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PALEONTOLOGÍA MEXICANA 59

CALCAREOUS NEOGENE MICROFOSSILS OF BAJA CALIFORNIA SUR, MEXICO

Part 1

NEOGENE MICROFOSSILS FROM THE SANTIAGO DIATOMITE, BAJA CALIFORNIA SUR, MEXICO

By
ANA LUISA CARREÑO

Part 2

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

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Part 1

NEOGENE MICROFOSSILS FROM THE SANTIAGO DIATOMITE, BAJA CALIFORNIA SUR, MEXICO

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ABSTRACT

A biostratigraphic study of the Santiago Diatomite—the diatomaceous outcrops in southernmost Baja California—was carried out using benthic and planktonic foraminifera and calcareous nannoplankton. The Santiago Diatomite is considered to be latest Miocene to middle Pliocene in age and to be associated with nearby upper Pliocene beds. The sediment was deposited during a transgressive event which resulted from local tectonic spreading of the Gulf of California. A paleobasin with its major depocenter at the Santiago site was formed.

Micropaleontological information suggests an upper bathyal paleodepth for the Santiago Diatomite, with an assemblage characteristic of transitional water masses—California current and the North Equatorial System—converging at this site.

In general, normal marine conditions existed, with the exception of some levels of laminated sediments that suggest decreased oxygen content. Dissolution of calcareous microfossils could be indicative of deposition near the carbonate compensation depth, or local upwelling.

Reconstruction of the evolution of the Santiago paleobasin suggests a probable association with a subaerial canyon that existed prior to this time, with later submersion and, finally, a regressive event during late Pliocene-Pleistocene time.

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

RESUMEN

El estudio bioestratigráfico de los sedimentos diatomíticos que afloran en la parte más austral de Baja California, para el cual se utilizó foraminíferos planctónicos, bentónicos y nannoplancton calcáreo, permite asignar una edad de miocénica tardía a pliocénica media a la Diatomita Santiago, que aflora cerca de capas del Plioceno superior. Estos sedimentos fueron depositados durante un evento transgresivo, como resultado de la apertura tectónica local del Golfo de California que formó una paleobahía, cuyo máximo centro de depósito fue el área de Santiago.

La información micropaleontológica obtenida indica, para la Diatomita Santiago, una paleoprofundidad batial superior, con un conjunto transicional característico de masas de agua asociadas a la corriente de California y al sistema Nordecuatorial, las cuales convergen en esta área.

En términos generales, se puede considerar que predominaron condiciones marinas normales durante el depósito, con excepción de algunas capas de sedimentos laminados, que sugieren decremento en el contenido de oxígeno. La ausencia de algunos taxa, así como la presencia de microfósiles calcáreos parcialmente disueltos, puede atribuirse a depósitos cercanos al límite de compensación del carbonato o a una surgencia local.

Se interpreta la evolución de la paleobahía Santiago, la cual señala una probable asociación con un cañón subaéreo preexistente, la posterior sumersión y finalmente un evento regresivo durante el Pleistoceno.

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

INTRODUCTION

Geological reconnaissance of Baja California represents a major contribution in the reconstruction of the detailed tectonic and marine history of the Gulf of California. No major published studies have been made on marine Neogene sediments from Baja California Sur, and only few studies have been reported from the northern part of Baja California.

Recent reports have been largely involved with geological and geophysical marine investigations on the origin and evolution of the gulf: several hypotheses attribute the origin of the Gulf of California to ocean-floor spreading and transform faulting (*e.g.*, Larson *et al.*, 1968; Moore and Buffinton, 1968; Atwater, 1970; Moore, 1973).

Moore and Curray (1982) reconstructed the history of the Gulf of California and proposed a single two-phase process: the late diffuse extension phase which is still occurring in the central northern gulf, following a phase characterized by a jump of the plate edge from transform motion off the west coast to approximately the back or the northeastern side of the coastal batholith.

