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## Part 2

# EARLY NEOGENE FORAMINIFERA AND ASSOCIATED MICROFOSSILS OF THE CERRO TIERRA BLANCA MEMBER (EL CIEN FORMATION), BAJA CALIFORNIA SUR, MEXICO

By

*Ana Luisa Carreño*

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## ABSTRACT

The foraminifera and associated microfossils from the type section of the Cerro Tierra Blanca Member (El Cien Formation), supposedly of late Oligocene age, indicate these strata to be of latest Oligocene to late Miocene age.

The analysis done from the sequence demonstrates several stratigraphic discontinuities that, associated with the scarce geological information from the area, are indicative of structural complexities not detected during the establishment of the type section. It was impossible to determine the stratigraphical relation between the strata studied and the supposed two other members of the formation for the same reasons—at El Cien—as well as with other sequences that crop out at El Cien-San Hilario, La Purísima or San Juan de la Costa.

The micropaleontological assemblage suggests initial subsidence and deposition of early Miocene volcanics and shelf marine clastics, followed by deposition of upper-bathyal diatomaceous sediments during earliest late Miocene. The observed microfossils are a mixture of low- and high-latitude species, such as the ones found at present, near the distal end of the California current off Baja California Sur, and indicate periods of low and high fertility. Based on the present results, it is not possible to determine if the El Cien Formation is a valid name for the beds surrounding El Cien, nor for those to the east.

Key words: Micropaleontology, Neogene, Baja California Sur, Mexico.

## RESUMEN

El conjunto de foraminíferos y microfósiles asociados, provenientes de la sección tipo del Miembro Cerro Tierra Blanca, de la Formación El Cien, considerado como oligocénico tardío, proporcionó evidencia para considerar a estas capas como oligocénicas tardías a miocénicas tardías.

El análisis de esta secuencia demostró la presencia de varias discontinuidades estratigráficas que, debido a la escasa información geológica del área, sólo pudieron ser inferidas como indicativas de complejidades estructurales, las cuales no fueron observadas durante el establecimiento de la sección tipo. Por esta misma razón, no fue posible determinar las relaciones estratigráficas que guardan los estratos estudiados con los otros dos miembros pertenecientes a esta formación, así como con las secuencias que afloran en las áreas de El Cien-San Hilario, La Purísima o San Juan de la Costa.

La información derivada de los microfósiles sugiere, para el área en general, subsidencia inicial y depósito durante el Mioceno temprano de material clástico marino de plataforma así como volcánico, seguido por depósitos diatomíticos de facies más profundas durante el Mioceno tardío basal.

Por otra parte, los microfósiles en su conjunto corresponden a una mezcla de especies de latitudes altas y bajas, muy similares a los conjuntos presentes cerca del límite distal de la actual corriente de California, mostrando períodos de fertilidad baja y alta.

Por último, con base en los resultados del presente estudio, no fue posible determinar si el nombre de Formación El Cien es válido para referirse a las capas que afloran en el área de El Cien y aquéllas hacia el este.

Palabras clave: micropaleontología, Neógeno, Baja California Sur, México.

## INTRODUCTION

Since Beal's (1948) and Mina's (1957) geological work, no major reconnaissance of the extensive Neogene marine deposits of Baja California Sur has been published, even though a great deal of attention has been focused in both the origin and evolution of the Gulf of California (Larson ***et al.***, 1968; Moore and Buffinton, 1968; Normark and Curray, 1968). The Tertiary marine deposits recognized to date in Baja California Sur have not been extensively studied, yielding only limited points of view about the marine events and their depositional and structural histories.

Applegate (1986), after his work in the El Cien area, documented the existence of a marine-continental sequence deposited during late

Oligocene-early Miocene time. He formally proposed that this sequence should be named the El Cien Formation. In that paper, there was a discussion concerning the validity of applying other formational names proposed in the past by several authors for the sediments of the El Cien area. The author came to the following conclusions: first, that the San Gregorio Formation of Beal (1948) is a valid name but should be restricted to the La Purísima area outcrops, located to the north of El Cien; second, that the Monterey Formation, of Blake (1856), does not exist in Baja California Sur; and third, that the Isidro Formation described by Heim (1922), as well as the San Ignacio and San Raymundo formations, named by Mina (1957), are of middle Miocene age and have not been found at the El Cien area and are not part of the El Cien Formation.

There are several reports on the upper Oligocene-lower Miocene marine sediments from the El Cien area, that represent isolated efforts to understand the complex stratigraphy of this region (Darton, 1921; Heim, 1922; Hanna, 1927; Applegate and Wilson, 1976; Hausback, 1984; Kim and Barron, 1986; Wilson, 1986; Kim, 1987).

The main objective of this study is to document the foraminifera and associated microfossils from the base of the type section of El Cien Formation—Cerro Tierra Blanca Member—and to combine the results of this study with the work by Kim and Barron (*op. cit.*) and Kim (*op cit.*), to present an interdisciplinary study of marine sections assigned to the upper Oligocene-lower Miocene in the Pacific Province south of the 30°N.

## STUDY AREA AND METHOD

El Cien Formation crops out over an extensive area of Baja California Sur, from Rancho el Aguajito, located 68 km to the north of La Paz, to as far as 40 km north of La Fortuna (Applegate, 1986; Plate 1). The larger area of exposed sediments occurs at both sides of the Transpeninsular Highway No. 1, from Km 100 to 120. The type section of El Cien Formation—137 m thick—was measured by Applegate (*op. cit.*) and lies at the western side of Cerro Colorado, located 5 km to the northeast of Pénjamo. It was lithologically described as siliceous shales, tuffs, limestones, sandstones, sandy shales, porcellanites, gypsumiferous sand, phosphoritic beds and conglomerates, and has variations in color from white and tan to green and brown. The stratigraphic sequence has "an average dip of 16° toward 82° to the east" and was subdivided into three units named, from the base to the top, Cerro Tierra Blanca Member, San Hilario Member and Cerro Colorado Member.

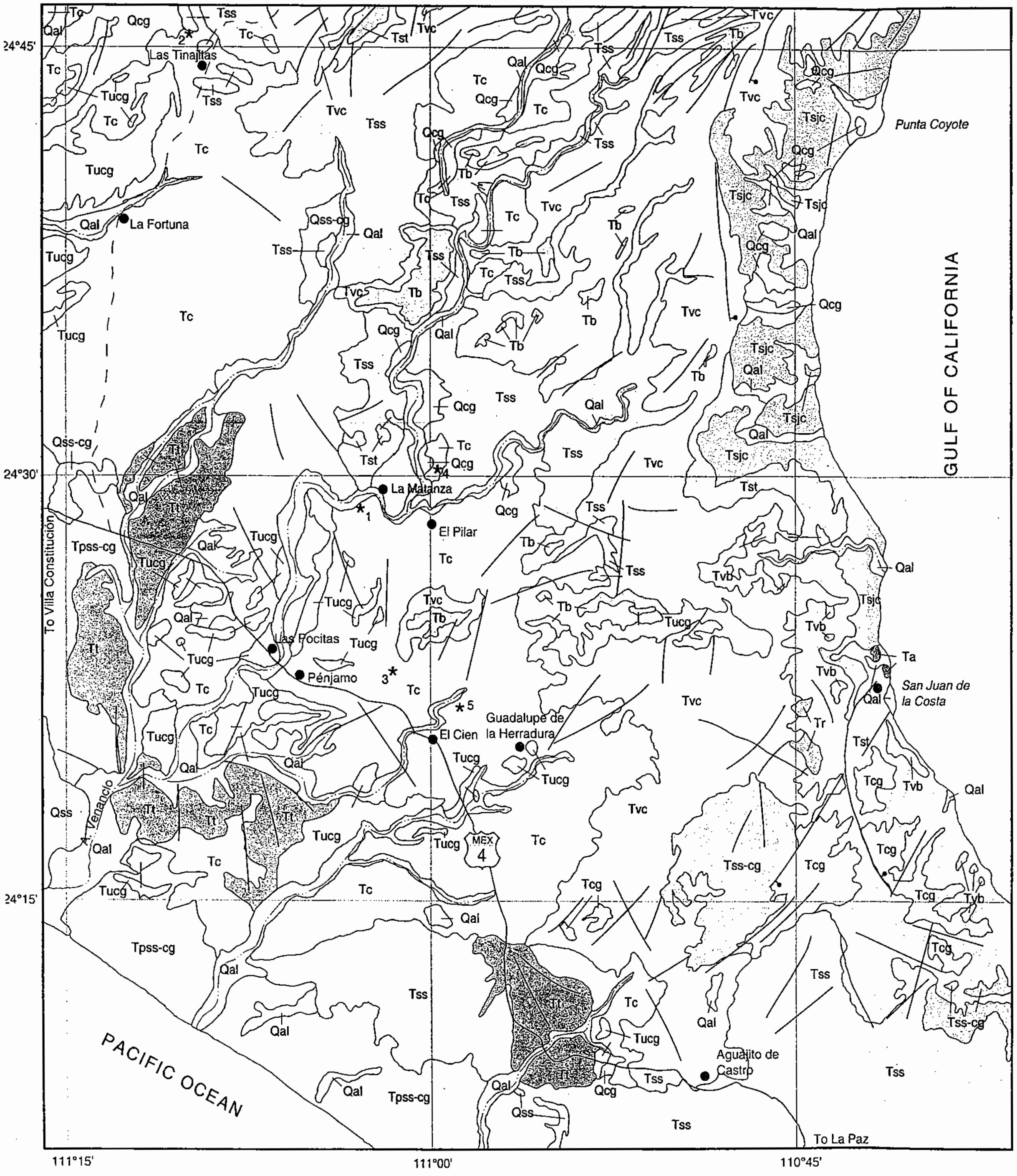
Throughout the type section, 50 samples were collected by Applegate, who gave them to the present author for micropaleontological study. Of these, only some of the 26 samples collected from the Cerro Tierra Blanca Member contain microfossils and constitute the basis of the present study. Applegate's lithological description of the type section of the Cerro Tierra Blanca Member has been slightly modified by the author, based on petrological work and it can be described as follows, from the base to the top: a volcanic-pebble conglomerate with sandy matrix, followed by five sandstone beds that become finer upwards with abundant calcareous concretions, covered by two levels of sandy tuff and continuous beds of silty shale, sandstone, diatomaceous shale, sandy tuff and shales (Figure 1). The top of the Cerro Colorado Member is a hard massive limestone known as Lajas Palo Verde (Ojeda-Rivera, 1979).

## POPULATION STRUCTURE

Where the El Cien Formation crops out, fossils are abundant. Applegate (1986) reports large numbers of marine mammal bones, marine turtle scutes, fish and shark's teeth of the genera ***Isurus*, *Galeocerdo*** and ***Charcharodon***.

At the Cerro Tierra Blanca stratotype, the microfossils are represented by planktonic and benthic foraminifera, ostracodes, calcareous nannoplankton, radiolarians, silicoflagellates, diatoms, sponge spicules, micromollusks—unidentified fragments—ichtyoliths and fish and shark's microteeth. Table 1 shows that the distribution and relative abundance of the microfossils are not consistent.

Microfossils found in samples 1 to 8 are not diagnostic of age. It is not until samples 9 to 23—except for 11, 17, 19 and 23—that the benthic foraminifera and planktonic microfossils have some age significance; therefore, the present author will only refer to those samples in the discussion.



