

EOCENE AND OLIGOCENE PLANKTONIC FORAMINIFERA FROM THE UPPER BUTANO SANDSTONE AND TYPE SAN LORENZO FORMATION, SANTA CRUZ MOUNTAINS, CALIFORNIA

R. Z. POORE AND E. E. BRABB

U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025

ABSTRACT

Planktonic foraminifers recovered from several horizons within the upper Butano Sandstone and the overlying Twobar Shale and Rices Mudstone Members of the type San Lorenzo Formation, Santa Cruz Mountains, California, range in age from zones P13-P14 to P19-P20. Assemblages from near the top of the Butano and the lower Twobar are referable to zones P13-P14 whereas those from the middle Twobar are referable to zones P15-P16. Assemblages recovered from the lower Rices are assigned to zonal interval P19-P20.

Following current age assignments of these planktonic foraminiferal zones, the middle Eocene-late Eocene boundary of international usage occurs within the Twobar Shale Member (*Amphimorphina jenkinsi* Zone of the Narizian Stage) and the Eocene-Oligocene boundary occurs within the lower part of the Rices Mudstone Member, most likely at the boundary between the Refugian and Zemorrian Stages.

INTRODUCTION

The San Lorenzo Formation represents a presumably continuous marine section that spans the Eocene-Oligocene boundary. It is exposed along the San Lorenzo River, in the Santa Cruz Mountains of the central California Coast Ranges (Fig. 1). The San Lorenzo Formation was originally defined by Arnold (1906) and assigned an Oligocene age because of its molluscan faunas. This unit has played an important role in the development of mid-Tertiary stratigraphy of the Pacific Coast and, for a time, the term San Lorenzo was considered synonymous with Oligocene and was applied to various stratigraphic units from British Columbia to southern California (Arnold and Hannibal, 1913; Clark, 1918).

Subsequent workers (e.g., Forrest and Schenck, in Weaver and others, 1944; Sullivan, 1962) suggested that the lower part of the San Lorenzo Formation and the upper part of the underlying Butano Sandstone were of late Eocene, not Oligocene, age (see Sullivan, 1962, for a historical review). Age assignments of these

workers were based largely on Pacific Coast molluscan and benthonic foraminifer provincial stages that were not necessarily correlated with an international standard.

Detailed studies of the benthonic foraminifers from the upper Butano and San Lorenzo Formations at the type section of the San Lorenzo Formation (Sullivan, 1962) and adjacent areas (Fairchild and others, 1969) have been made. However, planktonic microfossils from these units have received little attention.

Our purpose is to discuss several planktonic foraminiferal assemblages recovered from the type San Lorenzo Formation and the upper part of the underlying Butano Sandstone. An independent study of the nanofossils from this section has been conducted by Warren and Newell (in press).

SAN LORENZO FORMATION

At its type section, exposures along the San Lorenzo River in El/2 secs. 1 and 12, T. 9 S., R. 3 W., Big Basin quadrangle (Fig. 1), the San Lorenzo Forma-

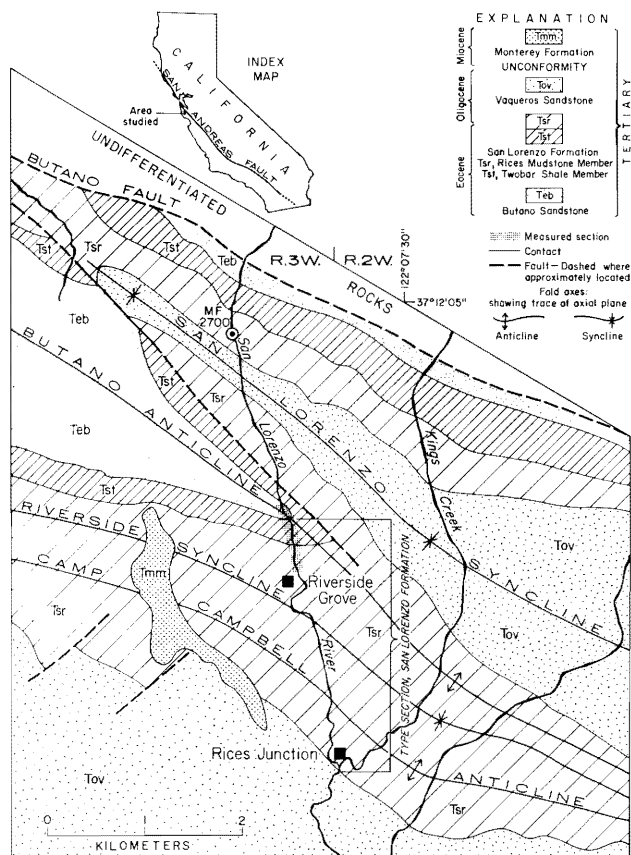


FIGURE 1

Geologic map of Big Basin-San Lorenzo River area, Santa Cruz Mountains, California, and location of sample Mf2700. Modified from Brabb (1964). Location of remaining samples yielding planktonic foraminifers is shown in Fig. 2.

tion conformably overlies approximately 160 ft (48.8 m) of the upper part of the Butano Sandstone (Arnold 1908). At this locality the Butano is a medium- to coarse-grained, massive, arkosic sandstone (Sullivan, 1962). Finer grained intercalations are present within the upper part of this sandstone, but the contact with the overlying San Lorenzo Formation is well defined.

FIGURE 2

Stratigraphic column, location of samples yielding planktonic foraminifers (e.g., Mf3304) and location of selected samples of Sullivan (1962) (e.g., B 2233); upper part of Butano Sandstone and type San Lorenzo Formation. Sample Mf2700 projected into the measured section (see Fig. 1). Samples Mf3300 and Mf3299 approximately equivalent to sample Mf3301.

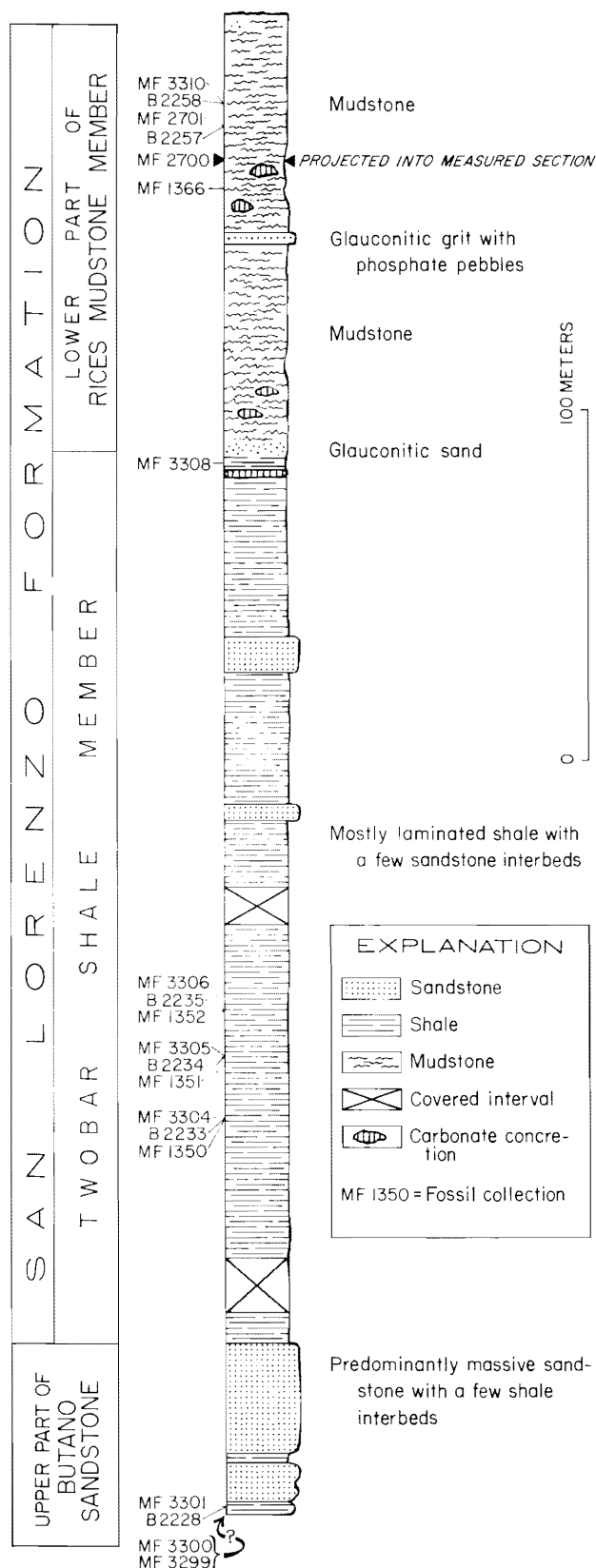


TABLE 1

Stratigraphic relation of sets of samples referred to in this report. See Figs. 1 and 2 for more detailed sample locations.

LITHOSTRATIGRAPHY		SAMPLES COLLECTED BY BRABB 1967	SAMPLES COLLECTED BY BRABB AND POORE, 1976	EQUIVALENT SAMPLES OF SULLIVAN 1962
SAN LORENZO FORMATION	RICES MUDSTONE MEMBER	MF 2701	MF 3310	B 2258 B 2257
		MF 2700		
		MF 1366		
	TWOBAR SHALE MEMBER		MF 3308	
		MF 1352	MF 3306	B 2235
		MF 1351	MF 3305	B 2234
		MF 1350	MF 3304	B 2233
	BUTANO SANDSTONE		MF 3301	B 2228
			MF 3300	
			MF 3299	

The San Lorenzo Formation has been divided into two members by Brabb (1960, 1964). The Twobar Shale Member consists mainly of laminated shale and fine-grained siltstone that exhibit fissile or slabby partings. A few sandstone beds are in the middle part of this member. As exposed along the San Lorenzo River, the Twobar is approximately 750 ft (228.6 m) thick. The overlying Rices Mudstone Member is composed of siltstone to medium-grained sandstone that does not exhibit fissile or slabby partings and is easily differentiated from the Twobar (Brabb, 1964). The contact between these members is abrupt and marked by abundant glauconite at the base of the Rices. Six- to eight-inch (15 to 20 cm) long and 1-inch (2.5 cm) diameter worm(?) tubes extend downward from the base of the Rices Mudstone Member into the uppermost beds of the Twobar Shale Member at a locality near the San Lorenzo River section (Brabb, 1964, p. 676-677). Thus the contact between these members may represent a paraconformity. The contact between the Rices Mudstone and the overlying Vaqueros Sandstone is conformable and gradational.

Estimates of the thickness of the Rices Mudstone Member at this locality vary from 970 ft (295.7 m) (Brabb, 1964) to 1,420 ft (432.8 m) (Sullivan, 1962). This discrepancy arises from differences in interpreta-

tion of minor faults, localized changes in attitude and correlation of key marker beds in the upper part of the section. We prefer the interpretation of Brabb (1964), but note that since our samples from the Rices Mudstone Member were taken from below the problem area, acceptance of the interpretation of Sullivan (1962) does not affect this study.

SAMPLE LOCATIONS

Stratigraphic allocation of samples from the upper Butano Sandstone and the type San Lorenzo Formation yielding planktonic foraminifers is shown in Fig. 2. The stratigraphic relationship between our samples and selected samples of Sullivan (1962) are summarized in Table 1. Samples examined during this study were collected at different times: one set was collected by Brabb in 1967, and the other set was collected in 1976 by Brabb and Poore. Field markers left at 1967 sampling localities were not present when this section was visited in 1976. Thus the exact relationship between some of the samples in the two sets is not precisely known. For example, samples Mf1351 and Mf3305 from the lower part of the Twobar Shale Member were collected at approximately the same stratigraphic horizon, and both samples are approximately equivalent to sample B 2234 of Sullivan (1962). We do not know, however, the exact stratigraphic order of the three samples. Likewise, the stratigraphic order of samples from the Butano Sandstone is obscure. Depending upon one's interpretation of attitude changes in the vicinity of the axis of the Butano Anticline, all samples could be from approximately the same stratigraphic level. Planktonic foraminifers from samples Mf3300, Mf3301 and perhaps Mf3299 are referable to the same zonal interval (see discussion below).

PLANKTONIC FORAMINIFERS

The distribution of planktonic foraminifers encountered during this study is shown in Table 2. For the construction of Table 2, samples collected during 1967 have been arbitrarily plotted below equivalent samples collected in 1976. Samples from the Butano Sandstone are plotted in numerical order. Abundance and preservation of planktonic foraminifers are variable. Crushed and otherwise deformed specimens are present in all samples and in some, for example Mf1350, deformed specimens outnumber nondeformed specimens. Benthonic foraminifers are usually more abundant than planktonic foraminifers and detrital quartz is very abundant in some samples (e.g., samples from the Butano

TABLE 2

Occurrence of planktonic foraminifers in the upper part of the Butano Sandstone and type San Lorenzo Formation. Open circles indicate one or two specimens per sample. Filled circles indicate at least several specimens per sample.