Different reports point out the existence of a protogulf prior to latest Miocene (Gastil ***et al.***, 1968; Ingle, 1973, 1974; Moore, 1973), and suggest that marine deposition in the northern portion of the gulf began during middle Miocene (Ingle, 1973) and that the initiation of the major period of basin formation and initial rifting on the trough might have started during early Miocene (Gastil ***et al.***, 1968). Although Moore and Curray (1982) stated that the first opening was completed at about 3.5 Ma, they suggested that, other than shelf deposits, no sediments older than 5.5 Ma (latest Miocene) would be found associated with the gulf. Applegate (personal communication) suggests that evidence exists for a seaway between what is now the Peninsula of Baja California and the mainland of Mexico from the upper Oligocene to the Holocene. This concept would eliminate the necessity of a protogulf.

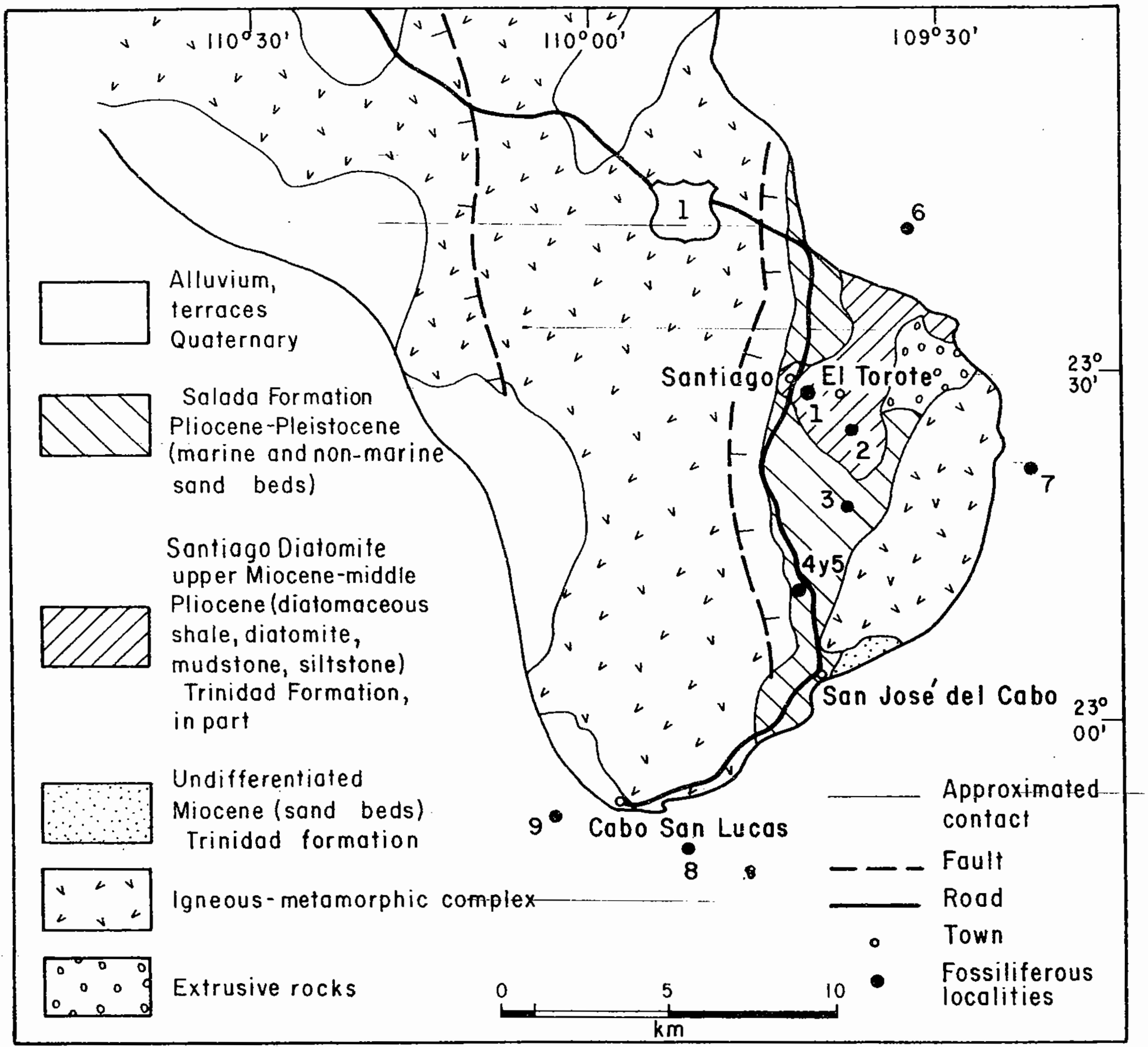
At present, the Neogene marine deposits recognized in southernmost Baja California are poorly studied and apparently represent littoral environments; these allow a partial view of the evolution of the marine events. Analysis of the vertical variation of planktonic foraminifera and coccoliths of the diatomaceous shale that crops out at Santiago, Baja California Sur, when compared with other nearby areas, marine and terrestrial deposits began in the gulf prior to 5.5 Ma. Data obtained from planktonic microfossils and benthic faunas provide some additional paleobathymetric and paleoceanographic information.