## EXPLANATION

Pleistocene and Holocene

Qal | Qss | Qcg
al-alluvium; ss-sandstone; cg-conglomerate

Qss-cg
Sandstone and conglomerate

Tucg
Conglomerate

Pliocene

Tpss-cg
Sandstone and conglomerate

Miocene

Tb
Basalt

Comondu Group

Tcg
Conglomerate

Tss-cg
Sandstone and conglomerate

Tvc
Volcaniclastics

Tvb
Volcanic breccia of intermediate composition

Tr
Rhyolite

Tst
Siliceous tuff

Tss
Sandstone

Oligocene and Miocene

Tc
El Cien Formation
(Shale, tuff, limestone, sandstone and conglomerate)

Tsjc
San Juan de la Costa Formation
(Phosphatic sandstone, mudstone, conglomerate and coquina)

Ta
Andesite

Paleocene and Eocene

Tt
Tepetate Formation

* Applegate's (1986) localities: 1–Rancho La Matanza, Loc. IGM 264; 2–Rancho Las Tinajitas, Loc. IGM 1581; 3–Cerro Colorado, Loc. IGM 1564, and Harley Hideway, Loc. IGM 290; 4–Cerro de la Estaca, Loc. IGM 1580 (El Pilar, Loc. 48, Gastil*et al.*, 1979); 5–Ten Minute, Loc. IGM 130, and LACM 1564

Geological information slightly modified from INEGI (1984)

0 10 km

Color separation was make electronically by Juan Manuel López and Jerjes Pantoja-Irys; initial drafting by Enrique Gutiérrez-Nav arrete

GEOLOGIC MAP SHOWING THE LOCATION OF THE EL CIEN FORMATION TYPE SECTION (*3) AND THE GEOGRAPHIC DISTRIBUTION OF THIS FORMATION (FROM APPLEGATE, 1986)

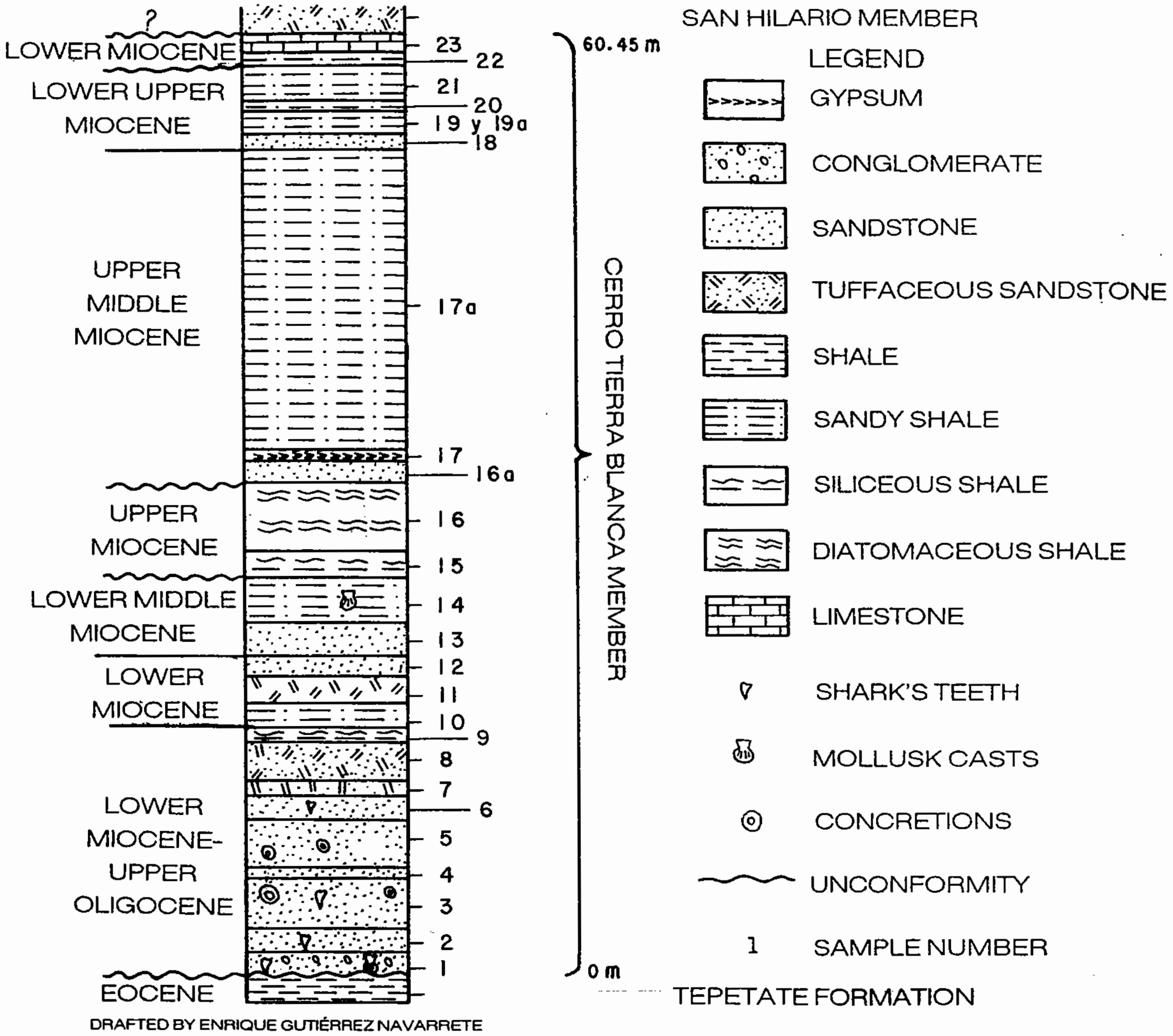


Figure 1.- Composite type section of the Cerro Tierra Blanca Member of the El Cien Formation at Cerro Colorado (unit numbering modified from Applegate, 1986). Ages for samples 1 to 9 are based on data from Applegate (*op. cit.*); up section in microfossils herein studied.

Generally, it was found that benthic foraminifera are more conspicuous in the middle and upper parts of the member, while calcareous nannoplankton is more frequent in only the upper part of it. The siliceous microfossils—diatoms and radiolarians—are most abundant in the middle part and this abundance is inversely related to the distribution of the calcareous microfossils.

Table 1.- Microfossil distribution throughout the Cerro Tierra Blanca Member. Abundance was estimated for each group, with different technique. A—abundant; C—common; R—rare; *—very rare.

| SAMPLE<br>GROUP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 16a | 17 | 17a | 18 | 19 | 19a | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Benthic foraminifera |  |  |  |  | R |  |  |  |  | A |  | R | A | A |  |  | A |  | A | A |  |  |  |  | A |  |
| Planktonic foraminifera |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | A |  |
| Coccoliths |  |  |  |  |  |  |  |  |  |  |  |  |  | C |  |  |  | C | C |  |  | C | C | C | A |  |
| Discoasters |  |  |  |  |  |  |  |  |  |  |  |  |  | R |  |  |  | C | R |  |  | R | R |  | A |  |
| Ostracodes |  |  | * | * |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Radiolarians |  |  |  |  |  |  |  |  | C | C |  | * |  |  | C | A | * |  | R | R |  |  |  |  |  |  |
| Diatoms |  |  |  |  |  |  |  |  | R | R |  | * |  |  | C | A | * |  |  |  |  |  |  |  |  |  |
| Ichthyoliths | C |  |  |  | C | C |  |  | C |  |  |  |  |  |  |  |  |  |  | C |  |  |  |  |  |  |
| Micromollusks | C | R |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Spicules |  |  |  |  |  |  |  |  | A | A |  | A |  |  | A | A | A |  |  |  |  |  |  |  |  |  |
| Fish's teeth | A | A |  | C | C | C |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Shark's teeth | A |  | R | C | C | C |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

## PRESERVATION

Because of the poor preservation and selective destruction by corrosion and overgrowth, it was impossible to identify with certainty several of the important index fossils. Many authors attribute the early diagenesis of carbonate to the fact that the calcareous ooze in many sites was deposited in deep water below the lysocline; moreover, Roth and Thierstein (1972) pointed out that the nannoplankton assemblage recovered from calcareous ooze at a depth of less than 150 m subbottom shows hardly any signs of overgrowth, but most assemblages from below the 150 to 200 m show overgrowth.

At the Cerro Tierra Blanca Member, the calcareous nannoplankton deposited in shallow water (neritic depth zone) shows evident signs of dissolution and overgrowth, particularly discoasters, which is the most resistant group, while intermediate in resistance to solution forms as ***Reticulofenestra*** and ***Helicosphaera*** are well preserved. Calcareous nannoplankton deposited in moderate deep water (upper-bathyal depth zone) are unaltered specimens; therefore, corroded and overgrown specimens arise from deposition well above the zone of calcium carbonate compensation (CCD).

Because the nannoplankton from the Cerro Tierra Blanca Member came mostly from friable sediments, lithification is not the cause of the early diagenesis in nannoplakton.

Plate 9 (figures 2, 3) and Plate 10 (figures 2, 3) show different ***Reticulofenestra*** species with the delicate grill which covers the central openings well preserved, and only in some cases the central areas appear blocky due to overgrowth with secondary calcite (Plate 10, figure 1). Secondary overgrowth on ***Discoaster deflandrei*** is shown in Plate 12 (figure 2, a, b, d, e). This calcite must have been derived from the ***in situ*** dissolution of other calcareous nannofossils that were not recorded at all as holococcoliths—and possibly planktonic foraminiferal tests—because there is not apparently any other source of calcite near the deposition area.

In any way, no satisfactory explanation could be emitted if we consider that, in general terms, the degree of overgrowth in a sediment of a certain type depends on the depth of burial. In view of the actual knowledge on early deep sea diagenesis the author is inclined to believe that, as Wise (1973) suggested, the bottom water condition during middle Tertiary times might have been more favorable for early dissolution and reprecipitation of skeletal calcite than are bottom waters today.

## REWORKING

Other problem affecting age determinations includes reworking of lower-middle Miocene fossils and older—particularly from the Paleogene—into the middle and upper Miocene. The most critical problem is at Oligocene-Miocene boundary, where Miocene index species are missing due probably to dissolution and dilution. Several index Oligocene species, as ***Dyctiococcytes bisectus*** are present, as well as species of ***Pyrocyclus*** and ***Chiasmolithus***; while in younger units it was possible to discriminate the reworked species because of the presence of younger index species. Due to these inconveniences, those strata were assigned to the latest Oligocene-early Miocene.

## SOME AGE CONSIDERATIONS BASED ON MACROFOSSILS

None of the previously recorded macrofossils from the Cerro Tierra Blanca Member, studied or in progress, seems to be age diagnostic; nevertheless, some approximations can be made, as result of their assemblage.

The mollusks are only found at the basal conglomerate—Harley's Hideway, locality IGM 290—and in sample 14. The assemblage is represented mostly by incomplete specimens of ***Vertipecten*** sp. cf. ***V. alexclarki*** Addicott, ***Oppenheimopecten*** sp. cf. ***O. santacruzensis*** Arnold, species that could be indicative of an Oligocene-Miocene age, together with ***Turritella inezana*** Conrad, which is characteristic of an early Miocene age, and ***Anadara (Cunearca) vanderhoofi*** Durham, which is assumed to be a late Oligocene species.

Applegate (1986) compared the shark's teeth of the genera ***Galeocerdo*** and ***Hemipristis***, collected in the basal bed of the Cerro Tierra Blanca Member, with those from the same genera found at the San

Hilario Member, and determined that the latter morphotypes are more advanced. The same author came to the conclusion that middle Miocene shark's teeth from several Baja California localities show important evolutionary changes when compared with the San Hilario Member assemblage, suggesting a considerable time span between these faunas; therefore, he assigns a late Oligocene age to the Cerro Tierra Blanca forms.

## CALCAREOUS MICROFOSSILS

The benthic foraminifera species (Table 2) from samples 9 to 12 are not diagnostic of age; the assemblage contains species such as ***Buliminella subfusiformis*** Cushman, ***Nonion incisum*** (Cushman), ***Baggina*** sp. cf. ***B. robusta*** Kleinpell and ***Oridorsalis umbonatus*** (Reuss), that based on Kleinpell (1938, 1980) have their first stratigraphic occurrences during the Oligocene or older times. The abundance of ***Valvulineria miocenica*** (Cushman), ***Nonion costiferum*** (Cushman) and the presence of ***Bolivina marginata adelaidana*** Cushman and Kleinpell, and the scarce record of ***Lenticulina mayi*** (Cushman and Parker) and ***L.*** sp. cf. ***L. beali*** (Cushman) suggest an age equivalent to the top of the Saucesian or the Relizian (lower Miocene).

On top of the section—samples 13 and 14—a ***Valvulineria*** flood occurs with many transitional forms, including ***V. miocenica*** and ***V.*** sp. cf. ***V. depressa*** (Cushman). This assemblage is indicative of a middle Miocene age; however, these species are associated with others such as ***Baggina subinequalis*** Kleinpell and ***Gyroidina soldanii rotundimargo*** K.E. and K.C. Stewart, which have their first occurrence in the early Mohnian, indicating an earliest middle Miocene age. Also present is ***Virgulina californiensis ticeensis*** Cushman and Kleinpell, which is restricted to the ***Bolivina modeloensis*** Zone of Kleinpell (1938, 1980).

Samples 16a, 17a and 18 contain almost the same assemblage, except for the absence of ***V. californiensis ticeensis*** and for the abundance of ***Uvigerina subperegrina*** Cushman and Kleinpell and ***U.*** sp. cf. ***U. peregrina*** Cushman, that could be indicative of the middle Mohnian or middle Miocene.