[illegible]

Sandstone). Fish teeth and debris are present in all samples, but are more common in samples from the Butano Sandstone and the Twobar Shale Member than in those from the Rices Mudstone Member. Pyrite and pyritized foraminifers were observed in all samples and are very abundant in sample Mf3308. Moderately well-preserved radiolarians occur in sample Mf3308 and in samples from the Rices. Occasional radiolarians observed in the remaining samples are pyritized.

ZONE ASSIGNMENTS AND AGE INTERPRETATIONS

BUTANO SANDSTONE

Although planktonic foraminifers recovered from sample Mf3299 are rare and poorly preserved, the forms identified are characteristic of middle Eocene assemblages. Most of the taxa are long ranging, but as noted by Bolli (1972), the first occurrence of *Globigerinatheka index* (s.l.) is within the *Globigerinatheka subconglobata* Zone (= *Globigerapsis kugleri* Zone of Bolli, 1957b; = P11 sensu Berggren, 1972). Thus the presence of *G. index* (s.l.) sets a lower limit of zone P11 for this assemblage. As noted earlier, this sample could be stratigraphically equivalent to Mf3300 and Mf3301 which yield assemblages here assigned to zones P13–P14 of Blow (1969). Taxa recorded from Mf3299

occur in this zonal interval; moreover, since the Butano Sandstone represents a presumably continuous, rapidly deposited sequence, it is probable that the assemblage from this sample is younger than zone P11.

The occurrence of *Globorotaloides suteri* in samples Mf3300 and Mf3301 is significant in that the lowest occurrence of this form is considered by Blow (1969) to approximate the lower limit of zone P13. A similar lower limit for the range of *G. suteri* is suggested by Bolli (1957b). In general the planktonic foraminifers from these samples are compatible with a zone P13 or P14 assignment. The presence of forms identified as *Globorotalia cerroazulensis frontosa* and *G. c. possagnoensis* in sample Mf3301 seems to be anomalous. According to Toumarkine and Bolli (1970), these forms are not normally present in zone P13 or post zone P13 assemblages. Fairly well-preserved, albeit extremely rare, specimens of these taxa occur in several samples from the lower part of the overlying Twobar Shale Member. At this time data are insufficient to determine if the presence of *Globorotalia cerroazulensis frontosa* and *G. c. possagnoensis* in these samples represents an upward extension of their ranges or is due to reworking.

TWOBAR SHALE MEMBER

The fairly diverse and moderately well-preserved planktonic assemblages observed in samples Mf1350 and

Mf3304 are very similar to the assemblage observed in Mf3301. An important addition in these samples, however, is *Globorotalia cerroazulensis cerroazulensis*. The lowest occurrence of this taxon is within the *Truncorotaloides rohri* Zone of Bolli (Toumarkine and Bolli, 1970, 1975). The *Truncorotaloides rohri* Zone of Bolli (1957b, 1966) is approximately equivalent to zone P14 of Blow (1969). Therefore the common presence of species such as "*Globigerinoides*" *higginsii* and "*Subbotina*" *senni* considered to be restricted to zone P14 or pre-zone P14 assemblages with *Globorotalia cerroazulensis cerroazulensis* in Mf1350 and Mf3304 strongly suggests assignment to zone P14. Bukry and others (in press) report a nannofossil assemblage indicative of the *Discoaster saipanensis* Subzone of Bukry (1973) from a horizon in the Twobar Shale Member equivalent to our samples Mf1350 and Mf3304. Warren and Newell (in press) report a nannofossil assemblage in Sullivan's sample B2233 which they prefer to assign to the *Discoaster bifax* Subzone of Bukry (1973), but which alternatively might be assigned to the *Discoaster saipanensis* Subzone (A. D. Warren, pers. comm., 1976). This subzone is basically equivalent to NP17 of Martini (1971) which Berggren (1972) correlates with planktonic foraminiferal zone P14. According to Roth and others (1971) the zone NP17–NP18 boundary occurs within foraminiferal zone P14, whereas Proto Decima and others (1975) suggest correlation of the base of zone NP18 with the base of zone P14. Although there is a slight discrepancy among workers in the alignment of planktonic foraminiferal and nannofossil zones in this interval, the two sets of data are in basic agreement.

The overlying samples from the Twobar Shale Member (i.e., Mf1351, Mf3305, Mf1352, Mf3306, and Mf3308) yielded planktonic foraminiferal assemblages that are quite different from those recorded below. With the exception of one specimen each of "*Subbotina*" *senni* and *Truncorotaloides* aff. *T. rohri* detected in Mf3305, and two specimens of *Truncorotaloides* aff. *T. rohri* in Mf1351 (all probably reworked), taxa considered to be restricted to pre-zone P15 assemblages by Bolli (1957b, 1966) and Blow (1969) were not detected. New elements in the planktonic assemblages considered to be of biostratigraphic importance include the first occurrences of *Globigerina utilisindex*, *G. senilis*, and *G. praebulloides* in Mf1351. *Globigerina angiporoides angiporoides* is rare but present in samples Mf1352 and Mf3306. In addition, specimens very close to *Pseudohastigerina barbadoensis* occur in Mf1352

and *Globorotalia cerroazulensis cocoaensis* is present in Mf3306.

On the basis of the stratigraphic ranges of these taxa as documented by Blow (1969), Bolli (1966), Jenkins and Orr (1973), and Toumarkine and Bolli (1970, 1975), our preferred interpretation is to refer samples Mf1351 and Mf3305 to zonal interval P15–16 and samples Mf1352 and Mf3306 to zone P16. The planktonic foraminiferal assemblage recovered from Mf3308 is too meager to allow a zonal or zonal interval assignment.

Most workers (e.g., Berggren, 1972; Blow, 1969; Bolli, 1966, 1972; Roth and others, 1971; Toumarkine and Bolli, 1970, 1975) agree that these foraminiferal zones are of late Eocene age. Thus as delineated by planktonic foraminifers the middle Eocene-late Eocene boundary of international usage falls between our samples Mf3304 and Mf1351.

On the basis of the nannofossil assemblages detected in Sullivan's samples by Warren and Newell (in press), the *Discoaster saipanensis* Subzone-*D. barbadoensis* Zone boundary and thus the middle Eocene-late Eocene boundary is placed above Sullivan's sample B 2242. Accepting the interpretations of the planktonic foraminiferal data of this report and correlations of zones based on foraminifers with zones based on nannofossils determined elsewhere (e.g., Berggren, 1972; Proto Decima and others, 1975; Roth and others, 1971), one would expect to find the above-mentioned nannofossil zone boundary lower in the section, below Sullivan's sample B 2234.

Clearly additional work is needed to resolve this problem and to refine correlations between zonations based on these two groups of planktonic microfossils. The important point, however, is that although they differ somewhat in detail, the two, independently derived, sets of data suggest and agree that the middle Eocene-late Eocene boundary occurs within the Twobar Shale Member.

RICES MUDSTONE MEMBER

Samples from the Rices Mudstone Member yielding planktonic foraminifers are from a restricted interval within the lower half of the member (Figs. 2 and 3). The two best assemblages (Mf2700 and Mf2701) contain common representatives of *Globigerina angiporoides angiporoides* and abundant phylogenetically advanced representatives of *Globigerina ampliapertura*. Although both these species range from the late Eocene into the Oligocene, their association in abundance sug-

LITHO-STRATIGRAPHY	PLANKTONIC FORAMINIFERAL ZONE	AGE	BENTHONIC FORAMINIFERAL STAGE/ZONE
NOT STUDIED			
SAN LORENZO FORMATION	XXXX P19-P20	OLIGOCENE	ZEMORRIAN <i>Uvigerina gallowayi</i> ZONE
TWOBAR SHALE MEMBER	X P16 X P15-P16 X P14	E O C E N E L A T E	"UPPER" REFUGIAN <i>Uvigerina vicksburgensis</i> ZONE ?
UPPER PART OF BUTANO SANDSTONE	X X P13-P14 X P13-P14 ?	M I D D L E	N A R I Z I A N <i>Amphimorphina jenkinsi</i> ZONE +?

FIGURE 3

Schematic diagram showing relationship between lithologic units, provincial benthonic foraminiferal stages and zones, planktonic foraminiferal zones, and age assignments. Age assignments based on planktonic foraminifers follow correlations of Berggren (1972). Benthonic stage and zone assignments have been slightly modified from Sullivan (1962). The extension of the *Amphimorphina jenkinsi* Zone below the base of the Two-bar Shale Member follows the report of Schenck (1936) of *Amphimorphina jenkinsi* from the upper Butano adjacent to our section. Sample Mf3308 (~6 ft below base of Rices Mudstone Member) yielded an upper Narizian ben-

gests an Oligocene age. The presence of forms close to *Globigerina ciperoensis* in Mf2701 agrees with this interpretation as *G. ciperoensis* first occurs within the lower part of P19-P20 combined interval (Berggren, 1972; Blow, 1969, 1970). Bukry and others (in press) report a nannofossil assemblage indicative of the Oligocene *Sphenolithus predistentus*-*S. ciperoensis* Zones from a sample approximately equivalent to Mf1366 and Mf3310. These nannofossil zones (= NP23-NP25) are correlated by Berggren (1972) to foraminiferal zones P19-P22. And, since the last occurrence of *Globigerina ampliapertura* approximates the base of zone P21 (base of P21 = base of NP24), our preferred interpretation is to assign our samples from this interval of the Rices Mudstone Member to zones P19-P20, and therefore consider them to be of Oligocene age.

Assuming a late Eocene age for the basal (Refugian) part of the Rices Mudstone Member (see following section), it follows that the Eocene-Oligocene boundary occurs in the lower part of the member just below our samples. We, therefore, have tentatively drawn the Eocene-Oligocene boundary at the Refugian-Zemorrian contact on Fig. 3.

CORRELATIONS WITH PROVINCIAL BENTHONIC FORAMINIFERAL STAGES

Correlations and age interpretations of Paleogene marine strata of the Pacific Coast are usually accomplished through the use of the provincial benthonic foraminiferal stages of Mallory (1959), Kleinpell (1938), and Schenck and Kleinpell (1936). In recent years, several workers (e.g., Berggren, 1972; Gibson, 1976; Lipps, 1967; Schmidt, 1975; Bukry and others, in press) have tried to correlate these provincial subdivisions of the Cenozoic with internationally recog-

thonic foraminiferal assemblage (K. McDougall, pers. comm., 1976). Thus the Narizian-Refugian boundary is arbitrarily placed at the contact between the Two-bar Shale and the Rices Mudstone Members. Since Kleinpell and Weaver (1963) indicate that the first occurrence of *Eponides kleinpelli* is within the *Uvigerina vicksburgensis* Zone of the Refugian Stage, the Refugian part of the Rices has been tentatively assigned to the *U. vicksburgensis* Zone on the basis of Sullivan's (1962) record of *Eponides kleinpelli* at the base of this interval. This interpretation, which suggests that the lower Refugian (*Uvigerina cocoensis* Zone) is missing in this section, combined with the presence of a glauconite-rich bed at the base of the Rices Mudstone Member, suggests that a hiatus exists between the two members.

nized subdivisions through the intermediary of planktonic microfossils. Although a complete review of these correlations is beyond the scope of this work, our data from the type San Lorenzo Formation do bear on one important point of correlation (Fig. 3).

The Narizian Stage has been shown on the basis of nannofossils and planktonic foraminifers to extend at least to the base of the middle Eocene (Schmidt, 1965; Gibson, 1976; Bukry and others, in press; Poore, 1976). Similarly the overlying Refugian Stage has been shown, on the basis of nannofossils and planktonic foraminifers, to be of late Eocene age (Lipps, 1967; Brabb and others, 1971; Warren and Newell, in press). But placement of the middle Eocene-late Eocene boundary within this interval, to date, has remained speculative.

Our data from the type San Lorenzo Formation in concert with the benthonic foraminiferal data of Sullivan (1962) indicate that the middle Eocene-late Eocene boundary of international usage occurs within the *Amphimorphina jenkinsi* Zone of the Narizian Stage.

