

PALEOCENE TO MIDDLE MIOCENE PLANKTIC FORAMINIFERA OF THE SOUTHWESTERN SALISBURY EMBAYMENT, VIRGINIA AND MARYLAND: BIOSTRATIGRAPHY, ALLOSTRATIGRAPHY, AND SEQUENCE STRATIGRAPHY

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ABSTRACT

The Paleocene to Middle Miocene sedimentary fill of the southwestern Salisbury Embayment contains a fragmental depositional record, interrupted by numerous local diastems and regional unconformities. Using planktic foraminiferal biostratigraphy, we have identified fifteen unconformity-bounded depositional units, assigned to six formations and seven alloformations previously recognized in the embayment. The units correlate with second- and third-order sequences of the Exxon sequence stratigraphy model, and include transgressive and high-stand systems tracts. Alloformation, formation, and sequence boundaries are marked by abrupt, scoured, burrowed, erosional surfaces, which display lag deposits, biostratigraphic gaps, and intense reworking of microfossils above and below the boundaries.

Paleocene deposits represent the upper parts of upper Paleocene Biochronozones P4 and P5, and rest unconformably on Cretaceous sedimentary beds of various ages (Maastrichtian to Albian). Lower Eocene deposits represent parts of Biochronozones P6 and P9. Middle Eocene strata represent mainly parts of Biochronozones P11, P12, and P14. Upper Eocene sediments include parts of Biochronozones P15, P16, and P17. Oligocene deposits encompass parts of Biochronozones P18–20 undifferentiated, P21a, and, perhaps, N4a. Lower Miocene deposits encompass parts of Biochronozones N4b to N7 undifferentiated. Middle Miocene strata represent mainly parts of Biochronozones N8, N9, and N10.

Nine plates of scanning electron micrographs illustrate the principal planktic foraminifera used to establish the biostratigraphic framework. Two new informal formae of *Praetenuitella prae gemma* Li, 1987, are introduced.

INTRODUCTION

In the past several years, a number of continuously cored boreholes have permitted the detailed stratigraphic analysis of subsurface sections of the Salisbury Embayment in Virginia (e.g., Gibson and others, 1980; Mixon, ed., 1989). We have examined planktic foraminiferal suites from three of these boreholes (Haynesville, Exmore, Kiptopeke), from outcrops along the Pamunkey River, Virginia, and from a continuously cored 1,386-m section near Salisbury, Maryland (Fig. 1). The purpose of this paper is threefold: 1) to describe and illustrate the Paleocene to middle Miocene planktic foraminiferal assemblages from these five sections; 2) to document the biostratigraphic successions in the southwestern part of the Salisbury Embayment; 3) to discuss the implications for allostratigraphy and sequence stratigraphy. This study refines and updates interpretations previously published by Gibson and others (1980), Gibson (1983),

Ward (1984), Poag and Ward (1987), Olsson and others (1988), and Poag (1989).

SECTIONS STUDIED

The Salisbury Embayment, a shallow, sediment-filled, structural depression, underlies most of the coastal plain of Virginia, Maryland, Delaware, and New Jersey (Fig. 1; Richards, 1948; Maher, 1971; Brown and others, 1972; Owens and Gohn, 1985). The embayment is the landward extension of the Baltimore Canyon Trough, the deepest offshore sedimentary basin of the U.S. Atlantic margin (Schlee, 1981; Poag, 1985, 1987; Grow and others, 1988; Poag and Ward, 1993). The five sections we studied are located in the southwestern part of the embayment, extending from near its updip limit to near its center.

Section 1. Near the updip limit of the Salisbury Embayment, Cenozoic sedimentary beds are exposed in the banks of the Pamunkey River for approximately 55 km between Wickham Crossing, Hanover County, Virginia, and Elsing Green, King William County, Virginia (see Ward, 1984, for detailed descriptions of these outcrops). We collected 32 samples from 12 exposures (Stops 1–5, 7, 10, 12–16 of Ward, 1984) to establish a composite stratigraphic section (Fig. 1).

Section 2. The Haynesville core (Mixon, ed., 1989) was drilled in 1984 by the U.S. Geological Survey at a site in central Richmond County, Virginia, 1 km northwest of Haynesville and 5 km east of Warsaw, at lat 37°57'13"N, long 76°40'26"W. Two core holes, with surface locations 30 m apart, penetrated a composite section 169 m thick (Fig. 1). We took 25 whole-core samples, 5–10 cm long (core diameter = 5 cm), near the principal lithostratigraphic boundaries and near other obvious lithologic changes (Poag, 1989).

Section 3. The Kiptopeke core was drilled in 1989 by the Virginia State Water Control Board at a site in Northampton County, Virginia, approximately 0.9 km southeast of Kiptopeke, at lat 37°08'07"N, long 75°57'08"W. Two core holes, with surface locations 30 m apart, penetrated a composite section 534.3 m thick (Fig. 1). The section was drilled without coring from 534.3 to 609.6 m. We took 24 samples in the same manner as described for the Haynesville core.

Section 4. The Exmore core was drilled in 1986 by the U.S. Geological Survey at a site in Accomack County, Virginia, 3.2 km west of Painter, and 4.8 km north of Exmore, on the west side of the lake on the property of the Eastern Shore Agricultural Experiment Station, at lat 37°35'08"N, long 75°49'09"W. The core hole penetrated a 425.8-m sedimentary section (Fig. 1). We collected 60 samples in the same manner as that described for the Haynesville core.

Section 5. The Hammond core (Anderson and others,

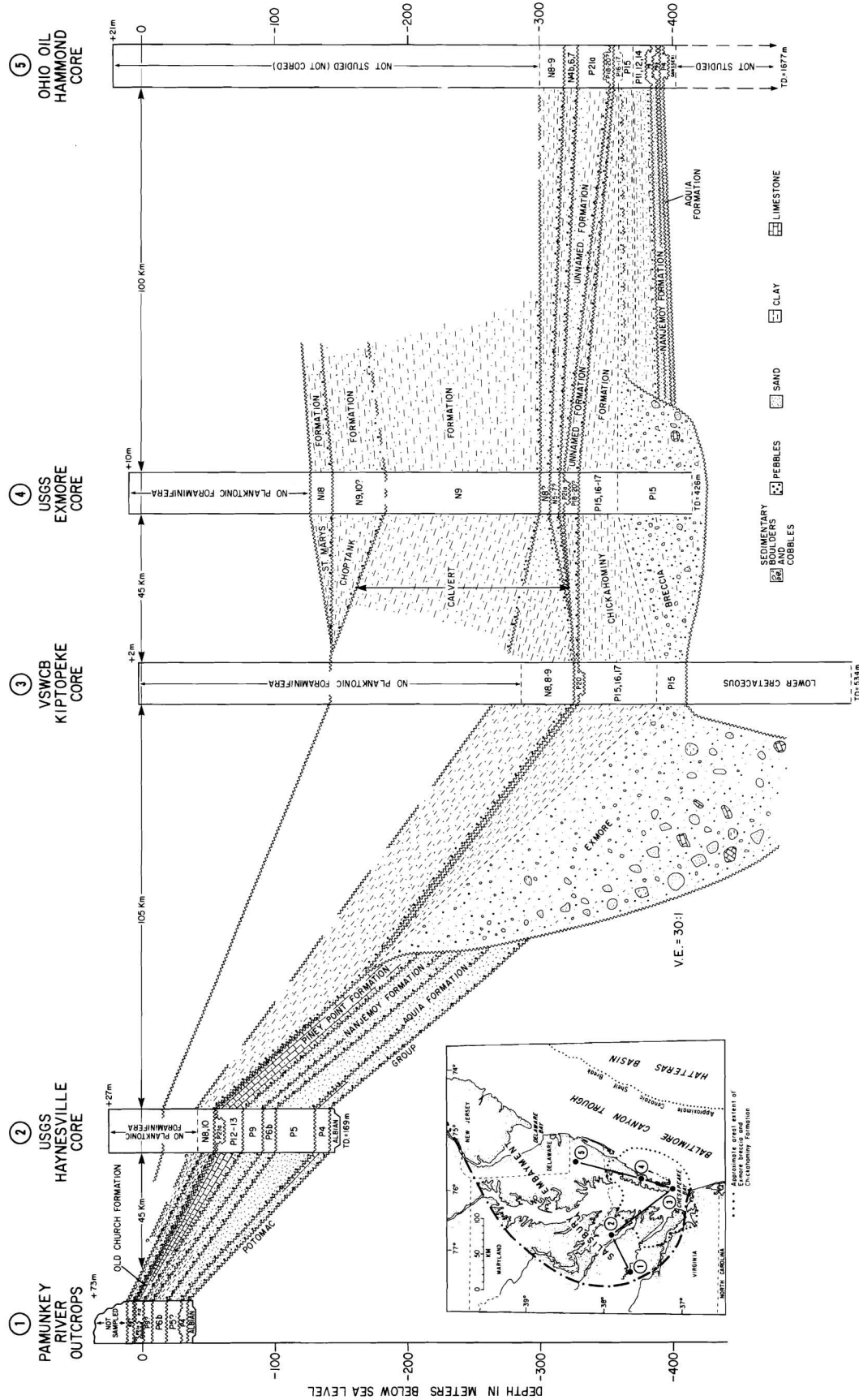


FIGURE 1. Location of sample sites in the Salisbury Embayment and cross section through sites showing lithostratigraphy (formations and lithofacies) and planktic foraminiferal zonation. USGS = United States Geological Survey; VSWCB = Virginia State Water Control Board. Stratigraphic data for the Haynesville corehole are from Poag (1989). See Figure 2 for geologic age of depositional units.

1948; Brown and others, 1972) was taken by the Ohio Oil Company in 1944 during drilling of an exploratory wildcat well on the farm of Larry G. Hammond, 9.6 km east of Salisbury, Wicomico County, Maryland, on the Mt. Herman Road, at lat 38°18'45"N, long 75°29'30"W (Fig. 1). Consecutive 3-m-long cores were taken in the Hammond well from 305 m to 1,690 m depth. One (or more) foraminiferal sample(s) was taken (in 1944) from an unspecified interval within each 3-m section of core. We obtained two different sets of washed foraminiferal residues, one (32 samples) from the Maryland Geological Survey, and one (also 32 samples) from the U.S. National Museum of Natural History; each set contained an identical succession of planktic foraminifera. For purposes of stratigraphic consistency, we arbitrarily assumed that each of the 32 samples from both sets (total of 64 samples) came from the top of the 3-m core it represented. This means that biostratigraphic boundaries in the Hammond section are only approximate, and that thin depositional units (<3 m thick) might not have been sampled.

SAMPLE PREPARATION AND ACCESSIBILITY

All samples except those from the Hammond core (which were washed prior to our acquisition) were washed on a 73- μ m sieve, dried, and picked under a binocular optical microscope. We illustrate selected specimens with scanning electron micrographs (Plates 1–9). Picked slides and illustrated specimens from the Hammond core are retained in the collections of the Maryland Geological Survey and the U.S. National Museum of Natural History. All other specimens are part of the U.S. Geological Survey collection in Woods Hole, Massachusetts.

DESCRIPTIVE BIOSTRATIGRAPHY

Most of the planktic foraminiferal assemblages contain suites of tropical and subtropical specimens, which allow use of the familiar tropical zonations of Blow (1979), Kennett and Srinivasan, (1983), Bolli and Saunders (1985), and Toumarkine and Luterbacher (1985). In some samples, however, decidedly temperate assemblages are present, which contain key species described by Jenkins (e.g., 1985; see also Olsson and others, 1987). Because definitive biozone markers are often rare or missing, however, we relied on the ranges of ancillary species to recognize biochronozones. Authors and synonymies for the species mentioned in this paper can be found in the references cited above.

PRE-PALEOCENE ZONATION

Cenozoic strata of the Salisbury Embayment generally rest unconformably upon either Lower Cretaceous nonmarine strata or Upper Cretaceous marine strata. The only marine Cretaceous strata we encountered in situ are Maastrichtian marine clayey sands in the Hammond well. The presence of *Archaeoglobigerina blowi*; *Ar. cretacea*; *Globigerinelloides multispina*; *Gs. subcarinatus*; *Rugoglobigerina subpennnyi*; *Pseudoguembelina excolata*; and *Guembelitra cretacea* (Pl. 1) indicate that this interval represents the *Gansserina gansseri* Biochronozone.

Albian nonmarine sands lie below Paleocene marine strata

at the Pamunkey River outcrops (Ward, 1984) and in the Haynesville core (Mixon, 1989). The Kiptopeke and Exmore cores did not recover in situ Cretaceous sediment, though Albian nonmarine sand was encountered at total depth in the Exmore core (Powars and others, 1992; Fig. 1). We infer that Lower Cretaceous nonmarine strata were penetrated in the basal uncored section at Kiptopeke.

