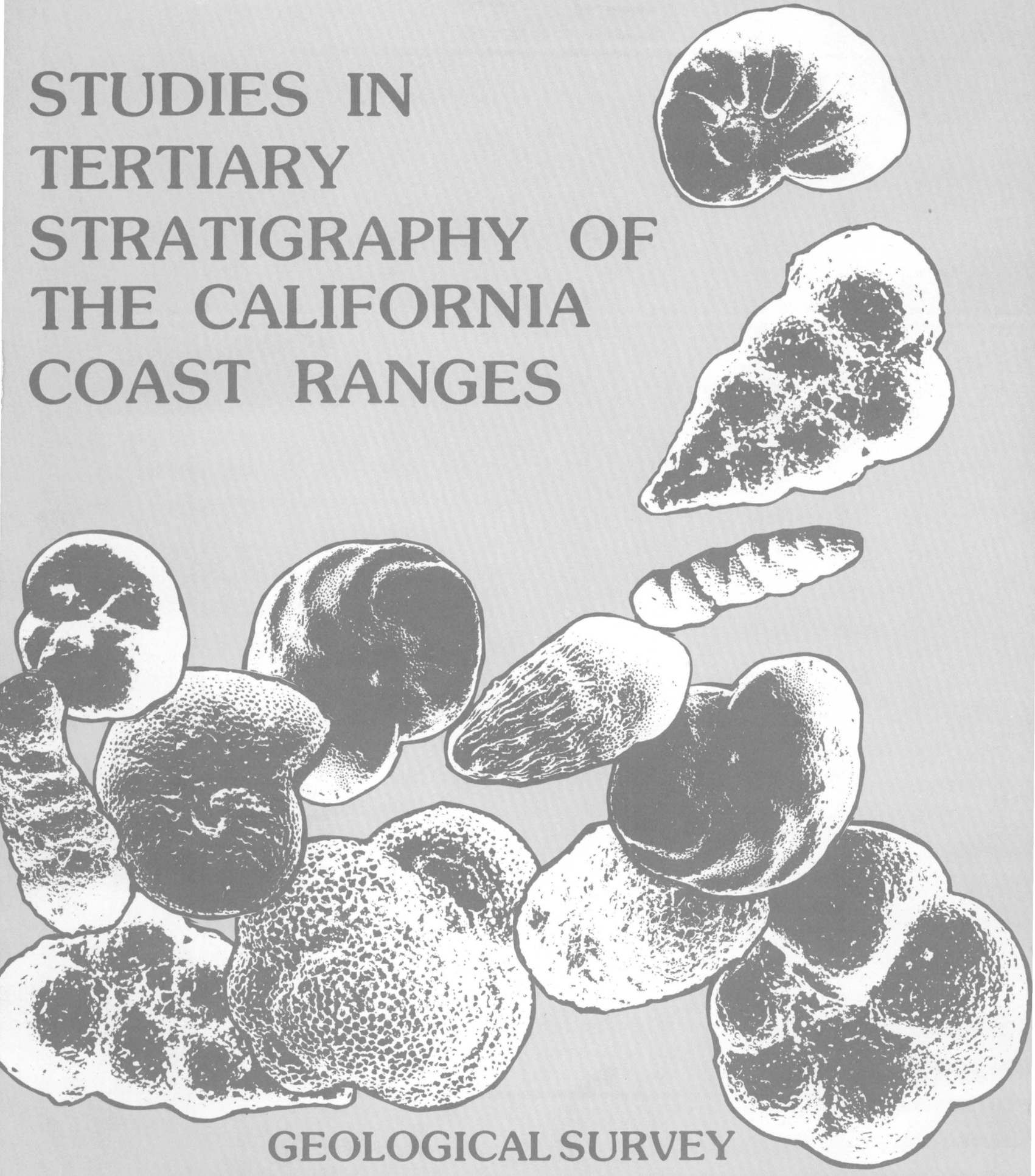
STUDIES IN TERTIARY STRATIGRAPHY OF THE CALIFORNIA COAST RANGES



GEOLOGICAL SURVEY
PROFESSIONAL PAPER 1213

COVER PHOTOGRAPH of benthic foraminifers from
the Bear Creek area, Santa Cruz Mountains

Studies in Tertiary Stratigraphy of the California Coast Ranges

Edited by EARL E. BRABB

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1213

A series of closely related biostratigraphic studies that define the character, age, and correlation of microfossils from Tertiary rocks of the California Coast Ranges, as a basis for correlating with international stratigraphic standards

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STUDIES IN TERTIARY STRATIGRAPHY OF THE CALIFORNIA COAST RANGES

INTRODUCTION

By EARL E. BRABB

The correlation of rocks of Paleogene age in California with those in Europe has had a long and complex history that can only be highlighted here. Kleinpell (1938, p. 168-181), in his classic work defining Miocene benthic[1] foraminiferal stages of California, attempted to correlate faunas of California with those of western Europe and elsewhere. He pointed out that rocks usually considered lower Miocene in California are probably correlative with those considered Oligocene in Europe. Schenck and Childs (1942) correlated the Vaqueros Sandstone of California with the middle and upper Oligocene of Europe and elsewhere, based on the stratigraphic occurrence of *Lepidocyclina*. Their correlation was discussed extensively by a number of paleontologists in the same report. Some favored a Miocene age based on similarities of the Vaqueros molluscan fauna with the Burdigalian faunas of Europe, and on the apparent Miocene age of vertebrates from beds below the Vaqueros. Others argued that some of the mollusks in the Vaqueros were similar to those considered Oligocene in Trinidad, and that the percentage of living mollusks in the Vaqueros Sandstone (1-2 percent) was most similar to faunas of Oligocene age. These differences in opinion proved to be irreconcilable in the attempt by the U.S. Committee on Stratigraphy to provide a standard correlation chart for marine Cenozoic formations of western North America (Weaver and others, 1944). Two standards had to be provided, one based largely on mollusks, echinoids, and corals, and the other on benthic foraminifers. This dual classification has persisted almost to the present.

The validity of some California Tertiary stages based largely on benthic foraminifers has been questioned in recent years. Pierce (1972) and Barron (1976) believed that the Delmontian Stage of Kleinpell (1938), for example, is coeval with the lower and middle part of his Mohnian Stage. Steineck and Gibson (1971), Gibson and Steineck (1972), Schmidt (1975), Bandy (1972) and Bukry, Brabb, and Vedder (1977) stated their belief that probably all of the California Paleocene and Eocene stages of Mallory (1959) are time-transgressive when compared to nannoplankton and planktonic foraminifer zonations. Hornaday and Philips (1972), on the other hand, challenged some of these opinions.

In order to further the study of the relation between California Paleogene stages based on benthic foraminifers with zonations based on planktic foraminifers and nannoplankton, nine paleontologists were invited to examine the faunas from several Coast Range sections measured by Brabb, Clark, and Throckmorton (1977). The results of their investigation were presented orally at a meeting of the International Subcommission on Paleogene Stratigraphy in Menlo Park, California on October 28, 1977. The talks were preceded by three days of field trips to the measured sections and were followed by a microscope workshop to debate the identification and age of the various faunas. The paleontologists were then encouraged to submit papers for this volume, and all have graciously complied.

Acknowledgments.—Professor Ch. Pomerol of the University of Paris, currently chairman of the International Subcommission on Paleogene Stratigraphy, provided the leadership and inspiration for a series of biostratigraphic meetings that began in Paris in 1968, continued in Germany in 1969 and in the Caribbean in 1973, and culminated in the 1977 California meeting.

[1]In this report, *benthic* refers to the seafloor habitat, and *benthonic* refers to the foraminiferal stages based on benthic organisms. Likewise, *planktic* organisms, that is, free floaters and weak swimmers, are distinguished from the *planktonic* zones based on plankton.

REGIONAL SETTING

The Paleogene faunas described in this report are from the California Coast Ranges (fig. 1). Most are from areas west of the San Andreas fault in the Santa Cruz Mountains of west-central California; a few are from areas east of the San Andreas fault from Mount Diablo to Devils Den. The Paleogene rocks west of the San Andreas fault rest either directly on crystalline metasedimentary and granitic rocks of the Salinian block or on sedimentary strata of Cretaceous age. East of the San Andreas fault, the Paleogene rocks commonly rest on Jurassic and Cretaceous strata of the Great Valley sequence, which in turn are faulted against a complex tectonic assemblage of Mesozoic sedimentary, metamorphic, and

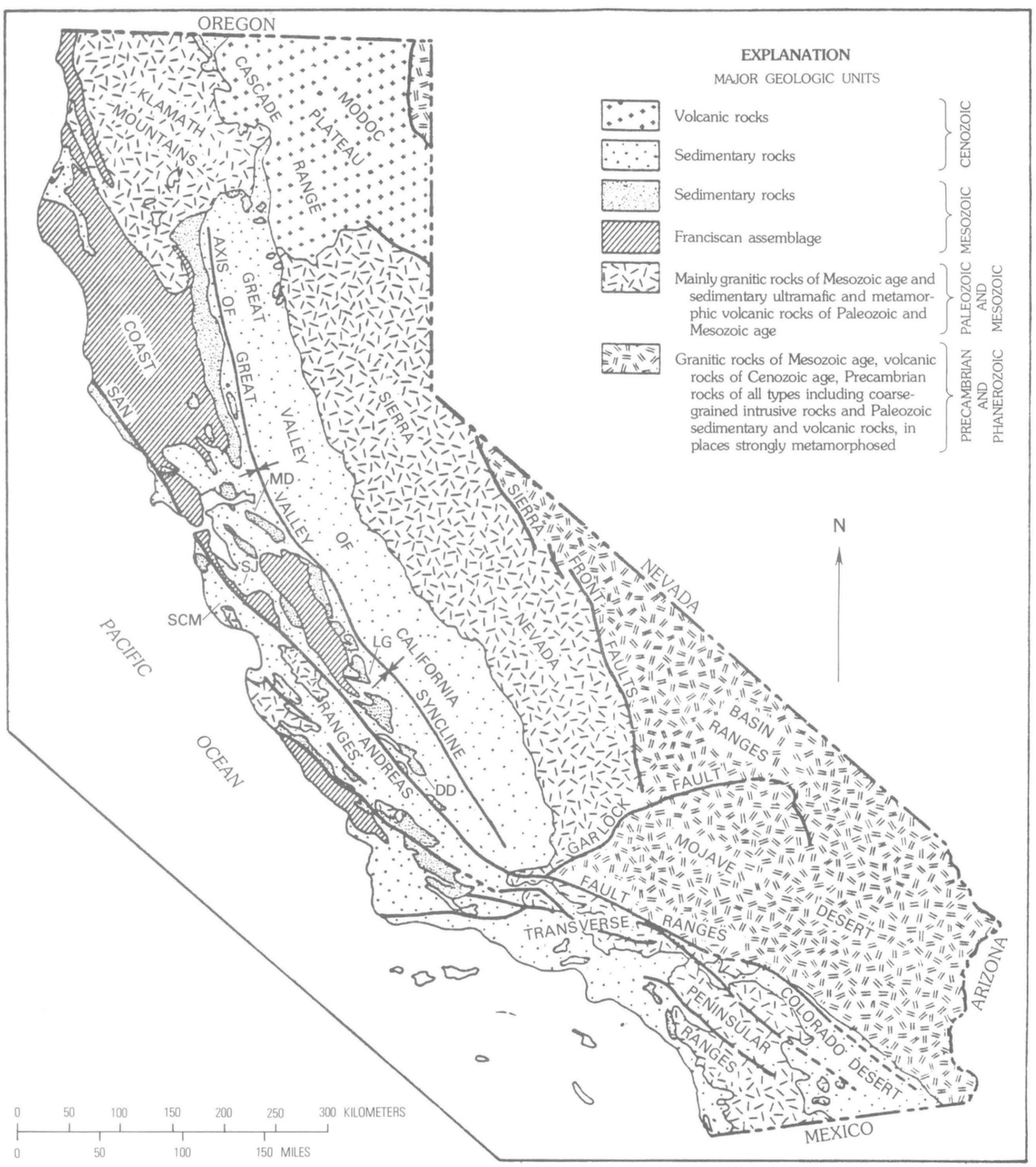

FIGURE 1.—Natural provinces of California, major geologic units and general location of areas sampled (modified from Hinds, 1952). MD, Mount Diablo; SJ, San Jose; SCM, Santa Cruz Mountains; LG, Lodo Gulch; DD, Devils Den.

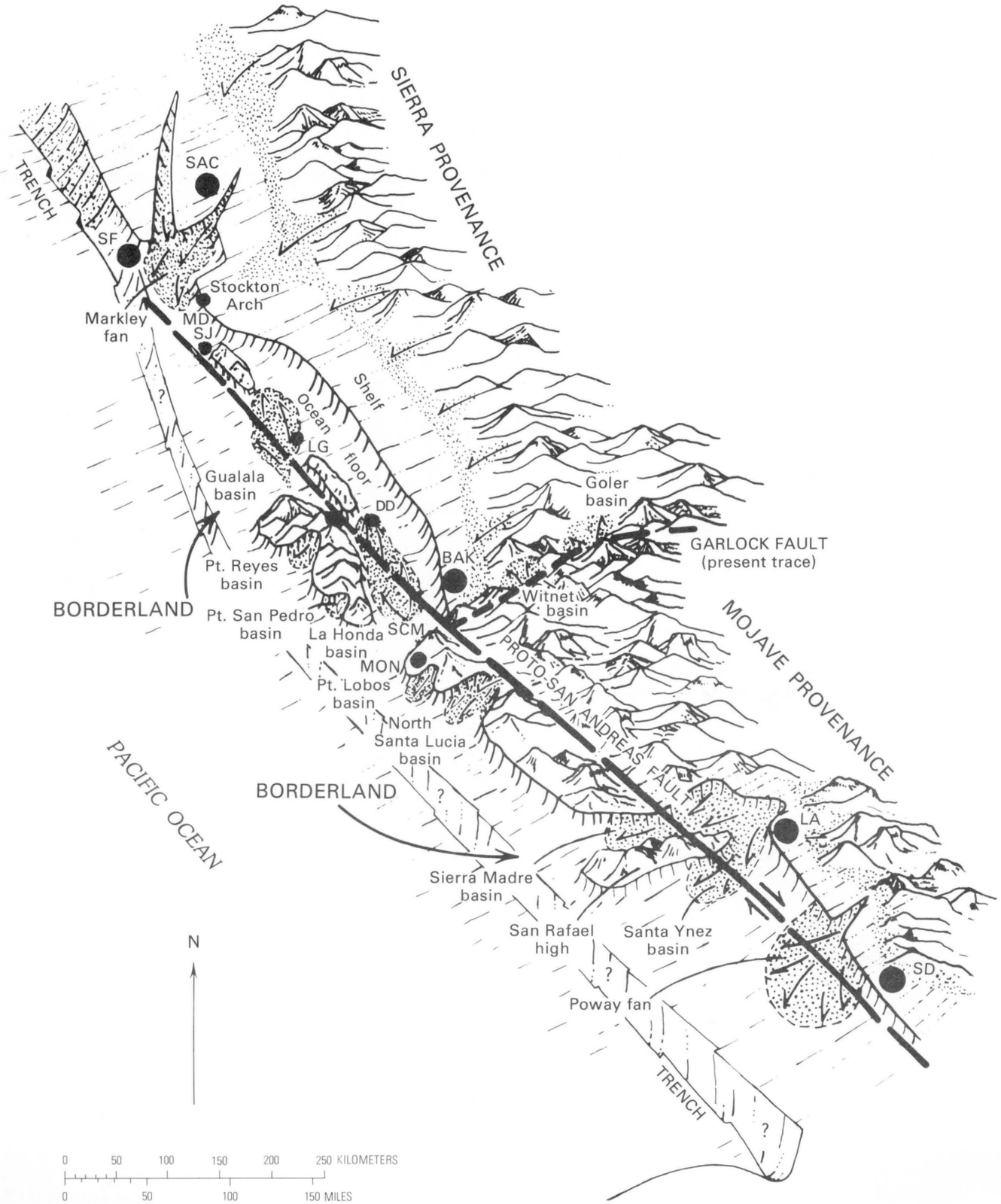

FIGURE 2.—Generalized restoration paleogeographic map of California during early Tertiary, based on restoration of 305 km of late Cenozoic right-lateral slip along the modern San Andreas fault (from Nilsen and Clark, 1975). The present location of the Garlock fault and the following geographic features are included for orientation purposes: SAC, Sacramento; SF, San Francisco; BAK, Bakersfield; MON, Monterey; LA, Los Angeles; SD, San Diego; DD, Devils Den; LG, Lodo Gulch; MD, Mount Diablo; SJ, San Jose; SCM, Santa Cruz Mountains.

igneous rocks that are commonly referred to by petroleum geologists as Franciscan "basement." The relation of Franciscan "basement" rocks to the granitic basement rocks along which they are juxtaposed by the San Andreas fault has long been one of the most intriguing and complex problems of California geology. A series of lectures edited by Nilsen (1977) gives a synopsis of the problems and some working hypotheses for the tectonic evolution of California during Mesozoic and Cenozoic time. The most significant concept for the purpose of this report is that the San Andreas and other northwest-trending strike-slip faults have displaced the Paleogene sequences hundreds of kilometers with respect to each other. The Santa Cruz Mountains, for example, were thought by Nilsen and Clark (1975) to have been opposite the Devils Den area, 250 km to the south, during the early Tertiary.

The paleogeography of central California during the Paleogene is not well established. Most published analyses are not based on a firm biostratigraphic framework, so that rocks of middle Eocene age in one area may be compared with rocks of late Eocene age in another. There is also a problem with displacement of the Paleogene sequences along secondary lateral faults. Although extensive lateral displacement along the San Andreas has been considered true since the classic report by Hill and Dibblee (1953), many new lateral faults have been discovered that make paleogeographic reconstructions more complex. Nevertheless, much progress has been made, especially by a few geologists who have attempted to apply modern sedimentological concepts to understanding Paleogene depositional patterns. Nilsen (1977) and Dibblee (1977) provided extensive bibliographies listing many of these studies, and they also provided the synthesis that is summarized below.

A generalized paleogeographic map of California during the early Tertiary, based on about 300 km of late Cenozoic right-lateral slip (fig. 2), shows that during the Paleogene the region between Devils Den and Mount Diablo was characterized by uplands in the Sierra Nevada, a linear basin in the area of the Great Valley in which a westward-thickening sequence of marine strata was deposited, islands on the continental borderland that contributed sediments in local areas, and a trench and subduction zone in what is now the Pacific Ocean. The La Honda basin, where all October 1977 field trips took place, was part of a continental borderland, mostly at lower bathyal and abyssal depths with open connections to the ocean.

PALEOGENE BENTHIC FORAMINIFERAL BIOSTRATIGRAPHY AND PALEOBATHYMETRY OF THE CENTRAL RANGES OF CALIFORNIA

By W. A. BERGGREN[1] and JANE AUBERT[2]

ABSTRACT

Paleogene foraminiferal assemblages of California have been examined from sections in the Lodo Gulch area, Fresno County; the Devils Den (aqueduct) area, Kern County; and the Smith and Empire Grade and Lompico areas, Santa Cruz County.

Benthic foraminifers indicate that the Lodo Formation in its type area was deposited during a single sedimentary cycle (lasting about 10 million years) at depths ranging from lower neritic (somewhat shallower than 200 m) near its base and in its upper part to middle and upper bathyal (about 600 m) in its lower part. The Gredal Shale Member of the Kreyenhagen Formation in the Devils Den (aqueduct) section contains a rich planktic foraminiferal fauna throughout and shows no evidence in its upper part of the neritic fauna present in the upper part of the type Lodo Formation. Middle bathyal depths (below 600 m) are suggested for the lower part of the Gredal and upper bathyal depths (above 600 m) for its upper part. The marked shallowing in these sections in Zone P9 is denoted by the local disappearance or sporadic occurrence of bathyal taxa (such as *Nuttallides truempyi*) with more extensive stratigraphic ranges elsewhere and coincides closely with a major eustatic sea-level fall recently delineated in seismic stratigraphy.

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The faunal assemblages from the Santa Cruz Mountains sections consist of predominantly benthic agglutinated foraminifers (with minor calcareous benthic and planktic foraminifers) which are characteristic of flysch deposits formed at the distal margins of turbidite fans in water depths of 1-2 km. Whereas the calcareous benthic assemblages of the Lodo Formation and Gredal Shale Member in the Devils Den area contain numerous cosmopolitan elements, the agglutinated flysch faunas of these units and those in the Santa Cruz Mountains appear to be less cosmopolitan, that is, they do not appear to be closely related to Paleogene flysch faunas of the Carpathian Mountains of Europe or the North Atlantic.

INTRODUCTION

California contains one of the best developed and representative Paleogene sequences in North America. Numerous studies have been devoted to the description of the foraminiferal faunas in this region (Martin, 1943; Israelsky, 1951, 1955; Mallory, 1959, 1970; Sullivan, 1962; Schmidt, 1970, 1975; Stinemeyer, 1976).

In connection with the Field Conference on the Paleogene sponsored by the International Commission on Paleogene Stratigraphy (October 1977) we were requested to make a preliminary study of prepared samples from four sections that represent a cross section of the California early Paleogene. The sections included: (1) the Lodo Formation at its type locality in the Lodo Gulch area, Fresno County; (2) the Lodo Formation, Avenal Sandstone, and Gredal Shale and lower part of the Point of Rocks Sandstone Members of the Kreyenhagen Formation in the Devils Den (aqueduct section) area, Kern County; (3) the Locatelli Formation in the Smith Grade-Empire Grade area in the Santa Cruz Mountains, Santa Cruz County; and (4) the Butano Sandstone in the Lompico area in the Santa Cruz Mountains, Santa Cruz County (fig. 3). The last two areas were visited during the course of the field conference.

Within the context of this preliminary analysis we have not been able to recognize and apply the California Paleogene foraminiferal stages of Mallory (1959). Mallory's stages are not time-stratigraphic units at all in the sense prescribed by the American Code of Stratigraphic Nomenclature or the International Stratigraphic Guide. These stages are better characterized as loosely defined assemblages of benthic foraminifers (faunules) and, as such, of ecologic rather than chrono-stratigraphic significance. Indeed, the California provincial stages are demonstrably time-transgressive (Steineck and Gibson, 1971; Poore, 1976; Bukry and others, 1977; see also Warren, 1977).

Details of the stratigraphic sections from which our samples have been collected are presented in Brabb, Clark, and Throckmorton (1977).

Acknowledgments.—This paper was presented, in considerably abbreviated form, at the Field Conference on the Paleogene of California held at Menlo Park, Calif. in late October-early November 1977.

We thank Earl E. Brabb and Joseph C. Clark (Indiana, Penn.) for providing the sample material upon which the investigation is based. Richard Z. Poore provided the Merle Israelsky foraminiferal collection from the type Lodo Formation on loan, and this proved extremely helpful to us. We thank Francis Saffon for the scanning electron micrographs prepared on the Cambridge Mark II instrument in the laboratories of Societe National Elf-Aquitaine (Production), Pau, France.

This investigation is part of a joint project with the Woods Hole Oceanographic Institution (sponsored by Chevron, Exxon, Marathon, Mobil, and Shell Oil Companies) and Societe National Elf-Aquitaine (Production) devoted to Cenozoic benthic foraminiferal biostratigraphy and ecology. We wish to thank B. U. Haq and R. C. Tjalsma of Woods Hole for discussions on Paleogene stratigraphy and for reviewing the manuscript.

SAMPLE MATERIALS

Nineteen samples, collected by Earl Brabb and prepared by the U.S. Geological Survey, have been examined from the type section of the Lodo Formation along Lodo Gulch (section TS, fig. 16 of Brabb, this volume). These samples were supplemented by a cursory examination of the Israelsky (1951) collection of 110 samples from two reference sections less than 1000 m south of Lodo Gulch. Fourteen samples collected by Brabb have been examined from the Lodo Formation and the Gredal Shale, and the Point of Rocks Sandstone Members of the Kreyenhagen Formation exposed in the Devils Den (aqueduct section) area, some 100 km southeast of the type Lodo.

Fourteen samples collected by Earl Brabb and Joseph C. Clark have been examined from the terrigenous arkosic sandstone and siltstone of the Locatelli Formation and Butano Sandstone in the Smith Grade-Empire Grade and Lompico areas of the Santa Cruz Mountains.

LODO GULCH AREA

The type section of the Lodo Formation at Lodo Gulch (fig. 4) is in the Tumey Hills, Fresno County, on the west side of the San Joaquin Valley. It is one of the most important reference sections for lower Paleogene stratigraphy of California and has been the subject of several studies on foraminifers (Martin,

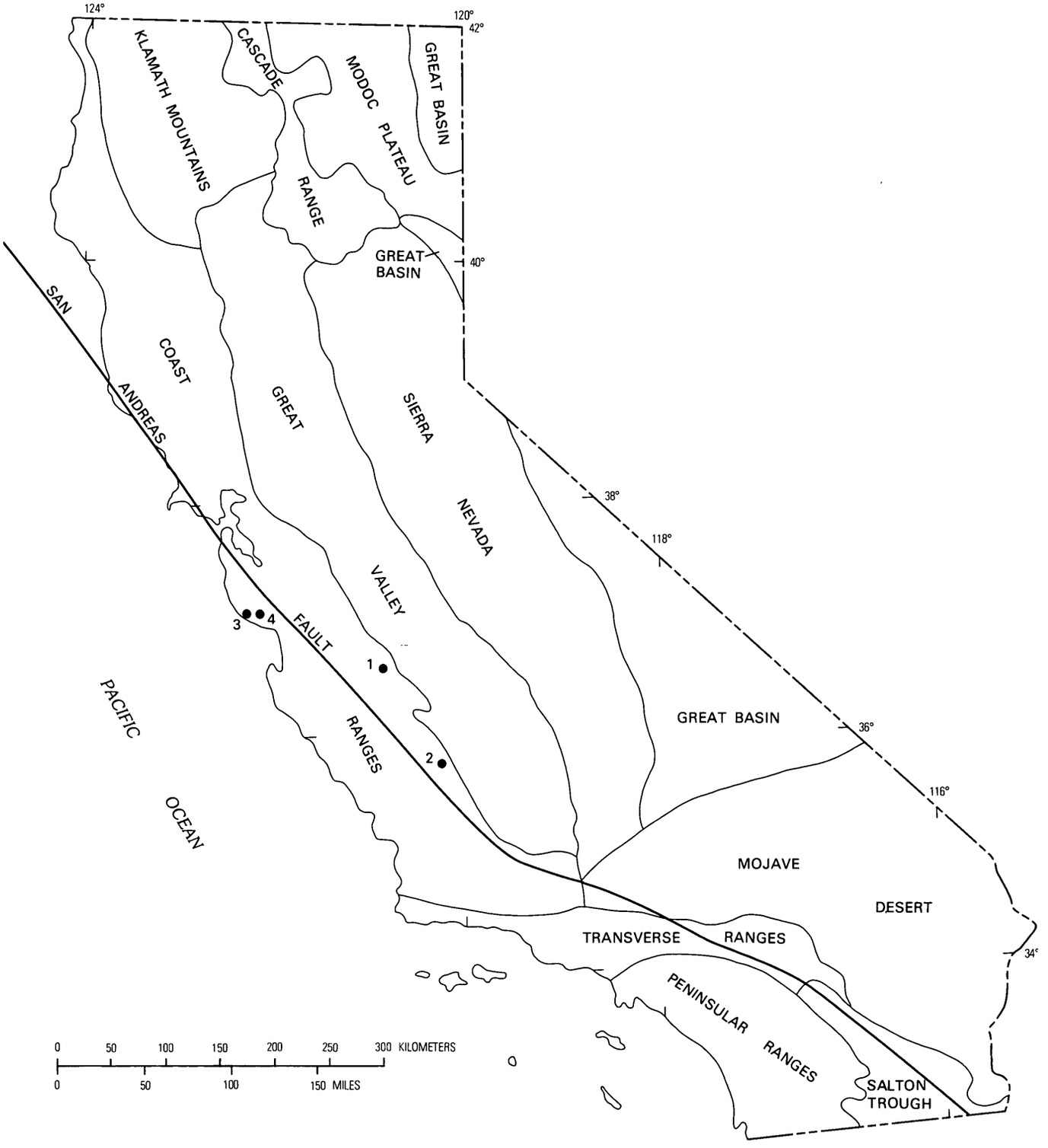


FIGURE 3.—Physiographic provinces of California and localities where microfossil assemblages were collected. 1, Lodo Gulch; 2, Devils Den; 3, Smith Grade-Empire Grade area; 4, Lompico.

1943; Israelsky, 1951, 1955; Mallory, 1959; Schmidt, 1970) and calcareous nannoplankton (Bramlette and Sullivan, 1961). At its type section the Lodo is approximately 360 m thick and is of late Paleocene and early Eocene (planktic foraminiferal Zone P4–P9) age. It is unconformably underlain by the Cretaceous part of the Moreno Shale and is overlain by the Domengine Sandstone of middle Eocene age. Molluscan faunas collected near the base of the Lodo Formation some 700 m northwest of its type section are correlated by Smith (1975) with the Martinez Stage of the provincial molluscan standard of Weaver and others (1944), and with mollusks from the Bracheux Sandstone of Paleocene age in the northern Paris Basin. A potassium-argon date of 58.5 m.y. (Funnell, 1964, p. 188, item 113) from glauconite in the basal beds of the Lodo Formation provides a minimum age on the *Planorotalites pseudomenardii* and *Heliolithus riedeli* Zones, within which the glauconite is situated (Bramlette and Sullivan, 1961; Schmidt, 1970). Additional details on the geologic and stratigraphic setting of the type Lodo Formation may be found in Israelsky (1951) and Schmidt (1970), and its relation to other Paleogene sections in central California is discussed by Schmidt (1975).

FORAMINIFERAL BIOSTRATIGRAPHY

The type Lodo Formation has been zoned with the aid of planktic foraminifers by Schmidt (1970), and our examinations have essentially confirmed his findings, including the probable presence of a short hiatus (or disconformity) between the Paleocene and Eocene about 50 m above the base of the type section at the Lodo Gulch (fig. 4). We did not find definitive evidence for the presence of Zone P6. The boundary between Zones P8 and P9 has been determined on the basis of the initial appearance of *Subbotina inaequispira, S. frontosa, S. linaperta* and *Acarinina densa* over the interval of samples 70–72 (Israelsky) and 1231 (Brabb). The top of the Lodo Formation is considered to lie within an interval equivalent to Zone P9, as differentiation between Zones P9 and P10 is often difficult, and planktic foraminifers diminish sharply in the upper 150 m of the type Lodo Formation as a result of shallowing.

Over 150 species of calcareous and agglutinated benthic foraminifers have been recorded from the Lodo Gulch section and the nearby Devils Den section some 100 km southeast of Lodo Gulch. Species of the calcareous genera *Anomalinoides, Bulimina, Trifarina, Cibicidoides,* and *Lenticulina* dominate these assemblages. Agglutinated taxa (including *Bathysiphon, Rhabdammina, Haplophragmoides, Cyclammina, Karreriella, Dorothia, Silicosigmoilina,* and *Tritaxilina)* occur throughout both sections and at some levels constitute almost the entire foraminiferal assemblage.

The distribution of species identified in the Brabb samples in the type Lodo Formation is shown in Table 1. Generalized foraminiferal assemblages are shown in figure 4 based on the more common or characteristic elements occurring over a given stratigraphic interval. It should be borne in mind that these assemblages are based on an examination of only 18 samples collected by Brabb and the more closely spaced samples in the Israelsky collection. Characteristic features of the benthic foraminiferal fauna of the Lodo Formation include the following:

1. There is a sequential influx of new taxa throughout the section.
2. There is a marked faunal change (reduction or disappearance of taxa from below and replacement of taxa above) in the interval above 150–100 m below the contact of the Domengine Sandstone and the Lodo Formation (above Israelsky sample 70 and Brabb sample 1231). Planktic foraminifers (particularly the angulo-conical morozovellids) exhibit a marked reduction over this interval as well and become rarer toward the upper part of the Lodo Formation.
3. An essentially threefold faunal subdivision can be made (from bottom to top): (1) The lower 15 m (approx.) contains a fauna similar to that in the Midway Group, including *Cibicidoides alleni, Osangularia plummerae, Anomalinoides danica rubiginosa,* and species of *Silicosigmoilina, Spiroplectammina, Clavulinoides,* and *Ammodiscus.* This interval corresponds essentially to Zone P4 and Israelsky samples 3–11. This interval is below the lowest sample (1251C) collected by Brabb, which is stratigraphically located between Israelsky samples 13 and 14. (2) The interval from about 15 m to 200 m, between Israelsky samples 12 to 70, contains an assemblage characterized or dominated by various bulminids, anomalinids, osangulariids, aragonids, *Nuttallides truempyi, Bathysiphon, Rhabdammina, Cyclammina, Silcosigmoilina,* and *Clavulinoides.* This interval corresponds essentially to Zones P5–P8. (3) The upper 175 m contains an assemblage characterized by various small cibicidids, anomalinids, bolivinids, *Florilus florinense, Uvigerina elongata, Eponides primus, Cyclammina,* and *Trochammina.* This interval presumably corresponds to Zone P9, although planktic foraminifers are sparse or rare over this interval.

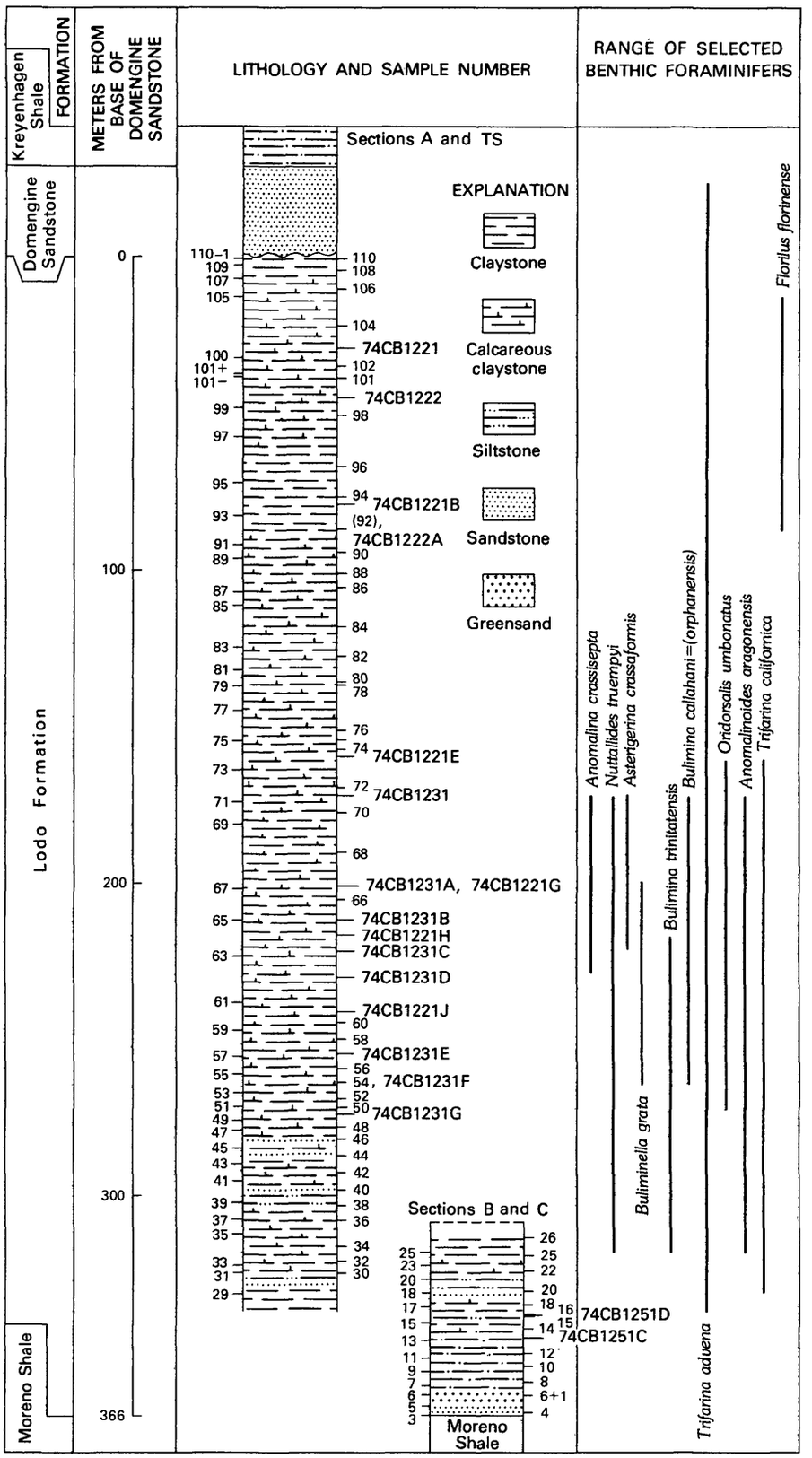
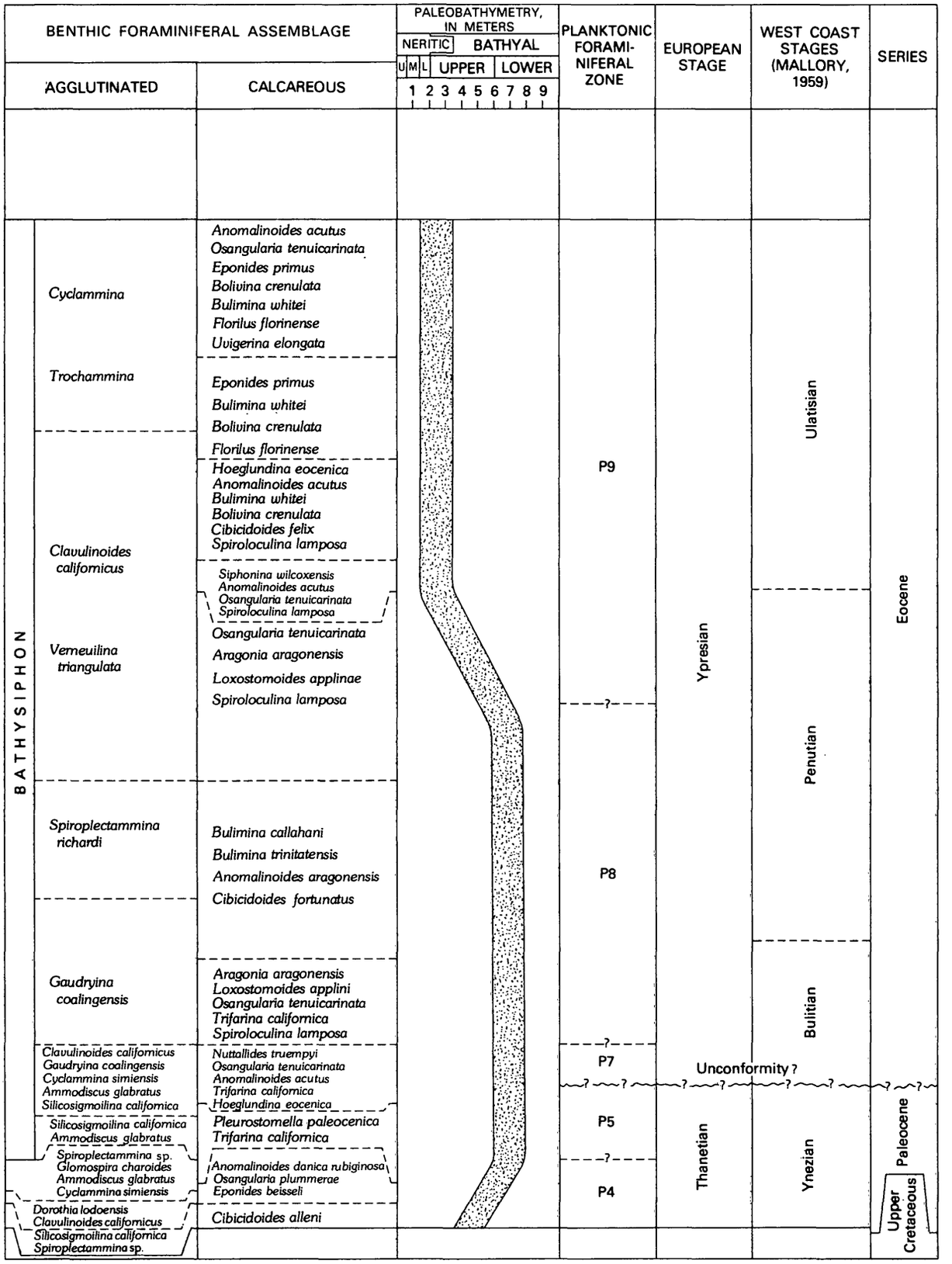


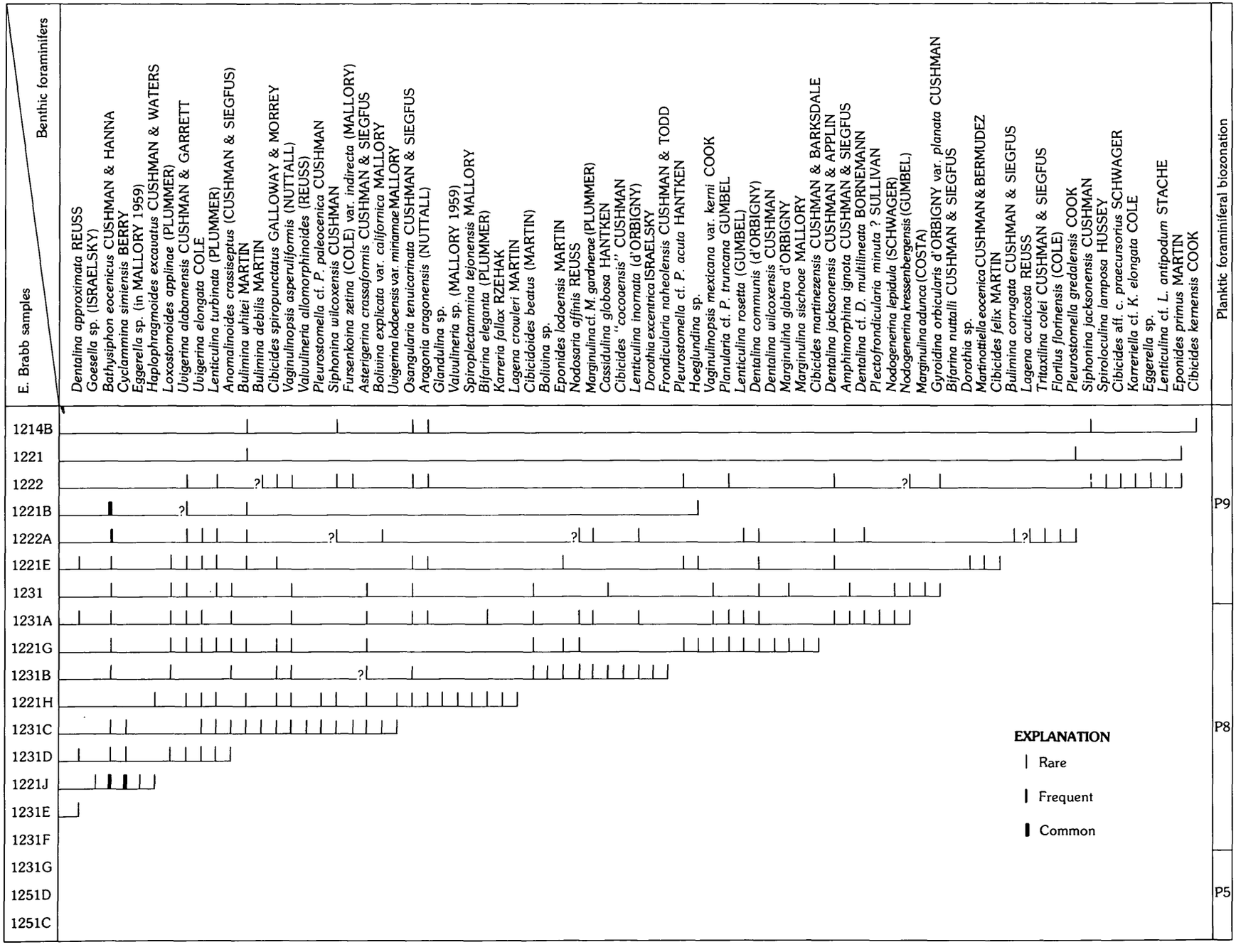
FIGURE 4.—Foraminiferal biostratigraphy and paleobathymetry of the Lodo Formation at its type locality in the Lodo Gulch area. The upper part of the section was sampled (small numbers) by Israelsky (1951, pl. 1, section A) along the first gulch south of Lodo Gulch. Samples collected by E. E. Brabb (74CB1221B and others) are projected into this section from the type section of the Lodo Formation along Lodo Gulch. (section TS). The lower part of the section was measured (small



sample numbers) by Israelsky (1951, pl. 1, section B) along a small gulch about 300 m south of the mouth of Lodo Gulch. Samples collected by E. E. Brabb (74CB1251D and others) in this section are projected from still another section about 700 m north of Lodo Gulch. (section C). The location of all these sections is shown on figure 16 of Brabb (this volume).

TABLE 1.—*Benthic foraminifers in the type Lodo Formation, Lodo Gulch, Fresno County, California*

TABLE 1.—*Benthic foraminifers in the type Lodo Formation, Lodo Gulch, Fresno County*—Continued



PALEOBATHYMETRY

Strict interpretation of Paleogene paleobathymetry based on analogy with present-day faunal counterparts is unreliable in view of demonstrable differences in distributional patterns (Lohmann and Tjalsma, 1975; Tjalsma and Lohmann, 1975) and water mass structure (Douglas and Savin, 1973; Boersma and Shackleton, 1977). Nevertheless, local and regional geologic information, distribution patterns of taxa with geophysically controlled paleobathymetry (Sclater and others, 1971; Berger, 1973), and distribution of associated faunal elements with a presumed stable ecology can be combined to allow a reasonable paleodepth estimate of special faunal associations.

We interpret the paleobathymetric history of the type Lodo Formation in terms of a single sedimentary cycle in which the middle part of the formation (corresponding to Zones P5 to P8) was deposited at middle to upper bathyal depths (about 600 m), whereas the lower (Zone P4) and upper (Zone P9) parts were deposited near the neritic-bathyal boundary (above 200 m). The following line of reasoning has been used.

1. Faunas from the Midway Group have been shown (Berggren and Aubert, 1975) to represent a cosmopolitan fauna formed at neritic depths. An association of some Midway elements with somewhat deeper water elements is seen at depths interpreted as upper-middle bathyal in Tunisia (Aubert and Berggren, 1975) and Bavaria (Hillebrandt, 1962), but these elements are not observed in the lower (Zone P4) part of the type Lodo Formation.
2. In the succeeding 150 m (Israelsky samples 13 to 63; Brabb samples 1251C to 1231C, fig. 4) a number of forms appear that are restricted to this interval but which have longer stratigraphic ranges in lower bathyal-abyssal deposits in the ocean (R. C. Tjalsma, oral commun., 1977). These include *Bulimina trinitatensis, Nuttallides truempyi, Anomalinoides aragonensis, Buliminella grata, Bulimina callahani (=orphanensis), Anomalina crassisepta,* and *Asterigerina crassaformis.* In addition several species of the agglutinated genera *Rhabdammina, Bathysiphon,* and *Cyclammina,* normally associated with bathyal deposits, appear within this interval as well. For example, *Nuttallides truempyi* is one of the dominant lower bathyal-abyssal taxa with an age range of Late Cretaceous (Maestrichtian) to latest Eocene (Laughton and others, 1972; Douglas, 1973; R. C. Tjalsma, oral commun., 1977). Its upper depth limit is not known with certainty, but it occurs in the late Eocene at DSDP (Deep Sea Drilling Project) Site 116 in middle bathyal depths (above 1000 m; Laughton and others, 1972). It does not occur in neritic (Midway type) faunas, and thus we suggest an upper depth limit of 500–600 m for this taxon, between upper and middle bathyal depths. *Bulimina callahani (=orphanensis)* has a stratigraphic range from Zones P6a to P8 (R. C. Tjalsma, oral commun., 1977; Berggren and Aubert, 1976) in oceanic sediments yet is essentially restricted to the upper half of Zone P8 in the type Lodo Formation. At Orphan Knoll (DSDP Site 111), *B. callahani (= orphanensis)* occurs in the lower Eocene with faunas from depths of more than 1 km. As with *Nuttallides truempyi,* its upper depth limit is suggested to lie near the upper-middle bathyal boundary (500–600 m). Upward shallowing is suggested by the nearly simultaneous local termination or disappearance of these taxa in the middle part of the section about 190 m above the base (175 m below the top) of the Lodo Formation at a level that corresponds closely to the planktic foraminiferal Zone P8–P9 boundary (characterized by the initial appearance of *Subbotina frontosa* = *S. boweri, S. linaperta, S. inaequispira,* and *Acarinina densa*) and their replacement by shallower water forms (cibicids, bolivinids, eponidids, *Florilus, Valvulineria,* and hispid uvigerinids of the *elongata* group characteristic of neritic depths: 50–200 m; Boersma, 1974).
3. A preliminary examination of the ostracode fauna in the Israelsky collections by R. H. Benson (Smithsonian Institution, written commun., 1977) indicates the presence of *Trachyleberidea* and *Cytherella*, both typical of bathyal deposits, *Argilloecia*, and some allochthonous specimen of *Loxoconcha. Krithe* (with markedly open vestibule) suggests that oxygen ranged between 4.5 and 5.5 ml/l. Very small eye tubercles present on an *Actinocythereis*-like form suggest (to Benson) water depths not in excess of 600–800 m, in good accord with estimates made above.

The presence of cyclamminids and *Bathysiphon* to the top of the type Lodo Formation at depths interpreted from other faunal evidence to have been near the shelf-slope break (about 200 m) suggest that the upper depth limits of these agglutinated benthic foraminiferal faunas were somewhat shallower during the Paleogene than during the Neogene and present day, perhaps because of the lack of a pronounced thermocline during this time.

DEVILS DEN (AQUEDUCT SECTION AREA)

The aqueduct section in the Devils Den area is located in Kern County some 100 km southeast of Lodo Gulch (fig. 3). Several hundred meters of Cretaceous, Paleocene, and Eocene strata are exposed there (Brabb and others, 1977, fig. 37), of which only a part (fig. 5) has been selected for study. Our preliminary examination of the planktic foraminiferal fauna suggests that the sequence studied spans Zones P5 to P9 and may include P10. Zones P5 to P6 are represented only in a fault-bounded part of the Lodo Formation.

Warren (1977) reported the presence of the calcareous nannoplankton *Tribrachiatus orthostylus* (NP12) to *Nannotetrina quadrata* (NP15) Zones in the aqueduct section. The presence of the *Discoaster lodoensis* (NP13) and *D. sublodoensis* (NP14) Zones in the lower part of the Gredal Shale Member of the Kreyenhagen Formation supports our assignment of this same interval to planktic foraminiferal Zones P8 and P9 (see also Wise and Constans, 1976). The upper 40–50 m of the Gredal Shale Member was placed by Warren in the *Nannotetrina quadrata* (NP15) Zone of middle Eocene age.

In summary, the sequence studied in the aqueduct section of Devils Den is correlative with most of the type Lodo Formation.

Planktic foraminifers (particularly acarininids and anguloconical morozovellids) are abundant and well preserved throughout the aqueduct section, in contrast to those in the Lodo Gulch area.

FORAMINIFERAL BIOSTRATIGRAPHY

The benthic foraminiferal taxa recorded from the Devils Den (aqueduct section) area (table 2), form the basis for the assemblage subdivision shown in figure 5. The basic features of the assemblages that should be noted are as follows:

1. Faunal elements similar to those from the Midway Group are absent at the base of the sequence studied, that is, in the lowest beds of the Lodo Formation, whereas the *Florilus-Eponides-Uvigerina* assemblage is absent at the top.
2. The assemblages are nearly identical with those present in the middle part of the type Lodo Formation at Lodo Gulch (*Nuttallides truempyi*, buliminids, osangulariids, anomalinids, cyclamminids, *Tritaxilina*, *Rhabdammina*, *Bathysiphon*).
3. Several of the taxa that disappear near the boundary between Zones P8 and P9 in the Lodo Gulch area appear to range well into Zone P9 in the Devils Den (aqueduct section) area (*N. truempyi*, *Anomalinoides crassiseptus*, *Asterigerina crassaformis*).
4. The upper part of the aqueduct section contains a fauna composed primarily of elements that range through a major part of the section: *Rhabdammina eocenica*, *Bathysiphon eocenicus*, *Cyclammina simiensis*, *Haplophragmoides* sp. cf. *H. eggeri*, *H. excavatus*, *Tritaxilina colei*, *T. principiensis*, *Karreriella mediaguaensis*, *Plectina cubensis*, *Anomalinoides crassiseptus*, *Cibicidoides fortunatus*, *Lenticulina* spp.