ACKNOWLEDGMENTS

We thank W. V. Sliter and W. O. Addicott for reading a draft of this manuscript and making helpful suggestions. Micrographs were taken with a Cambridge SEM operated by R. L. Oscarson. We thank S. E. Murphy for technical assistance throughout this project, C. Beaver for assistance in measuring the section, and K. McDougall for examination of benthonic foraminifers from several samples. W. N. Orr and W. A. Berggren kindly provided opinions on some of the taxa recorded in this study. Special thanks are due A. D. Warren and J. H. Newell for allowing us access to as yet unpublished data on nannofossils from the San Lorenzo Formation.

TAXONOMIC NOTES

Planktonic foraminifers recorded during this study are listed below. Additional references and comments are provided for selected taxa.

Catapsydrax primitiva (Blow and Banner)
Pl. 3, Fig. 9

Globigerinita unicava primitiva BLOW and BANNER, 1965, p. 114, pl. XIV, figs. J-L.

Chiloguembelina cubensis (Palmer)

Gümbelina cubensis PALMER, 1934, p. 74, figs. 1-6.

Clavigerinella sp.

Pl. 3, Fig. 10

Specimens recovered from the Butano Sandstone are broken and poorly preserved.

Globigerina ampliapertura Bolli

Pl. 1, Figs. 7-9

Globigerina ampliapertura BOLLI, 1957a, p. 108, pl. 22, figs. 5a-7b, not fig. 4a-b.

Globigerina angiporoides angiporoides Hornibrook

Pl. 1, Figs. 1-4

Globigerina angiporoides HORNIBROOK, 1965, p. 835, figs. 1a-i, 2.

The final chamber of this taxon is smaller than the penultimate chamber. The final chamber is often drawn down over the umbilical region. The aperture is a low slit, bordered by a distinct lip. As compared to *G. angiporoides minima*, *G. angiporoides angiporoides* is more tightly coiled and many specimens exhibit three chambers in the final whorl. In younger populations the final chamber of this taxon may be highly variable, and in some specimens it can take on the aspect of a bulla (Pl. 1, Fig. 4).

Globigerina angiporoides minima Jenkins

Pl. 1, Figs. 5-6

Globigerina angiporoides minima JENKINS, 1966, p. 1096, fig. 7, p. 52-57.

Globigerina angustiumbilitata Bolli

Pl. 8, Fig. 6

Globigerina ciperoensis angustiumbilitata BOLLI, 1957a, p. 109, pl. 22, figs. 12-13.

Globigerina aff. *G. ciperoensis* Bolli

Pl. 8, Fig. 7

Globigerina ciperoensis BOLLI, 1954, p. 1, figs. 3-6.

Specimens referred to this taxon in sample Mf2701 appear to be morphologically transitional forms between *G. angustiumbilitata* and *G. ciperoensis*.

Globigerina eocaena Gümbel (s.l.)

Pl. 4, Figs. 10-12

Globigerina eocaena GÜMBEL, 1868, p. 662, pl. 2, Figs. 109a-b.

Globigerina eocaena Gümbel. HAGN and LINDENBERG, 1969, p. 236, pl. 1, figs. 1-6.

The concept of *Globigerina eocaena* as revised by Hagn and Lindenberg (1966; 1969) encompasses forms recorded under several different names by various authors. As noted by Stainforth and others (1975), it is unusual for any two workers to treat this group in the same manner and at this time the biostratigraphic utility of these globigerinids is questionable. For the purpose of this study, specimens referable to *Globigerina yeguaensis* Weinzierl and Applin, *Globigerina galavisi* Bermúdez, *Globigerina corpulenta* Subbotina (= ?*Globigerina cryptomphala* Glaessner) and large generalized globigerinids have been recorded under the heading of *Globigerina eocaena* (s.l.).

***Globigerina officinalis* Subbotina**

Globigerina officinalis SUBBOTINA, 1953, pl. 11, figs. 1–7.

***Globigerina ouachitaensis* Howe and Wallace**
Pl. 5, Figs. 1–2; Pl. 8, Fig. 8

Globigerina ouachitaensis HOWE and WALLACE, 1932, p. 83, pl. 12, figs. 18–19.

Small, three-chambered forms (Pl. 8, Fig. 8) detected in several samples from the Twobar Shale Member are considered to represent atypical specimens of *G. ouachitaensis*.

***Globigerina praebulloides* Blow**
Pl. 7, Figs. 6–7

Globigerina praebulloides BLOW, 1959, p. 180, pl. 8, fig. 47, pl. 9, fig. 48.

Occasional specimens referable to *Globigerina praebulloides leroyi* Blow and Banner are recorded together with *G. praebulloides praebulloides* in Table 2 as *G. praebulloides* (s.l.).

***Globigerina praeturritilina* Blow and Banner**

Globigerina turritilina praeturritilina BLOW and BANNER, 1962, p. 99, pl. XIII, figs. A–C.

***Globigerina pseudovenezuelana* Blow and Banner**
Pl. 4, Figs. 8–9

Globigerina yeguaensis pseudovenezuelana BLOW and BANNER, 1962, p. 100, pl. XI, figs. J–L, N, O.

Globigerina venezuelana Hedberg. BOLLI, 1957b, p. 164, pl. 35, figs. 16–17.

***Globigerina senilis* Bandy**
Pl. 8, Figs. 10–11

Globigerina ouachitaensis senilis BANDY, 1949, p. 121, pl. 22, figs. 5a–c.

***Globigerina tripartita* Koch**

Globigerina bulloides tripartita KOCH, 1926, p. 746, fig. 21.

***Globigerina* sp. 1**
Pl. 3, Figs. 5–6

Two small, poorly preserved specimens of this form were detected. The specimens exhibit an umbilical-extraumbilical aperture, radially elongate chambers and are coiled in a low trochospiral.

***Globigerina utilisindex* Jenkins and Orr**
Pl. 7, Figs. 8–10.

Globigerina utilisindex JENKINS and ORR, 1973, p. 133, pl. 1, figs. 1–6, pl. 2, figs. 1–9, pl. 3, figs. 1–3.

This form has 3 to 3½ well-rounded chambers in the final whorl. The chambers increase fairly rapidly in size; the final chamber often making up half of the final whorl.

PLATE 1

Note that scale bars (delineated by white dots) are not uniform.

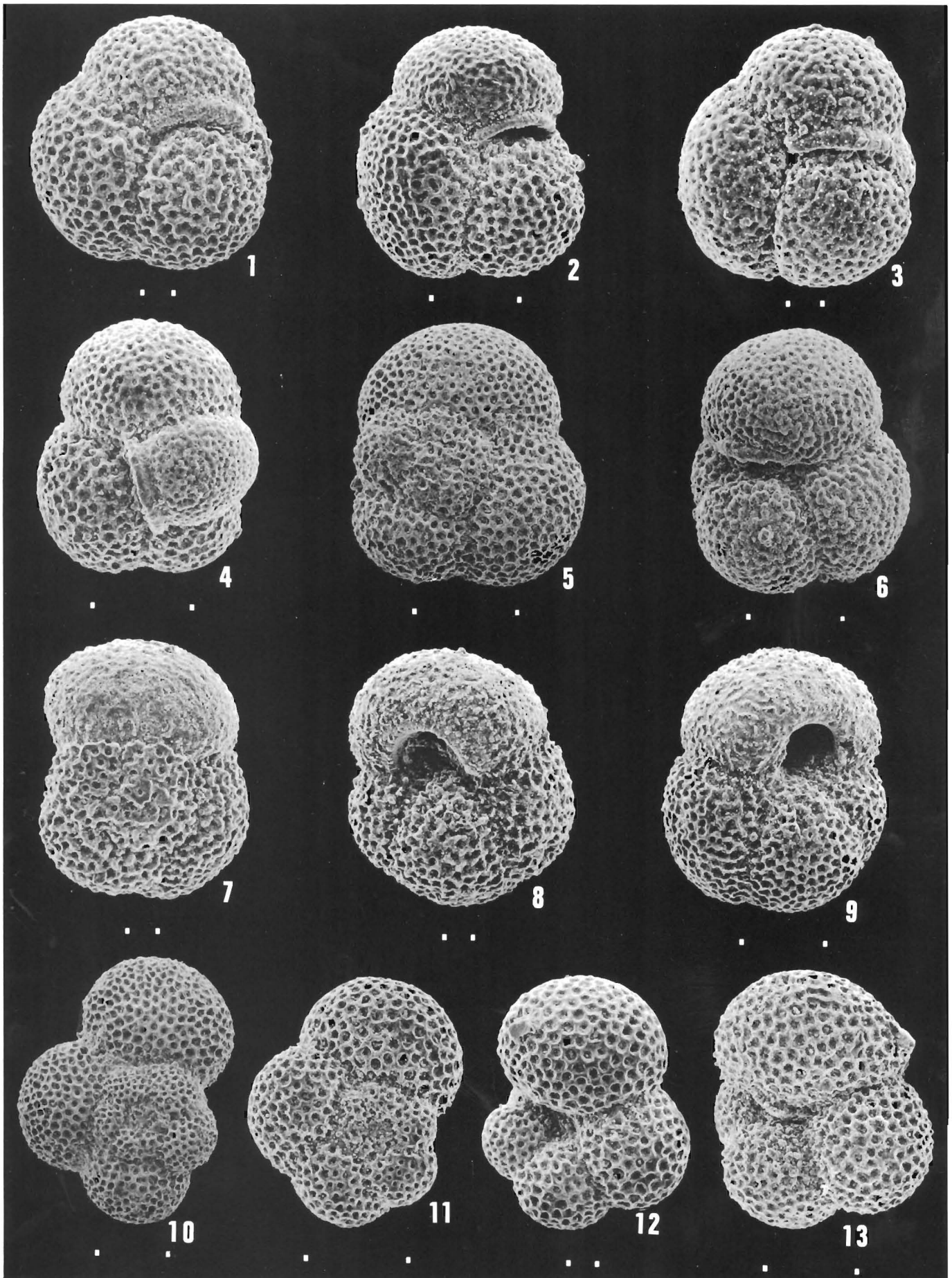
1–4 *Globigerina angiporoides angiporoides* Hornibrook. All specimens from Mf2701. 1. Umbilical view, scale bar = 30 µm. 2. Oblique umbilical view, scale bar = 100 µm. 3. Umbilical view, scale bar = 30 µm. 4. Umbilical view of specimen showing reduced “bulla-like” final chamber, scale bar = 100 µm.

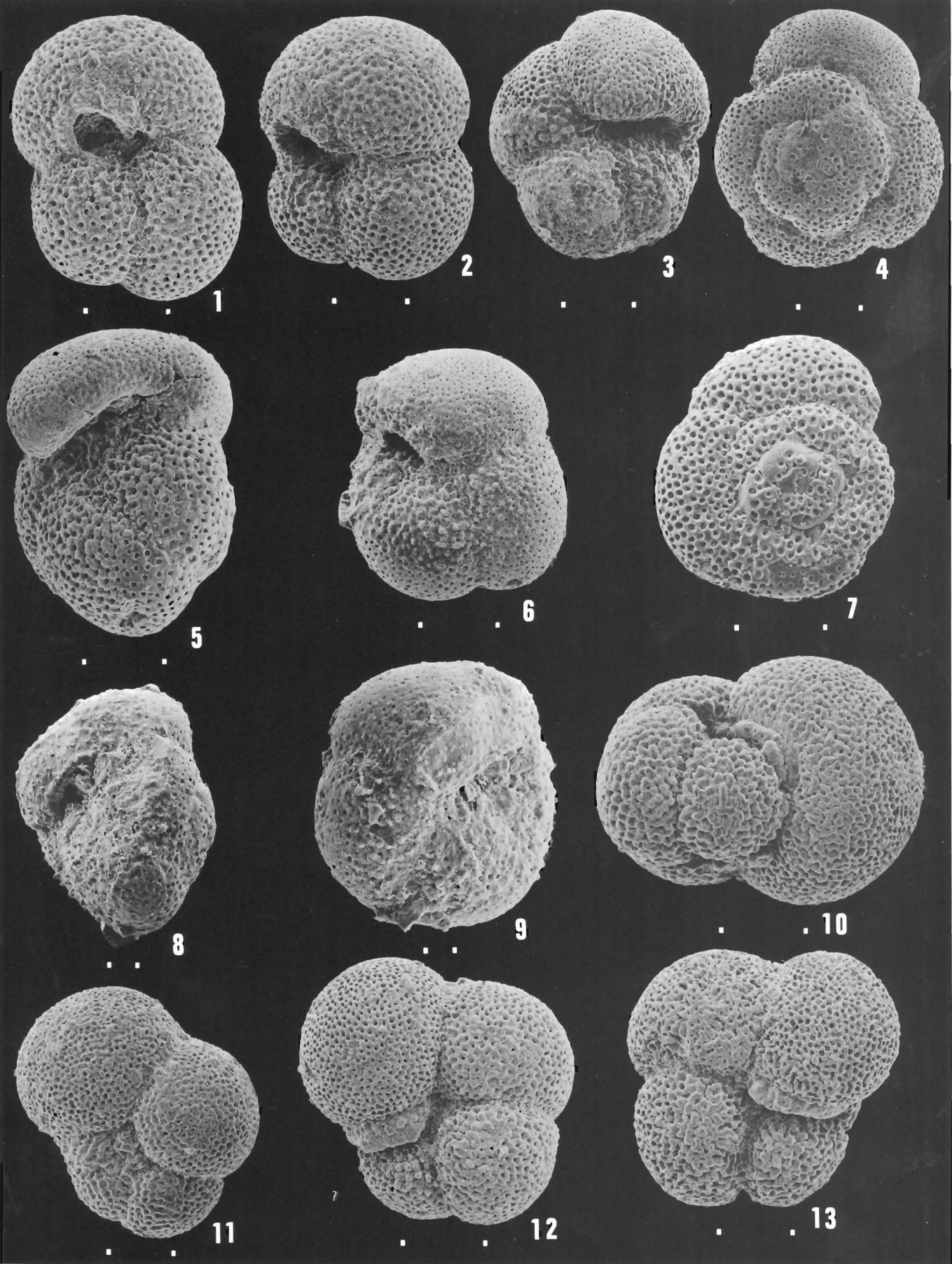
5–6 *Globigerina angiporoides minima* Jenkins. Both specimens from Mf1351. 5. Spiral view, scale bar = 100 µm. 6. Umbilical view, scale bar = 100 µm.

