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Foraminiferal biostratigraphy of Late Oligocene-Miocene reefal carbonates in southwestern Puerto Rico

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Abstract

Recently exposed Oligocene-Miocene (O-M) strata in Santa Elena, Guyanilla and the section at Playa de Jaboncilla, southwestern Puerto Rico show variations in lithology and in the occurence and relative abundance of planktonic and benthic foraminifers. The planktonic foraminifers are interspersed in the relatively deeper, open marine shelf segments, wheras the intervening shallower segments are characterized by an abundance of benthic foraminifers. Although shallow marine, smaller benthic foraminifers are generally of limited use for biostratigraphy, they are used in conjunction with planktonic taxa to develop a high-resolution biostratigraphy for the Oligocene-Miocene reefel carbonates of southwestern Puerto Rico.

Upper Oligocene mudstone and packstone and overlying Miocene argillaceous limestone and chalk yielded a diverse foraminiferal fauna comprising both planktonic (*Catapsydrax, Chiloguembelina, Dentoglobigerina, Globigerina, Globigerinoides*) and benthic (*Anomalinoides, Arcaias, Cancris, Elphidum, Eorupertia, Hanzawaia, Heterostegina, Lepidocyclina, Miogypsina, Miosorites, Neorotalia, Rosalina, Siphonina, Stilostomella* and *Yaucorotalia*) taxa. This assemblage indicates a late Oligocene-Miocene (P21 - M14 Zone)age for the Santa Elena and Playa de Jaboncilla sections, with a break in sedimentation at the top of the upper Oligocene. Significant shallowing occurred between the upper Oligocene and Miocene resulting in a hiatus, comparing well with the global seal-level regression at that time. This hiatus lasted for 3.3 million years as shown by the absence of planktonic foram Zone P22 (27.1 Ma - 23.8 Ma).

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ABSTRACT: Recently exposed Oligocene-Miocene (O-M) strata in Santa Elena, Guyanilla and the section at Playa de Jaboncilla, southwestern Puerto Rico show variations in lithology and in the occurrence and relative abundance of planktonic and benthic foraminifers. The planktonic foraminifers are interspersed in the relatively deeper, open marine shelf segments, whereas the intervening shallower segments are characterized by an abundance of benthic foraminifers. Although shallow marine, smaller benthic foraminifers are generally of limited use for biostratigraphy, they are used in conjunction with planktonic taxa to develop a high-resolution biostratigraphy for the Oligocene-Miocene reefal carbonates of southwestern Puerto Rico.

Upper Oligocene mudstone and packstone and overlying Miocene argillaceous limestone and chalk yielded a diverse foraminiferal fauna comprising both planktonic (*Catapsydrax, Chiloguembelina, Dentoglobigerina, Globigerina, Globigerinoides*) and benthic (*Anomalinoides, Archaias, Cancris, Elphidium, Eorupertia, Hanzawaia, Heterostegina, Lepidocyclina, Miogypsina, Miosorites, Neorotalia, Rosalina, Siphonina, Stilostomella* and *Yaucorotalia*) taxa. This assemblage indicates a late Oligocene-Miocene (P21 -M14 Zone) age for the Santa Elena and Playa de Jaboncilla sections, with a break in sedimentation at the top of the upper Oligocene. Significant shallowing occurred between the upper Oligocene and Miocene resulting in a hiatus, comparing well with the global sea-level regression at that time. This hiatus lasted for 3.3 million years as shown by the absence of planktonic foram Zone P22 (27.1 Ma - 23.8 Ma).

INTRODUCTION

Benthic foraminifers prosper in shallow-marine conditions and are commonly used in paleoenvironmental interpretation (for example, Hallock and Glenn 1986; Sen Gupta and Machain-Castillo 1993) as well as biostratigraphy (Robinson 1996). Although shallow marine benthic foraminifers are generally of limited use in high-resolution biostratigraphy owing to their restricted habitat and typically long stratigraphic range, they can be used in conjunction with planktonic foraminiferal assemblages from deeper, open shelf intervals within the same stratigraphic section to refine the biostratigraphy.

The integration of magnetostratigraphy and planktonic foraminiferal biostratigraphy has led to the development of a highly improved Tertiary geologic time scale (see Berggren et al. 1995; for detailed discussion). Larger foraminifera have also been used (e.g. Adams 1970) to improve Tertiary biochronology, e.g., 'Letter Classification' developed by Van der Vlerk (1955, 1959). Larger foraminiferal zonation of American Oligocene carbonates developed by Cole has been used with repeated success for stratigraphical analysis (see Bryan and Huddlestun 1991 for discussion). Nevertheless, difficulties that remain include the lack of sufficiently studied continuous sections, the geographic restriction of some species, and lack of calibration with standard planktonic foraminiferal zones. Improved magnetobiostratigraphic scale (Berggren et al. 1995), in conjunction with recent availability of continuously exposed sections amenable to close sampling at Santa Elena and Playa de Jaboncilla has encouraged us to develop an integrated biostratigraphy for the upper Oligocene – Miocene (O-M) strata using both benthic and planktonic foraminifera.

Although literature on the middle Tertiary stratigraphy of southwestern Puerto Rico is abundant (Seiglie and Bermudez 1969; Moussa and Seiglie 1970; Seiglie 1973; Seiglie and Moussa 1976; Kruchensky and Monroe 1975, 1978, 1979; Monroe 1980; Frost et al. 1983), detailed foraminiferal biostratigraphic studies have been limited in scope. Samples collected at close intervals from the recently exposed Santa Elena section and from the seacliff outcrops of Playa de Jaboncilla, in southwestern Puerto Rico (text-fig. 1), have yielded hundreds of planktonic and benthic foraminifers of late Oligocene and Miocene age. The continuous nature of the stratigraphic sections permit development of a detailed foraminiferal biostratigraphic framework. In this paper, we present late Oligocene-Miocene (O-M) foraminiferal biostratigraphy based on ranges and assemblages of larger and smaller benthic foraminifers and on the presence and distribution of planktonic foraminifers. Furthermore, correlating with the standard planktonic foraminiferal scale of Berggren et al. (1995) has resulted in refined stratigraphic ranges for benthic foraminifers.

Previous Stratigraphic Work

O-M stratigraphic subdivision of southwestern Puerto Rico has been proposed by Moussa and Seiglie (1970), Seiglie and Bermúdez (1969), Seiglie and Moussa (1976), Monroe (1980), and Frost et al. (1983). O-M rocks in southwestern Puerto Rico are divided into three main sequences: (a) a lower transgressive-regressive cycle of late Oligocene age comprising basal clastics and deeper shelf/reef tract sediments; (b) a middle sequence of hemipelagic deep shelfal/slope marls and chalks of early Miocene age; and (c) an upper, thick carbonate shelfal sequence of middle and late Miocene age (Moussa and Seiglie
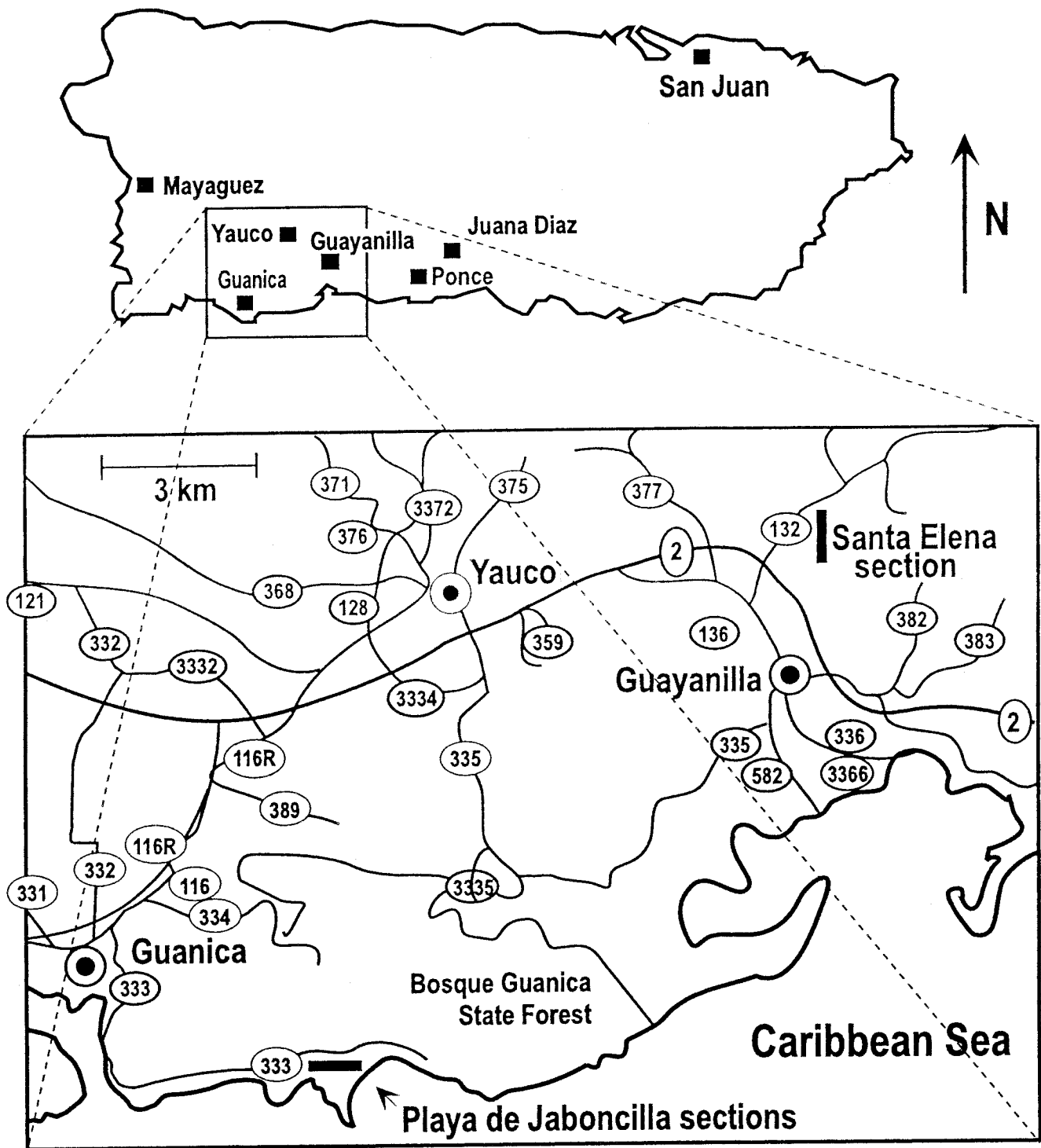
TEXT-FIGURE 1
Location map for studied sections in southwestern Puerto Rico.