PALEOCENE ZONATION

We sampled in situ upper Paleocene strata at three sites (Pamunkey River, Haynesville, Hammond well). We encountered *Planorotalites pseudomenardii* (Pl. 1), which is restricted to Biozone P4, at all three sites (Fig. 2). This species was accompanied by other diagnostic species (Pls. 1, 2) whose upper ranges (*Morozovella angulata*, *Mz. conicotruncata*, *Planorotalites pusilla pusilla*, and *Subbotina triangularis cancellata*), and lower ranges (*Mz. aequa*, *Muricoglobigerina aquiensis*, *Mu. chascanona*, *Ac. acarinata*, *Ac. perclara*, *Ac. tribulosa*, *Ac. trichotrocha*, *Su. velascoensis*, and *Mz. velascoensis*) overlap in Biochronozones P4. Biochronozones P5 is also represented at the Pamunkey River outcrops and in the Haynesville core (Fig. 2), as indicated by an overlap in the upper range of *Muricoglobigerina mckannai* with the lower ranges of *Acarinina apantesma* (Pl. 1) and *Mz. marginodentata*. Biochronozones P5 was not documented at the Hammond site, and no Paleocene biochronozones younger than P5 were noted at any site (Fig. 2).

EOCENE ZONATION

The oldest Eocene biochronozones represented in the study area is P6b (earliest Eocene; Fig. 2), in which the upper ranges of *Acarinina tribulosa*, *Ac. convexa*, *Ac. trichotrocha*, *Mz. aequa*, *Muricoglobigerina aquiensis*, *Mu. chascanona*, and *Planorotalites chapmani*, overlap the lower ranges of *Pseudohastigerina wilcoxensis* and *Truncorotaloides quetra* (Pls. 2, 3).

Early Eocene Biochronozones P9 is also represented at the Haynesville and Hammond sites (Fig. 2), as indicated by overlap of the upper range of *Muricoglobigerina soldadoensis soldadoensis* with the lower ranges of *Turborotalia griffinae*, *Acarinina cuneicamerata*, and *Ac. matthewsae* (Pls. 3, 4). A distinctive depositional unit known as the Woodstock Member of the Nanjemoy Formation overlies Biochronozones P6b at the Pamunkey River outcrops, and may represent Biochronozones P9 (Fig. 2); it contains, however, no planktic foraminifera diagnostic of this zone.

The next youngest Eocene sequence in the study area encompasses Biochronozones P11(?), P12, and P14 of the middle Eocene. Biochronozones P12 appears to be present at three sample localities (Fig. 2), but Biochronozones P11(?) and P14 are known only in the Hammond core. We recognized Biochronozones P12 by overlap between the upper ranges of *Pseudohastigerina wilcoxensis*, *Turborotalia possagnoensis*, *Acarinina broedermanni*, *Ac. aspensis*, *Ac. bullbrookii*, *Ac. praetopilensis*, *Ac. cuneicamerata*, *Ac. matthewsae*, *Globigerinoides(?) higginsii*, and *Tu. frontosa* with the lower ranges of *Truncorotaloides rohri* and *Hantkenina alabamensis* (Pls. 2–5).

In the Hammond core, overlap of the upper range of *Tur-*

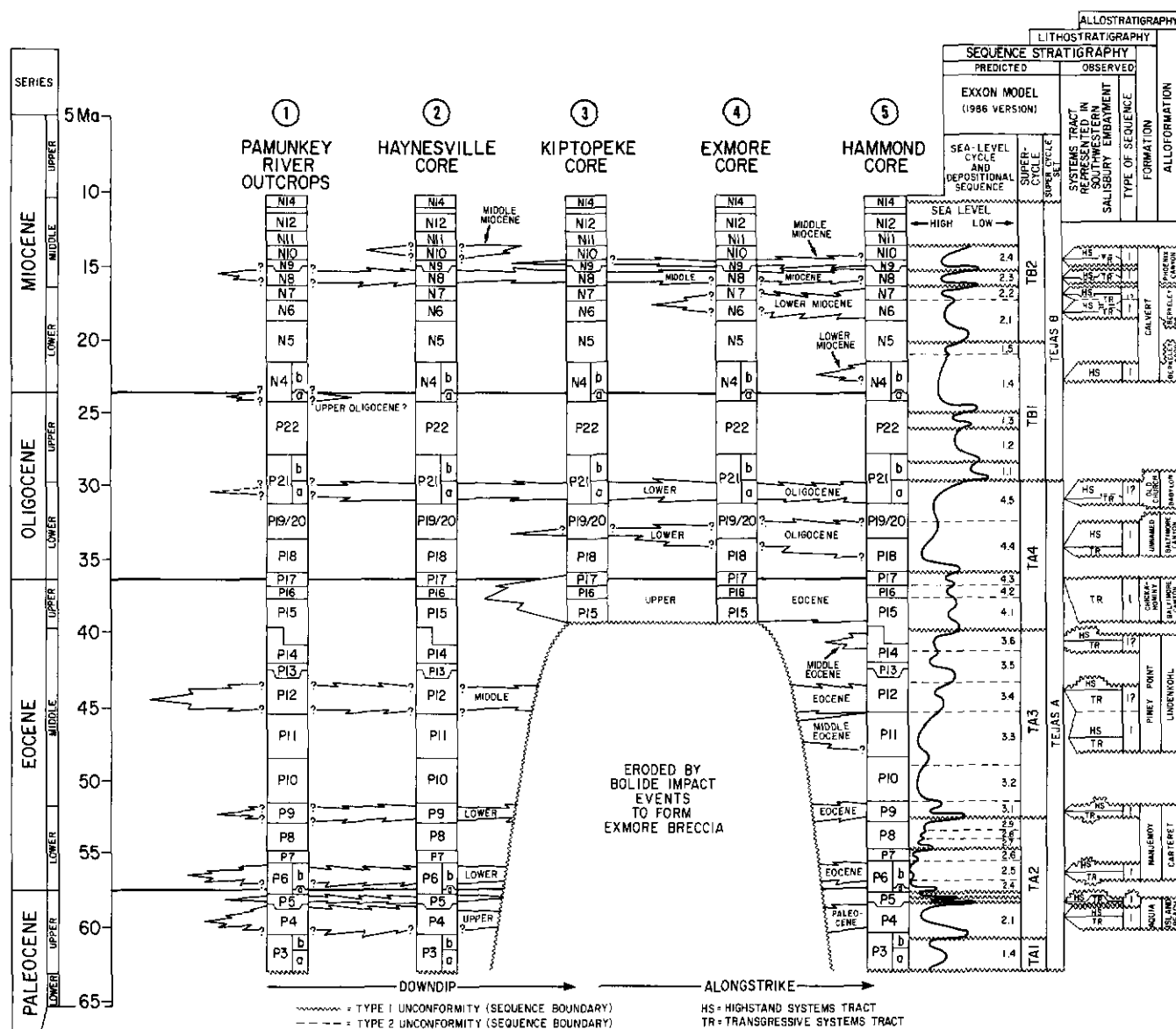


FIGURE 2. Composite stratigraphic section showing the biochronozones identified from planktic foraminiferal assemblages and correlations with the Exxon model of sequence stratigraphy, with formalized lithostratigraphic units, and with allostratigraphic units proposed by Poag and Ward (1993).

borotalia griffinae with the lower ranges of *Subbotina pseudoeocaena*, *Globigerinatheka index rubriformis*, and *Gk. index index* (Pls. 4, 5), is evidence that Biochronozones P11 is present below Biochronozones P12. In addition, the overlap of the upper range of *Acarinina primitiva*, *Ac. spinuloinflata*, and *Morozovella spinulosa*, with the lower range of *Turborotalia cerroazulensis* (Pls. 4, 5, 7), indicates the presence of Biochronozones P14 (Fig. 2).

Upper Eocene sequences in the study area are restricted to the three downdip core sites (Kiptopeke, Exmore, Hammond; Fig. 2), where they encompass parts of Biochronozones P15, P16, and P17. The key marker for Biozone P15, *Globigerinatheka semiinvoluta* (Pl. 5), is present in the Exmore breccia of the Exmore core (Poag and Aubry, in press; Figs. 1, 2). Its chronozones can be recognized by overlap of

the upper range of *Pseudohastigerina sharkriverensis* with the lower ranges of *Praetenuitella patefacta*, *Pt. impariapertura*, *Pt. praegemma*, *Turborotalia cocoaensis*, *Pseudohastigerina nagewichiensis*, *Globigerina praebulloides*, and *Gg. ouachitaensis* (Pls. 7, 9).

At the Kiptopeke site, Biochronozones P15 can be recognized by overlap of the upper range of *Globigerinatheka barri* with the lower range of *Ph. nagewichiensis*, *Pt. praegemma*, and *Gg. praebulloides*, below the lowest occurrence of *Cribohantkenina inflata* (Pl. 5). At the Hammond site, Biochronozones P15 can be recognized by overlap of the lower range of *Ph. nagewichiensis* with the occurrence of *Globigerina medizai* (Fig. 2).

At the Exmore and Kiptopeke sites, the lower strata of Biochronozones P15 comprise the Exmore impact breccia

(Poag and Aubry, in press; Figs. 1, 2). This unusual bolide-generated deposit contains chaotically mixed pebbles, cobbles, and boulders within a glauconitic sand matrix, which bears shock-metamorphosed quartz grains (Powars and others, 1990, 1992, 1993; Poag and others, 1992, 1994). The matrix, as well as individual clasts, contains foraminifera of Early Cretaceous, Late Cretaceous, Paleocene, early Eocene, middle Eocene, and late Eocene age (Poag and others, 1992; Poag and Aubry, in press; Fig. 2). At the Exmore site, this impact breccia is nearly 60 m thick (Fig. 1); there, a relatively complete assemblage of Biochronozones P15 planktic foraminifera, including *Gk. semiinvoluta* (Pl. 5), represents the youngest planktic suite present in the breccia. The chaotic lithology and mixed microfossil assemblages are similar in the Kiptopeke core (Figs. 1, 2), though *Gk. semiinvoluta* has not yet been identified there.

In the Hammond core, the upper interval of Biochronozones P15 comprises a clay-pebble conglomerate, which appears to be stratigraphically equivalent to the Exmore breccia in the Exmore and Kiptopeke cores; the clay-pebble conglomerate contains a mixture of predominantly lower to middle Eocene taxa plus a few Cretaceous and upper Eocene forms.

Biozone P16 can be recognized in the Kiptopeke core by the presence of *Cribohantkenina inflata* (Pl. 5), its defining taxon. However, the total range of *Ck. inflata* may not be represented at Kiptopeke, so placement of the P16 biozone boundaries is tentative (Poag and Aubry, in press; Fig. 2).

Biochronozones P17 can be tentatively distinguished only in the Kiptopeke core, as an interval above *Ck. inflata* containing the highest occurrences of *Hantkenina alabamensis* and *Pt. praegemma* (Fig. 2). *Cribohantkenina inflata* has not been found in the Exmore and Hammond cores, therefore we cannot distinguish biochronozones P16 from P17 in the interval above P15 at those sites. The uppermost part of Biochronozones P17, which is distinguished by *Turborotalia cunialensis*, has not been identified in the study area.

OLIGOCENE ZONATION

The oldest Oligocene species recorded in the study area occur in a sandy, sparsely fossiliferous interval which contains numerous specimens of reworked Eocene taxa and is present down dip at the Kiptopeke and Exmore sites (Figs. 1, 2). At Exmore, the combined presence of *Pseudohastigerina naguewichensis*, *Ph. micra*, *Turborotalia ampliapertura*, *Globigerina eocaena*, and *Gg. tapuriensis* (Pls. 5–7), is evidence that this interval is stratigraphically no younger than Biochronozones P19/20. The presence of *Catapsydrax unicavus* (Pl. 5) with *Tenuitella neoclemenciae* indicates that the interval is stratigraphically no older than Biochronozones P18.

In the Kiptopeke core, the occurrence of *Jenkinsella opima opima*, *Tu. ampliapertura*, *Dentoglobigerina pseudovenezuelana*, *Globigerina sellii*, and *Gg. tapuriensis* (Pls. 5–7), is evidence that only Biochronozones P20 is represented in the Oligocene deposits at this site (Fig. 2).

Part of Biochronozones P21a (early Oligocene) is present in the Haynesville, Exmore, and Hammond cores, and at the Pamunkey River outcrops (Fig. 2). Biochronozones P21a is characterized by overlap of the upper ranges of *Subbotina*

angiporoides, *Dentoglobigerina galavisi*, *Globigerina ouachitaensis*, *Gg. anguliofficialis*, and *Laterostomella cubensis*, with the lower ranges of *Globigerina angulissuturalis*, *Tenuitellina angustumbilicata*, and *Dentoglobigerina globularis* (Pls. 6–8). Biochronozones P21a has not been recognized in the Kiptopeke core, however, where the Oligocene section is thinner than 3 m.