Table 2.- Distribution of ostracoda and benthic and planktonic foraminifera throughout the Cerro Tierra Blanca Member. On the basis of 300 specimens per sample: *= 1-5 specimens; R= 6-25 specimens; C= 26-100 specimens; A= 101-200 specimens; VA= 201-300

| SPECIES / SAMPLE | 1-3 | 4 | 5 | 6-9 | 10 | 11 | 12 | 13 | 14 | 15-16 | 16a | 17 | 17a | 18 | 19-21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cytherella* sp. | | R | * | | | | | | | | | | | | | | |
| *Echinocythereis* sp. | | * | | | | | | | | | | | | | | | |
| *Trachyleberis* s. l. | | * | | | | | | | | | | | | | | | |
| *Baggina subinequalis* | | | | | | | | C | C | | C | | C | C | | | |
| *B.* sp. cf. *B. robusta* | | | | | | C | C | C | C | | R | | R | R | | A | |
| *Bolivina advena* | | | | | | | | R | R | | | | | | | R | |
| *B. marginata adelaidana* | | | | | | | | | R | | | | | | | C | |
| *B. subadvena acuminata* | | | | | | | | | R | | A | | | C | | C | |
| *Buliminella brevior* | | | | | | | | | | | | | | | | R | |
| *B. elegantissima* | | | | | | | | C | C | | R | | | | | A | |
| *B. subfusiformis* | | | | | A | A | | R | C | | C | | R | C | | A | |
| *Cassidulina* sp. cf. *C. californica* | | | | | R | | | | | | | | | | | C | |
| *Cassigerinella chipolensis* | | | | | | | | | | | | | | | | VA | |
| *Chiloguembelina* sp. group *cubensis* | | | | | | | | | | | | | | | | C | |
| *Globigerina bulloides bulloides* | | | | | | | | | | | | | | | | VA | |
| *G. ciperoensis angustiumbilicata* | | | | | | | | | | | | | | | | R | |
| *G. ciperoensis* s. l. cf. *G. ouachitaensis ciperoensis* | | | | | | | | | | | | | | | | R | |
| *G. pseudociperoensis* | | | | | | | | | | | | | | | | R | |
| *G. quadrilatera* | | | | | | | | | | | | | | | | VA | |
| *Globorotalia obesa* | | | | | | | | | | | | | | | | R | |
| *G. opima nana-G. continuosa* | | | | | | | | | | | | | | | | R | |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Guttulina* sp. | | | | | R | | | R | R | | | | | | | R | |
| *Gyroidina soldanii rotundimargo* | | | | | | R | | | R | | A | | | C | | | |
| *Lagena hispida* | | | | | | R | | | | | | | | | | R | |
| *Lenticulina cushmani* | | | | | | C | C | R | R | | | | R | A | | C | |
| *L. mayi* | | | | | | R | | | | | | | | | | | |
| *L. smileyi* | | | | | R | R | | | | | C | | R | R | | C | |
| *L.* sp. cf. *L. beali* | | | | | | R | | | | | | | | R | | R | |
| *Nodogenerian irregularis* | | | | | | | | | | | | | | R | | R | |
| *Nonion costiferum* | | | | | A | A | | C | | | | | | | | | |
| *N. incisum* | | | | | A | A | C | | | | VA | | R | | | C | |
| *Nonionella cushmani* | | | | | R | VA | | | | | | | | | | C | |
| *Oridorsalis umbonatus* | | | | | R | C | C | R | C | | | | R | VA | | R | |
| *Plectofrondicularia californica* | | | | | | | | | | | | | | | | R | |
| *Siphogenerina* sp. | | | | | | | | R | R | | | | R | R | | | |
| *Uvigerina obesa* | | | | | | | | R | R | | | | | | | | |
| *U. subperegrina* | | | | | | | | C | C | | | | VA | VA | | | |
| *U.* sp. cf. *U. peregrina* | | | | | | | | | | | | | A | A | | | |
| *Valvulineria miocenica* | | | | | | | A | VA | VA | | VA | | VA | VA | | | |
| *V.* sp. cf. *V. depressa* | | | | | | R | R | C | C | | C | | C | C | | R | |
| *Virgulina californiensis ticeensis* | | | | | | | | R | R | | | | | | | | |
| *V. schreibersiana* | | | | | | | | | | | | | R | | | C | |
| *V. subsquamosa* | | | | | | | | | R | | R | | | | | R | |

Surprisingly, the last sample that contains benthic foraminifera—sample 22—does not contain any diagnostic species of Mohnian age. The assemblage is dominated by ***Bolivina***, ***Nonion*** and ***Lenticulina***, particularly ***L.*** sp. cf. ***L. beali*** and ***L. smileyi*** Kleinpell. According to Kleinpell (1938), ***L. beali*** has its first occurrence at the top of the Saucesian stage—lowermost Miocene—while ***L. smileyi*** Kleinpell has a restricted occurrence at the base of the Relizian. Age ranges of ***Lenticulina*** spp. are not as well documented (G.H. Blake, written communication, July 31, 1989) as Kleinpell (***op. cit.***) would believe; nevertheless, the benthic foraminifera assemblage in this sample seems to be not younger than earliest Miocene.

This older age provides some evidence of an unconformity that will be discussed later.

Planktonic foraminifera are only present in sample 22, collected at the upper part of the Cerro Tierra Blanca Member (Table 2). The whole assemblage is composed of very delicate foraminifera shells with translucid chambers; many of them have the last chamber broken. Signs of dissolution are evidenced by the abundance of corroded shells. The dominant species are represented by ***Globigerina bulloides bulloides*** d'Orbigny, ***Globigerina quadrilatera*** Galloway and Wissler and many other of the ***Globigerina bulloides*** plexus, that provide no significant stratigraphic information.

However, the abundance of ***Cassigerinella chipolensis*** (Cushman and Ponton) is representative of the N14 Zone of Blow (1969), while sparse specimens of ***Globorotalia obesa*** Bolli extend the age range of the sample to the N15 Zone; both zones are from the upper part of the middle Miocene. These foraminifera are associated with rare ***Globigerina pseudociperoensis*** Bolli (***in*** Blow, 1969) and specimens of ***Globorotalia*** are very close to the species considered by Bolli and Saunders (1982) as transitional forms between ***Globorotalia opima nana*** Bolli and ***Globorotalia continuosa*** Blow. This assemblage ranges in age from N4 to N5—lower Miocene—Zones of Blow (***op. cit.***). In addition, the sample contains common ***Chiloguembelina*** sp. group ***cubensis*** Palmer, whose maximum range—for the group—is Zone N4, approximately. Kennett and Srinivanson (1983) proposed that this genus continues throughout the early Miocene and later is probably the origin of the genus ***Streptochilus***.

This evolutionary trends support an earliest Miocene age that agrees with the evidence provided by the benthic foraminifera in this sample.

Calcareous nannoplankton is present in only eight samples, and is generally very abundant, with the exception of samples 14 and 21 (Table 3). Despite their abundance, species exhibit both overgrowth and dissolution, making their identification difficult.

According to the species ranges given by Perch-Nielsen (1985), the presence in samples 14 and 19a of rare species of ***Reticulofenestra*** and ***Discoaster deflandrei*** Bramlette and Riedel can not give a restricted age assignment; while for sample 17, the co-occurrence of the last mentioned species together with ***Cyclicargolithus abisectus*** (Müller), suggest a late Oligocene-early Miocene age. In samples 17a to 18, the assemblage is dominated by several species of ***Reticulofenestra*** e.g. ***R.*** sp. aff. ***R. clatrata*** Müller, ***R.*** sp. cf. ***R. gartneri*** Roth and Hay, ***R.*** sp. cf. ***R. insignita*** Roth and Hay and the very abundant ***R. pseudoumbilica*** (Gartner). In addition, associated with those species are ***Cyclicargolithus floridanus*** (Roth and Hay), ***D. deflandrei***, and rare specimens of ***D. variabilis*** Martini and Bramlette. This flora suggests assignment to the upper part of the early Miocene Zone CN3/NN4, according to Bukry (1973).

Samples 20 to 21 are characterized—particularly sample 20—by abundant discoasters and fewer coccoliths; however, ***R. pseudoumbilica*** is the dominant form. The assemblage also contains ***Discoaster variabilis***, ***D. surculus*** Martini and Bramlette and the isolated occurrence of ***D.*** sp. aff. ***D. bellus*** Bukry and Percival. This assemblage is indicative of a late Miocene age.

The presence of ***Cyclicargotithus abisectus*** (Müller), ***Cy. floridanus***, ***Reticulofenestra*** sp. aff. ***R. clatrata***, ***R.*** sp. cf. ***R. insignita***, together with ***Discoaster adamanteus*** Bramlette and Wilcox and ***D.*** sp. aff. ***D. obtusus*** Gartner (Gartner, 1967) strongly suggest an older age, such as the late Oligocene to earliest Miocene for sample 22, and is in agreement with foraminifera age data.

If ***Dyctiococcites bisectus*** (Hay, Mohler and Wade) is not a reworked species like in other samples, its presence in this sample is indicative of a late Oligocene age.

The presence of ostracodes and micromollusks is considered insignificant because of their scarcity—and mainly occasional occurrences—

Table 3.- Distribution of calcareous nannoplankton throughout the Cerro Tierra Blanca Member. Species abundance is recorded as the logarithm of the abundance in a smear slide view at x 1,000. -2 = a single specimen in 100 fields of view; -1 = a single specimen in 10 fields of view; 0 = a single specimen in a field of view; * specimens considered reworked.

| **SAMPLE**<br>**SPECIES** | 1-13 | 14 | 15-16a | 17 | 17a | 18 | 19 | 19a | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Braarudosphaera bigelowii* | – | -2 | – | 0 | 0 | +1 | – | – | – | – | – | – |
| *B. discula* | – | -1 | – | 0 | 0 | +1 | – | – | – | – | – | – |
| *Chiasmolithus* sp. | – | – | – | – | – | – | – | – | – | – | * | – |
| *Coccolithus pelagicus* | – | – | – | – | – | – | – | – | -1 | – | – | – |
| *Cyclicargolithus abisectus* | – | – | – | -1 | * | * | – | -2 | * | – | -1 | – |
| *Cy. floridanus* | – | – | – | – | -2 | 0 | – | -1 | * | – | -1 | – |
| *Dictyococcites bisectus* | – | – | – | – | – | – | – | – | – | – | *? | – |
| *Discoaster adamanteus* | – | – | – | – | – | – | – | – | – | – | -1 | – |
| *D. barbadiensis* | – | – | – | – | – | – | – | – | – | – | * | – |
| *D.* sp. aff. *D. bellus* | – | – | – | – | – | – | – | – | -2 | – | – | – |
| *D. deflandrei* | – | -2 | – | -1 | -1 | -1 | – | – | – | – | 0 | – |
| *D.* sp. aff. *obtusus* | – | – | – | – | – | – | – | – | – | – | – | – |
| *D. surculus* | – | – | – | – | – | – | – | – | -1 | – | – | – |
| *D. variabilis* | – | – | – | – | – | -2 | – | – | -2 | -2 | – | – |
| *Helicosphaera* sp. cf. *H. rhomba* | – | – | – | – | – | – | – | – | -2 | -2 | – | – |
| *H. sellii* | – | – | – | – | – | – | – | – | -2 | -2 | – | – |
| *Pontosphaera multipora* | – | – | – | – | – | – | – | – | -1 | – | – | – |
| *P.* sp. cf. *P. discopora* | – | – | – | – | – | – | – | – | -2 | – | – | – |
| *Pyrocyclus*? sp. | – | – | – | – | – | – | – | – | – | – | * | – |
| *Reticulofenestra pseudoumbilica* | – | – | – | – | -2 | -1 | – | – | -1 | -2 | – | – |
| *R.* sp. aff. *R. clatrata* | – | -2 | – | – | – | * | – | – |  | – | -2 | – |
| *R.* sp. cf. *R. gartneri* | – | – | – | -1 | -2 | -2 | – | – | * | – | -2 | – |
| *R.* sp. cf. *R. laevis* | – | – | – | -2 | – | * | – | – | – | – | -2 | – |
| *R.* sp. cf. *R. insignita* | – | -2 | – | – | – | * | – | – | – | – | -2 | – |
| *Transversopontis* sp. | – | – | – | – | – | – | – | – | – | – | * | – |

besides, their poor preservation does not allow a taxonomic specific level assignment and therefore no significant information. All important calcareous microfossils are illustrated in Plates 1 to 11.

## SILICEOUS MICROFOSSILS

Radiolarians, diatoms and silicoflagellates in the Cerro Tierra Blanca Member are not continuously present. Radiolarians were too rare to be diagnostic; nevertheless, A. Molina-Cruz (oral communication, 1988) considers the whole assemblage to be Miocene.

According to J.A. Barron (written communication, July 25, 1988), the diatoms were too rare in samples 9 and 10 to be age diagnostic; however, sample 15 contains an assemblage that allowed him to make the assignment to Subzone d of the ***Denticulopsis hustedtii-Denticulopsis lauta*** Zone—8.4–8.9 Ma—based on the occurrence of ***Actinocyclus ingens*** Rattray, ***Denticulopsis dimorpha*** (Schrader), ***D. hustedtii*** (Simonsen and Kanaya), ***Delphineis*** sp. cf. ***D. sachalinensis*** (Scheshukova-Poretskaya), ***Rouxia californica*** Peragallo, ***Thalassionema hirosakiensis*** (Kanaya), ***Thalassiossira grunowii*** [= ***Coscinodiscus plicatus*** (Grunow)] and ***T.*** sp. 1 of Barron, 1981.

Sample 16 contains ***Actinoptychus minutus*** Greville, ***Denticulopsis hustedtii***, ***Delphineis*** sp. cf. ***D. sachalinensis***, ***Lithodesmium reynoldsii*** Barron, ***L. minusculum*** Grunow, ***Nitzchia*** sp. cf. ***N. burckliana*** (Schrader), ***N. kanayensis*** Schrader, ***Rouxia californica***, ***Rosiella tataunokuchiensis*** (Koizumi), and ***Thalassiosira*** sp. 1 of Barron, 1981, which are indicative of the lower part of the ***Denticulopsis hustedtii*** Zone (8.4–8.1 Ma). However, sample 16 also contains the silicoflagellate ***Distephanus pseudofibula*** (Schulz), which suggests a younger age, probably the latest Miocene.

The base—conglomerate and samples 2 to 9—of the Cerro Tierra Blanca Member lacks of diagnostic microfossils; according to the mollusks and shark's teeth (Applegate, 1986) found in this part of the section, it is upper Oligocene-lower Miocene in age. Calcareous nannoplankton assemblages indicate the same age for sample 17, a latest early Miocene for samples 17a and 18, an earliest late Miocene for samples 20 to 21, and a late Oligocene and/or early Miocene age for sample 22; as it was discussed before, planktonic foraminifera are only present in this last sample and confirm the same age given by nannoplankton. This points out towards a stratigraphic discontinuity.