7–9 *Globigerina ampliapertura* Bolli. All specimens from Mf2701. 7. Spiral view, scale bar = 30 µm. 8. Umbilical view, scale bar = 30 µm. 9. Umbilical view, scale bar = 100 µm.

10 *Globorotaloides suteri* Bolli, “lobate form.” Spiral view of specimen from Mf3304, scale bar = 100 µm.

11–13 *Globorotaloides suteri* Bolli. All from Mf2701. 11. Spiral view, scale bar = 100 µm. 12. Umbilical view, scale bar = 30 µm. 13. Umbilical view, scale bar = 100 µm.





Globigerinatheka index (Finlay) (s.l.)

Pl. 4, Figs. 5–7

Globigerinoides index FINLAY, 1939a, p. 125, pl. 14, figs. 85–88.Forms close to *G. index tropicalis* Blow and Banner occur in sample Mf1350. For the purposes of this report they have been included with *G. index index* in Table 2.**Globigerinatheka mexicana barri** Brönniman

Pl. 4, Figs. 3–4; Pl. 7, Fig. 3

Globigerinatheka barri BRÖNNIMANN, 1952, p. 27, text-figs. 3a–c, g–h; not 3d–f.Representatives of the *Globigerinatheka mexicana* plexus are very common in samples Mf3301 and Mf3304. Individuals comprising the populations are uniformly small (most specimens ~0.38 mm maximum diameter; maximum diameter of largest specimen observed approximately 0.42 mm), fairly compact, and most exhibit moderately incised sutures. Bullate specimens are abundant within the populations indicating the presence of the subspecies *G. mexicana barri* (Bolli, 1972). Specimens with final chambers comprising $\frac{1}{2}$ to $\frac{3}{4}$ of the test are referred to the subspecies *G. mexicana mexicana*. There is a complete gradation between bullate and nonbullate forms.**Globigerinatheka mexicana mexicana** (Cushman)

Pl. 4, Figs. 1–2

Globigerina mexicana CUSHMAN, 1925a, p. 6, Pl. 1, Fig. 8.**Globigerinita martini martini** Blow and Banner

Pl. 7, Fig. 4

Globigerinita martini martini BLOW and BANNER, 1962, p. 110, pl. XIV, fig. O.**Globigerinita martini scandretti** Blow and Banner

Pl. 7, Fig. 5

Globigerinita martini scandretti BLOW and BANNER, 1962, p. 111, pl. XIV, figs. V–X.**Globigerinita pera** (Todd)*Globigerina pera* TODD, 1957, p. 301, pl. 70, figs. 10–11.**"Globigerinoides" higginsii** Bolli

Pl. 8, Figs. 9, 12–13

"Globigerinoides" higginsii BOLLI, 1957b, p. 164, pl. 36, figs. 11–13.

Generic assignment of this taxon is still in doubt.

Globorotalia cerroazulensis cerroazulensis (Cole)

Pl. 2, Figs. 5–7

Globigerina cerroazulensis COLE, 1928, p. 17, pl. 1, figs. 11–13.*Globorotalia cerroazulensis cerroazulensis* Cole. TOUMARKINE and BOLLI, 1970, p. 144, pl. 1, figs. 19–24, pl. 2, figs. 3, 4, 20–25.**Globorotalia cerroazulensis cocoaensis** Cushman

Pl. 2, Figs. 8–9

Globorotalia cocoaensis CUSHMAN, 1928, p. 75, pl. 10, fig. 3.*Globorotalia cerroazulensis cocoaensis* Cushman. TOUMARKINE and BOLLI, 1970, p. 144, pl. 1, figs. 28–33, pl. 2, figs. 5–8, 27–28.**Globorotalia cerroazulensis frontosa** (Subbotina)

Pl. 2, Figs. 1–2; Pl. 7, Fig. 11

Globigerina frontosa SUBBOTINA, 1953, p. 84, pl. 12, figs. 3–7.

←

PLATE 2

Note that scale bars (delineated by white dots) are not uniform.

- 1–2 *Globorotalia cerroazulensis frontosa* (Subbotina). 1. Oblique umbilical view of specimen from Mf3304, scale bar = 100 μ m. 2. Umbilical view of 1, scale bar = 100 μ m.
- 3–4 *Globorotalia cerroazulensis pomeroli* Toumarkine and Bolli. Both specimens from Mf3304. 3. Umbilical view, scale bar = 100 μ m. 4. Spiral view, scale bar = 100 μ m.
- 5–7 *Globorotalia cerroazulensis cerroazulensis* (Cole). All specimens from Mf1350. 5. Side view, scale bar =

- 100 μ m. 6. Umbilical view, scale bar = 100 μ m. 7. Spiral view, scale bar = 100 μ m.
- 8–9 *Globorotalia cerroazulensis cocoaensis* Cushman. 8. Side view of specimen from Mf3306, scale bar = 30 μ m. 9. Umbilical view of 8, scale bar = 30 μ m.
- 10–13 *Globorotaloides wilsoni* (Cole). All specimens from Mf1350. 10. Side view, scale bar = 100 μ m. 11. Oblique spiral view, scale bar = 100 μ m. 12. Umbilical view, scale bar = 100 μ m. 13. Umbilical view, scale bar = 100 μ m.

In their delineation of the *Globorotalia cerroazulensis* lineage, Toumarkine and Bolli (1970) placed *Globigerina boweri* Bolli in synonymy with *G. frontosa* Subbotina and considered *Globorotalia cerroazulensis frontosa* as the first representative of the lineage. The concepts of their work are adopted in this study.

Globorotalia cerroazulensis pomeroli

Toumarkine and Bolli

Pl. 2, Figs. 3–4

Globorotalia cerroazulensis pomeroli TOUMARKINE and BOLLI, 1970, p. 140, pl. 1, figs. 10–18, pl. 2, figs. 1, 2, 11–19.

Globorotalia cerroazulensis possagnoensis

Toumarkine and Bolli

Pl. 7, Fig. 14

Globorotalia cerroazulensis possagnoensis TOUMARKINE and BOLLI, 1970, p. 139, pl. 1, figs. 4–9.

Of the members of the *Globorotalia cerroazulensis* lineage defined by Toumarkine and Bolli (1970), this taxon is the least distinctive. Identification of this form in our material was based primarily on the illustration of Delteil and Toumarkine (1975).

***Globorotalia gemma* Jenkins**

Pl. 8, Figs. 1–4

Globorotalia gemma JENKINS, 1966, p. 1115, fig. 11, nos. 97–103.

In samples Mf2700 and 2701 forms were encountered that appeared intermediate between *Globorotalia gemma* and *Globigerina angustiumbilitata*. It is likely that this situation is induced by poor preservation.

***Globorotalia increbescens* (Bandy)**

Globigerina increbescens BANDY, 1949, p. 120, pl. 23, fig. 3a–c.

One specimen referable to this species was found.

***Globorotalia opima nana* Bolli**

Globorotalia opima nana BOLLI, 1957a, p. 118, pl. 28, fig. 3.

Globorotaloides carcoselleensis Toumarkine and Bolli
Pl. 5, Figs. 3–4; Pl. 7, Figs. 1–2

Globorotaloides carcoselleensis TOUMARKINE and BOLLI, 1975, p. 81, pl. 5, figs. 23–28.

Our specimens appear identical to *Globorotaloides carcoselleensis* described from the Possagno section in Italy (Toumarkine and Bolli, 1975). The occurrence of *Globorotalia cerroazulensis cocoaensis* with *Globorotaloides carcoselleensis* in sample Mf3306 suggests that the upper limit of the range of *G. carcoselleensis* in our section and the Possagno section is approximately the same. This taxon has also been recorded from the middle Eocene horizons at Pacific DSDP Site 313 (Toumarkine, 1975).

***Globorotaloides* sp. 1**

This form is larger and exhibits more chambers in the final whorl than *Globorotaloides carcoselleensis*. In other aspects, however, the two forms are fairly similar and may be closely related.

***Globorotaloides suteri* Bolli**

Pl. 1, Figs. 10–13

Globorotaloides suteri BOLLI, 1957a, p. 117, pl. 27, figs. 9a–13b.

PLATE 3

Note that scale bars (delineated by white dots) are not uniform.

1–4 *Globorotaloides* sp. 1. All specimens from Mf3301.

1. Umbilical view, scale bar = 100 μ m. 2. Side view, scale bar = 30 μ m. 3. Spiral view, scale bar = 100 μ m. 4. Umbilical view, scale bar = 30 μ m.

5–6 *Globigerina* sp. 1. Both specimens from Mf1351. 5. Spiral view, scale bar = 30 μ m. 6. Umbilical view, scale bar = 100 μ m.

7 *Hantkenina alabamensis* Cushman. Side view of specimen from Mf3304, scale bar = 100 μ m.

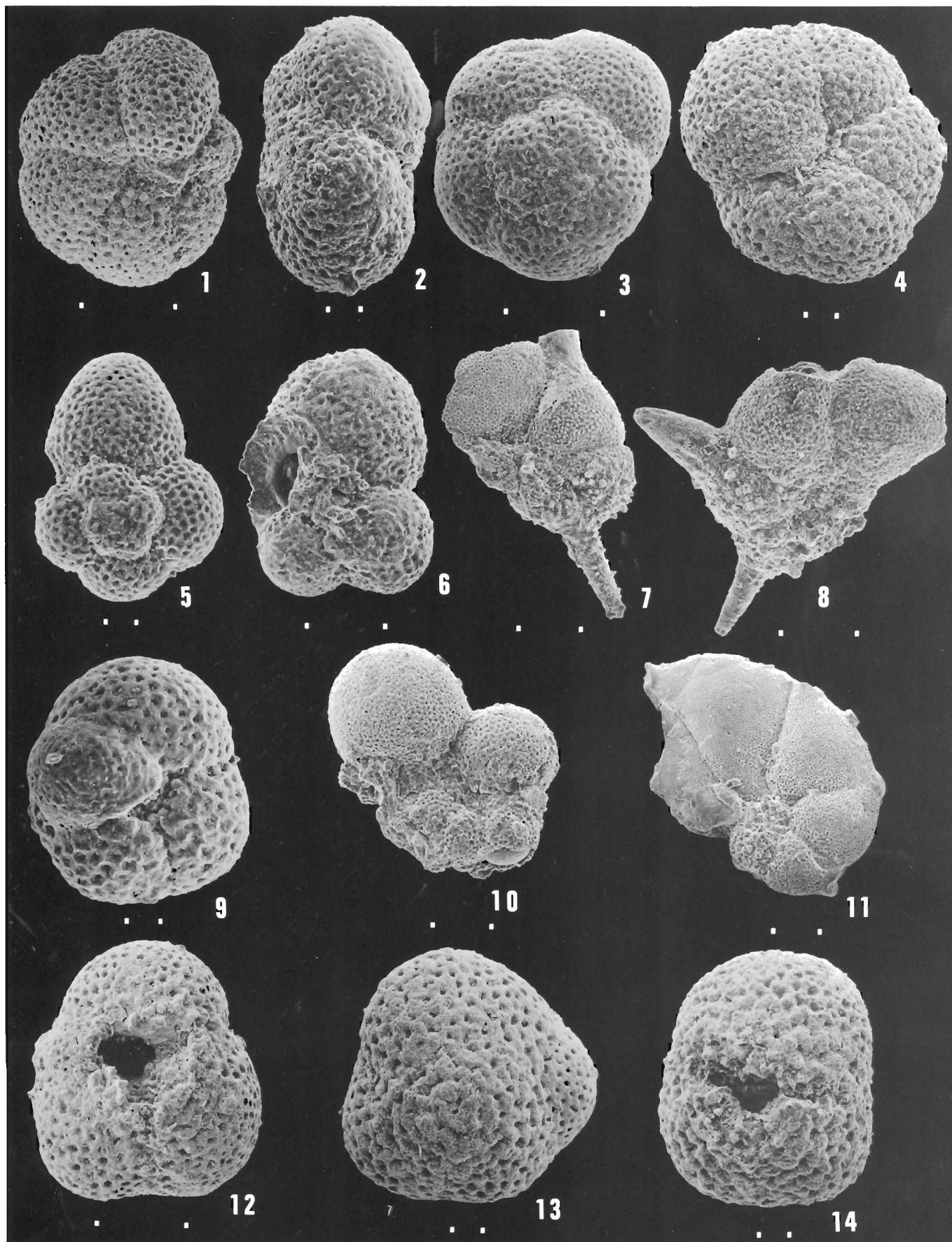
8 *Hantkenina* sp. Side view of specimen from Mf3304, scale bar = 100 μ m.