PALEOBATHYMETRY

The similarity of faunas in the aqueduct section with those in the Lodo Gulch area suggests similar water depths. The fact that some of the bathyal taxa (*Nuttalides truempyi*) range into Zone NP14 (equivalent to P9) and some (*Anomalinoides crassiseptus*, *Asterigerina crassaformis*) as high as NP15 (equivalent to P10) suggests that water depths were greater in the Devils Den area than in the Lodo Gulch area and that the shallowing near the boundary between Zones P8 and P9 in the Lodo Gulch area occurs within Zone P9 in the Devils Den area. The shallowing eliminated some of the taxa. Other taxa, however, persisted because the water depth was still well within their upper depth limit. It should be noted that *Bulimina callahani* (= *Bulimina orphanensis*) disappears near the boundary between Zones P8 and P9 in the Devils Den area as in the Lodo Gulch area, an apparent example of an evolutionary extinction as opposed to bathymetrically controlled local disappearance. A middle bathyal depth (below 600 m) is suggested for the Lodo Formation and lower part of the Gredal Shale Member in the Devils Den section, an upper bathyal depth (above 600 m) for the upper 40–50 m of the Gredal Shale Member, above the disappearance of *N. truempyi*.

SANTA CRUZ MOUNTAINS

Fourteen samples have been examined from the terrigenous arkosic sandstone and siltstone of the Locatelli Formation and the Butano Sandstone in the Smith Grade-Empire Grade and Lompico areas, respectively, of the Santa Cruz Mountains.

SMITH GRADE-EMPIRE GRADE AREA

The seven samples examined from the Locatelli Formation (Paleocene) span a stratigraphic interval of approximately 250 m (fig. 6).

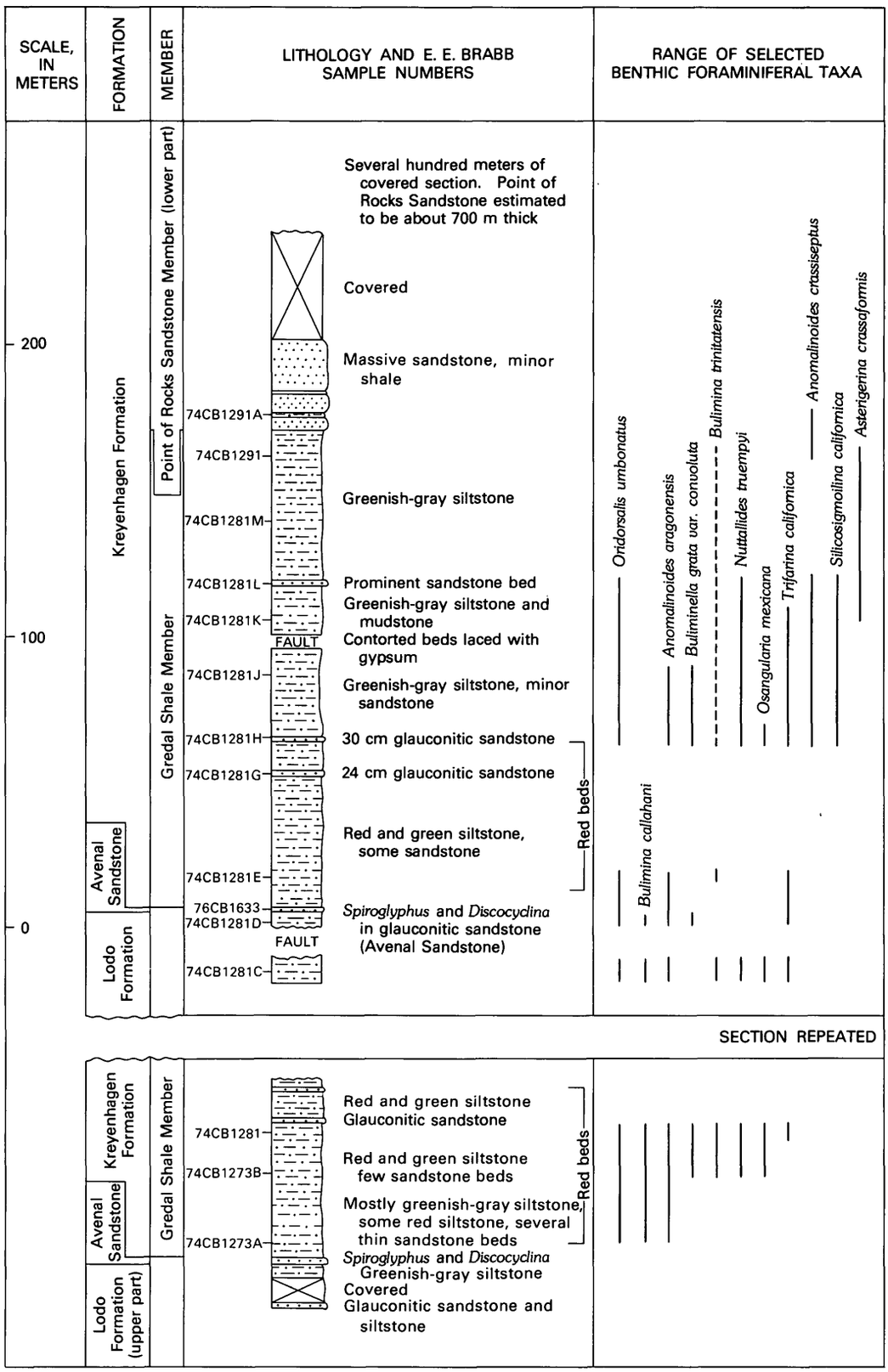


FIGURE 5.—Foraminiferal biostratigraphy and paleobathymetry of the Devils Den (aqueduct section) area.

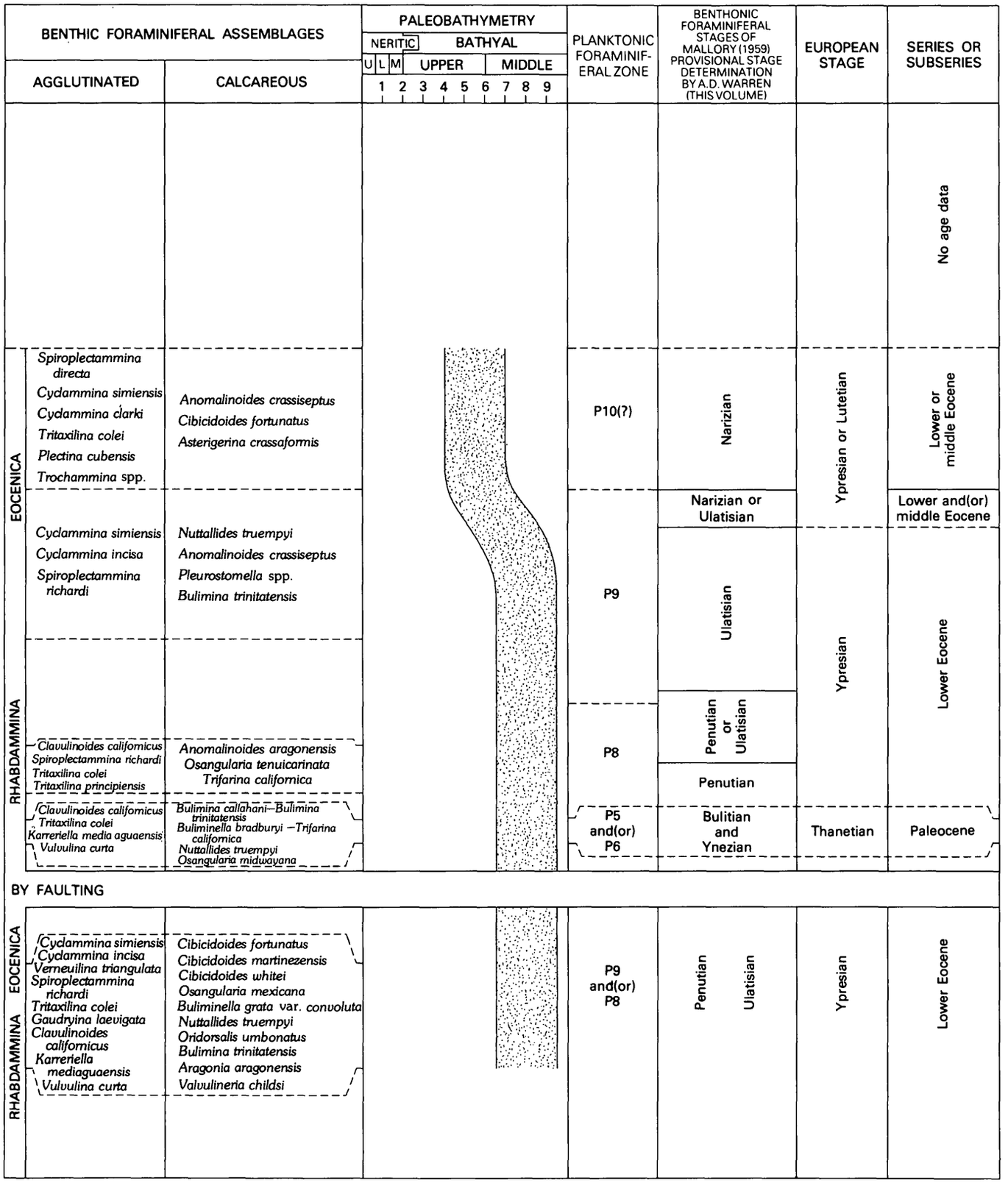
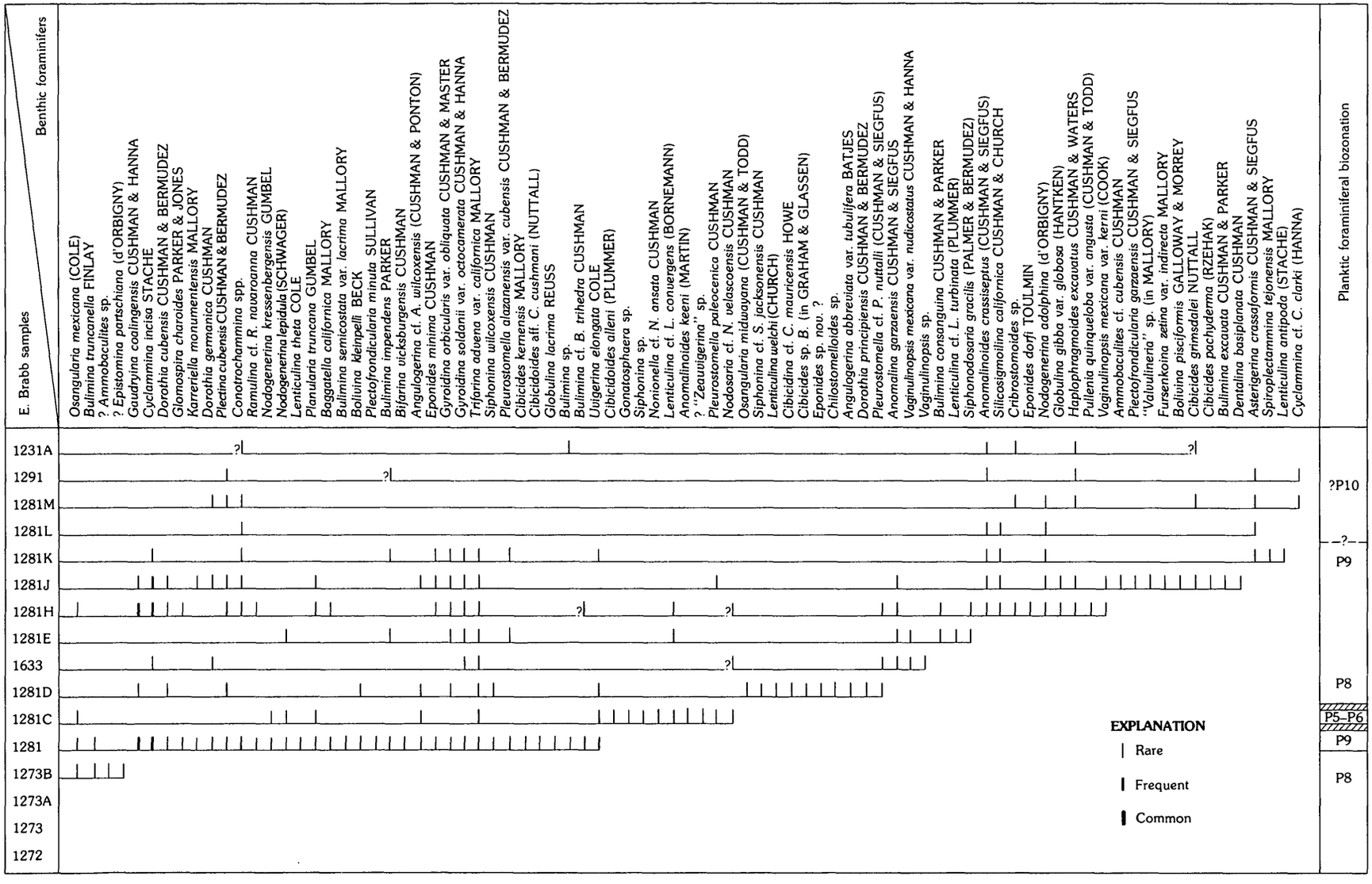


FIGURE 5.— Continued.

TABLE 2.—*Benthic foraminifers in the Devils Den (aqueduct) area, Kern County, California*

E. Brabb samples / Benthic foraminifers	1231A	1291	1281M	1281L	1281K	1281J	1281H	1281E	1633	1281D	1281C	1281	1273B	1273A	1273	1272
Bathysiphon eocenicus CUSHMAN & HANNA																
Rhabdammina eocenica CUSHMAN & HANNA																
Oridorsalis umbonatus (REUSS)																
Spiroplectammina directa (CUSHMAN & SIEGFUS)																
Cassidulina globosa HANTKEN																
Anomalinoides acutus (PLUMMER)																
Nuttallides truempyi (NUTTALL)																
Nodosaria arundinea SCHWAGER																
Cyclammina simiensis BERRY																
Cibicidoides spiropunctatus (GALLOWAY & MORREY)																
Cibicidoides whitei (MARTIN)																
Cibicidoides beatus (MARTIN)																
Cibicidoides fortunatus (MARTIN)																
Trochammina globigeriniformis (PARKER & JONES)																
Nodosaria ewaldi REUSS																
Spiroloculina cf. *S. lamposa* HUSSEY			?													
Lenticulina spp.																
Haplophragmoides cf. *H. eggeri* CUSHMAN																
Gaudryina cf. *G. laevigata* FRANKE																
Nodosarella advena (CUSHMAN & SIEGFUS)																
Eponides sp.																
Stilostomella sp.																
Bulimina callahani GALLOWAY & MORREY																
Buliminella bradburyi (MARTIN)																
Gonatosphaera eocenica MALLORY																
Pullenia eocenica CUSHMAN & SIEGFUS																
Anomalinoides welleri (PLUMMER) (=regina MARTIN?)																
Vaginulinopsis echinata THALMANN																
Bulimina whitei MARTIN																
Lenticulina pseudovortex (COLE)																
Nodosaria deliciae MARTIN																
Lenticulina cf. *L. vortex* (FICHTEL & MOLL)																
Cibicidoides eponidiformis (MARTIN)																
Valvulineria childsi (MARTIN)																
Bulimina curtissima CUSHMAN & SIEGFUS		?														
Eponides primus MARTIN																
Clavulinoides californicus MALLORY																
Tritaxilina colei CUSHMAN & SIEGFUS																
Verneuilina triangulata COOK																
Cibicidoides cf. *C. pseudowuellorstorfi* (COLE)						?										
Haplophragmoides spp.																
Dentalina spinosa d'ORBIGNY																
Marginulina subbullata HANTKEN																
Amphimorphina ignota CUSHMAN & SIEGFUS																
Alabamina wilcoxensis var. *californica* MALLORY																
"*Cibicides* sp." (in MALLORY no 42062)																
Tritaxilina principiensis (CUSHMAN & BERMUDEZ)																
Aragonia aragonensis (NUTTALL)																
Uvigerina lodoensis var. *miriamae* MALLORY																
Pullenia reussi CUSHMAN & TODD																
Pleurostomella acuta HANTKEN																
Bulimina cf. *B. instabilis* CUSHMAN																
Bulimina aff. *B. pyrula d'Orbigny* (in MALLORY)																
Bulimina pupoides d'Orbigny (in MALLORY)																
Bifarina nuttalli CUSHMAN & SIEGFUS																
Nodosarella constricta CUSHMAN & SIEGFUS																
Nodosarella ignota CUSHMAN & SIEGFUS																
Lenticulina ulatisensis BOYD				?												
Gyroidinoides cf. *G. subangulata* (PLUMMER)																
Karreriella mediaguaensis MALLORY																
Martinottiella eocenica CUSHMAN & BERMUDEZ																
Karreriella arenasensis CUSHMAN & BERMUDEZ																
Clavulinoides aspera CUSHMAN ?																
Vulvulina curta CUSHMAN & SIEGFUS																
Vaginulinopsis kelleyi MARTIN			?													
Trochamminoides contortus MALLORY																
Lenticulina terryi CORRYEL & EMBICH																
Bolivina huneri COLE					?											
Bulimina trinitatensis CUSHMAN & JARVIS	?	?	?						?							
Bulimina macilenta CUSHMAN & PARKER																
Anomalinoides aragonensis (COLE)																
Buliminella grata var. *convoluta* MALLORY																
Lagena substriata WILLIAMSON																
Amphimorphina californica (CUSHMAN & MASTER)																
Dentalina jacksonensis (CUSHMAN & APPLIN)																
Ammodiscus cf. *A. pennyi* CUSHMAN & JARVIS																
Haplophragmoides coalingensis CUSHMAN & HANNA																
Spiroplectammina richardi MARTIN																
Turritilina brevispira TEN DAM																
Trochammina spp.																
Silicosigmoilina cf. *S. perplexa* ISRAELSKY																
Nodosaria latejugata GUMBEL																
Cibicides cf. *C. martinezensis* CUSHMAN & BARKSDALE																
Osangularia tenuicarinata (CUSHMAN & SIEGFUS)																
Planktic foraminiferal biozonation	?P10			P9				P8			P5–P6	P9	P8			

TABLE 2.—*Benthic foraminifers in the Devils Den (aqueduct) area, Kern County, California*—Continued



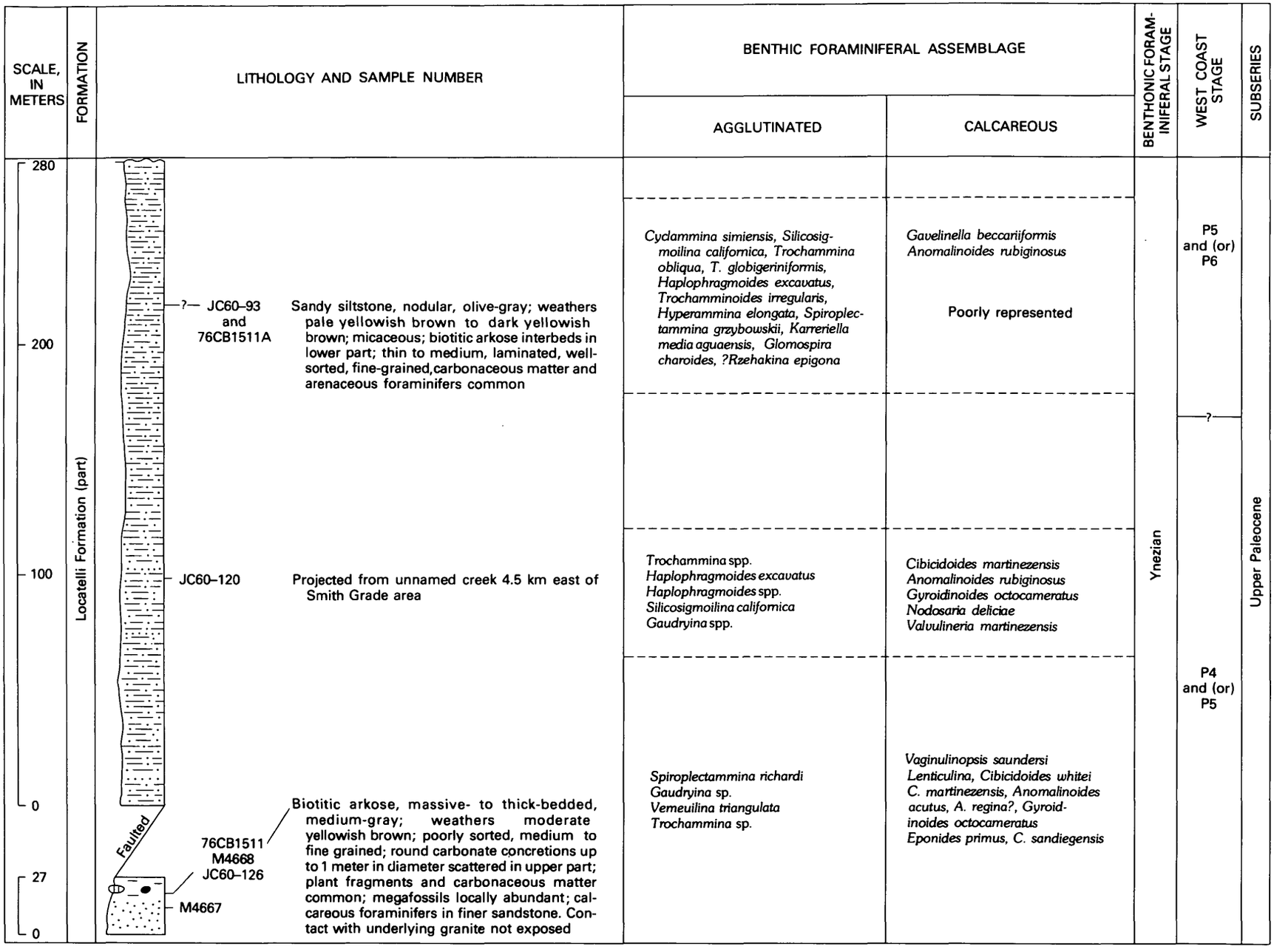


FIGURE 6.—Foraminiferal biostratigraphy of Locatelli Formation, Smith Grade-Empire Grade area.

Foraminiferal faunas consist of predominantly agglutinated forms with minor amounts of calcareous benthic and planktic elements. Planktic foraminifers in samples from the Locatelli Formation include *Subbotina triloculinoides*, *S. triangularis*, *S. velascoensis*, *Acarinina mckannai*, *A. acarinata* and *Morozovella aequa* and indicate a later Paleocene age (*Planorotalites pseudomenardii* (P4)—*Morozovella velascoensis* (P5) Zones). Agglutinated benthic foraminifers of the Locatelli Formation are markedly similar to those that occur in the type Lodo Formation, some 250 km (150 mi) southeast of the Santa Cruz Mountains. Among the more characteristic are *Bathysiphon eocenicus*, *Cyclammina simiensis*, *Glomospira charoides*, *Haplophragmoides excavatus*, *Hyperammina elongata*, *Karreriella media-aguaensis*, *Rhabdammina eocenica*, *Rzehakina epigona-lata*, *Spiroplectammina richardi*, and *Silicosigmoilina californica*.

Calcareous benthic taxa are sparsely represented in samples from the Locatelli Formation. Among the more diagnostic forms present are: *Anomalinoides acutus*, *A. rubiginosus*, *Gavelinella beccariiformis*, *Cibicidoides martinezensis*, *C. whitei*, *Osangularia* sp., and *Vaginulinopsis saundersi*.

The agglutinated benthic foraminiferal fauna of the Locatelli Formation, accompanied by infrequent calcareous benthic and planktic elements, has all the characteristics of a classic flysch assemblage. Most of the calcareous benthic taxa present are indicative of bathyal depths, although there is also a fairly diverse component of neritic elements (predominantly lagenids) similar to those in the Midway Group (see faunal list of Clark, 1966, table 2, also Clark *in* Brabb and others, 1977, table 5; we have also examined Clark's prepared slides of samples JC60-126, JC60-120, and JC60-93 in connection with this study). Precise estimates of deposition are not possible on the basis of this preliminary faunal examination but a general depth of 1-2 km is suggested.

LOMPICO AREA

The seven samples examined from the Butano Sandstone span a stratigraphic interval of approximately 1,000 m (fig. 7).

Calcareous faunas are exceedingly sparse in the samples of the Butano Sandstone we have examined, although Clark (1966, table 3, also Clark *in* Brabb and others, 1977, table 4) records a relatively diverse, albeit sparse, calcareous fauna (including lagenids, buliminids, pleurostomellids and anomalinids) from the middle siltstone member of the Butano Sandstone near Lompico.

Planktic foraminiferal faunas of the Butano Sandstone contain *Subbotina* sp. cf. *S. linaperta*, *S. turgida*, *Acarinina acarinata*, *A. coalingensis*, *A. wilcoxensis*, and *Morozovella subbotinae* and indicate an early Eocene age (*Morozovella aragonensis* (P8 Zone) for at least part of the middle siltstone member.

Agglutinated assemblages from the Butano Sandstone are poorly preserved and not directly comparable with those observed at equivalent levels in the Lodo Formation or Gredal Shale Member of the Kreyenhagen Formation. In general the samples from the Butano lack the diversity seen in samples from the Lodo (absence of *Cyclammina*, *Silicosigmoilina*, *Rzehakina*, *Rhabdammina*, *Verneuilina*, *Gaudryina*), but this may be due to the small number of samples studied. Among the more diagnostic forms present in the Butano Sandstone are *Bathysiphon eocenicus*, *Karreriella mediaguaensis*, and *Haplophragmoides obliquicameratus*. Calcareous benthic foraminifers, although sparse, include several forms also present in the type Lodo Formation. Among these are *Buliminella bradburyi*, *Bolivina crenulata*, *Anomalinoides welleri*, *Pleurostomella paleocenica*, *Hoeglundina eocenica*, and *Nuttallides truempyi*.

The agglutinated benthic fauna of the Butano suggests a depositional environment similar to that of the Locatelli Formation with water between 1 and 2 km.

SUMMARY

We have made a preliminary examination of samples from the type Lodo Formation in the Lodo Gulch area; the Lodo Formation and Gredal Shale Member of the Kreyenhagen Formation in the Devils Den area, and the Locatelli Formation and Butano Sandstone of the Santa Cruz Mountains, California. The following are our tentative conclusions.

1. The type Lodo Formation is of late Paleocene and early Eocene (Zones P4-P9) age and contains a benthic foraminiferal fauna that indicates deposition during a single sedimentary cycle ranging from lower neritic (somewhat shallower than 200 m) near the base to middle bathyal (about 600 m) in the lower part to outer neritic (200 m) in the upper part.
2. A relatively abrupt shallowing occurs near the boundary between Zones P8 and P9 in the Lodo Gulch area and is denoted by the disappearance of bathyal taxa (including *Nuttallides truempyi*) that have more extensive stratigraphic ranges elsewhere in deep-sea sections.

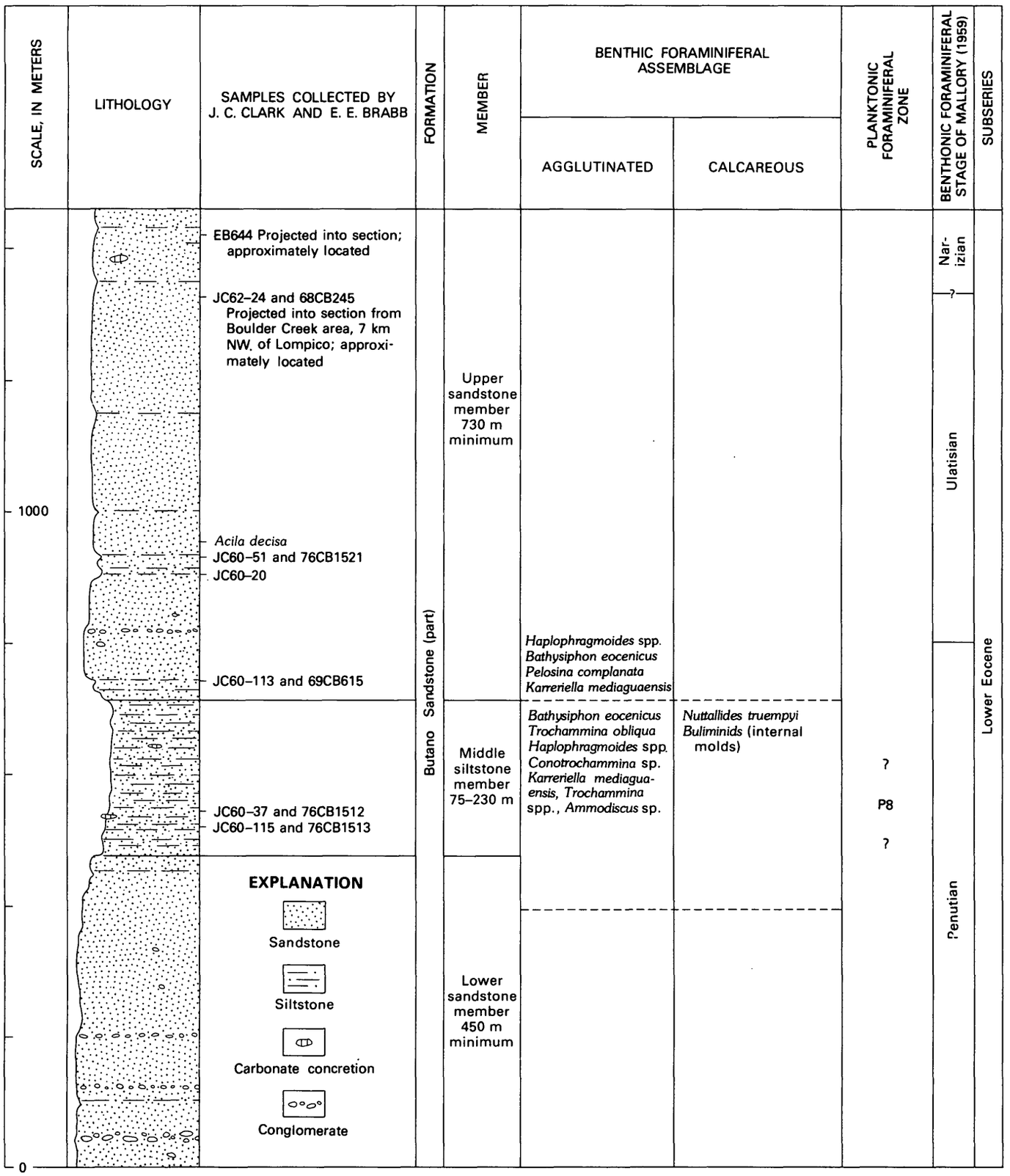


FIGURE 7.—Foraminiferal biostratigraphy of the Butano Sandstone in the Lompico area. Stratigraphic column from Clark (1966).

3. The common occurrence of cyclamminids and *Bathysiphon* in the type Lodo Formation at depths interpreted from other faunal evidence to have been near the shelf-slope break (about 200 m depth) suggests that the upper depth limit of the agglutinated benthic foraminiferal fauna was somewhat shallower during the Paleogene than during the Neogene and present day. This discrepancy may, in turn, be linked with the lack of a pronounced thermocline at the time.
4. The similarity of faunas from the Devils Den section with those in the Lodo Gulch area is marked; however, the presence of a rich planktic foraminiferal assemblage (particularly the angulo-conical morozovellids and acarininids) throughout the Devils Den section and the absence of shallow-water calcareous benthic assemblages (as seen in the type Lodo Formation) suggests deposition at middle bathyal depths (below 600 m) shallowing to upper bathyal (above 600 m) within Zone P9.
5. The relatively sudden shallowing in the late early Eocene (Zone P9) in these two sections (fig. 8) is remarkably close to a major eustatic sea-level change identified by Vail, Mitchum, and Thompson (1977) by seismic stratigraphic methods and merits further investigation.
6. The Locatelli Formation and Butano Sandstone of the Santa Cruz Mountains contain an agglutinated benthic foraminiferal fauna (with minor amounts of calcareous benthic and planktic elements) characteristic of flysch deposits elsewhere. Deposition in the distal part of turbidite fans at depths between 1 and 2 km is suggested.
7. In addition to containing elements that appear to be of Pacific affinities, the faunas of the Lodo Formation and the Gredal Shale Member of the Kreyenhagen Formation contain numerous cosmopolitan elements known from western Europe (Aquitaine Basin), West Africa (Angola), the North Atlantic (Orphan Knoll), and elsewhere. The agglutinated fauna appears to be less cosmopolitan, that is, not as closely related to the Paleogene flysch faunas of the Carpathians and North Atlantic.

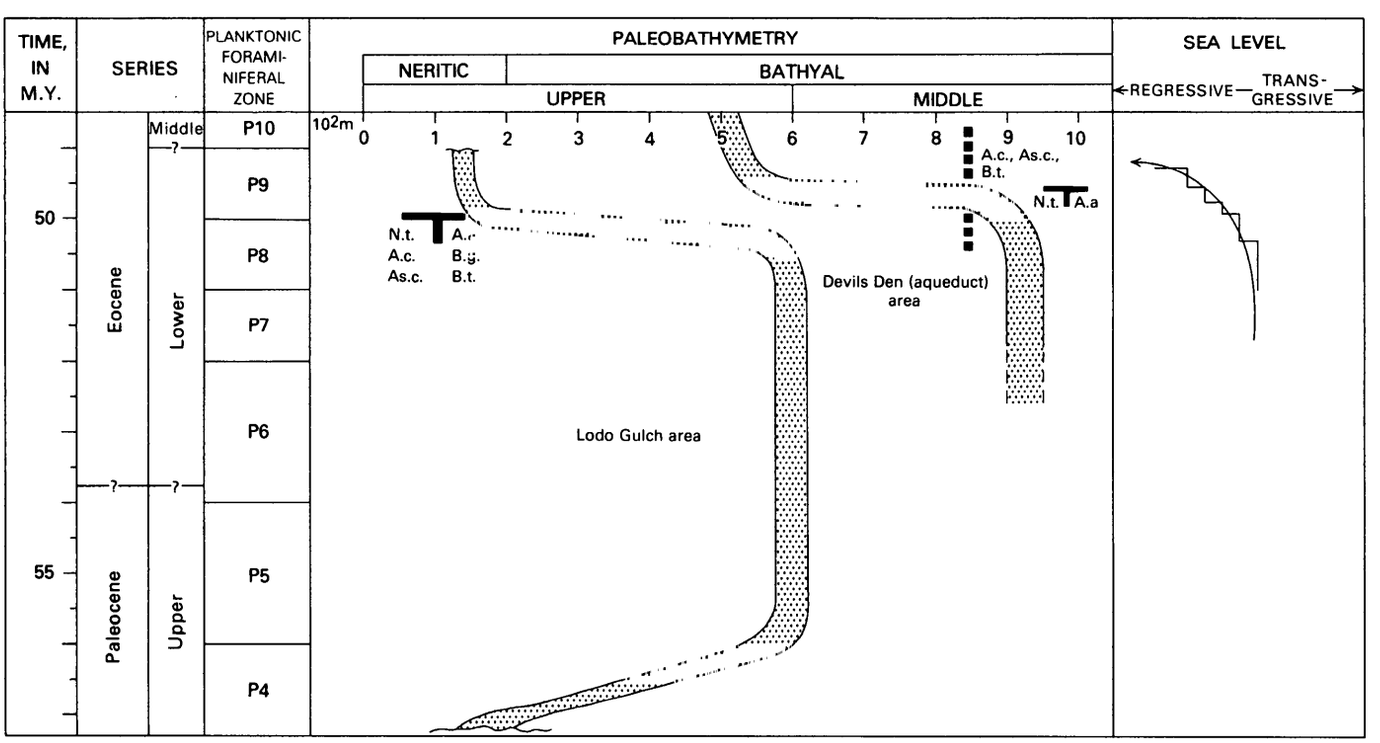


FIGURE 8.—Late Paleocene and early Eocene bathymetric history of Lodo Gulch and Devils Den (aqueduct) areas. N.t., *Nuttallides truempyi*; As.c., *Asterigerina crassaformis*; A.c., *Anomalinoides crassiseptus*; A.a., *Anomalinoides aragonensis*; B.g., *Buliminella grata*; B.t., *Bulimina trinitatensis*. The large black "T" refers to the last occurrence of the selected species; the vertical squares indicate a rare or sporadic occurrence of species.

LOWER TERTIARY NANNOPLANKTON BIOSTRATIGRAPHY IN THE CENTRAL COASTAL RANGES, CALIFORNIA

By A. D. WARREN[1]

ABSTRACT

Nannoplankton from the Devils Den, Lodo Gulch, and Media Agua Creek areas were correlated with Paleogene California benthic foraminiferal stages along the west side of the San Joaquin Valley. Based on nannoplankton chronology, the Ynezian Stage is of Paleocene and earliest Eocene age, the Bulitian, Penutian, and most of the Ulatisian Stages are of early Eocene age, and the upper Ulatisian and lower Narizian Stages are of early middle Eocene age. Estimated absolute ages for the tops of the Ynezian and Ulatisian Stages are 52 and 48 million years respectively.

Data from this and previous studies on the lower and middle Tertiary of California indicate the relations of the provincial benthic foraminiferal stages to nannoplankton and planktic foraminiferal age and zonal assignments. The Paleogene of California includes, from oldest to youngest, the Cheneyan, Ynezian, Bulitian, Penutian, Ulatisian, Narizian, Refugian, and Zemorrian Stages.

INTRODUCTION

Calcareous nannoplankton are one of the most important fossil groups for correlation of marine deposits, particularly in the middle- and low-altitude areas of the world. The main purpose of this study is to examine the vertical distribution of calcareous nannofossils within the Paleogene California benthic foraminiferal stages as represented in three areas, Devils Den aqueduct, Lodo Gulch, and Media Agua Creek (fig. 9), along the west side of the San Joaquin Valley. Each of these areas contains exposures of marine sedimentary rocks which may be assigned to the Ynezian, Bulitian, Penutian, Ulatisian, and Narizian provincial stages of Mallory (1959) based on vertical distribution of benthic foraminifers. The secondary purpose of this paper is to reexamine the Paleogene of California by extracting from this and previously published studies a synthesis of the relations of the lower and middle Tertiary provincial stages to nannoplankton zonations and, in turn, to planktic foraminiferal zonations, which are in wide use today by biostratigraphers everywhere.

The most commonly used nannoplankton and planktic foraminiferal zonations are those of Bukry (1973, 1975), Martini (1971), Blow (1969), Berggren (1972), and Hardenbol and Berggren (1978). The relationship between these zonations is shown of figure 10. The series designations of Bukry (1973, 1975) will be followed in this report.

Acknowledgments.—For providing samples and a measured section from the Devils Den (aqueduct) area, I thank D. W. Weaver. I am also grateful to J. H. Newell for much additional supplemental nannofossil data and discussion on the Lodo Gulch and Devils Den areas.

DEVILS DEN (AQUEDUCT) AREA

The aqueduct section in the Devils Den area, in sec. 34, T. 25 S., R. 18 E., Kern County, California, exposes approximately 300 m of fossiliferous marine sedimentary rocks (fig. 11). Rock units exposed there are, from oldest to youngest, the upper part of the Panoche Formation, Lodo Formation, Avenal Sandstone, and Gredal Shale and Point of Rocks Sandstone Members of the Kreyenhagen Formation. A fault approximately 210 m below the top of the exposure repeats the Lodo, the Avenal, and part of the Gredal. The aqueduct section was measured and collected in 1970 by D. W. Weaver, and his samples and stratigraphic column form the basis for data presented on this exposure. Geologic and locality maps for this area have been provided by Brabb, Clark, and Throckmorton (1977, figs. 36 and 38).

Age assignments using the provincial benthic foraminiferal stages of Mallory (1959) are as follows (fig. 11): Samples PR-1 to PR-26 are assigned to the lower Narizian Stage based on the presence of the following selected foraminiferal taxa:

Alabamina wilcoxensis californica Mallory
Anomalina crassisepta Cushman and Siegfus
A. dorri aragonensis Nuttall
Asterigerina crassaformis Cushman and Siegfus
Bulimina corrugata Cushman and Siegfus
Buliminella grata convoluta Mallory
Caucasina schencki (Beck)
Cibicides laimingi Mallory
C. spiropunctatus Galloway and Morrey
Vaginulinopsis asperuliformis Nuttall

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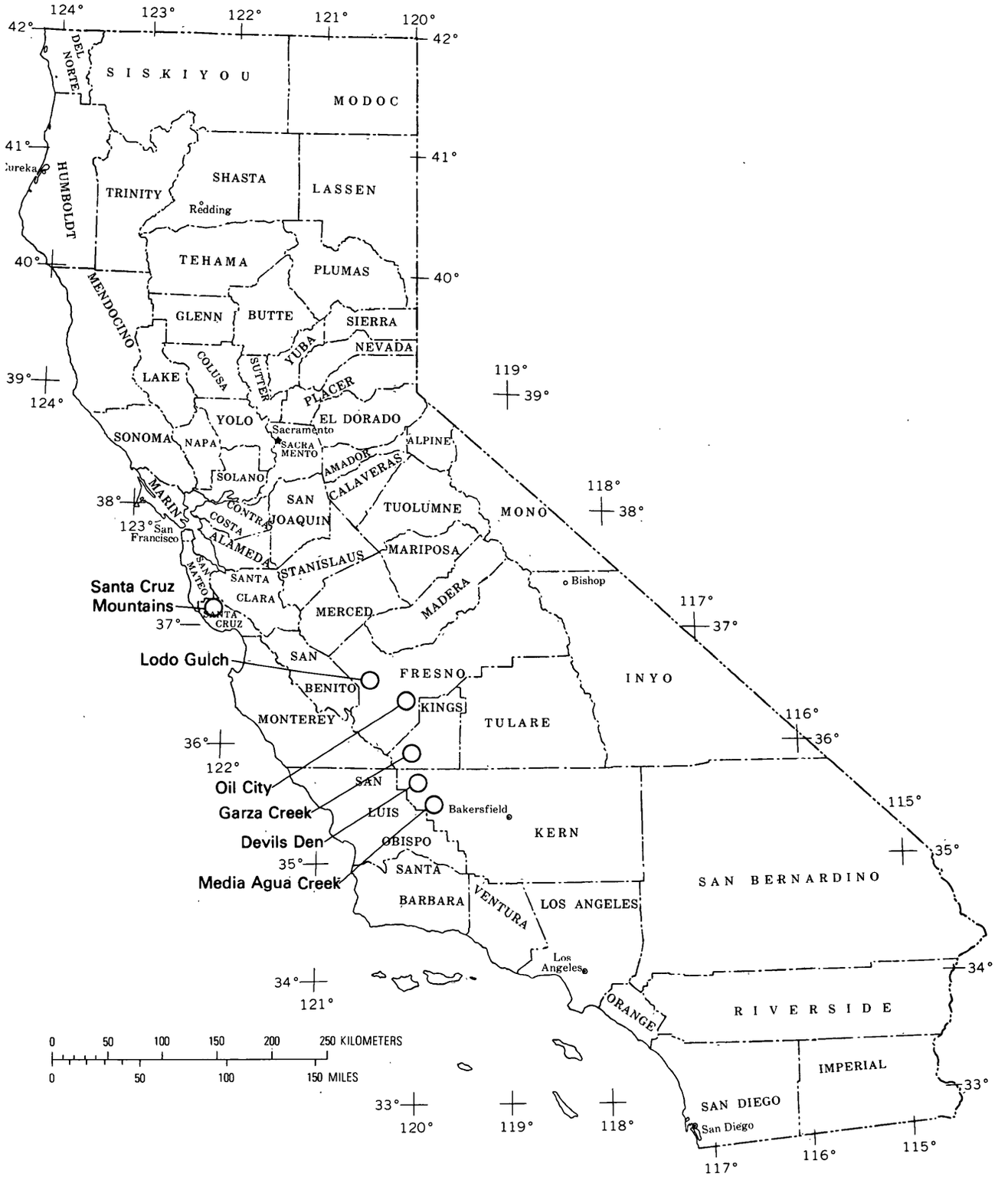


FIGURE 9.—Index map of the counties of California showing nannofossil localities.

PALEOGENE LOW-LATITUDE NANNOPLANKTON ZONATION OF BUKRY (1973, 1975)			PALEOGENE CALCAREOUS NANNOPLANKTON ZONATION OF MARTINI (1971) Boundaries between zones and series are dashed where relationship to Bukry's zonation approximate	
SERIES OR SUBSERIES	NANNOPLANKTON ZONES		SERIES OR SUBSERIES	NANNOPLANKTON ZONES
Miocene	*Triquetrorhabdulus carinatus*	*Discoaster druggii*	Miocene	NN2 *Discoaster druggi*
		Discoaster deflandrei		NN1 *Triquetrorhabdulus carinatus*
		Cyclicargolithus abisectus	Upper Oligocene	NP25 *Sphenolithus ciperoensis*
Oligocene	*Sphenolithus ciperoensis*			NP24 *Sphenolithus distentus*
	Sphenolithus distentus		Middle Oligocene	NP23 *Sphenolithus predistentus*
	Sphenolithus predistentus			
	Helicopontosphaera reticulata	*Reticulofenestra hillae*	Lower Oligocene	NP22 *Helicopontosphaera reticulata*
		Coccolithus formosus		NP21 *Ericsonia ? subdisticha*
		Coccolithus subdistichus		
Upper Eocene	*Discoaster barbadiensis*	*Isthmolithus recurvus*	Upper Eocene	NP20 *Sphenolithus pseudoradians*
				NP19 *Isthmolithus recurvus*
		Chiasmolithus oamaruensis		NP18 *Chiasmolithus oamaruensis*
Middle Eocene	*Reticulofenestra umbilica*	*Discoaster saipanensis*		NP17 *Discoaster saipanensis*
		Discoaster bifax	Middle Eocene	NP16 *Discoaster tani nodifer*
	Nannotetrina quadrata	*Coccolithus staurion*		NP15 *Chiphragmalithus alatus*
		Chiasmolithus gigas		
		Discoaster strictus		
	Discoaster sublodoensis	*Rhabdosphaera inflata*		NP14 *Discoaster sublodoensis*
		Discoasteroides kuepperi		
Lower Eocene	*Discoaster lodoensis*			NP13 *Discoaster lodoensis*
	Tribrachiatus orthostylus		Lower Eocene	NP12 *Marthasterites tribrachiatus*
	Discoaster diastypus	*Discoaster binodosus*		NP11 *Discoaster binodosus*
		Tribrachiatus contortus		NP10 *Marthasterites contortus*
Paleocene	*Discoaster multiradiatus*		Upper Paleocene	NP9 *Discoaster multiradiatus*
	Discoaster nobilis			NP8 *Heliolithus riedeli*
	Discoaster mohleri		Middle Paleocene	NP7 *Discoaster gemmeus*
	Heliolithus kleinpellii			NP6 *Heliolithus kleinpelli*
	Fasciculithus tympaniformis			NP5 *Fasciculithus tympaniformis*
	Cruciplacolithus tenuis		Lower Paleocene	NP4 *Ellipsolithus macellus*
				NP3 *Chiasmolithus danicus*
				NP2 *Cruciplacolithus tenuis*
Upper Cretaceous				NP1 *Markalius inversus*
			Upper Cretaceous	?

FIGURE 10.—Diagram showing relationship between the nannoplankton zones of Bukry (1973, 1975) and Martini

PALEOGENE PLANKTONIC FORAMINIFERAL ZONATION (1978)
MODIFIED AFTER BLOW (1969), BERGGREN (1972),
AND HARDENBOL AND BERGGREN (1982)

SERIES OR SUBSERIES	EUROPEAN STAGE BOUNDARY AGE IN M.Y.B.P.	PLANKTONIC FORAMINIFERAL ZONE
Miocene	Aquitanian	N5 *Globoquadrina dehiscens praedehiscens - Globoquadrina dehiscens*
		N4 *Globigerinoides quadrilobatus primordius/Globorotalia kugleri*
	24	
Upper Oligocene	Chattian	P22 *Globigerina angulisuturalis*
		P21 *Globigerina angulisuturalis/Globorotalia opima opima*
		P20 *Globigerina ampliapertura*
	32	
Lower Oligocene	Rupelian	P19 *Globigerina sellii/Pseudohastigerina barbadoensis*
		P18 *Globigerina tapuriensis*
	37	
Upper Eocene	Priabonian	P17 *Globigerina gortanii gortanii/Globorotalia centralis*
		P16 *Cribrohantkenina inflata*
		P15 *Globigerapsis mexicana*
	40	
Middle Eocene	Bartonian	P14 *Truncorotaloides rohri-Globigerinita howei*
		P13 *Orbulinoides beckmanni*
	44	
	Lutetian	P12 *Globorotalia lehneri*
		P11 *Globigerapsis kugleri*
		P10 *Hantkenina aragonensis*
	49	
Lower Eocene	Ypresian	P9 *Acarinina densa*
		P8 *Globorotalia aragonensis*
		P7 *Globorotalia formosa*
		P6 *Globorotalia subbotinae/Acarinina wilcoxensis*
	53.5	
Upper Paleocene	Thanetian	P5 *Globorotalia velascoensis*
		P4 *Globorotalia pseudomenardii*
		P3 *Globorotalia pusilla-Globorotalia angulata*
	60	
Lower Paleocene	Danian	P2 *Globorotalia uncinata-Globigerina spiralis*
		P1 *Globoconusa daubjergensis*
	65	
Upper Cretaceous	Maestrichtian	?

(1971) and the planktic foraminiferal zones of Blow (1969), Berggren (1972) and Hardenbol and Berggren (1978).

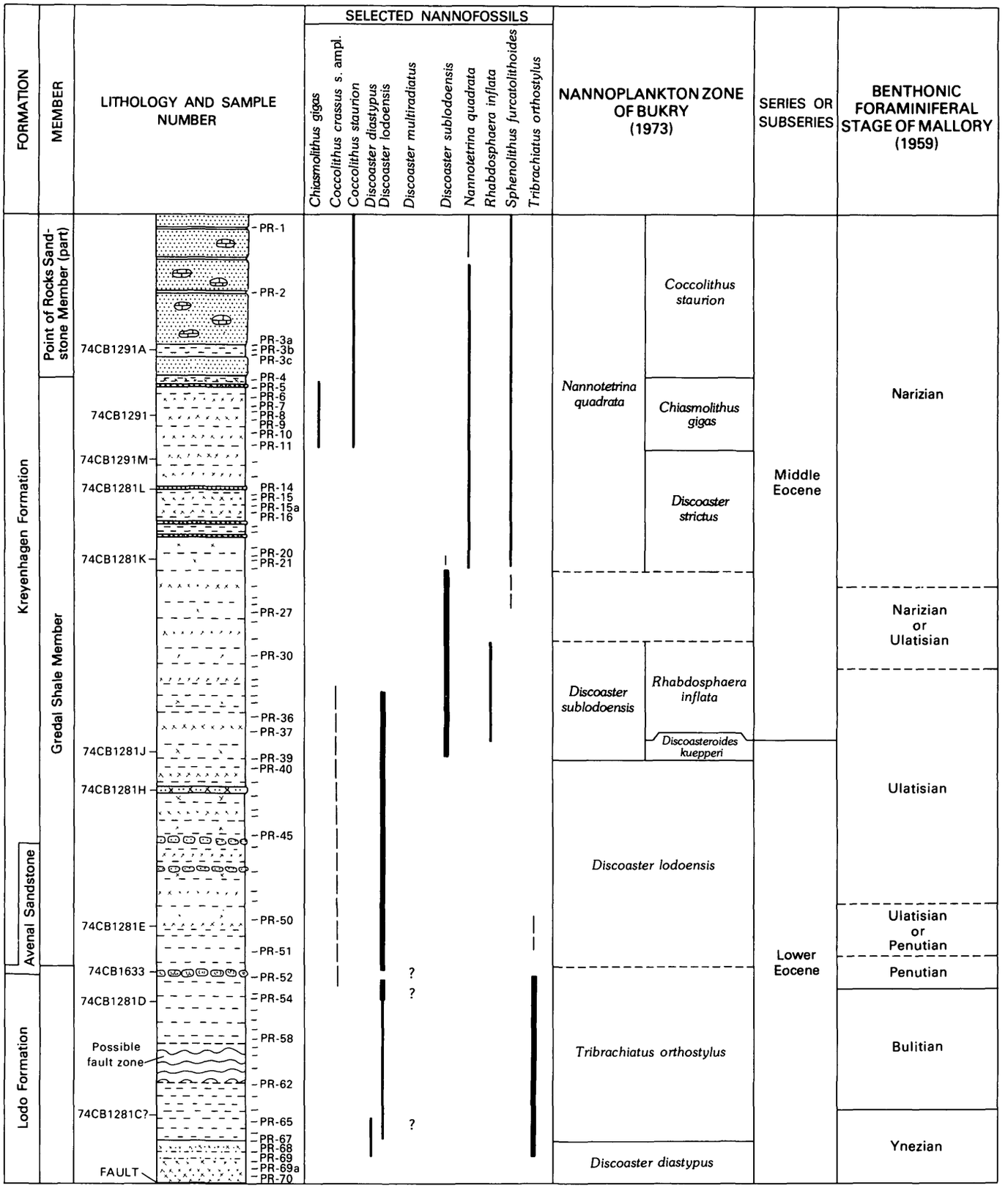


FIGURE 11A.—Biostratigraphy of the aqueduct section of the Devils Den Area. *A* is the upper part of the section exposed near the penstocks.