Another stratigraphic discontinuity is demonstrated lower in the section, among sample 14, of earliest middle Miocene age, based on calcareous nannoplankton, and samples 15 and 16 of late Miocene age evidenced by diatoms and silicoflagellates. Another conspicuous discontinuities are observed between sample l6 of late Miocene and 16a of late middle Miocene age (Figure 2).

## DISCUSSION

The results of the micropaleontological analysis show several stratigraphic discontinuities; to explain them in general, it is necessary to denote some inconsistencies and divergent opinions among several authors (Beal, 1948; Reyes-Domínguez and Rodríguez-Santana ***in*** Lozano-Romen, 1975; Ojeda-Rivera, 1979; Alatorre-Campos ***in*** López-Ramos, 1982; Gastil ***et al.***, 1979; Hausback, 1984; Kim and Barron, 1986; Kim, 1987), and Applegate (1986), as well as with the evidence from other authors working on the phosphoritic problem. The following paragraphs present the essential facts and show the complexity of the area and the great deal of work that is necessary to carry on in order to solve the differences.

In spite of the absence of geological mapping, an adequate formational scale and general lithological descriptions of the units, Applegate (1986) gave a new formational rank —named the El Cien Formation—to the sediments that crop out at the El Cien-San Hilario area, based on the presence of six conspicuous beds. The Lajas Palo Verde at the top of the Cerro Tierra Blanca Member; four phosphoritic horizons from the San Hilario Member; and the massive sandstone unit at the top of the same member.

The Lajas Palo Verde was described by Ojeda-Rivera (1979) as lenticular, strongly silicified metasomatite, whose stratigraphic level is sometimes upper in the section, and others slightly lower, within his Monterrey sequence—the massive limestone of Applegate (1986).

The phosphoritic facies of Ojeda-Rivera (*op. cit.*) include a main phosphoritic lower horizon—Humboldt's bed of Roca Fosfórica Mexicana—a secondary or upper one—Upper Humboldt—and several lenses of variable thickness distributed throughout the sequence. One of the lenses is a conspicuous phosphatic conglomerate with abundant marine vertebrate bones and shark's teeth, which is in contact with the Tepetate Formation—the Harley's Hideaway locality? Another conspicuous one is a 1-2 m thick local phosphoritic bed, located slightly above the Monterrey (*sic*)-San Isidro contact—Cerro Tierra Blanca-San Hilario members?

Ojeda-Rivera (*op. cit.*) correlates the above mentioned beds with the Lower Monterey Formation of California—early Miocene age—without analyzing the micropaleontological content of the phosphoritic beds.

Recently, work by Isaacs (1987) demonstrated that "...presently the Monterey Formation (and equivalents) extending 1,200 km north to south, from Eureka to Los Angeles and included early Miocene (c18 Ma, Zone NN3) to late Miocene (c6 Ma, Zone NN9) deposits, and though many Monterey sequences cover a much shorter time span and some Pliocene strata have been included locally. Thicknesses range from about 300 to 3,000 m with thicker accumulation for the most part in the late Miocene age...", which agrees with the results of this paper.

The southern California phosphoritic beds were first studied by Dietz and coworkers (1942), who recognized their Miocene age. Later, Woodring and coworkers (1946) studied a phosphoritic horizon from an unconformity between the Valmonte Diatomite and the Malaga Mudstone in Malaga Cove of the Palos Verdes Hill, and obtained a Mohnian-Delmontian age.

Emery (1960) pointed out that the fossil content in phosphorites from California belongs to two distinct groups: the first, characteristic of the upper part of the early Miocene to the basal late Miocene—Relizian, Luisian and Mohnian—and has not early Miocene—Saucesian—or latest Miocene—Delmontian—foraminifera; and the second group represented by late Pliocene to Holocene foraminifera.

D'Anglejan (1965) shows that the presence of apatite at the western coast of Baja California is not the result of direct precipitation from sea water, but is a diagenetic replacement of solid material, preferably rich in carbonate that occurs on an erosional unconformity over middle Miocene rocks.

No reliable ages from the different phosphoritic beds of the El Cien-San Hilario area have been published, and the phosphoritic horizons at the Cerro Colorado type section offer no micropaleontological information. Nevertheless, Alatorre-Campos (*in* Mayoral-Martínez, 1981) reports ***Valvulineria californica*** Cushman and other foraminifera for the middle part of what he calls the Monterrey Formation—El Cien Formation?—species that after Kleinpell (1980) are characteristic of a Relizian or Luisian or of the upper part of the early Miocene-basal middle Miocene

Kim (1987) considers that the planktonic foraminiferal fauna recovered from Arroyo San Hilario is late Oligocene in age—Zone P21-P22 of Blow 1969—because of the presence of ***Cassigerinella chipolensis, Chilogembelina cubensis, Globigerina ouachitaensis ouachitaensis*** Howe and Wallace, ***Globigerinita glutinata*** (Egger), ***G. uvula*** (Ehrenberg) and ***Globorotalia opima opima*** Bolli; whereas the benthic foraminifera at Cerro Colorado and at Arroyo San Hilario were considered indicative of the upper Zemorrian ***Uvigerina sparsicostata*** Zone of Kleinpell (1938, 1980).

Kim (1987) also reports from the Arroyo San Hilario a calcareous nannoplankton assemblage similar to those found in this paper in samples 14, 17 and 19a, considered by him as characteristic of the NP24 to CP19b Zones of Martini (1971) and Okada and Bukry (1980).

Applegate (1986) observed no major geological structures at the El Cien Formation exposures, except by the Aguajitos fault "...that cuts out the lower member of this formation..." He also states that here there are no sediments similar to those from Beal's San Gregorio Formation in the area, and he found no diatomites—by field examination only—in his Cerro Colorado section nor in Arroyo San Hilario. In addition, he noted that the beds that past workers called diatomites are actually white tuffs (Beal, 1948; Ojeda-Rivera, 1979; Alatorre-Campos *in* López-Ramos, 1982).

In fact, the El Cien Formation sequence forms the southwestern flank of a NW-SE oriented wide syncline (Ojeda-Rivera, 1979). Besides the Aguajito fault, at the southeastern edge of the area, the whole region shows extensive normal and lateral faulting (Hausback, 1984, p. 222), evidenced after Ojeda-Rivera (***op. cit.***) by displacement of conspicuous phosphoritic beds and is characterized by horst and graben structures and slight folding (Lozano-Romen, 1975).

Along Arroyo Guadalupe, Reyes-Domínguez and Rodríguez-Santana (*in* Lozano-Romen, *op. cit.*) found a strongly folded and faulted shale sequence that they named Lower Monterrey; to the south, at Arroyo San Hilario, the upper boundary of the same shale sequence is a 3 to 6° angular unconformity followed by the also by them named Upper Monterrey formation; the whole section may be equivalent to the El Cien Formation. Unfortunately, they never mentioned whether or not the upper section is folded.

Another erosional unconformity was pointed out by Ojeda-Rivera (1979, p. 61, fig. 14) at Arroyo San Hilario, within a sandy concretionary horizon between the contact of the upper part of the Monterrey (*sic*) Formation and the San Isidro Formation; and another one (Ojeda-Rivera, *op. cit.*, p. 62, fig. 16) between the upper phosphoritic bed and the lower sandstone, siltstone and shale sequence. At Arroyo San Hilario, Kim and Barron (1986) reported a section which lies unconformably between the Eocene Tepetate Formation and the Miocene Isidro Formation. However, Applegate (1986) always describes El Cien Formation as a conformable continuous stratigraphic sequence.

Based on Applegate (*op. cit.*, p. 150, fig. 3), both the Cerro Tierra Blanca and the San Hilario members are of late Oligocene age, while the Cerro Colorado Member is earliest Miocene in age. Except for *Anadara*? sp., in some strata of the Cerro Colorado Member (Applegate, *op. cit.*, p. 151, fig. 4), sample 28—Applegate's number—and the basal conglomerate—Harley's Hideaway locality—of the Cerro Tierra Blanca (*ibid.*, p. 152, fig. 4), the composite type section shows no abundant invertebrate faunas. Nevertheless, on the basis of the fauna collected from several informal localities not plotted in his map, Applegate (1986) discusses the probable age of the sediments of the El Cien Formation.

The present author considers the Harley's Hideaway locality IGM 290 as lower Miocene—discussed before—while Applegate (1986) mentioned the possibility of its being late Oligocene-lower Miocene in age.

From the San Hilario Member, Applegate (*op. cit.*) mentioned the Ten Minute locality LACM 5044—Los Angeles County Museum locality—where *Pecten* was collected and referred to *Aequipecten andersoni*

(Arnold). He adds: "...but this is evidently a different species, the age is probably Oligocene. From the same beds at Cerro Colorado locality IGM 1564 ***Pecten*** sp. cf. ***Pecten (Pecten) vanvlecki*** Arnold was collected, this species was described from the Vaqueros Formation and could be lower Miocene or Oligocene..." ***(sic)***. At the Museum of the Instituto de Geología collection, the material labeled LACM 5044 consists of several unidentified mollusk molds, and ***Amussiopecten vanvlecki*** that is a long-ranging Oligocene-Miocene species, that could not be indicative of a restricted age.

Later, Applegate (1986) states that he collected at the Ten Minute locality IGM 130 ***Turritella inezana*** Conrad and ***Anadara (Cunearca) vanderhoofi*** Durham, and because the latter was found—north of Punta San Telmo, Durham (1950)—150 feet stratigraphically higher than a ***Cornwallius*** tooth of supposed late Oligocene age (Vanderhoof, 1942), he assumes the same age for the sediments that crop out at the Ten Minute locality.

The above statement is not conclusive because of the endemic character of ***Anadara (Cunearca) vanderhoofi*** and because ***Cornwallius*** has been assigned either to latest Oligocene (Vanderhoff, 1942; Durham, 1950) or early Miocene (Applegate and Wilson, 1976; Gastil ***et al.***, 1979). On the other hand, due to the lower Miocene stratigraphic range of ***Turritella inezana***, the Oligocene age assignment for these beds is doubtful.

The Cerro Colorado Member is represented by Rancho Matanzas locality IGM 264, where Applegate (1986) collected ***Turritella inezana, Turritella ocoyana wittichi*** Hertlein and Jordan, and he assumes, in spite of the middle Miocene restricted range of the last mentioned species, that this fauna should not be younger than early Miocene.

Other Cerro Colorado Member localities correlated by Applegate (***op. cit.***) are: the Cerro de la Estaca locality IGM 1580, assigned by him to the early Miocene due to the presence of ***Turritella*** sp. cf. ***T. inezana bicarina*** Loel and Corey. The same species, together with the characteristic middle Miocene species ***Turritella ocoyana*** Conrad, are also reported from 6 km to the west of Rancho las Tinajitas locality IGM 1581 and assigned to the earliest middle Miocene.

No radiometric data exist from the type section. Applegate (1986, p. 156), based on Gastil and coworkers' (1979) radiometric ages from other localities, proposed the age range for the El Cien Formation between 27 to 20 Ma. From reported radiometric data (Gastil ***et al., op. cit.***) and from the author's point of view, there is only one locality that could be associated with the El Cien Formation. This locality is near El Pilar (Loc. 48 of Gastil ***et al., op. cit.***), where an age of 20.6±1.1 Ma (early Miocene) was obtained from fossiliferous strata with interbedded biotite ash—not plotted in the Plate 1, because the given coordinates 24°26'00"-110°00'00" are off the peninsula. Hausback (1984) also reports K-Ar ages of 25.5±0.4 Ma from a rhyolite tuff located 92 m above the base of Kim and Barron's (1986) late Oligocene diatom evidence, which is also important.

In summary, the following conclusions can be presented:

El Cien-San Hilario Cenozoic sediments are formed by deposition of the Paleocene-middle Eocene Tepetate Formation, which is unconformably overlain by volcanics or equivalents to what McFall (1969) refers to as the El Salto Formation—Loc. 49 at Rancho San Juan, of Gastil and coworkers (1979), and sample number 383-5-5 of Hausback (1984), at Punta San Telmo, among others—deposited prior and possibly coeval with marine deposition of San Gregorio—Lower Monterey or El Cien Formation, in part—that consists of a sequence of interbedded, commonly phosphatic siliceous shale, diatomite, pelletoidal phosphatic sandstone and rhyolite tuff, less diagenetically silicified than in other areas as La Purísima.

These deposits are overlain either conformably or unconformably by a sequence, mainly composed of pebble conglomerate and sandstone, interstratified with reworked pink tuff being primary volcanic deposits absent; above these sediments, the non-marine lowermost Comondú Formation lies conformably and most times in gradational contact with them (Hausback, 1984).

The stratigraphic relation between many of these volcanics and the marine sediments is still obscure; there is no geological mapping, nor petrographical work has been done; the most complete documented work can be found in Hausback (1984). Unfortunately, this paper covers only a part of the El Cien-San Hilario area; nevertheless, it is enough to describe the structural complexity of the area and to give an idea of the amount of field and interdisciplinary work that needs still to be done.