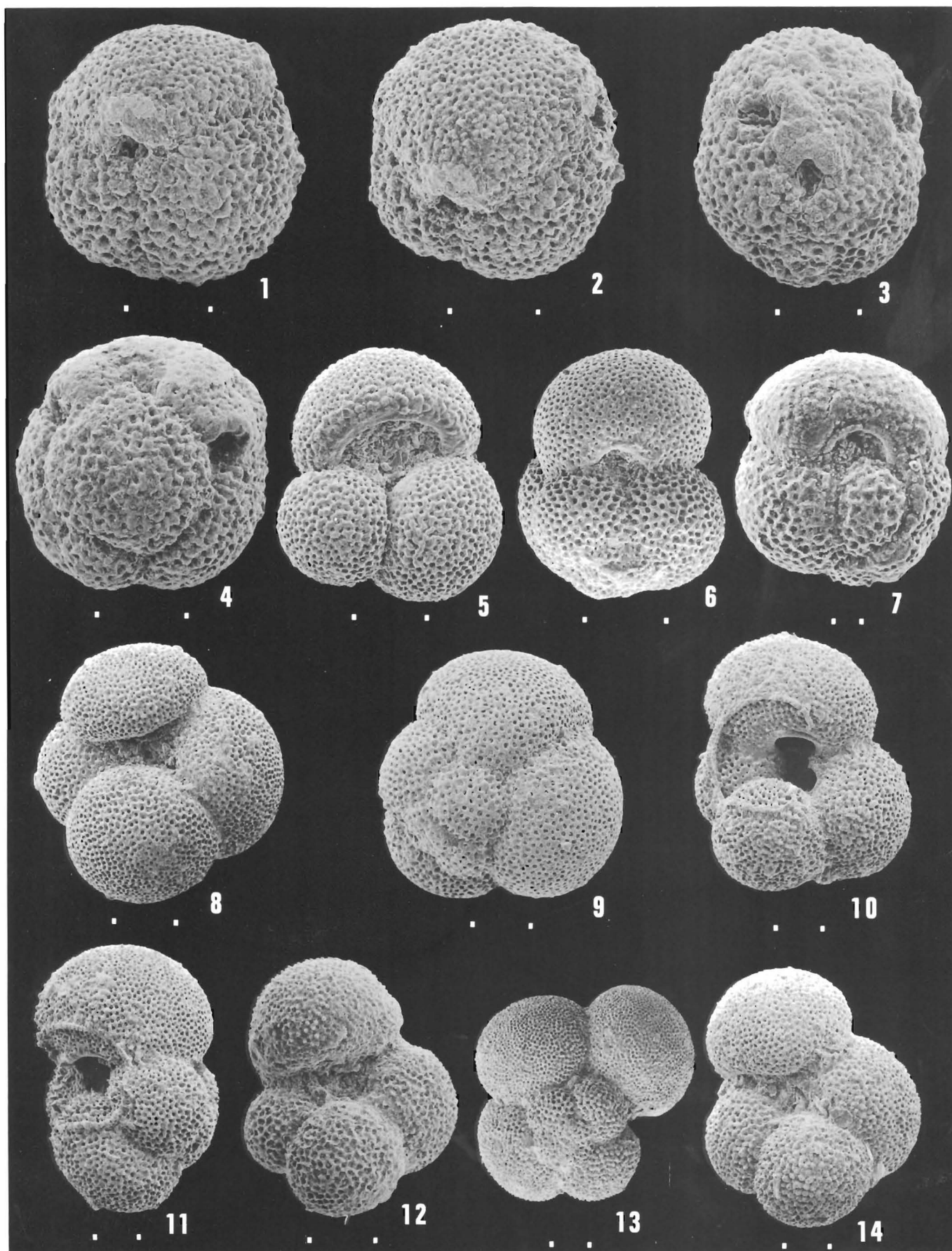
9 *Catapsydrax primitiva* (Blow and Banner). Umbilical view of specimen from Mf1351, scale bar = 30 μ m.

10 *Clavigerinella* sp. Side view of specimen from Mf3299, scale bar = 100 μ m.

11 *Hantkenina dumblei* Weinzierl and Applin. Side view specimen from Mf1350, scale bar = 100 μ m.

12–14 “*Subbotina*” *senni* (Beckmann). All specimens from Mf3304. 12. Umbilical view, scale bar = 100 μ m. 13. Spiral view, scale bar = 30 μ m. 14. Umbilical view, scale bar = 30 μ m.





Several samples from the Twobar Shale Member yielded specimens of *Globorotalia suteri* showing a tendency to develop separated chambers resulting in a distinct lobate equatorial outline not normally observed in this species. These forms clearly grade into more typical specimens of *G. suteri* exhibiting a rounded equatorial outline. Occurrence of the "lobate form" of *G. suteri* is listed separately in Table 2.

***Globorotaloides wilsoni* (Cole)**

Pl. 2, Figs. 10–13

Globigerina wilsoni COLE, 1927, p. 34, pl. 4, figs. 8–9. *Globorotalia bolivariana* (Petters). BOLLI, 1957b, p. 169, pl. 37, figs. 14–16.

Comparison by Poore of Bolli's hypotypes of "*bolivariana*" with Petters' holotype confirms previous suggestions (Gohrbandt, 1967; Beckmann, 1971) that Bolli's specimens are referable to *G. wilsoni*. The holotype of *G. bolivariana* is involute, whereas Bolli's specimens show at least one chamber of the penultimate whorl when viewed from the spiral side. This taxon exhibits a great deal of variability in samples from the Twobar Shale Member. Sample Mf1350 yielded heavily encrusted specimens almost identical to Bolli's hypotypes. Populations of *G. wilsoni* from samples higher in the section are thinner walled, and many specimens have between 4½ and 5 chambers in the final whorl.

***Hantkenina alabamensis* Cushman**

Pl. 3, Fig. 7

Hantkenina alabamensis CUSHMAN, 1925b, p. 3, pl. 1, figs. 1–6, pl. 2, fig. 5; text-fig. 1.

***Hantkenina dumblei* Weinzierl and Applin**

Pl. 3, Fig. 11

Hantkenina dumblei WEINZIERL and APPLIN, 1929, p. 402, pl. 43, fig. 5.

***Hantkenina* sp. (spp.)**

Pl. 3, Fig. 8

Several small, poorly preserved specimens and fragments of *Hantkenina* recovered from Mf3304 could not be allocated to any particular species.

***Morozovella lehneri* (Cushman and Jarvis)**

Pl. 8, Figs. 14–15

Globorotalia lehneri CUSHMAN and JARVIS, 1929, pl. 3, fig. 16.

Only one specimen of this taxon was found. Although the specimen does not exhibit radially elongate chambers normally associated with *M. lehneri*, it does compare favorably with several specimens of *M. lehneri* illustrated by Bolli (1957b) from the Navet Formation of Trinidad.

***Morozovella* sp. 1**

Pl. 6, Figs. 7–8

This form is similar to early Eocene species such as *Morozovella aequa* (Cushman and Renz). Most specimens have 3½ to 4 chambers in the outer wall, and some show an aborted bulla-like final chamber (Pl. 7, Fig. 8). A weakly developed keel composed of fused spines is present on all specimens.

PLATE 4

Note that scale bars (delineated by white dots) are not uniform.

- 1–2 *Globigerinatheka mexicana mexicana* (Cushman). 1. Side view of specimen from Mf3304, scale bar = 100 µm. 2. Oblique side view of 1, scale bar = 100 µm.
- 3–4 *Globigerinatheka mexicana barri* Brönnimann. Both from Mf3304. 3. Oblique side view, scale bar = 100 µm. 4. Oblique side view, scale bar = 100 µm.
- 5–6 *Globigerinatheka index* (Finlay) (s.l.). Both from Mf1350. 5. Umbilical view, scale bar = 100 µm. 6. Side view, scale bar = 100 µm. These specimens are close to *G. index tropicalis* Blow and Banner.
- 7 ?*Globigerinatheka index* (Finlay). Side view of single specimen found in Mf2701, scale bar = 30 µm.

- 8–9 *Globigerina pseudovenezuelana* Blow and Banner. 8. Umbilical view of specimen from Mf3304, scale bar = 100 µm. 9. Spiral view of specimen from Mf1350, scale bar = 100 µm.
- 10–12 *Globigerina eocaena* Gümbel (s.l.). 10. Umbilical view of specimen from Mf3304, scale bar = 100 µm. 11. Side view of specimen from Mf3304, scale bar = 100 µm. These specimens represent *Globigerina yeguaensis* Weinzierl and Applin forms. 12. Umbilical view of "generalized" form from Mf3305, scale bar = 100 µm.
- 13–14 *Subbotina hagni* (Gohrbandt). Both from Mf3301. 13. Spiral view, scale bar = 100 µm. 14. Umbilical view, scale bar = 100 µm.

Morozovella sp. 2
Pl. 6, Figs. 9–12

This form has 4 to 4½ chambers in the final whorl, and the umbilical side is more inflated than that of *Morozovella* sp. 1. Development of a keel is variable in specimens included to this category and it is possible

that more than one taxonomic unit has been included in this group.

Planorotalites pseudoscitula (Glaessner)
Pl. 7, Figs. 12–13

Globorotalia pseudoscitula GLAESSNER, 1937, p. 32, fig. 3a–c.

PLATE 5

Note that scale bars (delineated by white dots) are not uniform.

- 1–2 *Globigerina ouachitaensis* Howe and Wallace. Both from Mf2701. 1. Spiral view, scale bar = 30 µm. 2. Umbilical view, scale bar = 30 µm.
3–4 *Globorotaloides carcoselleensis* Toumarkine and Bolli. Both from Mf3304. 3. Umbilical view, scale bar = 30 µm. 4. Side view, scale bar = 30 µm.
5–7 *Truncorotaloides collactea* (Finlay). 5. Spiral view of specimen from Mf3301, scale bar = 30 µm. 6. Umbilical view of specimen from Mf3301, scale bar = 30 µm. 7. Spiral view of specimen from

- Mf3304, scale bar = 30 µm. Dark area at base of final chamber is *not* a sutural aperture.
8–9 *Subbotina linaperta* (Finlay). 8. Umbilical view of specimen from Mf3304, scale bar = 100 µm. 9. Oblique umbilical view of specimen from Mf3301, scale bar = 30 µm.
10 ?*Catapsydrax* sp. Side view of specimen from Mf1351, scale bar = 30 µm. Note presence of 2 apertures.
11–13 *Truncorotaloides bullbrookii* (Bolli). All from Mf3301. 11. Spiral view, scale bar = 100 µm. 12. Umbilical view, scale bar = 100 µm. 13. Side view, scale bar = 100 µm.

PLATE 6

Note that scale bars (delineated by white dots) are not uniform.