1975). The first two sequences are included in the Juana Diaz Formation and the overlying middle- and upper Miocene carbonate sequence in the Ponce Formation (Moussa and Seiglie 1970; Seiglie 1973; Kruchensky and Monroe 1975, 1978, 1979; Monroe 1980). Frost et al. (1983) divided the Juana Diaz For-

mation into two unnamed formations: the first to include the upper Oligocene deep shelf/forereef pelagic carbonates and reef tract sediments; and the second to include lower Miocene shelfal/slope marls and chalk (the "Angola limestone" of Seiglie and Bermúdez 1969), which unconformably overlie the

Oligocene reef facies and are in turn overlain by the Ponce Formation.

Stratigraphic and paleontologic studies by Moussa and Seiglie (1970), Seiglie and Bermúdez (1969), Seiglie (1973), Monroe (1980) and Frost et al. (1983) form the basis for stratigraphic correlation of the middle Tertiary rocks of southern Puerto Rico. Moussa and Seiglie (1970) observed five planktonic zones based on reconnaissance stratigraphy and micropaleontologic study of the entire middle Tertiary belt between Juana Díaz in the east and Guánica in the west (text-fig. 1). The planktonic foraminiferal zones recognized by them, from oldest to youngest, are *Globigerina ampliapertura* Zone, *Globorotalia opima opima-Globigerina ciperoensis ciperoensis* Zone, *Globigerina ciperoensis ciperoensis* Zone, *Globigerina kugleri* Zone and *Globigerinatella insueta-Globigerinoides sicanus* Zone.

Edinger and Risk (1994) studied Oligocene coral reef-tract development in southwestern Puerto Rico, noting general lithologies similar to those described by Frost et al. (1983). Upper Oligocene calcareous mudstone and packstone are separated from overlying chalk by a hiatus, represented in the Santa Elena section by a tan to reddish-brown mudstone that is directly overlain by cream-colored chalk (text-fig. 2). The overlying foraminifera-rich, white to cream colored argillaceous limestone and chalk contains gastropod, coral and skeletal debris with little influx of terrigenous clastic sediments.

At the sea cliff exposure of Playa de Jaboncilla, resistant, wedge-shaped to lensiform beds of argillaceous limestone alternate with thin beds of friable calcareous mudstone (text-fig. 3). Differential weathering imparts a sharply defined ledge and notch character to the seacliff face. The late Oligocene hemipelagic mudstone sequence and the overlying early Miocene chalk exposed at Santa Elena are not present at Playa de Jaboncilla. Instead, upper Oligocene shallow marine argillaceous and calcareous limestones of the Juana Diaz Formation are overlain by middle Miocene beach and carbonate shoal facies of the Ponce Formation (Frost et al. 1983).

Analytical Methods

Three sections were studied: the recently exposed Santa Elena section, 3 km northeast of Route 132, behind the Santa Elena Housing Development in Guayanilla; and two sections at the sea cliff outcrops at Playa de Jaboncilla on Route 333 along the coast inside Bosque Guanica State Forest. Fifty-seven rock samples were collected, at an average interval of 50 to 100cm, for foraminiferal content and biostratigraphic study. Crushed rock samples were washed under running water to separate the >35µm and <150µm fractions. Individual foraminiferal tests were studied under Wild M3C polarizing stereomicroscope (Planapo 1.0x). Thin sections were studied under camera-equipped Olympus research microscope (PROVIS AX70). Mounted individual foraminifera specimens were coated with carbon and observed under a JOEL JSM 6400 scanning electron microscope (SEM).

Species of benthic and planktonic foraminifera recorded from the studied sections in southwest Puerto Rico are known from earlier works on the Caribbean Paleogene. Therefore, extensive synonymies are not given. For the identification of benthic foraminiferal genera and species, the work of Frost and Langenheim (1974), Loeblich and Tappan (1988), and Bolli, Beckmann and Saunders (1994) were consulted. Papers by Cole

(1967), Seiglie and Bermudez (1969), Seiglie (1972), Seiglie et al. (1976), Todd and Low (1976), Monroe (1980), Frost et al. (1983), Katz and Miller (1993) and Robinson and Wright (1993) were also consulted for identification of species characteristic of the Caribbean region. For the planktonic foraminifera, papers by Kennett and Srinivasan (1983), Bolli and Saunders (1985), Spezzaferri and Premoli Silva (1991) and Berggren (1993) were consulted.
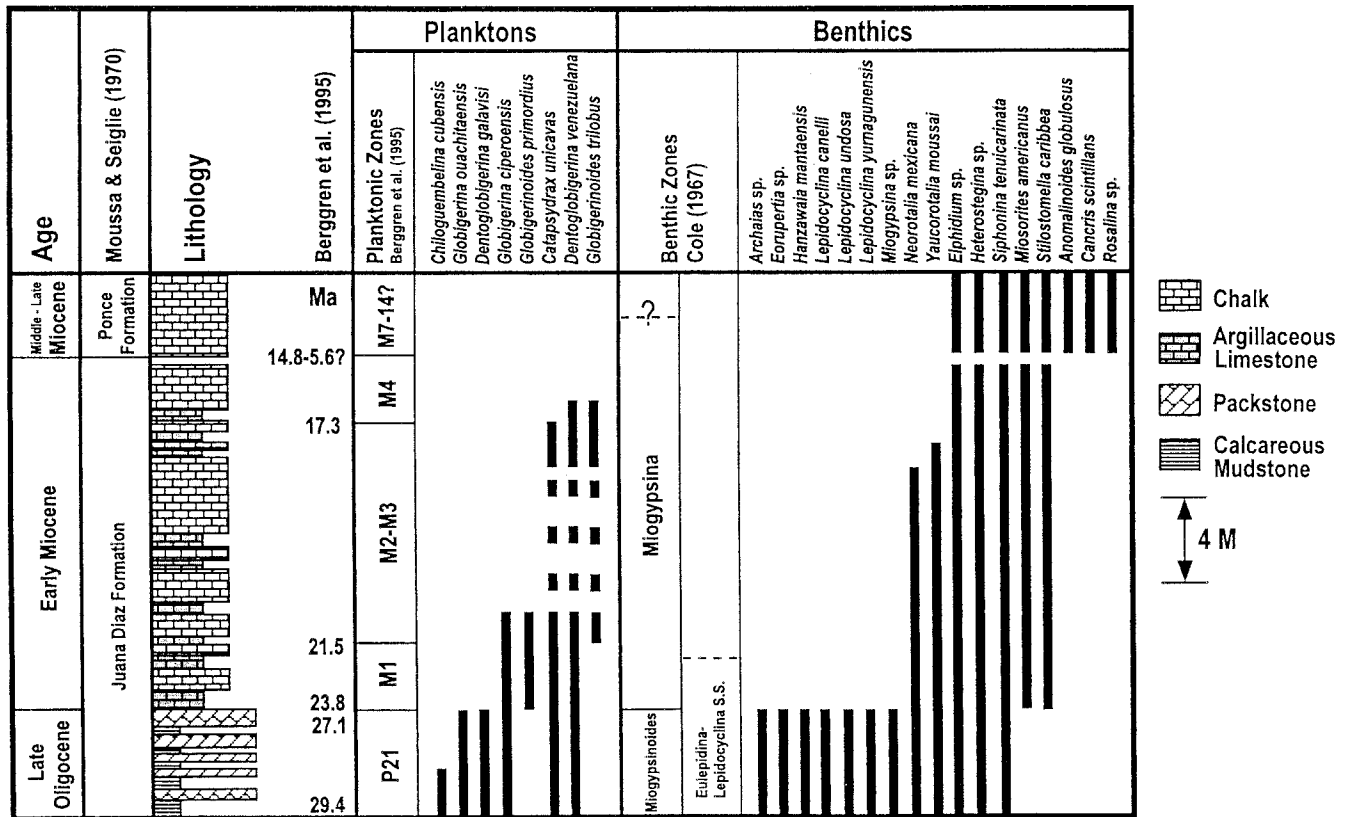
FORAMINIFERAL BIOSTRATIGRAPHY

