamaicensis (Cushman and Todd), sample BW245; 11–12, Uvigerina hispida-costa Cushman and Todd, sample BW252; 13–14, Ehrenbergina spinosissima Cushman and Jarvis, sample BW244.
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