The presence of upper Oligocene strata in the study area is debatable. Several investigators (Edwards, 1984, 1989, using dinoflagellates; Ward, 1984, using mollusks; Poag, 1989, using foraminifera) have dated the Old Church Formation along the Pamunkey River and in the Haynesville core, as either latest Oligocene or earliest Miocene age. The late Oligocene date based on foraminifera is equivocal, however, because the planktic microfossils are sparse and the ranges of some species in the Old Church strata are mutually exclusive. The regional relationships suggest to us that the late Oligocene and early Miocene specimens reported in the Haynesville core could have been reworked downward (as burrow-fill) into a barren lower Oligocene section prior to complete erosion of an original upper Oligocene section. The case for the presence of lower Oligocene strata along the Pamunkey River is more appealing to us (on the basis of foraminifera) because *Gg. ouachitaensis*, *Gg. anguliofficialis*, and *Dt. galavisi*, observed in that section, normally do not range above Biochronozones P21a. We cannot, however, eliminate the possibility that these latter taxa are reworked.

MIOCENE ZONATION

Miocene strata are present at all sites studied, but lower Miocene biochronozones can be firmly documented only in the Hammond core, farthest down dip (Figs. 1, 2). The oldest part of this lower Miocene section contains *Globoquadrina dehiscens*, *Jenkinsella acrostoma*, *Globigerinoides obliquus*, and *Gn. trilobus* (Pl. 8), whose lowest stratigraphic ranges are within Biochronozones N4b of the earliest Miocene. The next highest Hammond sample contains *Globoconella praescitula*, whose first occurrence datum is in Biochronozones N5, and *Gc. zealandica* (Pl. 8), whose first occurrence datum is in Biochronozones N6. The next highest Hammond sample contains *Fohsella birnageae*, (Pl. 8), whose first occurrence datum is in Biochronozones N7. In the Exmore core, a sandy interval containing no planktic foraminifera may be partly equivalent to lower Miocene Biochronozones N6–7 in the Hammond core.

Middle Miocene strata lie unconformably above the lower Miocene section in the Exmore and Hammond cores, above the lower Oligocene section in the Kiptopeke core, and above the lower Oligocene(?) section at the Pamunkey River site (Figs. 1, 2). The firmest documentation of the lower part of the middle Miocene section can be made in the Kiptopeke core. There, introduction of an entirely new suite of planktic species (most forms distinct from older taxa at the site) includes *Globigerinoides sicanus*, *Praeorbulina glomerosa curva*, and *Globoconella zealandica* (Pl. 8), whose overlapping ranges indicate Biochronozones N8 of the lowest middle Miocene. The overlap of *Globigerinoides altiapertura* and *Gn. sicanus* (Pl. 8) in the Haynesville core pro-

vides evidence that Biochronozone N8 is also present there (Fig. 2).

At the Exmore site (Fig. 2), the presence of Biochronozone N8 may be evidenced by the occurrence of *Globocornella zealandica*, *Jenkinsella bella*, and *Fohsella birnageae* (Pl. 8), all of which range no younger than Biochronozone N8. This inference is tenuous, however, because diagnostic species are missing.

In the Hammond core, the co-occurrence of *Jenkinsella semivera*, *Globoconella zealandica*, *Fohsella birnageae*, and *Globigerinoides sicanus* (Pl. 8), is evidence that Biochronozone N8 may be present there too, but in the same samples are *Globigerina bulloides* and *Gg. decoraperta*, which range no earlier than Biochronozone N9. Thus Biochronozones N8 and N9 cannot be clearly distinguished from each other in the Hammond core. An undifferentiated Biochronozone N8–9 is also present above the documented Biochronozone N8 in the Kiptopeke core (Fig. 2). For this study, no samples younger than Oligocene were sampled at the Pamunkey River outcrops, although Miocene and younger strata are known there (Ward, 1984).

An unusually thick interval (~470 m) encompassing part of Biochronozone N9 is present at the Exmore site (Figs. 1, 2); it is recognized by overlapping of the upper ranges of *Globoconella praescitula*, *Globigerinatella insueta*, *Globigerinoides sicanus*, *Praeorbulina glomerata glomerata*, and *Po. circularis* (Pl. 8), with the lower ranges of *Globigerina bulloides*, *Tenuitella neobrevispira* (Pl. 9), and *Hirvetella scitula*.

Biochronozone N10 can be recognized in the Haynesville core (Fig. 2) by the overlap of *Fohsella peripheroronda* (Pl. 8) with *Fo. praefohsi*. Biochronozone N10 may also be present in the Exmore core, but cannot be differentiated from Biochronozone N9 on the basis of the planktic foraminifera observed.

Younger Miocene planktic foraminifera (e.g., N18) are present at Exmore (Fig. 2), but elsewhere in the study area biochronozones younger than N10 cannot be recognized due to the lack of planktic foraminiferal assemblages in the generally shallow-marine facies (Fig. 1).

SEDIMENT REWORKING

Redeposition of older sediments into younger sections through erosion, as well as reworking of younger sediments into older sections through deep burrowing, are pervasive in the shallow-water sediments of the Salisbury Embayment (Edwards, 1984; Ward, 1984; Poag, 1989). Each unconformable sequence and alloformation boundary exhibits evidence of significant erosion, which has eliminated all (or most) alluvial and fluvial sediments that may have accumulated during lowstands of sea level (see several papers in Ward and Krafft, 1984). In combination with subsequent shoreface erosion and ravinement during the following relative sea-level rise, each sequence and alloformation boundary is a composite surface, which separates marine facies below from marine facies above. The sediments above the boundary contain reworked coarse clasts and redeposited microfossils, which may extend as high as several meters above the sequence boundary. Furthermore, erosion of updip exposures often supplies reworked older specimens to se-

quences deposited tens of millions of years later (for example, Cretaceous planktic foraminifera are present in Oligocene strata in Pamunkey River samples). In addition, burrows crossing sequence boundaries are numerous and deep, extending in some cases as far as 3 m below an unconformity (Ward, 1984; Mixon, ed., 1989). In fact, where a depositional unit is thin (a meter or so thick), a burrow may begin in one sequence, completely penetrate the underlying sequence, and terminate well below that in a third sequence. DiMarzio (1984), for example, illustrated burrows that carried middle Miocene sediments completely through the underlying Oligocene sequence, and displaced them several meters downward into the middle Eocene sequence. Numerous intrasequence (and intra-alloformation) unconformities and diastems are also present in the sections studied, and these exhibit similar redistribution of sediments through erosion and burrowing.

A particularly spectacular example of intense and extensive reworking, including 2-m thick boulders, is the bolide-generated Exmore breccia (Poag and others, 1992, 1994; Figs. 1, 2). Reworked marine and terrestrial sediments ranging from Early Cretaceous to middle Eocene are prominent throughout this widespread (8,000 km²) impact breccia.

ALLOSTRATIGRAPHY

Allostratigraphic units are mappable stratiform bodies of sedimentary rock, which are defined and identified on the basis of their bounding discontinuities (North American Commission on Stratigraphic Nomenclature, 1983). The term "discontinuities" includes, but is not limited to, unconformities. Thus all unconformity-bounded units are allostratigraphic units, though not all allostratigraphic units are unconformity bounded. The basic allostratigraphic unit is the *alloformation*. Poag and Ward (1993) used regional unconformities to define a formal framework of 12 alloformations for the Upper Cretaceous and Cenozoic strata of the contiguous Salisbury Embayment, Baltimore Canyon Trough, and Hatteras Basin (Fig. 1). Of the 12 alloformations proposed by Poag and Ward (1993), we have identified seven in the sections studied herein (Fig. 2). The correlations between alloformations and formations also are illustrated in Figure 2.

SEQUENCE STRATIGRAPHY

Since the publication of the Exxon model of sequence stratigraphy (Vail and others, 1977), and its subsequent modification (Haq and others, 1988; Posamentier and others, 1988; Van Wagoner and others, 1988, 1990), several authors have discussed its application to the sedimentary successions of the U.S. Middle Atlantic margin (e.g., Hazel and others, 1984; Kidwell, 1984; Poag and Schlee, 1984; Olsson and Wise, 1987; Olsson and others, 1987; Poag, 1987, 1992; Poag and Ward, 1987, 1993; Greenlee and others, 1988, 1992; Miller and others, 1990).

The continuous cores and outcrops analyzed herein present an excellent opportunity to examine more fully the relationships between the observed stratigraphy of the Salisbury Embayment and that predicted by the Exxon model. We have used the DNAG time scale (Palmer, 1983), which is different from that of the Exxon model, but this is not a

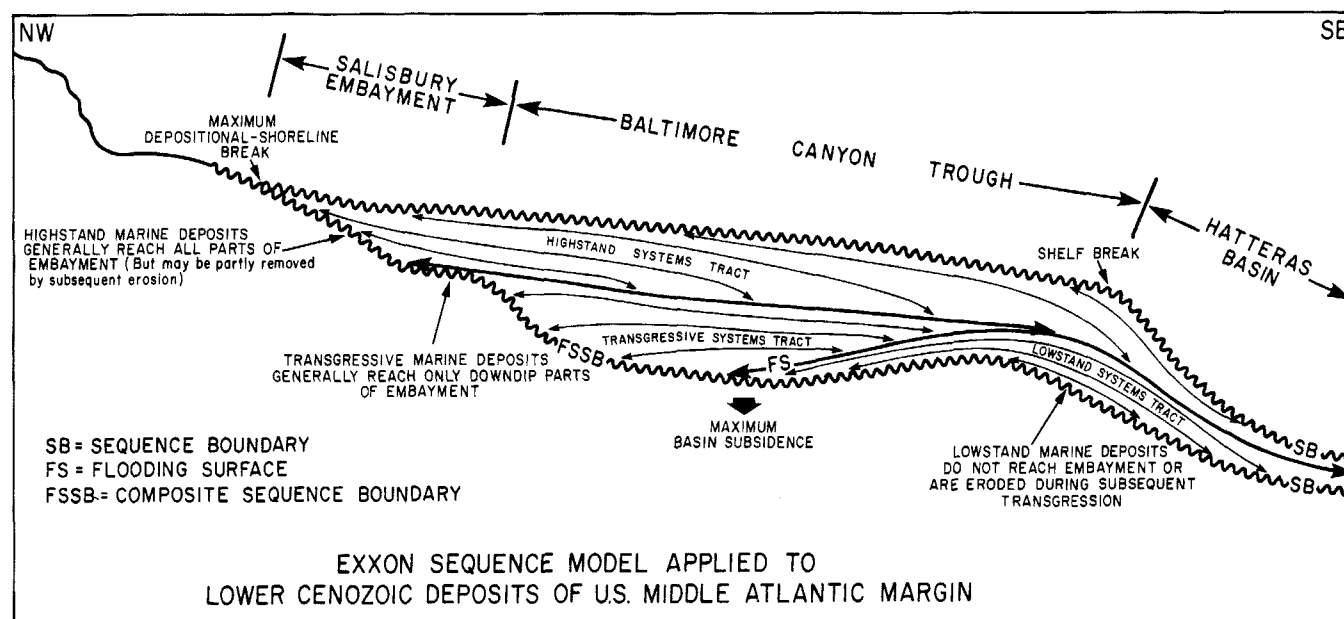


FIGURE 3. Diagrammatic representation of systems tracts that can be recognized by biostratigraphic correlation between the Paleocene to middle Miocene sediments of the Salisbury Embayment (and contiguous offshore basins) and the Exxon model.

critical factor for correlation, because the common link between the observed stratigraphic framework and that of the Exxon model is the planktic foraminiferal biostratigraphy (Figs. 1, 2).

Figures 2 and 3 illustrate our interpretation of which supercycles, cycles, and sequences are represented in the southwestern part of the Salisbury Embayment; the figures also show which systems tracts of the model correlate biostratigraphically with the observed sequences. Five unconformable boundaries (Type 1 unconformities) of five second-order sequences (TA2 through TB2) of the Exxon model are represented by stratigraphic gaps (erosional unconformities) in the study area. These gaps, and nine additional ones, break up the depositional record into 15 depositional units, which correlate biostratigraphically with third-order sequences of the Exxon model.

The Salisbury Embayment occupied the inner part of the continental shelf, nearly 200 km from the shelf edge, throughout the Cenozoic (Fig. 1; Poag, 1989; Poag and Sevon, 1989; Poag and Ward, 1993), and lowstand systems tracts seldom accumulated in the embayment (or if they did, subsequent transgressive erosion removed them; Fig. 3). The transgressive and highstand systems tracts predicted by the Exxon model, however, are well represented by observed sequences in the embayment.