Santa Elena Section

The stratigraphic section exposed at Santa Elena spans an interval from late Oligocene to middle late Miocene (ca. 30 to 5.6 Ma; text-fig 3). Planktonic foraminiferal faunas dominate the deeper, open marine shelf segments, whereas the intervening shallower segments are characterized by an abundance of benthic foraminifers. Their preservation varies from good, especially in the lower part, to increasingly poor in the top of the section above the unexposed part. The zonal scheme of Berggren et al. (1995) has been applied to the studied interval.

The upper Oligocene portion of the Santa Elena section is about 5m thick, and consists of grayish tan, buff to orange-colored calcareous mudstone interbedded with debris flows of unsorted reef skeletal materials. The base of the strata is not exposed in this section. The foraminiferal fauna, dominated by planktonic taxa, is assigned to Zone P21. In agreement with Berggren et al. (1995), Zone P21 is subdivided into two subzones based on the last occurrence (LO) of *Chiloguembelina cubensis* (Palmer) 1934 at 3m. Moreover, the association of *Catapsydrax unicavas* Bolli, Loeblich and Tappan 1957, *Dentoglobigerina galavisi* (Bermúdez) 1961, *D. venezuelana* (Hedberg) 1937, *Globigerina ciperoensis* Bolli 1957, and *G. ouachitaensis* Howe and Wallace 1932 is equivalent in age to *Globigerina angulisuturalis/ Paragloborotalia opima opima* Concurrent Range Zone (Berggren et al. 1995). The benthic fauna includes *Lepidocyclina undosa* Cushman 1919, *L. yurnagunensis* Cushman 1919, *L. canelli* Lemoine and Douvillé 1904, *Hanzawaia mantaensis* Galloway and Morrey 1929, *Elphidium* sp., *Neorotalia mexicana* (Nuttal) 1928, *Miogypsina* sp., *Heterostegina* sp., *Eorupertia* sp., *Yaucorotalia moussai* Seiglie 1972, *Archaias* sp., and *Siphonina tenuicarinata* Cushman 1927 (text-fig. 3). *Lepidocyclina yurnagunensis, Hanzawaia mantaensis* and *Yaucorotalia moussai* in particular have been reported extensively only from the late Oligocene of the Antillean Caribbean and the Gulf regions (Katz and Miller 1993; Robinson 1993). The benthic foraminiferal assemblage compares well with the larger foraminifera *Miogypsinoides* Zone of Cole (1967). The upper boundary of this zone is difficult to mark because an unconformity truncates the sequence in its uppermost part.

Cream-colored chalk containing both planktonic and benthic foraminifera of early Miocene age overlie the upper Oligocene mudstone. The association of planktonic taxa includes *Catapsydrax unicavas, Dentoglobigerina venezuelana, Globigerina ciperoensis, Globigerinoides primordius* Blow and Banner 1962 and *Gl. trilobus* (Reuss) 1850 with the benthic species *Lepidocyclina undosa, L. canelli, Elphidium* sp., *Heterostegina* sp., *Miosorites americanus* (Cushman) 1918, *Siphonina tenuicarinata, Neorotalia mexicana, Miogypsina* sp., *Eorupertia* sp., *Yaucorotalia moussai* and *Stilostomella caribbea* Cushman 1939 marks Zone M1 (between 5m and 8.5m). The FO of *Globigerinoides primordius* and *Gl. trilobus*

TEXT-FIGURE 2
Lithostratigraphy, and planktonic and benthic foraminiferal biostratigraphy of the Santa Elena section, Guayanilla. Between 49m and 19.8m (29.2m thick), the section is covered and is represented as a gap in the figure. The biostratigraphic scheme is adopted from zonal stratigraphy of Berggren et al. (1995).

and the LO of *Globigerina ciperoensis* and *Globigerinoides primordius* just above the Zone M1 is the basis for zonal assignment. Although *Globigerinoides primordius* and *Gl. trilobus* first appear in the late Oligocene Zone P22 (Kennett and Srinivasan 1983; Bolli and Saunders 1985; Spezzaferri and Premoli Silva 1991), their association with *Miosorites americanus* and *Stilostomella caribbea,* which first appear in the earliest Miocene (Seiglie et al. 1976), helped in limiting the lower boundary of M1 Zone. The larger foraminiferal assemblage confers well with that from the Caribbean region (Bolli, Beckmann and Saunders 1994).

Zone P22 (27.1 Ma – 23.8 Ma) is missing in the studied section. The time span for this hiatus is estimated to be 3.3 million years, which matches well with the synchronous oxygen isotope decline in both benthic and planktonic foraminifera, indicating sea level fall and growth of ice (Miller et al. 1987). Frost et al. (1983) interpreted this hiatus to be 1.5 to 2.0 million years based on their study of Oligocene reef development.

The overlying, 10.5m (8.5m–18.5m) thick chalk and argillaceous limestone, containing primarily larger and smaller benthic foraminiferal species including *Miosorites americanus, Siphonina tenuicarinata, Stilostomella caribbea, Neorotalia mexicana, Yaucorotalia moussai, Elphidium* sp. and *Heterostegina* sp. is assigned to M2-M3 Zones. The planktonic foraminiferal species *Catapsydrax unicavas, Dentoglobigerina venezuelana, Globigerina ciperoensis, Globigerinoides pri-*

mordius and *Gl. trilobus* are common in the lower 80cm of the zone. After a marked decrease in abundance between 9.3m and 15.5m, the long ranging species *Catapsydrax unicavas, Dentoglobigerina venezuelana* and *Globigerinoides trilobus* gradually increase again in the upper portion of the zone (15.5m and 18.5m). The LO of *Catapsydrax unicavas* at 18.5m is utilized to demarcate the upper boundary of the M2-M3 Zone. It is not possible to mark the boundary between Zones M2 and M3, because marker planktonic species are absent. Nevertheless, the LO of benthic foraminifers *Neorotalia mexicana* and *Yaucorotalia moussai* near the top of the M2-M3 Zone indicate that they don't occur in sediments younger than M3 Zone.

The extent of the overlying late early Miocene Zone M4 (18.5m to 21m) is difficult to demarcate, because planktonic foraminifera occur only in the bottom part of the zone and only long-ranging benthic foraminiferal taxa (*Elphidium* sp., *Heterostegina* sp., *Miosorites americanus, Siphonina tenuicarinata* and *Stilostomella caribbea*) are present. Furthermore, it is not possible to estimate the time span for this interval because the top is not exposed in this section.