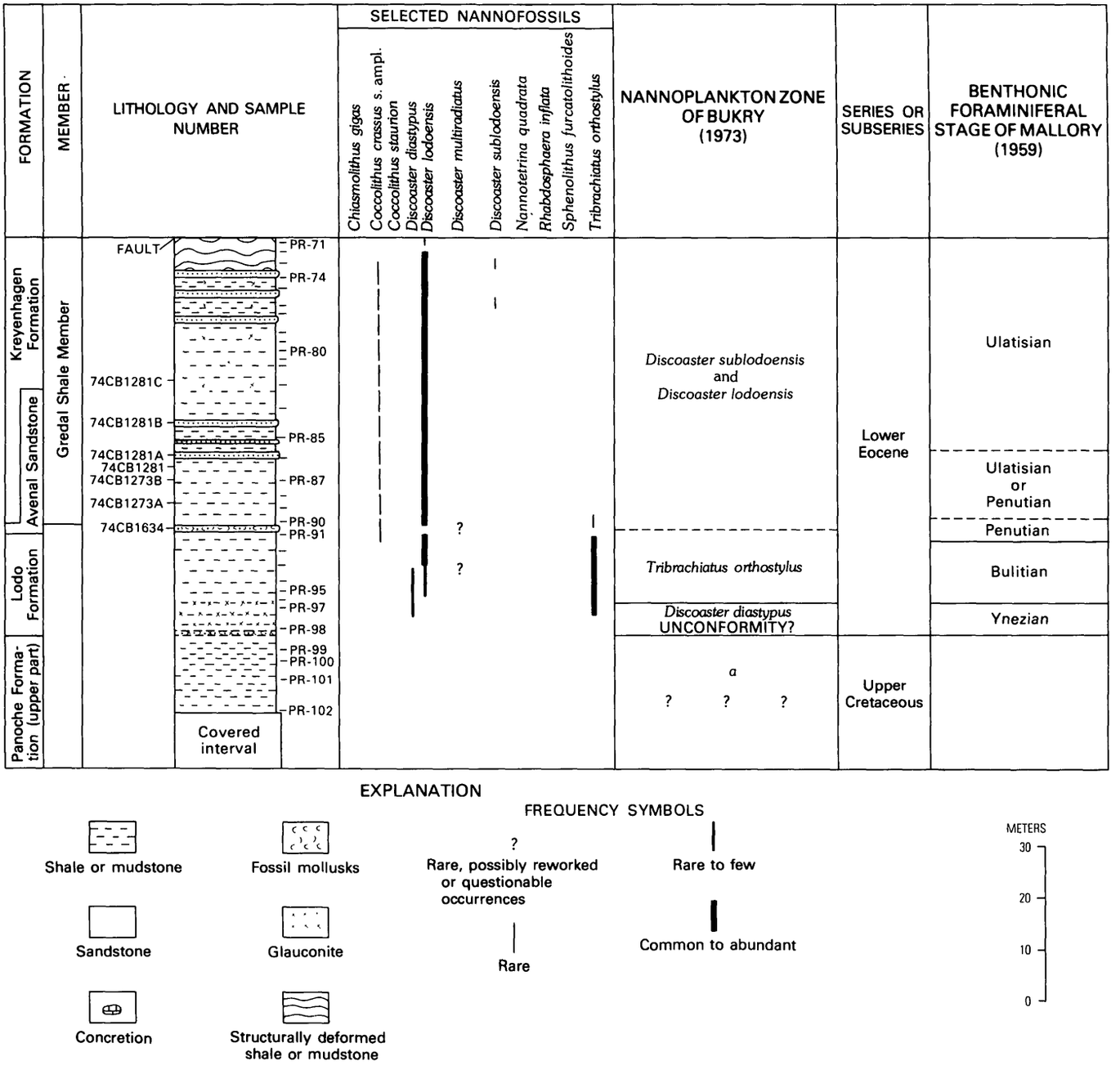


FIGURE 11*B*.—Lower part of the aqueduct section in the Devils Den area. Section measured and collected in 1970 by D. W. Weaver (PR sample numbers). Other samples were collected by E. E. Brabb. See Berggren and Aubert, this volume, for discussion. Lithostratigraphy from Dibblee (1973). Series assignments for formations are based on repeated faulted nannoplankton zonal assignments of Bukry (1973a, b). (See also Berggren and Aubert, this volume.)

Samples PR-27 to PR-31 cannot be assigned with certainty to either the Ulatisian or Narizian Stage although most workers would probably classify these samples as Ulatisian based on rare to few occurrences of the following selected taxa:

Bulimina debilis Martin
Gaudryina jacksonensis coalingensis Cushman and Hanna
Nodosaria latejugata Gumbel
Vaginulinopsis mexicana (Cushman) vars.

Samples PR-32 to PR-49 are assigned to the Ulatisian Stage on the basis of the following selected taxa:

Bifarina nuttalli Cushman and Siegfus
Globorotalia aragonensis Nuttall
Nodosaria latejugata Gumbel
Lenticulina ulatisensis (Boyd)
Trifarina advena californica Mallory
Uvigerina lodoensis Martin and vars.
Vaginulinopsis mexicana (Cushman) vars.
Valvulineria indiscriminata Mallory

McKeel and Morin (1979) have investigated the taxonomic status of *Valvulineria indiscriminata* Mallory and have determined that it is a planktic species referable to the genus *Planorotalites*. In addition, they consider *Globorotalia pseudochapmani* Gohrbandt to be a junior synonym of *Planorotalites indiscriminata* (Mallory), having had the opportunity of comparing hypotypes of the latter species to paratypes or topotypes of the former provided by Gohrbandt and finding them to be conspecific. Mallory (1959) indicates that this species is restricted to his Ulatisian Stage.

Samples PR-50 and PR-51 are either Penutian or Ulatisian as the taxa present are not clearly diagnostic of either stage.

The Avenal Sandstone is assigned to the Penutian Stage on the basis of *Pseudosphragmina psila* (Woodring), and *Rotularia (Spiroglyphus) tinajasensis* (Hanna and Hertlein), a worm tube, collected by the author from the Avenal Sandstone.

Samples PR-52 and PR-53 are assigned to the Penutian Stage based on the occurrence of the following selected taxa:

Angulogerina wilcoxensis (Cushman and Ponton)
Eponides lodensis Martin
Pseudophragmina psila (Woodring)
Lenticulina laimingi (Israelsky)
Siphonina wilcoxensis Cushman
Verneuilina triangulata Cook

Lenticulina laimingi (Israelsky) was first recognized as a distinctive species by Cook (1950) but was not formally described at that time. The species appears to range from within the Bulitian Stage to the top of the lower Penutian Stage and is present in the Lodo Formation at its type locality in the Lodo Gulch area and in the Lodo Formation in the Devils Den and Media Agua Creek areas.

Samples PR-54 to PR-64 are assigned to the Bulitian Stage on the basis of the following selected taxa:

Bulimina excavata Cushman and Parker (rare)
Cibicides kernensis Cook
Globorotalia californica Smith (rare)
Lenticulina laimingi (Israelsky)

Samples PR-65 to PR-70 are assigned to the upper Ynezian Stage on the basis of the following selected taxa:

Anomalina dorri Cole
Bulimina excavata Cushman and Parker (common)
Chiloguembelina midwayensis subcylindrica Beckman
Globorotalia californica Smith (common)
G. marginodentata Subbotina

Samples PR-71 to PR-98 are in that part of the section repeated by faulting and represent part of the Ulatisian, Penutian, Bulitian, and Ynezian Stages. These stage assignments are based on the occurrence of the same foraminifers below the fault as above the fault, thus providing paleontological evidence of the repeated section.

Samples PR-99 to PR-102 are from the upper part of the Panoche Formation and contain only crushed arenaceous foraminifers except for sample PR-101, in which Cretaceous radiolarians were recognized by M. B. Mickey (oral commun., 1975). Radiolarian species present are *Amphipyndax plousios, Dictyomitra* cf. *multicostata* and *Stichomitra asymbatos*, all of which have been reported from the Late Cretaceous of California by Foreman (1968).

Some of the nannoplankton from the Devils Den section are shown on Figure 10. Additional nannoplankton from samples collected by E. E. Brabb are shown on table 3. The stratigraphic position of the Brabb samples is shown in the report by Aubert and Berggren (this volume, fig. 4).

The ages of nannoplankton from the aqueduct section in the Devils Den area are also shown on figure 11 and table 3. These age assignments follow the zonal criteria and series correlations proposed by Bukry (1973a and b, 1975). Nannoplankton zones recognized are the *Discoaster diastypus, Tribrachia-*

tus orthostylus, Discoaster lodoensis, Discoaster sublodoensis, and *Nannotetrina quadrata* Zones. Placement of boundaries between the *Tribrachiatus orthostylus* and *Discoaster lodoensis* Zones and the *Discoaster sublodoensis* and *Nannotetrina quadrata* Zones are not precise. The boundary between the *Tribrachiatus orthostylus* and *Discoaster lodoensis* Zones is arbitrarily and tentatively drawn here to approximate the highest occurrence of persistent and common to abundant *Tribrachiatus orthostylus* and the lowest occurence of *Coccolithus crassus* s. ampl. The boundary between the *Discoaster sublodoensis* and *Nannotetrina quadrata* Zones must be below sample PR-21 and above sample PR-30, but the absence of both *Rhabdosphaera inflata* and *Nannotetrina quadrata* in samples from that interval precludes a more precise placement based on the criteria proposed by Bukry (1973). The highest occurrence of persistent and common to abundant *Discoaster sublodoensis* as noted in sample PR-27 might serve locally as a useful reference point approximating the top of the *Discoaster sublodoensis* Zone.

Having now resolved the placement of both provincial stage and nannoplankton zonal boundaries within the aqueduct section in the Devils Den area, we may draw the following conclusions regarding that section:

1. The boundary between the Ynezian and Bulitian States lies within the lower part of the *Tribrachiatus orthostylus* Zone and very near the top of the *Discoaster diastypus* Zone, and the boundary between the Ulatisian and Narizian Stages is closely associated with the top of the *Discoaster sublodoensis* Zone.
2. Age assignments based on nannoplankton as proposed by Bukry (1973, 1975) require that the upper Ynezian, Bulitian, Penutian, and lower and middle Ulatisian Stages be of early Eocene age and that the uppermost Ulatisian and lower Narizian be of early middle Eocene age.
3. A hiatus or unconformity at the contact between the Upper Cretaceous Panoche Formation and the Lodo Formation is suggested by the absence of any Paleocene nannoplankton zones.
4. At Devils Den, the Panoche Formation is of Late Cretaceous age, and, on the basis of nannoplankton, the Lodo Formation, Avenal Sandstone, and lower part of the Gredal Shale Member of the Kreyenhagen Formation are of early Eocene age, and the upper part of the Gredal Shale Member and lower part of the Point of Rocks Member of the Kreyenhagen are of middle Eocene age.

LODO GULCH AREA

The Lodo Formation at its type locality at Lodo Gulch, secs. 28 and 29, T. 15 S., R. 12 E., Fresno County, California, is a continuous section of marine sedimentary rocks approximately 360 m thick. Martin (1943) and Israelsky (1951, 1955) provided foraminiferal data on the type Lodo, which Mallory (1959, p. 29, 33, 37, 51, 53 and fig. 7) used to generalize the approximate position of his lower Tertiary benthic foraminiferal stages within that section. In a classic report, Bramlette and Sullivan (1961) described in detail the nannoplankton flora of the type Lodo Formation including data on the overlying Domengine and Kreyenhagen Formations from other localities. Utilizing distributional data of Bramlette and Sullivan (1961, table 1) and Hay and others (1967, fig. 5), Poore (1976) reinterpreted zonal assignments within the type Lodo Formation to prove the presence of six nannoplankton zones within that unit, the *Discoaster mohleri, D. nobilis, D. multiradiatus, D. diastypus, Tribrachiatus orthostylus,* and *Discoaster lodoensis* Zones of Bukry (1973); the lower three zones are placed in the Paleocene by the majority of nannoplankton workers, and the higher three are considered to be early Eocene. Figure 12 illustrates the relations in the Lodo Gulch area of the formations, provincial benthic foraminiferal stages, vertical distribution of key nannofossil taxa, and nannoplankton zones to one another as derived from published data of the authors cited above. Additional nannoplankton from this section are shown on table 3.

Keeping in mind that the placement of benthic foraminiferal stage boundaries in figure 12 is only approximate, the following conclusions may be drawn as regards the exposures in the Lodo Gulch area:

1. The Ynezian-Bulitian boundary as approximately delimited by Mallory (1959, p. 29 and 33) appears to be within the *Discoaster diastypus* Zone.
2. Following Bukry's (1973a and b, 1975) correlation of nannoplankton zones with European Tertiary series, and the correlations in this report between the nannoplankton zones and the benthic foraminiferal stages, most of the Ynezian Stage is of Paleocene age, and the uppermost Ynezian, Bulitian, Penutian, and lower and middle Ulatisian Stages are of early Eocene age.
3. A hiatus may be present between the Moreno Shale and the overlying type Lodo Formation as

TABLE 3.—*Identification and age of nannoplankton samples*

[For the stratigraphic position of these samples, see the

Area	Rock Units	Sample Numbers	*Braarudosphaera discula* *Campylosphaera dela* *C. eodela*	*Chiasmolithus bidens* *C. californicus* *C. consuetus*	*C. expansus* *C. gigas* *C. grandis*	*C. solitus* *Chiphragmalithus calathus* *Coccolithus cavus*	*C. crassus* *C. cribellum* *C. eopelagicus*	*C. magnicrassus* *C. pelagicus* *C. subdistichus*	*Cruciplacolithus staurion* *Cyclicargolithus floridanus* *Cyclococcolithina formosa*	*C. gammation* *C. pseudogammation* *Dictyococcites bisectus*	*D. scrippsae* *Discoaster barbadiensis* *D. binodosus*	*D. cruciformis* *D. deflandrei* *D. diastypus*	*D. distinctus* *D. elegans* *D. gemmifer*	*D. germanicus* *D. helianthus* *D. lenticularis*	*D. lodoensis* *D. minus* *D. multiradiatus*	*D. nobilis* *D. nodifer* *D. nonaradiatus*	*D. saipanensis* *D. strictus*
Lodo Gulch area	Kreyenhagen Shale	74CB1214B	•		●	● ●	●	●	•		●	•	•				• ●
Lodo Gulch area	Domengine Sandstone	76CB1662	•		●	●	• ●	●	●	•	●	•	• ●	●	•	•	●
Lodo Gulch area	Domengine Sandstone	76CB1661	•		●	●	• ●	•	●	•	●		• ●	•	•		●
Lodo Gulch area	Lodo Formation	76CB1654	•	•	• ●	• ●	• ●	● ●	●		●	• •	• ●	● ●	●		
Lodo Gulch area	Lodo Formation	76CB1653	•	•	• ●	• ●	• ●	• ●	●	•	•	•		●	●	•	
Lodo Gulch area	Lodo Formation	74CB1221		•	• •	●		• ●	●	•	• •	•	•	•	●		
Lodo Gulch area	Lodo Formation	74CB1221A	●	• ●	• •	●		● ●	●	•	• •		• •	•	●		
Lodo Gulch area	Lodo Formation	74CB1221B	•	•	• •	• ●	•	• ●	●		•	• •	•	• •	●		
Lodo Gulch area	Lodo Formation	74CB1222A		•	• •	•	●	●	●		•	•	•		●		
Lodo Gulch area	Lodo Formation	74CB1221C	• •	•	• •	•	●	• ●	●		• •	• •		•	●		
Lodo Gulch area	Lodo Formation	74CB1222B		● •	• ●	•	●	● ●	●		•		•	•	●		
Lodo Gulch area	Lodo Formation	74CB1222C	•	•	• ●	•	•	● ●	●		•	• •	•	•	●		
Lodo Gulch area	Lodo Formation	74CB1221D	• •	•	• ●		•	● ●	●		• •	• •	• ●	•	●		
Lodo Gulch area	Lodo Formation	74CB1222D	● •	• •	• ●	●	• •	• ●	●		• •	• •	• ●	●	●		
Lodo Gulch area	Lodo Formation	74CB1221E	●	• •	• ●	●	•	• ●	●		● •	• •	●	• • ●	●		
Lodo Gulch area	Lodo Formation	74CB1231	● •	• ●	● ●	●	• •	● •	●		• •	• •	• •	• •	●		
Lodo Gulch area	Lodo Formation	74CB1221F	● •	• •	• ●	●	•	● •	●	•	• •	● •	• ●	• •	●		
Lodo Gulch area	Lodo Formation	74CB1231A			• ●	●	●	● •	●	●		•	• ●	• ●	●		
Lodo Gulch area	Lodo Formation	74CB1221G	● •	•	• ●	●	•	● ●	●	●	•		• ●	• • •	●		
Lodo Gulch area	Lodo Formation	74CB1231B	● •	•	• ●	●	•	● •	●	•	• •	• •	●	●	●		
Lodo Gulch area	Lodo Formation	74CB1221H	●	•	• ●	●	•	● ●	●	•	• •	• •	●		■		
Lodo Gulch area	Lodo Formation	74CB1231C	● •	• •	• ●	●	•	● ●	●	•	• •	• •	•	•	●		
Lodo Gulch area	Lodo Formation	74CB1231D	●		• ●	●	•	● •	●	●	•		• ●	• •	■		
Lodo Gulch area	Lodo Formation	74CB1231E	● •	•	● ●	●	•	● •	●	•	• •	•	• ●		●		
Lodo Gulch area	Lodo Formation	74CB1231F	• •	• •	• ●	●	●	● ●	●	•	• •	● •	• ●	•	●		
Lodo Gulch area	Lodo Formation	74CB1231G	● •	• •	● ●	●	•	● •	●	•	•	● •	• •	•	■		
Lodo Gulch area	Lodo Formation	74CB1251D	• •	● • •		●	•	■				•			• ●	●	
Lodo Gulch area	Lodo Formation	74CB1251C	•	• • •		•	•	■	•						• ●	●	
Devils Den area	Wagonwheel Formation	76CB1644						● ●	● •	●	●	•				•	
Devils Den area	Kreyenhagen Formation, Point of Rocks Sandstone Member	74CB1291A	•		• •	•	●	●	●		•					• •	
Devils Den area	Kreyenhagen Formation, Gredal Shale Member	74CB1291	•		●	● •	●	●	• ●		•					●	•
Devils Den area	Kreyenhagen Formation, Gredal Shale Member	74CB1281M	•		•	●	•	●	●		•					•	•
Devils Den area	Kreyenhagen Formation, Gredal Shale Member	74CB1281L	•		•	● •	•	●	■		•					•	•
Devils Den area	Kreyenhagen Formation, Gredal Shale Member	74CB1281K	•		•	●	●	●	• ■	•	●		• •			●	• •
Devils Den area	Kreyenhagen Formation, Gredal Shale Member	74CB1281J	•		●	●	● ●	●	• ■	●	●		●	•	•		
Devils Den area	Kreyenhagen Formation, Gredal Shale Member	74CB1281H	●		• ●	● • •	● •	•	●			●	•	●	●	•	
Devils Den area	Kreyenhagen Formation, Gredal Shale Member	74CB1281F	●		• •	• • •	●	●	●	●		•		●	●	•	
Devils Den area	Kreyenhagen Formation, Gredal Shale Member	74CB1281E	●		• ●	● ●	● •	• ●	●	●			●	● ●	●		
Devils Den area	Lodo(?) Formation	74CB1281D	• •	• •	• •	●	● •	● ●	●	•	•	●	•	• •	● •		
Devils Den area	Lodo(?) Formation	74CB1281C	● ●	● ● •		• ●	●	● •	•	• ●	● ●	●		•			

SECTION REPEATED

Area	Rock Units	Sample Numbers	*Braarudosphaera discula* *Campylosphaera dela* *C. eodela*	*Chiasmolithus bidens* *C. californicus* *C. consuetus*	*C. expansus* *C. gigas* *C. grandis*	*C. solitus* *Chiphragmalithus calathus* *Coccolithus cavus*	*C. crassus* *C. cribellum* *C. eopelagicus*	*C. magnicrassus* *C. pelagicus* *C. subdistichus*	*Cruciplacolithus staurion* *Cyclicargolithus floridanus* *Cyclococcolithina formosa*	*C. gammation* *C. pseudogammation* *Dictyococcites bisectus*	*D. scrippsae* *Discoaster barbadiensis* *D. binodosus*	*D. cruciformis* *D. deflandrei* *D. diastypus*	*D. distinctus* *D. elegans* *D. gemmifer*	*D. germanicus* *D. helianthus* *D. lenticularis*	*D. lodoensis* *D. minus* *D. multiradiatus*	*D. nobilis* *D. nodifer* *D. nonaradiatus*	*D. saipanensis* *D. strictus*
Devils Den area	Gredal Shale Member of Kreyenhagen Formation	74CB1281	•		●	●	● •	●	• ●	●	●	•	●	•	●	●	
Devils Den area	Gredal Shale Member of Kreyenhagen Formation	74CB1273B	●	•	●	• ●	● •	• ●	●	●	● •		•	● ●	●		
Devils Den area	Gredal Shale Member of Kreyenhagen Formation	74CB1273A	●	•	• ●	● ●	● • ●	● ●	■	●	●	•	•	● ●	■		
Devils Den area	Lodo(?) Formation	74CB1273	•	• •	• ●	• ●	• ●	● ●	●		● •	•		● ●	● •		

EXPLANATION

FREQUENCY SYMBOLS

• Rare

• Few

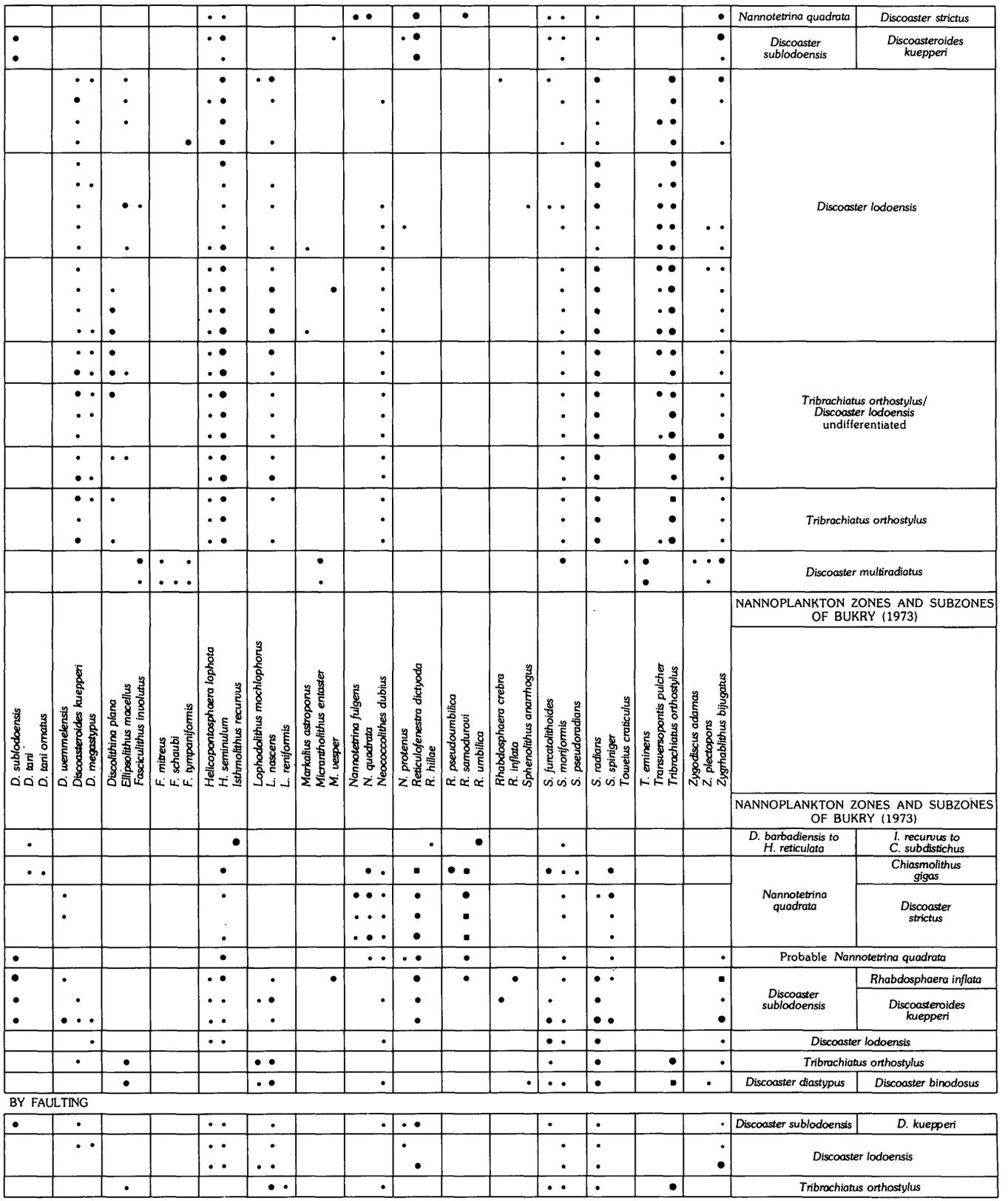
● Common

■ Abundant

Interpreted by J. H. Newell

NANNOPLANKTON SPECIES

collected by E. E. Brabb in the Devils Den and Lodo Gulch areas
report by Berggren and Aubert (this volume, fig.4)]



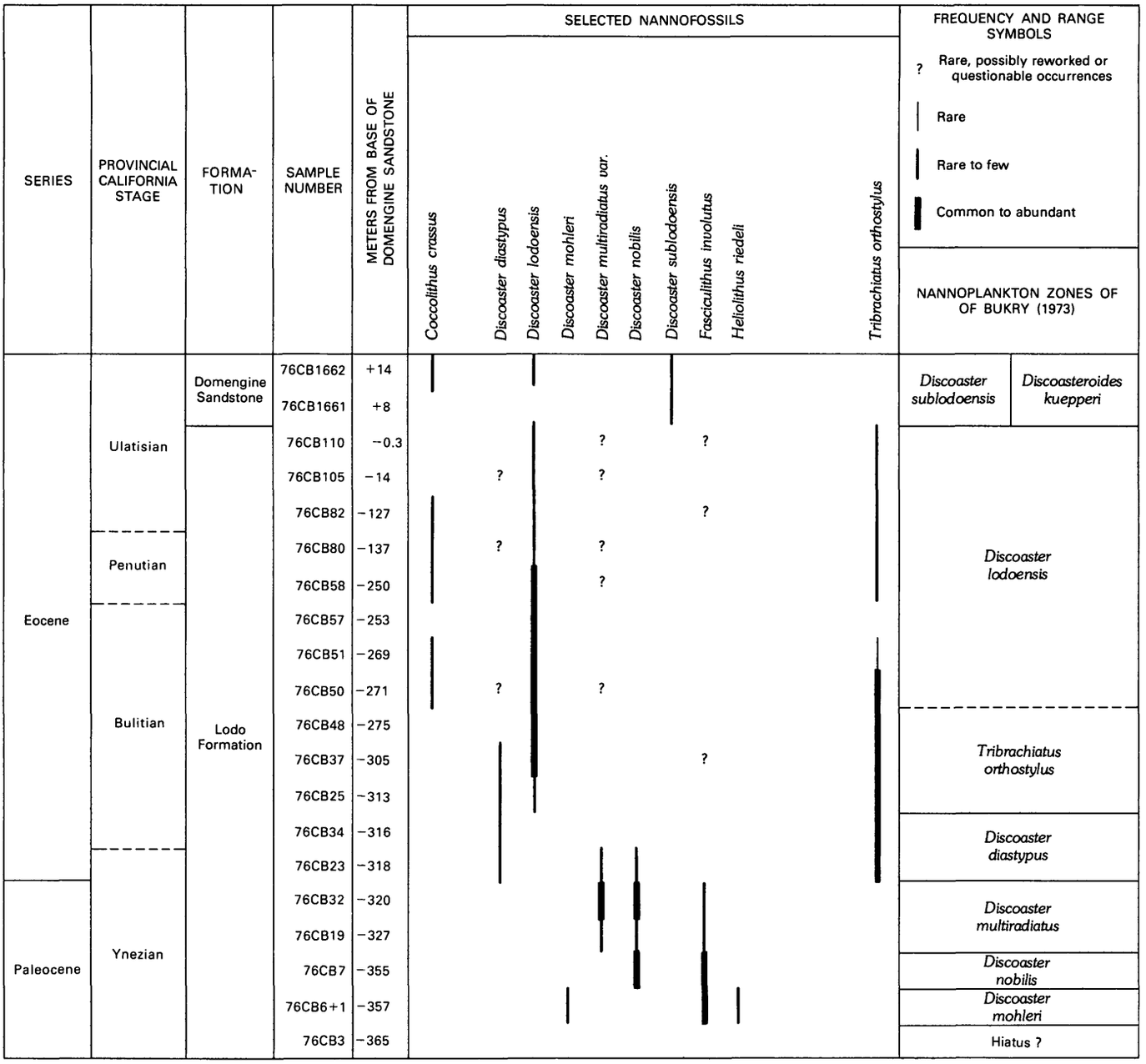


FIGURE 12.—Selected nannofossil distributions, nannoplankton zonation, and benthic foraminiferal stages in the Lodo Gulch area. The lithostratigraphy is from Israelsky (1951, fig. 2). Sample numbers and nannoplankton frequency and range are from Bramlette and Sullivan (1961). Nannoplankton zonal assignments are by Poore (1976). Benthic foraminiferal stage assignments are by Mallory (1959). Dashed lines indicate stage and zone boundaries are approximately located.

suggested by the absence of any Paleocene nannofossil zones older than the *Discoaster mohleri* Zone within the type Lodo.

4. On the basis of nannoplankton in the Lodo Gulch area, the Lodo Formation is of late Paleocene and early Eocene age.

MEDIA AGUA CREEK AREA

At Media Agua Creek, in sec. 22, T. 28 S., R. 19 E., Kern County, California, a continuous section of lower Tertiary marine sedimentary rocks over 700 m thick is exposed. Rock units present, from oldest to youngest, are the Lodo(?) Formation, Avenal Sand-

stone, Gredal Shale and Point of Rocks Sandstone Members of the Kreyenhagen Formation following stratigraphic nomenclature modified from Dibblee (1973a, p. 8-13). Mallory (1959, 1970), after detailed foraminiferal analysis, selected the Media Agua Creek exposures as the type sections for the benthic foraminiferal zones of his Ynezian and Bulitian Stages and the type section of his Penutian Stage; he also delimited the position of the Ulatisian and lower Narizian Stages within that section. Sullivan (1964, 1965) provided detailed nannoplankton data from Mallory's samples; Poore (1976) used these data to establish the position of the nannoplankton zones of Bukry (1973) in the Media Agua Creek section. Consequently, the Media Agua Creek section is perhaps the single most important reference section for the lower Tertiary in California by virtue of its wealth of disciplinary controls.

Figure 13 illustrated the relations at Media Agua Creek of the provincial stages, formations, vertical distribution of key nannofossil taxa, and nannoplankton zones to one another as derived from published data of the authors cited in the preceding paragraph. However, I have placed the boundary between the *Discoaster lodoensis* and *Discoaster sublodoensis* Zones at the approximate middle of the Gredal Shale Member rather than at the base of the Gredal as shown by Poore (1976, pl. 1); this interpretation is based on the first stratigraphic occurrence of *Discoaster sublodoensis* in Sample A-7052 as reported by Sullivan (1965).

From previously published data from the various authors cited above, the following conclusions may be drawn as regards the Media Agua Creek section:

1. The Ynezian-Bulitian boundary at Media Agua Creek is coincident with the top of the *Discoaster diastypus* Zone.
2. Age assignments based on nannoplankton as proposed by Bukry (1973, 1975) require that the lower Ynezian Stage be Paleocene and that the upper Ynezian, Bulitian, Penutian, and the lower Ulatisian be of early Eocene age. It is not possible from the available data to determine if the middle and upper Ulatisian at Media Agua Creek is in part of early middle Eocene age as noted in other exposures along the west side of the San Joaquin Valley, but the lower Narizian here is clearly of early middle Eocene age.
3. The absence of the *Discoaster multiradiatus* Zone suggests a hiatus within that part of the Lodo(?) Formation assigned by Mallory to the Ynezian Stage. A second hiatus or unconformity may be present at or near the contact between the Panoche and Lodo(?) Formations as suggested by the absence of any recognizable Paleocene nannoplankton zones older than the *Discoaster nobilis* Zone.
4. At Media Agua Creek, on the basis of nannoplankton, the lowermost 10 m of the Lodo(?) Formation is Paleocene, and the remainder of the Lodo(?), the Avenal Sandstone, and the lower part of the Gredal Shale Member of the Kreyenhagen Formation are of early Eocene age. The upper part of the Gredal Shale Member and the lower part of the Point of Rocks Sandstone Member of the Kreyenhagen Formation (Mallory, 1970. fig. 3) are late early Eocene and (or) early middle Eocene age, and the middle and upper parts of the Point of Rocks Sandstone Member are of early middle Eocene age.

COMPARISON OF THE THREE AREAS

New and previously published data from the Devils Den, Lodo Gulch, and Media Agua Creek areas make possible a comparison of lower Tertiary benthic foraminiferal stages of California and nannoplankton zones as represented along the west side of the San Joaquin Valley. Figure 14 illustrates those relations and permits the following observations to be made:

1. The Ynezian Stage in this area has been shown to include the *Discoaster mohleri, Discoaster nobilis, Discoaster multiradiatus, Discoaster diastypus* and lowermost part of the *Tribrachiatus orthostylus* Zones and thus is of late Paleocene to early Eocene age based on the nannoplankton chronology of Bukry (1973a and b, 1975). The Bulitian, Penutian, and Ulatisian Stages include the *Discoaster diastypus, Tribrachiatus orthostylus, Discoaster lodoensis*, and the *Discoaster sublodoensis* Zones and are thus of early Eocene and early middle Eocene age. The top of the Ulatisian Stage appears to coincide with the top of the *Discoaster sublodoensis* Zone, for which Bukry estimated an absolute age of 48 million years. The lower Narizian Stage is represented by the *Nannotetrina quadrata* Zone of early middle Eocene age, for which Bukry estimated an absolute age at the zonal top of 45 million years.
2. The time-transgressive nature of rock units is rather strikingly demonstrated along the west side of the San Joaquin Valley by the time-stratigraphic relations between the Gredal Shale and the Point of Rocks Sandstone Members of the Kreyenhagen Formation at the Media Agua Creek and at the Devils Den aqueduct sections. Mallory (1970, fig. 3) divided his Point of Rocks Formation at Media Agua Creek into lower, middle, lower-

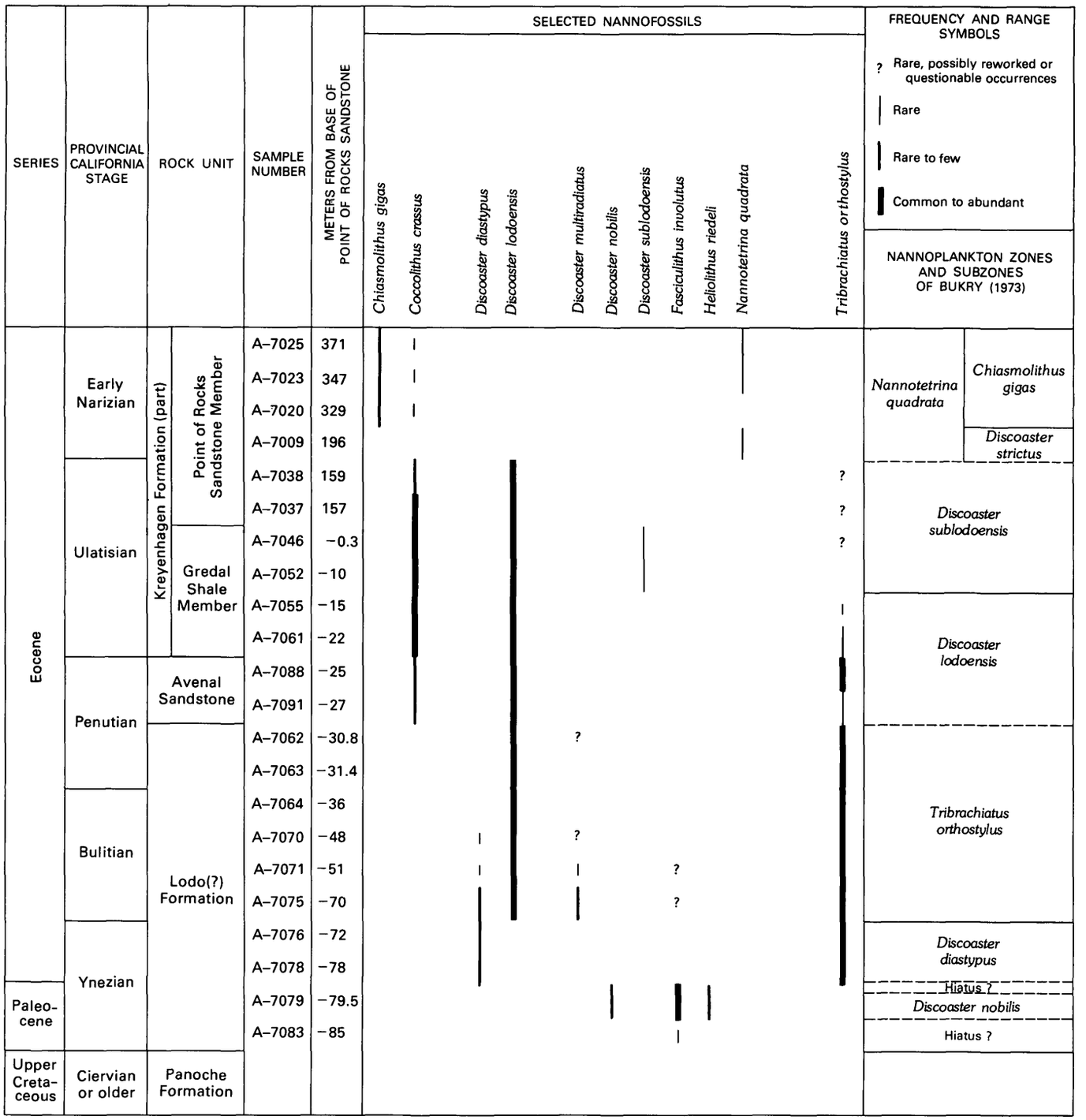


FIGURE 13.—Formations, selected nannofossil distributions, nannoplankton zonation, and benthic foraminiferal stages in the Media Agua Creek area. Lithostratigraphy is from Dibblee (1973a, p. 8-13). Sample numbers and nannoplankton frequency and range are from Sullivan (1964, 1965). Nannoplankton zonal assignments are by Poore (1976). Dashed lines indicate boundaries of the zone are approximately located. Benthic foraminiferal stage assignments are by Mallory (1959).

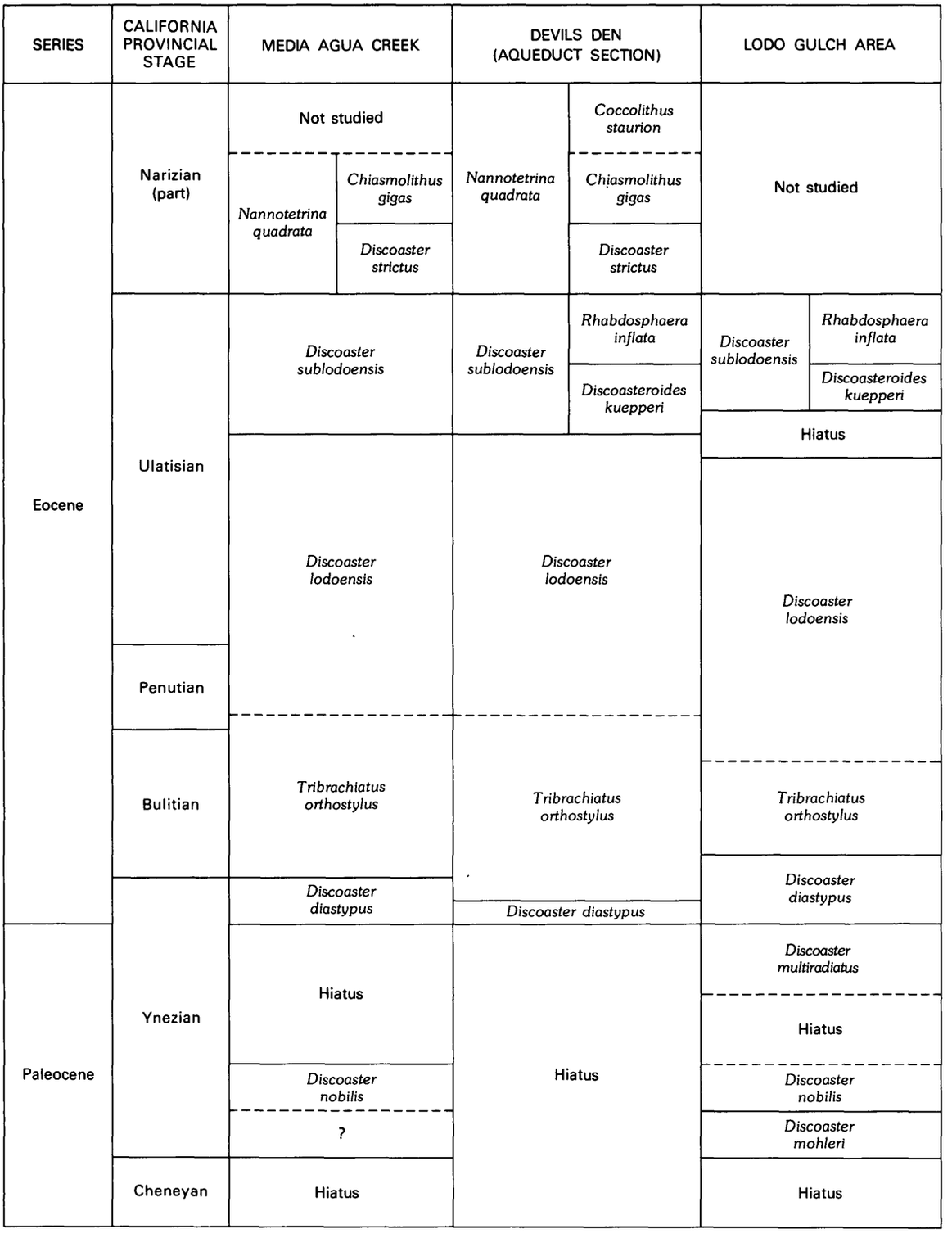


FIGURE 14.—Correlations of provincial benthic foraminiferal stages of California to nannoplankton zones and subzones, Devils Den, Lodo Gulch, and Media Agua Creek areas.

upper and upper-upper members. Dibblee (1973a, p. 10 and 12) assigned clay shale underlying his Point of Rocks Sandstone at Media Agua Creek to the Gredal Shale Member of the Kreyenhagen. Nannoplankton and foraminiferal data from this and previous studies indicate that the Gredal and lower and middle parts of the Point of Rocks at Media Agua Creek are equivalent in a time sense to the entire Gredal exposed in the aqueduct section in the Devils Den area and that the unit referred to as the lower-upper member of the Point of Rocks at Media Agua Creek is equivalent to that part of the Point of Rocks exposed at the Devils Den aqueduct section. Thus the base of the Point of Rocks at Media Agua Creek is much older than the base of the Point of Rocks at the Devils Den aqueduct; the difference in age may be estimated at 2.5 to 3 million years by referring to the estimated absolute ages of the nannoplankton zones and subzones of Bukry (1975, table 2). At Point of Rocks, a locality within the Devils Den area only 2.5 km southeast of the aqueduct, the basal 23 m of the Point of Rocks Sandstone Member was assigned by Mallory (1959, p. 55 and 57) to the Ulatisian, whereas at the aqueduct exposure the top of the Ulatisian is within the Gredal Shale Member at least 50 m below the base of the Point of Rocks Sandstone Member. Another case of a formation boundary transgressing time is exemplified by the difference in age of the top of the type Lodo Formation in the Lodo Gulch area compared to the top of the Lodo Formation in the Devils Den area and in the Lodo(?) Formation at Media Agua Creek. Nannoplankton and foraminiferal data indicate that the type Lodo Formation is equivalent in a time sense to the Lodo and Lodo(?) Formations, Avenal Sandstone and the lower part of the Gredal Shale Member of the Kreyenhagen Formation as exposed at Devils Den and Media Agua Creek. Thus the top of the Lodo Formation at its type locality in the Lodo Gulch area is demonstrably younger than the top of the Lodo Formation at Devils Den and the Lodo(?) Formation at Media Agua Creek as defined by Dibblee (1973a).

3. Nannoplankton data from this study and from Bramlette and Sullivan (1961) and Sullivan (1965) further suggest that the Domengine Sandstone in the Lodo Gulch area, the Domengine Formation and Canoas Siltstone Member of the Kreyenhagen Shale at Oil City (fig. 9), and the Canoas at Garza Creek are time equivalents to at least part of the upper 82 m of the Gredal Shale Member in the Devils Den aqueduct section and to at least parts of the lower and middle Point of Rocks Sandstone Member in the Media Agua Creek section.

THE PALEOGENE OF CALIFORNIA: SUMMARY

It is now feasible to summarize the relations of the lower and middle Tertiary provincial benthic foraminiferal stages of California to nannoplankton and planktic foraminiferal zonations that are being widely used today for correlation of marine sedimentary deposits throughout the world. Figure 15 illustrates those relations and is a synthesis of nannoplankton, foraminiferal, and stratigraphic data from this report and from the following authors: Berggren (1972), Blow (1969), Brabb, Bukry, and Pierce (1971), Bramlette and Sullivan (1961), Bukry (1973, 1975), Bukry, Brabb, and Vedder (1977), Cifelli (1951), Cook (1950), Goudkoff (1945), Hardenbol and Berggren (in press), Hay and others (1967), Kleinpell (1938), Loeblich (1958), Mallory (1959, 1970), Martin (1964), Martini (1971), Poore (1976), Schenck and Kleinpell (1936), Schmidt (1970, 1975), Smith (1974), Sullivan (1964, 1965), Tipton (1980), Warren (1980), and Warren and Newell (1976). Most of the nannoplankton data used for determining relations between nannoplankton zones and provincial benthic foraminiferal stages as shown in figure 15 were obtained from the type sections and type areas for these stages or from the type localities of the foraminiferal zones used to define such stages with three exceptions; no nannoplankton data have as yet been obtained from the type sections or areas of the Cheneyan, upper Narizian, or Zemorrian Stages. The *Cruciplacolithus tenuis* and *Sphenolithus distentus* Zones are shown on figure 15 in their normal positions within the zonal sequence of Bukry (1973), although I believe neither zone has been recognized to date in California. Figure 15 shows that on the basis of nannoplankton data the Cheneyan and most of the Ynezian are of Paleocene age, the uppermost Ynezian, Bulitian, Penutian, and most of the Ulatisian are of early Eocene age, the upper Ulatisian and most of the Narizian are of middle Eocene age. Most of these age assignments are at variance with ages (based essentially on benthic foraminifers and megafossils) assigned by Kleinpell (1938), Mallory (1959), and Goudkoff (1955).

To be sure, additional data would be welcome before every detail of figure 15 is accepted as fact, particularly precise placement of most of the planktic foraminiferal zones P1 through P14. However, assuming that future data would cause no major readjustment in age at the base of the Cheneyan or the top of the Zemorrian Stages (and there is good reason for

ORIGINAL PROVINCIAL AGE/STAGE ASSIGNMENTS OF KLEINPELL (1938), SCHENCK AND KLEINPELL (1936), MALLORY (1959) AND GOUDKOFF (1945)		AGE ASSIGNMENTS USED IN THIS REPORT BASED ON PALEOGENE LOW-LATITUDE NANNOPLANKTON ZONATION OF BUKRY (1973 AND 1975)			PALEOGENE NANNOPLANKTON ZONATION OF MARTINI (1971)	PALEOGENE PLANKTONIC FORAMINIFERAL ZONATION MODIFIED AFTER BLOW (1969), BERGGREN (1972), AND HARDENBOL AND BERGGREN (1982)		
SERIES OR SUBSERIES	STAGE	SERIES OR SUBSERIES	ZONE/SUBZONE		ZONE	SERIES OR SUBSERIES	EUROPEAN STAGE BOUNDARY AGE IN M.Y.B.P.	ZONE
Upper Eocene	Narizian	Middle Eocene	*Reticulofenestra umbilica*	*Discoaster saipanensis*	NP17	Middle Eocene	40	P14
				Discoaster bifax	NP16		Bartonian	P13
			Nannotetrina quadrata	*Coccolithus staurion*	NP15		44	P12
				Chiasmolithus gigas			Lutetian	P11
				Discoaster strictus				P10
Middle Eocene	Ulatisian		*Discoaster sublodoensis*	*Rhabdosphaera inflata*	NP14			
				Discoasteroides kuepperi				
		Lower Eocene	*Discoaster lodoensis*		NP13	Lower Eocene	49	P9
Lower Eocene	Penutian						Ypresian	P8
	Bulitian		*Tribrachiatus orthostylus*		NP12			P7
			Discoaster diastypus	*Discoaster binodosus*	NP11			P6
				Tribrachiatus contortus	NP10			
Paleocene	Ynezian	Paleocene	*Discoaster multiradiatus*		NP9		53.5	P5
			Discoaster nobilis		NP8	Upper Paleocene	Thanetian	P4
			Discoaster mohleri		NP7			
			Heliolithus kleinpellii		NP6			
			Fasciculithus tympaniformis		NP5			P3
			Cruciplacolithus tenuis		NP4			
	Cheneyan				NP3		60	P2
					NP2	Lower Paleocene	Danian	P1
Upper Cretaceous	Ciervian	Upper Cretaceous			NP1			
					–	Upper Cretaceous	65 Maestrichtian	–

FIGURE 15.—Correlations of Paleogene provincial benthic foraminiferal stages of California to calcareous microplankton zonations.

making that assumption), then the Paleogene of California should be recognized as including all of those provincial stages from the base of the Cheney-an to the top of the Zemorrian which have been shown by nannoplankton chronology to range in age from Paleocene to Oligocene.

CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY OF THE PALEOGENE OF THE SANTA CRUZ MOUNTAINS, CALIFORNIA

By BILAL U. HAQ[1]

Eighteen samples of calcareous nannofossils (centrifugally concentrated) were examined in detail from the sections of the Locatelli Formation in the Smith Grade area, the Butano Sandstone in the Lompico area, the Butano Sandstone and Twobar Shale Member of the San Lorenzo Formation in the Bear Creek area, and the Twobar Shale Member along the San Lorenzo River. The preservation of the nannofossils is generally very poor, speciments are rare and zone diagnostic species are lacking. Age assignments are, consequently, difficult and time-consuming and have to be based on the overall composition of the assemblages. Zonal assignments are thus approximate, based mainly on the current ranges of taxa (after Bukry, 1971 and Martini, 1971).

In the Smith Grade area, collection 76CB1511A from the Locatelli Formation has only a few fragments of late Paleocene discoasters, but collection JC60-120d (table 4) from 4.5 km to the east has an assemblage that can be correlated with the *Fasciculithus tympaniformis* (NP5) Zone of late Paleocene age. In the Lompico area, collections JC60-37d, 76CB1521, JC60-51 and JC62-24b indicate that the lower part of the Butano Sandstone is of early Eocene (NP12 and NP13 Zones) and middle Eocene (NP15 and NP16 Zones) age. Collection 76CB1573 and

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TABLE 4.—*Nannoplankton from the Paleogene of the Santa Cruz Mountains*
[JC samples collected by J. C. Clark, CB samples collected by E. E. Brabb. n.d., not determinable]

Nannoplankton	[1]JC60-120d	[2]JC60-37d	[2]76CB1521	[2]JC60-51	[2]JC62-24b	[2]76CB1574	[2]76CB1573	[2]68CB202	[3]68CB204	[3]68CB205	[3]68CB206	[3]76CB1571	[3]76CB1451A
Chiasmolithus californicus								X					
C. consuetus	X												
C. expansus						X							
C. gigas													X
Coccolithus bisectus										X	X	X	
C. eopelagicus		X			X	X	X	X	X	X			X
C. [illegible]	X	X			X	X	X	X	X	X	X	X	X
[illegible]										X			
[illegible]		X	X		X		X	X	X	X			X
C. inversus				X	X			X					
Cyclolithella inflexa					X								
Dictyococcites hesslandii							X						X
Discoaster barbadiensis					X		X	X		X		X	X
D. binodosus							X						?
D. delicatus							X						
D. distinctus													X
D. lodoensis		X	X										
D. mirus			X					X	X				
D. saipanensis							X	X					
Ericsonia subpertusa	X	X											
Fasciculithus tympaniformis	X												
Helicosphaera seminulum					X								
Heliorthus concinnus						X							
Impiaster obscurus ?								X					
Lithostromation perdurum													X
Nannotetrina aff. *N. cristata*			X										
Pemma angulatum													X
Pontosphera multipora					X								
P. plana					X	X							
Reticulofenestra dictyoda		?					X						X
R. umbilica				X			X	X					
Rhabdosphera sp.					X								
Sphenolithus moriformis								X		X			
S. orphanknolli							X						
S. predistentus										X			
S. aff. *S. radians*							X						
Thoracosphaera saxea								X					
T. spp.										X			
Z[illegible]	X												
Zygrhablithus [illegible]		X						X					X
Zone assignment	NP5	NP12-13	NP14-15	NP14? 15?	NP15-16	n.d.	NP16-17	NP16-17	n.d.	NP19-20	n.d.	n.d.	NP15

[1]Locatelli Formation.
[2]Butano Sandstone.
[3]Twobar Shale Member of San Lorenzo Formation.