The dominance of transgressive and highstand systems tracts in the southwestern Salisbury Embayment, as deduced from planktic correlations with the Exxon model, finds support in the work of Darby (1984). Darby studied the origin and deposition of coarse basal conglomerates, which mark unconformable sequence boundaries (SB's) at the Pamunkey River outcrops. He concluded that each basal conglomerate was formed by rapid shoreface erosion during a relative rise of sea level (which deposited a transgressive systems tract). This erosion reworked the entire thickness of preceding low-

stand fluvial and estuarine sediments that might have accumulated. The erosion also reworked the upper parts of the preceding shallow marine highstand deposits to form a flooding surface sequence boundary (FSSB), at which younger marine deposits rest unconformably on older marine deposits. Kidwell (1984) found similar relationships at unconformities within outcropping Miocene strata of the Salisbury Embayment. She (p. 54) referred most of the unconformities to "... ravinement surfaces formed erosively during early transgression or late regression."

TYPES OF UNCONFORMITIES IN THE EMBAYMENT

The question of what types of unconformities (Type 1 or Type 2 of the Exxon model) are represented in the study area cannot be answered by stratigraphic data from the Salisbury Embayment alone, as nearly the entire Embayment was subject to sequential subaerial and submarine erosion at every sequence boundary. This gives each alloformation and sequence boundary the appearance of a Type 1 unconformity. This interpretation is confirmed in part, by offshore investigations (Poag and Schlee, 1984; Poag, 1987, 1992; Poag and Low, 1987; Miller and others, 1990; Greenlee and others, 1992; Poag and Ward, 1993), which demonstrate that the eight regional unconformities (alloformation boundaries) of the Salisbury Embayment can be traced into the offshore strata of the Baltimore Canyon Trough and Hatteras Basin (a result of shelf exposure and coeval submarine erosion farther offshore). By definition, therefore, these are Type 1 unconformities.

DEVIATIONS FROM THE EXXON MODEL

The observed depositional and erosional patterns of the study area generally coincide with the sequences and sys-

tems tracts predicted by the Exxon model, with four notable exceptions. First, the Exxon model indicates that Biochronozones P15, P16, and P17 represent three separate third-order sequences, whereas we interpret these three zones to be encompassed in a single composite depositional unit. This unit is the lower part of the Baltimore Canyon Alloformation (Fig. 2), in which the bolide-generated Exmore breccia (an instantaneous deposit) is conformably overlain by massive, microfossil-rich, bathyal clays of the Chickahominy Formation (Figs. 1, 2). The Chickahominy Formation is a condensed section, which exhibits no evidence of internal discontinuities or of significant fluctuations in paleodepth.

The second deviation from the Exxon model concerns the lack of type 2 unconformities in the study area. The model calls for 12 type 2 unconformities in the stratigraphic interval we analyzed (Fig. 2). Though the sampling may not have been sufficient to detect all of these, it seems unlikely that we would have missed them all. Greenlee and others (1992), likewise, noted a lack of type 2 unconformities in the Neogene strata of the Baltimore Canyon Trough.

A third deviation is the seeming lack of lowstand deposits in this part of the embayment. The dominance of transgressive and highstand systems tracts here contrasts with the Neogene record from the Baltimore Canyon Trough, where Greenlee and others (1992) found mainly highstand and lowstand deposits.

The fourth deviation from the Exxon model is the presence of the thick (possibly 1,000–2,000 m thick) bolide-generated Exmore breccia (Powars and others, 1993; Poag and others, 1994). Its basal contact is a major unconformity not accounted for by the model. This remarkable deposit accumulated within a few minutes or hours during the early part of the P15 transgression (Figs. 1, 2).

SUMMARY AND CONCLUSIONS

Core holes and outcrops in the southwestern Salisbury Embayment contain an incomplete record of late Paleocene through middle Miocene marine deposition, punctuated by erosional unconformities, which can be identified and dated on the basis of planktic foraminiferal assemblages. The great distance (~200 km) of the embayment from the edge of the continental shelf, coupled with frequent cycling of relative sea level and periodic uplift of continental source terrains, combined to produce regional unconformities that correspond to alloformation boundaries proposed by Poag and Ward (1993) and to second- and third-order *sequence* boundaries of the Exxon model of sequence stratigraphy. These unconformities also generally correspond to formation and member boundaries of the formalized lithostratigraphic framework of the Atlantic Coastal Plain. In spite of pervasive sediment reworking (upward and downward), we can document seven alloformations and 15 shallow-to-deep marine sequences in the embayment. All seven alloformations and 13 sequences can be recognized in the farthest downdip site (Hammond core), but the number of alloformations and sequences diminishes updip.

Despite the variety of paleoenvironments sampled, and the numerous stratigraphic gaps, six of the depositional units can be recognized throughout the ~15,000 km² study area

on the basis of planktic foraminifera. A cross section (Fig. 1) and a composite stratigraphic column (Fig. 2) show that the upper Paleocene is represented at most sites by biochronozones P4 and P5; the lower Eocene by P6b, P9; and the middle Eocene by P11, P12, and P14. Upper Eocene sediments representing Biochronozones P15, P16, and P17 are restricted to the three downdip sites (Kiptopeke, Exmore, and Hammond well). Zone P15 is particularly thick; a composite section ~126 m thick includes the bolide-generated Exmore breccia and the lower part of the Chickahominy Formation, but seismic evidence from Chesapeake Bay (Powars and others, 1993; Poag and others, 1994) suggests that P15 could be as thick as 1,000–2,000 m.

Oligocene assemblages are less diagnostic than those of other depositional units. Two lower Oligocene units encompass parts of undifferentiated Biochronozones P18–P19/20 and Biochronozones P21a. Equivocal Oligocene sections in a core near Haynesville, Va., and along the Pamunkey River contain either Biochronozones P21a of the lower Oligocene, or N4a of the uppermost Oligocene.

Lower Miocene deposits represent parts of Biochronozones N4b in the Hammond well, and undifferentiated N6–7 at the Hammond and Exmore sites. A middle Miocene unit representing Biochronozones N8 is present at every site; N9 and N10 also are present in the embayment, but have more limited areal extent. Younger Miocene rocks in the study area contain too few planktic foraminifera for biozonation.

Critics of the widely used Exxon sequence stratigraphy model point to a sparsity of biostratigraphic documentation required to recognize and date the sequences and their unconformable boundaries. This lack has produced an unfortunate tendency to use the model as an unyielding global template into which local data are forced. The biostratigraphic framework documented herein provides a sound basis for testing models of sequence stratigraphy, for recognizing the bounding unconformities of alloformations, and for correlating deposits of the Salisbury Embayment with other cored and outcrop sections.

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PLATE 1

Scanning Electron Micrographs

Depths given in ft to match original coring records

1, 2 *Globigerinelloides multispina*, Hammond core, 1,360–1,370 ft. 1 edge view; ×183. 2 lateral view; ×183. 3, 4 *Globigerinelloides subcarinatus*, Hammond core, 1,360–1,370 ft. 3 edge view; ×183. 4 lateral view; ×183. 5, 6 *Archaeoglobigerina cretacea*, Hammond core, 1,360–1,370 ft. 5 edge view; ×156. 6 umbilical view; ×140. 7, 8 *Archaeoglobigerina blowi*, Hammond core, 1,360–1,370 ft. 7 edge view; ×101. 8 umbilical view; ×101. 9, 10 *Rugoglobigerina rugosa*, Hammond core, 1,360–1,370 ft. 9 edge view; ×152. 10 umbilical view; ×152. 11 *Rugoglobigerina subpennyi*, Hammond core, 1,360–1,370 ft. umbilical view; ×160. 12 *Guembelitra cretacea*, Hammond core, 1,360–1,370 ft. apertural view; ×211. 13 *Heterohelix striata*, Hammond core, 1,360–1,370 ft. lateral view; ×183. 14 *Heterohelix glabrans*, Hammond core, 1,360–1,370 ft. lateral view; ×129. 15 *Planoglobulina carseyae*, Hammond core, 1,360–1,370 ft. lateral view; ×117. 16 *Pseudoguembelina excolata*, Hammond core, 1,360–1,370 ft. lateral view; ×137. 17, 18 *Planorotalites pseudomenardii*, Hammond core, 1,350–1,360 ft. 17 edge view; ×121. 18 umbilical view; ×121. 19, 20 *Planorotalites pusilla pusilla*, Hammond core, 1,350–1,360 ft. 19 umbilical view; ×222. 20 edge view; ×222. 21, 22 *Morozovella velascoensis parva*, Hammond core, 1,350–1,360 ft. 21 umbilical view; ×117. 22 edge view showing broken final chamber; ×117. 23, 24 *Morozovella angulata*, Hammond core, 1,350–1,360 ft. 23 umbilical view; ×125. 24 edge view; ×125. 25, 26 *Acarinina apantesma*, Hammond core, 1,350–1,360 ft. 25 edge view; ×140. 26 umbilical view; ×140. 27, 28 *Muricoglobigerina soldadoensis soldadoensis*, Hammond core, 1,350–1,360 ft. 27 umbilical view; ×140. 28 edge view; ×140. 29, 30 *Muricoglobigerina aquiensis*, Hammond core, 1,350–1,360 ft. 29 umbilical view; ×137. 30 edge view; ×137.

PLATE 2

Scanning Electron Micrographs

Depths given in ft to match original coring records

1, 2 *Acarinina subsphaerica*, Hammond core, 1,350–1,360 ft. 1 edge view; ×148. 2 umbilical view; ×148. 3, 4 *Acarinina convexa*, Hammond core, 1,350–1,360 ft. 3 edge view; ×257. 4 umbilical view; ×257. 5, 6 *Acarinina acarinata*, Hammond core, 1,350–1,360 ft. 5 edge view; ×140. 6 umbilical view; ×140. 7, 8 *Subbotina velascoensis*, Hammond core, 1,350–1,360 ft. 7 edge view; ×109. 8 umbilical view; ×109. 9 *Subbotina triangularis*, Hammond core, 1,350–1,360 ft. umbilical view; ×160. 10, 11 *Eoglobigerina trivialis*, Hammond core, 1,350–1,360 ft. 10 edge view; ×183. 11 umbilical view (final chamber broken); ×183. 12, 13 *Morozovella subbotinae subbotinae*, Hammond core, 1,340–1,350 ft. 12 edge view; ×101. 13 umbilical view; ×101. 14, 15 *Morozovella subbotinae gracilis*, Hammond core, 1,340–1,350 ft. 14 edge view; ×105. 15 umbilical view; ×105. 16, 17 *Morozovella aequa*, Hammond core, 1,340–1,350 ft. 16 edge view; ×105. 17 umbilical view; ×105. 18, 19 *Muricoglobigerina soldadoensis angulosa*, Hammond core, 1,340–1,350 ft. 18 edge view; ×117. 19 umbilical view; ×117. 20, 21 *Muricoglobigerina esnehensis*, Hammond core, 1,340–1,350 ft. 20 umbilical view; ×129. 21 edge view; ×117. 22, 23 *Muricoglobigerina aquiensis*, Hammond core, 1,340–1,350 ft. 22 umbilical view; ×148. 23 edge view; ×148. 24, 25 *Acarinina triplex*, Hammond core, 1,340–1,350 ft. 24 edge view; ×125. 25 umbilical view; ×125. 26, 27 *Acarinina broedermanni*, Hammond core, 1,340–1,350 ft. 26 umbilical view; ×156. 27 edge view; ×156. 28, 29 *Acarinina aspensis*, Hammond core, 1,340–1,350 ft. 28 edge view; ×137. 29 umbilical view; ×137.