- 1–3 *Truncorotaloides topilensis* (Cushman). All from Mf1350. 1. Spiral view, scale bar = 100 µm. 2. Side view, scale bar = 100 µm. 3. Umbilical view, scale bar = 100 µm.
4–6 *Truncorotaloides rohri* Brönnimann and Bermúdez. All from Mf1350. 4. Spiral view, scale bar = 30 µm. At least two sutural apertures are present. 5. Side

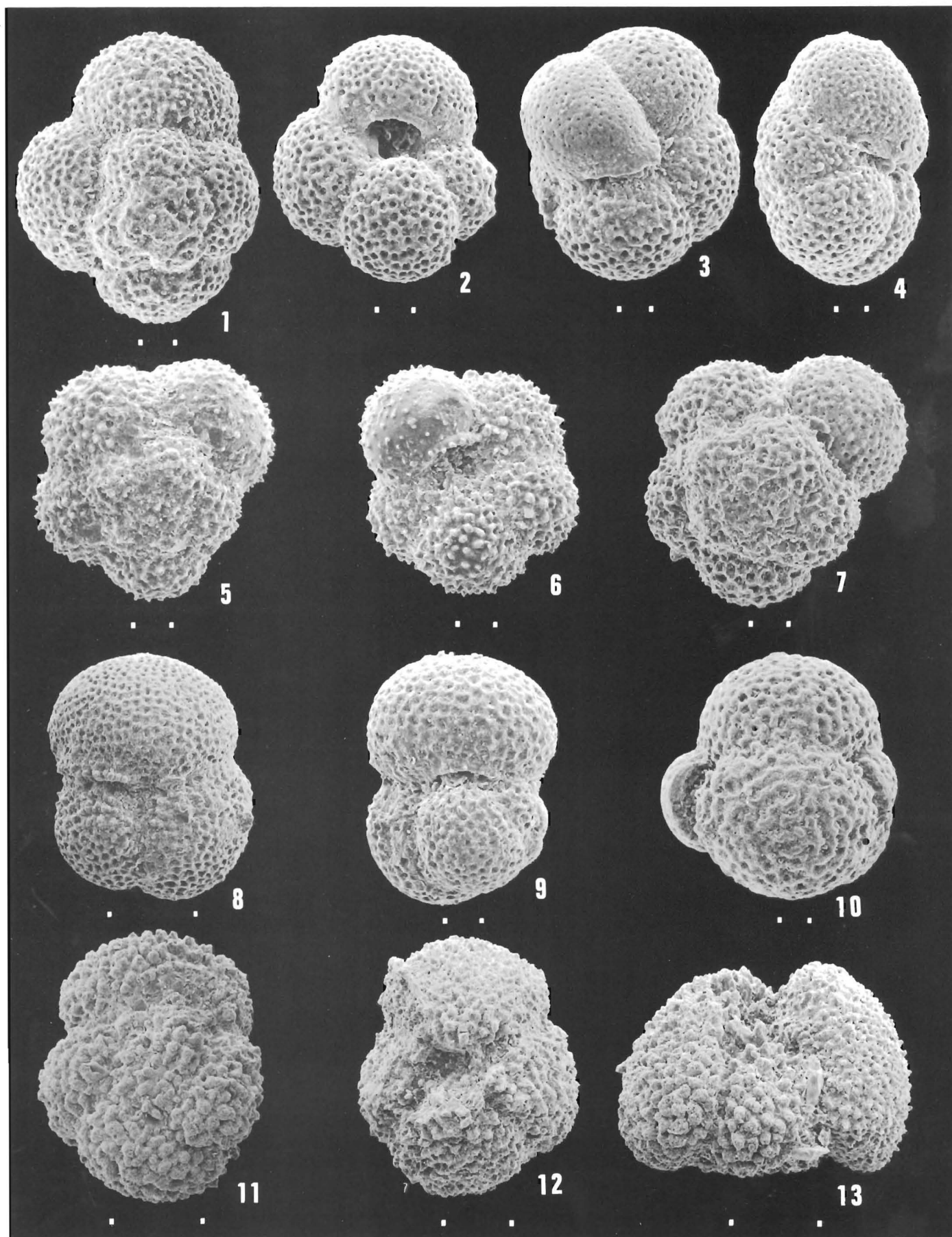
- view, scale bar = 100 µm. 6. Umbilical view, scale bar = 100 µm.
7–8 *Morozovella* sp. 1. Both from Mf3301. 7. Spiral view, scale bar = 100 µm. 8. Umbilical view, scale bar = 100 µm.
9–12 *Morozovella* sp. 2. All from Mf3301. 9. Spiral view, scale bar = 100 µm. 10. Side view, scale bar = 100 µm. 11. Spiral view, scale bar = 100 µm. 12. Umbilical view, scale bar = 100 µm.

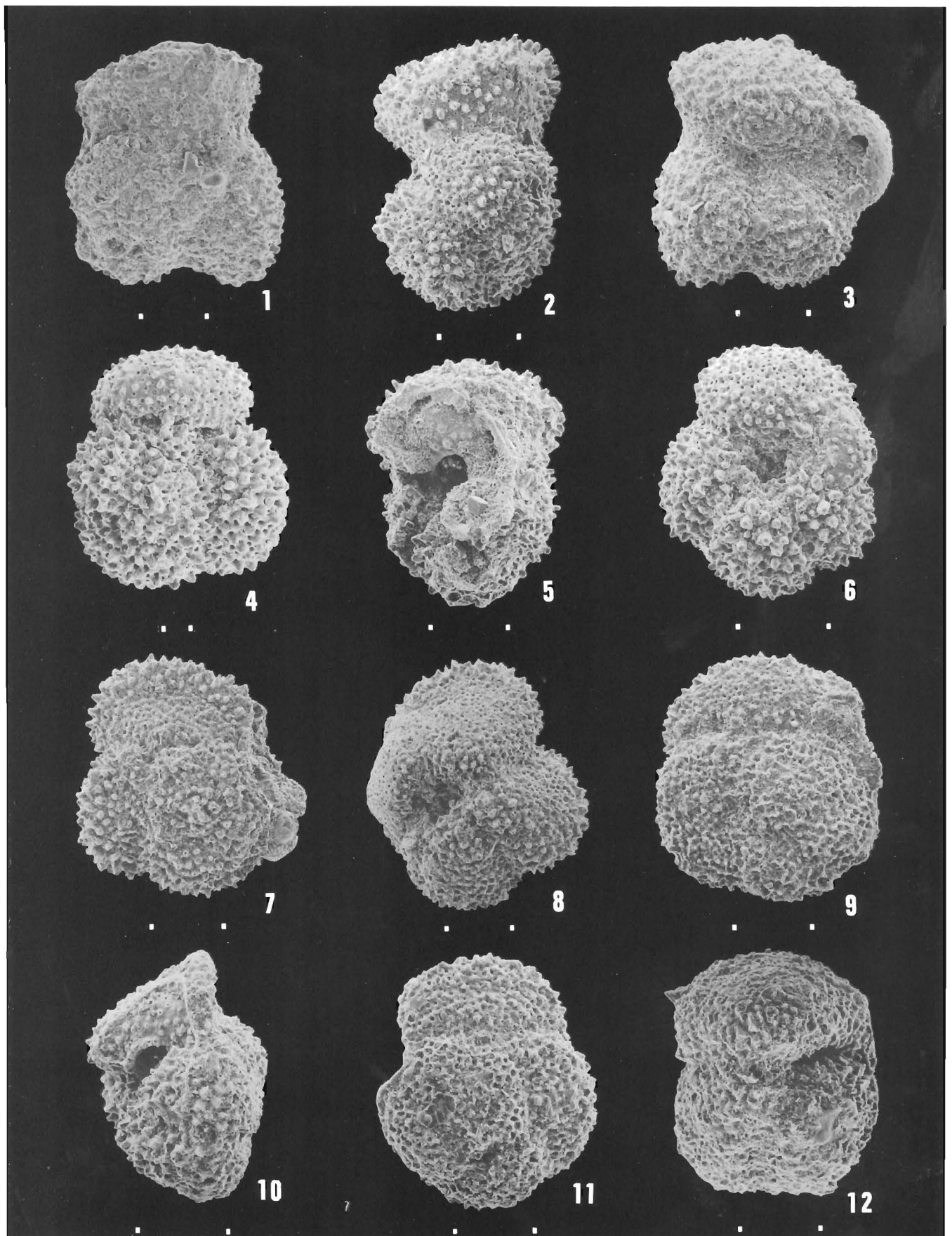
PLATE 7

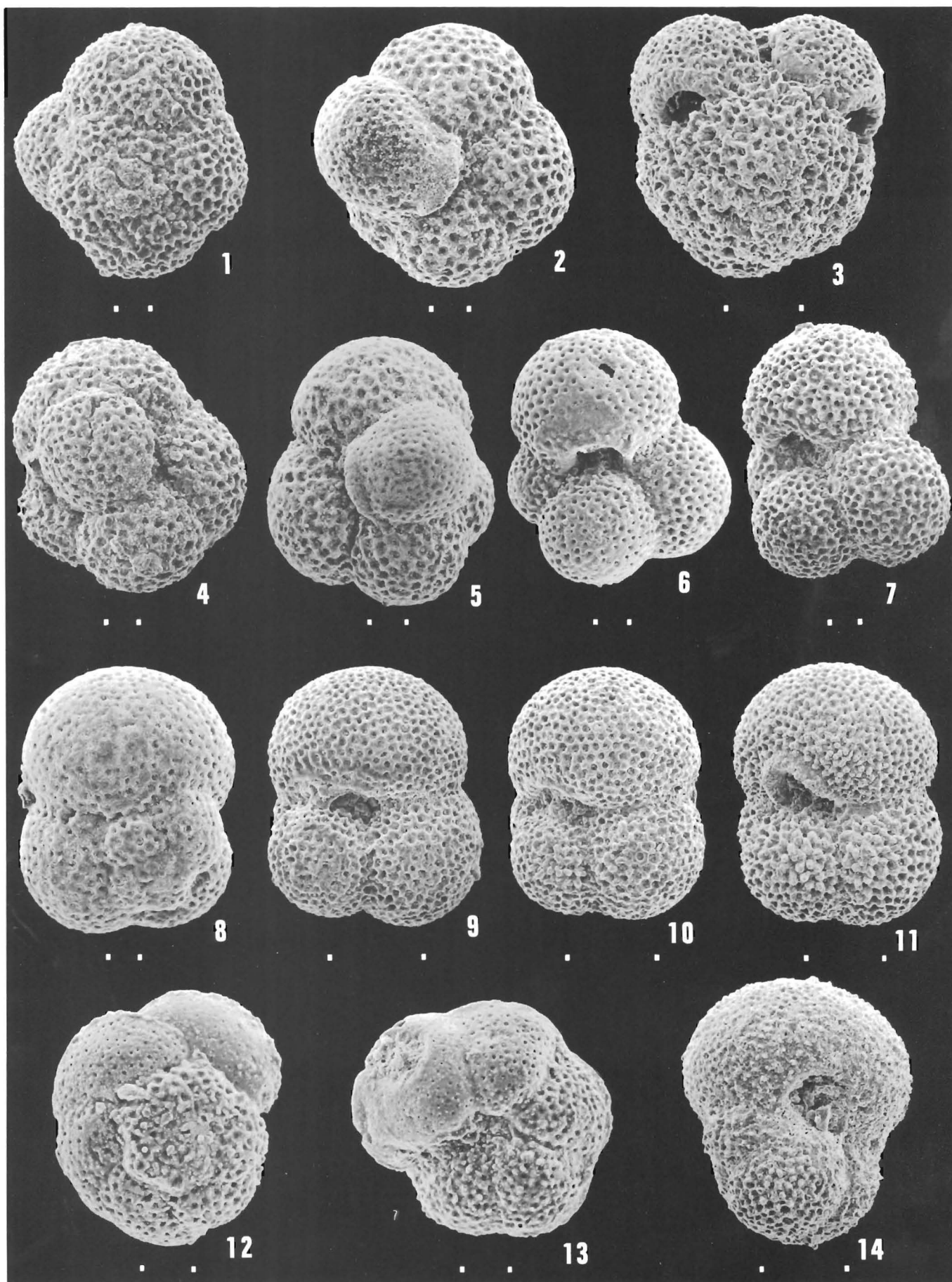
Note that scale bars (delineated by white dots) are not uniform.