68CB202 from the Bear Creek area shows that the upper part of the Butano Sandstone is of middle Eocene (NP16 and NP17 Zones) age.

Collection 76CB1451A from the Twobar Shale Member of the San Lorenzo Formation along the San Lorenzo River indicates that the lower part of this member is of middle Eocene (NP15 Zone) age. This collection also contains *Neochiastozygus dubius* fragments that may be reworked from older strata.

The middle part of the Twobar Shale Member, represented by collection 68CB205 from the Bear Creek area, is of late Eocene (NP19 and NP20 Zones) age. Thus the boundary between the middle and late Eocene is probably within the Twobar Shale Member.

DEFINITION OF THE LODO FORMATION

By EARL E. BRABB

ABSTRACT

The section along Lodo Gulch, described in general terms by White (1940) and Martin (1943, section I-S), is the type section of the Lodo Formation. Sections along the first gulch south of Lodo Gulch (section A of Israelsky, 1951 and the so-called Lodo Gulch section of Schoellhamer and Kinney, 1953), along the second gulch south of Lodo Gulch (section I-X of Martin, 1943 and section B of Israelsky, 1951), and about 700 m north of Lodo Gulch (section C of Brabb, Clark, and Throckmorton, 1977) are reference sections.

DISCUSSION

The name Lodo, Spanish for mud, was proposed in an abstract by R. T. White (1938) for a small gulch in the Tumey Hills, about 75 km west of Fresno, Calif. (figs. 1 and 16, this report); the exact location of Lodo Gulch is shown on maps by Martin (1943, fig. 1) and Israelsky (1951, fig. 2). In this same abstract, White also proposed the name Lodo Formation for 350 m of predominantly claystone that rests, according to White, disconformably on the Moreno Shale and is overlain conformably by the Domengine Sandstone.

Two years later, White (1940, fig. 1), in an expanded report, showed a generalized stratigraphic column for the Lodo Formation in Lodo Gulch. He used the term "type locality" for this section in both his 1938 abstract and his report, and it is clear from his descriptions that he intended this section to be the type section for the formation. This definition is accepted here as the type section of the Lodo (section TS, fig. 16, this report). Martin (1943), in a report that described foraminifers from samples collected by White, provided a figure entitled, "Sketch map of the Lodo Formation in the type area." Taken literally, the map indicates that the type area includes all of the Lodo Formation in secs. 20, 28, and 29, T. 15 S., R. 12 E. This definition of the type area is accepted here (see fig. 16, this report).

Some confusion has been introduced by authors who measured sections in the type area of the Lodo Formation but not in the type section along Lodo Gulch. According to the International Stratigraphic Guide (Hedberg, 1976, p. 26) and the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961, p. 654), sections subsidiary to the type section (holostratotype) are reference sections. Martin (1943, fig. 1), for example, showed two sections (I-S and I-X) as a composite type section of the Lodo. This definition is not accepted here. Martin's section I-S is in Lodo Gulch and is the type section (TS, fig. 16, this report), but section I-X (section B, fig. 16, this report) is in the second gulch south of Lodo Gulch and is therefore here designated a reference section.

The label "Lodo Gulch section" on the map by Schoellhamer and Kinney (1953) is misleading. This section (section A, fig. 16, this report) is not in Lodo Gulch, but is in the first gulch south of Lodo Gulch. The label on Schoellhamer and Kinney's map led me to conclude wrongly that Israelsky's (1951) section A (section A, fig. 16, this report) is along Lodo Gulch. Thus, section A on the stratigraphic column of Brabb, Clark, and Throckmorton (1977, fig. 42) is a composite of samples collected by me along Lodo Gulch, the type section, and samples described by Israelsky from section A, the first gulch south of Lodo Gulch. Section A of Israelsky is in the type area but is not the type section. The "Lodo Gulch section" of Schoellhamer and Kinney (1953) and section A of Israelsky (1951) are the same as section A of this report (fig. 16), which is here designated the principal reference section.

Section B of Israelsky (1951), which gives supplementary information on the lower part of the Lodo, is the same as White's (1943) section I-X and section B of this report; it is a reference section. Section C of Brabb, Clark, and Throckmorton (1977, p. 105-109) also gives supplementary information on the lower part of the formation; it is the same as section C of

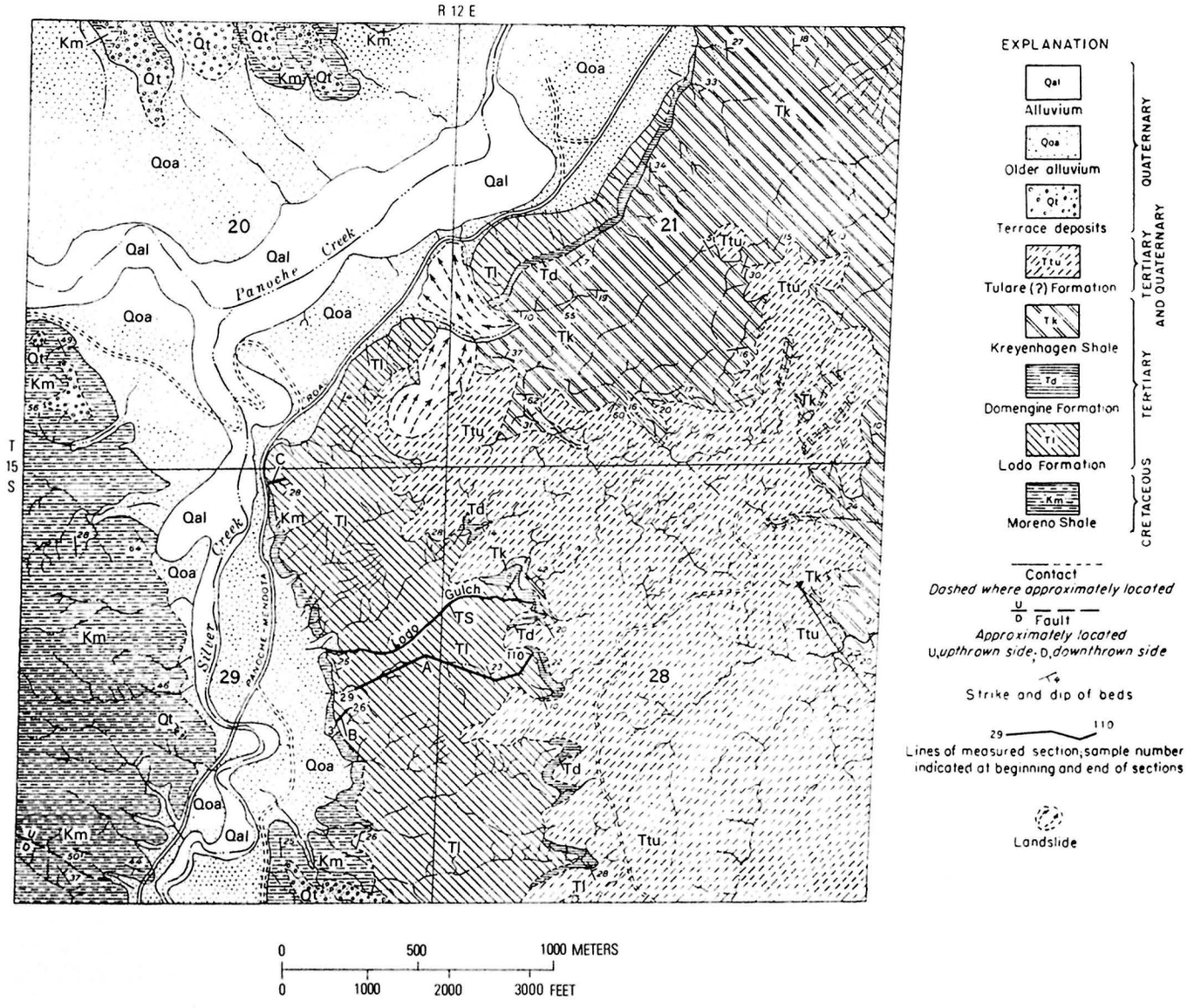


FIGURE 16.—Geologic map of the northwest Tumey Hills showing location of type section (TS) and reference sections (A, B, and C) for Lodo Formation. Geology and location of sections from Israelsky (1951) and Brabb, Clark, and Throckmorton (1977). TS, section of White (1940) and section I-S of Martin (1943); A, section A of Israelsky (1951) and "Lodo Gulch section" of Schoellhamer and Kinney (1953); B, section I-X of Martin (1943) and section B of Israelsky (1951); and C, section C of Brabb, Clark, and Throckmorton (1977).

this report (fig. 16), which is also here designated a reference section.

To recapitulate, the type section of the Lodo Formation is along Lodo Gulch (section TS, fig. 16, this report). This section is described in general terms by White (1940, p. 1736) and Martin (1943, section I-S). Section A (fig. 16, this report) (section A of Israelsky, 1951 and the "Lodo Gulch section" of Schoellhamer and Kinney, 1953) in the first gulch south of Lodo Gulch is the principal reference section. Section B (fig. 16, this report) (section I-X of Martin, 1943 and section B of Israelsky, 1951) in the second gulch south of Lodo Gulch and section C (fig. 16, this report) (section C of Brabb, Clark, and Throckmorton, 1977) about 700 m north of Lodo Gulch are reference sections. All of these sections are in the type area of the Lodo Formation.

Foraminifers from the type section (TS, fig. 16, this report) of the Lodo Formation 61 to 350 m above the base and from the nearby reference section (section B, fig. 16, this report), 10 m to 60 m above the base of the formation, were described by Martin (1943). Fossils from other reference sections in the type area have been described by Israelsky (1951, 1955), Bramlette and Sullivan (1961), Smith (1975) and others.

LARGE FORAMINIFERS OF EOCENE AGE FROM THE COAST RANGES OF CALIFORNIA

By ALPHONSE BLONDEAU and EARL E. BRABB

ABSTRACT

Large foraminifers from an unnamed limestone of Eocene age and from reworked boulders within the unconformably overlying Temblor Formation of Miocene age in the vicinity of San Jose, from the Domengine Formation of early and middle Eocene age near Mount Diablo, and from the Avenal Sandstone of early and middle Eocene age in the Devils Den area, all in California include *Nummulites willcoxi* (Heilprin), *N. striatoreticulatus* (L. Rutten), *Eoconuloides lopeztrigoi* (Palmer), *Amphistegina parvula* (Cushman), *Discocyclina (Discocyclina) marginata* (Cushman), *Pseudophragmina (Proporocyclina) clarki* (Cushman), *P. (P.) teres* (Cole and Gravell), *Asterocyclina aster* (Woodring), and *Eofabiana grahami* (Kupper). These species, which collectively have been reported previously from other areas in California, from Oregon and Washington, and from the Gulf Coast and Caribbean region, indicate a middle Eocene age.

INTRODUCTION

Many reports have been published on large foraminifers of Eocene age from the Pacific Coast region, but almost all of these date from the 1920's and 1930's. (See for example the reports by Palmer, 1929, Nelson and Schenck, 1930, Woodring, 1930, Keenan, 1932, and Schenck, 1933). The timing of these reports is significant because the California Eocene zonations based on benthic foraminifers were not published until the 1940's (Laiming, 1943) and 1950's (Mallory, 1959), and the application of zonations based on planktic foraminifers have only been made in the last few years. Thus, the stratigraphic relation between the large foraminifers from the Pacific Coast and those used for interregional and intercontinental correlation is not well established. Moreover, knowledge about the evolution and distribution of large foraminifers has increased so much in the past 30 years that the time is opportune for a new look at the Pacific Coast assemblages.

The fossils described in this study were all collected east of the San Andreas fault from the Mount Diablo to the Devils Den areas (fig. 1). In the conceptual scheme of Nilsen and Clarke (1975), the large foraminifers were deposited on the ocean floor in a linear basin along the margins of the continent. The sandstone and shale that make up most of the Eocene sequence were derived from the Sierra Nevada region and narrow islands within the linear basin. The sands were probably displaced downslope from upper neritic depths to a bathyal environment, carrying the larger foraminifers with them.

The specimens were nearly all cemented together by calcite, so that it was necessary to study them in thin sections that could not always be oriented in the most desirable direction. The study was further complicated by the great variety and plasticity of forms that create nomenclatural, classification, and correlation problems to an extent generally unknown in Europe.

Acknowledgments.—We are grateful to Erik Osbun, who provided several collections of large foraminifers from the Sveadal area. A. D. Warren kindly pointed out the occurrence of large foraminifers in the aqueduct section near Devils Den and provided several unattached specimens for study. J. Butterlin provided much useful information on the stratigraphic occurrence of similar large foraminifers in the Caribbean region. K. N. Sachs and René Herb reviewed the manuscript and provided many helpful suggestions.

STRATIGRAPHY

DEVILS DEN AREA

The Devils Den area has a nearly complete section of Paleogene rocks that is easily accessible, moderately well exposed, and not too complicated structurally. Unfortunately, calcareous microfossils have been leached out of most exposures. In the late 1960's, however, the Barrenda Mesa Water District made a cut for a canal that exposed rocks containing well-preserved calcareous microfossils. The nannoplankton are described by Warren (this volume) and the smaller foraminifers by Berggren and Aubert (this volume). We report on a single bed containing large foraminifers. The rock unit nomenclature is from Dibblee (1973a, fig. 6) and the biostratigraphy is from Warren (this volume).

The large foraminifers, collections 76CB1633, 1634, and 1641 (table 5) are from the Avenal Sandstone. The Avenal Sandstone contains, in addition to the large foraminifers, abundant worm tubes called *"Spiroglyphus" (Rotularia)* in several reports. The geographic and geologic position of the sandstone and the fossils collected from it are provided by Brabb, Clark, and Throckmorton (1977, p. 94–103).

MOUNT DIABLO AREA

Large foraminifers were collected from one locality (EB611) on the south flank of Mount Diablo (fig. 17) about 0.65 km north-northwest of the Mount Diablo State Park headquarters. This locality is also shown on a map by Brabb, Clark, and Throckmorton (1977, fig. 33) and on another map by Watson (1941, pl. 4, locality LSJU 986). The fossils occur about 70 m above the base of the Domengine Formation, as mapped by Brabb, Sonneman, and Switzer (1971), in a part of the formation that is predominantly siltstone and claystone. The bed with the fossils is a calcareous sandstone a few centimeters thick.

The fossils from EB611 are listed on table 5. The fauna includes *Asterocyclina aster*, which is present in all the other samples collected and which is widely distributed at other localities on the Pacific Coast (see the description of the species).

The age of the beds from which the large foraminifers were collected is not well established. Berry (1964) considered the Domengine Formation in the Mount Diablo area to be of middle Eocene age and correlative with the Ulatisian and part of the Narizian Stages of Mallory (1959), but the faunas he used to date the rocks were collected several kilometers northeast of EB611.

Collection EB611 is stratigraphically below I. P. Colburn's samples IPC-524, IPC-642, and IPC-644, which A. A. Almgren *(in* Colburn, 1961, p. 186, 203, 204) considered correlative with the B-1 zone of Laiming (1943), and is close stratigraphically to IPC-648, which Almgren correlated with Laiming's B-3 and B-4 zones. Mallory (1959, p. 18) generally correlated the B zones of Laiming with his Ulatisian Stage. In turn, he correlated the Ulatisian Stage with the Gulf Coast Claiborne Group of middle Eocene age. Thus, collection EB611 would probably be considered middle Eocene age by traditional American usage.

SAN JOSE AREA

Large foraminifers from the San Jose area were first described and illustrated by Schenck (1929, p. 224-227). Bailey and Everhart (1964) described the geology of the area. Locality 71CB983 (see figs. 18 and 19), now covered by a newly constructed house, is about one-half kilometer northwest of LSJU 309, from which the holotype of *Discocyclina californica* was obtained. Within a few centimeters of 71CB983C, which contains the large foraminifers listed on table 5, another sample (71CB983A) was collected that contains the following smaller foraminifers, according to W. A. Berggren (written commun., 1977):

Acarinina coalingensis (Cushman and Hanna)
Subbotina patagonica (Todd and Kniker)
Acarinina acarinata Subbotina
A. soldadoensis (Bronnimann)
Morozovella subbotinae (Morozova)
M. gracillis (Bolli)
M. formosa (Bolli)

Several species of agglutinated foraminifers

Berggren believes that this assemblage is correlative with the *Morozovella formosa* Zone (P7), early Eocene.

Locality 71CB971B is in an abandoned limestone quarry that was still accessible in 1971 when it was last visited.

TABLE 5.—*Large foraminifers from the California Coast Ranges*

Locality	San Jose		Mount Diablo		Sveadal		Devils Den		
Collection	71CB-983C	71CB-971B	EB633	EB611	OSBUN 1-1	OSBUN 49-6	76CB-1633	76CB-1634	76CB-1641
Age	Late middle Eocene	Early and middle Eocene	Late middle Eocene and early late Eocene	Middle Eocene	Early and middle Eocene	Early and middle Eocene	Early Eocene to early middle Eocene	Early Eocene to early middle Eocene	Early Eocene to early middle Eocene
Nummulites willcoxi	X		X						
N. striatoreticulatus	X		X						
N. sp.		X					X	X	
Eoconuloides lopeztrigoi		X	X			X		X	
Amphistegina parvula		X	X				X	X	X
Eoconuloides wellsi		X					X	X	
Amphistegina sp.	X	X		X	X	X			
Discocyclina (Discocyclina) marginata	X	X	X						
D. sp.				X			X	X	X
Pseudophragmina (Proporocyclina) flintensis	X	X	X	X					
P. clarki	X	X	X						
P. teres		X							
Asterocyclina aster	X	X	X	X	X	X			
Eofabiania grahami	X	X	X	X	X	X			

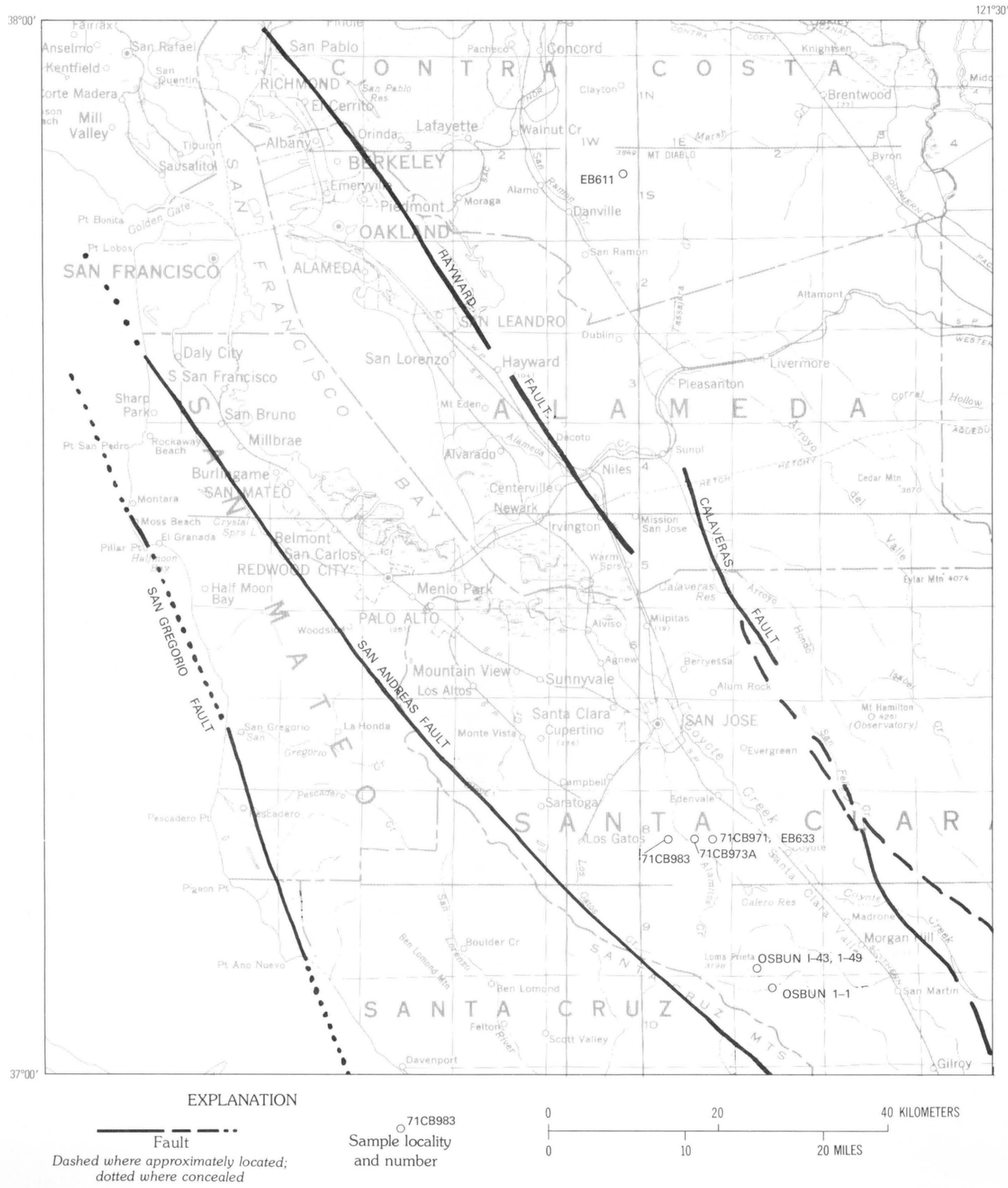


FIGURE 17.—Localities where large foraminifers were collected in the San Francisco Bay region.

SVEADAL AREA

In the Sveadal area near Loma Prieta (figs. 17 and 19), Osbun (1975) discovered large foraminifers (table 5, collections 49-6 and 1-1) in limestone boulders in a basal conglomerate of the Temblor Formation of Miocene age. These boulders were presumably derived from the erosion of the limestone in the vicinity of localities 71CB983 and 71CB971 near San Jose (fig. 18).

AGE

The large foraminifers from the Devils Den area are in rocks correlated by Warren (this volume) on the basis of calcareous nannoplankton with the Penutian Stage of Mallory (1959) and the *Discoaster lodoensis* Zone of Bukry (1973). Both these correlations suggest an early Eocene age (Brabb and others, 1977, fig. 2). These correlations are supported by the occurrence of planktic foraminifers of Zone P7 (lower Eocene) stratigraphically close to the beds with large foraminifers in the San Jose area. On the other hand, the large foraminifers (table 5) have age ranges that are much more suggestive of the middle Eocene. Of course, the large foraminifers could be early Eocene in some areas and middle Eocene in others, but we are in-

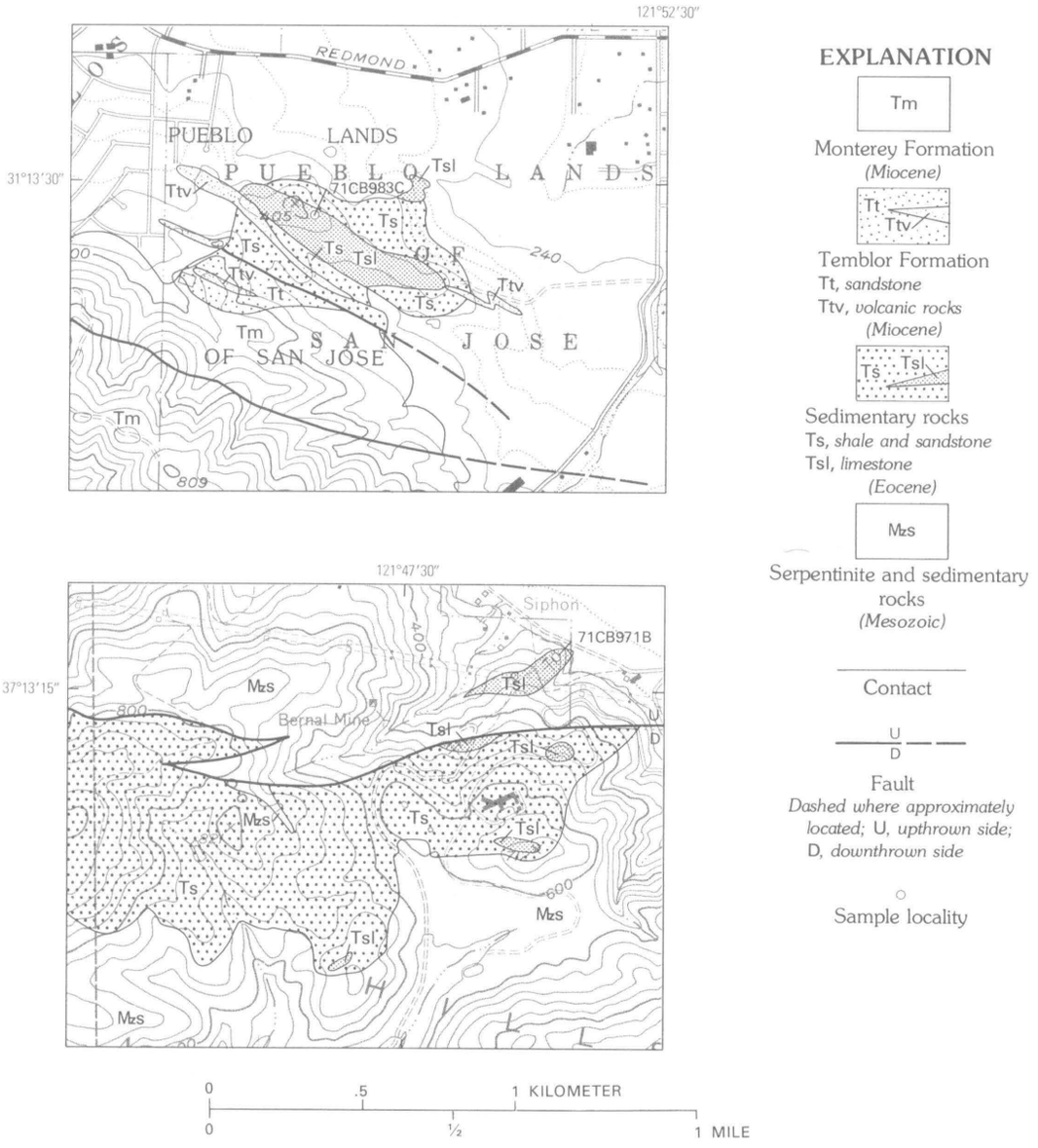
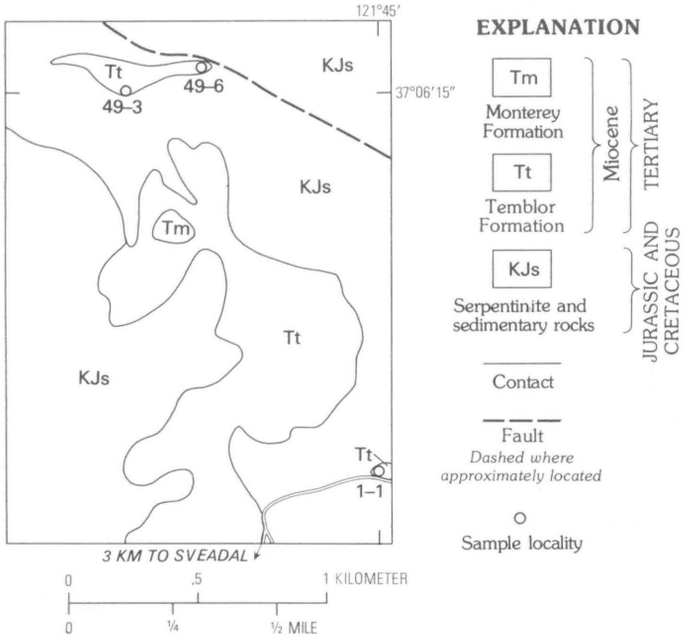


FIGURE 18.—Geologic map of the southern San Jose area showing localities where large foraminifers were collected. Bases from Los Gatos and Santa Teresa Hills 7.5-minute quadrangles. Geology generalized from Bailey and Everhart (1964).

clined to view these assemblages as closely related and probably the same age, middle Eocene.



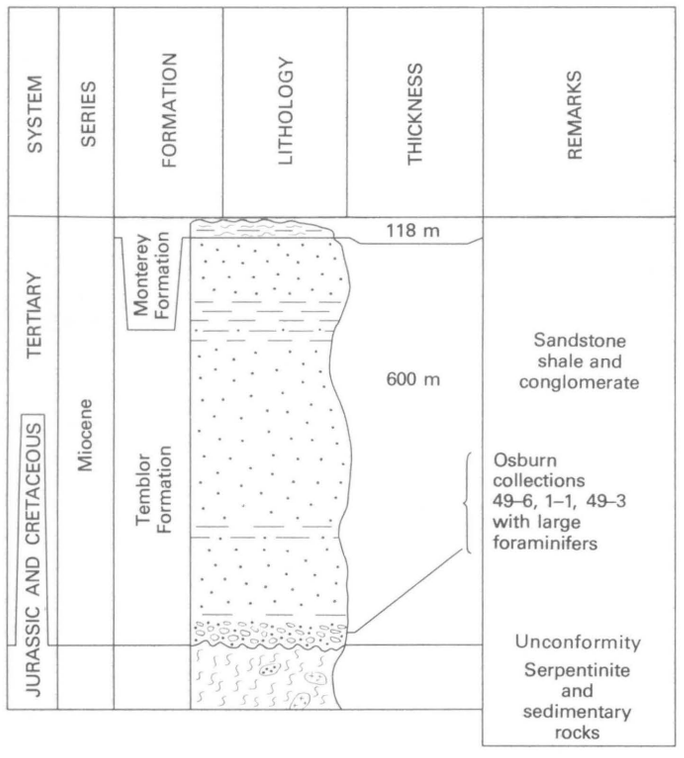


FIGURE 19.—Geologic map and stratigraphic column for Sveadal area. Geology from Osbun (1975).

SYSTEMATIC PALEONTOLOGY

Nummulites willcoxi Heilprin, 1882

Plate 6, figures 6, 7, 10

Operculinoides willcoxi (Heilprin). Cole, 1958, pl. 33, figs. 3-12.

Camerina willcoxi (Heilprin). Cole and Applin, 1964, pl. 4, figs. 9, 14-16.

Nummulites willcoxi Heilprin. Butterlin, 1966, pl. XIV, figs. 1-10.

Nummulites willcoxi Heilprin. Butterlin, 1971, pl. VI, figs. 1-8.

Description. Small lenticular species, diameter to thickness 3.6:0.6 mm; globular in juvenile stage with diameter to thickness 1.6:0.65 mm; tends to become flat by growth from the foot of the spire; more loosely coiled spire in outer parts of the test; thin septa curved at top; diameter of the protoconch approximately 100 μm.

Young specimens cannot be distinguished from *N. trinitatensis* (Nuttall). Older specimens have a somewhat flattened marginal area in contrast to the rounded marginal area of *N. trinitatensis*.

Distribution. California, locality 71CB983C and EB633 near San Jose; Florida, Mexico, Caribbean, Panama, and Columbia.

Range. Top of middle Eocene to base of upper Eocene.

Nummulites striatoreticulatus L. Rutten, 1928

Plate 6, figure 9

Camerina striatoreticulata (L. Rutten). Cole, 1958, pl. 32, Figs. 1-16

Nummulites striatoreticulata L. Rutten. Butterlin, 1966, fig. 5.

Description. Globular species from 1 to 3 mm in diameter, sinuous septal filament, more or less granulated, thick spiral laminae loosely coiled. Septa straight and inclined in lower part, curved in upper part. Small protoconch of megalospheric form.

Distribution. California, locality 71CB983C near San Jose; Cuba, Haiti, Mexico, Jamaica, Costa Rica, and Colombia.

Range. Top of middle Eocene to basal upper Eocene.

Nummulites **sp.**

Description. Small, lenticular, globular forms 1 mm in diameter. Lack the granular form of *N. striatoreticulatus*. More globular than *N. willcoxi*. Unfortunately, they are only observable in thin sections.

Distribution. California, locality 71CB971B near San Jose.

Family AMPHISTEGINIDAE

Genus *Eoconuloides* Cole and Bermudez, 1944

Eoconuloides lopeztrigoi (D. K. Palmer, 1934)

Plate 6, figures 3, 13

Amphistegina lopeztrigoi D. K. Palmer, 1934, pl. 5, fig. 6-8.
Amphistegina lopeztrigoi D. K. Palmer. Barker and Grimsdale, 1936, pl. 30, fig. 2; pl. 32, fig. 1-3; pl. 34, fig. 1; pl. 38, fig. 3.
Amphistegina lopeztrigoi D. K. Palmer. Levin, 1957, pl. 4, fig. 8-9, 13-14.
Amphistegina lopeztrigoi D. K. Palmer. Butterlin, 1966, pl. XIV, fig. 14.
Amphistegina lopeztrigoi D. K. Palmer. Butterlin, 1968, pl. III, fig. 8.

Description. Small thin spiral lamina, slightly trochoidal, showing pillars in relief, generally well marked.

Distribution. California, localities EB633 and 71CB971B near San Jose; Caribbean, Columbia, Venezuela.

Range. From the base to the summit of the middle Eocene and basal upper Eocene.

Remarks. Butterlin (1970) showed that *Eoconuloides parvulus* evolved into *Eoconuloides lopeztrigoi* and *Eoconuloides wellsi.*

Eoconuloides wellsi Cole and Bermudez, 1944

Plate 6, figure 4

Description. Test conical with flat base, apex bluntly rounded; peripheral angle subacute; surface smooth. Specimen: height, 0.8 mm to 1.6 mm; diameter of base: 0.96 mm to 1.20 mm. On slightly oblique horizontal sections, the final chambers are subdivided into chamberlets in the peripheral section; axial sections show the trochoid character of test; the spiral wall has differences in thickness, the thicker walls having irregularly developed pillars; the thin peripheral walls appear to lack pillars.

Range. Lower Eocene to middle Eocene.

Amphistegina parvula (Cushman, 1919)

Plate 6, figure 1, 2, 14

Nummulites parvula Cushman, 1919, pl. 4, fig. 3-6.
Amphistegina parvula (Cushman). Cole, 1958, pl. 25, fig. 17-19.
Amphistegina cf. *parvula* (Cushman). Butterlin, 1968, pl. II, fig. 8.
Amphistegina parvula (Cushman). Butterlin, 1970, pl. 3, fig. 5-6.

Description. Amphistegina with slightly asymmetrical axial cut. Has very thick walls and very corroded and barely visible pillars. Septa inclined and curved. In a good equatorial cut, could be confused with a very small nummulite. An axial cut shows the distinction.

Distribution. California, localities EB633 and 76CB971B near San Jose and Osbun 49-6 near Sveadal; Caribbean region (abundant).

Range. Lower Eocene to lower part of upper Eocene.

Remarks. All collections observed are rich in Amphistegines. New species are probably present. Uncemented material and separate specimens are necessary for a detailed study.

Family DISCOCYCLINIDAE

The classification of Discocyclinidae is a complex problem for American species. The classifications are numerous and varied: Vaughan and Cole (1941), Bronnimann (1945), Cole (1948), and Caudri (1972). We accept Cole's classification for our work.

Discocyclina (Discocyclina) marginata (Cushman, 1919)

Orthophragmina marginata Cushman, 1919, pl. 1, fig. 2: pl. 2, fig. 1.
Orthophragmina marginata Cushman, 1920, pl. IX, fig. 1-2.
Discocyclina (Discocyclina) marginata (Cushman). Cole and Gravell, 1952, pl. 93, fig. 1-9; pl. 94, fig. 1-8; pl. 95, fig. 7-8.
Discocyclina (Discocyclina) marginata (Cushman). Cole and Applin, 1964, pl. 10, fig. 1-8.

Description. Lenticular species, inflated, diameter 10-14 mm, equatorial chambers higher than wide (h/w = 1.5) and very small. Thirty to forty rows of lateral chambers are very compressed and poorly visible.

Distribution. California, localities 71CB983C, 71CB978B, and EB633 near San Jose; Caribbean region (Cuba, St. Bartholomew), Florida, Georgia.

Range. Middle Eocene.

Remarks. Previously described in California as *D. californica* (Schenck, 1929, pl. 28, fig. 5; pl. 29, fig. 1-3; pl. 30, fig. 2-3), according to Cole and Applin (1964).

Pseudophragmina (Proporocyclina) flintensis (Cushman)

Plate 6, figure 12

Orthophragmina flintensis Cushman, 1917, pl. 40, fig. 1-2.
Orthophragmina flintensis Cushman, 1919, pl. IX, fig. 3-6.
Proporocyclina flintensis (Cushman). Cole, 1958, pl. 50, 51, 52, figs. 1-2.
Pseudophragmina (Pseudophragmina) flintensis (Cushman). Butterlin, 1971, pl. IV, fig. 8.
Proporocyclina flintensis (Cushman). Caudri, 1972, pl. 1, fig. 4.

Description. Test diameter 5 mm, circular, compressed and ornate with granules. Narrow equatorial chambers, radially lengthened to the periphery. Complete radial septa, almost rectilinear. Small and narrow lateral chambers.

Distribution. California, localities 71CB983C, 71CB978B, and EB633 near San Jose, EB611 near Mount Diablo (see also Cole, 1958) and Orocopia Mountains (Cole, 1958); Caribbean (with *Lepidocyclina antillea*), Nicaragua, Georgia, Texas, Florida, Panama.

Range. Top of middle Eocene to upper Eocene.

Pseudophragmina (Proporocyclina) clarki (Cushman)

Plate 6, figure 17

Orthophragmina clarki Cushman, 1920, pl. VII, fig. 4-5.
Discocyclina clarki (Cushman). Schenck, 1929, pl. 27, fig. 1, 2, 5, and text fig. 7.
Discocyclina clarki (Cushman). Keenan, 1932, pl. 4, fig. 1-2.
Pseudophragmina (Proporocyclina) clarki (Cushman). Cole, 1958, pl. 52, fig. 3-11.
Pseudophragmina (Proporocyclina) clarki (Cushman). Cole and Applin, 1964, pl. 9, fig. 1-4.

Description. Circular flat test, 3-6 mm in diameter (larger than that of *Pseudophragmina (Proporocyclina) flintensis*), with pillars and central granules. Large embryonic apparatus. In equatorial section, the length and width of the embryonic apparatus are 0.2 mm. In axial section, the length is 0.2 mm and the height is 0.175 mm. Equatorial chambers 1.5 to 2 times higher than wide, lateral chambers narrow and very elongated.

Distribution. California, localities 71CB983C, EB633, and 71CB971B near San Jose. Type locality: Domengine Creek near Mount Diablo, California; also Oregon, Washington (Berthiaume, 1938), Mexico, Peru, and Florida.

Range. Middle Eocene.

Pseudophragmina (Proporocyclina) teres Cole and Gravell, 1952

Pseudophragmina (Proporocyclina) teres Cole and Gravell, 1952, pl. 101, fig. 1-8.
Pseudophragmina (Proporocyclina) teres Cole and Gravell, 1952. Cole and Applin, 1964, pl. 8, fig. 1-7.

Description. Circular species, flat, inflated in the center, diameter 5-6 mm, with pillars and central granules. Equatorial chambers squared toward the center, elongated toward the periphery (h/w approx. 2). Lateral chambers with thick borders and roofs that are flat and barely visible.

Distribution. California, locality 71CB971B near San Jose; Caribbean, Cuba, Florida.

Range. Middle Eocene.

Remarks. Probably present in other samples.

Genus *Asterocyclina* Gumbel, 1870
Asterocyclina aster (Woodring, 1930)

Plate 6, figure 11

Actinocyclina aster Woodring, 1930, fig. 3-6; pl. 16, fig. 1-4; pl. 17, fig. 1-2.

Description. Very flat species with 5 to 13 radiating enlargements. Diameter 5 to 11 mm.

Distribution. California, locality EB611 near Mount Diablo, EB633, 71CB983C, and 71CB971B near San Jose; Osbun 1-1 and 49-6 near Sveadal. Type locality is in Santa Ynez Range, Santa Barbara County.

Range. Upper Eocene (Woodring, 1930), lower and middle Eocene (Berthiaume, 1938; Cole, 1958), middle Eocene (Cole and Gravell, 1952).

Remarks. Cole (1958) put *A. aster* in synonymy with *A. penonensis* of Cole and Gravell (1952). Butterlin (1970) disagrees with this synonymy and lists several reasons for considering the two forms as separate species. Present in all the samples.

Family CYMBALOPORIDAE
Genus *Eofabiana* Kupper, 1955
Eofabiana grahami Kupper, 1955

Plate 6, figures 8, 16

Eofabiana grahami Kupper, 1955, pl. 19, figs. 1-7.

Description. Conical test, primary (first) chambers poorly developed and spirally arranged, not divided into chamberlets. Apertures on the umbilical side.

Distribution. California and the Caribbean.

Range. Lower to middle Eocene.

LOCALITY DESCRIPTIONS

SAN JOSE AREA

Locality 71CB983C, lat 37°13.44′N., long 121°53.29′W., Los Gatos 7.5-minute quadrangle, 1953 edition. Unnamed sedimentary rocks of Eocene age. This locality is within the same limestone lentil and very close geographically to LSJU 309, from which the holotype of *Discocyclina californica* Schenck, 1929 was obtained. The general geology and a more detailed description of the lithology are provided by Bailey and Everhart (1964, p. 69–71 and pl. 1). Collected by Earl Brabb, 1971.

Locality 71CB971B, lat 37°13.25′N., long 121°47.14′W., Santa Teresa Hills 7.5-minute quadrangle, 1953 edition. Unnamed sedimentary rocks of Eocene age. Float pieces of limestone from a small abandoned limestone quarry roughly 0.6 km east of the portal of the Bernal Mine. Collected by Earl Brabb, 1971.

Locality EB633, lat 37°12.9′N., long 121°47.5′W., Santa Teresa Hills 7.5-minute quadrangle, 1953 edition. Unnamed sedimentary rocks of Eocene age. Float pieces of limestone collected by Edgar Bailey in 1948.

SVEADAL AREA

Locality Osbun 1-1, lat 37°05.47′N., long 121°45.03′W., Loma Prieta 7.5-minute quadrangle, 1955 edition. Fossils from conglomerate at or near the base of the Temblor Formation of Miocene age. From small outcrop on north side of road to Sveadal. Collected by E. D. Osbun, 1971. See geologic map by McLaughlin and others (1971); additional maps and a description of the rocks provided in Osbun (1975).

Locality Osbun 49-3, lat 37°06.27′N., long 121°45.68′W., Loma Prieta 7.5-minute quadrangle. Fossils from conglomerate at or near the base of the Temblor Formation of Miocene age. From nose of hill at about 1160 ft (354 m) elevation. Collected by E. D. Osbun, 1971.

Locality Osbun 49-6, lat 37°06.31′N., long 121°45.5′W., Loma Prieta 7.5-minute quadrangle. Fossils from conglomerate at or near the base of the Temblor Formation of Miocene age. From small knob along ridge crest, elevation about 1170 ft (357 m). Collected by E. D. Osbun, 1971.

MOUNT DIABLO AREA

Locality EB611, lat 37°51.35′N., long 121°56′W., Diablo 7.5-minute quadrangle, 1953 edition. Southwest side of road from Mount Diablo State Park headquarters to Junction Camp. From glauconitic limestone near the base of the Domengine Formation where it rests unconformably on shale of Late Cretaceous age. Mapped as lower siltstone and claystone member of Domengine Sandstone by Brabb, Sonneman, and Switzer (1971). Collected by Earl Brabb, 1963. Not exposed in 1976.

DEVILS DEN AREA

Locality 76CB1633, lat 35°42.4′N., long 120°01.1′W., Sawtooth Ridge 7.5-minute quadrangle, 1961 edition (photorevised 1973). Gredal Shale Member of Kreyenhagen Formation. Along north bank of cut for aqueduct, about 20 m east of dirt access road, about 12 m stratigraphically below base of red bed unit, from 50-cm-thick coarse-grained sandstone bed.

Locality 76CB1634, lat 35°42.3′N., long 121°01.3′W. Gredal Shale Member of Kreyenhagen Formation. Along north bank of cut for aqueduct, about 60 m east of two metal posts and 7 m east of telephone box. Same stratigraphic level as 76CB1633 but from part of section duplicated by faulting.

Locality 76CB1641, lat 35°43.8′N., long 121°01.3′W. Gredal Shale Member of Kreyenhagen Formation. About 600 m N.63 W. from BM611 from sandstone rubble on hillside. Probably from same stratigraphic level as 76CB1633 and 76CB1634, but sandstone at this locality appears to be several meters thick.

Locality 76CB1671, about 4 m stratigraphically below 76CB1634. Gredal Shale Member of Kreyenhagen Formation. Sample collected by A. D. Warren.

EOCENE TO MIOCENE CALCAREOUS PLANKTON FROM THE SANTA CRUZ MOUNTAINS AND NORTHERN SANTA LUCIA RANGE, CALIFORNIA

By RICHARD Z. POORE and DAVID BUKRY

ABSTRACT

Stratigraphically diagnostic calcareous plankton (coccoliths and planktic foraminifers) were recovered from two measured sections (Zayante Creek and San Lorenzo River sections) in the Santa Cruz Mountains, one section (Año Nuevo section) along the adjacent coast, and several samples from the Church Creek Formation in the northern Santa Lucia Range.

Samples from below the uppermost sheared part of the Vaqueros(?) Formation of Hall, Jones, and Brooks (1959) as exposed on the coast at the Año Nuevo section yield coccolith assemblages referable to the upper Oliogocene *Sphenolithus ciperoensis* Zone and the lower Miocene *Triquetrorhabdulus carinatus* Zone. Samples from the sheared upper part of the Vaqueros(?) Formation contain coccoliths that are indicative of the Miocene *Helicosphaera ampliaperta* Zone or the *Sphenolithus heteromorphus* Zone.

Late Oligocene coccoliths were recovered from the Vaqueros Sandstone at Zayante Creek in the Santa Cruz Mountains. The sparse low-diversity assemblages in most samples could not be assigned to specific zones.

Diverse calcareous plankton assemblages were recovered from samples from the San Lorenzo River section. Coccoliths from the upper part of the Butano Sandstone and lower part of the Twobar Shale Member of the San Lorenzo Formation are referable, respectively, to the *Discoaster bifax* Subzone and *Discoaster saipanensis* Subzone of the middle Eocene *reticulofenestra umbilica* Zone. Planktic foraminifer assemblages from the same samples correlate with middle Eocene Zones P 13 to P 14. Coccoliths from the upper part of the Twobar Shale Member are assigned to the upper Eocene *Discoaster barbadiensis* Zone. Samples from this same interval yield planktic foraminifers assigned to upper Eocene Zones P 15 to P 16. A sample from the overlying Rices Mudstone Member of the San Lorenzo Formation contains a coccolith assemblage referable to the Oligocene *Sphenolithus distentus* Zone. Planktic foraminifer assemblages from this level are assigned to Oligocene zonal interval P 19 - P 20.

Planktic foraminifers in several samples from the Church Creek Formation, northern Santa Lucia Range, are correlated with upper Eocene Zones P 16 to P 17.

INTRODUCTION

A number of stratigraphic sections in and around the Santa Cruz Mountains and the Santa Lucia Range were examined for coccoliths and planktic foraminifers as part of a field conference and meeting held in Menlo Park, California, by the International Commission on Paleogene Stratigraphy. In this report, data from the Zayante Creek and the San Lorenzo River sections of the Santa Cruz Mountains are presented along with data from the coastal Año Nuevo section (fig. 20). In addition, the occurrence of planktic foraminifers in several samples from the Church Creek Formation in the Church Creek area of the northern Santa Lucia Range are discussed. Brabb, Bukry, and Pierce (1971) and Brabb, Clark, and Throckmorton (1977) give detailed location information for sections and most samples that were examined for this report. Locality data for samples not mentioned in the above reports are given at the end of this report. The zonation of Blow (1969) is employed for planktic foraminifers, and the zonation of Bukry (1975) is used for coccoliths.

Correlation of biostratigraphic zones to subdivisions of the Cenozoic follows Hardenbol and Berggren (1978) for the Eocene and Oligocene, and Ryan and others (1975) for the Miocene.

Acknowledgments.—We thank Earl Brabb, John Barron, and Kristin McDougall for comments concerning this manuscript.

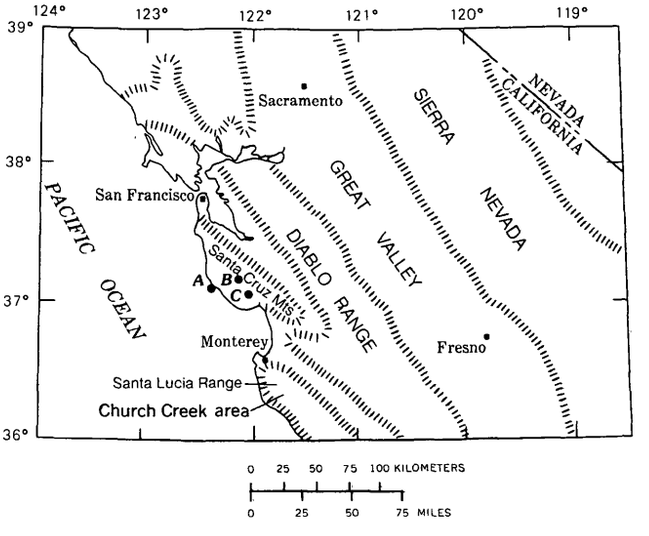


FIGURE 20.—Index map showing general location of sections. Map from Brabb, Bukry, and Pierce (1971). Section A is in the Año Nuevo area; section B, along the San Lorenzo River, and section C, along Zayante Creek.

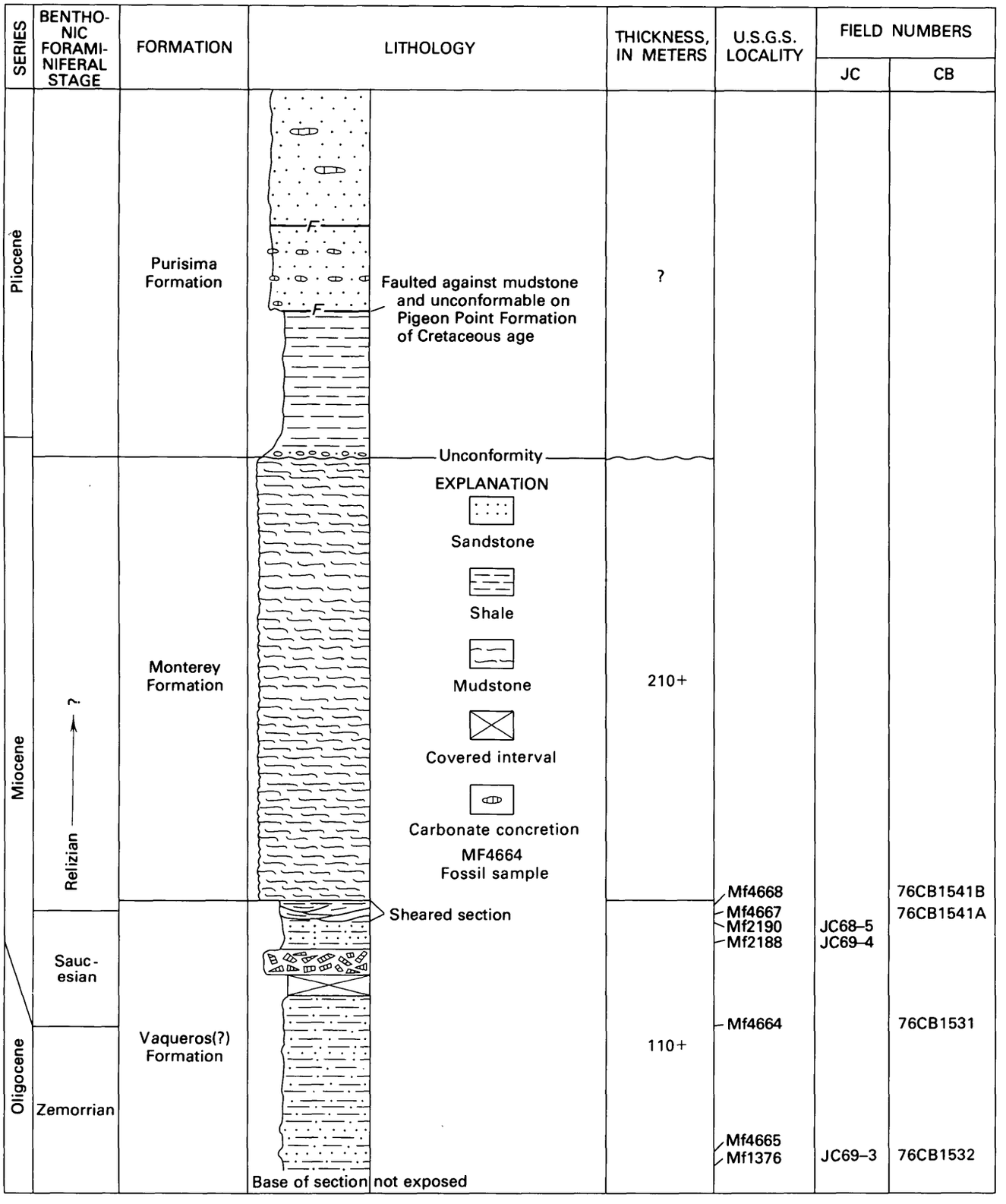


FIGURE 21.—Generalized stratigraphic column of the Año Nuevo section and location of samples yielding calcareous plankton. Modified from Brabb, Clark, and Throckmorton (1977, fig. 31). Position of benthic foraminiferal stages from McDougall (this volume). Position of Oligocene-Miocene boundary estimated from our samples.