PLATE 3

Scanning Electron Micrographs

Depths given in ft to match original coring records

1, 2 *Acarinina nicoli*, Hammond core, 1,340–1,350 ft. 1 edge view; ×129. 2 umbilical view; ×129. 3, 4 *Parasubbotina pseudobulloides*, Hammond core, 1,340–1,350 ft. 3 edge view; ×140. 4 umbilical view (final two chambers broken); ×140. 5, 6 *Subbotina hornibrooki*, Hammond core, 1,340–1,350 ft. 5 edge view; ×125. 6 umbilical view; ×125. 7, 8 *Pseudohastigerina wilcoxensis*, Hammond core, 1,340–1,350 ft. 7 lateral view; ×160. 8 edge view (final chamber broken); ×160. 9, 10 *Morozovella aragonensis*, Hammond core, 1,330–1,340 ft. 9 edge view; ×109. 10 umbilical view; ×109. 11, 12 *Muricoglobigerina soldadoensis angulosa*, Hammond core, 1,330–1,340 ft. 11 umbilical view; ×78. 12 edge view; ×78. 13, 14 *Acarinina nitida*, Hammond core, 1,330–1,340 ft. 13 umbilical view; ×121. 14 edge view; ×121. 15, 16 *Acarinina bullbrooki*, Hammond core, 1,330–1,340 ft. 15 umbilical view; ×109. 16 edge view; ×109. 17, 18 *Acarinina aspensis*, Hammond core, 1,330–1,340 ft. 17 edge view; ×125. 18 umbilical view; ×125. 19, 20 *Acarinina cuneicamerata*, Hammond core, 1,330–1,340 ft. 19 umbilical view; ×105. 20 edge view; ×105. 21, 22 *Acarinina broedermanni*, Hammond core, 1,330–1,340 ft. 21 umbilical view; ×168. 22 edge view; ×168. 23, 24 *Acarinina pseudotopilensis*, Hammond core, 1,330–1,340 ft. 23 edge view; ×105. 24 umbilical view; ×105. 25, 26 *Subbotina hornibrooki*, Hammond core, 1,330–1,340 ft. 25 edge view; ×94. 26 umbilical view; ×94. 27, 28 *Globigerina lozanoi*, Hammond core, 1,330–1,340 ft. 27 umbilical view; ×113. 28 edge view; ×113. 29, 30 *Planorotalites planoconica*, Hammond core, 1,330–1,340 ft. 29 umbilical view; ×164. 30 edge view (final chamber broken); ×164.

PLATE 4

Scanning Electron Micrographs

Depths given in ft to match original coring records

1, 2 *Morozovella spinulosa*, Hammond core, 1,320–1,330 ft. 1 edge view; ×90. 2 umbilical view; ×90. 3, 4 *Acarinina cuneicamerata*, Hammond core, 1,320–1,330 ft. 3 umbilical view; ×117. 4 edge view; ×117. 5, 6 *Acarinina bullbrooki*, Hammond core, 1,320–1,330 ft. 5 umbilical view; ×117. 6 edge view; ×117. 7, 8 *Truncorotaloides topilensis*, Hammond core, 1,320–1,330 ft. 7 umbilical view; ×86. 8 edge view; ×86. 9, 10 *Truncorotaloides libyaensis*, Hammond core, 1,320–1,330 ft. 9 umbilical view; ×90. 10 edge view; ×90. 11, 12 *Subbotina pseudoeocaena*, Hammond core, 1,320–1,330 ft. 11 umbilical view; ×78. 12 edge view; ×78. 13 *Turborotalia frontosa*, Hammond core, 1,320–1,330 ft. edge view; ×940. 14 *Turborotalia inconstans*, Hammond core, 1,320–1,330 ft. umbilical view; ×144. 15 *Globigerinoides(?) higginsii*, Hammond core, 1,320–1,330 ft. lateral view; ×98. 16, 17 *Globigerinoides(?) higginsii*, Hammond core, 1,310–1,320 ft. 16 edge view; ×109. 17 umbilical view; ×109. 18, 19 *Globigerinatheka subconglobata*, Hammond core, 1,320–1,330 ft. 18 lateral view; ×90. 19 lateral view; ×90. 20, 21 *Turborotalia possagnoensis*, Hammond core, 1,310–1,320 ft. 20 edge view; ×113. 21 umbilical view; ×113. 22, 23 “*Hastigerina*” *bolivariana*, Hammond core, 1,310–1,320 ft. 22 umbilical view; ×133. 23 edge view; ×133. 24, 25 *Turborotalia wilsoni*, Hammond core, 1,310–1,320 ft. 24 edge view; ×156. 25 umbilical view; ×156. 26, 27 *Hantkenina alabamensis*, Hammond core, 1,300–1,310 ft. 26 oblique edge view; ×82. 27 lateral view; ×82. 28, 29 *Morozovella lehneri*, Hammond core, 1,300–1,310 ft. 28 umbilical view; ×86. 29 oblique edge view; ×86.