The uppermost 4m (49m to 53m), above the unexposed part of the section, is probably of latest middle Miocene to late Miocene age (M7 – M14?) as evidenced by the presence of *Cancris scintillans* (Coryell and Mossman) 1942, *Anomalinoides globulosus* (Chapman and Parr) 1937 and *Rosalina* sp. 1. These species are known to occur in this time interval from elsewhere
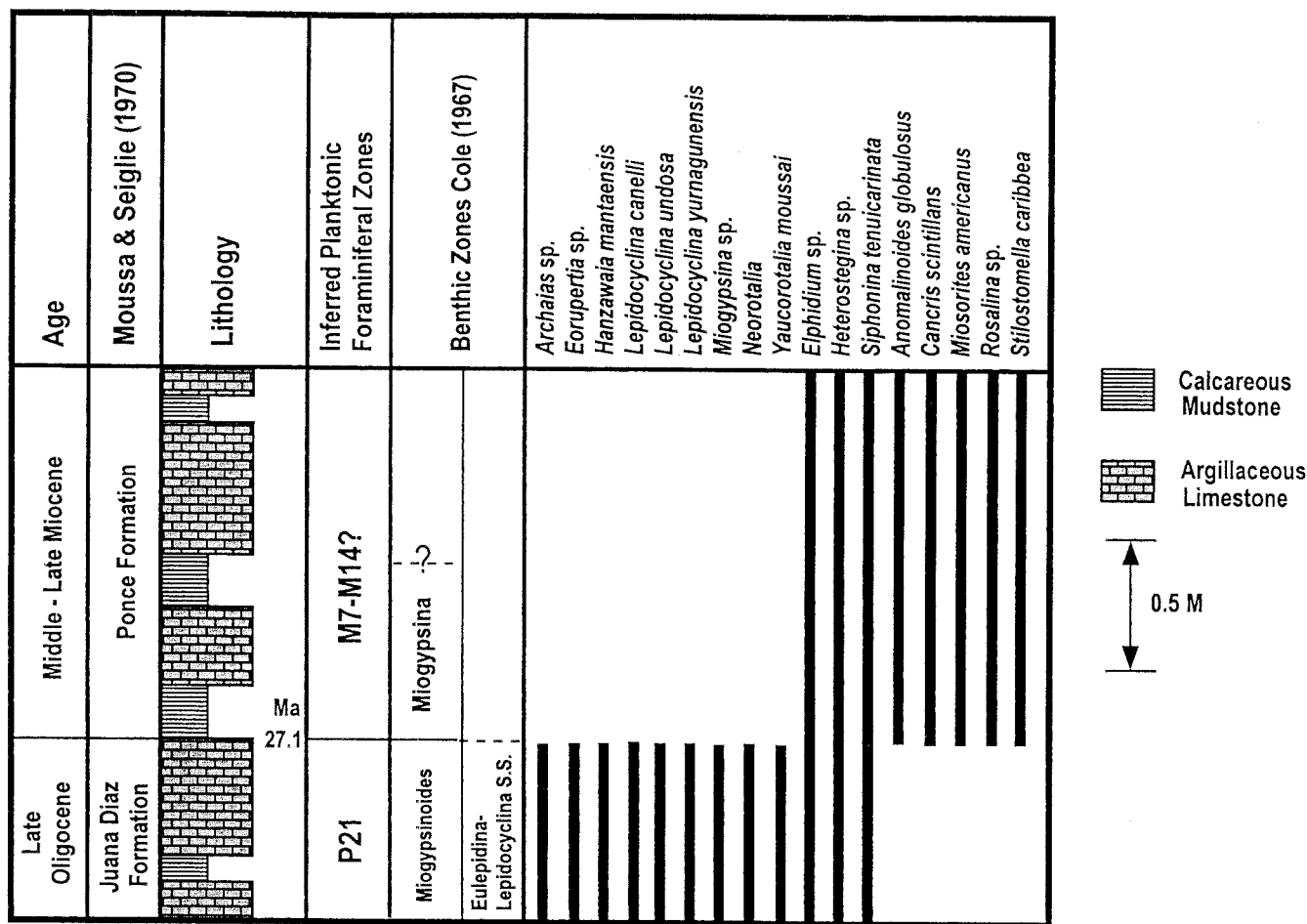
TEXT-FIGURE 3
Lithostratigraphy and planktonic and benthic foraminiferal biostratigraphy of the Playa de Jaboncilla outcrop. The biostratigraphic scheme is adopted from zonal stratigraphy of Berggren et al. (1995).

in the Caribbean region (Katz and Miller 1993). Although Frost et al. (1983) indicated this interval to be of late Miocene age, the presence of a long-ranging foraminiferal faunal association makes it difficult to date this interval.

Playa de Jaboncilla Section

The well-exposed argillaceous limestone and calcareous mudstones in the Playa de Jaboncilla sea cliff sections contain only benthic foraminifera and so are difficult to correlate with the planktonic zonal scheme (text-fig. 4). The lower Miocene chalk, which is exposed at Santa Elena, is not present at Playa de Jaboncilla. Instead, beach and carbonate shoal facies of the uppermost middle Miocene to upper Miocene Ponce Formation (Frost et al. 1983) rest with angular unconformity on the shallow marine upper Oligocene calcareous mudstone. The late Oligocene benthic fauna includes *Lepidocyclina undosa, L. yurnagunensis, L. canelli, Hanzawaia mantaensis, Elphidium* sp., *Neorotalia mexicana, Miogypsina* sp., *Heterostegina* sp., *Eorupertia* sp., *Yaucorotalia moussai, Archaias* sp. and *Siphonina tenuicarinata*. The overlying uppermost middle Miocene to late Miocene strata contains *Cancris scintillans, Anomalinoides globulosus* and *Rosalina* sp. 1.

CONCLUSIONS

In the Santa Elena section, planktonic and benthic foraminifers typify the upper Oligocene-Miocene interval, whereas benthic foraminifers dominate the Playa de Jaboncilla section. There is no direct evidence for deposition of lower Miocene hemipelagic sediments in the Playa de Jaboncilla section. The combined use of benthic and planktonic foraminiferal zones has here resulted in the development of a better resolved biostratigraphy for the Santa Elena and Playa de Jaboncilla sequences, both of which are marked by frequent oscillations of sea level. We conclude that in oscillating marine environments, the biostratigraphic control provided by both benthic and planktonic foraminifers is potentially superior to that provided by only planktonic foraminifers.

The absence of Zone P22 (27.1 Ma – 23.8 Ma) in the studied section, as evidenced by the lack of both planktonic and benthic foraminifera of that zone suggest significant shallowing at the Oligocene/Miocene boundary. Although Frost et al. (1983) interpreted this hiatus to be 1.5 to 2.0 million years based on their study of Oligocene reef development, the present study indicates this to be of 3.3 million years. The time span for this

non-deposition matches well with the synchronous oxygen isotope decline in both benthic and planktonic foraminifera, global sea-level regression and growth of Antarctic ice (e.g. Miller et al. 1987).

TAXONOMIC NOTES

Planktonic Foraminifera

Genus CATAPSYDRAX Bolli, Loeblich and Tappan 1957

Catapsydrax unicavus Bolli, Loeblich and Tappan
Plate 1, figures A, B

Catapsydrax unicavus BOLLI, LOEBLICH and TAPPAN 1957, p. 37, pl. 7, figs. 9a-c.

Remarks: Four chambers in the last whorl and a well-developed bulla, which is attached on three sides covering the umbilicus, characterize this valuable marker species. Various names have been given based on the number of apertures (Bolli and Saunders 1985): *Catapsydrax unicavus* Bolli, Loeblich and Tappan for one aperture, *C. dissimilis dissimilis* for two apertures and *C. dissimilis ciperoensis* for three to four apertures. Only specimens close to the holotype (Bolli, Loeblich and Tappan 1957) have been included in *C. unicavus*.

Genus CHILOGUEMBELINA Loeblich and Tappan 1956

Chiloguembelina cubensis (Palmer)
Plate 1, figures C, F

Guembelina cubensis PALMER 1934, p. 73, figs. 1-6.
Chiloguembelina cubensis (Palmer) JENKINS 1985, p. 274, pl. 6, fig. 6.

Remarks: Chiloguembelina cubensis is most abundant and widely distributed in both tropical and temperate regions ranging from middle Eocene to late Oligocene. The extinction level of *C. cubensis* appears to be a widespread marker in the late Oligocene.

Genus DENTOGLOBIGERINA Blow 1979

Dentoglobigerina galavisi (Bermudez)
Plate 2, figure D, E

Globigerina galavisi BERMUDEZ 1961, p. 681, pl. 2, figs. 1a-d.
Dentoglobigerina galavisi (Bermudez) SPEZZAFERRI and PREMOLI Silva 1991, p. 239, pl. 2, figs. 1-3. –BERGGREN 1993, p. 207.