TABLE 6.—*Distribution of coccoliths and resultant zone assignments for the Año Nuevo section.*

[Species shown by asterisk are considered to be reworked]

Sample number	*Campylosphaera eodela**	*Chiasmolithus* sp.	*Coccolithus* spp.	*Cyclicargolithus abisectus*	*C. floridanus*	*Dictyococcites bisectus*	*D. scrippsae*	*Discoaster deflandrei*	*D. divaricatus*	*D. exilis*	*D. lodoensis**	*D. variabilis*	*Discoaster* spp.	*Discolithina multipora*	*D. plana s. ampl.*	*Helicosphaera carteri*	*H. euphratis*	*H. intermedia*	*Helicosphaera* spp.	*Reticulofenestra* spp.	*Sphenolithus belemnos*	*S. conicus*	*S. dissimilis*	*S. heteromorphus*	*S. moriformis*	*S. radians**	*Tessellatolithus* sp.	*Tribrachiatus orthostylus**	*Triquetrorhabdulus carinatus*	*Trochoaster* sp.	*Zygrhablithus* sp.	Coccolith zone of Bukry (1975)	Age
76CB1541B Mf4668			×		×			×		aff.		aff.				×			×	×				×	aff.								
76CB1541A Mf4667			×		×			×		aff.		aff.				×			×	×				×		aff.							
JC68–5 Mf2190			×		×			×		aff.										×				×									
JC69–4 Mf2188			×		×			×		aff.		aff.		×		×				×					aff.								
76CB1531 Mf4664	×		×	aff.	×	×	×	×		aff.		×		×	×	×		aff.		×		cf.	aff.		×	aff.	×		aff.	×			
76CB1532 Mf4665			×	×	aff.	×	aff.		×	aff.				×	×			×	aff.	×			aff.	aff.	×		×	×	×	aff.			
JC69–3 Mf1376			×	aff.	×	×	×	×						×				×		×					×	aff.			×		×		

AÑO NUEVO SECTION

A composite section for the Año Nuevo area with the location of samples yielding stratigraphically diagnostic assemblages of calcareous plankton is shown in figure 21. Coccoliths were found throughout the Vaqueros(?) Formation of Hall, Jones, and Brooks (1959) in this section (table 6). Planktic foraminifers are sparse and poorly preserved in samples Mf4664 and Mf4665, but several species were identified (table 7. Planktic foraminifers are common to abundant in samples Mf4667 and Mf4668 but are so poorly preserved and distorted that no confident identifications were possible. The ranges of several important taxa detected in our samples are shown in figure 22.

TABLE 7.—*Distribution of planktic foraminifers in samples from the Año Nuevo section*

Taxon	Sample number 76CB1532 (Mf4665)	76CB1531 (Mf4664)
Globigerina angustiumbilicata Bolli	---	x
G. juvenilis Bolli	x	x
G. praebulloides Blow	x	x
G. woodi Jenkins	x	x
G. tripartita Koch	---	x
Globorotalia nana Bolli	x	x
G. munda Jenkins	aff.	aff.
Catapsydrax unicavus Bolli, Loeblich and Tappan	---	x
Globigerinita praestainforthi Blow	aff.	aff.
Globorotaloides suteri Bolli	x	x

The coccoliths *Triquetrorhabdulus carinatus* or *T.* sp. cf. *T. carinatus* and *Dictyococcites bisectus* in samples Mf1376 through Mf4664 (table 6) are secondary zonal guide taxa that indicate assignment of this interval to the upper Oligocene *Sphenolithus ciperoensis* Zone. The occurrence of *Globorotalia nana* in this interval is compatible with an upper Oligocene assignment. The next higher sample (Mf2188) lacks *Dictyococcites bisectus* and contains *Helicosphaera carteri*, a form restricted to the Miocene and younger strata. We assign this assemblage to the *Triquetrorhabdulus carinatus* Zone and place the Oligocene-Miocene boundary (see fig. 21) between sample Mf2188 and sample Mf4664. Samples Mf2190, Mf4667, and Mf4668 from the sheared section of the Vaqueros(?) Formation, just below the Monterey Formation, contain few to common *Sphenolithus heteromorphus*, which indicates correlation with the lower and middle Miocene *Helicosphaera ampliaperta* Zone or the lower middle Miocene *Sphenolithus heteromorphus* Zone. Thus this sheared zone is near the lower Miocene-middle Miocene boundary. Our age interpretations when compared to the California benthic

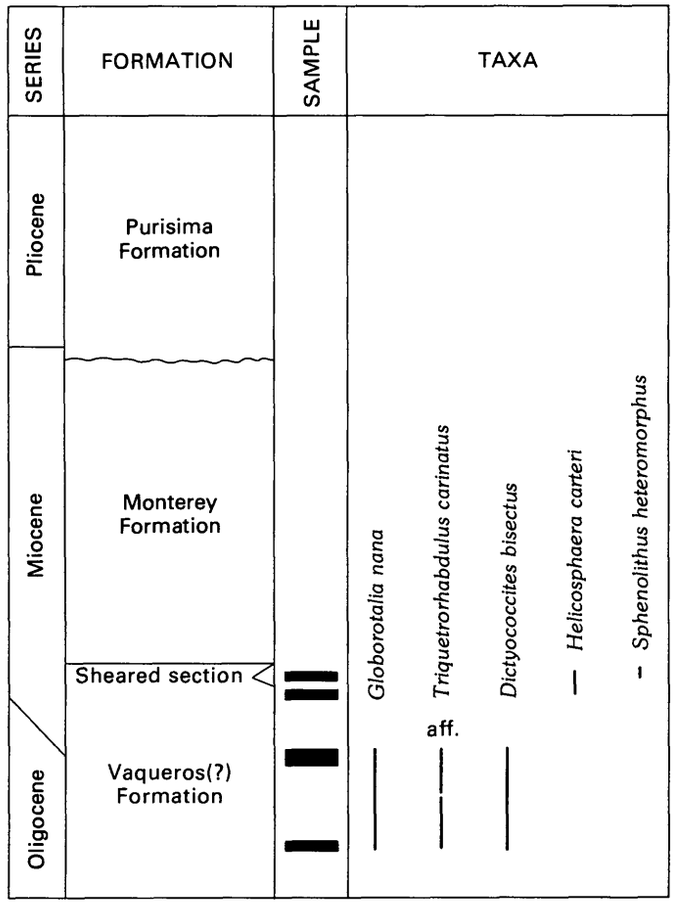


FIGURE 22.—Ranges of selected calcareous plankton in the Año Nuevo section.

foraminiferal stage determinations for this section (McDougall, this volume; Brabb and others, 1977) suggest that the Zemorrian Stage-Saucesian Stage boundary is within the uppermost Oligocene or lower Miocene and the Saucesian Stage-Relizian Stage boundary is within the lower Miocene or middle Miocene.

ZAYANTE CREEK SECTION

The stratigraphic columns and locations of samples yielding coccoliths from the Zayante Creek section (north limb) are shown on figure 23. Coccolith assemblages from the upper part of the Rices Mudstone Member of the San Lorenzo Formation cannot be assigned to a specific zone or limited zonal interval but are probably of late Oligocene age (fig. 23, table 8). Meager coccolith assemblages from the overlying Vaqueros Sandstone suggest correlation with the upper Oligocene *Sphenolithus distentus* Zone or *Sphenolithus ciperoensis* Zone. An assemblage from the lower part of the Lambert Shale (JC 61-11d) is tentatively considered to be of Miocene age because with the exception of a few fragmented specimens, *Dictyococcites bisectus* is absent whereas it is fairly common in samples from the underlying Vaqueros Sandstone.

Only sparse, juvenile planktic foraminifers that could not be identified with certainty were found in the Zayante Creek Section.

SAN LORENZO RIVER SECTION

The stratigraphic column for the San Lorenzo River section and locations of samples containing calcareous plankton are shown on figure 24. Data on planktic foraminifers from this section were reported by Poore and Brabb (1977). Coccoliths in samples from the upper part of the Butano Sandstone and the Twobar Shale Member of the San Lorenzo Formation are listed in table 9. Ranges of selected planktic foraminifers and coccoliths in the San Lorenzo River section are shown on figure 25. Poore and Brabb's (1977) rationale for planktic foraminifer zone assignments are briefly summarized below.

The occurrence of *Globorotaloides suteri* in Mf3301 (upper part of Butano Sandstone) and *Globorotalia cerroazulensis cerroazulensis* in Mf1350 and Mf3304 (lower part Twobar Shale Member of San Lorenzo Formation) indicate a zonal assignment no lower than Zone P 13 and Zone P 14 respectively, whereas taxa such as *"Globigerinoides" higginsi* and *Truncorotaloides rohri* in these samples indicate an assignment no higher than Zone P 14. The occurrence of *Globigerina angiporoides minima* and *G. praebulloides* in Mf1351 and Mf3305 followed by the occurrence of typical representatives of *G. angiporoides angiporoides* in Mf1352 and Mf3306 indicate assignment of these levels to Zone P 15 to Zone P 16.

Samples from the lower part of the Rices Mudstone Member of the San Lorenzo Formation are assigned to Oligocene zonal interval P 19 - P 20 because of the occurrence of *Globigerina ampliapertura* and associated coccoliths (see below).

After completion of Poore and Brabb's (1977) study, two additional samples containing diagnostic planktic foraminifers were discovered in the Twobar Shale Member (table 10). Planktic foraminifers in sample Mf4756, from the San Lorenzo River section (fig. 24), are referable to middle Eocene Zone P 14. Planktic foraminifers in sample Mf2657, from the upper part of the type Twobar Shale Member in the nearby Kings Creek section, are referable to upper Eocene Zone P 15 or Zone P 16. Thus these data corroborate the study of Poore and Brabb (1977) showing that the Zone P14 - P15 boundary (middle Eocene-upper Eocene boundary of Hardenbol and Berggren,

TABLE 8.—*Distribution of coccoliths and zone assignments for the Zayante Creek section.*
[Taxa shown with asterisk are considered to be reworked]

Sample number field fossil collection	*Coccolithus formosus**	*C. pelagicus* (s. ampl.)	*Cyclicargolithus abisectus*	*C. floridanus*	*Dictyococcites bisectus*	*D. scrippsae*	*Discoaster deflandrei*	*D. divaricatus*	*D. lodoensis**	*Discolithina plana* (s. ampl.)	*Discolithina* spp.	*Helicosphaera euphratis*	*H. intermedia*	*H. obliqua*	*H. perchnielsenasae*	*H. recta*	*Isthmolithus recurvus**	*Reticulofenestra* spp.	*Sphenolithus dissimilis*	*S. moriformis*	*S. radians**	*Sphenolithus* spp.	*Tessellatolithus* sp.	*Tribrachiatus orthostylus**	*Zygrhablithus* sp.	Coccolith zone of Bukry (1975)	Age
JC61-11d		×	aff.	×	aff.	aff.	×	aff.			×	×		×				×		×					×	?	Miocene
76CB1592 Mf4677		×		×	×	×	×		×		×	aff.	aff.		aff.	aff.		×	×	×			×			*Sphenolithus ciperoensis* or *Sphenolithus distentus*	Late Oligocene
76CB1595 Mf4680	aff.	×		×	×	×			aff.									×	aff.	×				×	×		
76CB1601 Mf4681	×	×	aff.	×	×	×	×		×	×	×				×		aff.	×			cf.	×	×	×	×		
76CB1603 Mf4683		×		×	×	×	×		×	×	×	×	×					×	×	×	cf.						
76CB1606 Mf4685		×		×	×	×												×		×						?	Late Oligocene?
76CB1607 Mf4686		×		×	×	×																					

1978) is within the lower part of the Twobar Shale Member of the San Lorenzo Formation.

Coccoliths in samples from the San Lorenzo River section support the age interpretations derived from planktic foraminifers. The presence of *Reticulofenestra umbilica* in sample Mf3301 and *Dictyococcites bisectus* in sample Mf3304 indicates assignment of these samples respectively to the *Discoaster bifax* Subzone and the *Discoaster saipanensis* Subzone of the middle Eocene *Reticulofenestra umbilica* Zone. The assemblage from the next higher sample (Mf3305) is difficult to assign to a zone, but the occurrence of *Sphenolithus predistentus, Pedinocyclus larvalis*, and *Chiasmolithus altus* in Mf3306 suggests correlation of this sample with the upper Eocene *Discoaster barbadiensis* Zone. The sparse assemblage of sample Mf3308 contains *Discoaster saipanensis* and is therefore referable to the same zone. We did not recover age-diagnostic coccolith assemblages from the Rices Mudstone Member of the San Lorenzo Formation in our study; however, Bukry, Brabb, and Vedder (1977) reported an assemblage, containing *Cyclicargolithus abisectus*, from a sample (68CB123) equivalent to our sample Mf3310, that they questionably assign to the Oligocene *Sphenolithus distentus* Zone.

Figure 26 summarizes the relation of lithostratigraphy and biostratigraphic determinations derived from planktic foraminifers, coccoliths, and benthic foraminifers from the San Lorenzo River section. Planktic foraminifer data indicate that the Zone P 14 - P 15 boundary occurs in the lower part of the Twobar Shale Member of the San Lorenzo Formation, that is, between the levels delineated by samples Mf3304 and Mf3305. Coccolith data show that the boundary between the *Discoaster saipanesis* Subzone of the *Reticulofenestra umbilica* Zone and the *Discoaster barbadiensis* Zone is at approximately the same place, that is, between samples Mf3304 and Mf3306. The two data sets are in good agreement and show that at this location the middle Eocene-upper Eocene boundary coincides with the base of the *Amphimorphina jenkinsi* Zone of the Narizian Stage. As noted above, we did not recover age-diagnostic coccoliths from the Rices Mudstone Member of the San Lorenzo Formation; however, Warren and Newell (1980) report *Discoaster barbadiensis* from the lower (Refugian) part of the Rices Mudstone Member at this section, which suggests an upper Eocene assignment. In addition, other published studies (Brabb and others, 1971; Lipps, 1967a) suggest an upper Eocene assignment for at least part of the Refugian Stage at other localities. Thus the Eocene-Oligocene boundary in the San Lorenzo River section is tentatively placed in the lower part of the Rices at the boundary between the Refugian and the Zemorrian stages. The remaining data from this section indicate an Oligocene

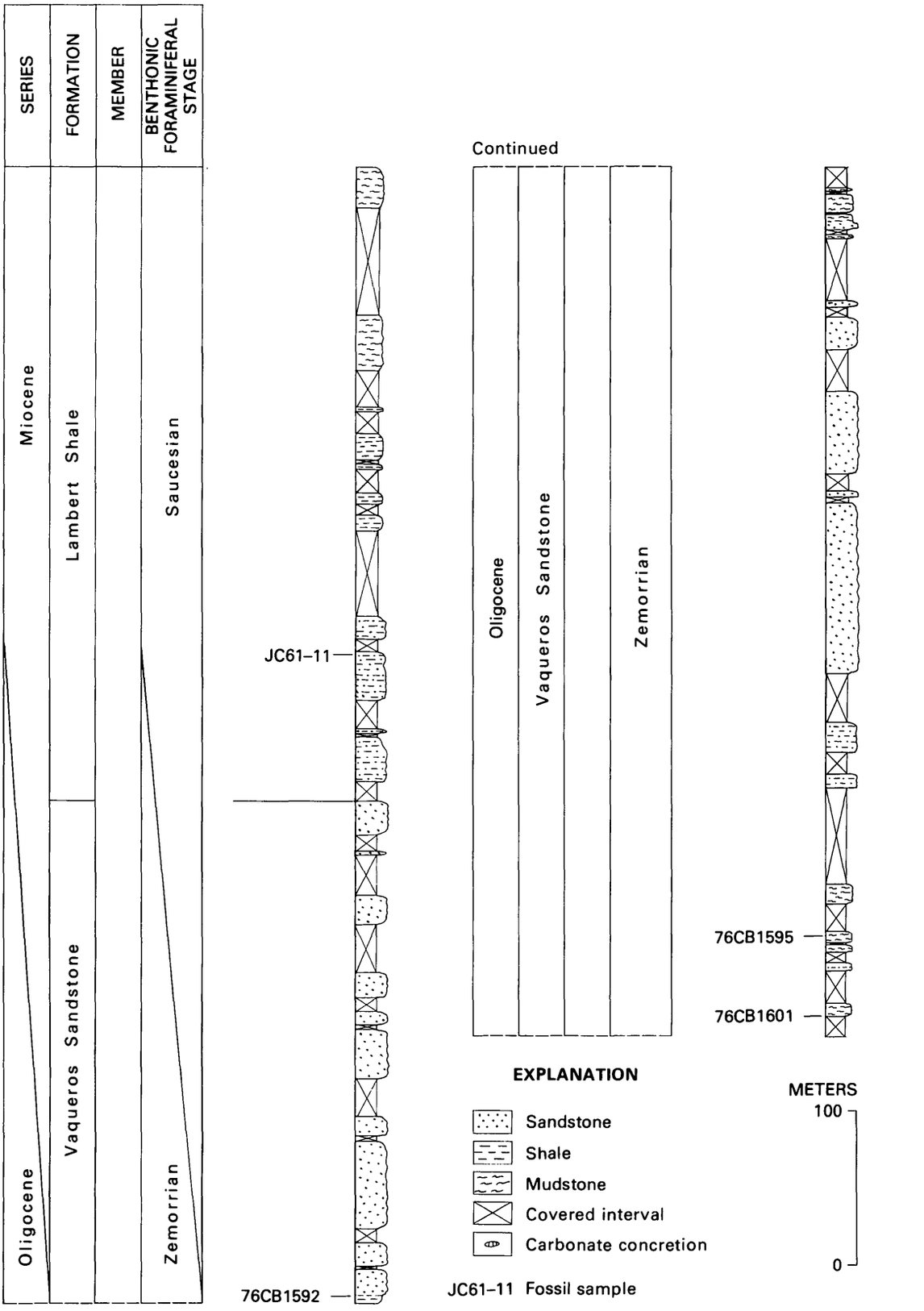


FIGURE 23.—Stratigraphic column for north limb of Zayante Creek section and location of samples yielding calcareous nannofossils. Modified from Brabb, Clark, and Throckmorton (1977, fig. 20). Benthic foraminiferal stage boundaries are from McDougall (this volume). Data on coccoliths and benthic foraminifers from the Lambert Shale are from different samples. No samples were examined from the south limb of the Zayante Creek section for this study.

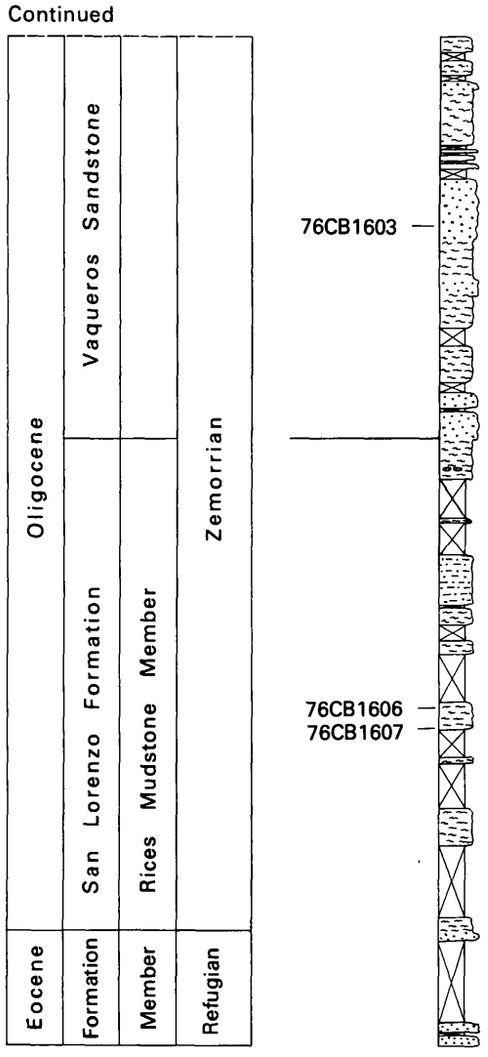


FIGURE 23.—Continued.

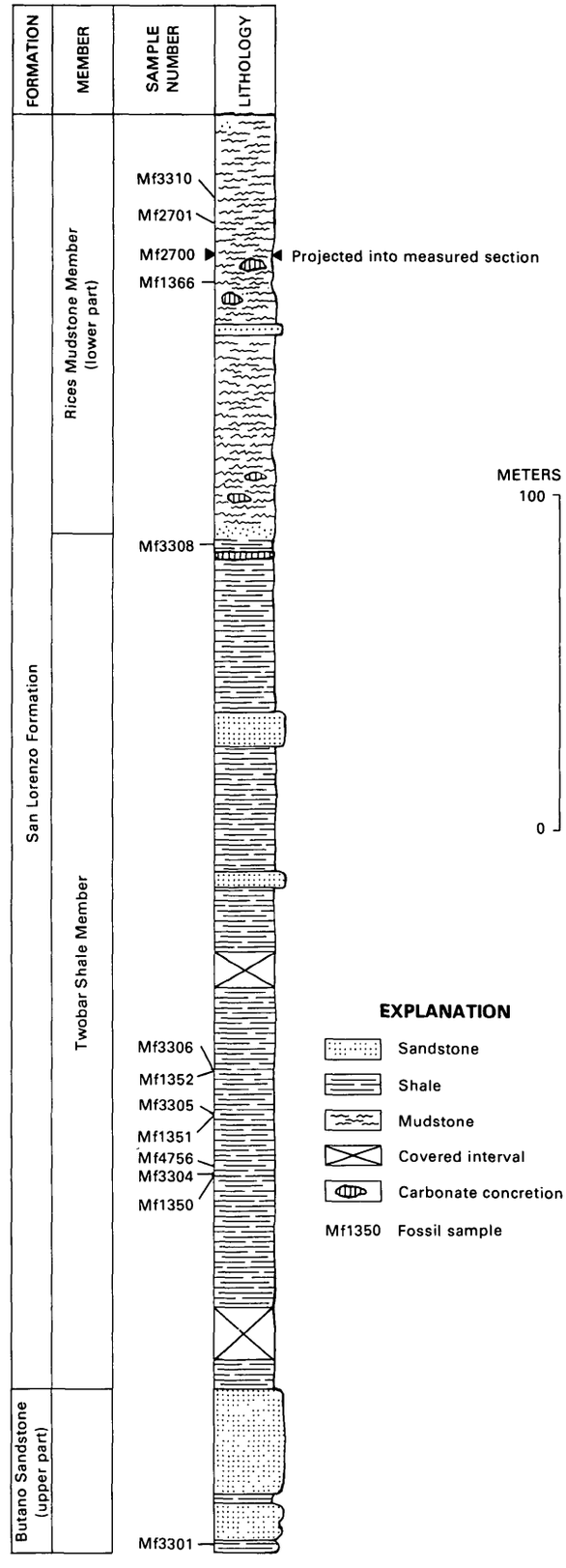


FIGURE 24.—Stratigraphic column for San Lorenzo River section and location of samples yielding calcareous plankton. Modified from Poore and Brabb (1977, fig. 2). Sample 68CB123 of Bukry, Brabb, and Vedder (1977) is approximately equivalent to sample Mf3310.

TABLE 9.—*Distribution of coccoliths and zone assignments for the San Lorenzo River section.*

[Taxa shown with asterisk are considered to be reworked]

Taxon \ Sample number	76CB1455 Mf3308	76CB1453 Mf3306	76CB1452 Mf3305	76CB1451 Mf3304	76CB1442 Mf3301
Braarudosphaera bigelowi	X	X	X		X
Bramletteius serraculoides					X
Campylosphaera dela			X		X
Chiasmolithus altus		X			
C. expansus		X			
C. grandis					X
C. solitus			aff.		aff.
*Coccolithus cribellum**		X			X
C. formosus	X	X	X	X	X
C. staurion	X	X	X	X	X
Coccolithus spp.		X*			X
*Cruciplacolithus tenuis**					X
Cyclicargolithus floridanus	X	X	X	X	X
Cyclicargolithus? luminus		X			
*Cyclococcolithina gammation**		X		X	X
C. kingi					X
Daktylethra punctulata		X	X		X
Dictyococcites bisectus	X	X	X	X	
D. scrippsae	X	X	X	X	X
Discoaster barbadiensis		X			X
D. elegans		X	X	X	X
*D. lodoensis**					X
D. nodifer		X	X		X
D. saipanensis	X	X		X	
D. tani					X
Discolithus distinctus		X	X		X
Discolithus spp.	X		X		X
Helicosphaera bramlettei		X	X		cf.
H. compacta			X		X
H. lophota				cf.	X
H. seminulum				X	X
Lanternithus minutus		X	X		
Lithostromation perdurum		cf.	cf.		
*Lophodolithus reniformis**					X
Micrantholithus altus		X			
M. basquensis		X	X		
M. flos		aff.			
Pedinocyclus larvalis		X			
Pemma angulatum		X			
Reticulofenestra oamaruensis					X
R. reticulata	X	X	X	X	X
R. umbilica	X		X		X
R. spp.	X	X	X	X	X
Rhabdosphaera tenuis					X
Rhabdosphaera spp.		X	X		X
Sphenolithus furcatolithoides					X
S. moriformis		X		X	X
S. predistentus		X	cf.		
S. pseudoradians		X		X	X
S. radians				X	X
S. spiniger			X	X	X
Sphenolithus spp.	X	X	X		X
Thoracosphaera sp. (spp.)	X	X	X		X
*Tribrachiatus orthostylus**		X			X
Transversopontis pulcheroides		X	X		
Zygolithus dubius	X	X			
Zygrhablithus bijugatus	X	X	X	X	X
Coccolith zone or subzone of Bukry (1975)	*Discoaster barbadiensis* zone		*Discoaster saipanensis* subzone		*Discoaster bifax* subzone
Age	Late Eocene		Middle Eocene		

FIGURE 25.—Ranges of selected calcareous plankton and resultant zone assignments for the San Lorenzo River section.

assignment for at least the lower part of the *Uvigerina gallowayi* Zone of the Zemorrian Stage.

CHURCH CREEK AREA

Brabb, Bukry, and Pierce (1971) reported coccoliths indicative of the *Discoaster barbadiensis* Zone and benthic foraminifers referable to the Refugian Stage from the Church Creek Formation in the Church Creek area of the Santa Lucia Range (fig. 20). As there are few published records of planktic foraminifers in California marine strata assigned to the Refugian Stage, samples from this unit including those reported by Brabb, Bukry, and Pierce (1971) were examined for planktic foraminifers. Most samples are barren of planktic foraminifers or contain poorly preserved, nondiagnostic assemblages. Two samples, however, did yield relatively diverse assemblages (table 11). The assemblages present in samples Mf2616 and Mf2626 are compatible with the upper Eocene assignment derived from coccoliths of this

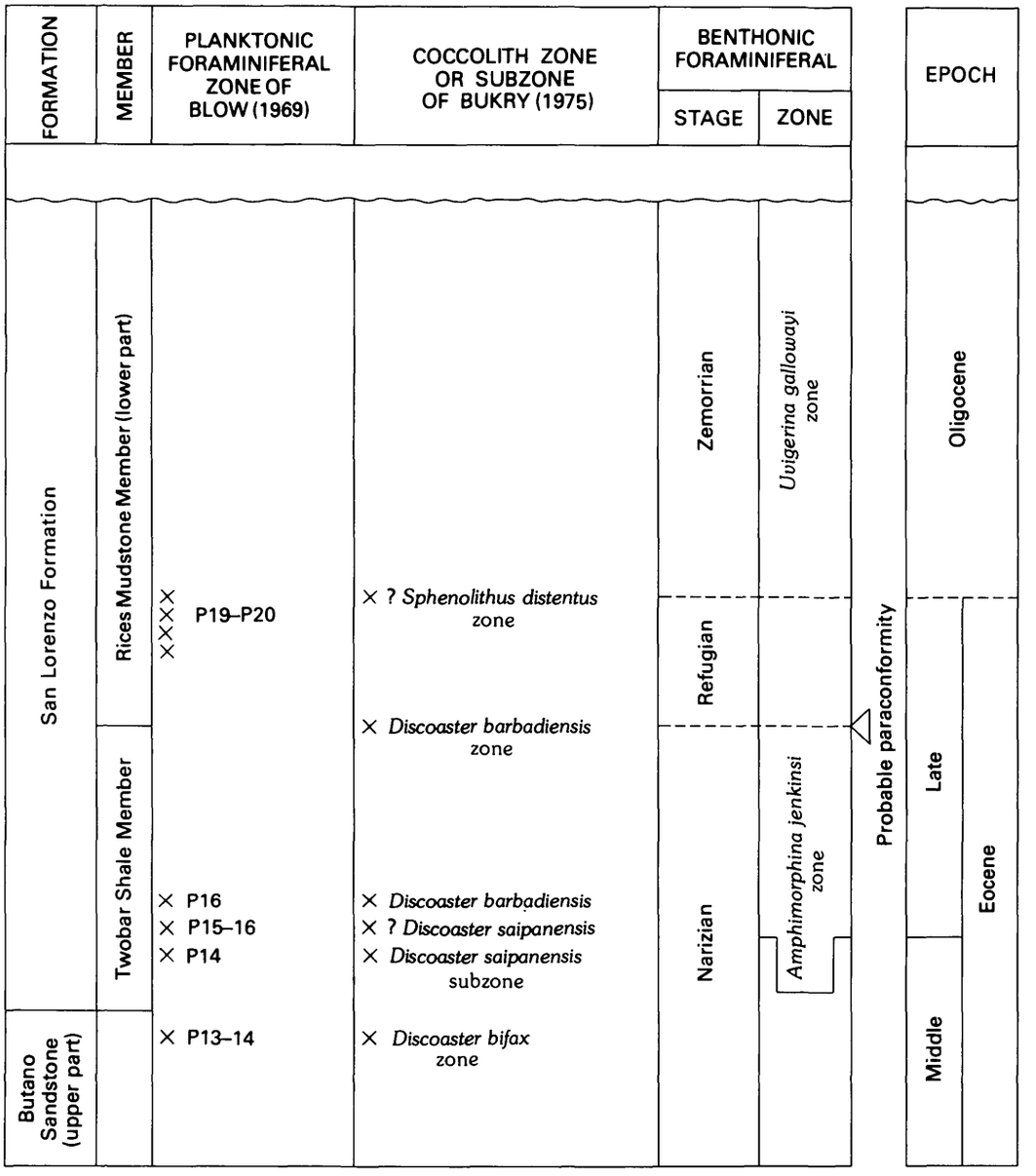


FIGURE 26.—Summary of lithostratigraphy and biostatigraphic determinations for the San Lorenzo River section. Data on benthic foraminifers from McDougall (this volume). The *Valvulineria tumeyensis* Zone and *Uvigerina vicksburgensis* Zone of the Refugian Stage appear to be present, albeit poorly developed (McDougall, this volume). Modified from Poore and Brabb (1977, fig. 3). Sample levels for calcareous plankton are shown by X.

formation. Moreover, the occurrence of *Globorotalia gemma* is significant in that this form ranges no lower than Zone P 16 (Blow, 1969). Thus these assemblages are correlative with Eocene Zones P 16 or P 17.

DISCUSSION

Planktic calcareous microfossils were either absent or very sparse and poorly preserved in most samples from sections we examined for this field conference. Additionally, most zone assignments for planktic foraminifer or coccolith assemblages were based on secondary rather than primary zone indicators. Even though we employed concentration techniques in coccolith preparations, primary zone indicators were still not encountered in most samples. The absence of calcareous plankton in these sections is due to a variety of factors including: unfavorable facies, geographic limits of index taxa, diagenesis, and the deep weathering characteristic of the Coast Ranges. Nonetheless, the record from the San Lorenzo River section is valuable information concerning upper middle Eocene to upper Eocene calcareous plankton from the Pacific coast. Undoubtedly these data will become important in future studies concerning biogeography of calcareous plankton of this region. Similarly, data from the San Lorenzo River section show that the middle Eocene-upper Eocene boundary of international usage is approximated by the base of the *Amphimorphina jenkinsi* Zone of the Narizian Stage and further that in this area, the Narizian Stage-Refugian Stage boundary is in the upper Eocene. Data from the Zayante Creek and Año Nuevo sections, albeit sparse, suggest that the Zemorrian Stage-Saucesian Stage boundary is uppermost Oligocene or lower Miocene on the basis of calcareous plankton.

TABLE 10.—*Occurrence of planktic foraminifers and zone assignments from samples Mf4756 and Mf2657, from the Twobar Shale Member of the San Lorenzo Formation in the San Lorenzo River and Kings Creek sections*

Taxon	Sample number Mf 4756	Mf 2657
Chiloguembelina sp.	x	---
Globigerina angiporoides angiporoides Hornibrook	---	x
G. angiporoides minima Jenkins	x	x
G. eocaena Gumbel s.l.	x	---
G. praebulloides Blow	---	x
G. praeturritilina Blow and Banner	---	x
G. pseudovenezuelana Blow and Banner	---	x
G. senilis Bandy	x	x
G. tripartita Koch	---	x
G. utilisindex Jenkins and Orr	x	---
Globigerinatheka index (Finlay) s.l.	x	---
G. mexicana (Cushman) s.l.	x	---
Globigerinita martini Blow and Banner s.l.	x	x
"Globigerinoides" higginsi Bolli	x	---
Globorotalia cerroazulensis (Cole)	---	x
Globorotaloides carcoselleensis Toumarkine and Bolli	x	x
G. wilsoni (Cole)	x	x
Gümbelitria columbiana Howe	x	---
Hantkenina sp.	---	x
Planorotalites pseudoscitula Glaessner)	x	---
Pseudohastigerina lillisi (Church)	x	x
P. micra (Cole)	x	x
Truncorotaloides collactea (Finlay)	x	---
T. rohri Bronnimann and Bermudez	x	---
Zone assignment	P14	P15-P16

TABLE 11.—*Planktic foraminifers and zone assignments for samples from the Church Creek Formation, Santa Lucia Range.*

Taxon	Sample number Mf2616	Mf2626
Globigerina angiporoides angiporoides Hornibrook	x	---
G. a. minima Jenkins	x	---
G. officinalis Subbotina	x	---
G. ouachitaensis Howe and Wallace	x	---
G. praebulloides Blow	x	---
G. pseudovenezuelana Blow and Banner	---	x
G. tripartita Koch	---	x
Globigerinita martini Blow and Banner (s.l.)	x	x
Globorotalia gemma Jenkins	x	x
Globorotaloides suteri Bolli	x	---
Zone assignment	P16 or P17	P16 or P17

TAXONOMIC NOTES

Comments in this section are restricted to planktic foraminifers illustrated on plates 7 and 8. A more complete discussion and illustrations of plankton foraminifers from the San Lorenzo River section are presented in Poore and Brabb (1977). Coccoliths identified during the present study are listed at the end of this report along with reference to a publication giving a representative light-microscope illustration.

Chiloguembelina cubensis (Palmer)
Plate 7, figures 1, 2

Gumbelina cubensis Palmer, 1934, p. 235-254, figs. 1-6.

Chiloguembelina cubensis occurs as a minor component in several of the planktic assemblages from the San Lorenzo River section. The lower stratigraphic limit of this taxon is ambiguous, but is probably no lower than Zone P 13. Several workers (Jenkins and Orr, 1972; Berggren and Amdurer, 1973) suggest that the last occurrence of *Chiloguembelina cubensis* can be used to divide Oligocene Zone P 21 into two informal subzones.

Globigerina praeturritilina Blow and Banner
Plate 8, figures 7, 8

Globigerina turritilina praeturritilina Blow and

Banner, 1962, p. 99, pl. XIII, figs. a-c.

The relatively high spire, open umbilicus, and arching aperture of this taxon serve to distinguish it from large generalized middle and late Eocene *Globigerina*.

Globorotalia sp. aff. *G. munda* Jenkins
Plate 8, figures 5, 6

Globorotalia munda Jenkins, 1966, p. 1121, pl. 13, no. 152-166, text fig. 14, no. 126-133.

This form is sparse in samples Mf4664 and Mf4665 from the Año Nuevo section. Poor preservation and few individuals available for study preclude a more positive identification.

Globorotalia nana Bolli
Plate 8, figures 1-4

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

As presently understood, typical *Globorotalia nana* ranges no higher than upper Oligocene Zone P 22 (Blow, 1969; Stainforth and others, 1975). Other similar forms, such as *Globorotalia pseudocontinuosa* Jenkins, however, range well into the Miocene. Thus care must be taken in making a pre-Miocene assignment based solely on the occurrence of *Globorotalia nana*.

Gümbelitria columbiana Howe
Plate 7, figures 7-9

Gümbelitria columbiana Howe, 1939, p. 62, pl. 8, figs. 12 and 13.

Poorly preserved specimens of this taxon are present in sample Mf4756 from the San Lorenzo River section. *Gümbelitria columbiana* was not detected in the other middle and upper Eocene samples from this section (Poore and Brabb, 1977).

Pseudohastigerina lillisi (Church)
Plate 7, figures 3,6

Pullenia lillisi Church, 1931, p. 209, pl. A, fig. 10

The concepts of McKeel and Lipps (1975) are followed in identifying this species. Thus the tendency towards loose coiling in mature specimens and the relatively high arched aperture distinguish *Pseudohastigerina lillisi* from *P. micra*.

Pseudohastigerina micra (Cole)
Plate 7, figures 4, 5

Nonion micrus Cole, 1927, p. 22, pl. 5, fig. 12

Pseudohastigerina micra ranges from within basal middle Eocene Zone P 10 through Oligocene zonal interval P 19 - 20. This taxon is fairly common in the Pacific coast rocks of appropriate age and is often useful as a secondary indicator for detecting the lower Eocene-middle Eocene boundary.

CALCAREOUS NANNOFOSSILS

Some representative coccolith species that are well known from the Gulf Coast, Europe, and Deep Sea Drilling Project cores are illustrated (pl. 9) to show the typical moderate preservation state of northern California assemblages.

LOCALITY DATA

Samples Mf2616 and Mf2626 from the Santa Lucia Range.

Both samples are from the Church Creek Formation in the Chews Ridge 7.5-minute quadrangle, Monterey County, California. Samples were collected by E. E. Brabb in 1969.

Sample Mf2616, field number 69CB651. Lat 36° 16′4″ N., long 121° 34′8″ W.

Sample Mf2626, field number 69CB642. Lat 36° 16′9″ N., long 121° 35′6″ W.

Sample taken at creek junction, elevation 2,860 ft (872 m).

ILLUSTRATION REFERENCES FOR IDENTIFIED COCCOLITH SPECIES

Braarudosphaera bigelowi (Gran and Braarud)—Bybell, 1975.
Bramletteius serraculoides Gartner—Gartner, 1969.
Campylosphaera dela (Bramlette and Sullivan)—Bramlette and Sullivan, 1961.
C. eodela Bukry and Percival—Bukry and Percival, 1971.
Chiasmolithus altus Bukry and Percival—Burkry and Percival, 1971.
C. expansus (Bramlette and Sullivan)—Bramlette and Sullivan, 1961.
C. grandis (Bramlette and Riedel)—Bramlette and Sullivan, 1961.
C. solitus (Bramlette and Sullivan, 1961).
Coccolithus cribellum (Bramlette and Sullivan)—Bramlette and Sullivan, 1961.
C. formosus Kamptner—Kamptner, 1963.
C. staurion Bramlette and Sullivan—Bramlette and Sullivan, 1961.
Cruciplacolithus tenuis (Stradner) s. ampl.—Martini, 1971.
Cyclicargolithus abisectus (Muller)—Bukry and Percival, 1971.
C. floridanus (Roth and Hay)—Bramlette and Wilcoxon, 1967 (as *C. neogammation*).
C.? luminus (Sullivan) n. comb.—basionym: *Cyclococcolithus luminus* Sullivan, 1965, p. 33, pl. 3, figs. 9a, b.
Cyclococcolithina gammation (Bramlette and Sullivan)—Bukry, 1974.
C.? kingi (Roth)—Gartner, 1971 (as *C. protoannula*).
Daktylethra punctulata Gartner—Gartner and Bukry, 1969.
Dictyococcites bisectus (Hay, Mohler, and Wade)—Bukry and Percival, 1971.
D. scrippsae Bukry and Percival–Bukry and Percival, 1971
Discoaster barbadiensis Tan—Bramlette and Sullivan, 1961.
D. deflandrei Bramlette and Riedel—Bramlette and Wilcoxon, 1967.

Discoaster divaricatus Hay–Hay and others, 1967.
D. elegans Bramlette and Sullivan–Bramlette and Sullivan, 1961.
D. exilis Martini and Bramlette—Martini and Bramlette, 1963.
D. lodoensis Bramlette and Riedel—Bramlette and Sullivan, 1961.
D. nodifer (Bramlette and Riedel)—Bukry, 1974.
D. saipanensis Bramlette and Riedel—Bukry, 1974.
D. tani Bramlette and Riedel—Bramlette and Riedel, 1954.
D. variabilis Martini and Bramlette, 1963.
Discolithina distincta (Bramlette and Sullivan)—Bramlette and Sullivan, 1961.
D. multipora (Kamptner)—Kamptner, 1948.
D. plana (Bramlette and Sullivan)—Bramlette and Sullivan, 1961.
Helicosphaera bramlettei (Muller)—Muller, 1970.
H. carteri (Wallich)—Bramlette and Wilcoxon, 1967.
H. compacta Bramlette and Wilcoxon—Bramlette and Wilcoxon, 1967.
H. euphratis Haq—Haq, 1973.
H. intermedia Martini—Haq, 1973.
H. obliqua Bramlette and Wilcoxon—Bramlette and Wilcoxon, 1967.
H. perch nielsenasae Haq—Haq, 1973.
H. recta Haq—Haq, 1973.
Isthmolithus recurvus Deflandre—Hay and others, 1966.
Lanternithus minutus Stradner—Gartner and Burky, 1969.
Lophodolithus reniformis Bramlette and Sullivan—Bramlette and Sullivan, 1961.
Micrantholithus flos Deflandre—Sullivan, 1964.
Pedinocyclus larvalis (Bukry and Bramlette)—Bukry and Bramlette, 1971.
Pemma angulatum Martini—Martini, 1959.
P. basquensis (Martini) s. ampl.—Bybell, 1975.
Reticulofenestra oamaruensis (Deflandre)—Stradner and Edwards, 1968.
R. reticulata (Gartner and Smith)–Bybell, 1975
R. umbilica (Levin)—Bybell, 1975.
Rhabdosphaera tenuis Bramlette and Sullivan—Bramlette and Sullivan, 1961.
Sphenolithus belemnos Bramlette and Wilcoxon—Bramlette and Wilcoxon, 1967.
S. conicus Bukry—Bukry, 1971.
S. dissimilis Bukry and Percival—Bukry and Percival, 1971.
S. furcatolithoides Locker—Locker, 1967.
S. heteromorphus Deflandre—Bramlette and Wilcoxon, 1967.
S. moriformis (Bronnimann and Stradner)—Bramlette and Wilcoxon, 1967.
S. predistentus Bramlette and Wilcoxon—Bramlette and Wilcoxon, 1967.
S. pseudoradians Bramlette and Wilcoxon—Bramlette and Wilcoxon, 1967.
S. radians Deflandre—Sullivan, 1965.
S. spiniger Bukry—Bukry, 1971.
Transversopontis pulcheroides (Sullivan)–Sullivan, 1964 (as *Discolithus pulcheroides*).
Tribrachiatus orthostylus Shamrai—Bramlette and Sullivan, 1961 (as *Discoaster tribrachiatus*).
Triquetrorhabdulus carinatus Martini—Bramlette and Wilcoxon, 1967.
Zygolithus dubius Deflandre—Bybell, 1975.
Zygrhablithus bijugatus (Deflandre)—Bybell, 1975.

Indeterminate or undifferentiated species of the following genera are also tabulated:

Chiasmolithus Hay, Mohler, and Wade, 1966.
Coccolithus Schwarz, 1894.
Discolithina Loeblich and Tappan, 1963.
Helicosphaera Kampter, 1954
Reticulofenestra Hay, Mohler, and Wade, 1966.
Rhabdosphaera Haeckel, 1894.
Sphenolithus Deflandres, 1952.
Tessellatolithus Haq, 1968.
Thoracosphaera Kamptner, 1927.
Trochoaster Klumpp, 1953.
Zygrhablithus Deflandre, 1959.

UPPER EOCENE TO LOWER MIOCENE BENTHIC FORAMINIFERS FROM THE SANTA CRUZ MOUNTAINS AREA, CALIFORNIA

By KRISTIN MCDOUGALL

ABSTRACT

Benthic foraminiferal assemblages from three sections (San Lorenzo River, Zayante Creek, and Año Nuevo sections) in the Santa Cruz Mountains area, California, provide a sequence of species that are diagnostic of the middle Tertiary California benthic foraminiferal stages—Narizian through Relizian Stages. The lower Narizian *Bulimina corrugata* Zone is recognized in the San Lorenzo River section by the presence of restricted early Narizian species such as *Amphimorphina becki, Cibicides pachyderma, Karreriella elongata,* and *Pleurostomellina alternans.* The upper Narizian *Amphimorphina jenkinsi* Zone is recognized in this section by the presence of *Uvigerina garzaensis nudorobusta, Eggerella elongata,* and the first occurrence of many species that range into younger strata. The Refugian Stage is recognized in the strata above a glauconite bed in the Twobar Shale Member of the San Lorenzo Formation. These Refugian faunas contain species typical of deeper water and have a more northern aspect than present in the type area of the Refugian Stage, and prove additional data on the age ranges of the diagnostic Refugian species.

Parts of the Zemorrian Stage are recognized from all three sections examined. The lower Zemorrian *Uvigerina gallowayi* Zone is identified in the San Lorenzo River and Zayante Creek sections by diagnostic species such as *Uvigerina gallowayi, Textularia shivelyi, Pseudonodosaria gallowayi,* and *Uvigerinella obesa impolita.* The upper Zemorrian *Uvigerinella sparsicostata*

Zone is recognized in the Zayante Creek and Año Nuevo sections by the lowest occurrences of *Siphogenerina nodifera, S. mayi, S. multicostata, Bulimina carneroensis*, and *Uvigerinella sparsicostata*. Saucesian faunas identified from the Año Nuevo section include *Baggina robusta, Bolivina marginata adelaidana*, and *Dentalina quadrulata*. This section also contains Relizian assemblages, which are identified by the presence of poorly preserved specimens of *Siphogenerina hughesi* and *Valvulineria californica*. The lower Zemorrian-upper Zemorrian and Zemorrian-Saucesian boundaries are gradational owing to continuous deposition and unchanged bathymetric conditions; this necessitates some modification of species ranges and diagnostic species defining the stage and zone boundaries.

The infrequent and sporadic occurrences of planktic foraminifers and nannofossils in these sections do not allow definitive calibration of planktic foraminiferal zone boundaries to benthic foraminiferal stage or zone boundaries but do suggest the following correlations: (1) the lower Narizian-upper Narizian boundary corresponds approximately to the middle Eocene-upper Eocene boundary (2) the Refugian Stage is upper Eocene, (3) the Zemorrian Stage is Oligocene, and (4) the Saucesian Stage is lower Miocene.

INTRODUCTION

Benthic foraminifers were examined from three sections in the central California Coast Ranges as part of the field conference and meeting held by the International Commission on Paleogene Stratigraphy in 1977. The purpose of this meeting was to correlate the West Coast zonal schemes based on benthic foraminifers to zonal schemes of wider usage based on nannofossils and planktic foraminifers, and ultimately to correlate the California sequences with the European stages. The purpose of this paper, therefore, is to provide the stage, zonal, and subzonal assignments based on benthic foraminifers.

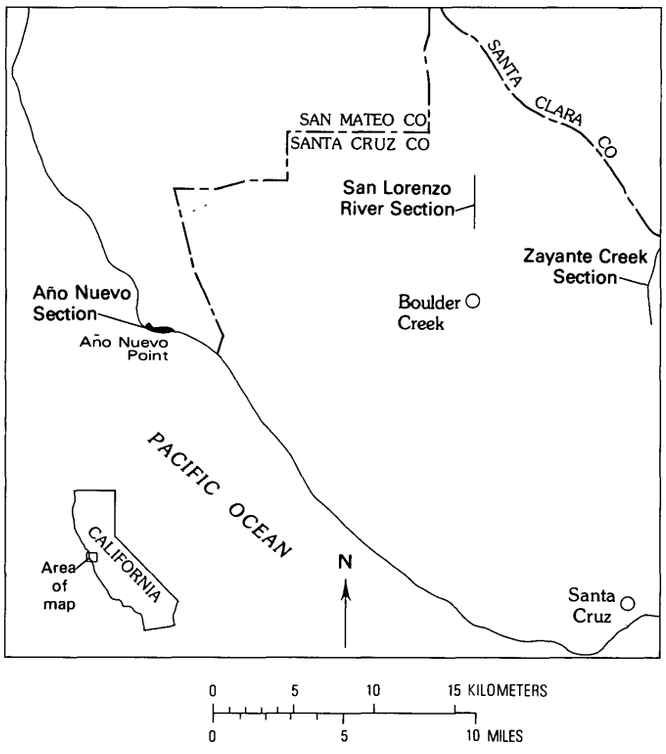


FIGURE 27.—General location of sections examined for this study.

The impetus for microfossil studies and the development of a zonal scheme was the discovery of oil in California in the early part of the twentieth century. This activity led to the development of a Tertiary zonal scheme based on benthic foraminifers. The definitions and descriptions of these stages and zones are given in Kleinpell (1938), Mallory (1959), and Donnelly (1976—this modified the original definition of Schenck and Kleinpell, 1936). Work since then has been directed toward describing faunas and extending these zonal schemes along the west coast of North America. Extension of these stages outside their type localities has resulted in correlation problems. Planktic foraminiferal nannofossil studies (Steineck and Gibson, 1971; Bukry and others, 1977; Poore, 1976, and this volume) have demonstrated that the benthic foraminiferal stages are commonly time-transgressive from one area to another when compared to zonal schemes based on planktic organisms. Benthic foraminiferal studies should now be directed toward recognizing the problems and causes, and resolving them.

Benthic foraminifers from the Santa Cruz Mountains (San Lorenzo River and Zayante Creek sections, fig. 27) and along the adjacent coast (Año Nuevo section, fig. 27) were analyzed to determine stage and zone boundaries. These sections provide a nearly continuous sequence from the Narizian Stage to the Relizian Stage (fig. 28). The benthic foraminiferal assemblages include species from bathymetric facies different than in the type areas of the stages and zones and thus provide additional information on species age ranges and environmental tolerances. This information suggests that minor revisions are needed in the benthic foraminiferal criteria used to recognize the stages and zones. Planktic microfossil data, though sparse or limited, do suggest that these stages can be correlated with international time scales. The sections examined in this report do not overlap enough in time, however, to consider the problem of time-transgressive stages. As more complex sampling and more detailed work with planktic and benthic organisms is done, factors contributing to or causing the time-transgressive stages can be identified and perhaps resolved.

Acknowledgments—I thank W. V. Sliter, R. Z. Poore, and E. E. Brabb for discussions and suggestions on the manuscript and also Robert Oscarson

and M. G. Murphy for assisting in the preparation of the plates. Special thanks are given to E. E. Brabb for measuring sections and collecting the samples used in this study.