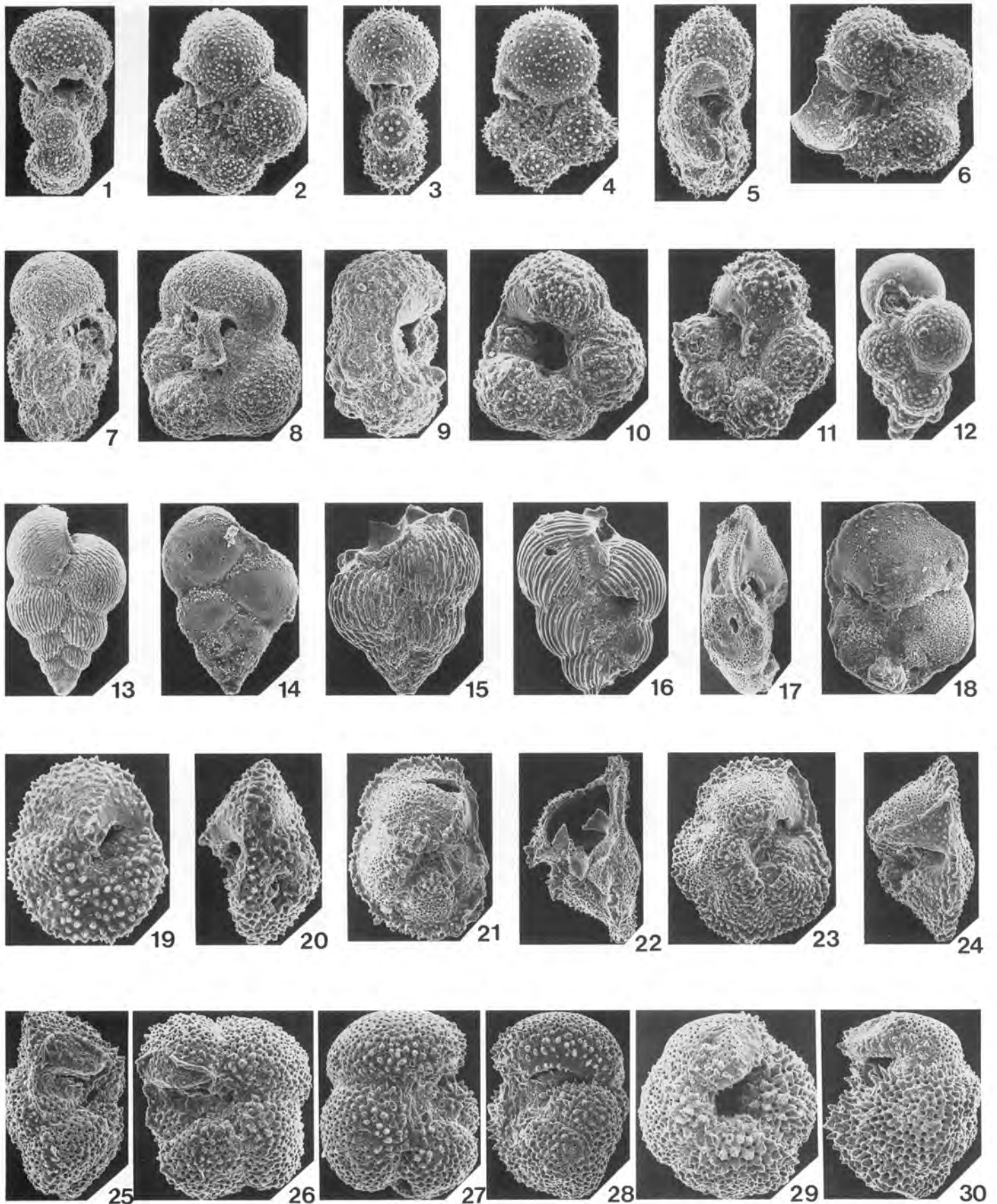


PLATE 1

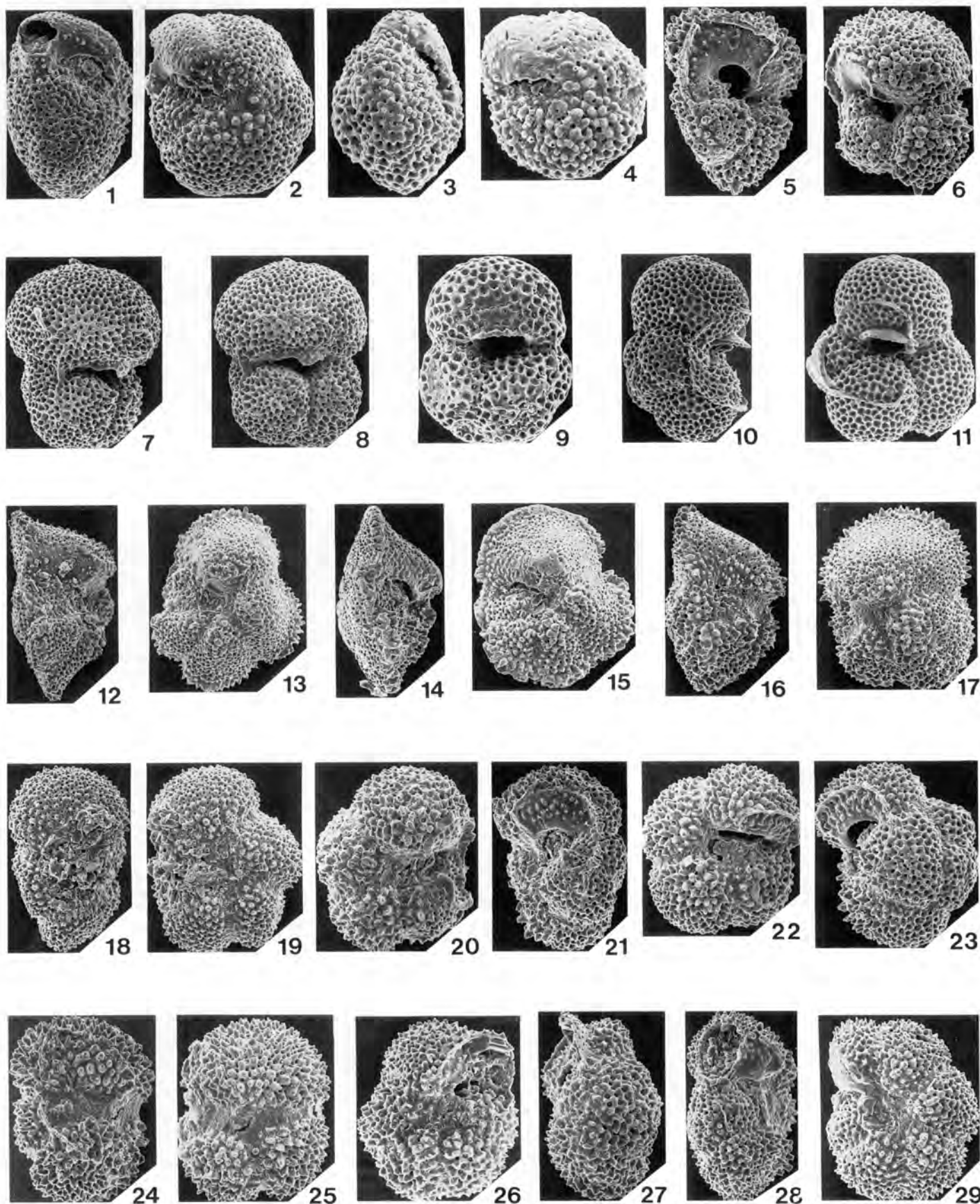


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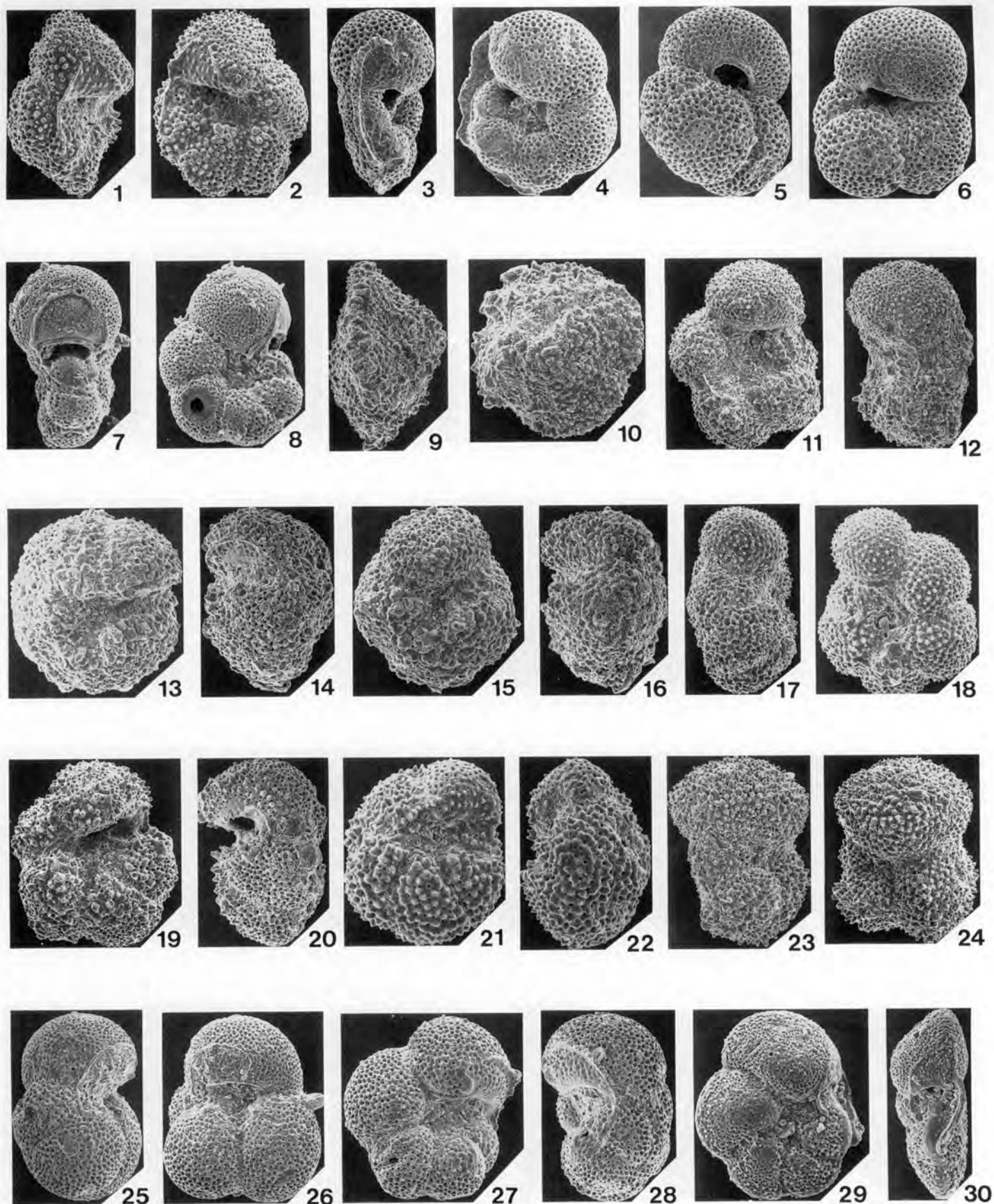


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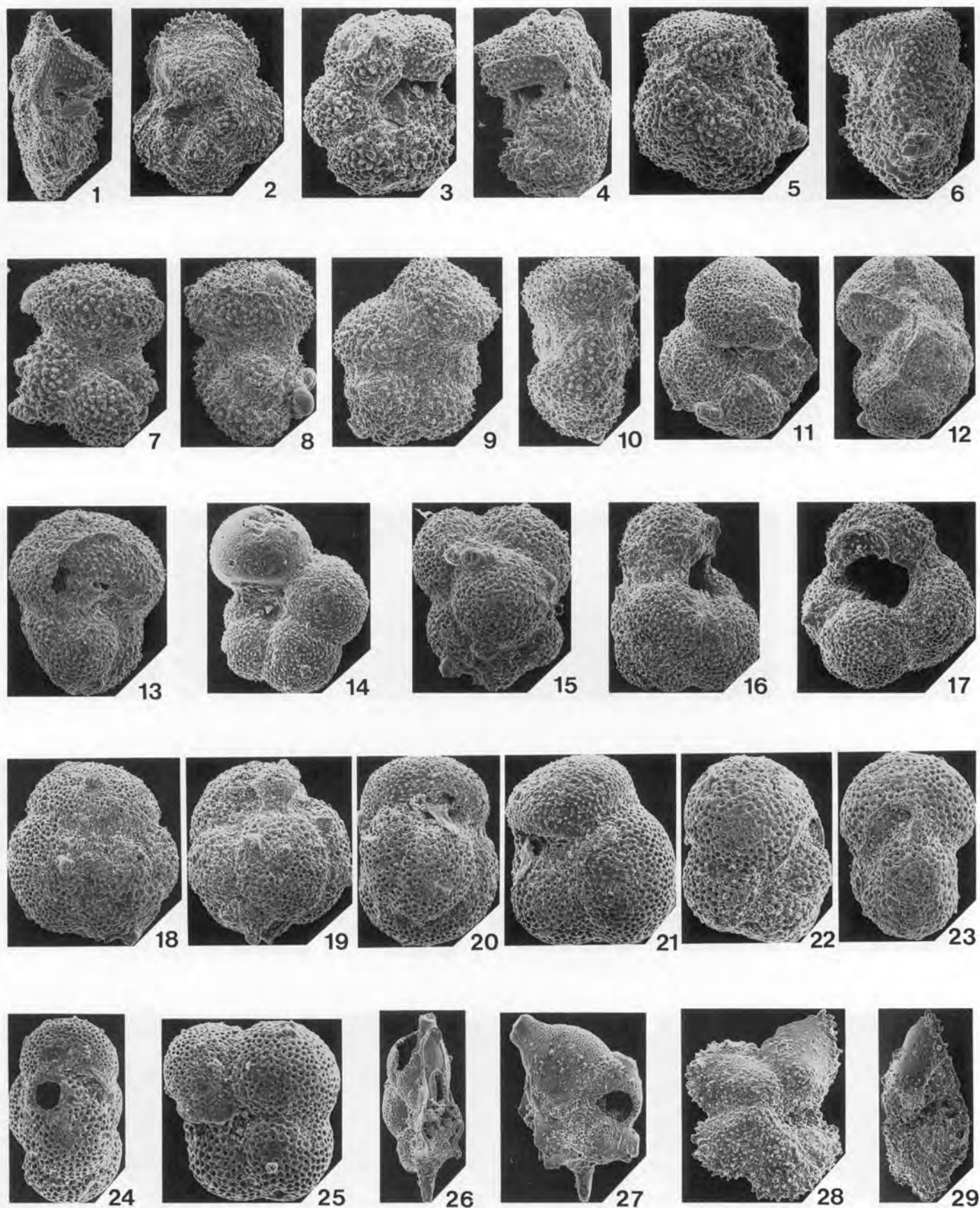


PLATE 4



PLATE 5

Scanning Electron Micrographs

Depths given in ft to match original coring records

1, 2 *Acarinina broedermanni*, Hammond core, 1,300–1,310 ft. 1 umbilical view (final chamber broken); ×129. 2 edge view; ×129. **3** *Turborotalia frontosa*, Hammond core, 1,300–1,310 ft; oblique view; ×109. **4, 5** *Globigerina hagni*, Hammond core, 1,300–1,310 ft. 4 umbilical view; ×90. 5 edge view; ×90. **6, 7** *Globigerina cryptomphala*, Hammond core, 1,300–1,310 ft. 6 oblique edge view; ×94. 7 oblique umbilical view; ×94. **8, 9** *Acarinina primitiva*, Hammond core, 1,300–1,310 ft. 8 edge view; ×105. 9 umbilical view; ×105. **10, 11** *Muricoglobigerina senni*, Hammond core, 1,300–1,310 ft. 10 umbilical view; ×109. 11 lateral view; ×109. **12, 13** *Globigerina lozanoi*, Hammond core, 1,300–1,310 ft. 12 umbilical view; ×55. 13 edge view; ×55. **14** *Globigerinathea semiinvoluta*, Exmore core, 1,264.5 ft., lateral view; ×82. **15** *Cribrohantkenina inflata*, Kiptopeke core, 1,130.3 ft. apertural view; ×47. **16, 17** *Turborotalia pomeroli*, Hammond core, 1,290–1,300 ft. 16 edge view; ×86. 17 umbilical view; ×86. **18, 19** *Globigerina gortanii*, Hammond core, 1,290–1,300 ft. 18 oblique umbilical view; ×70. 19 oblique edge view; ×70. **20** *Catapsydrax unicavus*, Kiptopeke core, 1,203 ft; umbilical view; ×168. **21** *Dentoglobigerina tripartita*, Kiptopeke core, 1,203 ft; umbilical view; ×86. **22** *Globigerina tapuriensis*, Kiptopeke core, 1,173 ft; umbilical view; ×90. **23** *Globigerina tapuriensis*, Kiptopeke core, 1,203 ft; umbilical view; ×78. **24** *Globigerina sellii*, Kiptopeke core, 1,173 ft; umbilical view; ×94. **25** *Guembelitra columbiana*, Exmore core, 1,203 ft; lateral view; ×304. **26** *Hantkenina alabamensis*, Exmore core, 1,159 ft; lateral view; ×39. **27** *Globigerinathea index index*, Exmore core, 1,159 ft; lateral view; ×101.

PLATE 6

Scanning Electron Micrographs

Depths given in ft to match original coring records

1 *Globigerinathea index tropicalis*, Exmore core, 1,159 ft; lateral view; ×82. **2, 3** *Turborotalia pomeroli*, Exmore core, 1,203 ft. 2 umbilical view; ×86. 3 edge view; ×86. **4** *Dentoglobigerina pseudovenezuelana*, Exmore core, 1,203 ft; umbilical view; ×62. **5** *Globigerina venezuelana*, Exmore core, 1,203 ft; umbilical view; ×70. **6, 7** *Globigerina venezuelana*, Hammond core, 1,240–1,250 ft. 6 edge view; ×129. 7 umbilical view; ×129. **8** *Dentoglobigerina galavisi*, Exmore core, 1,203 ft; umbilical view; ×70. **9–11** *Cassigerinella winniana*, Exmore core; 9 1,203 ft; lateral view; ×254. 10, 593 ft (reworked specimen); lateral view showing aperture; ×242. 11 (same specimen as 10); edge view showing frilled apertural lip; ×242. **12** *Catapsydrax unicavus*, Exmore core, 1,203 ft; umbilical view; ×109. **13** *Laterostomella cubensis*, Exmore core, 1,203 ft; lateral view showing proliferation of final chambers; ×172. **14** *Subbotina angiporoides*, Exmore core, 1,203 ft; oblique umbilical view; ×121. **15, 16** *Turborotalia ampliapertura*, Hammond core, 1,240–1,250 ft. 15 edge view; ×101. 16 umbilical view; ×101. **17, 18** *Globigerina officinalis*, Hammond core, 1,240–1,250 ft. 17 edge view; ×105. 18 umbilical view; ×105. **19** *Globigerina eoacena*, Kiptopeke core, 1,146 ft; umbilical view; ×78. **20** *Globigerina euapertura*, Kiptopeke core, 1,173 ft; umbilical view; ×86. **21, 22** *Jenkinsella opima nana*, Hammond core, 1,240–1,250 ft. 21 umbilical view; ×152. 22 edge view; ×152. **23** *Turborotalia cocoensis*, Exmore core, 1,117 ft; edge view; ×70. **24** *Chiloguembelina martini*, Exmore core, 1,117 ft; lateral view; ×90. **25, 26** *Testacarinata inconspicua*, Exmore core, 1,203 ft; umbilical views; 25 ×240; 26 ×316. **27, 28** *Testacarinata aculeata*, Exmore core, 1,203 ft. 27 edge view; ×215. 28 umbilical view; ×215.

PLATE 7

Scanning Electron Micrographs

Depths given in ft to match original coring records

1, 2 *Turborotalia cerroazulensis*, Hammond core, 1,220–1,230 ft. 1 umbilical view; ×109. 2 edge view; ×109. **3** *Jenkinsella mayeri*, Exmore core, 1,104 ft; umbilical view; ×154. **4, 5** *Globigerina woodi connecta*, Hammond core, 1,220–1,230 ft. 4 oblique edge view; ×148. 5 umbilical view; ×148. **6, 7** *Globigerina anguliofficialis*, Hammond core, 1,210–1,220 ft. 6 umbilical view; ×207. 7 edge view; ×207. **8, 9** *Globigerina officinalis*, Hammond core, 1,210–1,220 ft. 8 edge view; ×183. 9 umbilical view; ×183. **10, 11** *Globigerina praebulloidis leroyi*, Hammond core, 1,210–1,220 ft. 10 edge view; ×140. 11 umbilical view; ×140. **12, 13** *Globigerina ouachitaensis*, Hammond core, 1,210–1,220 ft. 12 edge view; ×176. 13 umbilical view; ×176. **14, 15** *Pseudohastigerina danvillensis*, Hammond core, 1,210–1,220 ft. 14 edge view; ×183. 15 lateral view; ×183. **16, 17** *Pseudohastigerina nagewichiensis*, Hammond core, 1,210–1,220 ft. 16 edge view; ×230. 17 lateral view; ×230. **18, 19** *Globorotaloides suteri*, Hammond core, 1,210–1,220 ft. 18 umbilical view; ×160. 19 edge view; ×160. **20, 21** *Jenkinsella opima nana*, Hammond core, 1,150–1,160 ft. 20 edge view; ×172. 21 umbilical view; ×172. **22** *Jenkinsella opima opima*, Exmore core, 1,068 ft; umbilical view; ×121. **23, 24** *Jenkinsella semivera*, Hammond core, 1,150–1,160 ft. 23 edge view; ×125. 24 umbilical view; ×125. **25, 26** *Neoglobobulimina continua*, Hammond core, 1,150–1,160 ft. 25 umbilical view; ×121. 26 edge view; ×121. **27, 28** *Globigerina angulissuturalis*, Hammond core, 1,150–1,160 ft. 27 edge view; ×140. 28 umbilical view; ×140.