Remarks: Test large, high trochospiral, four to five chambers in the final whorl, initially subspherical, later chambers compressed with distinctly cancellate test. Specimens occur throughout P21 Zone, but never in abundance.

Dentoglobigerina venezuelana (Hedberg)
Plate 1, figure D, E

Globigerina venezuelana HEDBERG 1937, p. 681, pl. 92, figs. &a-b.
Globoquadrina venezuelana (Hedberg) KENNETT and SRINIVASAN 1983, p. 180, pl. 44, figs. 5-7.
Dentoglobigerina venezuelana (Hedberg) BERGGREN 1993, p. 208, pl. 8, figs. 16-19.

Remarks: Bolli and Saunders (1985) classified *Globigerina venezuelana* within the *Globigerina yeguaensis - G. pseudovenezuelana - G. euapertura - G. venezuelana* group, as they are characterized by similar morphology and are dominant component within the Oligocene-Miocene fauna. Kennett and Srinivasan (1983) placed the same species in the genus *Globoquadrina* on the basis of phylogeny, whereas Berggren

(1993) placed it under *Dentoglobigerina* based on the cancellate test. Researchers differ in the definition of *Globigerina venezuelana* (Kennett and Srinivasan 1983; Berggren 1993) and related species. *Dentoglobigerina venezuelana,* as defined by Berggren (1993), is used here to avoid lengthy subjective discussion.

Genus GLOBIGERINA d'Orbigny 1826

Globigerina ciperoensis Bolli
Plate 2, figure C, F

Globigerina ciperoensis BOLLI 1957, p. 109, pl. 22, figs. 12a-c. -KENNETT and SRINIVASAN 1983, p. 29, pl. 4, figs. 6-8. – BOLLI and SAUNDERS 1985, p. 182-183, pl. 13, figs. 1-11.
Globigerina ciperoensis ciperoensis BOLLI 1957, p.109, pl. 22, figs. 10a-b.
Globigerina ciperoensis angulisuturalis BOLLI 1957, p.109, pl. 22, figs. 11a-c.
Globigerina fariasi BERMÚDEZ 1961, p. 1181, pl. 3, figs. 5a-c.

Remarks: Globigerina ciperoensis, which first occurs in the Zone P21 at Santa Elena, is characterized by its small test, low to medium trochospiral, spherical chambers that increase uniformly in size as added, a circular aperture opening into a large, open umbilicus. The studied specimens are identical to those recorded from eastern Jamaica (Kennett and Srinivasan 1983).

Globigerina ouachitaensis Howe and Wallace
Plate 1, figure G; Plate 2, figure B

Globigerina ouachitaensis HOWE and WALLACE 1932, p. 74, pl. 10, figs. 7a-c.
Globigerina ouachitaensis SPEZZAFERRI and PREMOLI SILVA 1991, p. 242, 244, pl. 5, figs. 1a-d, pl. 6, figs. 5a-c.

Remarks: Test medium, trochospiral, equatorial periphery elongate with four rapidly enlarging chambers in the last whorl. This species is characterized by a wide umbilicus of quadrate outline. *Globigerina ouachitaensis* is restricted to the Zone P21 at Santa Elena section.

Genus GLOBIGERINOIDES Cushman 1927

Globigerinoides primordius Blow and Banner
Plate 1, figure J, Plate 2, figure A

Globigerinoides primordius BLOW and BANNER 1962, p. 15, pl. 9, figs. Dd-Ff.
Globigerinoides primordius KENNETT and SRINIVASAN 1983, p. 57, pl. 11, figs. 1-3.

Remarks: Globigerinoides primordius, which first occurs in the Zone M1 at Santa Elena, is characterized by a low trochospiral test, three and a half to four chambers in the final whorl, with a low arched interiomarginal primary aperture and a single supplementary aperture on spiral side. The studied specimens are similar to those recorded by Kennett and Srinivasan (1983).

Globigerinoides trilobus (Reuss)
Plate 1, figure H, I

Globigerinoides triloba REUSS 1850, p. 374, pl. 47, figs. 11a-c.

Remarks: This long ranging Miocene species, common in the Santa Elena material, has one to three strong elongated chambers, increasing rapidly in size and a flattened to gently convex spiral side. Although, there is confusion regarding the exact status of this species (see Bolli and Saunders 1985, p. 196-198), the present specimens are similar to those from the Cipero and Lengua formations, Trinidad (Bolli 1957).

Benthic Foraminifera

Genus ANOMALINOIDES Brotzen 1942

Anomalinoides globulosus (Chapman and Parr)
PLATE 2, figure G

Anomalina globulosus CHAPMAN and PARR 1937, p. 117, pl. 9, fig. 27.
Anomalinoides globulosus (Chapman and Parr) VAN MORKHOVEN, BERGGREN and EDWARDS 1986, p. 36-38, pl. 9, fig. 1-3. –KATZ and MILLER 1993, p.234, pl. 19, figs. 11-13.

Remarks: Miller and Katz (1987) reported the first occurrence of *Anomalinoides globulosus* in the Zone N12 from Jamaica and other locations. This easily recognizable species, common in both Santa Elena and Playa de Jaboncilla sections, is similar to those described from Buff Bay, Jamaica (Katz and Miller 1993).

Genus ARCHAIAS de Montfort 1808

Archaias sp.
PLATE 3, figure A, B

Remarks: Rare specimens were scattered through the upper Oligocene segment of both Santa Elena and Playa de Jaboncilla sections.

Genus CANCRIS de Montfort 1808

Cancris scintillans (Coryell and Mossman)
PLATE 2, figure K

Valvulineria scintillans CORYELL and MOSSMAN 1942, p. 236, pl. 36, figs. 13-15.
Cancris scintillans (Coryell and Mossman) KATZ and MILLER 1993, p.235, pl. 19, figs. 3-4.

Remarks: The morphologic variation of *Cancris scintillans* compares well with that of Jamaican specimens described by Katz and Miller (1993). Specimens from Puerto Rico show less prominent knobs surrounding the umbilical region.

Genus ELPHIDIUM de Montfort 1808

Elphidium sp. (de Montfort)
Plate 2, figure J; plate 3, figure E

Elphidium sp. DE MONTFORT 1808, p. 66. –KATZ and MILLER 1993, p. 242, pl. 13, figs. 7, 8.

Remarks: This long ranging taxa, present throughout both sections, is identical to Jamaican specimens from Buff Bay (Katz and Miller 1993).

Genus EORUPERTIA Yabe and Hanzawa 1925

Eorupertia sp.?
Plate 3, figure C, D

Remarks: Specimens are difficult to place under either *Eorupertia* or *Victoriella*, as these two genera are differentiated by only the wall structure. Although, our specimens resemble *E. bermudezi* (Anisgrad 1957; Robinson and Wright 1993), we did not specify it because of the lack of individual specimens.

Genus HANZAWAIA Asano 1944

Hanzawaia mantaensis (Galloway and Morrey)
Plate 2, figure H, I

Anomalina mantaensis GALLOWAY and MORREY 1929, p. 28, pl. 4, figs. 5a-c.
Cibicides mantaensis (Galloway and Morrey) RENZ 1948, p. 128, pl. 11, figs. 8a-b. – BERMÚDEZ 1949, p. 302, pl. 25, figs. 22-24.
Hanzawaia mantaensis (Galloway and Morrey) VAN MORKHOVEN, BERGGREN and EDWARDS 1986, p. 105-107, pl. 32, figs. 1-2. –KATZ and MILLER 1993, p. 238, pl. 19, figs. 8-10.

Remarks: This species, restricted to the late Oligocene, is identical to Jamaican specimens from Buff Bay (Katz and Miller 1993). It has a plano-convex test with strongly curved sutures, a clear umbilical boss and an acute periphery.

Genus HETEROSTEGINA d'Orbigny 1826

Heterostegina sp.
Plate 3, figure F

Remarks: Although study of random sections of Heterostegina compares well with that of *Heterostegina (Vlerkina) antillea* Cushman 1919 described from Jamaica (Robinson and Wright (1993), lack of individual specimens made specific identification difficult for this taxon. This long ranging taxa is present throughout both sections.