SAN LORENZO RIVER SECTION

The San Lorenzo River section is in the Santa Cruz Mountains northwest of the town of Santa Cruz (fig. 27). Tertiary rock units exposed along this river section include the Butano Sandstone, San Lorenzo Formation, and Vaqueros Sandstone. New benthic foraminiferal data (table 12) from the San Lorenzo Formation augment and modify (fig. 29) the earlier work by Sullivan (1962). Detailed descriptions of the lithology, structure, and sample localities are given in Sullivan (1962), Poore and Brabb (1977), and Brabb, Clark, and Throckmorton (1977). See table 13 for field numbers and the corresponding sample numbers used in this report.

SERIES	BENTHONIC FORAMINIFERAL STAGE	BENTHONIC FORAMINIFERAL ZONE	SUBZONE	SAN LORENZO RIVER	ZAYANTE CREEK	AÑO NUEVO
Miocene	Relizian		No subzones			Mf4668 Mf4662
	Saucesian	*Uvigerinella obesa impolita*				
		Plectofrondicularia miocenica				
		Siphogenerina transversa			Mf4671	
Oligocene	Zemorrian	*Uvigerinella sparsicostata*			Mf4677 Mf4679 Mf4681	Mf4664 Mf1374–1376 Mf4665
		Uvigerina gallowayi		Mf2700–2701 Mf1366–1363	Mf4682–4683	
Eocene	Refugian	*Uvigerina vicksburgensis*		Mf1364–1365		
		Valvulineria tumeyensis	*Uvigerina atwilli*	Mf1360–1362		
			Cibicides haydoni	?Missing ?		
	Narizian	*Amphimorphina jenkinsi*	No subzones	Mf1355–1357 Mf1350–1352		
		Bulimina corrugata	*Uvigerina garzaensis*	Mf3304		
			Uvigerina churchi			

FIGURE 28.—Stratigraphic relations and stage and zone assignments of samples examined for this study. Benthic foraminiferal stages and zones were defined by Schenck and Kleinpell (1936), Kleinpell (1939), Mallory (1959), and Donnelly (1976).

TABLE 12.—*Benthic foraminifers from the San Lorenzo River section of Brabb, Clark, and Throckmorton (1977, fig. 12)*

Benthonic foraminiferal stage	Narizian							Refugian					Early Zemorrian				
	Early		Late														
Taxon	Mf3304	Mf1350	Mf1351	Mf1352	Mf1355	Mf1356	Mf1357	Mf1360	Mf1361	Mf1362	Mf1364	Mf1365	Mf1366	Mf2700	Mf2701	Mf1367	Mf1368
Amphimorphina becki Mallory	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Anomalina garzaensis Cushman and Siegfus	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Asterigerina crassaformis Cushman and Siegfus	R	—	R	—	—	—	—	—	—	—	—	—	?	—	—	—	—
Bathysiphon eocenica Cushman and Hanna	F	F	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bathysiphon spp.	F	—	—	—	—	—	—	—	—	—	—	—	F	—	—	—	—
Bifarina eleganta (Plummer)	F	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Boldia cf. *B. hodgei* (Cushman and Schenck)	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bolivina sp.	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bulimina corrugata Cushman and Siegfus	F	—	—	—	—	F	C	—	—	—	—	—	—	—	—	—	—
Bulimina curtissima Cushman and Siegfus	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chilostomella sp.	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cibicides pachyderma (Rzehak)	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cibicides spp.	F	—	F	—	—	R	—	—	—	—	—	—	—	—	—	—	—
Cibicides spiropunctatus Galloway and Morrey	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dentalina spinosa ornatior Sullivan	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dorothia cubana (Cushman and Bermudez)	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Eggerella elongata Blaisdell	F	F	?	—	F	C	—	—	—	—	—	—	—	—	—	—	—
Eggerella subconica Parr	F	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
?*Eggerella subconica* Parr	F	—	F	—	—	F	—	—	—	—	—	—	—	—	—	—	—
Ellipsonodosaria atlantisae hispidula Cushman		F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gyroidina orbicularis planata Cushman	F	—	—	—	—	—	—	R	—	—	—	—	—	A	—	R	F
Haplophragmoides spp.	C	—	—	—	F	F	—	F	—	—	F	—	—	—	—	—	—
Karreriella elongata Mallory	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lenticulina midwayensis (Plummer)	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lenticulina pseudovortex (Cole)	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lenticulina spp.	F	R	—	—	—	F	—	C	C	F	C	F	F	—	—	—	—
Marginulina subbullata Hantken	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Marginulina subbullata of Mallory	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Martinottiella eocenica Cushman and Bermudez	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nodosaria cf. *N. gyrata* Mallory	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nodosaria longiscata d'Orbigny	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nodosaria pyrula d'Orbigny	F	R	—	—	—	F	—	—	—	—	—	—	—	—	—	—	—
Nodosaria spp.	F	—	—	—	R	F	F	F	F	—	—	—	—	—	—	—	—
Oridorsalis umbonatus (Reuss)	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Plectina garzaensis Cushman and Siegfus	C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pleurostomella alternans Schwager	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Praeglobobulimina pupoides (d'Orbigny)	F	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudonodosaria inflata (Bornemann)	R	—	—	—	—	—	—	F	F	—	—	—	F	F	—	—	—
Pullenia quinqueloba (Reuss)	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quinqueloculina minuta Beck	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rhabdammina eocenica Cushman and Hanna	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Reophax pilulifer H. B. Brady	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Spiroplectammina richardi Martin	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Uvigerina churchi Cushman and Siegfus	C	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vaginulinopsis saundersi (Hanna and Hanna)	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Anomalina cf. *A. umbonata* Cushman	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Boldia hodgei (Cushman and Schenck)	—	R	—	—	F	—	F	C	C	F	—	—	—	—	—	—	—
Bolivina gracilis Cushman and Applin	—	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bolivina kleinpelli Beck	—	R	F	—	—	—	—	F	F	—	—	—	—	F	—	—	—
Bolivina scabrata Cushman and Bermudez	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bulimina microcostata Cushman and Parker	—	F	C	—	—	—	—	—	—	—	—	—	—	—	—	—	—
?*Buliminella* sp.	—	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cassidulina diversa Cushman and Stone	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cassidulina spp.	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cibicides falconensis Renz	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fursenkoina californiensis (Cushman)	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fursenkoina dibollensis (Cushman and Applin)	—	C	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gyroidina condoni (Cushman and Schenck)	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lenticulina insuetus (Cushman and Stainforth)	—	F	—	—	—	F	—	—	—	—	—	—	—	—	—	—	—
Marginulina spp.	—	R	—	—	—	—	—	—	—	—	—	—	—	—	F	—	—
Plectofrondicularia spp.	—	R	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Praeglobobulimina cf. *P. ovata* (d'Orbigny)	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pseudoparrella cf. *P. danvillensis* (Howe and Wallace)	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Stainforthia sp.	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Stichocassidulina cf. *S. thalmani* Stone	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Stilostomella adolphina (d'Orbigny)	—	F	—	—	—	—	—	—	—	—	—	—	—	F	—	—	—
Stilostomella advena (Cushman and Laiming)	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Uvigerina elongata Cole	—	F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 12.—*Benthic foraminifers from the San Lorenzo River section of Brabb, Clark, and Throckmorton (1977, fig. 12)*—Continued

Benthonic foraminiferal stage	Narizian							Refugian					Early Zemorrian				
	Early		Late														
Taxon	Mf3304	Mf1350	Mf1351	Mf1352	Mf1355	Mf1356	Mf1357	Mf1360	Mf1361	Mf1362	Mf1364	Mf1365	Mf1366	Mf2700	Mf2701	Mf1367	Mf1368
Haplophragmoides deflata Sullivan	—	—	C	F	—	—	—	—	—	—	—	—	—	—	—	—	—
Haplophragmoides sp. 1	—	—	F	A	—	—	—	—	—	—	—	—	—	—	—	—	—
Bolivinoides mexicanus (Cole)	—	—	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fursenkoina bramletti (Galloway and Morrey)	—	—	F	—	—	—	—	—	—	—	—	—	—	A	R	—	—
Stilostomella sp.	—	—	F	—	—	—	—	—	—	—	—	—	—	F	R	—	—
Trifarina wilcoxensis (Cushman and Ponton)	—	—	R	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bulimina sculptilis lacinata Cushman and Parker	—	—	—	—	C	A	—	—	—	—	—	—	—	—	—	—	—
Lenticulina coaledensis (Detling)	—	—	—	—	F	F	A	—	—	—	—	—	—	—	—	—	—
Plectofrondicularia packardi Cushman and Schenck	—	—	—	—	F	R	F	C	C	F	C	—	—	—	—	—	—
Saracenaria cf. *S. hantkeni* Cushman	—	—	—	—	R	—	—	—	—	—	—	—	—	—	—	—	—
Uvigerina garzaensis Cushman and Siegfus	—	—	—	—	C	C	C	—	—	—	—	—	—	—	—	—	—
Valvulineria tumeyensis (Cushman and Simonson)	—	—	—	—	C	F	F	—	—	—	—	—	—	—	—	—	—
Globobulimina pacifica Cushman	—	—	—	—	—	R	—	F	—	—	—	—	—	—	—	—	—
Lenticulina welchi (Church)	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—	—	—
Orthomorphina rohri (Cushman and Stainforth)	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—	—	—
Planularia markleyana Church	—	—	—	—	—	R	R	—	—	—	—	—	—	—	—	—	—
Stilostomella lepidula (Schwager)	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—	—	—
Plectofrondicularia vaughani Cushman	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—	—
Spiroloculina texana Cushman and Ellisor	—	—	—	—	—	—	R	—	—	—	—	—	—	—	—	—	—
Cassidulina cf. *C. crassipunctata* Cushman and Hobson	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—
Cibicides elmaensis Rau	—	—	—	—	—	—	—	C	—	—	—	—	—	—	—	—	—
Cibicides haydoni (Cushman and Schenck)	—	—	—	—	—	—	—	C	F	F	—	—	—	—	—	—	—
Cyclammina pacifica Beck	—	—	—	—	—	—	—	F	F	F	—	—	—	A	—	—	—
Dentalina cocoaensis (Cushman)	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—
Dentalina jacksonensis (Cushman and Applin)	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—
Dentalina cf. *D. soluta* Reuss	—	—	—	—	—	—	—	R	—	—	—	—	—	—	—	—	—
Globocassidulina globosa (Hantken)	—	—	—	—	—	—	—	F	A	—	—	—	—	—	—	—	—
Guttulina frankei Cushman and Ozawa	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—
Guttulina irregularis (d'Orbigny)	—	—	—	—	—	—	—	F	F	F	—	—	—	—	—	—	—
Karreriella washingtonensis Rau	—	—	—	—	—	—	—	F	R	—	—	—	—	—	—	—	—
Lagena hexagona (Williamson)	—	—	—	—	—	—	—	R	F	—	—	—	—	—	—	—	—
Melonis sp.	—	—	—	—	—	—	—	R	—	—	—	—	—	—	—	—	—
Plectofrondicularia packardi multilineata Cushman and Simonson	—	—	—	—	—	—	—	F	F	—	—	—	—	F	—	—	—
Quinqueloculina imperialis Hanna and Hanna	—	—	—	—	—	—	—	R	—	—	—	—	—	—	F	—	—
Saracenaria schencki Cushman and Hobson	—	—	—	—	—	—	—	F	F	—	—	—	—	—	—	—	—
Spiroplectammina directa (Cushman and Siegfus)	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—
Uvigerina cocoaensis species group	—	—	—	—	—	—	—	A	—	—	F	F	—	—	—	—	—
Anomalina californiensis Cushman and Hobson		—	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—
Gyroidina soldanii d'Orbigny	—	—	—	—	—	—	—	R	—	—	—	—	—	—	F	—	—
Lenticulina cf. *L. pseudorotulata* (Asano)	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—	—
Marginulina adunca (Costa)	—	—	—	—	—	—	—	—	R	—	—	—	—	—	—	—	—
Trifarina hannai (Beck)	—	—	—	—	—	—	—	—	R	—	—	—	—	—	—	—	—
Lenticulina chehalisensis Rau	—	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—
Marginulina alazaensis Nuttall	—	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—
Nodosaria sp.	—	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—
Nonion halkyardi Cushman	—	—	—	—	—	—	—	—	F	—	—	—	—	—	—	—	—
Sigmomorphina schencki Rau	—	—	—	—	—	—	—	—	R	—	—	—	—	—	—	—	—
Cyclammina spp.	—	—	—	—	—	—	—	—	—	—	—	—	C	—	—	—	—
?*Eponides* sp.	—	—	—	—	—	—	—	—	—	—	—	—	F	—	—	—	—
Cassidulina crassipunctata Cushman and Hobson	—	—	—	—	—	—	—	—	—	—	—	—	—	F	—	—	—
Cassidulinoides californiensis Bramlette	—	—	—	—	—	—	—	—	—	—	—	—	—	A	C	—	—
Lagena costata (Williamson)	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—
Lagena cf. *L. costata* (Williamson)	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—
Lagena semistriata Williamson	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—
Lenticulina inornata (d'Orbigny)	—	—	—	—	—	—	—	—	—	—	—	—	—	A	A	F	C
Nonionella miocenica Cushman	—	—	—	—	—	—	—	—	—	—	—	—	—	F	—	—	—
Cibicides pseudoungerianus evolutus Cushman and Hobson	—	—	—	—	—	—	—	—	—	—	—	—	—	F	—	—	—
Bulimina inflata Seguenza	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—	—	—
Lagena becki Sullivan	—	—	—	—	—	—	—	—	—	—	—	—	—	F	—	—	—
Lagena vulgaris Williamson	—	—	—	—	—	—	—	—	—	—	—	—	—	F	—	—	—
Marginulina exima Neugeboren	—	—	—	—	—	—	—	—	—	—	—	—	—	F	—	—	—
Bolivina marginata Cushman	—	—	—	—	—	—	—	—	—	—	—	—	—	—	R	—	—
Praeglobobulimina ovata d'Orbigny)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	F	—
Uvigerina auberiana d'Orbigny	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	F

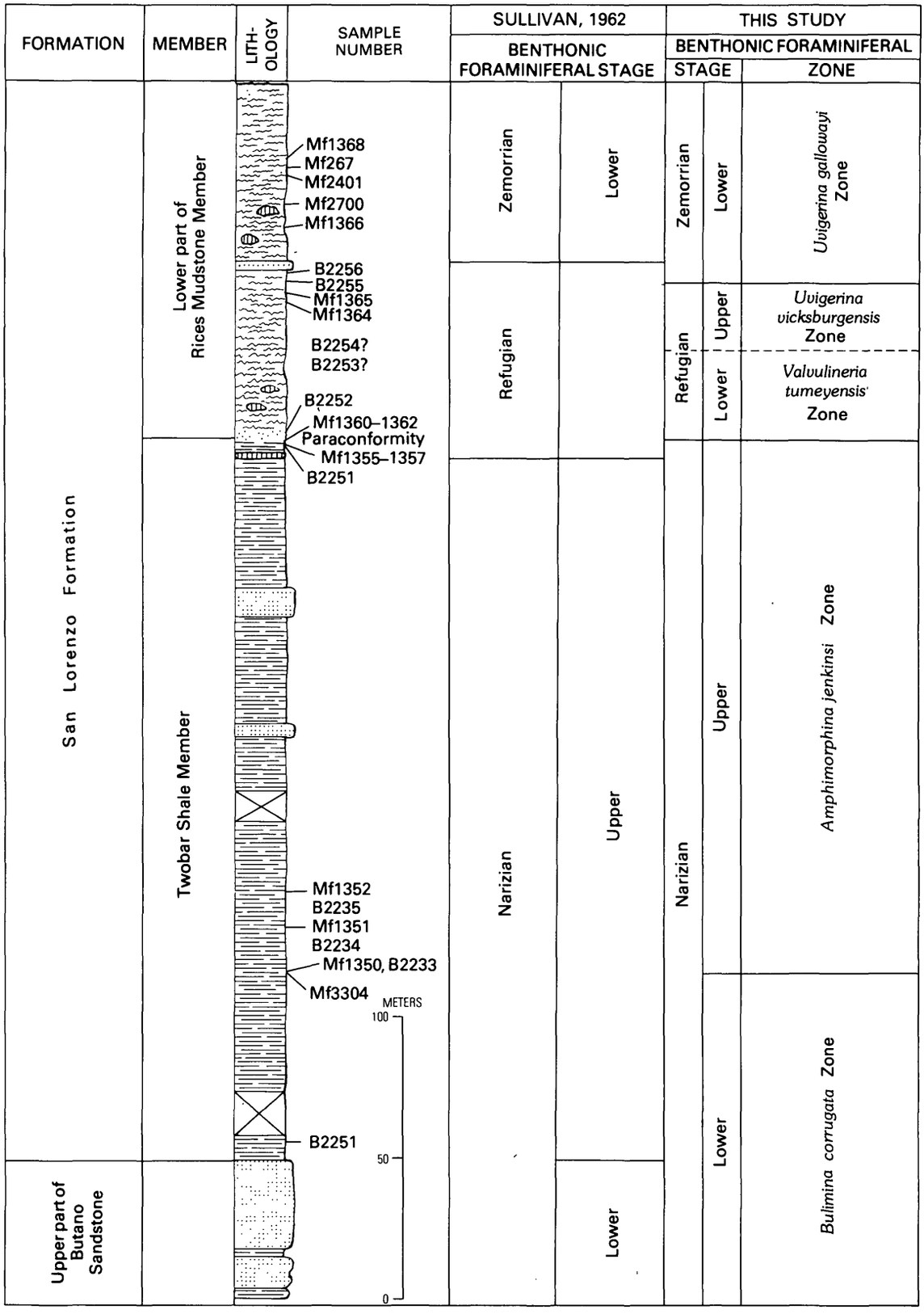


FIGURE 29.—Age interpretations of San Lorenzo River Section as determined by Sullivan (1962) and this study. Mf localities are from U.S. Geological Survey microfossil locality register, Menlo Park, Calif., and B localities are from University of California, Berkeley, fossil locality register. Stratigraphic column from Poore and Brabb (1977, fig. 2).

TABLE 13.—*Key to field numbers and sample numbers*

[Field numbers with the prefix 76CB and EB were collected by E. E. Brabb. Numbers preceded by JC were collected by J. C. Clark]

Sample number	Field number	Section	Sample number	Field number	Section
Mf1350	75CB1352	San Lorenzo River	MF2192	JC-68-3	Año Nuevo
Mf1351	76CB1353	Do	Mf2193	JC-68-2	Do
Mf1352	76CB1354	Do	Mf2194	JC-63-4	Do
Mf1355	EB256G	Do	Mf2195	JC-68-1	Do
Mf1356	EB256B	Do	Mf2700	EB395D	San Lorenzo River
Mf1356	EB256K	Do	Mf2701	EB675	Do
Mf1360	EB256A	Do	Mf3304	76CB1451	Do
Mf1361	EB236D	Do	Mf4531	JC-67-5	Año Nuevo
Mf1362	EB256L	Do	Mf4661	76CB1541	Do
Mf1364	EB256N	Do	Mf4664	76CB1531	Do
Mf1365	EB256P	Do	Mf4665	76CB1532	Do
Mf1367	EB676	Do	Mf4667	76CB1521A	Do
Mf1368	EB677	Do	Mf4668	76CB1541B	Do
Mf1374	JC-69-1	Año Nuevo	Mf4671	76CB1562	Zayante Creek
Mf1375	JC-69-2	Do	Mf4677	76CB1592	Do
Mf2188	JC-69-4	Do	Mf4679	76CB1593	Do
Mf2189	JC-69-6	Do	Mf4681	76CB1601	Do
Mf2190	JC-68-4	Do	Mf4682	76CB1602	Do
Mf2191	MC-68-4	Do	Mf4683	76CB1603	Do

The oldest of the samples examined, Mf3304 (fig. 29), is from the lower part of the Twobar Shale Member of the San Lorenzo Formation. This sample was taken from just below sample B2233 (University of California, Berkeley number). Sullivan (1962) considered all the samples in the lower part of the San Lorenzo Formation to be of late Narizian age and diagnostic of the *Amphimorphina jenkinsi* Zone (fig. 29). Sample Mf3304 contains a more diverse and abundant microfauna than that recovered by Sullivan (1962) and suggests instead an early Narizian age. This sample includes species such as *Dorothia cubana* and *Lenticulina midwayensis* (fig. 30), which are usually considered to be diagnostic of the Ulatis-

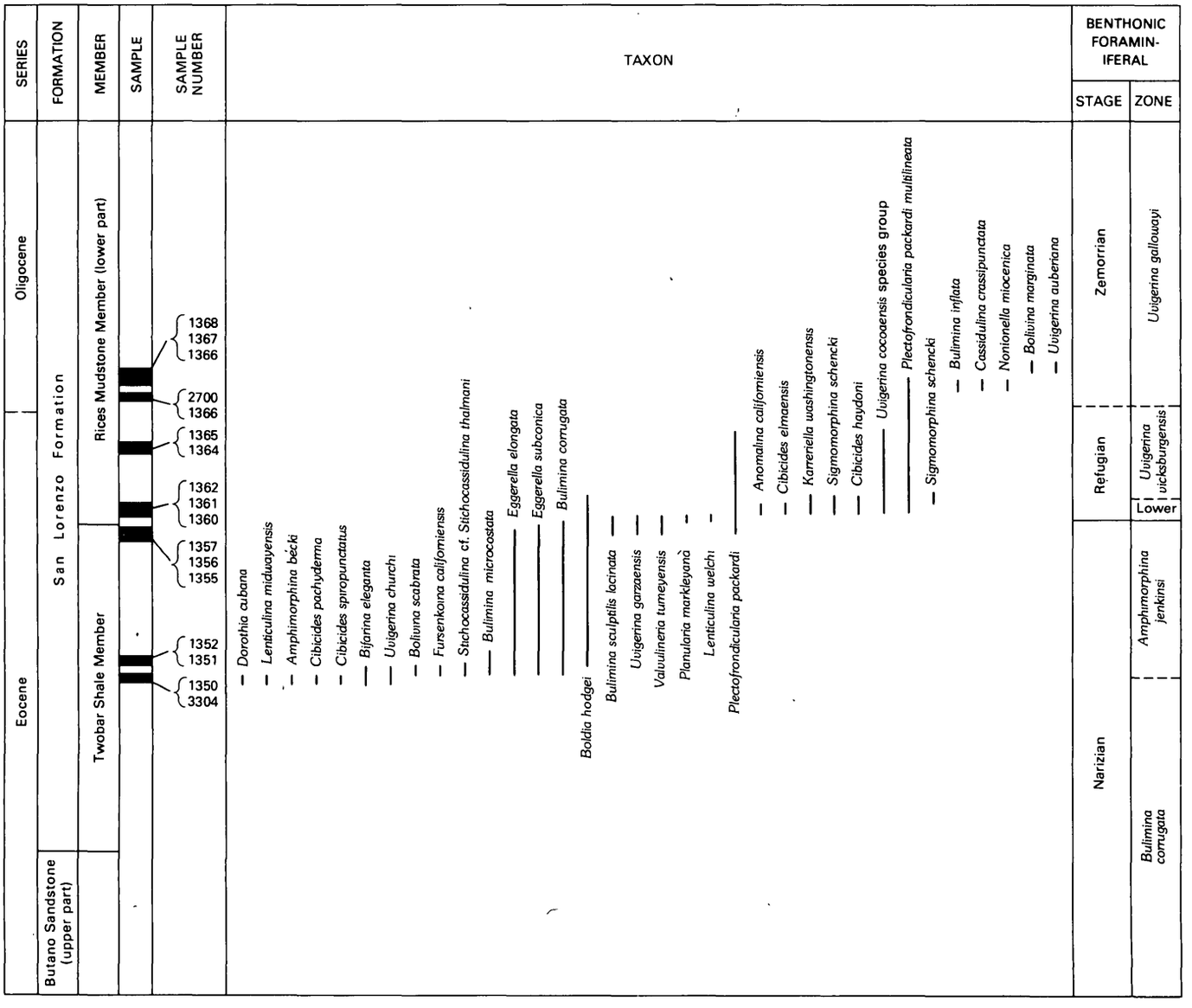


FIGURE 30.—Stratigraphic distribution of selected benthic foraminiferal species diagnostic of Narizian through lower Zemorrian Stages in San Lorenzo River section.

ian Stage. Species restricted to the lower Narizian, or which last occur in the lower Narizian *Bulimina corrugata* Zone include *Amphimorphina becki, Anomalina garzaensis, Bulimina curtissima, Cibicides pachyderma, C. spiropunctata, Ellipsonodosaria atlantisae hispidula, Karreriella elongata, Lenticulina pseudovortex,* and *Pleurostomella alternans* (fig. 30). The sample also contains many longer ranging species typical of the Narizian and the early Tertiary. There are no species definitive of or restricted to the late Narizian. The upper Narizian Stage assignment by Sullivan (1962) was based on the presence of several specimens he identified as *Amphimorphina jenkinsi* from sample B2231, which is from just above the contact between the Butano Sandstone and the San Lorenzo Formation. The specimen of *Amphimorphina jenkinsi* illustrated by Sullivan (1962, pl. 14, fig. 15) indicates that his identification is tenuous at best. Several specimens from near the top of the Butano Sandstone are identified as *Amphimorphina becki* by me from unpublished benthic foraminiferal data from sample Mf3301. These specimens represent a transitional form between *A. becki* and *A. jenkinsi*, with the peripheral ridges gone and only the basal costae remaining. This may be the form Sullivan (1962) and Schenck (1936) identify as *A. jenkinsi*; however, it is not *Amphimorphina jenkinsi.*

Less than one-third of the species from Mf3304 are also in the overlying sample Mf1350 (fig. 30). All of the species common to both samples are long-ranging species, except *Bifarina elegans* and *Uvigerina churchi*, which are rare in the upper Narizian. In this section both last occur in Mf1350 (fig. 30). The new benthic foraminiferal data indicate that the lower Narizian *Bulimina corrugata* Zone should be extended into the lower part of the Twobar Shale Member of San Lorenzo Formation (fig. 29). The data are insufficient to identify the subzone represented by this assemblage. The lower Narizian-upper Narizian boundary is between samples Mf3304 and Mf1350. Thus, in the San Lorenzo River section, Mf3304 is the stratigraphically highest sample in the lower Narizian *Bulimina corrugata* Zone and Mf1350 is the stratigraphically lowest sample in the upper Narizian *Amphimorphina jenkinsi* Zone.

The next group of samples, Mf1350 through Mf1357 (fig. 30), represents the upper Narizian *Amphimorphina jenkinsi* Zone. Present in these samples are numerous species that are restricted to or last occur in the upper Narizian such as *Bolivina scabrata, Bulimina corrugata, Bulimina microcostata, Eggerella elongata, Lenticulina welchi, Planularia markleyana, Stichocassidulina* cf. *S. thalmani,* and *Uvigerina garzaensis*. Also present are species which first appear in the upper Narizian, such as *Boldia hodgei, Bulimina sculptilis lacinata, Plectofrondicularia packardi,* and *Valvulineria tumeyensis*. The late Narizian age for this interval is in agreement with Sullivan (1962).

Overlying Mf1357 is a glauconite bed that marks the base of the Rices Mudstone Member of the San Lorenzo Formation. The contact between the Twobar Shale and Rices Mudstone Members is believed to represent a paraconformity (Poore and Brabb, 1977). Benthic foraminiferal assemblages from the samples, Mf1360–Mf1362, above the glauconite are diagnostic of the lower Refugian. There is an abrupt change in the fauna, and species that continue from the older samples are long-ranging or those whose most common occurrence is in the Refugian, such as *Boldia hodgei* and *Plectofrondicularia packardi.* Species diagnostic of the Refugian Stage that first appear in these samples include *Anomalina californiensis, Cibicides elmaensis, Karreriella washingtonensis, Saracenaria schencki, Sigmomorphina schencki, Plectofrondicularia packardi multilineata*, and the *Uvigerina cocoaensis* species group (fig. 30). This association of species suggests an early Refugian age (fig. 29); however, the lower Refugian *Cibicides haydoni* Subzone of Donnelly (1976) or the "basal" Refugian faunas of McDougall (1975) appear to be partly or completely missing.

The benthic faunas from the Refugian type section are from only a limited bathymetric facies and are therefore not expected to be characteristic of all Refugian faunas. Schenck and Kleinpell (1936) in the original definition recognized the possibility of problems with paleoecologic facies and designated the fauna of the Lincoln Creek Formation (Lincoln Formation of Weaver, 1912) of Washington as representing a deeper water facies of the Refugian Stage. A similar fauna occurs in the San Lorenzo River section. In the deeper water facies of the Lincoln Creek Formation, *Cibicides elmaensis* and *Uvigerina cocoaensis* occur in the lower Refugian (Rau, 1958, 1966; Donnelly, 1976). The first occurrence of *Uvigerina cocoaensis* in the lower Refugian coincides with the worldwide first occurrence of the species (Lamb, 1964; Boersma, 1974). This first occurrence of *Uvigerina cocoaensis* can only be observed along the west coast of North America where the appropriate bathymetric facies is present. The first occurrence of *Uvigerina cocoaensis* in West Coast sections often records the first occurrence of appropriate bathymetric conditions and not the evolutionary first occurrence of the species. Also diagnostic of the lower Refugian in Washington and Oregon (Rau, 1958, 1966) are the species *Karreriella washingtonensis, Sigmomorphina schencki, Saracen-*

aria schencki, and *Cibicides haydoni*. The latter species also typifies the lower Refugian *Valvulineria tumeyensis* Zone of California (Donnelly, 1976).

The Refugian faunas also occur in samples Mf1364-Mf1365. Assignment to the upper Refugian *Uvigerina vicksburgensis* Zone is suggested but is not well documented. Diagnostic early Refugian species are not recognized in these samples, but many specimens cannot be identified. Sullivan (1962)reported Refugian faunas throughout samples B2252 to B2254. In B2253 to B2256, specimens that were identified by Sullivan (1962) as *Uvigerina gallowayi* are closer to *Uvigerina jacksonensis* and should be considered part of the *Uvigerina cocoaensis* species group, not *Uvigerina gallowayi*. This is the only new species in these samples, and it is not a good indicator of the upper Refugian Stage.

Placement of the lower and upper boundaries of the Refugian Stage and the species identifications of this report differ from those proposed by Sullivan (1962). Although sample B2251 was placed in the Refugian, it contains only species diagnostic of the Narizian *Amphimorphina jenkinsi* Zone, such as *Eggerella elongata, Bulimina microcostata, Planularia tolmani, Lenticulina welchi (Robulus chiranus* of Sullivan, 1962), and *Uvigerina garzaensis nudorobusta*. This sample should be considered Narizian. Only the last species is known to extend into the lower Refugian, and its presence in B2252 is questionable. The bathymetric conditions of B2251 and B2252 are different, and as the glauconite appears to represent a form of unconformity, the presence of the rare *Uvigerina garzaensis nudorobusta* is probably due to reworking. The placement of the boundary at the base of the glauconite, that is, above the highest sample in the Twobar Shale Member and below the lowest sample in the Rices Mudstone Member, coincides with the unconformity, the abrupt faunal change, and the occurrence of diagnostic Refugian species. The abrupt faunal change was also noted by Sullivan (1962) between samples B2251 and B2252.

The Refugian-Zemorrian boundary is placed above sample Mf1365 and below B2255 of Sullivan (1962). Sample Mf1365, which is below B2255, contains a faunal assemblage diagnostic of the Refugian Stage. There are few species in sample B2255 and in the overlying sample, B2256. *Plectofrondicularia packardi* and *P. p. multilineata* are present, but the upper limit of these species is not clearly defined. *Uvigerina jacksonensis (Uvigerina gallowayi* of Sullivan, 1962) ranges from late Eocene through the early Oligocene (Lamb, 1964; Boersma, 1974). Also, *Bolivina marginata* occurs in both these samples, and the first occurrence of this species is in the early Zemorrian (Kleinpell, 1938). The placement of the Refugian-Zemorrian boundary (fig. 28) between Mf1365 and B2255 is compatible with the data.

The Zemorrian Stage is very poorly developed in the samples examined for this study. There is a gradual faunal change in samples Mf1366 through Mf1368, the result of the improved preservation of the faunas and the development of the Zemorrian fauna.

TABLE 14.—*Benthic foraminifers from the Zayante Creek section of Brabb, Clark, and Throckmorton (1977, fig. 22)*

Benthic foraminiferal stages	Zemorrian			Saucesian(?)		
	Early		Late			
	Sample					
Taxon	Mf4683	Mf4682	Mf4681	Mf4679	Mf4677	Mf4671
Bolivina marginata Cushman	C	F	A	—	—	—
Cibicides pseudoungerianus evolutus Cushman and Hobson	F	C	C	—	—	—
Fursenkoina cf. *F. bramletti* (Galloway and Morrey)	F	F	—	—	—	—
Gyroidina orbicularis planata Cushman	C	F	A	—	F	F
Haplophragmoides sp.	F	R	—	—	—	—
Lenticulina simplex (d'Orbigny)	?	—	—	C	C	?
Lenticulina spp.	A	—	—	—	—	F
Nodosaria holserica Schwager	F	F	—	—	—	—
Oridorsalis umbonatus (Reuss)	F	R	—	—	—	—
Plectofrondicularia miocenica Cushman	F	—	—	—	—	—
Plectofrondicularia packardi multilineata Cushman and Simonson	F	—	—	—	—	—
Plectofrondicularia vaughani Cushman	F	—	F	—	—	—
Pullenia salisburyi Stewart and Stewart	F	F	—	—	—	—
Textularia shivelyi Kleinpell	F	F	—	—	—	—
Textularia sp. of Fairchild and others	F	—	—	—	—	—
Uvigerinella sparsicostata Cushman and Laiming	A	—	—	C	—	—
Verneuilina sp. of Fairchild and others	A	C	F	—	—	—
Ammodiscus incertus d'Orbigny	—	R	—	—	—	—
Anomalina californiensis Cushman and Hobson	—	C	F	F	—	—
Bathysiphon eocenica Cushman and Hanna	—	A	—	F	—	—
Buliminella curta Cushman	—	R	—	—	—	—
Cassidulina crassipunctata Cushman and Hobson	—	A	—	—	—	—
Cyclammina incisa (Stache)	—	A	—	C	A	—
Cyclammina sp.	—	F	A	—	—	—
?Dentalina quadrulata Cushman and Laiming	—	F	—	—	—	—
Dentalina sp.	—	F	—	—	—	—
Fissurina sp.	—	F	R	—	—	—
Frondicularia tenuissima Hantken	—	F	—	—	—	—
Gaudryina gracilis Cushman and Laiming	—	F	—	—	—	—
Gaudryina triangularis Cushman	—	F	R	—	—	—
Globobulimina pacifica Cushman	—	C	—	R	F	—
?Karreriella sp.	—	F	—	C	—	—
Lagena sulcata (Walker and Jacob)	—	F	F	—	—	—
Lenticulina calcar (Linne)	—	F	—	—	—	—
Lenticulina cf. *L. clypeiformis* (d'Orbigny)	—	C	—	—	—	—
Lenticulina inornata (d'Orbigny)	—	C	A	—	F	—
Lenticulina mayi (Cushman and Parker)	—	F	—	—	—	—
Lenticulina spp.	—	A	—	—	—	—
Marginulina alazaensis Nuttall	—	F	—	—	—	—
Marginulina dubia Neugeboren	—	F	—	—	—	—
Marginulina subbullata Hantken	—	F	—	—	—	—
Nodosaria longiscata d'Orbigny	—	F	—	—	—	—
Nonionella cf. *N. miocenica* Cushman	—	F	—	—	—	—
Pseudonodosaria gallowayi (Cushman)	—	F	—	—	—	—
Pseudonodosaria inflata (Bornemann)	—	F	A	—	—	F
Reophax pilulifer H. B. Brady	—	A	—	A	—	—
Saracenaria cf. *S. schencki* Cushman and Hobson	—	F	—	—	—	—
Siphogenerina nodifera Cushman and Kleinpell	—	F	—	A	A	A
Stilostomella advena (Cushman and Laiming)	—	R	—	—	—	—
Uvigerina auberiana d'Orbigny	—	C	—	—	—	—
Uvigerina gallowayi Cushman	—	F	—	—	—	—
Buliminella subfusiformis Cushman	—	—	F	—	A	—
Stilostomella sp.	—	—	F	—	—	—
Cibicides floridanus (Cushman)	—	—	—	F	—	—
Globocassidulina elobosa (Hantken)	—	—	—	R	—	—
Melonis pompilioides (Fichtel and Moll)	—	—	—	R	—	—
Nodosaria parexilis Cushman and Stewart	—	—	—	R	—	—
Sphaeroidina bulloides d'Orbigny	—	—	—	C	—	—
Spiroplectammina sp.	—	—	—	F	—	—
Cibicides sp.	—	—	—	—	R	R
Cyclammina spp.	—	—	—	—	F	R
?Globobulimina pacifica Cushman	—	—	—	—	F	—
Gyroidina sp.	—	—	—	—	R	—
Marginulina sp.	—	—	—	—	F	—
Marginulina subrecta Franke	—	—	—	—	R	—
Martinottiella patens (Cushman and Laiming)	—	—	—	—	F	—
Orthomorphina rohri (Cushman and Stainforth)	—	—	—	—	F	—
Stilostomella lepidula (Schwager)	—	—	—	—	A	—
Nonionella costifera (Cushman)	—	—	—	—	—	F

Species diagnostic of the Zemorrian Stage include *Bolivina marginata, Bulimina inflata, Nonionella miocenica*, and *Uvigerina auberiana* (fig. 30). Also present are several species that first occur in the late Refugian but continue into the Zemorrian, including *Cassidulinoides californiensis* and *Cassidulina crassipunctata*. Much better data are obtained by Sullivan (1962) because the U. C. Berkeley samples stratigraphically higher than Mf1368 contain abundant diagnostic Zemorrian species.

Based on the data discussed above, the San Lorenzo River section contains faunas assignable to the early and late Narizian, part of the early Refugian, the late Refugian, and the early Zemorrian.

ZAYANTE CREEK SECTION

The Zayante Creek section is north of the town of Santa Cruz in the Santa Cruz Mountains (fig. 27). Only assemblages (table 14) from the north limb of the San Lorenzo syncline along the upper part of Zayante Creek were used. Samples are from the Vaqueros Sandstone and Lambert Shale. Detailed sample locality, sedimentologic, and structural descriptions are given by Brabb, Clark, and Throckmorton (1977). See table 13 for field numbers and corresponding microfossil locality (Mf) numbers used in this report.

The lowest sample examined in this section, Mf4683 (fig. 31), contains a fauna indicative of the lower Zemorrian *Uvigerina gallowayi* Zone. Diagnostic species include *Bolivina marginata, Nodosaria holserica*, and *Textularia shivelyi*. The next stratigraphically higher sample, Mf4682, is more diverse and has a better developed early Zemorrian fauna. Included in this sample are species continuing from the Refugian *(Anomalina californiensis* and *Cassidulina crassipunctata*), as well as the early Zemorrian species from the underlying sample. Additionally this sample contains species restricted to the early Zemorrian *(Pseudonodosaria gallowayi* and *Uvigerina gallowayi*) and species which first occur in the early Zemorrian *(Gaudryina gracilis* and *Siphogenerina nodifera*). The presence of *Uvigerinella sparsicostata* in Mf4683 indicates the close proximity of the early Zemorrian-late Zemorrian boundary.

Faunas diagnostic of the Zemorrian Stage (fig. 31, samples Mf4681 to Mf4671) continue throughout the remainder of the section. Species diagnostic of the early Zemorrian do not appear above Mf4682, there-

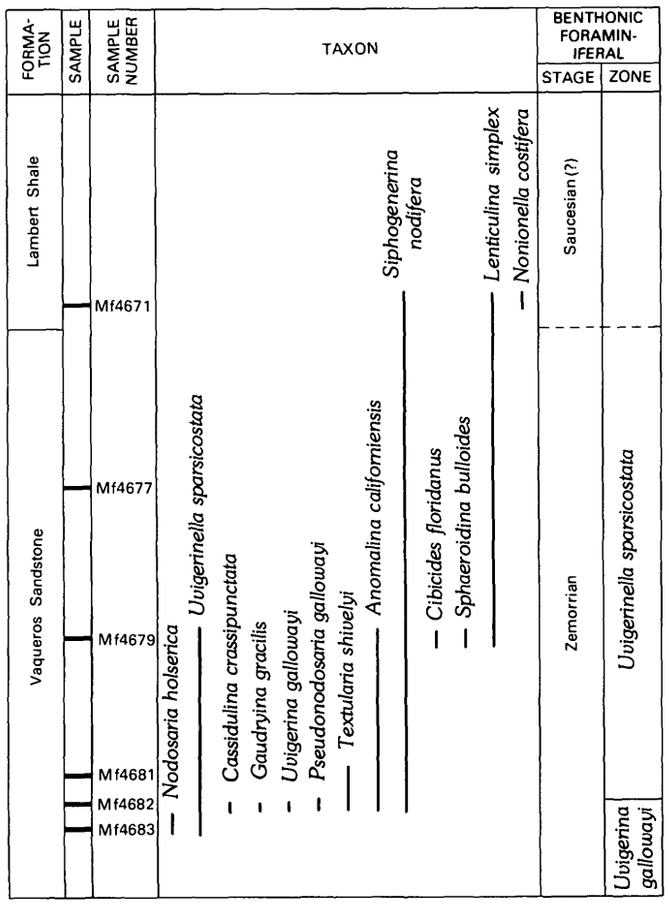


FIGURE 31.—Stratigraphic distribution of selected diagnostic benthic foraminifers in Zayante Creek section representing Zemorrian and Saucesian(?) Stages.

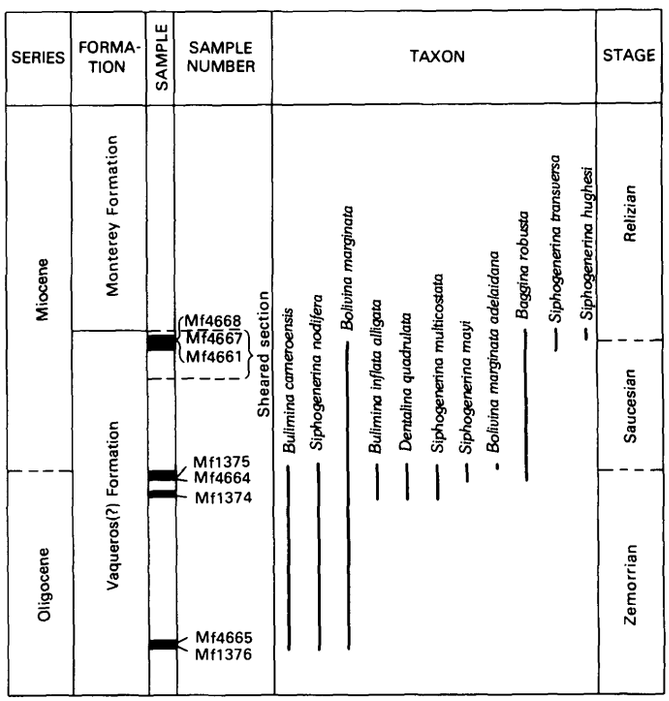


FIGURE 32.—Stratigraphic distribution of selected benthic foraminifers diagnostic of Zemorrian through Relizian Stages in the Año Nuevo section of Brabb, Clark, and Throckmorton (1977, fig. 31).

TABLE 15.—*Benthic foraminifers from the Año Nuevo section*

Benthonic foraminiferal stages	Late Zemorrian			Sauce-sian			Relizian	
	Sample							
Taxon	Mf4665	Mf1376	Mf1374	Mf4664	Mf1375	Mf4661	Mf4667	Mf4668
Anomalina californiensis Cushman and Hobson	A	F	—	F	—	—	—	—
Astacolus sp.	F	—	—	F	—	R	—	—
Bulimina carneroensis Cushman and Kleinpell	F	F	—	F	—	—	—	—
Bolivina marginata Cushman	F	F	—	C	F	—	—	—
Cassidulina crassipunctata Cushman and Hobson	A	F	F	—	F	—	—	—
Cassidulina margareta Karrer	F	F	—	A	F	—	—	F
Cibicides americanus (Cushman)	R	—	F	—	—	—	—	—
Cibicides cf. *C. americanus* (Cushman)	R	—	—	—	—	—	—	—
Cibicides floridanus (Cushman)	C	F	—	C	F	—	—	F
Cibicides pseudoungerianus evolutus Cushman and Hobson	A	—	F	—	F	—	—	—
Cyclammina cancellata Brady	F	—	—	F	—	—	—	—
Dentalina cooperensis Cushman	F	—	—	F	R	—	—	—
Fursenkoina bramletti (Galloway and Morrey)	R	—	—	F	—	F	—	—
Glandulina laevigata d'Orbigny	F	—	—	—	—	—	—	—
Globobulimina pacifica Cushman	R	—	—	F	F	—	—	—
Gyoidina orbicularis planata Cushman	R	F	—	—	F	—	—	—
Gyroidina soldanii d'Orbigny	A	R	F	F	—	—	—	—
Lagena costata (Williamson)	F	—	—	—	—	—	—	—
Lagena semistriata Williamson	R	—	—	—	—	—	—	—
Lenticulina barbati Cushman	F	—	R	F	—	—	—	—
Lenticulina calcar (Linne)	F	—	—	—	—	—	—	—
Lenticulina cf. *L. calcar* (Linne)	F	—	R	F	—	—	—	—
Lenticulina cf. *L. clypeiformis* (d'Orbigny)	F	—	—	F	F	—	—	—
Lenticulina coloratus (Stache)	R	—	—	—	—	—	—	—
Lenticulina pseudorotulata (Asano)	R	—	—	F	—	—	—	—
Lenticulina sp. of Fairchild and others	F	—	—	C	F	—	—	—
Lenticulina spp.	F	—	—	R	—	—	F	F
Marginulina spp.	F	—	F	R	—	—	—	—
Martinottiella patens (Cushman and Laiming)	F	—	—	F	F	—	—	—
Nodosaria parexilis Cushman and Stewart	F	—	—	C	F	—	—	—
Nodosaria parexilis sentifera Cushman and Parker	F	—	—	—	—	—	—	—
Nonionella incisa kernensis Kleinpell	F	—	—	—	—	—	—	—
Nonionella miocenica Cushman	F	—	—	F	—	—	—	—
Orthomorphina rohri (Cushman and Stainforth)	F	—	—	F	—	—	—	—
Plectofrondicularia miocenica directa Cushman and Laiming	C	—	F	F	F	—	—	—
Plectofrondicularia vaughani Cushman	F	—	—	F	F	—	—	—
Pseudonodosaria inflata (Costa)	F	—	—	F	F	—	—	—
Reophax pilulifera Brady	F	—	—	—	—	—	—	—
Reophax spp.	F	—	—	F	—	—	—	—
Siphogenerina nodifera Cushman and Kleinpell	A	C	—	A	F	—	—	—
Stilostomella advena (Cushman and Laiming)	C	—	—	—	—	—	—	—
?*Uvigerina gallowayi* Cushman	F	—	—	F	—	—	—	—
?*Uvigerina* sp.	R	—	—	—	—	—	—	—
Verneuilina sp. of Fairchild and others	R	R	—	F	F	—	—	—
Haplophragmoides sp.	R	—	—	—	—	—	—	—
Cibicides americanus crassiseptus Cushman and Laiming	F	—	F	—	F	—	—	—
Bathysiphon spp.	—	R	F	F	—	—	—	—
Stilostomella sanctaecrucis Kleinpell	—	F	—	—	F	—	—	—
Trochammina spp.	—	F	—	R	F	—	—	—
Ammodiscus cf. *A. incertus* d'Orbigny	—	—	F	—	—	—	—	—
Bolivina spp.	—	—	F	F	—	F	F	—
Bulimina inflata alligata Cushman and Laiming	—	—	F	F	F	—	—	—
Buliminella curta Cushman	—	—	F	—	—	F	—	—
Cyclammina spp.	—	—	F	—	F	—	—	—
Dentalina quadrulata Cushman and Laiming	—	—	F	F	—	—	—	—
Lenticulina sp. A	—	—	R	F	—	—	—	—
Melonis pompilioides (Fichtel and Moll)	—	—	R	—	F	—	—	—
Nodosaria longiscata d'Orbigny	—	—	F	F	F	—	—	—
Nodosaria pyrula d'Orbigny	—	—	F	—	F	—	—	—
Oridorsalis umbonatus (Reuss)	—	—	F	—	F	—	—	—
Plectofrondicularia californica Cushman and Stewart	—	—	F	—	F	—	—	—
Pullenia multilobata Chapman	—	—	R	F	—	—	—	—
Siphogenerina multicostata Cushman and Jarvis	—	—	C	R	—	—	—	—
Stilostomella sp.	—	—	F	—	—	—	—	—
Sphaeroidina bulloides d'Orbigny	—	—	F	C	F	—	—	—
Uvigerina auberiana d'Orbigny	—	—	F	C	F	A	—	F
Baggina robusta Kleinpell	—	—	—	F	—	A	—	F
Bolivina marginata adelaidana Cushman and Kleinpell	—	—	—	F	—	—	—	—
[illegible]	—	—	—	R	—	—	—	—
[illegible]	—	—	—	R	—	—	—	—
[illegible]	—	—	—	F	—	—	—	—
Gaudryina gracilis Cushman and Laiming	—	—	—	F	—	—	—	—
Lagena acuticosta (Reuss)	—	—	—	F	—	—	—	—
Lagena hexagona (Williamson)	—	—	—	F	—	—	—	—
Lagena vulgaris Williamson	—	—	—	F	—	—	—	—
Lenticulina pseudocultratus (Cole)	—	—	—	F	—	—	—	—
Lenticulina pseudovortex (Cole)	—	—	R	—	—	—	—	
[illegible]	—	—	F	—	—	—	—	
[illegible]	—	—	—	F	—	—	—	—
[illegible] d'Orbigny	—	—	—	R	F	C	—	—
[illegible]	—	—	—	F	—	F	—	—
Saracenaria cf. *S. schencki* Cushman and Hobson	—	—	—	F	R	—	—	—
Siphogenerina mayi Cushman and Parker	—	—	F	F	—	—	—	—
Stilostomella adolphina (d'Orbigny)	—	—	—	C	F	—	—	—
[illegible]	—	—	—	F	—	—	—	—
[illegible]	—	—	—	F	—	—	—	—
[illegible]	—	—	—	F	—	—	—	—

TABLE 15.—Continued

Benthonic foraminiferal stages	Late Zemorrian			Sauce-sian			Relizian	
	Sample							
Taxon	Mf4665	Mf1376	Mf1374	Mf4664	Mf1375	Mf4661	Mf4667	Mf4668
[illegible]	—	—	—	—	R	—	—	R
[illegible]	—	—	—	—	?	—	—	—
[illegible]	—	—	—	—	—	F	—	R
Bolivina advena Cushman	—	—	—	—	—	R	—	—
Bulimina spp.	—	—	—	—	—	R	—	—
Chilostomella sp.	—	—	—	—	—	F	—	—
Pseudonodosaria gallowayi (Cushman)	—	—	—	—	—	F	—	—
Siphogenerina transversa Cushman	—	—	—	—	—	A	—	A
Cassidulina sp.	—	—	—	—	—	—	F	—
Epistominella spp.	—	—	—	—	—	—	F	—
Gyroidina sp.	—	—	—	—	—	—	R	—
Siphogenerina hughesi Cushman	—	—	—	—	—	—	—	F
Elphidium sp.	—	—	—	—	—	—	—	?
Nodosaria sp.	—	—	—	—	—	—	—	F
Nonionella costifera (Cushman)	—	—	—	—	—	—	—	F
Valvulineria californica variations	—	—	—	—	—	—	—	C

fore the early Zemorrian-late Zemorrian boundary is placed between Mf4682 and Mf4681. The late Zemorrian assemblages are dominated by *Siphogenerina nodifera, Uvigerinella sparsicostata*, and several agglutinated species as well as a number of species which first appear in the Zemorrian, including *Lenticulina simplex, Buliminella subfusiformis, Sphaeroidina bulloides*, and *Cibicides floridanus.*

The last sample, Mf4671, is from the Lambert Shale. Few of the species from the underlying samples occur but *Nonionella costifera* is present. The first occurrence of *Nonionella costifera* and several other species was considered by Kleinpell (1938) to mark the base of the Saucesian Stage. As none of the other species occur in Mf4671, it is only questionably assigned to the Saucesian Stage.

AÑO NUEVO SECTION

The Año Nuevo section is compiled from strata exposed in the sea cliffs north and east of Año Nuevo Point (fig. 27). Samples Mf1374-M1376 (north of Año Nuevo Point) were previously reported on by Clark *(in* Brabb and others, 1977). Both the Vaqueros(?) and Monterey Formations were sampled; however, only assemblages from the Vaqueros(?) Formation are discussed here (table 15). Localities and sedimentological and structural relations are described in Brabb, Clark, and Throckmorton (1977). See table 13 for field numbers and corresponding Mf numbers used in this report.