Because of the scarce geological information that is available, it is very difficult to discriminate if the micropaleontologic stratigraphic discontinuities that reflect from this study are caused by structural complexities or by stratigraphical causes, due to the frequency of the unrecorded unconformities, faulting, etc., or because of the sampling control.

It is conclusive that the diatom, foraminiferal and calcareous nannoplankton evidence indicates the existence of well documented late Oligocene sediments (Kim and Barron, 1986; Kim, 1987), supported by radiometric ages (Hausback, 1984); at the same time, the analyses made herein demonstrate that sediments ranging from latest Oligocene to at least earliest late Miocene are present.

Despite their abundance and bad preservation, the mollusks could only be determined as ***confer***. On the other hand, Oligocene species were found together with Miocene ones; the most abundant was ***Anadara (Cunearca) vanderhoffi*** Durham, that is an endemic species. All this lead the author to consider the ages based on these assemblages with restricted confidence. Therefore, the type section of the El Cien Formation, particularly the Cerro Tierra Blanca Member, and the beds that Applegate (1986) correlates with it, have a structural complexity that does not allow demonstration of continuity or conformable deposition.

## PALEOECOLOGICAL APPROACH

Due to the erratical distribution of the macro- and microfossil content throughout the Cerro Tierra Blanca Member, it was only possible to give paleoclimatic and paleoceanographic trends, based on different groups for each different level.

According to M. del C. Perrilliat (oral communication, 1988), the invertebrate fauna labelled as collected at Harley's Hideaway—basal conglomerate—is a shallow marine temperate to tropical association; while after Applegate (1986), the shark's teeth of the same locality are a mixture of deep as well as shallow water faunas and tentatively suggest turbidity slides that carried shallow water fossils into deeper environment; therefore, he concludes that the El Cien Formation, at its type locality, is deep marine at the base of the Cerro Tierra Blanca Member, with species confined to tropical waters with no evidence to support the contention of upwelling.

As noted in the precedent pages, no microfossils were found in the basal conglomerate; nevertheless, two points are considered of importance:

1. The Harley's Hideaway invertebrate collection of the Instituto de Geología is constituted by very poorly preserved sparse mollusks, generally broken and abundant cast and molds, that could well be considered as a mixture of different fossilization processes as well as of transport.

2. The shark's teeth and the invertebrates fauna come from the basal conglomerate at Harley's Hideaway locality IGM 290, from approximately 5 km to the NE of Pénjamo. Applegate (1986, fig. 10) shows an unconformable conglomerate resting over the Tepetate Formation and he does not mention any fossil collection. This conglomerate, located 11 km to the north of El Cien, seems to be formed by well-cemented large boulders, while the material from Harley's Hideaway, at the Museum of the Instituto de Geología, seems to be a volcanic breccia with washed material.

As no macrofossils were found or reported from the higher beds of the Cerro Tierra Blanca Member, the following considerations are based on the microfossil content. During Oligocene or early Miocene—samples 4 and 5—the ostracodes, despite their uncertain specific taxonomic affinity, had a general morphological pattern of their valves indicative of a shallow neritic biofacies, while the benthic foraminifera—samples 10 to 12 and 22—are dominated by species considered by Ingle (1980) as characteristic of inner and outer shelf biofacies (0–150 m). Kim (1987) suggests that benthic foraminifera biofacies at Cerro Colorado and at Arroyo San Hilario represent surface, intermediate, and deep-water masses off Mexico during late Oligocene time—Zemorrian Stage—and littoral, shelf, upper-bathyal, and middle-bathyal water depths, between 10 and 1,500 m. The planktonic foraminifera are dominated by ***Globigerina bulloides plexus***, which constitutes at this latitude a typical species of the present California current, suggesting a cool-water influx, and also by minor species that give to the whole assemblage a temperate character. This mixed condition is supported by nannoplankton, because of its low diversity, and also by the presence of ***Reticulofenestra*** species, ***Cyclicargolithus floridanus*** and ***Discoaster deflandrei***.

The abundance of the highly soluble *Braarudosphaera bigelowii* (Gran and Braarud), associated to the frequency of ***B. discula*** Bramlette and Riedel, support the interpretation of a continental margin shallow-water deposit.

Similar temperate conditions seem to prevail during the upper part of the earliest middle Miocene (samples 13, 14, 17, 18) with a slight tendency to be deeper, because of the abundance of ***Uvigerina, Baggina*** and ***Gyroidina***, species indicative of outer-shelf upper-bathyal biofacies (Ingle, 1980), while nannoplankton represents an assemblage characteristic of temperate waters being always very close to the continental margin.

The late Miocene nannoplankton assemblages (samples 20, 21) indicate, despite the discoaster variety that could suggest little warm-water influx, that a dominant colder condition prevails, or at least a mixed temperate environment, by the presence of abundant ***Reticulofenestra pseudoumbilica*** (Wise, 1973; Bukry, 1978). No ***Braarudosphaera*** was recorded, suggesting a deposit slightly distant from the coast, but always near a continental margin.

Nevertheless, diatoms (samples 15, 16) strongly suggest a cold-water environment. Based on J.A. Barron (written communication, July 25, 1988), the diatom assemblage corresponds or is associated to the cool-water California current.

The interpretation of a continental-margin deposit is strengthened because neither amauroliths nor ceratoliths were recorded, and these are open-ocean characteristic forms, and by the virtual absence of nassellarians in samples that contain radiolarians (A. Molina-Cruz, oral communication, 1988).

The change to deeper conditions is associated with lithological changes; the shallow deposits correspond to sandstone, while the deeper ones are shale or diatomaceous shale that could be also associated with changes in submarine topography and/or related to current circulation variations evidenced by diatomaceous sediments of late Miocene age, in contrast with older deposits that lack siliceous microfossils and even planktonic foraminifera. All these suggest deposition from a distal boundary of the California current and therefore low fertility.

No anaerobic restricted basin environment associated with benthic foraminifera was found at the Cerro Tierra Blanca Member; nevertheless, the occurrences of authigenic phosphorite as a significant sedimentary character suggest intersection of the oxygen minimum layer with the continental margin. Phosphoritic beds have been reported throughout the area, including several strata reported in this paper, indicating the possibility of this type of environment being associated to the Cerro Tierra Blanca Member or to the upper sections (Kim, 1987).

## CONCLUSIONS

Under micropaleontological basis, a latest Oligocene to basal late Miocene age was demonstrated for the Cerro Tierra Blanca Member—at its type locality—of the El Cien Formation, originally supposed to be late Oligocene.

The formational name given by Applegate (1986) was used by him to substitute San Gregorio (Beal, 1948), Monterey (Blake, 1856) and Isidro (Heim, 1922), names that have been used for the strata that crop out at the El Cien-San Hilario area. Based on results from the present paper, it is not possible to determine if the El Cien Formation is a valid name for the beds surrounding and those to the east of the El Cien, Baja California Sur.

The micropaleontological study herein also demonstrates several stratigraphic discontinuities, whose interpretation becomes difficult either due to scarce geological information, absence of geological mapping or petrological work done at the type section; therefore, correlation of the Cerro Tierra Blanca Member with the San Hilario and Cerro Colorado members of the El Cien Formation—at its type locality—and with the El Cien-San Hilario area sediments, as well as with those from the San Juan de la Costa or La Purísima and the relationship with the volcanic units, is still obscure.

The current geological information, together with the micropaleontological results obtained, render enough evidence for a discontinuity or unconformable deposition of the Cerro Tierra Blanca Member.

McLean and coworkers (1984) and Kim and Barron (1986) have demonstrated the existence of late Oligocene sequences deposited at upper-bathyal depths. In contrast, Smith (1984), Kim (1987) and this paper have found the shallow character of the unconformably overlain

Miocene sequence, which is also supported by Hausback (1984), who recognizes either an abrupt period of uplift or a gap in the deposition record.

The microfossil content of the Cerro Tierra Blanca Member suggests shallow water depths during early Miocene, to upper bathyal during earliest late Miocene, in a mixed temperate environment associated at least with the distal boundary of the California current.

The phosphoritic horizon abundance reported at El Cien-San Hilario, San Juan de la Costa, and off the peninsula of Baja California, and recently at Santo Domingo, in Baja California Sur, suggests the possibility of their association with an oxygen minimum environment.

From the data presented in this paper, it is concluded that the Cerro Tierra Blanca Member fits partially on Ingle's (1981) Neogene basinal deposition cycle, represented by initial subsidence and deposition of Oligocene-lower Miocene volcanics, continental and/or shallow marine clastics, followed by deposition of middle to upper Miocene diatomaceous sediments.

The reliable information obtained from the microfossils studied demonstrates the need of extensive field and multidisciplinary work to be done in a near future.

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PLATES 2-12

## PLATE 2

## OSTRACODA AND BENTHIC FORAMINIFERA

All figures are electron scanning micrographs

Figure 1. *Cytherella*? sp., carapace, external view right valve x 120, sample 5.

—— 2. *Trachyleberis*? sp., carapace, external view right valve x 120, sample 4.

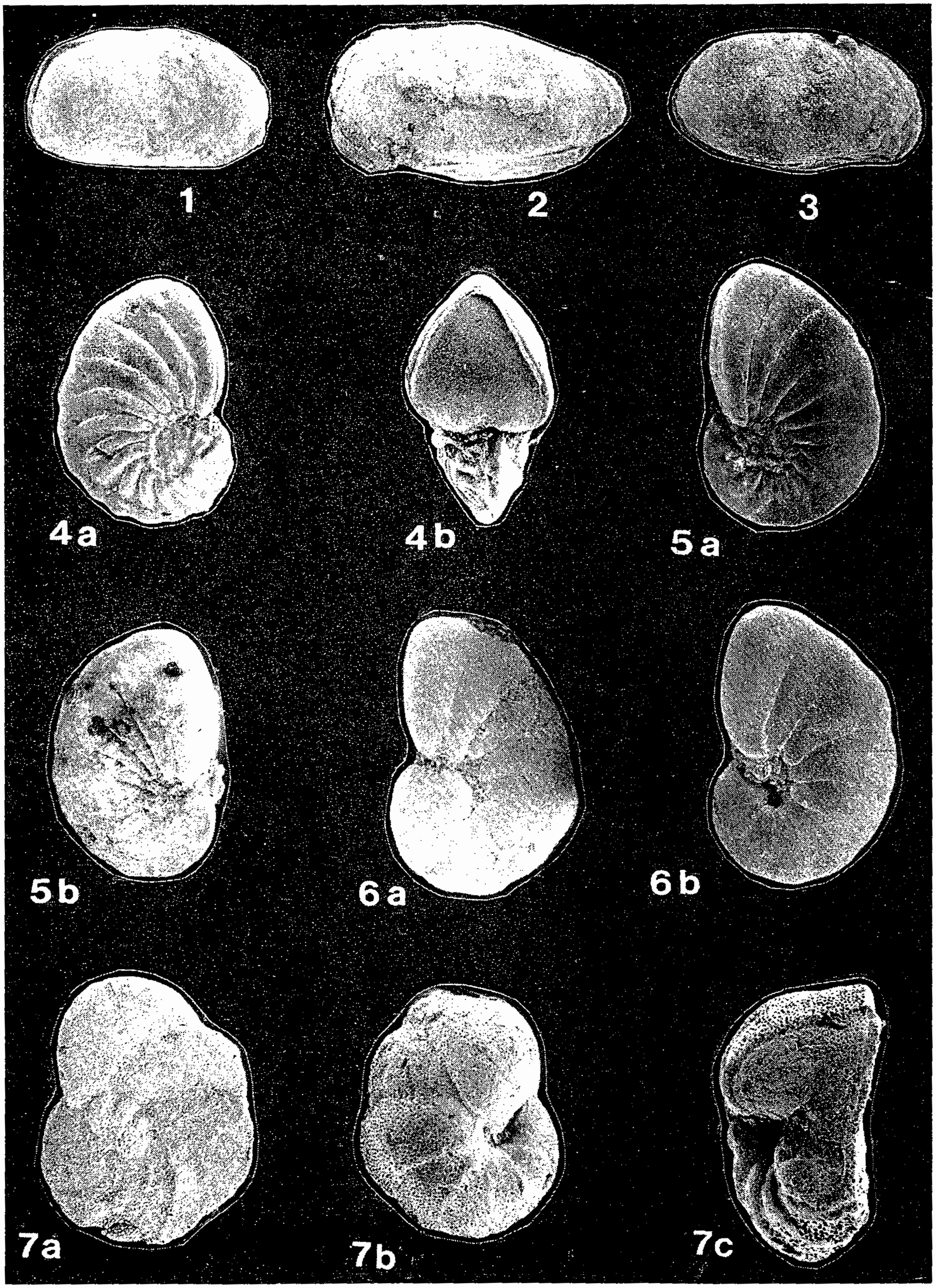
—— 3. *Echinocythereis*? sp., carapace, external view right valve x 120, sample 5.

—— 4. ***Nonion costiferum*** (Cushman). (a) dorsal view x 100; (b) peripherical view x 100, sample 13.

—— 5. ***Nonion incisum*** (Cushman). (a) dorsal view x 100; (b) ventral view x 100; (c) peripherical view x 120; sample 10.