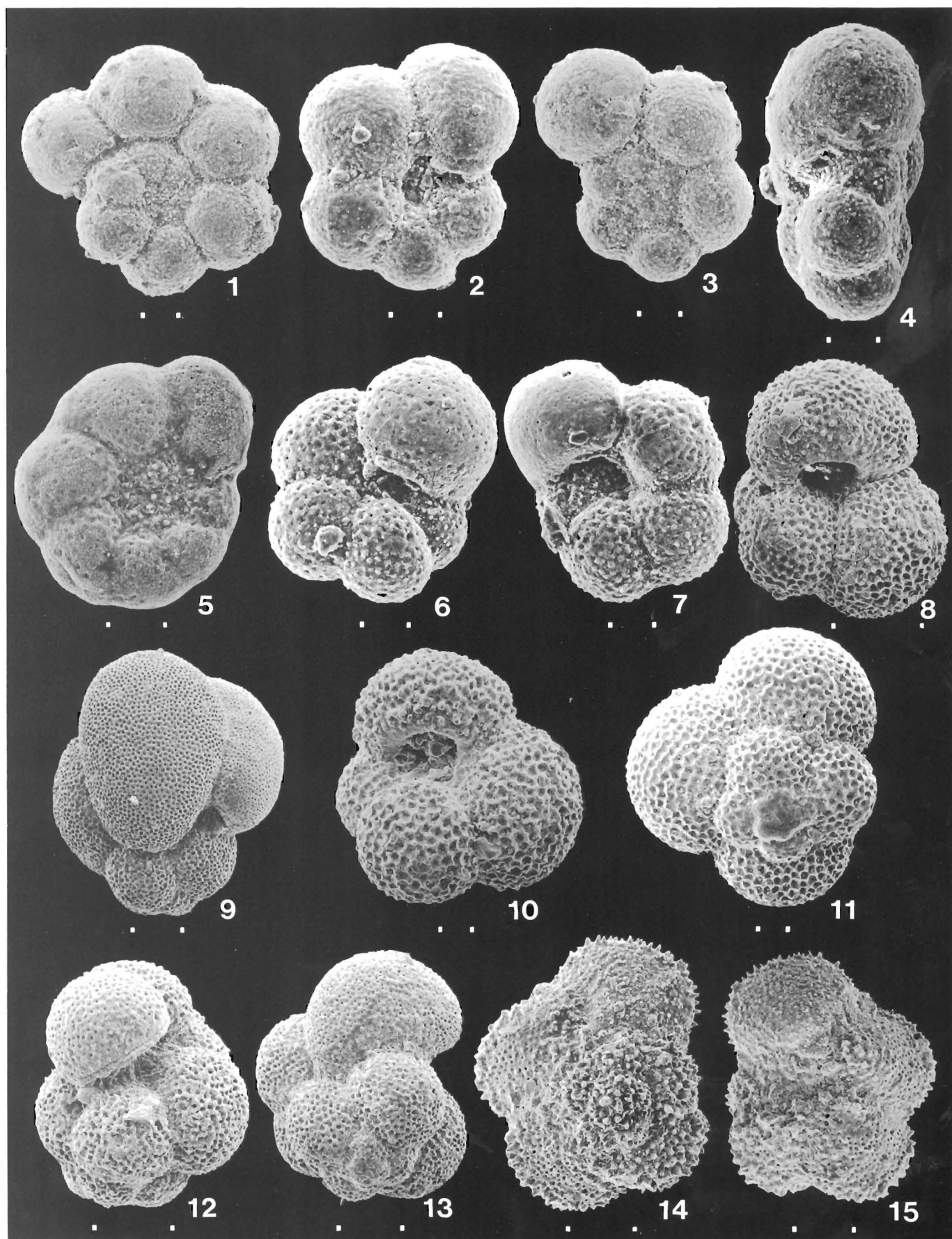
- 1–2 *Globorotaloides carcoselleensis* Toumarkine and Bolli. Both from Mf3305. 1. Spiral view, scale bar = 30 µm. 2. Umbilical view, scale bar = 30 µm.
3 *Globigerinatheka mexicana barri* Brönnimann. Side view of specimen from Mf3304, scale bar = 100 µm.
4 *Globigerinita martini martini* Blow and Banner. Umbilical view of specimen from Mf3301, scale bar = 30 µm.
5 *Globigerinita martini scandretti* Blow and Banner. Umbilical view of specimen from Mf1351, scale bar = 30 µm.
6–7 *Globigerina praebulloides* Blow (s.l.). Both from Mf1352. 6. Umbilical view, scale bar = 30 µm. This individual is referable to *G. praebulloides leroyi* Blow and Banner. 7. Umbilical view, scale bar =

- 30 µm. This individual is referable to *G. praebulloides praebulloides* Blow.
8–10 *Globigerina utilisindex* Jenkins and Orr. All from Mf1351. 8. Spiral view, scale bar = 30 µm. 9. Umbilical view, scale bar = 100 µm. 10. Umbilical view, scale bar = 100 µm.
11 *Globorotalia cerroazulensis frontosa* (Subbotina). Umbilical view of specimen from Mf1350, scale bar = 100 µm.
12–13 *Planorotalites pseudoscitula* (Glaessner). Both from Mf1350. 12. Spiral view, scale bar = 30 µm. 13. Umbilical view, scale bar = 30 µm.
14 *Globorotalia cerroazulensis possagnoensis* Toumarkine and Bolli. Side view of specimen from Mf3301, scale bar = 100 µm.









Pseudohastigerina aff. *P. barbadoensis* Blow
Pl. 8, Fig. 5

Pseudohastigerina barbadoensis BLOW, 1969, p. 409, pl. 53, figs. 7–9, pl. 54, figs. 1–3.

Specimens very close to *P. barbadoensis* were encountered in sample Mf1352. They differ from typical *P. barbadoensis* in having slightly curved rather than straight sutures.

Pseudohastigerina lillisi (Church)

Pullenia lillisi CHURCH, 1931, p. 209, pl. A, fig. 10.
Pseudohastigerina lillisi (Church). McKEEL and LIPPS, 1975, pl. 3, fig. 7, pl. 4, fig. 5.

Pseudohastigerina micra (Cole)

Nonion micrus COLE, 1927, p. 22, Pl. 5, Fig. 12.

Subbotina hagni (Gohrbandt)
Pl. 4, Figs. 13–14

Globigerina hagni GOHRBANDT, 1967, p. 324, pl. 1, figs. 1–9.

The line of demarcation between the *Subbotina* and *Globigerina* is not fully established. In this study *S. hagni* and *S. linaperta*, which evolves in the Paleocene, are placed in *Subbotina* whereas other globigerinids are arbitrarily placed in *Globigerina*.

Subbotina linaperta (Finlay)
Pl. 5, Figs. 8–9

Globigerina linaperta FINLAY, 1939a, p. 125, pl. 13, figs. 54–57.

“Subbotina” senni (Beckmann)
Pl. 3, Figs. 12–14

Sphaeroidinella senni BECKMANN, 1953, p. 394, pl. 26, figs. 2–4, text-fig. 20.

Some workers (Mallory, 1970; Schmidt, 1970) consider “*Subbotina*” *senni* to be closely related to *Globigerapsis* (= *Globigerinatheka*). This form is common in the early and middle Eocene of the Pacific Coast and is usually recorded as *Sphaeroidina gredalensis* Cook.

Truncorotaloides bullbrooki (Bolli)
Pl. 5, Figs. 11–13

Globorotalia bullbrooki BOLLI, 1957b, p. 167, pl. 38, figs. 4–5.

Truncorotaloides collectea (Finlay)
Pl. 5, Figs. 5–7

Globorotalia collectea FINLAY, 1939b, p. 327, pl. 29, figs. 164–165.

Truncorotaloides collectea (Finlay). JENKINS, 1965, p. 843, figs. 1–27.

This form is characterized by its small “spinose” test, umbilical aperture, and normally 5 chambers in the final whorl. The spiral side of this taxon varies from convex to flattened (Jenkins, 1965). *Globigerina medizai* Toumarkine and Bolli is very similar to, if not identical to, *Truncorotaloides collectea*.

Truncorotaloides rohri Brönnimann and Bermúdez
Pl. 6, Figs. 4–6

Truncorotaloides rohri BRÖNNIMANN and BERMÚDEZ, 1953, p. 818, pl. 87, figs. 7–9.

←

PLATE 8

Note that scale bars (delineated by white dots) are not uniform.

- 1–4 *Globorotalia gemma* Jenkins. All from Mf2701. 1. Spiral view, scale bar = 30 μ m. 2. Umbilical view, scale bar = 30 μ m. 3. Spiral view, scale bar = 30 μ m. 4. Side view, scale bar = 30 μ m.
- 5 *Pseudohastigerina* aff. *P. barbadoensis* Blow. Side view of specimen from Mf1352, scale bar = 30 μ m.
- 6 *Globigerina angustiumbilitata* Bolli. Umbilical view of specimen from Mf2701, scale bar = 30 μ m.
- 7 *Globigerina* aff. *G. ciperoensis* Bolli. Umbilical view of specimen from Mf2701, scale bar = 30 μ m. Specimen represents transitional form (?) between *G. angustiumbilitata* and *G. ciperoensis*.
- 8 *Globigerina ouachitaensis* Howe and Wallace. Um-

- bilical view of atypical 3-chambered form from Mf3306, scale bar = 100 μ m.
- 9, 12–13 “*Globigerinoides*” *higginsii* Bolli. 9. Oblique side view of specimen from Mf1350, scale bar = 100 μ m. 12. Side view of specimen from Mf3301, scale bar = 100 μ m. 13. Oblique side view of specimen from Mf3301, scale bar = 100 μ m.
- 10–11 *Globigerina senilis* Bandy. Both from Mf1351. 10. Spiral view, scale bar = 30 μ m. 11. Umbilical view, scale bar = 30 μ m.
- 14–15 *Morozovella lehneri* (Cushman and Jarvis). 14. Spiral view of specimen from Mf3301, scale bar = 100 μ m. 15. Umbilical view of 14, scale bar = 100 μ m.

Of the three varieties of *T. rohri* originally designated by Brönnimann and Bermúdez (1953), *T. rohri* var. *guaracaraensis* and *T. rohri* var. *piparoensis* are included in the concept of *T. rohri*.

Many individuals of *T. rohri* and *T. topilensis* in these samples possess small "bulla-like" final chambers. Several specimens of *Morozovella* sp. 1 also exhibit this feature.

Truncorotaloides topilensis (Cushman)

Pl. 6, Figs. 1-3

Globigerina topilensis CUSHMAN, 1925a, p. 7, pl. 1, fig. 9.