PLATE 8

Scanning Electron Micrographs

Depths given in ft to match original coring records

1, 2 *Globigerina labiacrassata*, Hammond core, 1,150–1,160 ft. 1 edge view; ×113. 2 umbilical view; ×113. **3, 4** *Globigerina eoacena*, Hammond core, 1,150–1,160 ft. 3 edge view; ×105. 4 umbilical view; ×105. **5, 6** *Globoconella zealandica*, Exmore core, 1,054 ft. 5 edge view; ×152. 6 umbilical view; ×152. **7, 8** *Laterostomella cubensis*, Hammond core, 1,150–1,160 ft. 7 edge view; ×164. 8 lateral view; ×164. **9** *Fohsella peripheroronda*, Exmore core, 1,054 ft; umbilical view; ×148. **10** *Jenkinsella siakensis*, Exmore core, 1,022 ft; umbilical view; ×105. **11** *Fohsella birnageae*, Exmore core, 1,022 ft; umbilical view; ×156. **12** *Jenkinsella acrostoma*, Exmore core, 1,022 ft; umbilical view; ×152. **13** *Globoconella praescitula*, Exmore core, 1,014 ft; umbilical view; ×121. **14** *Dentoglobigerina altispira altispira*, Exmore core, 1,014 ft; oblique lateral view; ×117. **15** *Jenkinsella siakensis*, Exmore core, 1,014 ft; umbilical view; ×121. **16–18** *Globoquadrina dehiscens*, Exmore core, 1,014 ft. 16 umbilical view; ×129. 17 umbilical view; ×94. 18 edge view; ×94. **19** *Sphaeroidinellopsis disjuncta*, Exmore core, 1,014 ft; lateral view; ×94. **20** *Globoquadrina baroemenensis*, Kiptopeke core, 1,054 ft; umbilical view; ×74. **21** *Globigerinatella insueta*, Exmore core, 1,014 ft; lateral view; ×109. **22** *Globigerinoides sicanus*, Exmore core, 1,014 ft; lateral view; ×78. **23** *Globigerinoides trilobus*, Exmore core, 1,014 ft; lateral view; ×94. **24** *Menardella praemenardii*, Exmore core, 1,014 ft; umbilical view; ×105. **25, 26** *Praeorbulina circularis*, Exmore core, 905 ft. 25 basal view; ×90. 26 oblique basal view; ×620. **27** *Globigerina druryi*, Exmore core, 636 ft; umbilical view; ×121.

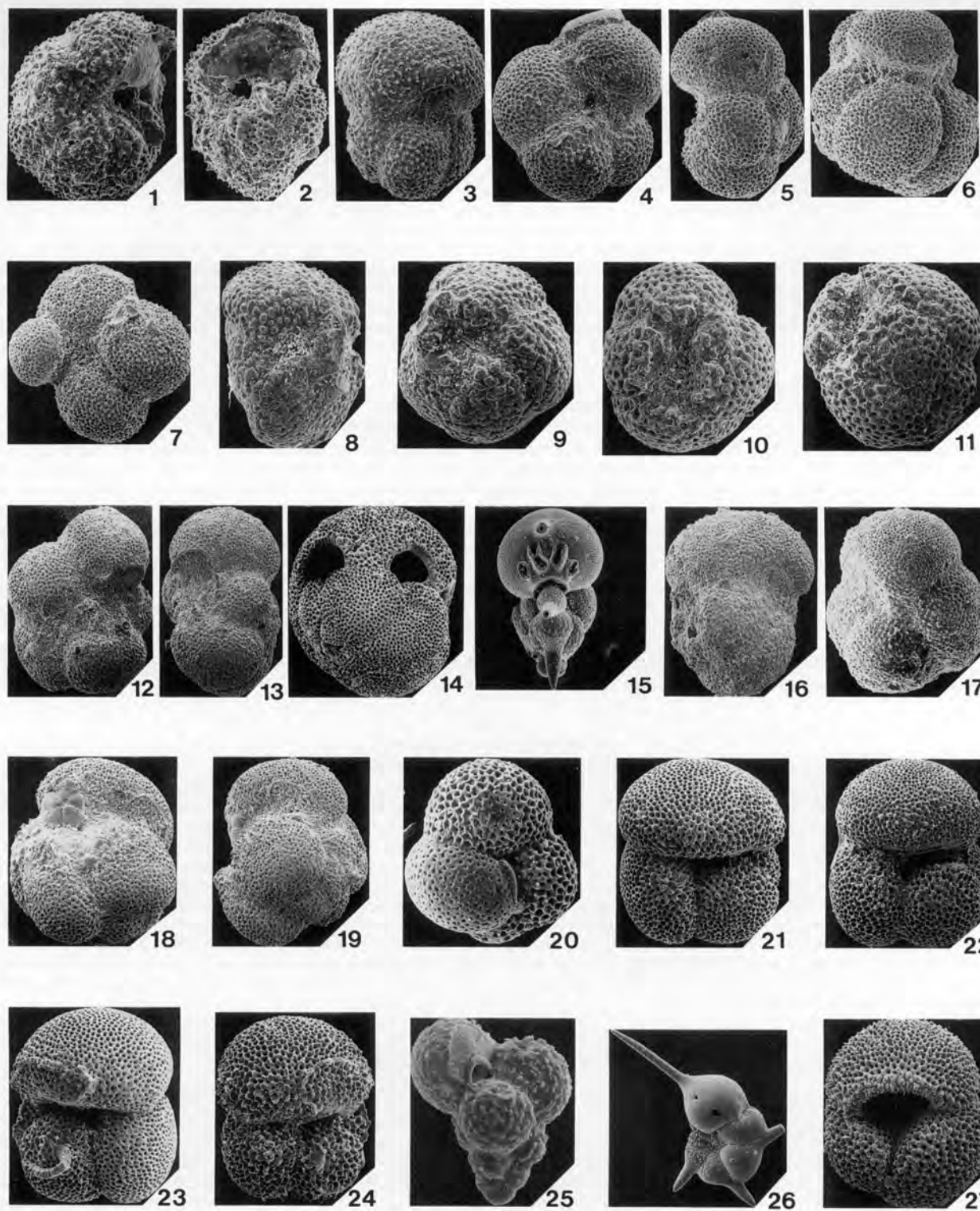


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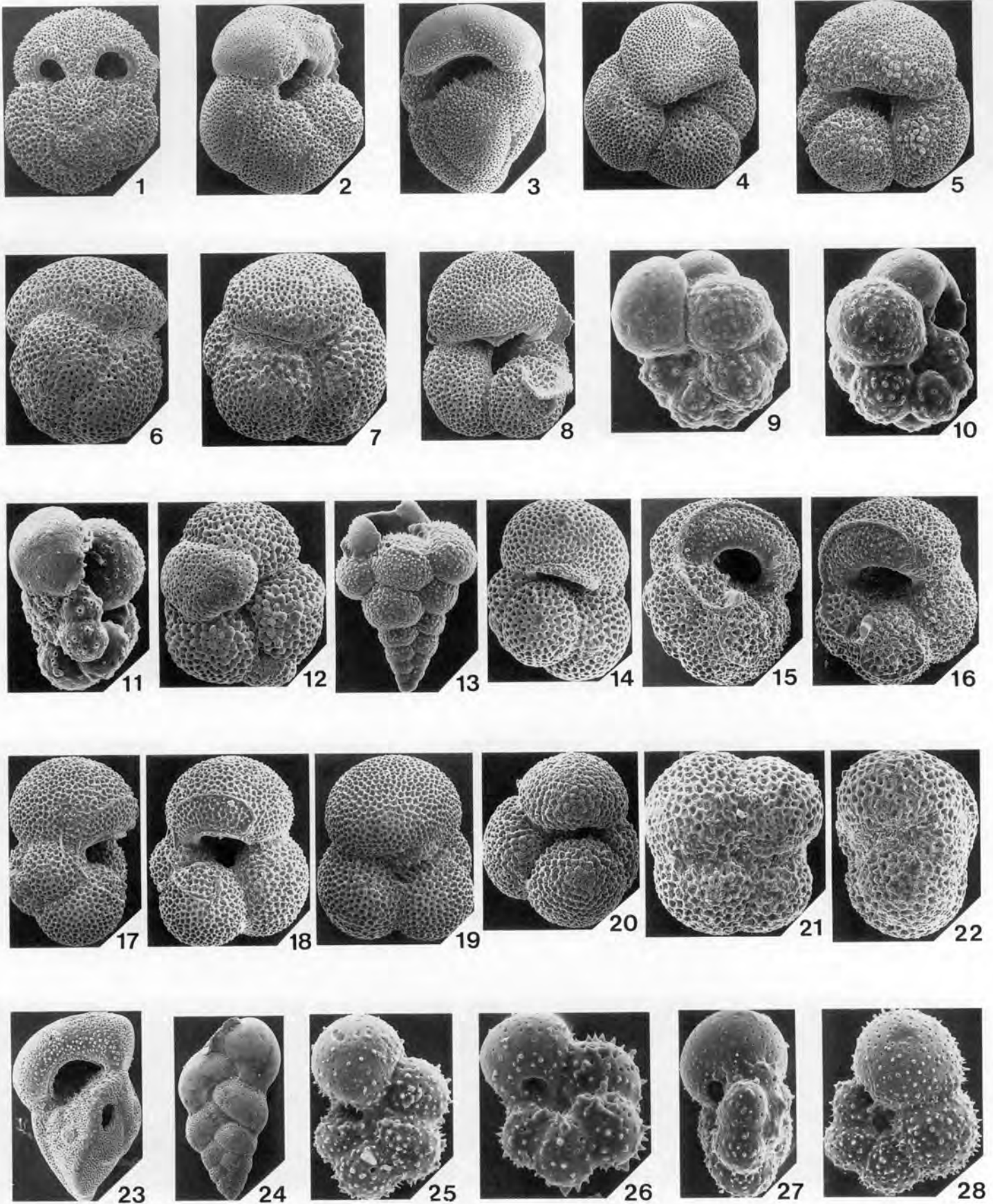