STUDY AREA

On the right side of road No. 1, in its part from San José del Cabo to La Paz, about 8 km from Santiago, Baja California Sur (Figure 1), there are several isolated exposures of marine diatomaceous shale, here called Santiago Diatomite.

This area, located at the tip of Baja California, is physiographically known as the Los Cabos Region. It forms the southern part of the peninsula; to the west, it is bounded by the Gulf of California; to the north by the La Paz isthmus region; and to the east and south by the Pacific Ocean.

The La Paz fault is a major structural feature; the rocks to the north are completely different from those to the south; therefore, the presence of Comondú volcanics has not been demonstrated to the south of La Paz fault.



DRAWN BY ENRIQUE GUTIÉRREZ NAVARRETE

Figure 1.- Generalized geological map and paleontological localities mentioned in this study. Faults mostly normal, recognized on the field are not mappable. 1—Santiago Diatomite section; 2—El Refugio (Hertlein, 1966); 3—Las Tunas (Miller, 1980); 4 and 5—Rancho Algodones area (Espinosa-Arrubarrena, 1979; Torres-Roldán, 1980; localities from Shepard, 1964); 6—BAC 53 (Sample 104) 23°42.1'-109°36.7' (Santiago canyon); 7—BAC 17 (Sample 36) 23°22.6'-109°23.3' (Los Frailes canyon); 8—BAC 60 (Sample 115) 22°46.9'-109°52.9' (Cardonal canyon); 9—BAC 64 (Sample 111) 22°49.8'-110°3.9' (Vigía canyon).

This area is underlain by Cretaceous granitic batholithic rocks, which form the western range at the Los Cabos Region. The structure is dominated by northeast trending normal faulting, which has produced a series of horsts and grabens, at the southeastern edge of the continental block. On the southeastern side of the tip metasediments and granites exist which may have at one time been connected to the batholiths.

The geology of the tip of Baja California is poorly studied. The Neogene formations, as described by Heim (1922), include Comondú, Isidro and Salada; Beal (1948) described San Gregorio; Mina (1957) described San Zacarías, Santa Clara, Zorra, San Ignacio, San Raymundo, Tortugas and Atajo Comondú, and Pantoja-Alor and Carrillo-Bravo (1966) described Trinidad. Except for the last formation, the rest of them is not recognized in the Los Cabos Region (Figure 2).