The lowest samples in this section, Mf4665 and Mf1376 (fig. 32), are representative of the upper Zemorrian *Uvigerinella sparsicostata* Zone. *Bolivina marginata* and *Siphogenerina nodifera* are still present, but *Uvigerinella sparsicostata* is not. Species diagnostic of the late Zemorrian include *Bulimina carneroensis, Cassidulina margareta, Nonionella incisa*

kernensis, Siphogenerina mayi, and *Siphogenerina multicostata*. These species are present in Mf4664, stratigraphically higher in the section but in association with species diagnostic of the Saucesian Stage such as *Baggina robusta, Bolivina marginata adelaidana, Bulimina inflata alligata*, and *Dentalina quadrulata.*

Kleinpell (1938) indicated that *Siphogenerina mayi*, though diagnostic of the late Zemorrian, could be found in the early Saucesian. He subsequently recognized a similar range for *Siphogenerina multicostata* (Boris Laiming, oral commun., 1972). The fauna represented in Mf4664 is similar to the assemblages of the San Joaquin Valley (Tipton and others, 1973), where the bathymetric conditions remain unchanged across the Zemorrian-Saucesian boundary. The result is a gradual change in the fauna and a mixing of the Zemorrian and Saucesian species. The boundary is placed at sample Mf4664 with the full realization that the precise location cannot be defined as it is not known when the mixing of faunas occurred. The slight range extension of *Bulimina carneroensis* and *Siphogenerina multicostata* should be noted. Sample Mf1374 is probably also in this zone, but the faunas are less diverse.

Assemblages diagnostic of the Saucesian Stage occur in the sheared section in the upper part of the Vaqueros(?) Formation. Samples Mf4661 and Mf2188-Mf2191 of Clark *(in* Brabb and others, 1977), from this interval, are poorly preserved. Diagnostic species present include many of the Saucesian species discussed earlier and *Siphogenerina transversa*. This species ranges from the Zemorrian and Saucesian into Miocene faunas but is most characteristic of the Saucesian.

Samples Mf4667 and Mf4668, also from the sheared section but higher than Mf4661, contain only siliceous molds of foraminifers. Many of these can be identified to species. Present in this sample are *Siphogenerina hughesi* and *Valvulineria californica*, which are diagnostic of the Relizian Stage. Since the section is sheared and the faunas are only represented by siliceous molds, interpretations in this interval are highly speculative.

SUMMARY

Correlation of faunal assemblages in the three sections yields a nearly continuous sequence from the lower Narizian Stage to the Relizian Stage (fig. 33). Stage boundaries are recognized by distinctive benthic foraminiferal assemblages associated with the base of each new stage (fig. 34) or by the gradual change in the faunas. Zonal and subzonal boundaries are less easily recognized because faunal changes are subtle and more frequently recognized by changes in the dominance of species.

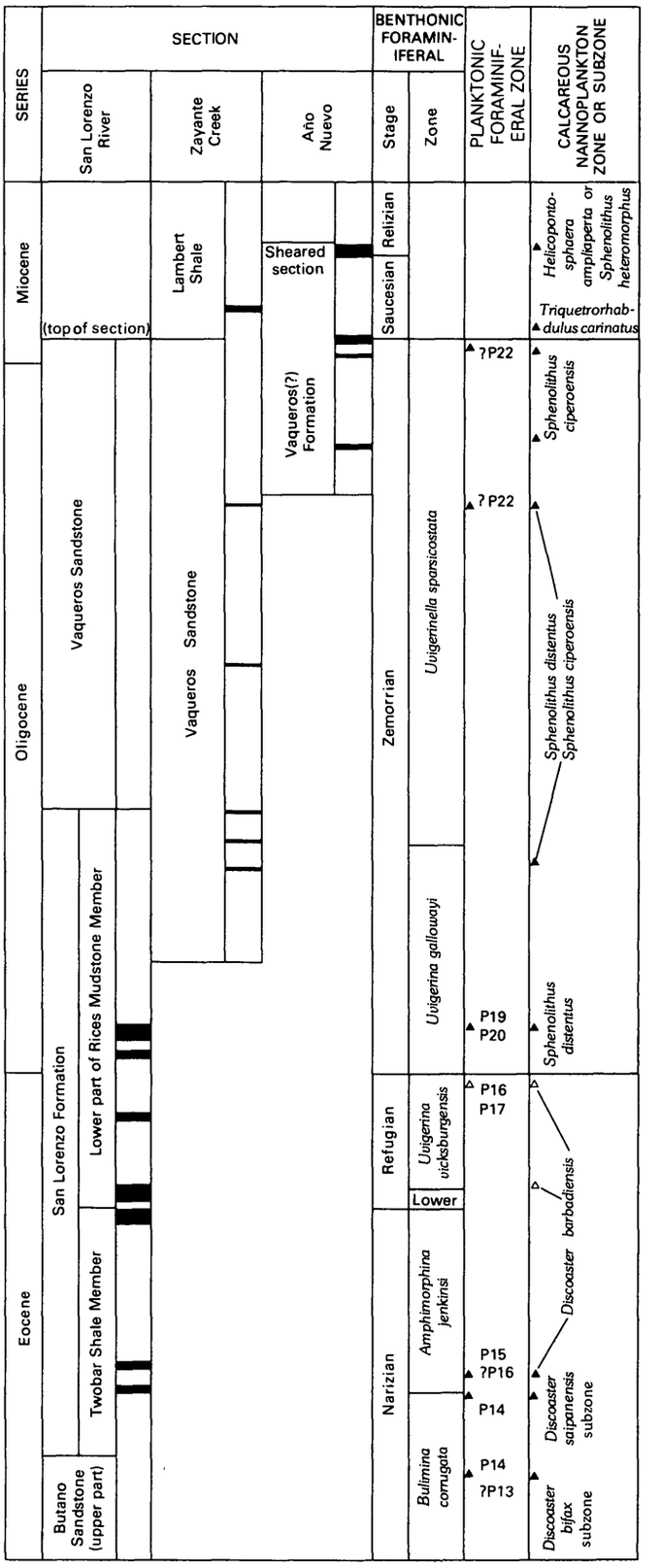


FIGURE 33.—Correlation of the San Lorenzo River, Zayante Creek, and Año Nuevo sections with California benthic foraminiferal zones and stages. Open triangles, Church Creek section, Santa Lucia Range (Poore and Bukry, this volume). Filled triangles, San Lorenzo River, Zayante Creek, or Año Nuevo sections (Poore and Bukry, this volume).

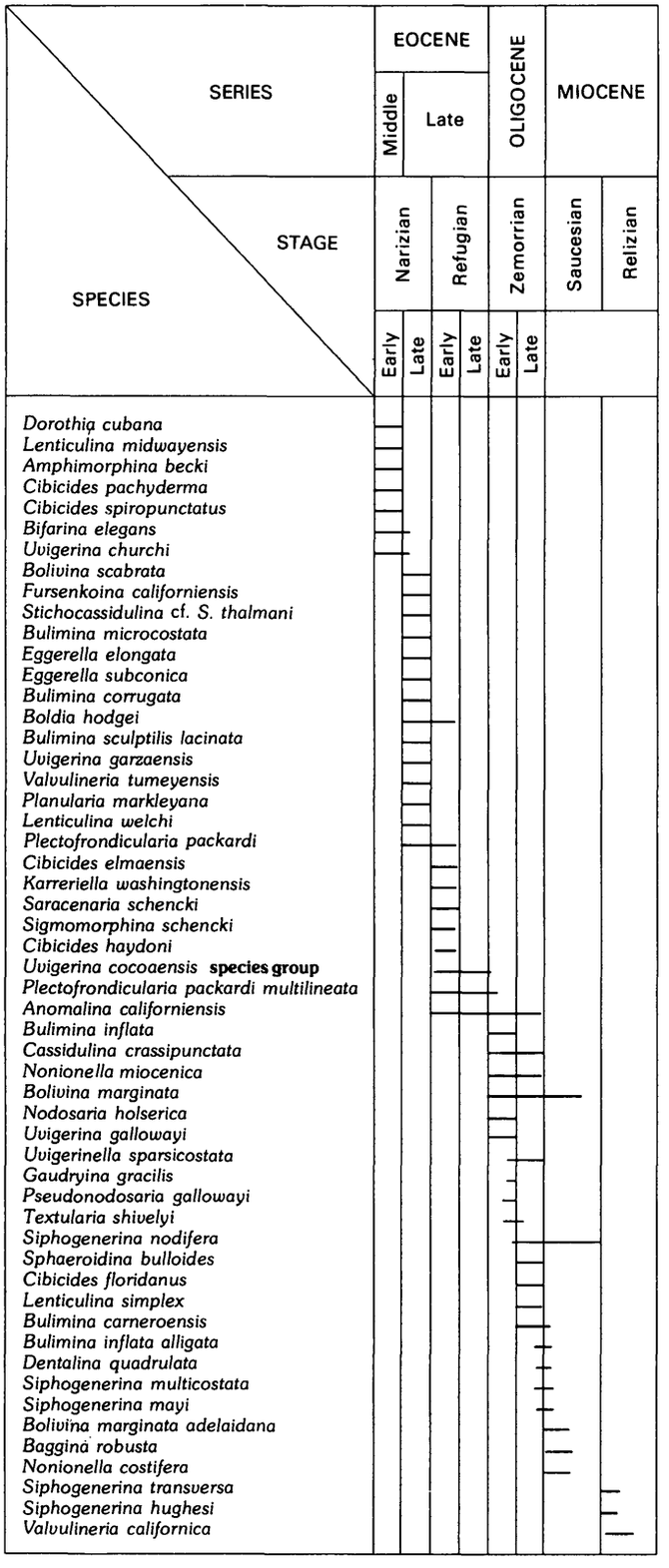


FIGURE 34.—Ranges of species diagnostic of middle Tertiary benthic foraminiferal stages (Narizian through Relizian Stages) and zones of the Santa Cruz Mountains, California.

The Narizian Stage is represented in the San Lorenzo section by assemblages of the lower and upper Narizian *Bulimina corrugata* and *Amphimorphina jenkinsi* Zones. Recognition of these zones requires no modification of the original description of the zones. The lower Narizian-upper Narizian boundary corresponds to the Zone P 14 - P 15 boundary and the *Discoaster saipanensis* Zone-*Discoaster barbadiensis* Zone boundary (Poore and Bukry, this volume). This boundary corresponds to the middle Eocene - upper Eocene boundary.

In the San Lorenzo River section, the Refugian Stage is marked by an abrupt faunal and lithologic change, associated with the onset of shallower water conditions. The extended range of several Refugian species, *Boldia hodgei* and *Plectofrondicularia packardi*, noted by previous workers and in the modified description of the Refugian Stage (Donnelly, 1976), is confirmed in this section. The Refugian faunas are poorly preserved, but they do suggest that additional revisions are needed in the definition of diagnostic Refugian faunas. The Refugian faunas in the San Lorenzo River section represent a deeper bathymetric facies than those in the type area in California. They resemble faunas in the Lincoln Creek Formation of Washington. The recognition of a bathyal Refugian fauna requires the downward range extension of *Cibicides elmaensis* and various members of the *Uvigerina cocoaensis* species group, along with the addition of diagnostic species such as *Karreriella washingtonensis, Saracenaria schencki*, and *Sigmomorphina schencki*. Also since the paleoecologic facies present in the San Lorenzo section are different than the facies of the type area (Cañada de Santa Anita), many of the diagnostic late Refugian species do not appear.

Planktic microfossils from the San Lorenzo River section and correlative sections suggest that the Refugian-Zemorrian boundary lies between Zone P 17 and Zone P 19 and between the *Discoaster barbadiensis* Zone and *Sphenolithus distentus* Zone (Poore and Bukry, this volume). Neither nannofossils nor planktic foraminifers were sufficiently diverse or abundant in this section to locate the boundary more closely.

The Zemorrian Stage can be recognized in all three sections. The criteria for recognition of the Zemorrian Stage and the Zemorrian zones (*Uvigerina gallowayi* and *Uvigerinella sparsicostata*) need little modification from the original description of Kleinpell (1939). Both the early Zemorrian-late Zemorrian and the Zemorrian-Saucesian boundaries are marked by the presence in a sample of species of both zones or stages. This mixing of faunas would be expected in

closely sampled intervals and where environmental conditions are relatively consistent across the boundary. Early and late Zemorrian species are present in sample Mf4682 in the Zayante Creek section, and both Zemorrian and Saucesian species are present in Mf4664 in the Año Nuevo section.

Planktic foraminifers diagnostic of Zones P 19 and P 20 and nannofossils diagnostic of the *Sphenolithus distentus* Zone are associated with the early Zemorrian. The *Sphenolithus distentus* Zone and *Sphenolithus ciperoensis* Zone and Zone P 22(?) (Poore and Bukry, this volume) are associated with the late Zemorrian. In the Año Nuevo section, upper Oligocene *Sphenolithus ciperoensis* Zone (sample Mf4664) and Miocene *Triquetrorhabdulus carinatus* Zone (sample Mf2188) nannofossils are recognized (Poore and Bukry, this volume). These zone and age assignments coupled with the benthic foraminiferal data support the interpretation that Mf4664 and Mf1376 straddle the Zemorrian-Saucesian boundary.

Faunas diagnostic of the Saucesian Stage occur in one sample (Año Nuevo section) and questionably in a second (Zayante Creek section). Nannofossils associated with this interval indicate that the Saucesian Stage is Miocene (Poore and Bukry, this volume).

Faunas of Relizian age in the Año Nuevo section are correlative with the *Helicopontosphaera ampliaperta* or *Sphenolithus heteromorphus* Zone (Poore and Bukry, this volume) and therefore are also Miocene.

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[Italic numbers indicate principal reference]

PLATES 1-17

[Contact photographs of the plates in this report are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225]

PLATE 1

[All samples from either the aqueduct section in the Devils Den area or from the Lodo Gulch section. All figures × 65]

FIGURE 1. *Ammodiscus* cf. A. *pennyi* Cushman and Jarvis
Aqueduct section, sample 76CB 1281H

2, 3, 4. *Cyclammina incisa* (Stache)
Aqueduct section, sample 76CB 1281

5. *Cyclammina simiensis* Berry
Aqueduct section, sample 76CB 1281

6. *Cyclammina* cf. *C. clarki* (Hanna)
Aqueduct section, sample 76CB 1291

7. *Spiroplectammina richardi* Martin
Lodo Gulch section, sample 76CB 1231B

8, 9. *Spiroplectammina directa* (Cushman and Siegfus)
Aqueduct section, sample 76CB 1281M

10. *Verneuilina triangulata* Cook
Lodo Gulch section, sample 76CB 1231A

11. *Gaudryina coalingensis* Cushman and Hanna
Lodo Gulch section, sample 76CB 1231A

12. *Gaudryina* cf. *G. laevigata* Franke
Aqueduct section, sample 76CB 1281

13. *Clavulinoides californicus* Mallory
Aqueduct section, sample 76CB 1281

14. *Dorothia germanica* Cushman
Aqueduct section, sample 76CB 1281

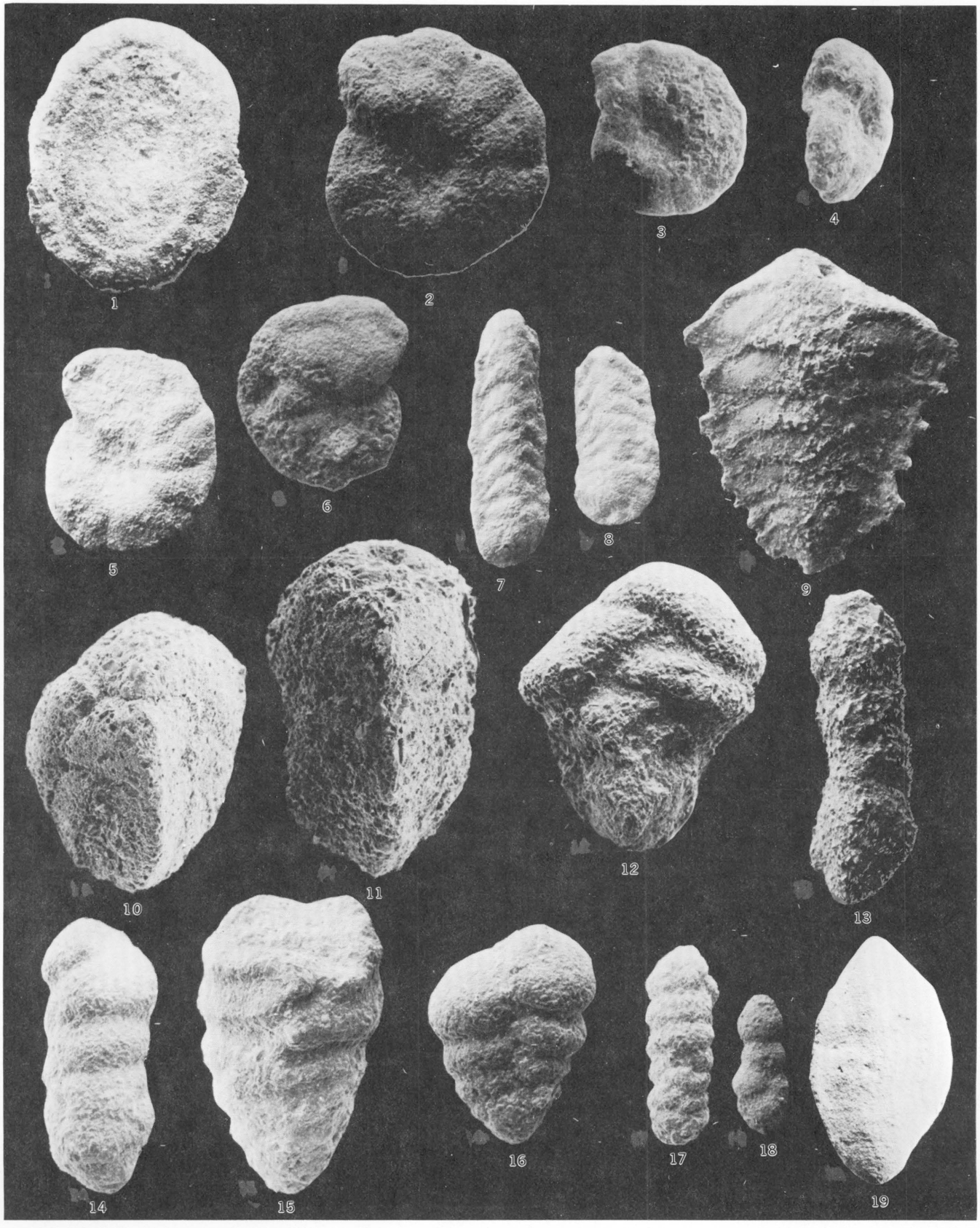
15. *Tritaxilina colei* Cushman and Siegfus
Aqueduct section, sample 76CB 1281

16. *Karreriella monumentensis* Mallory
Aqueduct section, sample 76CB 1281

17. *Karreriella mediaguaensis* Mallory
Aqueduct section, sample 76CB 1281

18. *Martinottiella eocenica* Cushman and Bermudez
Aqueduct section, sample 76CB 1281

19. *Silicosigmoilina californica* Cushman and Church
Aqueduct section, sample 76CB 1281L



BENTHIC FORAMINIFERS FROM THE CALIFORNIA COAST RANGES

PLATE 2

[All samples from either the aqueduct section in the Devils Den area or from the Lodo Gulch section]

FIGURE 1. *Lenticulina ulatisensis* (Boyd)
Aqueduct section, sample 76CB 1273, × 65

2, 3. *Vaginulinopsis mexicana* var. *kerni* (Cook)
Lodo Gulch section, samples 76CB 1221G, 76 CB 1231A, × 100

4, 5. *Vaginulinopsis asperuliformis* (Nuttall)
Lodo Gulch section, sample 76CB 1231B, × 100

6. *Vaginulinopsis mexicana* var. *nudicostatus* (Cushman and Hanna)
Lodo Gulch section, sample 76CB 1231A, × 15

7. *Amphimorphina ignota* Cushman and Siegfus
Aqueduct section, sample 76CB 1281D, × 65

8. *Plectofrondicularia kerni* Cook
Lodo Gulch section, sample 76CB 1231D, × 65

9. *Plectofrondicularia whitei* Martin
Lodo Gulch section, sample 76CB 1231, × 65

10. *Plectofrondicularia minuta* Sullivan
Aqueduct section, sample 76CB 1281, × 65

11, 12. *Buliminella grata* var. *convoluta* Mallory
Aqueduct section, sample 76CB 1281, × 65

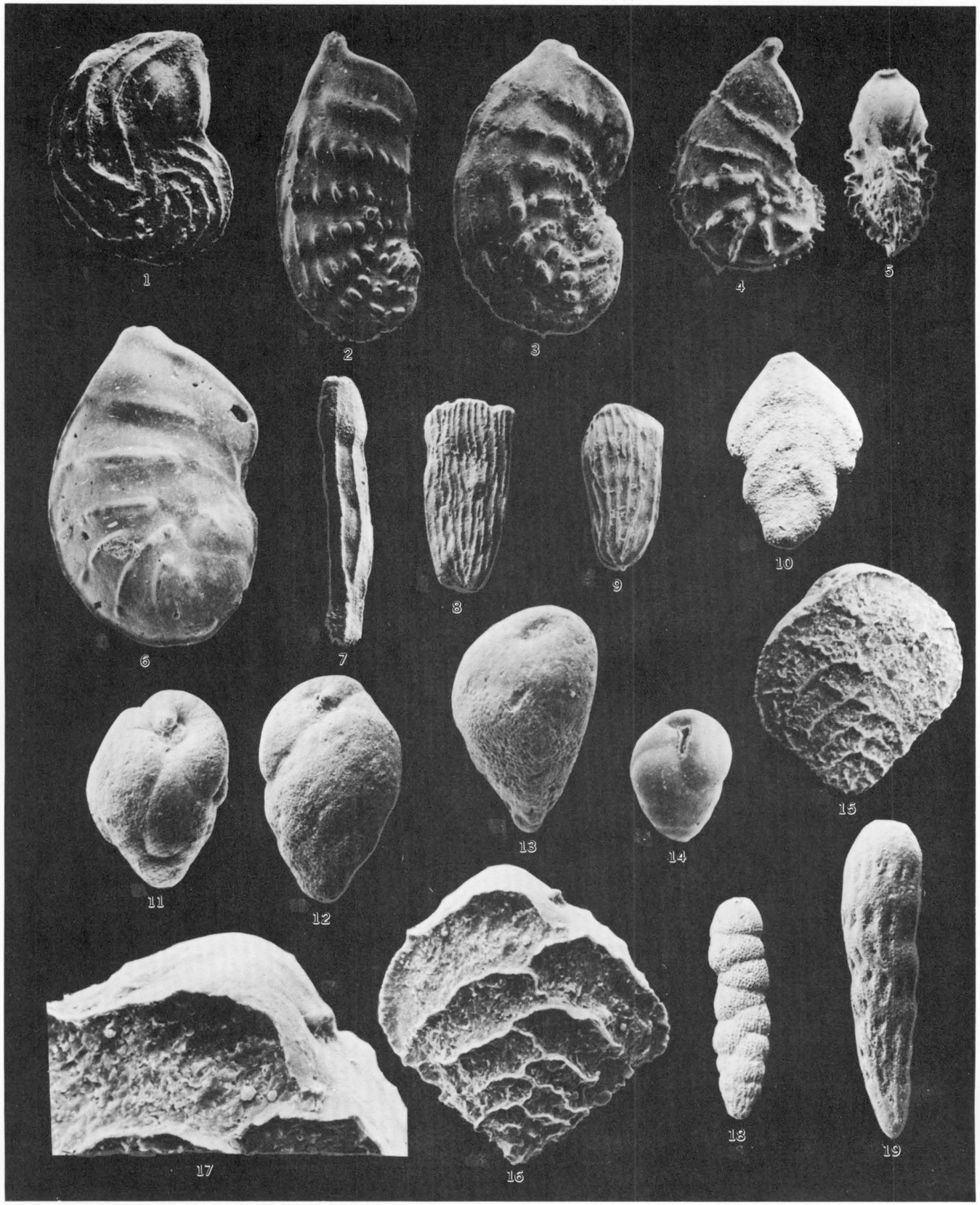
13. *Buliminella bradburyi* (Martin)
Aqueduct section, sample 76CB 1281, × 100

14. *Turritilina abbreviata* Ten Dam
Lodo Gulch section, sample 76CB 1221G, × 65

15, 16, 17. *Aragonia aragonensis* (Nuttall)
Lodo Gulch section, samples 76CB 1221E, × 100
76CB 1221G, × 200
76CB 1221G, × 235

18. *Bifarina eleganta* (Plummer)
Lodo Gulch section, sample 76CB 1221H, × 65

19. *Bifarina nuttalli* Cushman and Siegfus
Aqueduct section, sample 76CB 1633, × 100



BENTHIC FORAMINIFERS FROM THE CALIFORNIA COAST RANGES

PLATE 3

[All samples from either the aqueduct section in the Devils Dens area of from the Lodo Gulch section]

FIGURES 1-5. *Bulimina callahani* Galloway and Morrey
Lodo Gulch section sample 76CB 1231D, 1-4; × 200
Aqueduct section, sample 76CB 1281D, 5; × 120

6. *Bulimina curtissima* Cushman and Siegfus 1221G, × 200

7. *Bulimina impendens* Parker and Bermudez
Lodo Gulch section, sample 76CB 1231D, × 200

8. *Bulimina macilenta* Cushman and Parker
Lodo Gulch section, sample 76CB 1231B, × 65

9, 10. *Bulimina trinitatensis* Cushman and Jarvis
Aqueduct section, sample 76CB 1281, 9; × 65, 10; × 235

11, 12. *Bulimina whitei* Martin
Aqueduct section, sample 76CB 1273, × 100

13. *Bolivina huneri* Howe
Aqueduct section, sample 76CB 1281, × 135

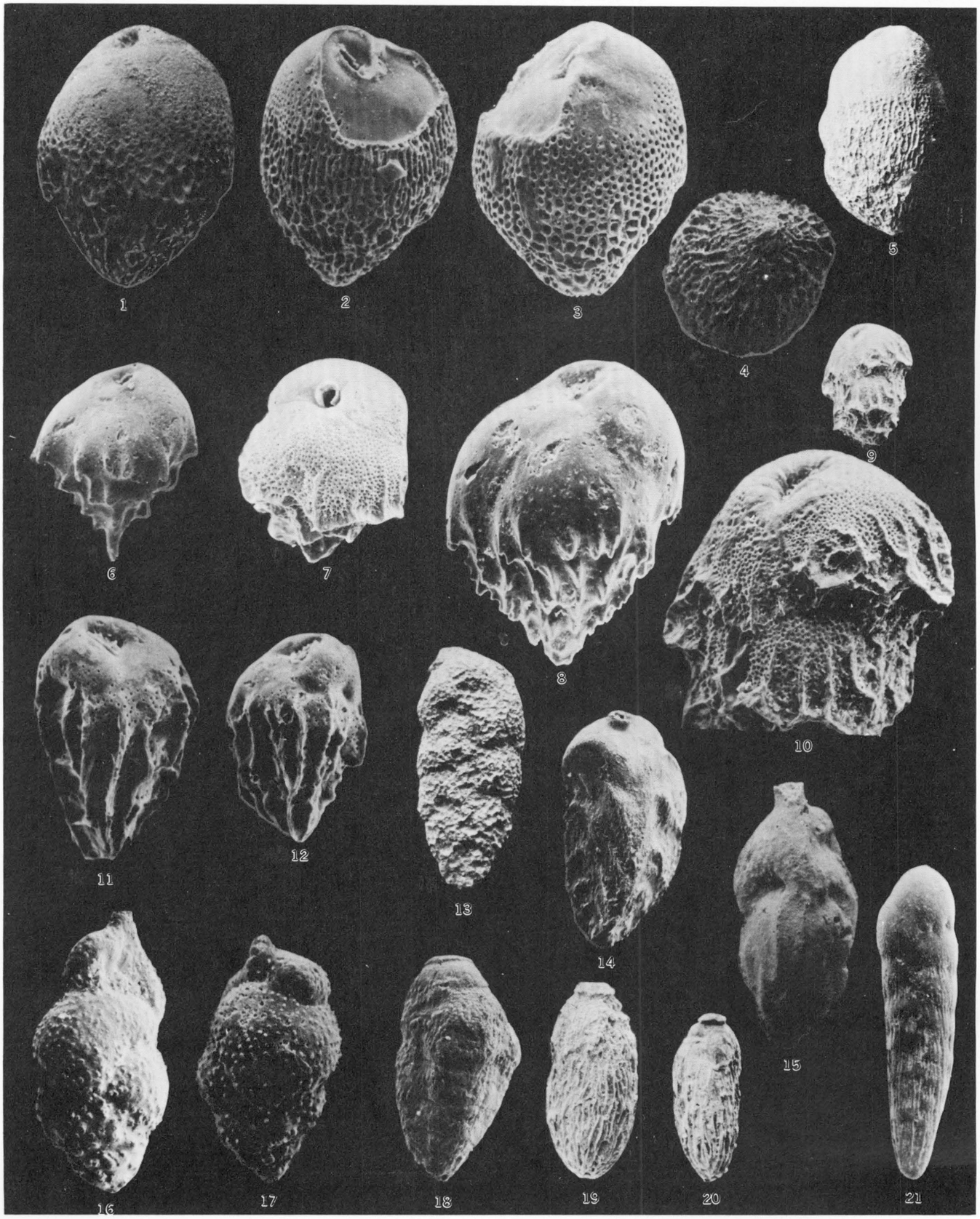
14. *Angulogerina* cf. *A. wilcoxensis* Cushman and Ponton
Aqueduct section, sample 76CB 1281C, × 100

15. *Trifarina advena* var. *californica* Mallory
Aqueduct section, sample 76CB 1281D, × 100

16, 17. *Uvigerina elongata* Cole
Lodo Gulch section, sample 76CB 1231, 76CB 1231C, × 200

18, 19, 20. *Uvigerina lodoensis* var. *miriamae* Mallory
Lodo Gulch section, sample 76CB 1221G, 18; × 200
76CB 1221G, 19; × 135
sample 76CB 1221C, 20; × 135

21. *Loxostomoides applinae* (Plummer)
Lodo Gulch section, sample 76CB 1231D, × 65



BENTHIC FORAMINIFERS FROM THE CALIFORNIA COAST RANGES

PLATE 4

[All samples are from either the aqueduct section in the Devils Den area or from the Lodo Gulch section]

FIGURE 1. *Nodosarella advena* Cushman and Siegfus
Aqueduct section, sample 76CB 1281E, × 65

2, 3, 4. *Nuttallides truempyi* (Nuttall)
Aqueduct section, sample 76CB 1281, × 65

5. *Baggatella californica* Mallory
Aqueduct section, sample 76CB 1281, × 100

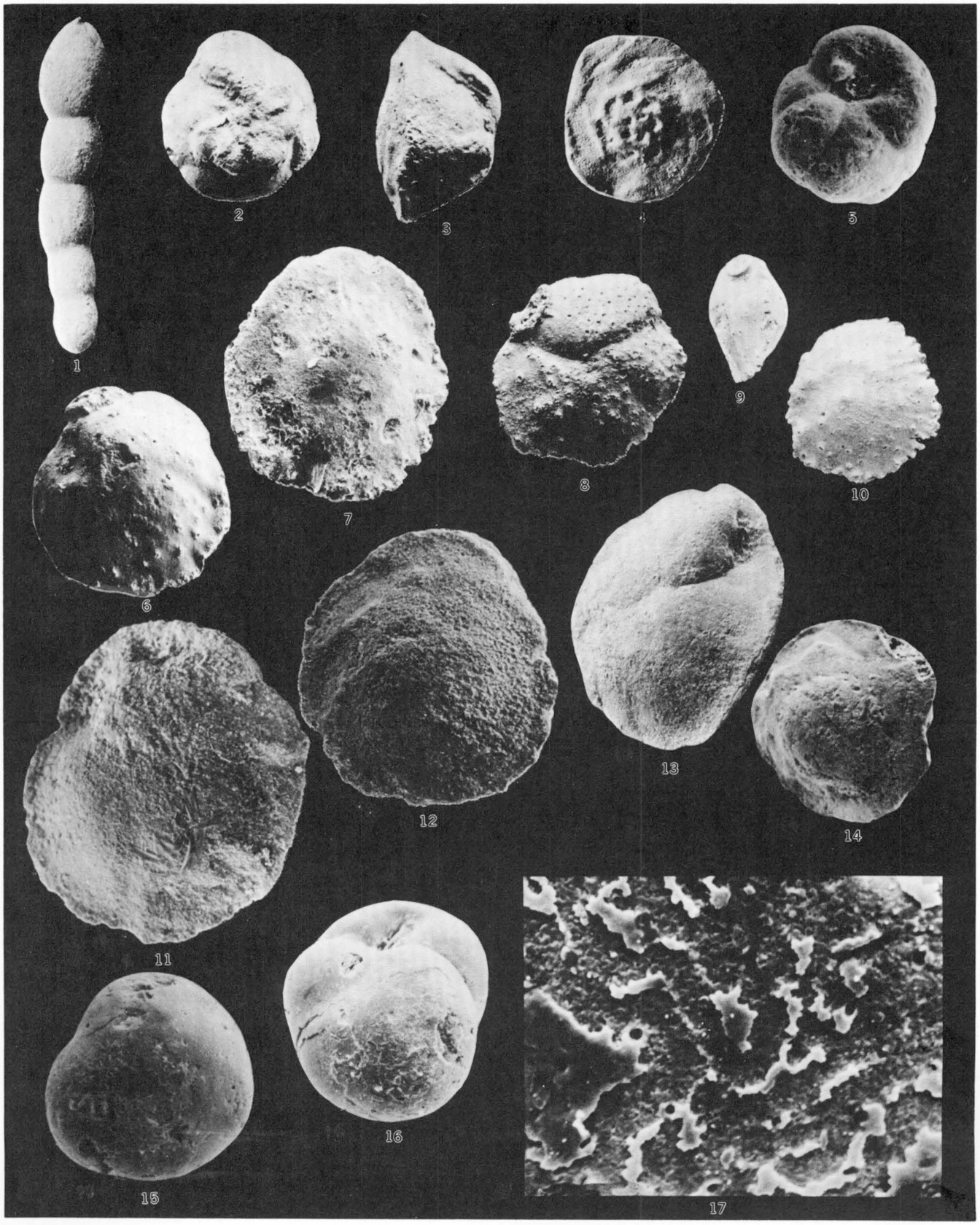
6, 7. *Siphonina* cf. *jacksonensis* Cushman
Aqueduct section, sample 76CB 1281D, × 135

8, 9, 10. *Siphonina wilcoxensis* Cushman
Aqueduct section, sample 76CB 1281D, × 100

11, 12. *Osangularia tenuicarinata* (Cushman and Siegfus)
Aqueduct section, sample 76CB 1281, × 100

13, 14. *Osangularia mexicana* (Cole)
Aqueduct section, sample 76CB 1281, × 165

15, 16, 17. *Globocassidulina globosa* Hantken
Lodo Gulch section, sample 76CB 1231B, 15, 16; × 100, 17; × 665



BENTHIC FORAMINIFERS FROM THE CALIFORNIA COAST RANGES

PLATE 5

[All samples are from either the aqueduct section in the Devils Den area or from the Lodo Gulch section. All figures × 65]

FIGURES 1, 2, 3. *Anomalinoides acutus* (Plummer)
Lodo Gulch section, sample 76CB 1231C

4, 5, 6. *Anomalinoides crassiseptus* (Cushman and Siegfus)
Aqueduct section, sample 76CB 1281H

7, 8, 9. *Anomalinoides aragonensis* (Cole)
Lodo Gulch section, sample 76CB 1231G

10, 11, 12. *Anomalinoides keeni* (Martin)
Lodo Gulch section, sample 76CB 1231B

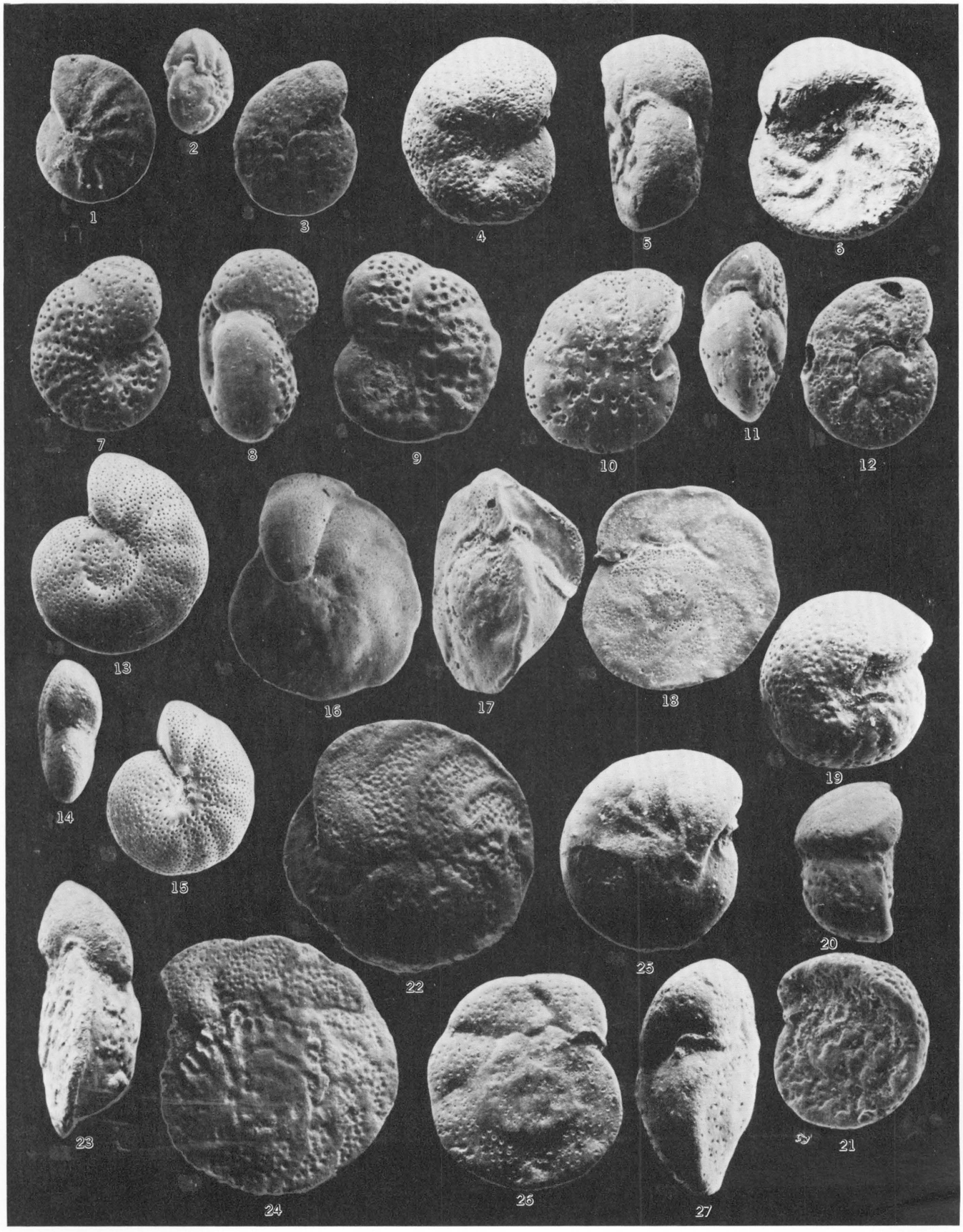
13, 14, 15. *Anomalinoides garzaensis* (Cushman and Siegfus)
Aqueduct section, sample 76CB 1281

16, 17, 18. *Cibicidoides beatus* (Martin)
Lodo Gulch section, sample 76CB 1231C

19,20, 21. *Cibicidoides grimsdalei* (Nuttall)
Aqueduct section, sample 76CB 1281J

22, 23, 24. *Cibicidoides fortunatus* (Martin)
Aqueduct section, sample 76CB 1284

25, 26, 27. *Cibicidoides whitei* (Martin)
Aqueduct section, sample 76CB 1281J



BENTHIC FORAMINIFERS FROM THE CALIFORNIA COAST RANGES

PLATE 6

[All figures × 20]

FIGURES 1, 2, 14. *Amphistegina parvula* (Cushman) (p. 46)
1, Equatorial section; 2, Subaxial section, locality 76CB1633 (Devils Den)
14, Axial section, locality 71CB971B (San Jose)

3, 13. *Eoconuloides lopeztrigoi* (D. K. Palmer) (p. 46)
3, Axial section, locality 76CB1634 (Devils Den)
13, Axial section, 71CB971B (San Jose)

4. *Eoconuloides wellsi* Cole and Bermudez (p. 46)
Subequatorial section, 76CB1634 (Devils Den)

5. *Pseudophragmina* sp.
Axial section, 76CB1641 (Devils Den)

6, 7, 10. *Nummulites willcoxi* Heilprin (p. 45)
6, 7, Subaxial section; 10, Equatorial section, 71CB983C (San Jose)

8, 16. *Eofabiana grahami* Kupper (p. 47)
8, Locality 71CB983C (San Jose);
16, Osbun 49-6 (Sveadal)

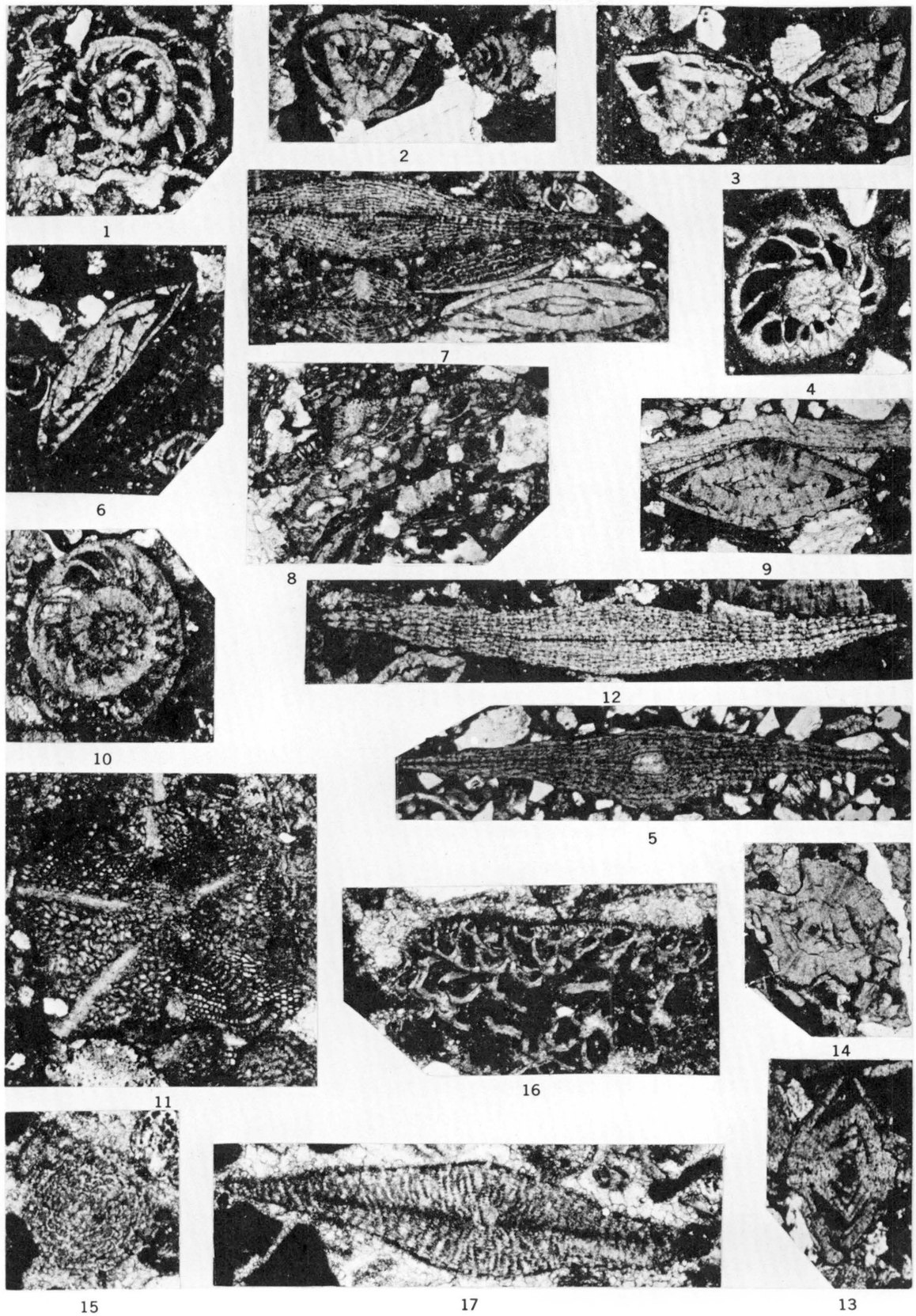
9. *Nummulites striatoreticulatus* L. Rutten (p. 45)
Axial section, 71CB983C (San Jose)

11. *Asterocyclina aster* (Woodring) (p. 47)
Subequatorial section, 71CB983C (San Jose)

12. *Pseudophragmina (Proporocyclina) flintensis* (Cushman) (p. 46)
Axial section

15. *Sphaerogypsina* sp. Osbun 49-6 (Sveadal)

17. *Pseudophragmina (Proporocyclina) clarki* (Cushman) (p. 47)
Axial section (A); Locality Osbun 1-1B (Sveadal)



LARGE FORAMINIFERS FROM CALIFORNIA

PLATE 7

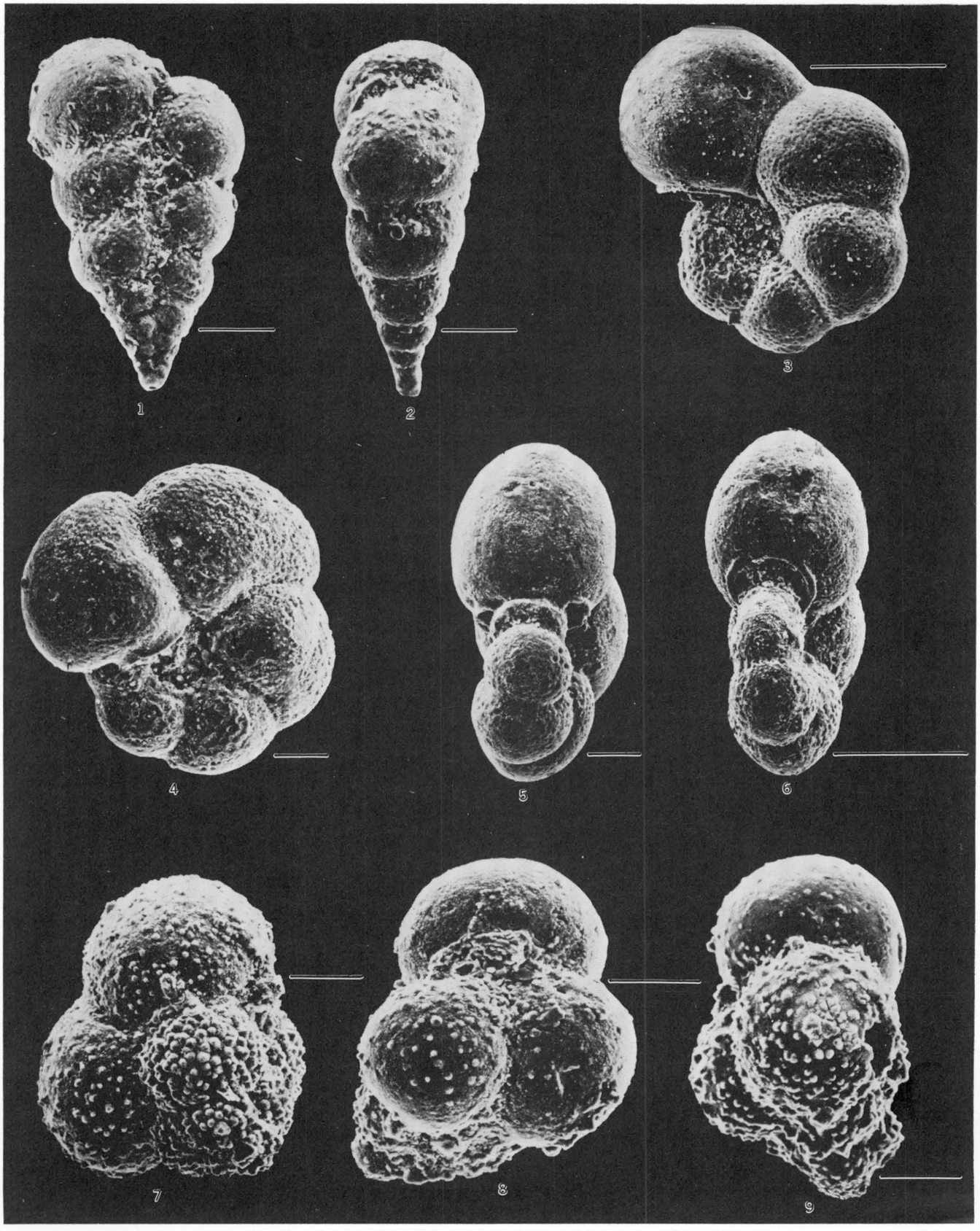
[Scale bar varies]

FIGURES 1, 2. *Chiloguembelina cubensis* (Palmer). 1, Side view, sample Mf1350. 2, Edge view of fig. 1. Scale bar=30 μm for both. (p. 59)

3, 6. *Pseudohastigerina lillisi* (Church). 3, Side view, sample Mf1351. 6, Edge view, sample Mf1351. Scale bar=100 μm for both. (p. 60)

4, 5. *Pseudohastigerina micra* (Cole). 4, Side view, sample Mf1351. 5, Edge view, sample Mf1351. Scale bar=30μm for both. (p. 60)

7–9. *Gümbelitria columbiana* Howe. All specimens from sample Mf4746. 7, Oblique spiral view. 8, Oblique umbilical view. Scale bar=30 μm for all. (p. 60)



PLANKTIC FORAMINIFERS FROM SAN LORENZO FORMATION

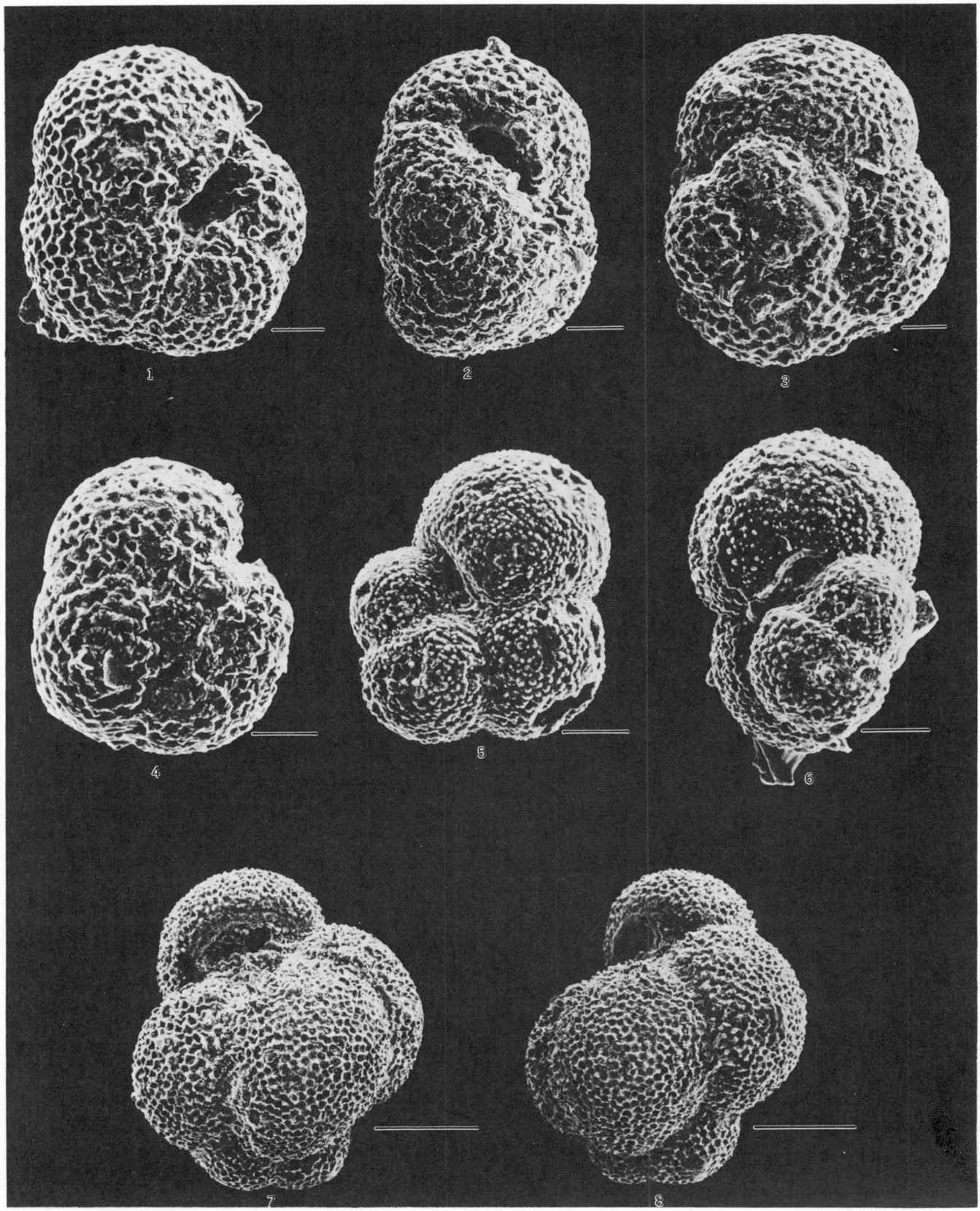
PLATE 8

[Scale bar varies]

FIGURES 1-4. *Globorotalia nana* Bolli. All specimens from the Vaqueros(?) Formation, Año Nuevo section. 1, Umbilical view, sample Mf4665. 2, Side view, sample Mf4664. 4, Spiral view, sample Mf4665. Scale bar=30 μm for all. (p. 60)

5, 6. *Globorotalia* sp. aff. *G. munda* Jenkins. Both specimens from sample Mf4665 in the Vaqueros(?) Formation, Año Nuevo section. 5, Umbilical view. 6, Side view. Scale bar=30 μm for both. (p. 60)

7, 8. *Globigerina praeturritilina* Blow and Banner. 7, Oblique umbilical view, sample Mf3305 from the Twobar Shale Member of the San Lorenzo Formation, San Lorenzo River section. 8, Oblique side view of fig. 7. Scale bar=100μm for both. (p. 59)



PLANKTIC FORAMINIFERS FROM AÑO NUEVO AND SAN LORENZO RIVER SECTIONS

PLATE 9

[All figures are photomicrographs at the same magnification; scale bar equals 5 μm. BF, bright field; XP, cross-polarized light]

FIGURES 1, 2. *Bramletteius serraculoides* Gartner. Sample Mf3301 from the Butano Sandstone in the San Lorenzo River section. 1, XP. 2, BF.