PLATE 6

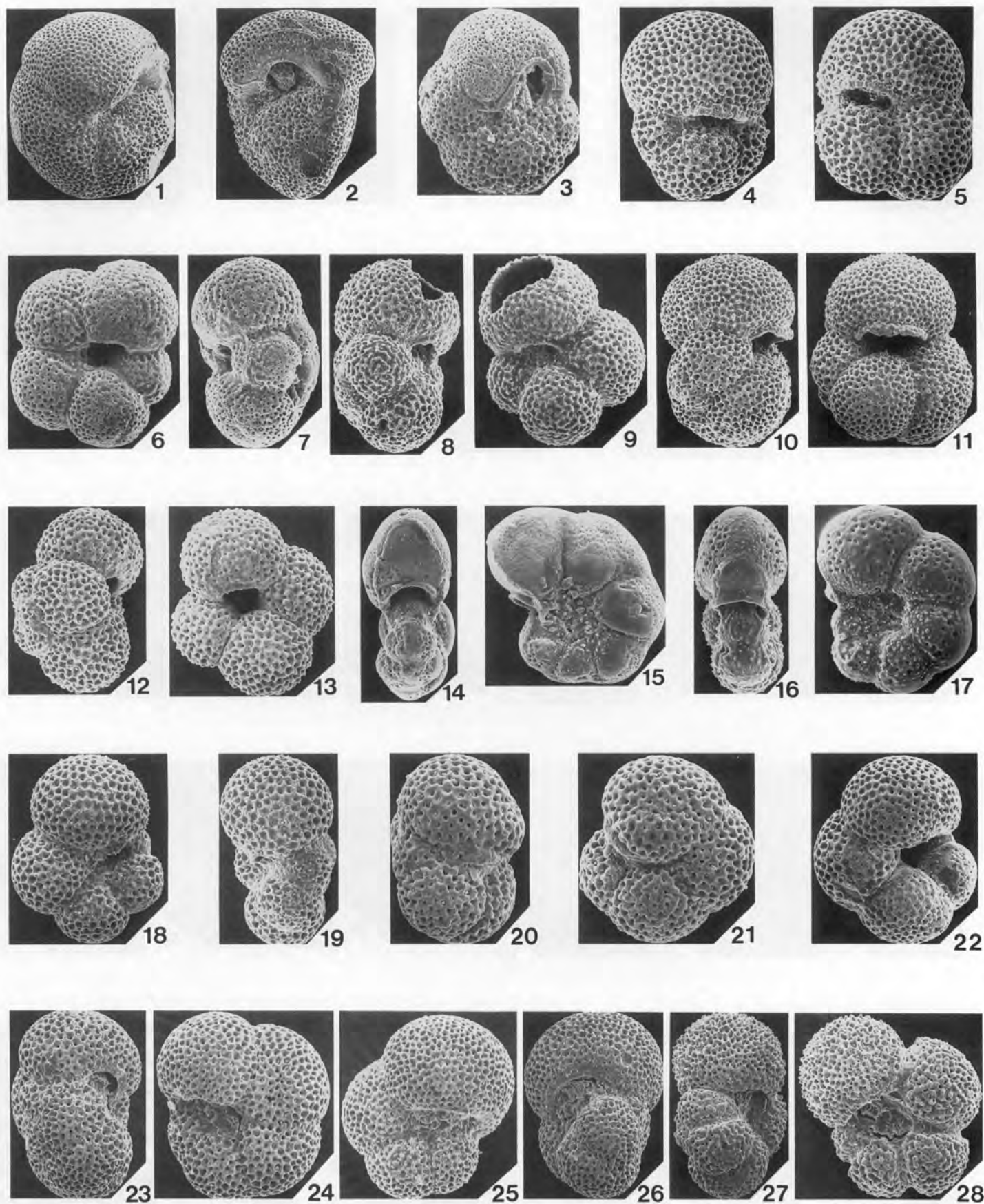


PLATE 7

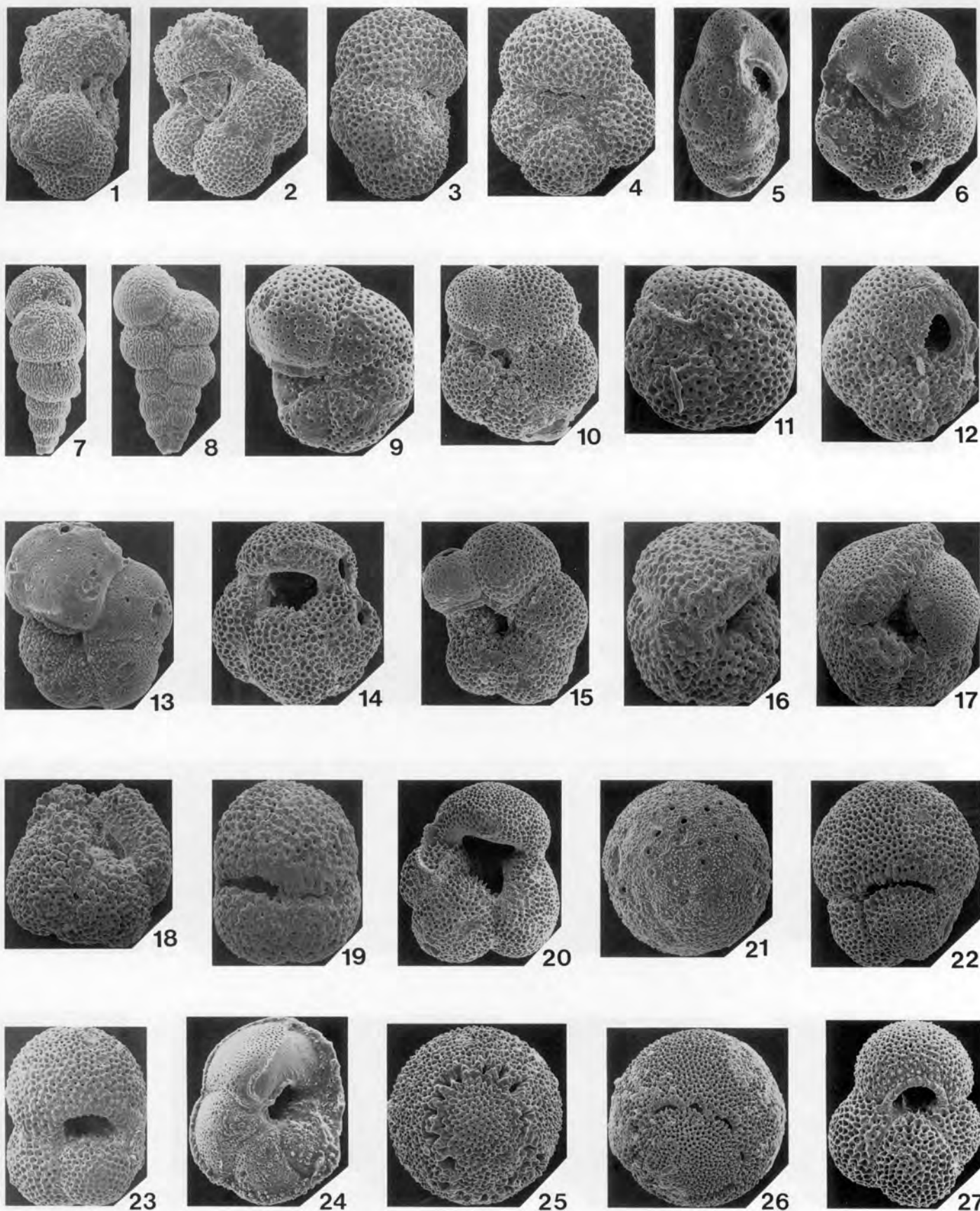


PLATE 8

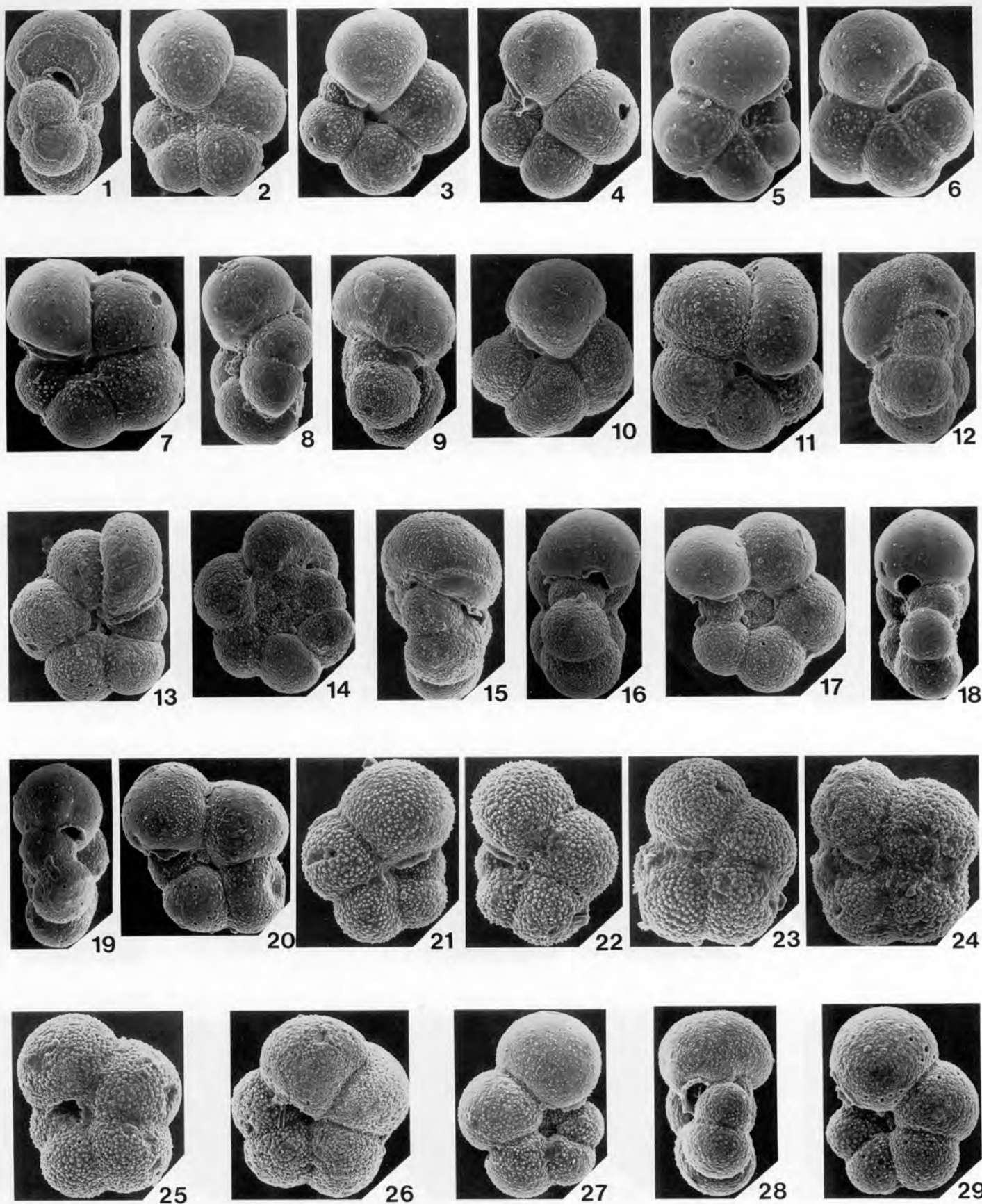


PLATE 9

PLATE 9

Scanning Electron Micrographs

Depths given in ft to match original coring records

1–8 *Praetenuitella praegemma* Li, 1987, forma *typica*. 1, 2 Hammond core, 1,240–1,250 ft; $\times 179$. 1 edge view. 2 umbilical view. 3, 4 Exmore core, 1,150 ft, umbilical views. 3 $\times 195$. 4 $\times 156$. 5–7 Exmore core, 1,159 ft, umbilical views. 5 $\times 254$. 6 $\times 218$. 7 $\times 205$. 8 Exmore core, 1,117 ft; edge view, umbilicus partly filled; $\times 148$. **9–10** *Praetenuitella praegemma* Li, 1987, specimens transitional between forma *typica* and forma *pendulocamerata*, Exmore core. 9 edge view showing pendulous, asymmetrical final chamber; aperture does not cross periphery; 1,150 ft; $\times 183$. 10 umbilical view of same specimen showing pendulous final chamber overlapping umbilicus, 1,117 ft; $\times 176$. **11–15** *Praetenuitella praegemma* Li, 1987, forma *pendulocamerata*, Exmore core, 1,117 ft. 11 umbilical view showing narrow, pendulous final chamber (diagnostic character) partly covering umbilicus; $\times 176$. 12 edge view of same specimen showing pendulous, asymmetrical, final chamber and low aperture crossing periphery (diagnostic character); $\times 176$. 13 umbilical view showing narrow, pendulous, final chamber partly covering umbilicus; $\times 150$. 14 spiral view showing evolute coil; $\times 156$. 15 edge view of same specimen showing pendulous, asymmetrical, final chamber and low aperture crossing periphery; $\times 164$. **16, 17** *Praetenuitella impariapertura* Li, 1987, Exmore core, 1,117 ft. 16 edge view showing aperture extending up face of symmetrical final chamber; $\times 152$. 17 umbilical view of same specimen showing open umbilicus and globose chambers; $\times 150$. **18–20** *Praetenuitella patefacta* Li, 1987, Exmore core, 1,159 ft. 18 edge view showing highly arched aperture on umbilical side of nearly symmetrical final chamber; $\times 176$. 19 edge view showing highly arched aperture on umbilical side of nearly symmetrical final chamber; $\times 133$. 20 umbilical view of same specimen; $\times 144$. **21–25** *Tenuitella gemma*, Exmore core. 21, 22 umbilical views; 1,068 ft. 21 $\times 226$. 22 $\times 250$. 23–25 umbilical views; 1,028 ft. 23 $\times 289$. 24 $\times 257$. 25 $\times 234$. **26** *Tenuitellinata* cf. *T. pseudoedita*, Exmore core, 1,022 ft, umbilical view; $\times 218$. **27–29** *Tenuitella neobrevispira* Li, 1987, Exmore core, 1,014 ft. 27 umbilical view; $\times 176$. 28 edge view; $\times 226$. 29 umbilical view; $\times 250$.