Genus LEPIDOCYCLINA Gümbel 1870
Subgenus LEPIDOCYCLINA Gümbel 1870

Lepidocyclina (Lepidocyclina) canelli Lemoine and Douvillé
Plate 3, figures I, J

Lepidocyclina (Lepidocyclina) canelli LEMOINE and DOUVILLÉ 1904, p. 20, pl. 1, fig. 1. –COLE 1961, p. 383-389, pl. 30, figs. 1-13. – ROBINSON and WRIGHT 1993, p. 316-317, pl. 22, figs. 6-7.
Lepidocyclina (Lepidocyclina) matleyi VAUGHAN 1928, pl. 46, figs. 1-3.
Lepidocyclina (Lepidocyclina) asterodisca SACHS 1959, p. 406, pl. 35, figs. 7-9.
Lepidocyclina (Lepidocyclina) waylandvaughani SACHS and GORDON 1962, p. 15, pl. 1, figs. 5, 10.
Lepidocyclina (Lepidocyclina) parvula CUSHMAN, EAMES ET AL. 1962, p. 306, pl. 8, figs. 2-3.

Remarks: Lepidocyclina (Lepidocyclina) canelli occurs in the upper Oligocene and lower Miocene section; below Zone N7 at Santa Elena, whereas in Playa de Jaboncilla it is found only in the upper Oligocene segment. The illustrated specimen from lower Miocene sediments is similar to those recorded by Robinson and Wright (1993). For discussion on the status of the subgenus and synonymy see Robinson and Wright (1993).

Subgenus NEPHROLEPIDINA Douvillé 1911

Lepidocyclina (Nephrolepidina) yurnagunensis Cushman
Plate 3, figures G, O

Lepidocyclina canellei LEMOINE and DOUVILLÉ, variety *yurnagunensis,* CUSHMAN 1919, p. 54, pl. 12, figs. 7-8.
Lepidocyclina (L.) yurnagunensis Cushman, VAUGHAN 1926, 391-393, pl. 25, figs. 2-6. –COLE 1968, pl. 23, fig. 8, pl. 24, figs. 5, 8.
Lepidocyclina yurnagunensis Cushman 1919, subsp. *morganopsis* Vaughan 1933, COLE 1952, p. 23, pl. 15, figs.1-2, 4-5. –ROBINSON and WRIGHT 1993, p. 319-321, pl. 23, fig. 3, pl. 24, figs. 2-4.

Remarks: For discussion on the status of the subgenus and synonymy see Robinson and Wright (1993). *Lepidocyclina (Nephrolepidina) yurnagunensis,* abundant in the upper Oligocene segment of both the sections, is comparable with Jamaican specimens (Robinson and Wright 1993) and with those from other sections of southwestern Puerto Rico (Frost et al. 1983).

Subgenus EULEPIDINA Douvillé 1911

Lepidocyclina (Eulepidina) undosa *Cushman*
Plate 3, figures K, L

Lepidocyclina undosa CUSHMAN 1919, p. 65, pl. 2, fig. 1a.
Lepidocyclina (Nephrolepidina) undosa Cushman, VAUGHAN 1928, pl. 48, fig. 3.
Lepidocyclina (Nephrolepidina) crassata Cushman, VAUGHAN 1928, pl. 45, figs. 4, 5.
Lepidocyclina (Eulepidina) undosa Cushman, COLE 1945, p. 43-44, pl. 1, figs. 14-15. - SACHS and GORDON 1962, p. 15-16, pl. 1, fig. 9. -ROBINSON and WRIGHT 1993, p. 323-324, pl. 22, figs. 1-2.

Remarks: This is a common index foraminifer for the late Oligocene of the Caribbean region. It disappears just above the Oligocene-Miocene (N4) boundary (Robinson and Wright 1993). *Lepidocyclina (Eulepidina) undosa* is variable in its embryonic chambers and in the degree of inflation of the test. Although some authors (e.g. Eames et al. 1968) regard the variations in embryonic chambers as distinct species, we have grouped *L. favosa, L. gigas* and *L. undosa* together following Robinson and Wright (1993).

Genus MIOGYPSINA Sacco 1893

***Miogypsina* sp.**
Plate 3, figures H, P

Remarks: Lack of individual specimens made specific identification difficult for this taxon. *Miogypsina* sp. is restricted in the late Oligocene part of both the sections.

Genus MIOSORITES Seiglie, Grove and Rivera 1976

Miosorites americanus (Cushman)
Plate 3, figures M, N, Q

Orbitolites americanus CUSHMAN 1918, p. 99, pl. 43, figs. 12-14, pl. 44, figs. 1, 2.
Sorites marginalis FROST and LANGENHEIM (not Lamarck 1816) 1974, p. 61-63, pl. 7, figs. 1-5.
Miosorites americanus (Cushman) SEIGLIE, GROVE and RIVERA 1976, p. 867-871, pl. 1, figs. 5,6, pl. 2, figs. 1-6, pl. 3, figs. 1, 2, pl. 4, figs. 1, 2.

Remarks: Miosorites americanus has been reported only from the Caribbean region, but under different names by numerous authors (see Seiglie et al. 1976 for discussion). The presently studied specimens, easily identified in thin section, are similar in morphology to specimens from Puerto Rico described by Monroe (1973) and Seiglie et al. (1976).

Genus NEOROTALIA Bermudez 1952

Neorotalia mexicana (Nuttall)

Rotalia mexicana Nuttall 1928, p. 374, pl. 50, figs. 6-8.
Neorotalia mexicana (Nuttall) BERMÚDEZ 1952, p. 75, pl. 12, fig. 4. –ROBINSON and WRIGHT 1993, p. 327, pl. 27, fig. 7.
Pararotalia mexicana (Nuttall) POAG 1966, p. 414, pl. 6, figs. 11-19.

Remarks: Because most of the specimens were observed under random thin sections, the distinction between *N. mexicana* and *N. mecatepecensis* is difficult to recognize. Therefore, both the species are considered together. This species is very common in upper Oligocene segment of both the sections.

Genus SIPHONINA Reuss 1850

Siphonina tenuicarinata Cushman
Plate 4, figures A, E

Siphonina tenuicarinata CUSHMAN 1927, p. 166, pl. 26, fig. 11-12. –VAN MORKHOVEN, BERGGREN and EDWARDS 1986, p. 206-209, pl. 70, figs. 1-3. –KATZ and MILLER 1993, p. 240, pl. 16, figs. 1-3.

Remarks: Siphonina tenuicarinata is present in both Oligocene and Miocene part of the Santa Elena and Playa de Jaboncilla sections. Some of the specimens may be *S.* cf. *pulchra* (see Cushman and Todd 1945).

Genus STILOSTOMELLA Guppy 1894

Stilostomella caribbea Cushman
Plate 4, figures B, C

Stilostomella caribbea CUSHMAN 1939, p. 72, pl. 13, fig. 4.

Remarks: Test robust, uniserial, rectilinear to arcuate, chambers subglobular with aperture arcuate as a result of a small tooth-like projection from one side. This species frequent in the Miocene of both sections, is a very common form in the Caribbean region.

Genus ROSALINA d'Orbigny 1826

Rosalina sp. 1 Katz and Miller
Plate 4, figures D, G

PLATE 1
F is Light Microscope microphotograph and rest are SEM microphotographs of planktonic foraminifera.

A,B *Catapsydrax dissimilis* Bolli, Loeblich and Tappan: A ×200, B ×350;