—— 6. ***Nonionella cushmani*** R.E. and K.C. Stewart. (a) dorsal view x 150; (b) ventral view x 160, sample 22.

—— 7. ***Valvulineria miocenica*** Cushman. (a) dorsal view x 100; (b) peripherical view x 120, sample 14.



OSTRACODA AND BENTHIC FORAMINIFERA

## PLATE 3

## BENTHIC FORAMINIFERA

All figures are electron scanning micrographs

Figure 1. ***Valvulineria*** sp. cf. ***Valvulineria depressa*** Cushman, dorsal view x 100, sample 14.

—— 2. ***Baggina subinequalis*** Kleinpell. (a) dorsal view x 120; (b) ventral view x 110, sample 14.

—— 3. ***Baggina*** sp. cf. ***Baggina robusta*** Kleinpell, dorsal view x 100, sample 14.

—— 4. ***Lenticulina cushmani*** (Galloway and Wissler), lateral view x 100, sample 17a.

—— 5. ***Lenticulina mayi*** (Cushman and Parker), lateral view x 100, sample 22.

—— 6. ***Lenticulina*** sp. cf. ***Lenticulina beali*** Cushman, lateral view x 84, sample 18.

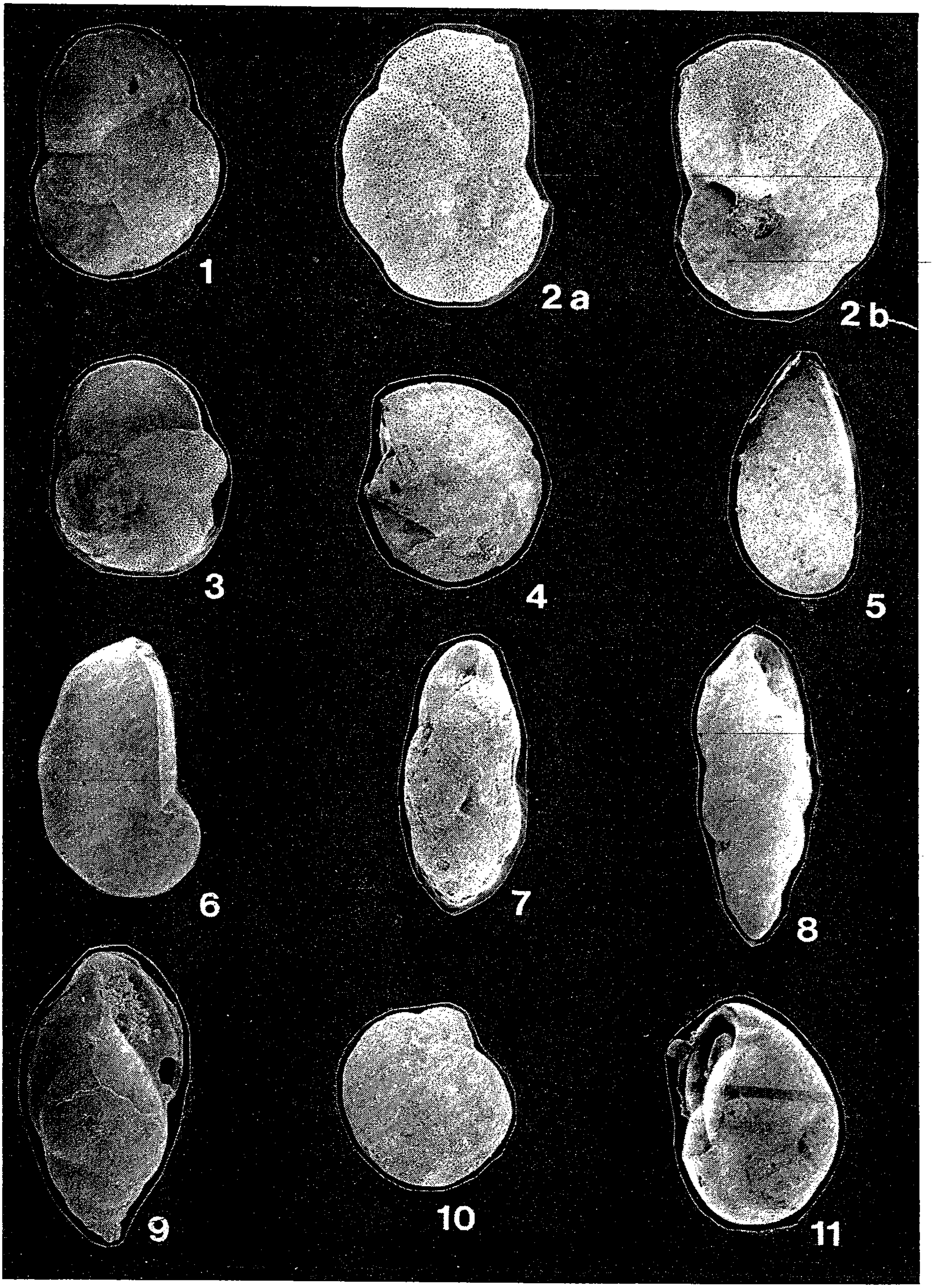
—— 7. ***Buliminella elegantissima*** (d'Orbigny), side view x 180, sample 14.

—— 8. ***Buliminella subfusiformis*** Cushman, side view x 130, sample 10.

—— 9. ***Buliminella brevior*** Cushman, side view x 220, sample 22.

—— 10. ***Oridorsalis umbonatus*** (Reuss), dorsal view x 130, sample 10.

—— 11. ***Cassidulina*** sp. cf. ***Cassidulina californica*** Cushman and Hughes, side view x 330, sample 10.



BENTHIC FORAMINIFERA

## PLATE 4

## BENTHIC FORAMINIFERA

All figures are electron scanning micrographs

Figure 1. *Gyroidina soldanii rotundimargo* R.E. and K.C. Stewart. (a) dorsal view x 100; (b) ventral view x 120, sample 18.

—— 2. *Guttulina* sp., side view x 240, sample 14.

—— 3. *Plectofrondicularia californica* Cushman and Stewart, side view x 75, sample 22.

—— 4. *Nodogenerina irregularis* Kleinpell, side view x 130, sample 18.

—— 5. *Bolivina marginata adelaidana* Cushman and Kleinpell, side view x 130, sample 22.

—— 6. *Bolivina advena* Cushman, side view x 120, sample 22.

—— 7. *Bolivina subadvena acuminata* Natland, side view x 180, sample 16a.

—— 8. *Virgulina subsquamosa* Egger, side view x 150, sample 14.

—— 9. *Virgulina californiensis ticeensis* Cushman and Kleinpell, side view x 100, sample 17a.

—— 10. *Virgulina schreibersiana* Csjek, side view x 220, sample 17a.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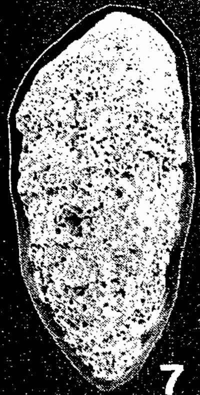
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BENTHIC FORAMINIFERA

## PLATE 5

## BENTHIC AND PLANKTONIC FORAMINIFERA

All figures are electron scanning micrographs

Figure 1. ***Uvigerina subperegrina*** Cushman and Kleinpell, side view x 130, sample 17a.

—— 2. ***Uvigerina*** sp. cf. ***Uvigerina peregrina*** Cushman, side view x 100, sample 17a.

—— 3. ***Uvigerina obesa*** (Cushman), side view x 100, sample 14.

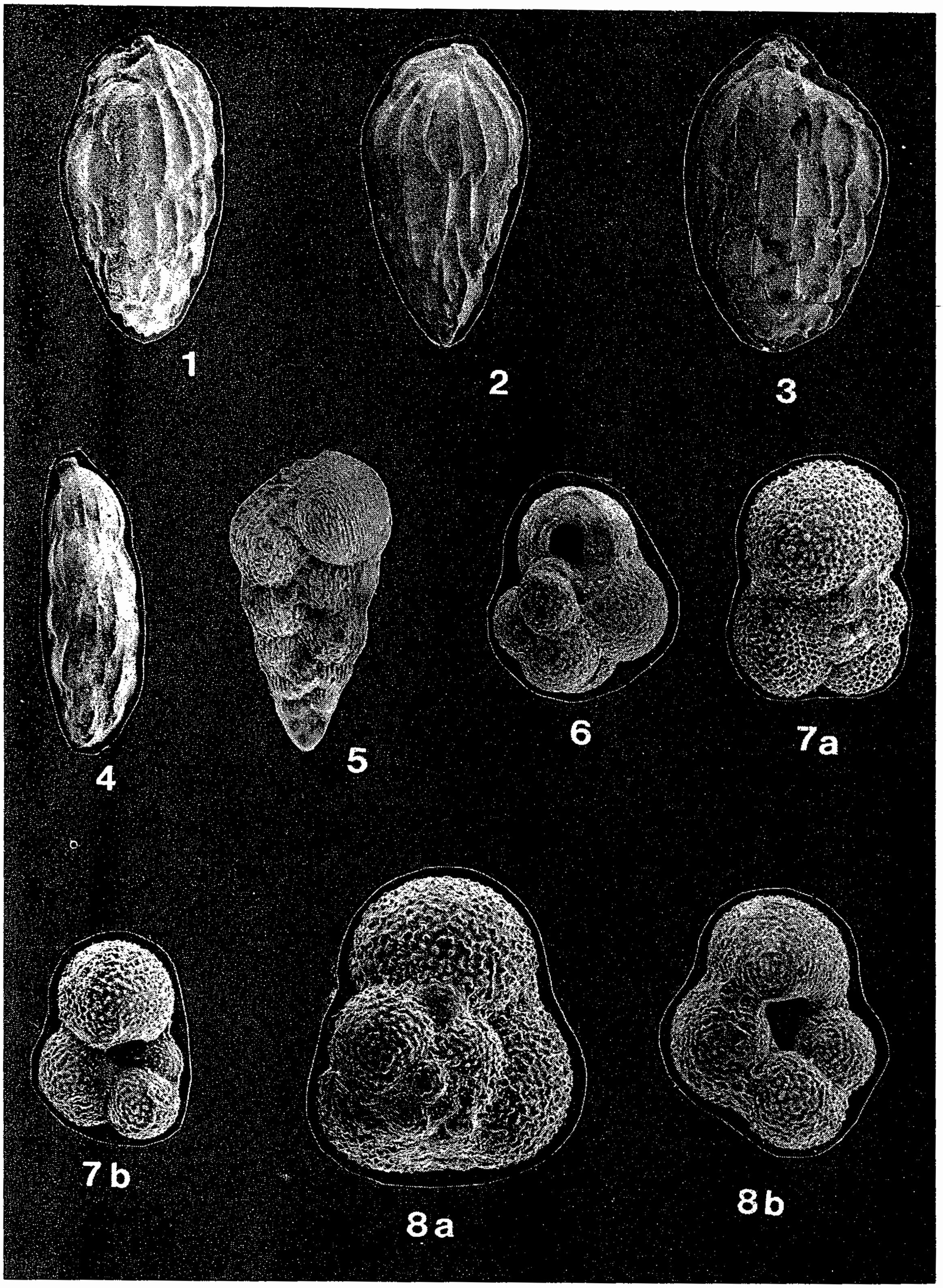
—— 4. ***Siphogenerina*** sp., side view x 100, sample 14.

—— 5. ***Chiloguembelina*** sp. group ***cubensis*** Palmer, side view x 230, sample 22.

—— 6. ***Cassigerinella chipolensis*** (Cushman and Ponton), spiral view x 240, sample 22.

—— 7. ***Globigerina bulloides bulloides*** d'Orbigny. (a) spiral view x 240; (b) umbilical view x 270, sample 22.

—— 8. ***Globigerina quadrilatera*** Galloway and Wissler. (a) spiral view x 330; (b) umbilical view x 270, sample 22.