3, 4. *Coccolithus formosus* Kamptner. Sample Mf3306 from the Twobar Shale Member in the San Lorenzo River section. 3, XP. 4, BF.

5. *Daktylethra punctulata* Gartner. Sample Mf3306 from the Twobar Shale Member in the San Lorenzo River section; XP.

6. *Discoaster barbadiensis* Tan. Sample Mf3301 from the Butano Sandstone in the San Lorenzo River section; BF.

7. *Discoaster deflandrei* Bramlette and Riedel. Sample Mf4668 from the Vaqueros(?) Formation in the Año Nuevo section; BF.

8. *Discoaster nodifer* (Bramlette and Riedel). Sample Mf3301 from the Butano Sandstone in the San Lorenzo River section; BF.

9. *Discoaster saipanensis* Bramlette and Riedel. Sample Mf3306 from the Twobar Shale Member in the San Lorenzo River section; BF.

10, 11. *Dictyococcites bisectus* (Hay, Mohler, and Wade). Sample Mf4664 from the Vaqueros(?) Formation in the Año Nuevo section. 10, BF. 11, XP.

12, 13. *Lanternithus minutus* Stradner. Sample Mf3306 from the Twobar Shale Member in the San Lorenzo River section. 12, BF. 13, XP.

14. *Micrantholithus altus* Bybell and Gartner. Sample Mf3306 from the Twobar Shale Member in the San Lorenzo River section; BF.

15. *Reticulofenestra reticulata* (Gartner and Smith). Sample Mf3306 from the Twobar Shale Member in the San Lorenzo River section; XP.

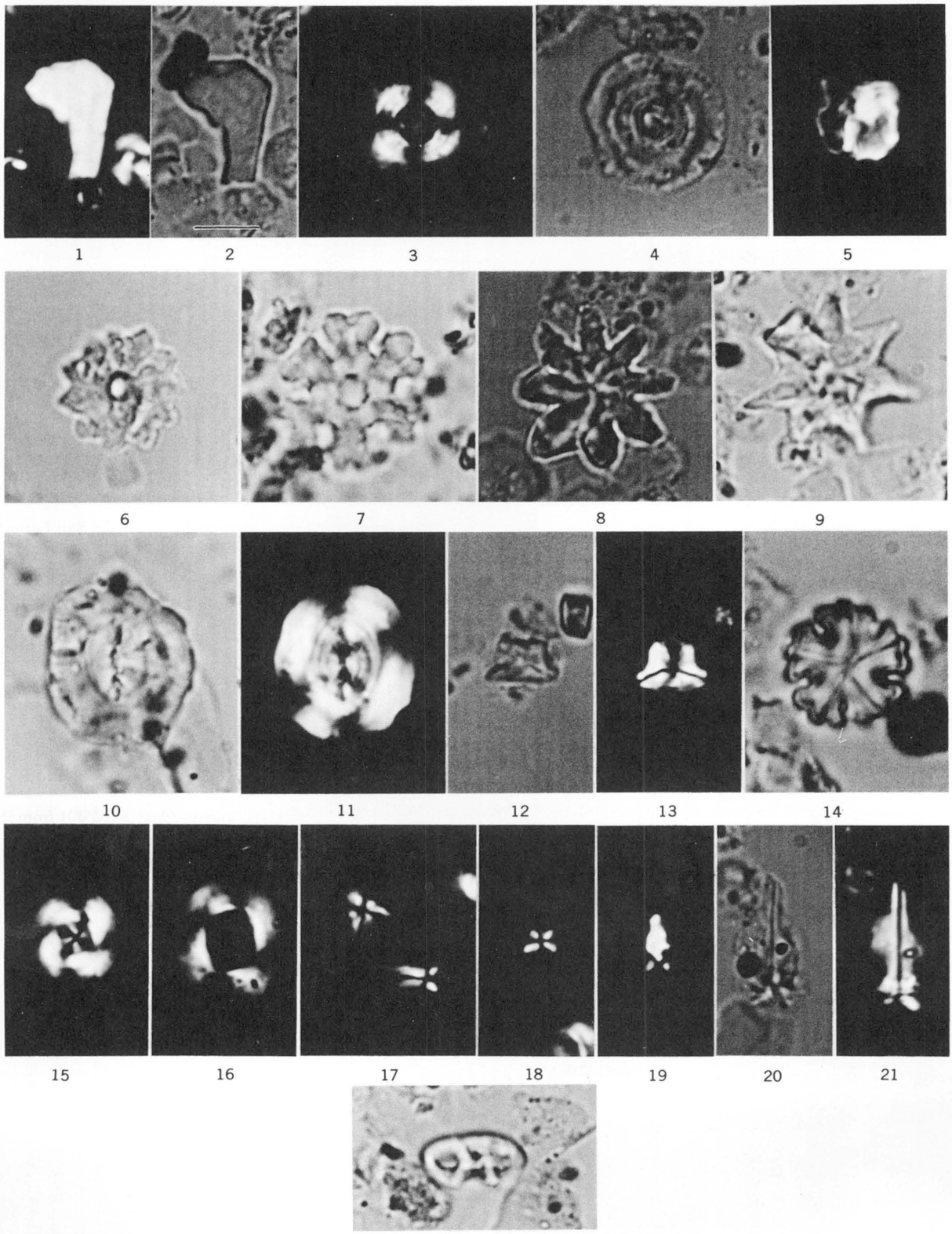
16. *Reticulofenestra umbilica* (Levin). Sample Mf3301 from the Butano Sandstone in the San Lorenzo River section; XP.

17. *Sphenolithus furcatolithoides* Locker, below; *Sphenolithus spiniger* Bukry, above. Sample Mf3301 from the Butano Sandstone in the San Lorenzo River section; XP.

18, 19. *Sphenolithus heteromorphus* Deflandre. Sample Mf4668 from the Vaqueros(?) Formation in the Año Nuevo section; XP. 18, Basal spines. 19, Apical and basal spines.

20, 21. *Sphenolithus pseudoradians* Bramlette and Wilcoxon. Sample Mf3301 from the Butano Sandstone in the San Lorenzo River section. 20, BF. 21, XP.

22. *Zygolithus dubius* Deflandre. Sample Mf3306 from the Twobar Shale Member in the San Lorenzo River section; BF.



1 2 3 4 5

6 7 8 9

10 11 12 13 14

15 16 17 18 19 20 21

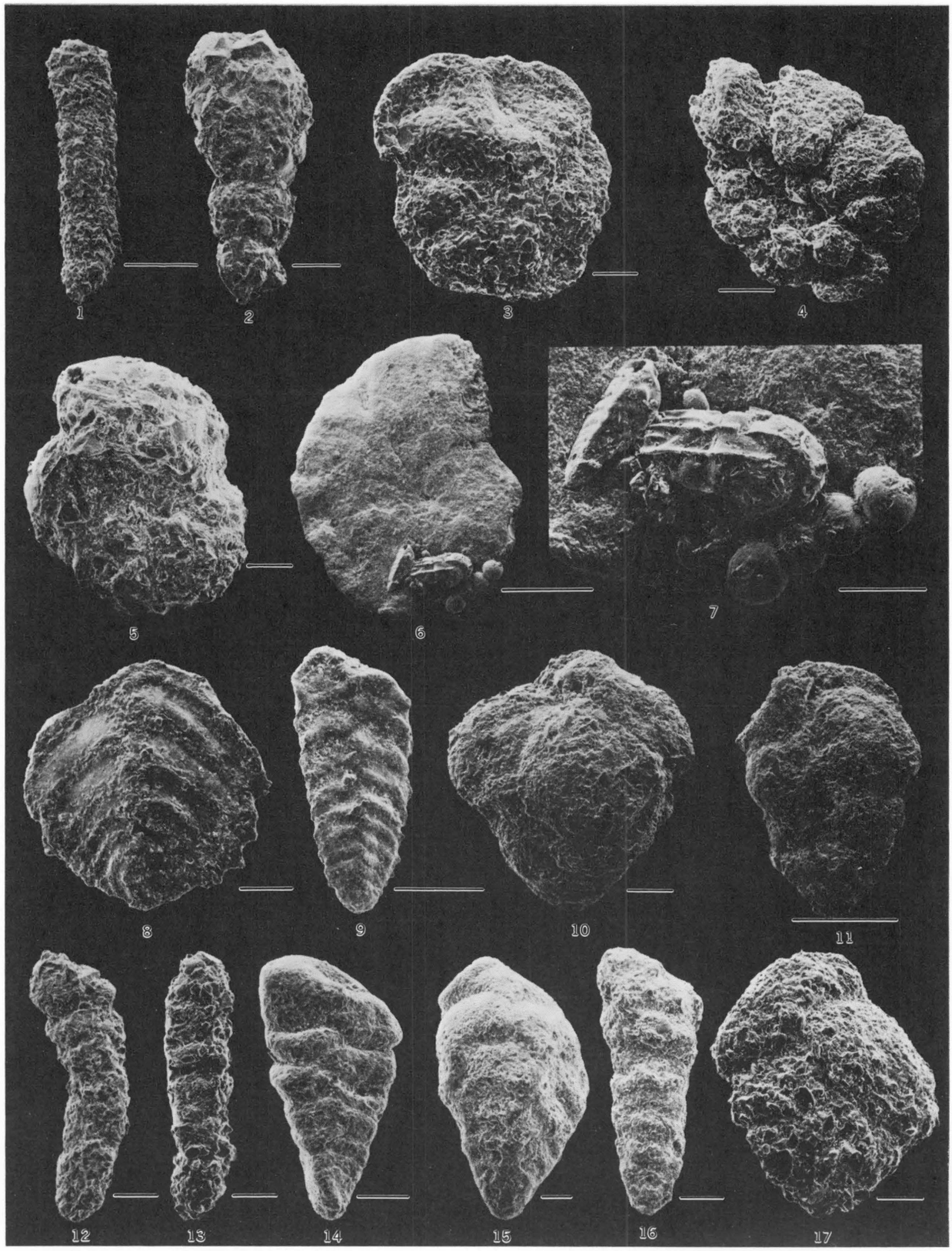
22

CALCAREOUS NANNOFOSSILS FROM THE SANTA CRUZ MOUNTAINS

PLATE 10

FIGURE

1. *Rhabdammina eocenica* Cushman and Hanna, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 300 μm. USNM no. 262082
2. *Reophax pilulifer* Brady, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 300 μm. USNM no. 262083
3. *Haplophragmoides deflata* Sullivan, Mf1352 (field no. 76CB1354), San Lorenzo River section. Bar equals 100 μm. USNM no. 262084
4. *Haplophragmoides* sp. #1, Mf1352 (field no. 76CB1354), San Lorenzo River section. Bar equals 100 μm. USNM no. 262085
5. *Haplophragmoides* sp., Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262086
6. *Cyclammina cancellata* Brady *obesa* Cushman and Laiming, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 1 mm. USNM no. 262087
7. *Bolivina marginata* Cushman, *Siphogenerina nodifera* Cushman and Kleinpell, and *Orthomorphina rohri* (Cushman and Stainforth) attached to the test of *Cyclammina cancellata* Brady *obesa* Cushman and Laiming, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 300 μm.
8. *Spiroplectammina richardi* Martin, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262088
9. *Spiroplectammina directa* (Cushman and Siegfus), Mf1360 (field no. EB256A), San Lorenzo River section. Bar equals 100 μm. USNM no. 262089
10. *Verneuilina* sp., Mf4683 (field no. 76CB1603), Zayante Creek section. Bar equals 100 μm. USNM no. 262090
11. *Verneuilina* sp., Mf4683 (field no. 76CB1603), Zayante Creek section. Bar equals 30 μm.
12. *Gaudryina gracilis* Cushman and Laiming, Mf4682 (field no. 76CB1602, Zayante Creek section. Bar equals 100 μm. USNM no. 262092
13. *Gaudryina gracilis* Cushman and Laiming, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262093
14. *Gaudryina triangularis* Cushman, Mf4682 (field no. 76CB1602), Zayante Creek section. Bar equals 100 μm. USNM no. 262094
15. *Dorothia cubana* (Cushman and Bermudez), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262095
16. *Eggerella elongata* Blaisdell, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262096
17. *Eggerella subconica* Parr, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262097



BENTHIC FORAMINIFERS FROM THE SANTA CRUZ MOUNTAINS

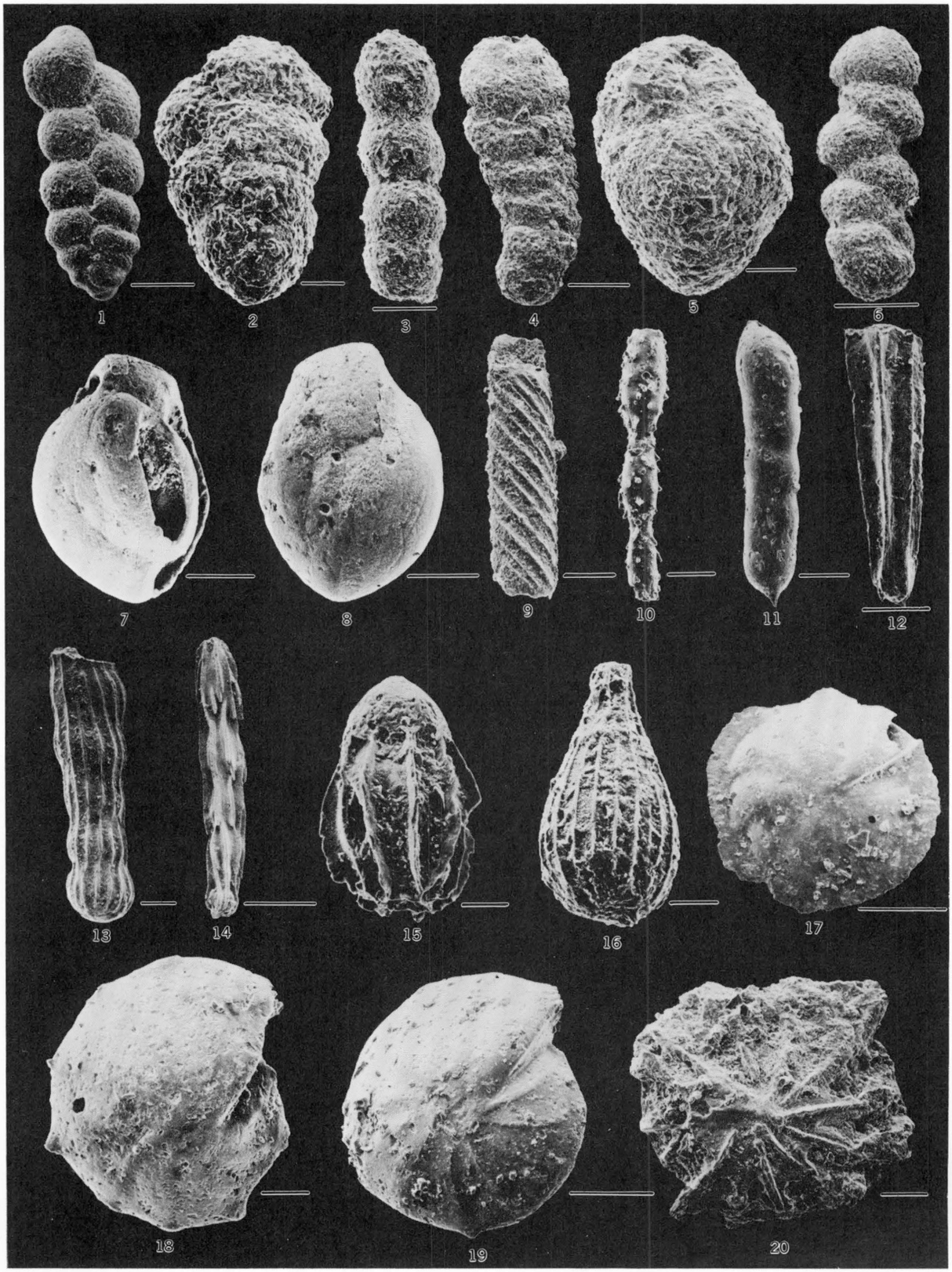
PLATE 11

FIGURE

1. *Karreriella elongata* Mallory, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262098
2. *Karreriella washingtonensis* Rau, Mf1360 (field no. EB256A3), San Lorenzo River section. Bar equals 100 μm. USNM no. 262099
3. *Martinottiella eocenica* Cushman and Bermudez, Mf3304 (field no. 76CB1451, San Lorenzo River section. Bar equals 100 μm. USNM no. 262100
4. *Martinottiella patens* (Cushman and Laiming), Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 300 μm. USNM no. 262101
5. *Plectina garzaensis* Cushman and Siegfus, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262102
6. *Plectina garzaensis* Cushman and Siegfus, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 300 μm. USNM no. 262103

7, 8. *Quinqueloculina minuta* Beck, Mf3304 (field no. 76CB1451), San Lorenzo River Section. Bar equals 100 μm. USNM no. 262104

9. *Nodosaria gyrata* Mallory, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262105
10. *Nodosaria parexilis sentifera* Cushman and Parker, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 100 μm. USNM no. 262106
11. *Dentalina cooperensis* Cushman, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262107
12. *Dentalina quadrulata* Cushman and Laiming, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262108
13. *Dentalina* sp., Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262109
14. *Dentalina spinosa ornatior* Smith, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 300 μm. USNM no. 262110
15. *Lagena acuticosta* Reuss, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 30 μm. USNM no. 262111
16. *Lagena semistriata* Williamson, Mf2700 (field no. EB395D), San Lorenzo River section. Bar equals 30 μm. USNM no. 262112
17. *Lenticulina barbati* (Cushman and Hobson), Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 300 μm. USNM no. 262113
18. *Lenticulina calcar* (Linne), Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 100 μm. USNM no. 262114
19. *Lenticulina* cf. *L. clypeiformis* d'Orbigny, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 300 μm. USNM no. 262115
20. *Lenticulina insuetus* (Cushman and Stainforth), Mf1350 (field no. 76CB1352), San Lorenzo River section. Bar equals 100 μm. USNM no. 262116

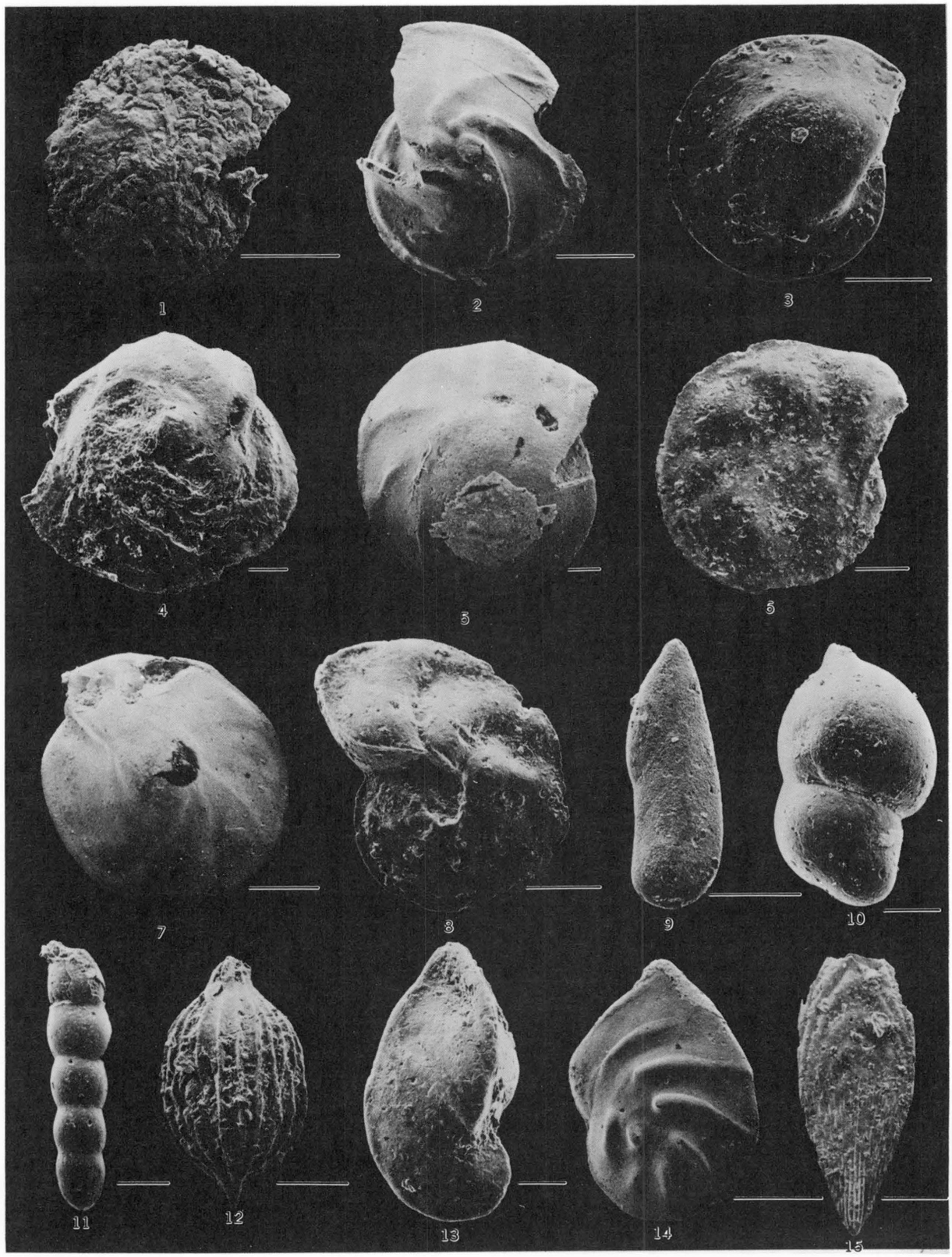


BENTHIC FORAMINIFERS FROM THE SANTA CRUZ MOUNTAINS

PLATE 12

FIGURE

1. *Lenticulina insuetus* (Cushman and Stainforth), Mf1356 (field no. EB256B), San Lorenzo River section. Bar equals 300 μm. USNM no. 262117
2. *Lenticulina midwayensis* (Plummer), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 300 μm. USNM no. 262118
3. *Lenticulina pseudocultratus* (Cole), Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 2621109
4. *Lenticulina pseudovortex* (Cole), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262120
5. *Lenticulina* sp., Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262121
6. *Lenticulina* sp., Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 300 μm. USNM no. 262122
7. *Lenticulina* spp., Mf304 (field no. 76CB1451), San Lorenzo River section. Bar equals 300 μm. USNM no. 262123
8. *Lenticulina welchi* (Church), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262124
9. ?*Marginulina* sp., Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262125
10. *Marginulina subbullata* Hantken, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262126
11. *Orthomorphina rohri* (Cushman and Stainforth), Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 300 μm. USNM no. 262127
12. *Pseudonodosaria gallowayi* (Cushman), Mf4682 (field no. 76CB1602), Zayante Creek section. Bar equals 100 μm. USNM no. 262128
13. *Saracenaria schencki* Cushman and Hobson, Mf1360 (field no. EB256A3), San Lorenzo River section. Bar equals 100 μm. USNM no. 262129
14. *Vaginulinopsis saundersi* (Hanna and Hanna), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 300 μm. USNM no. 262130
15. *Plectofrondicularia miocenica directa* Cushman and Laiming, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 300 μm. USNM no. 262131

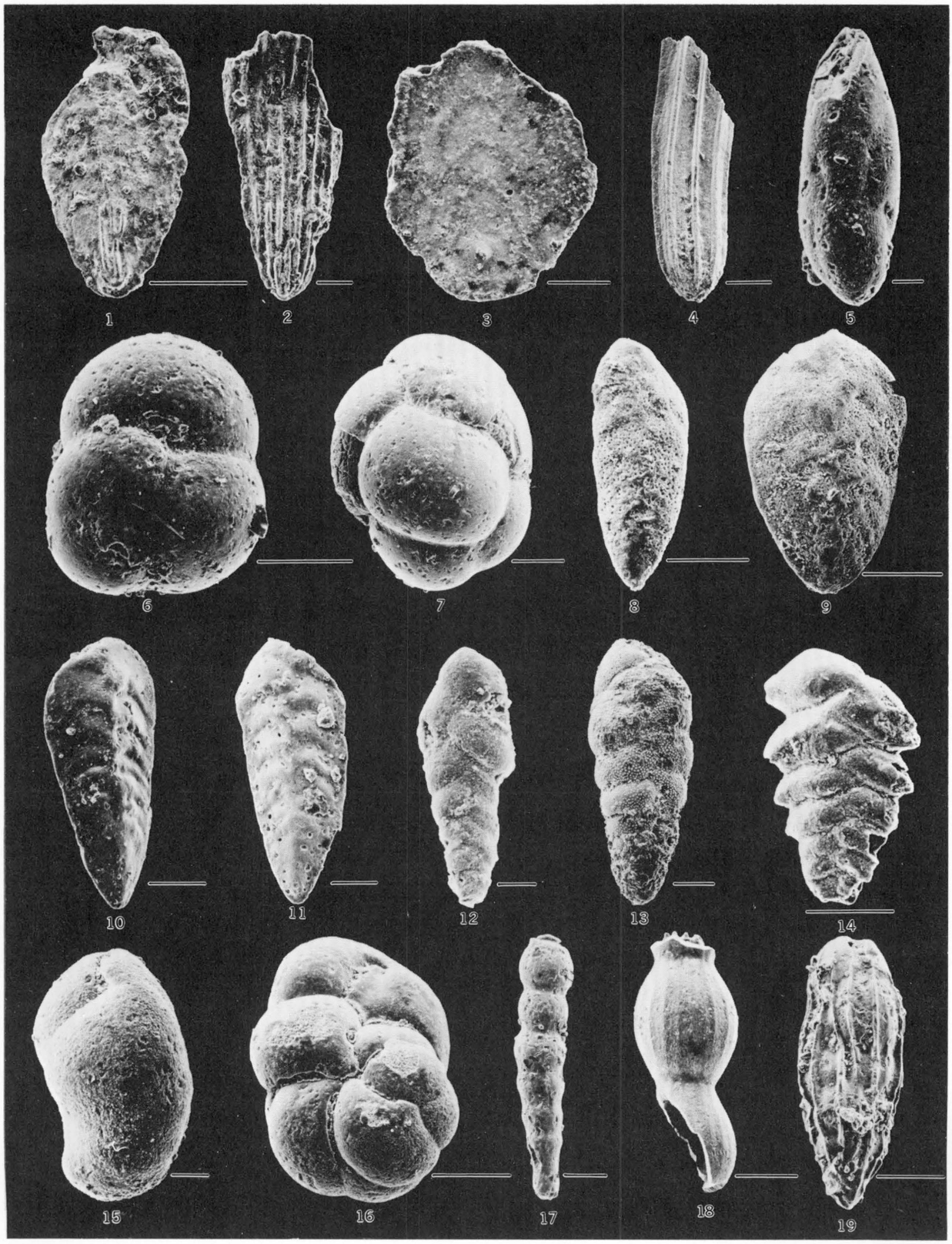


BENTHIC FORAMINIFERS FROM THE SANTA CRUZ MOUNTAINS

PLATE 13

FIGURE

1. *Plectofrondicularia packardi* Cushman and Schenck, Mf1360 (field no. EB256A), San Lorenzo River section. Bar equals 100 μm. USNM no. 262132
2. *Plectofrondicularia packardi multilineata* Cushman and Simonson, Mf1360 (field no. EB256A), San Lorenzo River section. Bar equals 100 μm. USNM no. 262133
3. *Plectofrondicularia vaughani* Cushman, Mf1360 (field no. EB256A), San Lorenzo River section. Bar equals 100 μm. USNM no. 262134
4. *Amphimorphina becki* Mallory, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262135
5. *Buliminella elegantissima* (d'Orbigny), Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 30 μm. USNM no. 262136
6. *Sphaeroidina bulloides* d'Orbigny, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262137
7. *Sphaeroidina bulloides* d'Orbigny, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262138
8. *Bolivina kleinpelli* Beck, Mf2700 (field no. EB395D), San Lorenzo River section. Bar equals 100 μm. USNM no. 262139
9. *Bolivina marginata* Cushman, Mf2701 (field no. EB675), San Lorenzo River section. Bar equals 100 μm. USNM no. 262140
10. *Bolivina marginata* Cushman, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262141
11. *Bolivina marginata* Cushman, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 100 μm. USNM no. 262142
12. *Bolivina scabrata* Cushman and Bermudez, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 30 μm. USNM no. 262143
13. *Bolivina* sp., Mf4661 (field no. 76CB1451), Año Nuevo section. Bar equals 100 μm. USNM no. 262144
14. *Bolivinoides mexicanus* (Cole), Mf1351 (field no. 76CB1353), San Lorenzo River section. Bar equals 100 μm. USNM no. 262145
15. *Cassidulinoides californiensis* Bramlette, Mf2700 (field no. EB395D), San Lorenzo River section. Bar equals 30 μm. USNM no. 262146
16. *Stichocassidulina* cf. *S. thalmani* Stone, Mallory, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262147
17. *Stilostomella advena* (Cushman and Laiming), Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 100 μm. USNM no. 262148
18. *Stilostomella wegimanni* (Cole), Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 300 μm. USNM no. 262149
19. *Bulimina carneroensis* Cushman and Kleinpell, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 100 μm. USNM no. 262150

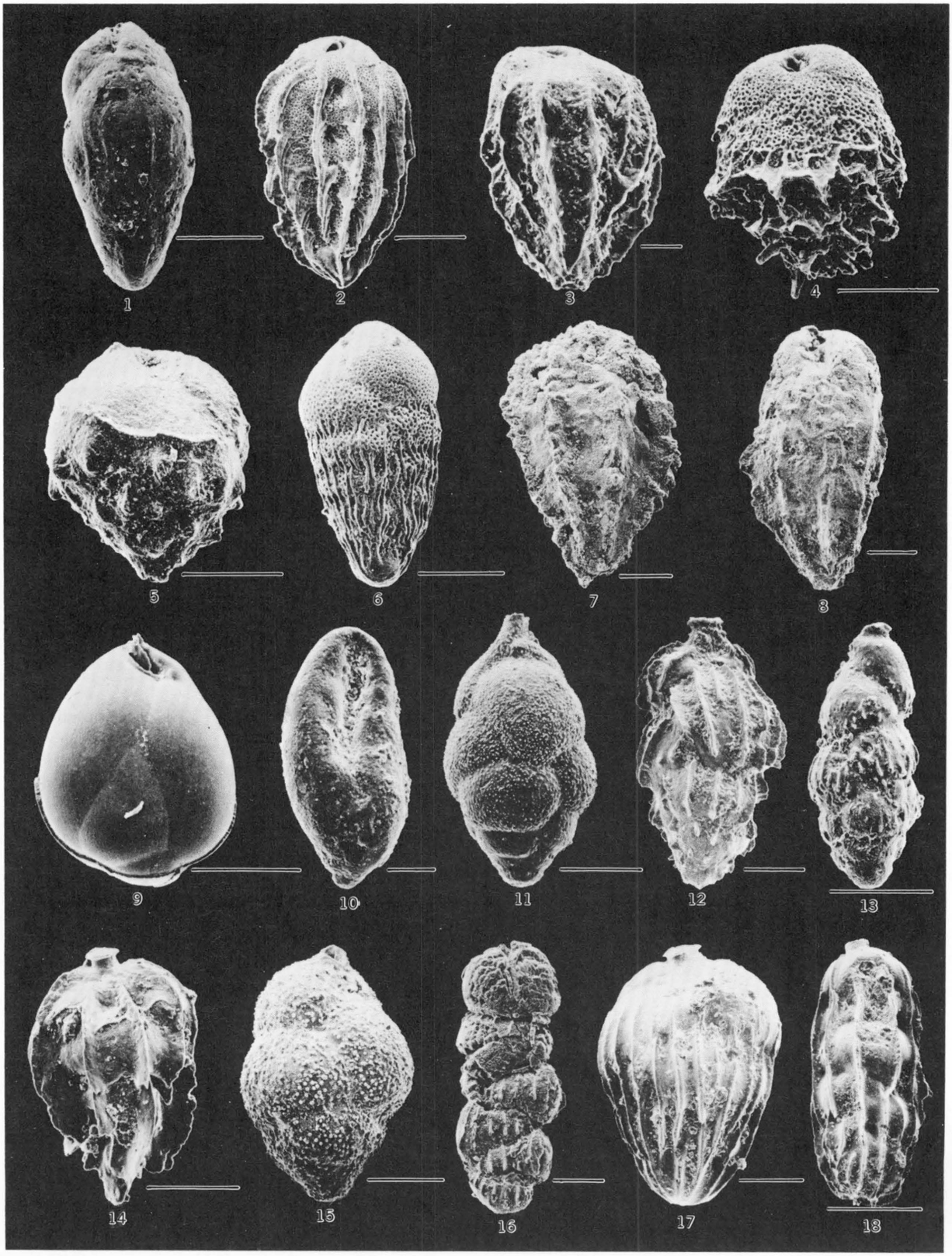


BENTHIC FORAMINIFERS FROM THE SANTA CRUZ MOUNTAINS

PLATE 14

FIGURE

1. *Bulimina carneroensis* Cushman and Kleinpell, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262151
2. *Bulimina corrugata* Cushman and Siegfus, Mf1357 (field no. EB256K), San Lorenzo River section. Bar equals 100 μm. USNM no. 262152
3. *Bulimina corrugata* Cushman and Siegfus, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 30 μm. USNM no. 262153
4. *Bulimina curtissima* Cushman and Siegfus, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262154
5. *Bulimina inflata alligata* Cushman and Laiming, Mf2700 (field no. EB395D), San Lorenzo River section. Bar equals 100 μm. USNM no. 262155
6. *Bulimina microcostata* Cushman and Parker, Mf1531 (field no. 76CB1353), San Lorenzo River section. Bar equals 100 μm. USNM no. 262156
7. *Bulimina sculptilis lacinata* Cushman and Parker, Mf1356 (field no. EB256B), San Lorenzo River section. Bar equals 100 μm. USNM no. 262157
8. *Bulimina sculptilis lacinata* Cushman and Parker, Mf1356 (field no. EB256B), San Lorenzo River section. Bar equals 100 μm. USNM no. 262158
9. *Globobulimina pacifica* Cushman, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262159
10. *Uvigerina auberiana* d'Orbigny, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262161
11. *Uvigerina auberiana* d'Orbigny, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262161.
12. *Uvigerina churchi* Cushman and Siegfus, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262162
13. *Uvigerina elongata* Cole, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262163
14. *Uvigerina gallowayi* Cushman, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 100 μm. USNM no. 262164
15. *Uvigerina garzaensis* Cushman and Siegfus, Mf1356 (field no. EB256B), San Lorenzo River section. Bar equals 100 μm. USNM no. 262165
16. *Siphogenerina mayi* Cushman and Parker, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262166
17. *Siphogenerina multicostata* Cushman and Jarvis, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262167
18. *Siphogenerina nodifera* Cushman and Kleinpell, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 300 μm. USNM no. 262168



BENTHIC FORAMINIFERS FROM THE SANTA CRUZ MOUNTAINS

PLATE 15

FIGURE

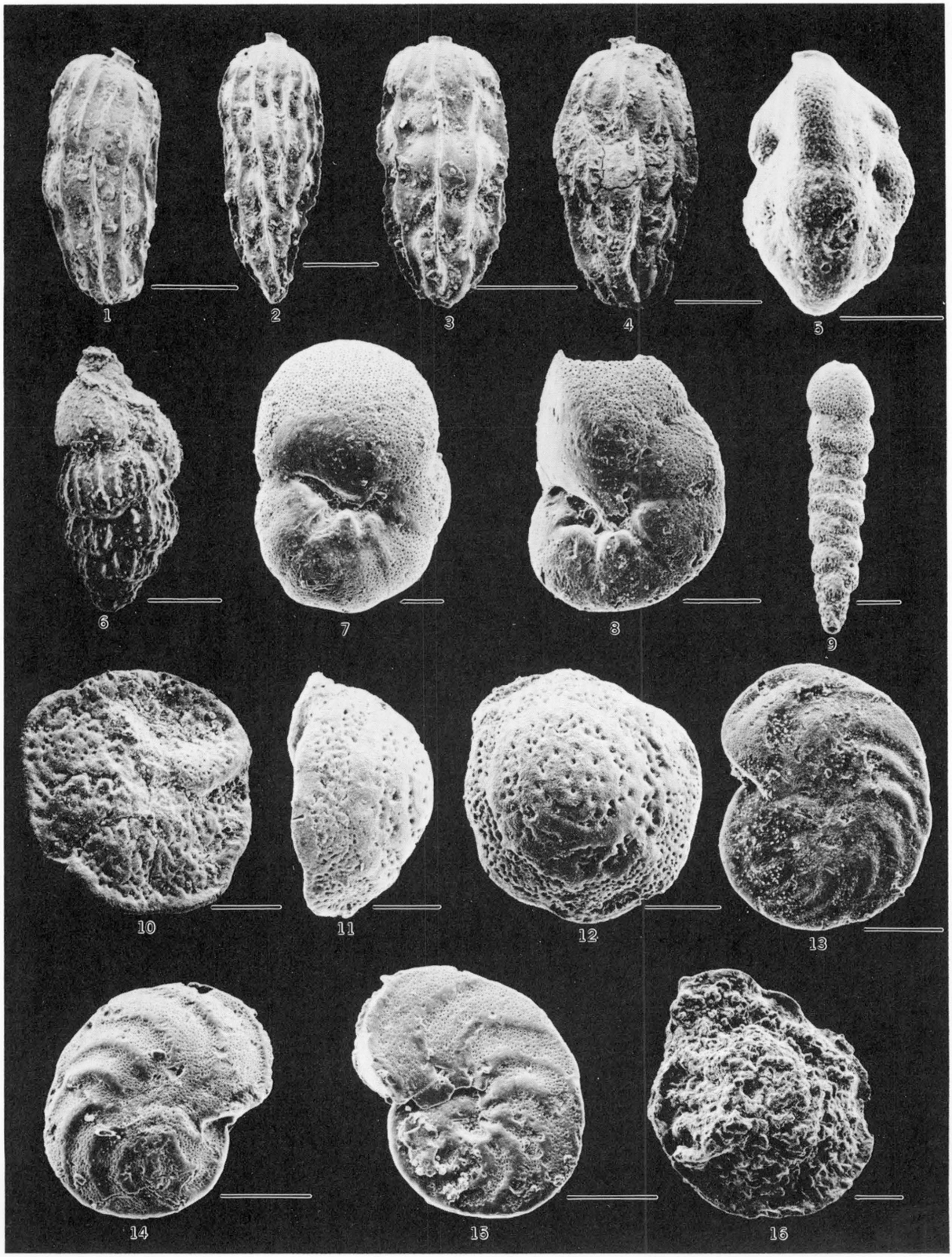
1. *Siphogenerina nodifera* Cushman and Kleinpell, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 300 μm. USNM no. 262169
2. *Siphogenerina nodifera* Cushman and Kleinpell, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 300 μm. USNM no. 262170
3. *Siphogenerina nodifera* Cushman and Kleinpell, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 300 μm. USNM no. 262171
4. *Siphogenerina nodifera* Cushman and Kleinpell, Mf4682 (field no. 76CB1602), Zayante Creek section. Bar equals 300 μm. USNM no. 262172
5. *Trifarina wilcoxensis* (Cushman and Ponton), Mf1531 (field no. 75CB1353), San Lorenzo River section. Bar equals 100 μm. USNM no. 262173
6. *Uvigerinella sparsicostata* Cushman and Laiming, Mf4683 (field no. 76CB1603), Zayante Creek section. Bar equals 100 μm. USNM no. 262174
7. *Baggina robusta* Kleinpell, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262175
8. *Valvulineria araucana* (d'Orbigny), Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262176
9. *Bifarina eleganta* (Plummer), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262177

10, 11, 12. ?*Neoeponides* sp., Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262178

13. *Cibicides floridanus* (Cushman), Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262179

14, 15. *Cibicides americanus crassiseptus* Cushman and Laiming, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 100 μm. USNM no. 262180

16. *Cibicides haydoni* (Cushman and Schenck), Mf1360 (field no. EB2456A) San Lorenzo River section. Bar equals 100 μm. USNM no. 262181

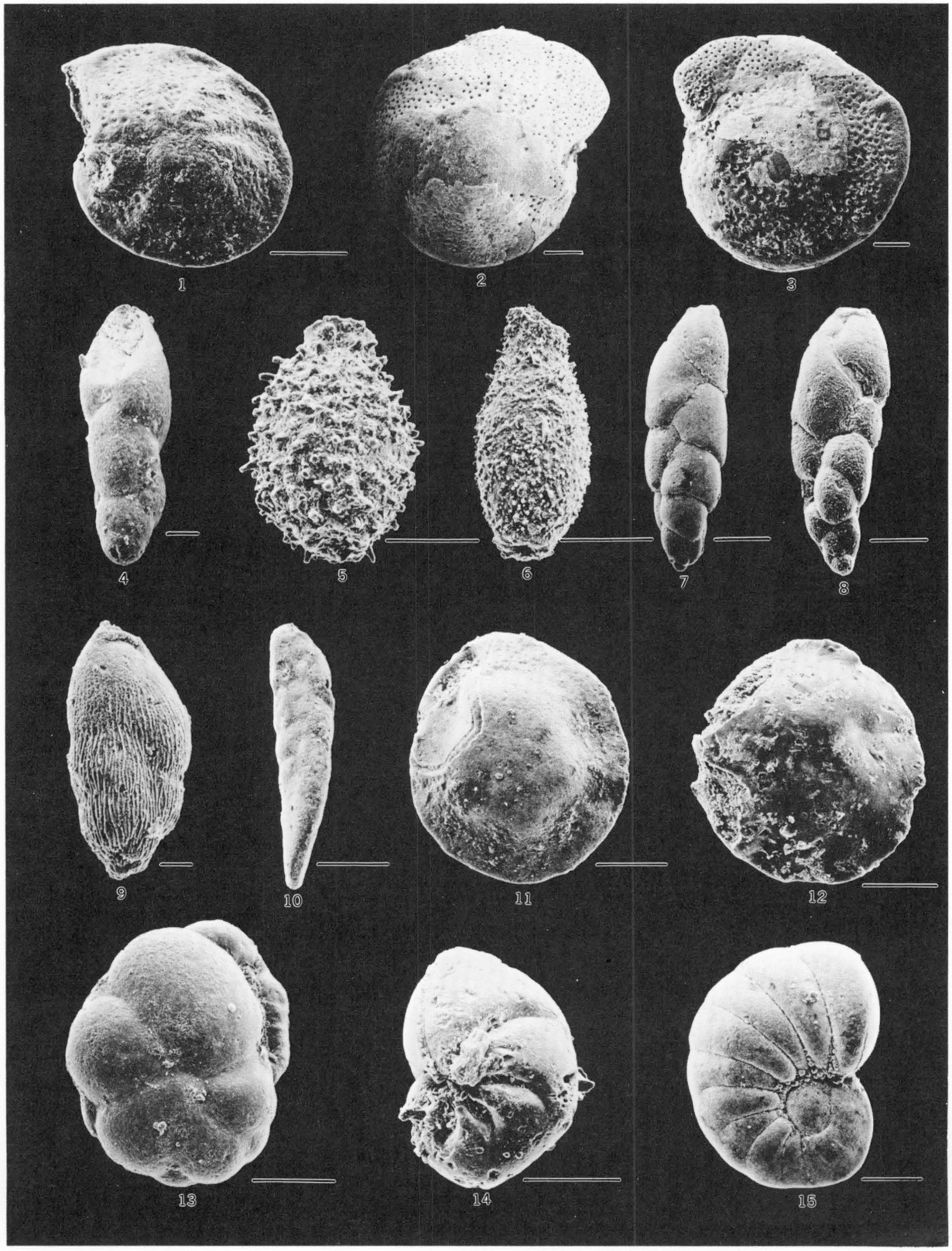


BENTHIC FORAMINIFERS FROM THE SANTA CRUZ MOUNTAINS.

PLATE 16

FIGURE

1. *Cibicides pseudoungerianus evolutus* Cushman and Hobson, Mf2700 (field no. EB395D), San Lorenzo River section. Bar equals 100 μm. USNM no. 262182
2, 3. *Cibicides spiropunctatus* Galloway and Morrey, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262183
4. *Pleurostomella alternans* Schwager, Mf3304 (field no. 76C B1451), San Lorenzo River section. Bar equals 30 μm. USNM no. 262184
5. *Nodosarella atlantisae hispidula* (Cushman), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262185
6. *Nodosarella atlantisae hispidula* (Cushman), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262186
7. *Fursenkoina bramlettei* (Galloway and Morrey), Mf4667 (field no. 76CB1541), Año Nuevo section. Bar equals 100 μm. USNM no. 262187
8. *Fursenkoina bramletti* (Galloway and Morrey), Mf1531 (field no. 75CB1353), San Lorenzo River section. Bar equals 100 μm. USNM no. 262188
9. *Fursenkoina californiensis* (Cushman), Mf3304 (field no. 75CB1451), San Lorenzo River section. Bar equals 30 μm. USNM no. 262189
10. *Fursenkoina dibollensis* (Cushman and Applin), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262190
11. *Cassidulina crassipunctata* Cushman and Hobson, Mf2700 (field no. EB395D), San Lorenzo River section. Bar equals 100 μm. USNM no. 262191
12. *Cassidulina crassipunctata* Cushman and Hobson, Mf1360 (field no. EB256A), San Lorenzo River section. Bar equals 100 μm. USNM no. 262192
13. *Cassidulina diversa* Cushman and Stone, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262193
14. *Nonionella miocenica* Cushman, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 100 μm. USNM no. 262194
15. *Nonionella miocenica* Cushman, Mf2700 (field no. EB395D), San Lorenzo River section. Bar equals 100 μm. USNM no. 262195



BENTHIC FORAMINIFERS FROM THE SANTA CRUZ MOUNTAINS

PLATE 17

FIGURE 1, 2. *Pullenia quinqueloba* (Reuss), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262196

3. *Pullenia miocenica* Kleinpell, Mf4664 (field no. 76CB1531), Año Nuevo section. Bar equals 100 μm. USNM no. 262197

4. *Gyroidina orbicularis planata* Cushman, Mf2700 (field no. EB395D), San Lorenzo River section. Bar equals 100 μm. USNM no. 262198

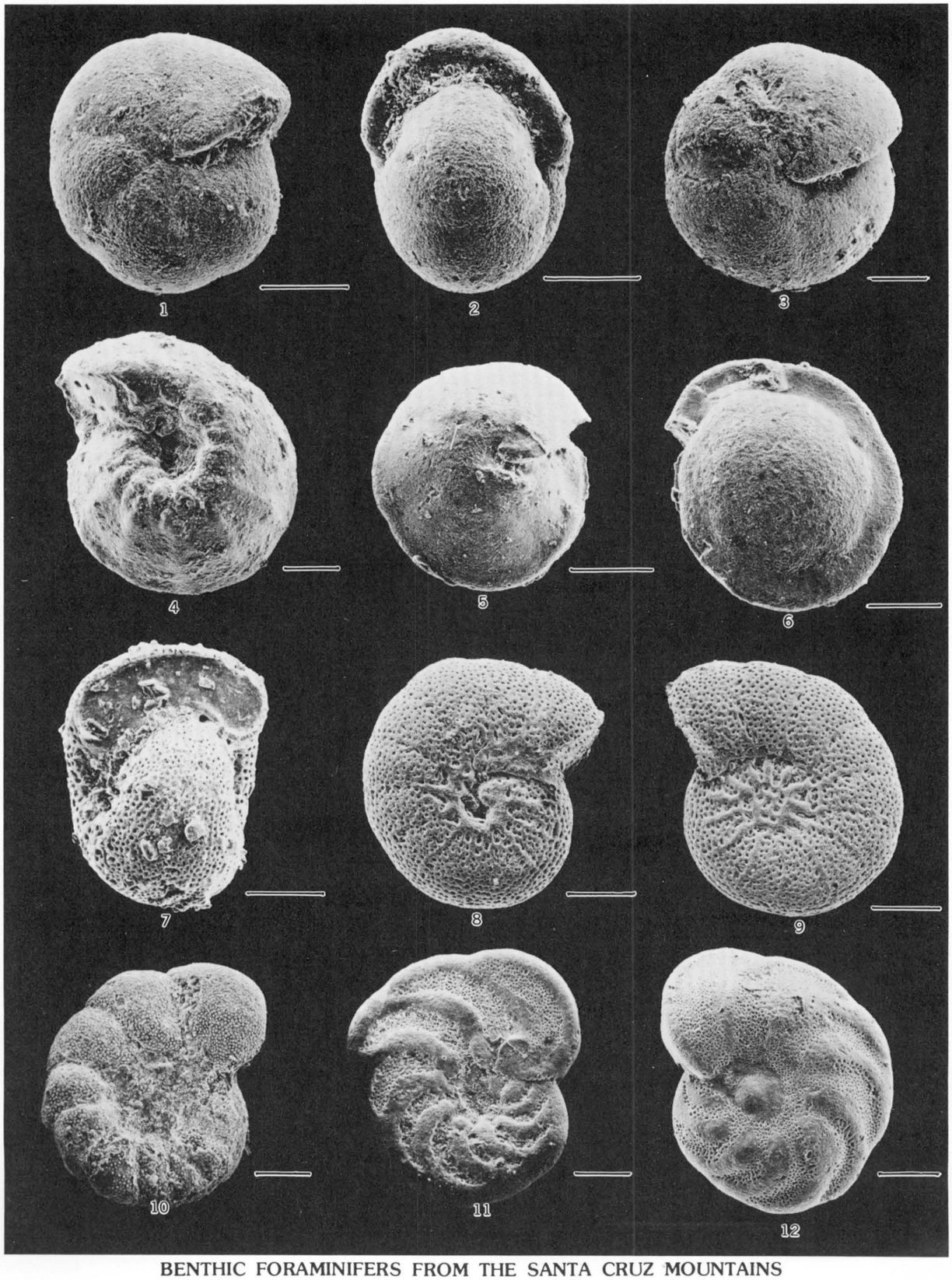
5, 6. *Oridorsalis umbonatus* (Reuss), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262199

7. *Anomalina californiensis* Cushman and Hobson, Mf4665 (field no. 76CB1532), Año Nuevo section. Bar equals 100 μm. USNM no. 262200

8, 9. *Anomalina garzaensis* Cushman and Siegfus, Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262201

10. *Anomalina salinasensis* Kleinpell, Mf4661 (field no. 76CB1541), Año Nuevo section. Bar equals 100 μm. USNM no. 262202

11, 12. *Boldia hodgei* (Cushman and Schenck), Mf3304 (field no. 76CB1451), San Lorenzo River section. Bar equals 100 μm. USNM no. 262203



BENTHIC FORAMINIFERS FROM THE SANTA CRUZ MOUNTAINS


DEPARTMENT OF THE INTERIOR
U.S.
March 3, 1849