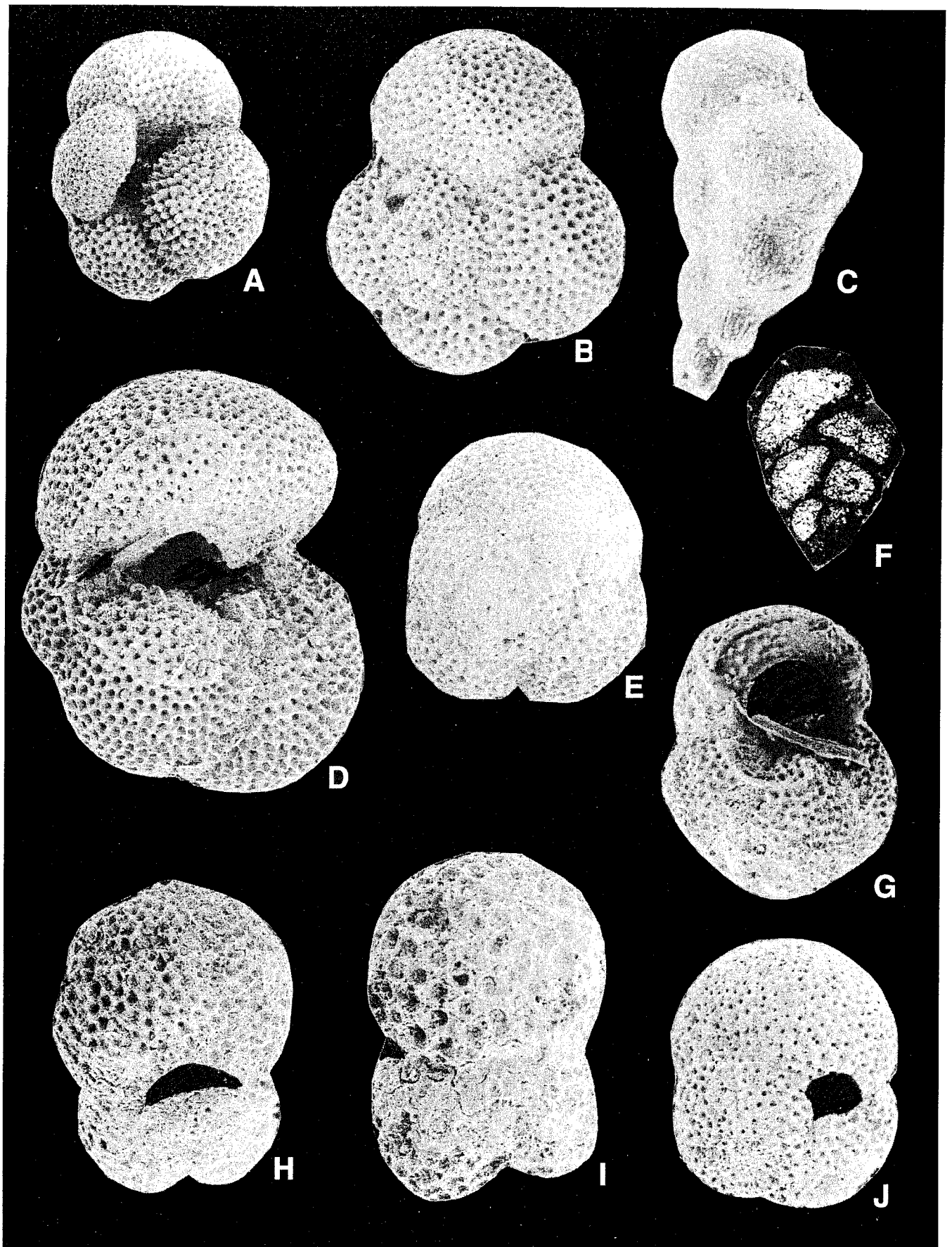C,F *Chiloguembelina cubensis* (Palmer): C ×250, F ×200;

D,E *Dentoglobigerina venezuelana* Hedberg: D ×400, E ×300;

G *Globigerina ouachitaensis* Howe and Wallace: G ×200;

H,I *Globigerinoides trilobus* (Reuss): H, I ×200;

J *Globigerinoides primordius* Blow and Banner: J ×200.

Rosalina sp. 1 KATZ and MILLER 1993, p. 240, pl. 19, figs. 1, 2.

Remarks: This species has a highly perforate test near the periphery and an open umbilicus. The presently studied specimens are similar in morphology to specimens from Buff Bay, Jamaica (Katz and Miller 1993).

Genus YAUCOROTALIA Seiglie 1972

Yaucorotalia moussai Seiglie
PLATE 4, figures F, G-H

Yaucorotalia moussai SEIGLIE 1972, p. 118, pl. 1, fig. 1-6.

Remarks: This species, originally described from the Tertiary of Puerto Rico (Seiglie 1972), is very common in the Oligocene portion of both the Santa Elena and Playa de Jaboncilla sections. Presently studied specimens are identical to the ones described by Seiglie (1972).

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PLATE 2
SEM microphotographs of planktonic (A-F) and benthic foraminifera (G-K).

A   *Globigerinoides primordius* Blow and Banner: A ×200;

B   *Globigerina ouachitaensis* Howe and Wallace: G ×200;

C   *Globigerinoides ciperoensis* Bolli: C, F ×200;

D,E   *Dentoglobigerina galavisi* (Bermudez): D, E ×200;

G   *Anomalinoides globulosus* (Chapman and Parr): G ×150;

H,I   *Hanzawaia mantaensis* Galloway and Morrey: H, I ×150;

J   *Elphidium* sp.: J ×150;

K   *Cancris scintillans* (Coryell and Mossman): K ×150
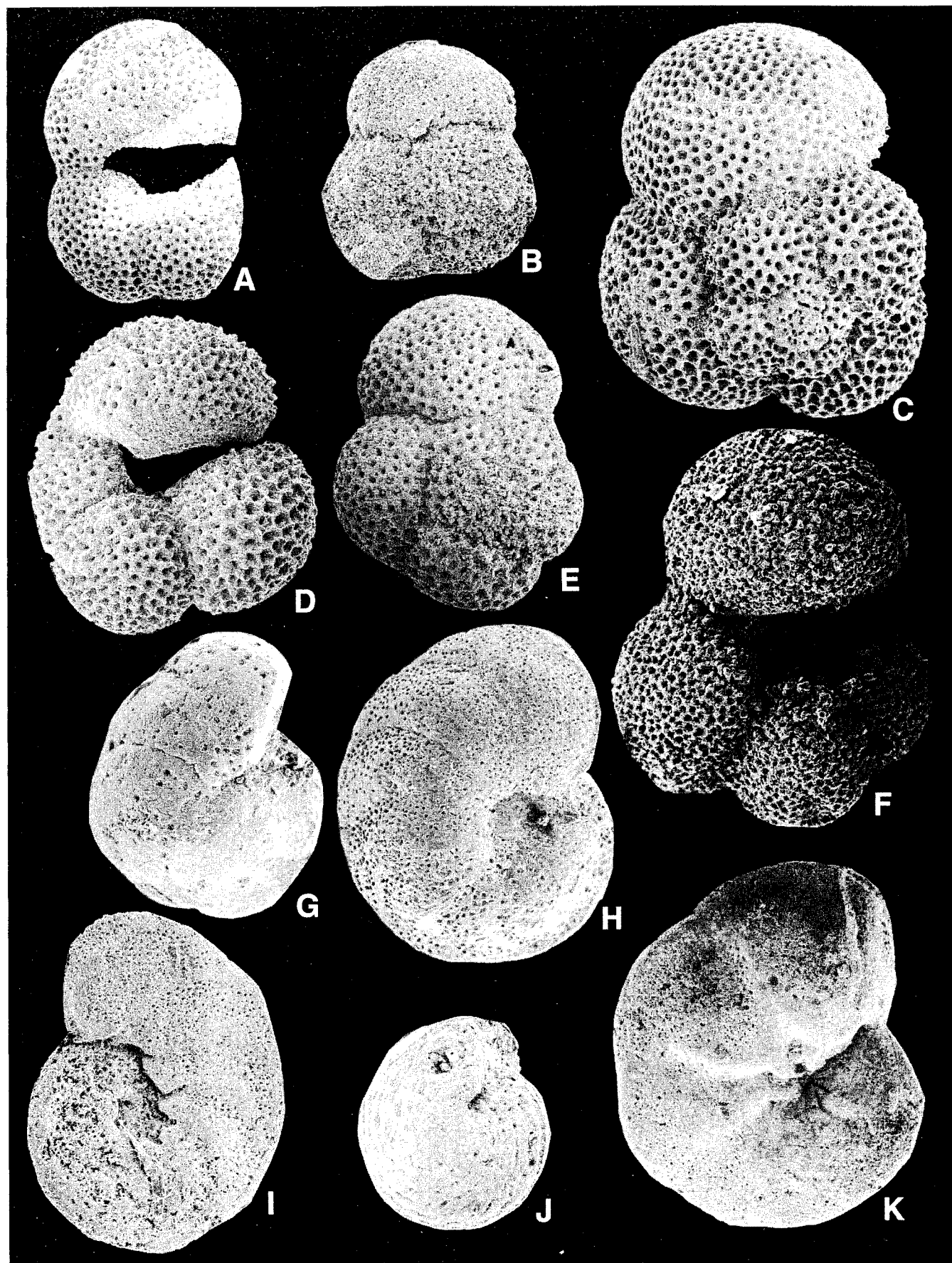
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PLATE 3
Light Microscope thin section microphotographs of benthic foraminifera.