BENTHIC AND PLANKTONIC FORAMINIFERA

## PLATE 6

## PLANKTONIC FORAMINIFERA

All figures are electron scanning micrographs

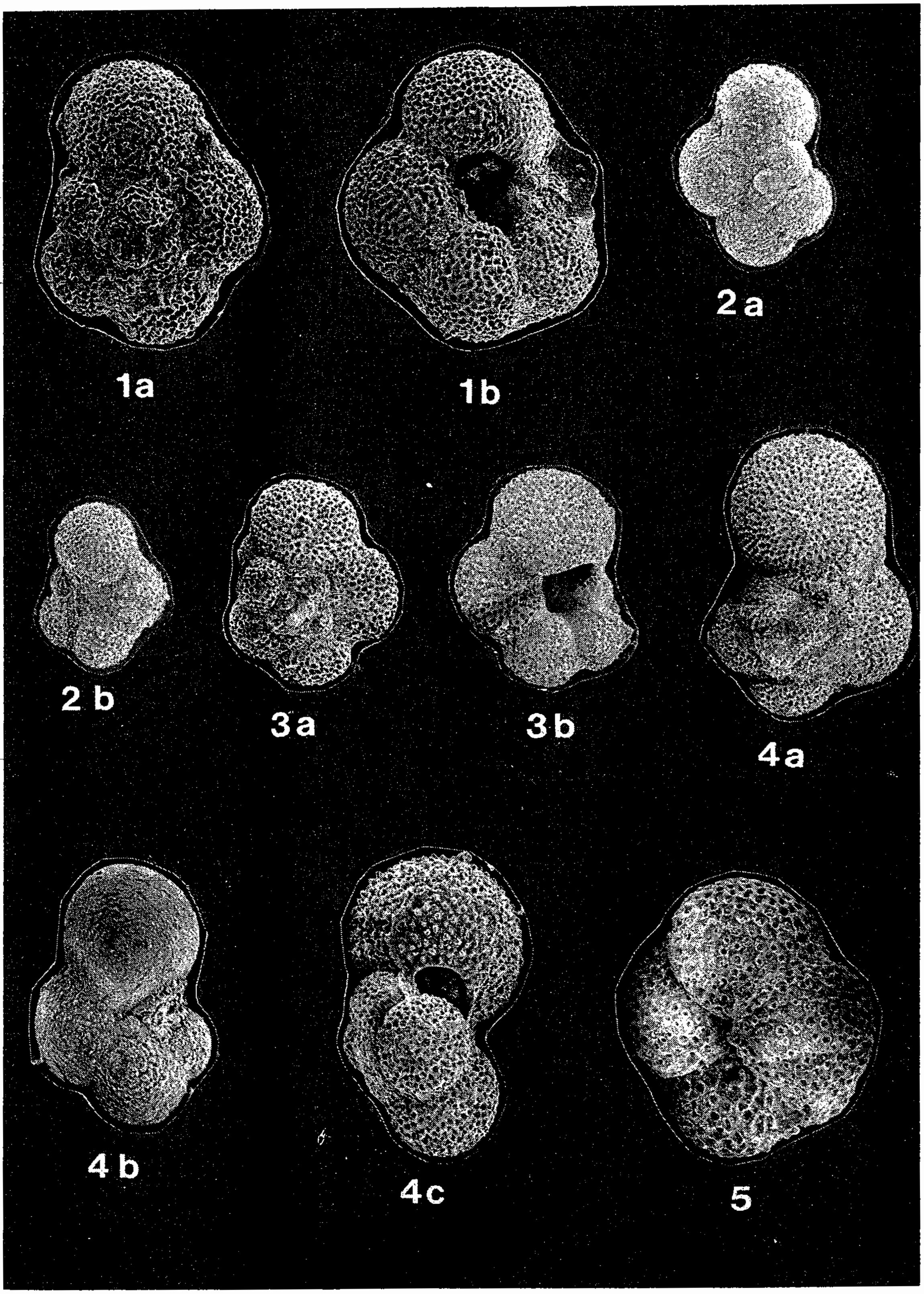
Figure 1. *Globigerina pseudociperoensis* Blow. (a) spiral view x 240; (b) umbilical view x 240, sample 22.

—— 2. *Globigerina ciperoensis angustiumbilicata* Bolli. (a) spiral view x 200; (b) umbilical view x 200, sample 22.

—— 3. *Globigerina ciperoensis* s.l. cf. *Globigerina ouachitaensis ciperoensis* Bolli *in* Blow, 1969. (a) spiral view x 300; (b) umbilical view x 200, sample 22.

—— 4. *Globorotalia obesa* Bolli. (a) spiral view x 200; (b) umbilical view x 270; (c) peripherical view x 270, sample 22.

—— 5. *Globorotalia nana* Bolli - *Globorotalia continuosa* Blow of Bolli and Saunders, 1982. Umbilical view x 300, sample 22.



PLANKTONIC FORAMINIFERA

## PLATE 7

## CALCAREOUS NANNOPLANKTON

All figures are electron scanning micrographs

Figure 1. ***Discoaster surculus*** Martini and Bramlette, distal side x 4,500, sample 20.

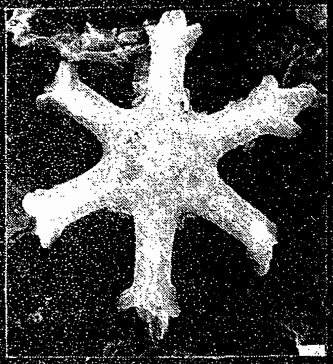
—— 2. ***Discoaster adamanteus*** Bramlette and Wilcox, proximal side x 11,000, sample 18.

—— 3. ***Discoaster variabilis*** Martini and Bramlette, distal side x 10,000, sample 20.

—— 4. ***Discoaster*** sp. aff. ***D. bellus*** Bukry and Percival, proximal side x 16,000, sample 17.

—— 5. ***Discoaster*** sp. aff. ***D. obtusus*** Gartner, proximal side x 9,500, sample 22.

—— 6. ***Discoaster deflandrei*** Bramlette and Riedel, proximal side x 4,000, sample 17a.



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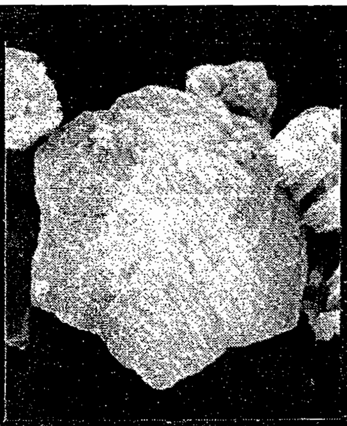

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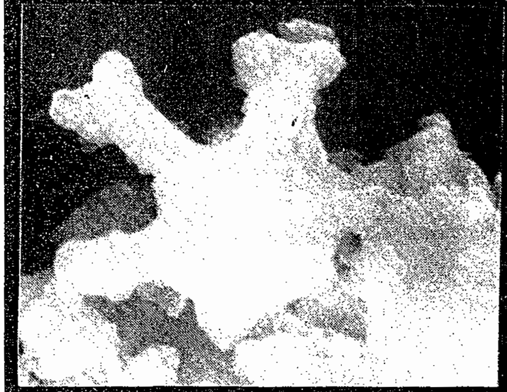

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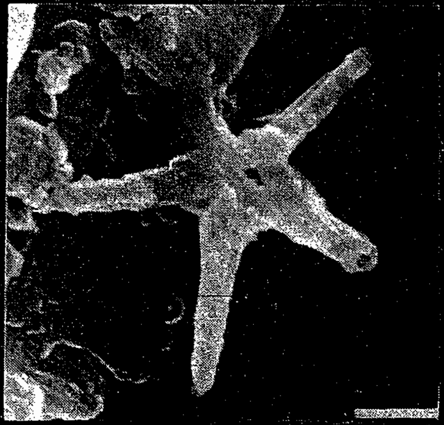

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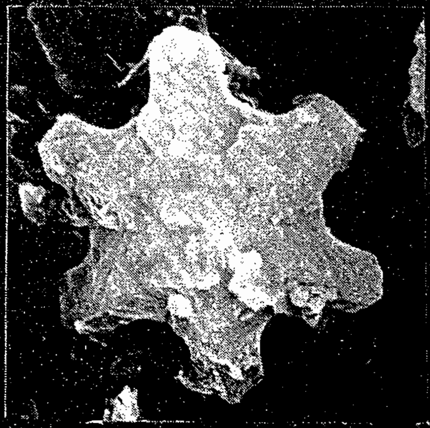

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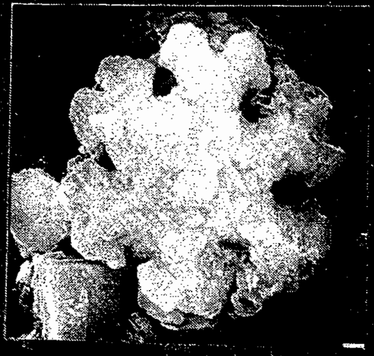

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CALCAREOUS NANNOPLANKTON

## PLATE 8

## CALCAREOUS NANNOPLANKTON

All figures are electron scanning micrographs

Figure 1. *Braarudosphaera bigelowii* (Gran and Braarud), proximal side x 6,000, sample 22.

—— 2. *Helicosphaera sellii* Bukry and Bramlette. (a) proximal side x 7,500; (b) distal side x 8,000, sample 21.

—— 3. *Helicosphaera* sp. cf. *Helicosphaera rhomba* Bukry, proximal side x 7,800, sample 20.

—— 4. *Dictyococcites bisectus* (Hay, Mohler and Wade), distal side x 5,400, sample 22.

—— 5. *Cyclicargolithus abisectus* (Müller), coccosphere x 6,000, sample 18.


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2 b


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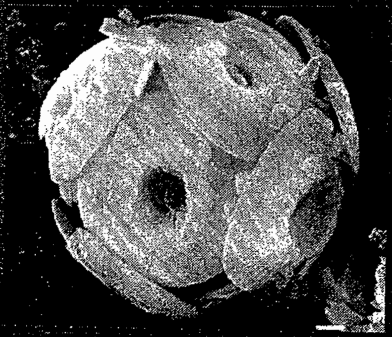
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CALCAREOUS NANNOPLANKTON

## PLATE 9

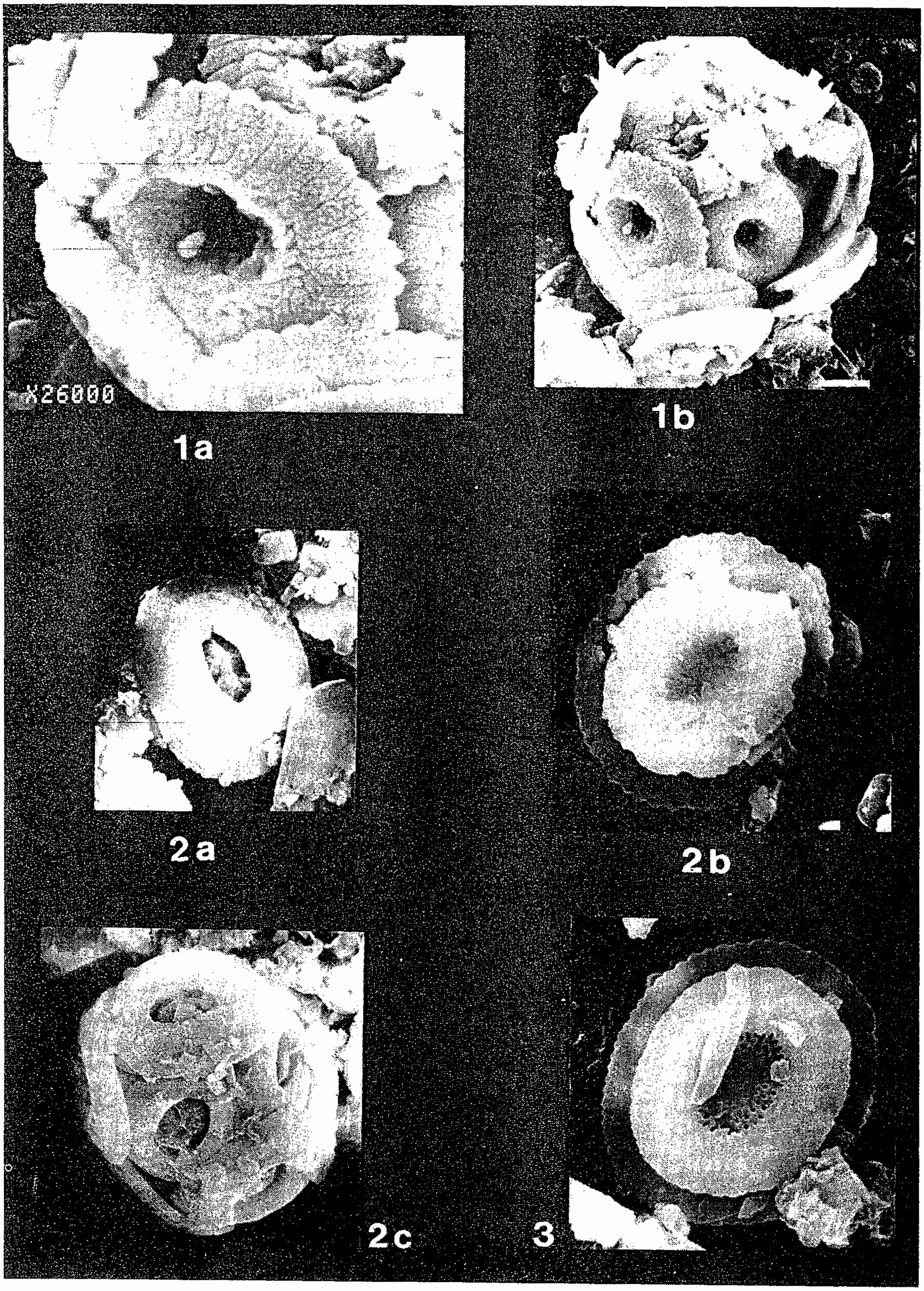
## CALCAREOUS NANNOPLANKTON

All figures are electron scanning micrographs

Figure 1. ***Cyclicargolithus floridanus*** (Roth and Hay). (a) distal side x 26,000; (b) coccosphere x 9,200, sample 18.

—— 2. ***Reticulofenestra pseudoumbilica*** (Gartner). (a) distal side x 18,000; (b) proximal side x 9,400; (c) coccosphere x 4,800, sample 18.

—— 3. ***Reticulofenestra*** sp. cf. ***R. gartneri*** Roth and Hay, proximal side x 10,000, sample 18.