REFERENCES

- ARNOLD, R., 1906, Tertiary and Quaternary pectens of California: U.S. Geol. Survey Prof. Paper 47, 262 p.
- , 1908, Descriptions of new Cretaceous and Tertiary fossils from the Santa Cruz Mountains, California: U.S. Natl. Mus. Proc., v. 34, no. 1617, p. 345-384.
- ARNOLD, R., and HANNIBAL, H., 1913, The marine Tertiary stratigraphy of the north Pacific Coast: Am. Philos. Soc. Proc., v. 3, p. 576-585.
- BANDY, O. L., 1949, Eocene and Oligocene foraminifera from Little Stave Creek, Clarke County, Alabama: Am. Paleontology Bull., v. 32, no. 131, p. 1-211.
- BECKMANN, J. P., 1953, Die Foraminiferen der Oceanic Formation (Eocaen-Oligocaen) von Barbados, Kl. Antillen.: Eclogae Geol. Helvetiae, v. 46, no. 2, p. 301-412.
- , 1971, The Foraminifera of Sites 68 to 75: Deep Sea Drilling Proj. Initial Repts., v. 8, p. 713-725.
- BERGGREN, W. A., 1972, A Cenozoic time-scale—some implications for regional geology and paleobiogeography: Lethaia, v. 5, p. 195-215.
- BLOW, W. H., 1959, Age, Correlation, and Biostratigraphy of the upper Tocuyo (San Lorenzo) and Pozon Formations, eastern Falcon, Venezuela: Am. Paleontology Bull., v. 39, no. 178, 251 p.
- , 1969, Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy: Internat. Conf. Planktonic Microfossils, 1st, Geneva (1967), Proc., Leiden, E. J. Brill, v. 1, p. 199-422.
- , 1970, Validity of biostratigraphic correlations based on the Globigerinacea: Micropaleontology, v. 16, no. 3, p. 257-268.
- BLOW, W. H., and BANNER, F. T., 1962, The mid-Tertiary (Upper Eocene-Aquitania) Globigerinaceae, in Eames, F. E., Banner, F. T., Blow, W. H., and Clarke, W. J., Fundamentals of Mid-Tertiary Stratigraphical Correlation: Cambridge Univ. Press, p. 61-151.
- BOLLI, H., 1954, Note on *Globigerina concinna* Reuss 1850: Cushman Found. Foram. Research Contr., v. 5, pt. 1, p. 1-3.
- , 1957a, Planktonic Foraminifera from the Oligocene-Miocene Cipero and Lengua Formations of Trinidad, B. W. I.: U.S. Natl. Mus. Bull. 215, p. 97-124.
- , 1957b, Planktonic Foraminifera from the Eocene Navet and San Fernando Formations of Trinidad, B. W. I.: U.S. Natl. Mus. Bull. 215, p. 155-172.
- , 1966, Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera: Asoc. Venezolana Geologia, Minería y Petróleo Bol. Inf., v. 9, no. 1, p. 3-32.
- , 1972, The genus *Globigerinatheka* Brönnimann: Jour. Foram. Research, v. 2, no. 3, p. 109-136.
- BRABB, E. E., 1960, Geology of the Big Basin area, Santa Cruz Mountains, California: Dissertation Abs., v. 21, no. 5, p. 1163.
- , 1964, Subdivision of San Lorenzo Formation (Eocene-Oligocene), west-central California: Am. Assoc. Petroleum Geologists Bull., v. 48, no. 5, p. 670-679.
- BRABB, E. E., BUKRY, D., and PIERCE, R. L., 1971, Eocene (Refugian) nannoplankton in the Church Creek Formation near Monterey, Central California: U.S. Geol. Survey Prof. Paper 750-C, p. C44-C47.
- BRÖNNIMANN, P., 1952, *Globigerinoita* and *Globigerinatheka*, new genera from the Tertiary of Trinidad, W. I.: Cushman Found. Foram. Research Contr., v. 3, pt. 1, p. 25-28.
- BRÖNNIMANN, P., and BERMÚDEZ, P. J., 1953, *Truncorotaloides*, a new foraminiferal genus from the Eocene of Trinidad, B. W. I.: Jour. Paleontology, v. 27, no. 6, p. 817-820.
- BUKRY, D., 1973, Low-latitude coccolith biostratigraphic zonation: Deep Sea Drilling Proj. Initial Repts., v. 15, p. 685-703.
- BUKRY, D., BRABB, E. E., and VEDDER, J. G., in press, Correlation of Tertiary nannoplankton assemblages from the Coast and Peninsular Ranges of California: Second Latin American Geol. Congr., Caracas, Venezuela.
- CHURCH, C. C., 1931, Foraminifera of the Kreyenhagen Shale: California Div. Mines State Mineralogists Rept., v. 27, p. 202-213.
- CLARK, B. L., 1918, The San Lorenzo Series of Middle California: California Univ. Pub. Geol. Sci., v. 11, no. 2, p. 45-234.
- COLE, W. S., 1927, A foraminiferal fauna from the Guayabal Formation in Mexico: Bulls. Am. Paleontology, v. 14, no. 51, 46 p.
- , 1928, A foraminiferal fauna from the Chapapote Formation in Mexico: Bulls. Am. Paleontology, v. 14, no. 53, 31 p.
- CUSHMAN, J. A., 1925a, New foraminifera from the Upper Eocene of Mexico: Cushman Lab. Foram. Research Contr., v. 1, no. 3, p. 4-8.
- , 1925b, A new genus of Eocene Foraminifera: U.S. Natl. Mus. Proc., v. 66, no. 2567, p. 1-4.
- , 1928, Additional Foraminifera from the Upper Eocene of Alabama: Cushman Lab. Foram. Research Contr., v. 4, pt. 3, p. 73-79.
- CUSHMAN, J. A., and JARVIS, P. W., 1929, New Foraminifera from Trinidad: Cushman Lab. Foram. Research Contr., v. 5, no. 72, p. 6-17.
- DELTEIL, P. J., and TOUMARKINE, M., 1975, Précisions sur le Tertiaire allochtone du Tell oronais oriental: Eclogae Geol. Helvetiae, v. 68, no. 1, p. 65-78.
- FAIRCHILD, W. W., WESENDUNK, P. R., and WEAVER, D. W., 1969, Eocene and Oligocene Foraminifera from the Santa

- Cruz Mountains, California: California Univ. Pubs. Geol. Sci., v. 81, 144 p.
- FINLAY, H. J., 1939a, New Zealand Foraminifera: Key species in stratigraphy—No. 2: Royal Soc. New Zealand Trans., v. 69, no. 1, p. 89–128.
- , 1939b, New Zealand Foraminifera: Key species in stratigraphy—No. 3: Royal Soc. New Zealand Trans., v. 69, no. 3, p. 309–329.
- GIBSON, J. M., 1976, Distribution of planktonic foraminifera and calcareous nannoplankton, Late Cretaceous and Early Paleogene, Santa Ynez Mountains, California: Jour. Foramin. Research, v. 6, no. 2, p. 87–106.
- GLAESSNER, M. F., 1937, Planktonforaminiferen aus der Kreide und dem Eozän und ihre stratigraphische Bedeutung: Moscow Univ., Lab. Paleont., Studies Micropaleont., v. 1, pt. 1, p. 27–46.
- GOHRBANDT, K. H. A., 1967, Some new planktonic foraminiferal species from the Austrian Eocene: Micropaleontology, v. 13, no. 3, p. 319–326.
- GÜMBEL, C. W., 1868, Beiträge zur Foraminiferenfauna der nordalpinen, älteren Eocänegebilde oder der Kressenberger Nummulitenschichten: Bayerische Akad. Wiss. Abh., II Cl., 10, II Abth., p. 579–730.
- HAGN, H., and LINDENBERG, H. G., 1966, Revizija *Globigerina* (*Subbotina*) *eocaena* Gümbel iz Eocena predgorij Bavorskikh Alp: Voprosy Mikropaleontologii, v. 10, p. 342–358, Moscow.
- , 1969, Revision der von C. W. Gümbel 1868 aus dem Epizän des Bayerischen Alpenvorlandes Beschriebenen planktonischen foraminiferen: Internat. Conf. Planktonic Microfossils, 1st, Geneva (1967), Proc., Leiden, E.J. Brill, v. 2, p. 229–49.
- HORNIBROOK, N. DE B., 1965, *Globigerina angiporoides* n. sp. from the upper Eocene and lower Oligocene of New Zealand and the status of *Globigerina angipora* Stache, 1865: New Zealand Jour. Geology and Geophysics, v. 8, no. 2, p. 834–838.
- HOWE, H. V., and WALLACE, W. E., 1932, Foraminifera of the Jackson Eocene at Danville Landing on the Ouachita, Catahoula Parish, Louisiana: Louisiana Dept. Cons., Geol. Bull., no. 2, 188 p.
- JENKINS, D. G., 1965, A re-examination of *Globorotalia col-lactea* Finlay, 1939: New Zealand Jour. Geology and Geophysics, v. 8, no. 5, p. 843–849.
- , 1966, Planktonic foraminiferal zones and new taxa from the Danian to Lower Miocene of New Zealand: New Zealand Jour. Geology and Geophysics, v. 8, no. 6, p. 1088–1126.
- JENKINS, D. G., and ORR, W. N., 1973, *Globigerina utilisindex* n. sp. from the Upper Eocene–Oligocene of the Eastern Equatorial Pacific: Jour. Foramin. Research, v. 3, no. 3, p. 133–136.
- KLEINPELL, R. M., 1938, Miocene stratigraphy of California: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 450 p.
- KLEINPELL, R. M., and WEAVER, D. W., 1963, Oligocene biostratigraphy of the Santa Barbara embayment, California: California Univ. Pubs. Geol. Sci., v. 43, 250 p.
- KOCH, R., 1926, Mitteltertiäre Foraminiferen aus Bulongan, Ost-Borneo: Eclogae Geol. Helvetiae, v. 19, no. 3, p. 722–751.
- LIPPS, J. H., 1967, Planktonic foraminifera, intercontinental correlation and age of California mid-Cenozoic microfaunal stages: Jour. Paleontology, v. 41, no. 4, p. 994–999.
- MALLORY, V. S., 1959, Lower Tertiary biostratigraphy of the California Coast Ranges: Tulsa, Okla., Am. Assoc. Petroleum Geologists, 416 p.
- , 1970, Lower Tertiary foraminifera from the Media Agua Creek Drainage area, Kern County, California: Thomas Burke Memorial Washington State Museum Research Rept., no. 2, 211 p.
- MARTINI, E., 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation: Internat. Conf. Planktonic Microfossils, 2nd, Roma, Proc., p. 739–785.
- MCKEEL, D. R., and LIPPS, J. H., 1975, Eocene and Oligocene Planktonic Foraminifera from the Central and Southern Oregon Coast Range: Jour. Foramin. Research, v. 5, no. 4, p. 249–269.
- PALMER, D. K., 1934, The foraminiferal genus *Gümbelina* in the Tertiary of Cuba: Soc. Cubana Hist. Nat. Mem., v. 8, p. 73–76.
- POORE, R. Z., 1976, Microfossil correlation of California lower Tertiary sections: a comparison: U.S. Geol. Survey Prof. Paper 743-F, p. F1–F8.
- PROTO DECIMA, F., ROTH, P. H., and TODESCO, L., 1975, Nannoplankton calcareo del Paleocene e dell'Eocene della Sezione di Possagno: Schweizerische Paläontologische Abhandlungen, v. 97, p. 35–55.
- ROTH, P. H., BAUMANN, P., and BERTOLINO, V., 1971, Late Eocene–Oligocene calcareous nannoplankton from central and northern Italy: Internat. Conf. Planktonic Microfossils, 2nd, Roma, Proc., p. 1069–1097.
- SCHENK, H. G., 1936, Nuculid bivalves of the genus *Acila*: Geol. Soc. America Spec. Paper 4, 149p.
- SCHENCK, H. G., and KLEINPELL, R. M., 1936, Refugian Stage of Pacific Coast Tertiary: Am. Assoc. Petroleum Geologists Bull., v. 20, p. 215–225.
- SCHMIDT, R. R., 1970, Planktonic foraminifera from the lower Tertiary of California: California Univ., Los Angeles, Ph.D. thesis, 339 p.
- SCHMIDT, R. R., 1975, Upper Paleocene-middle Eocene planktonic biostratigraphy from the Great Valley of California and adjacent areas, and correlation to the west coast microfossil stages, in WEAVER, D. W., ed., and others, Paleogene symposium and selected technical papers: Am. Assoc. Petroleum Geologists–Soc. Econ. Paleontologists and Mineralogists–Soc. Explor. Geophysicists, Pacific Sec., Ann. Mtg., April 1975, Long Beach, Calif., p. 439–455.
- STAINFORTH, R. M., LAMB, J. L., LUTERBACHER, H., BEARD, J. H., and JEFFORDS, R. M., 1975, Cenozoic planktonic foraminiferal zonation and characteristics of index forms: Kansas Univ. Paleont. Contr., Art. 62, 425 p.
- SUBBOTINA, N. N., 1953, Globigerinidy, Khantkhenidy i Globorotaliidy: Vses. Neft. Nauchno-Issled. Geol.-Razved. Inst. Trudy, n. s., v. 76, 294 p.
- SULLIVAN, R. R., 1962, Foraminifera from the type section of the San Lorenzo Formation, Santa Cruz County, California: California Univ. Pub. Geol. Sci., v. 37, no. 4, p. 233–352.
- TODD, R., 1957, Smaller Foraminifera, in Geology of Saipan,

- Mariana Islands: U.S. Geol. Survey Prof. Paper 280-H, p. 265-320.
- TODD, R., and KNIKER, H. T., 1952, An Eocene foraminiferal fauna from the Agua Fresca Shale of Magallanes Province, southernmost Chile: Cushman Found. Foram. Research Spec. Publ. no. 1, 28 p.
- TOUMARKINE, M., 1975, Middle and Late Eocene Planktonic Foraminifera from the northwestern Pacific, Leg 32 of the Deep Sea Drilling Project, in LARSON, R. L., MOBERLY, R., and others, Initial Reports of the Deep Sea Drilling Project: Washington (U.S. Govt. Printing Office), v. 32, p. 735-751.
- TOUMARKINE, M., and BOLLI, H. M., 1970, Evolution de *Globorotalia cerroazulensis* (Cole) dans L'Eocene moyen et superieur de Possagno (Italie): Rev. Micropaleontologie, v. 13, no. 3, p. 131-145.
- TOUMARKINE, M., and BOLLI, H. M., 1975, Foraminiferes Planktoniques de l'Eocene moyen et Superieur de la Coupe de Possagno: Schweizerische Paläontologische Abhandlungen, v. 97, p. 69-185.
- WARREN, A. D., and NEWELL, J. H., in press, Plankton biostratigraphy of the Refugian and adjoining stages of the Pacific Coast Tertiary, in Orville Bandy Memorial Volume: New York, Springer-Verlag.
- WEAVER, C. E., and others, 1944, Correlation of the marine Cenozoic formations of western North America: Geol. Soc. America Bull., v. 55, no. 5, p. 569-598.
- WEINZIERL, L. L., and APPLIN, E. R., 1929, The Claiborne Formation on the Coastal Domes: Jour. Paleontology, v. 3, no. 4, p. 384-410.

Revised Ms accepted April 1977