A,B *Archaias* sp.: A, B ×50;

C,D *Eorupertia* sp.: C, D ×25;

E *Elphidium* sp.: E ×150;
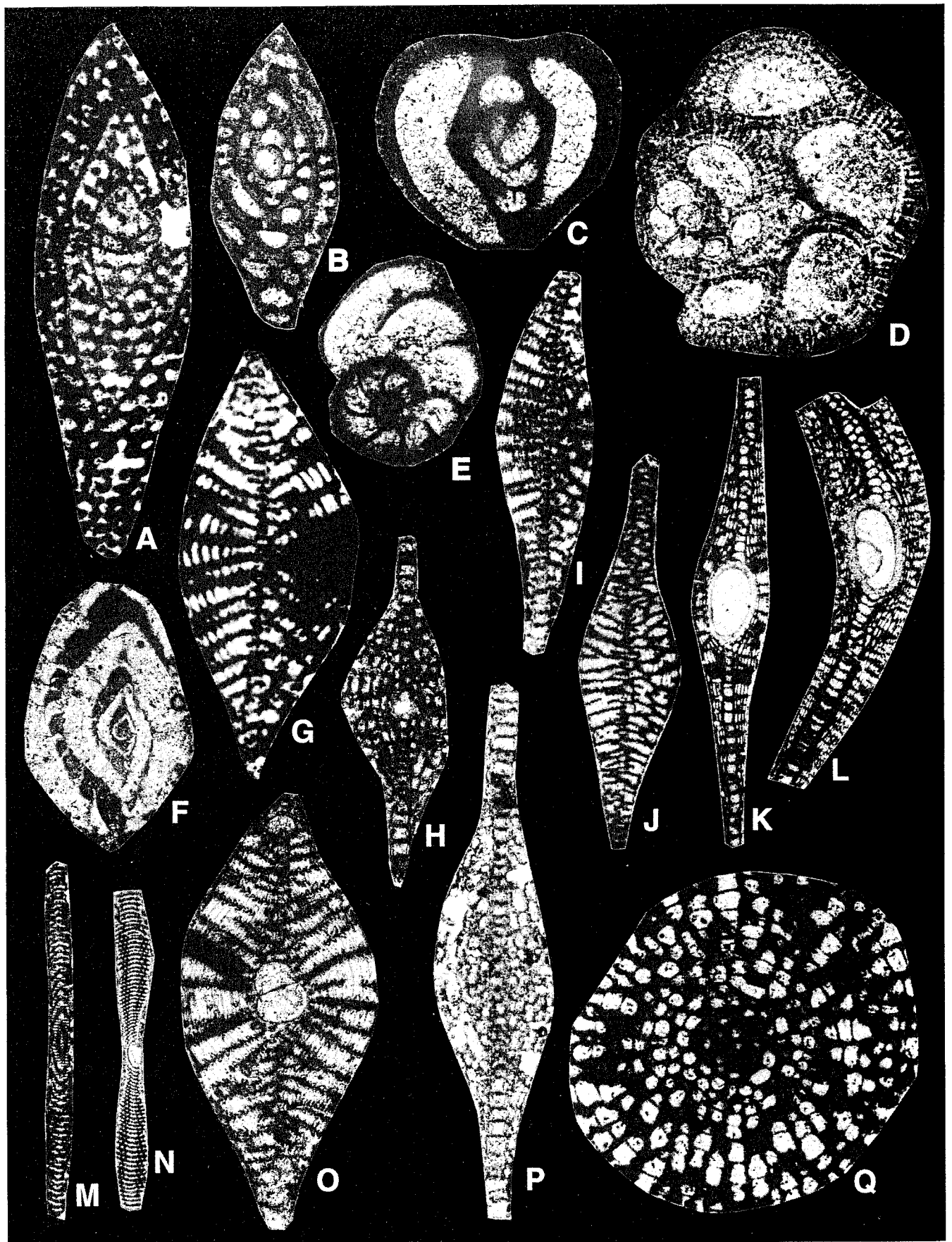
F *Heterostegina* sp.: F ×25;

G,O *Lepidocyclina (Nephrolepidina) yurnagunensis* Cushman: G, O ×40;

H,P *Miogypsina* sp.: H ×45, P ×50;

I,J *Lepidocyclina (Lepidocyclina) canellei* (Lemoine and Douville): I, J X35;

K,L *Lepidocyclina (Eulepidina) undosa* Cushman: K, L ×15;

M,N,Q *Miosorites americanus* (Cushman): M, N ×30, Q ×80.

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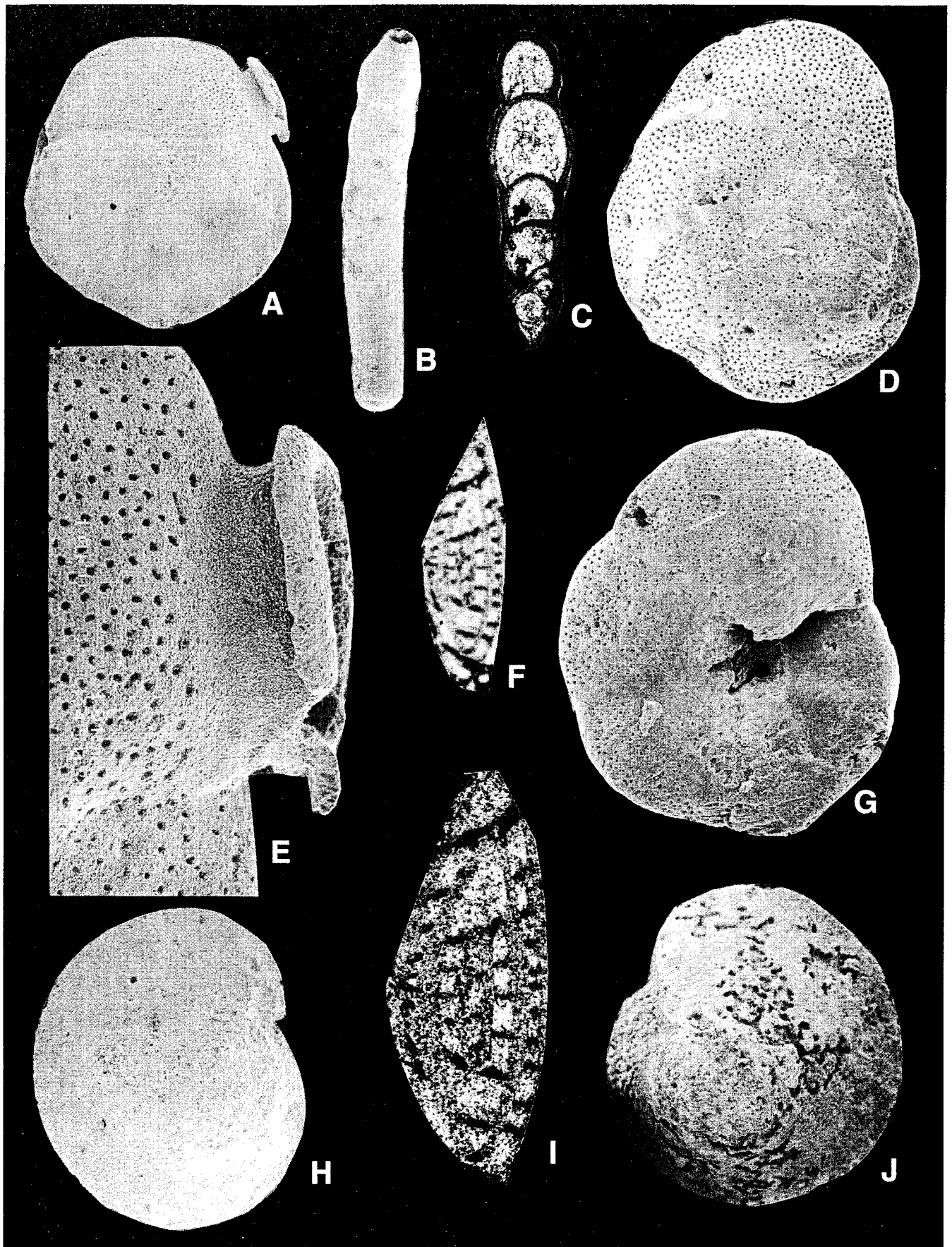

PLATE 4

C, F and I are light microscope thin section microphotographs and the others are SEM microphotographs of benthic foraminifera.

A,E *Siphonina tenuicarinata* Cushman: A ×100, E ×450;

B,C *Stilostomella caribbea* (Cushman): B, C ×100;

D,G *Rosalina* sp. 1: D, G ×200;

F,H-J *Yaucorotalia moussai* Seiglie: F ×40, H-I ×90.

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