CALCAREOUS NANNOPLANKTON

## PLATE 10

## CALCAREOUS NANNOPLANKTON

All figures are electron scanning micrographs

Figure 1. ***Reticulofenestra*** sp. cf. ***R. insignita*** Roth and Hay, proximal side x 10,000, sample 17.

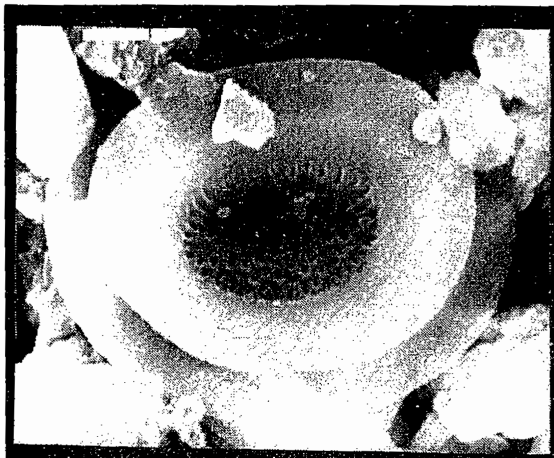
—— 2. ***Reticulofenestra*** sp. cf. ***R. laevis*** Roth and Hay, proximal side x 12,000, sample 17.

—— 3. ***Reticulofenestra*** sp. aff. ***R. clatrata*** Müller, distal side x 11,000, sample 17.

—— 4. ***Coccolithus pelagicus*** (Wallich), distal side x 10,000, sample 20.

—— 5. ***Pontosphaera*** sp. cf. ***P. discopora*** Schiller, distal side x 10,000, sample 20.

—— 6. ***Pontosphaera multipora*** (Kamptner), distal side x 9,400, sample 20.



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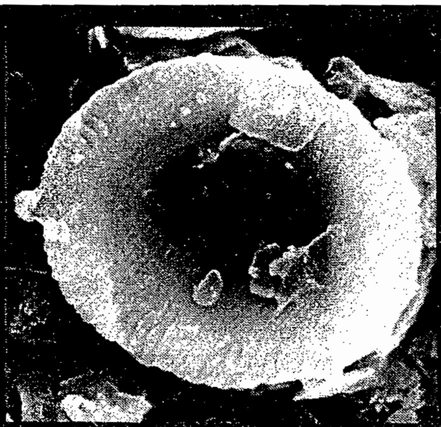

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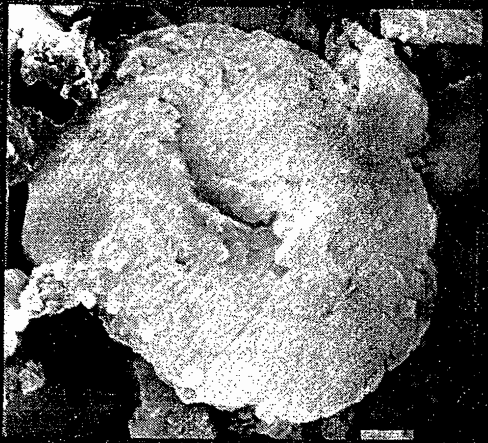

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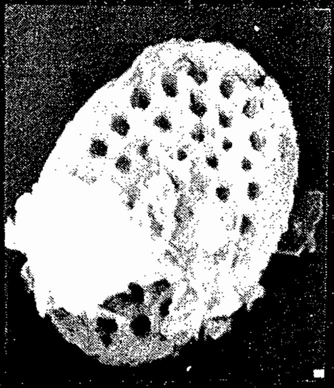

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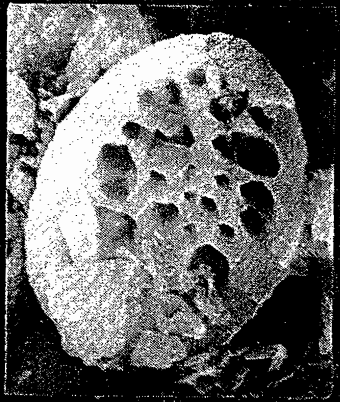

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CALCAREOUS NANNOPLANKTON

# PLATE 11

## CALCAREOUS NANNOPLANKTON

Figures 1 to 3 are electron scanning micrographs, magnification is indicated in each figure; 4 to 8 are cross-polarized light, approximately x 3,000

Figure 1. *Pyrocyclus*? sp., side view x 13,000, sample 22.

—— 2. *Transversopontis* sp., distal side x 16,000, sample 22.

—— 3. *Chiasmolithus* sp., distal side x 6,400, sample 22.

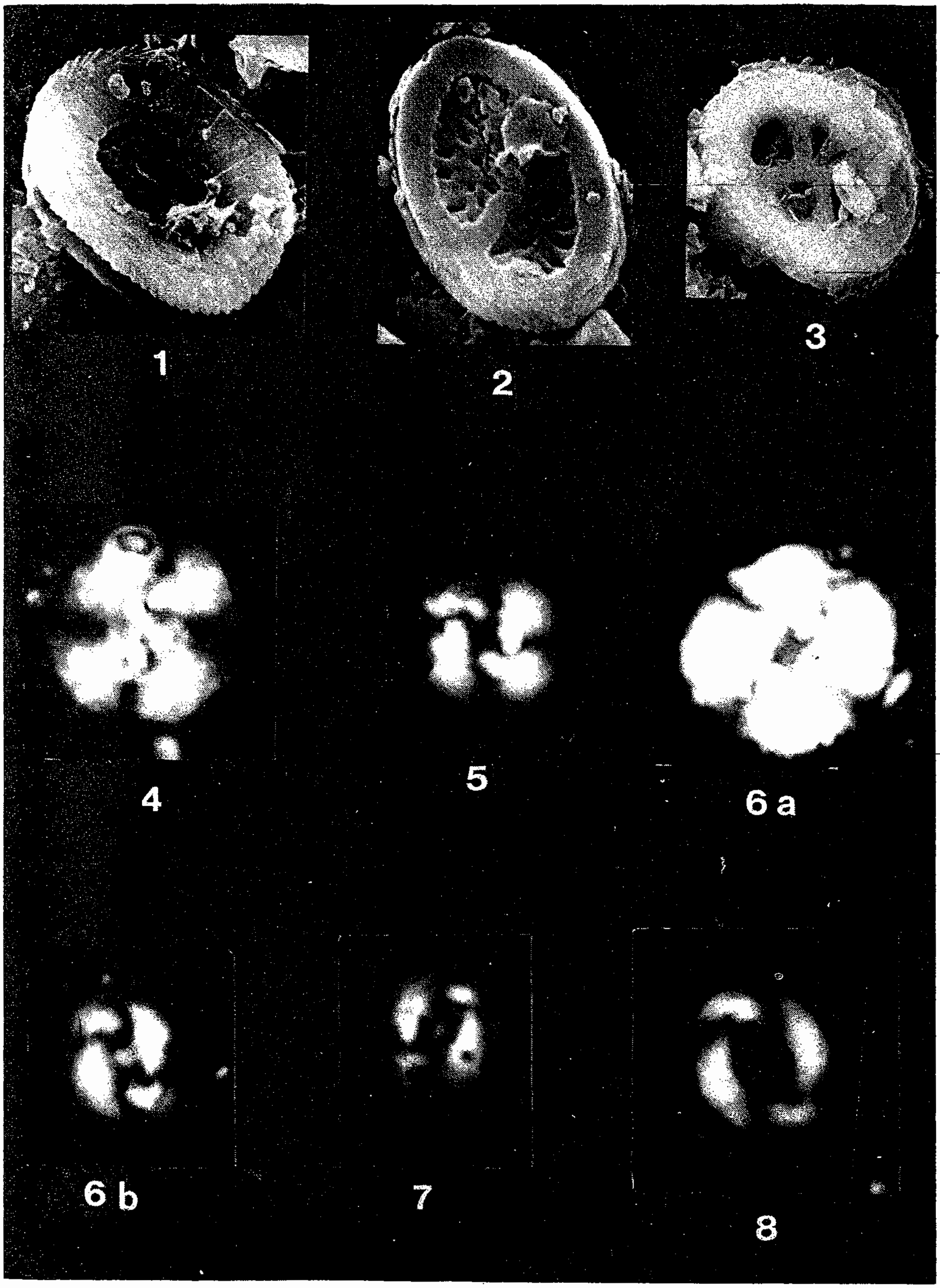
—— 4. *Dictyococcites bisectus* (Hay, Mohler and Wade), sample 22.

—— 5. *Cyclicargolithus floridanus* (Roth and Hay), sample 18.

—— 6. *Reticulofenestra pseudoumbilica* (Gartner). (a) 45°; (b) 60°, sample 18.

—— 7. *Reticulofenestra* sp. cf. *Reticulofenestra gartneri* Roth and Hay, sample 18.

—— 8. *Reticulofenestra* sp. cf. *Reticulofenestra laevis* Roth and Hay, sample 17.



CALCAREOUS NANNOPLANKTON

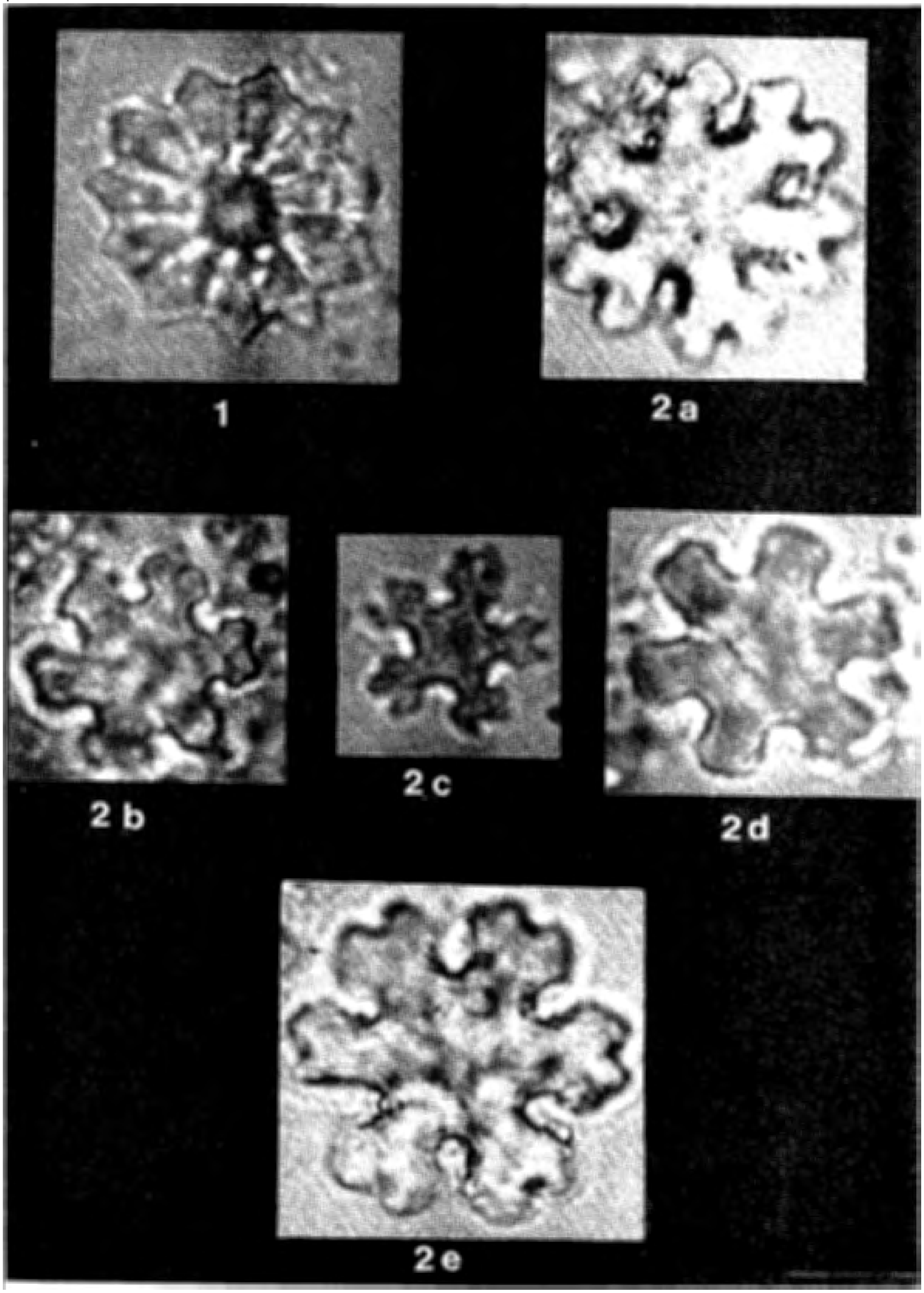
## PLATE 12

## CALCAREOUS NANNOPLANKTON

All figures are phase contrast, approximately x 3,000

Figure 1. ***Discoaster barbadiensis*** Tan, sample 22.

—— 2. ***Discoaster deflandrei*** Bramlette and Riedel, showing different stages of overgrowth; (a) and (b) sample 20; (c) 5 ray phenotype, sample 20; (d) sample 18; (e) sample 17a.



CALCAREOUS NANNOPLANKTON