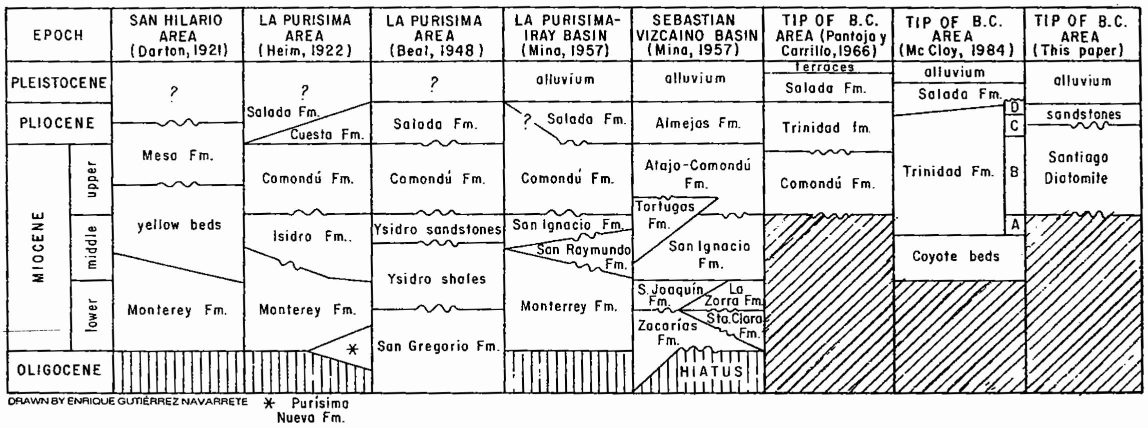


Figure 2.- Generalized stratigraphic correlation chart showing the section studied with respect to Baja California formations.

Normark and Curray (1968) pointed out that "The identification of Comondú, at the southern tip, is based only on lithological similarities, while the reflection profiles show no suggestion of sediments under the volcanic, as defined for the tip of Baja, Ysidro Formation, of Beal". For these authors, the Beal's Ysidro Formation, defined by Pantoja-Alor and Carrillo-Bravo (1966) as the Pliocene Trinidad formation, is combined with the Comondú volcanics.

The arroyo Santiago, the head of the Santiago's Valley inland (where the study area is located), is aligned with the Santiago submarine canyon (Shepard, 1964); this author indicates that the formation of the Santiago's granitic canyon took place when the Los Cabos Region stood higher than now above sea level. The granitic rocks of the Los Cabos block range from 54–88 Ma (Gastil *et al.*, 1976); on the other hand, after Hausback (1984), the granitic Los Cabos province was probably already upheaving along the La Paz fault, prior to the early Miocene Comondú deposition. After 12 Ma, the same author suggests that the movement along the La Paz fault probably includes the downdropping of the Los Cabos block and significant left-lateral strike-slip faulting.

Despite the scarcity of geological information, paleontological work has been carried out, because of the abundance of fossiliferous localities. Some isolated localities have been reported by Hertlein (1966). On the other hand, Shepard (1964) reports a shale (sample 104) from the west wall of the Santiago canyon, where this canyon joins the Palmas canyon, dredged during the Bacanyon Sea Expedition. The dredged shale is partly laminated and partly nodular and it has a manganese coating. From this shale, F. L. Parker (*in* Shepard, 1964) identified foraminifera of probable Miocene age. Pliocene ***Pecten*** specimens were dredged (sample 36) in the northern wall of the Los Frailes canyon.

A sample from the eastern side of the Los Cabos Region (sample 115) in the northern wall of the canyon yielded diatomite and laminated shale; the diatoms suggest a Miocene age, but the silicoflagellates indicate a probable Pliocene age, while south of Cabo San Lucas, in the western wall of the Vigía canyon, foraminifera from a laminated shale (sample 111) appear to be Pliocene or Pleistocene in age. Location of all these samples is shown in Figure 1.

At Rancho El Refugio, approximately 15 km south of the study area, middle Pliocene sands and silts contain mollusks (Hertlein, 1966). Previous work in diatom assemblages (Hanna and Brigger, 1966) in the Santiago area—probably some of these outcrops—suggests an age equivalent to the late part of the Miocene (Delmontian).

Nine kilometers to the southeast of Santa Anita, a locality known as Rancho Algodones contains a large and diverse fauna. Espinosa-Arrubarrena (1979, 1980) suggested an age equivalent to middle?-late Pliocene for the marine sediments that contain shark's teeth; Durham (*in* Espinosa-Arrubarrena, 1979) deduced a similar age for the same beds on the basis of invertebrate fauna. He suggested the possibility of a younger age based on the time scale of Berggren and Van Couvering (1974). The vertebrate fauna found in Rancho Algodones indicates a Blancan age (Torres-Roldán, 1980).

Miller (1980) assigned a Blancan age to the Las Tunas local fauna, located 14 km to the northeast of Santa Anita and approximately 30 km to the south of Santiago (Figure 1). Moreover, Addicott (*in* Miller, 1980) indicated that this assignment, when used as Durham (1950) and Hertlein (1966) did, might well be middle Pliocene.

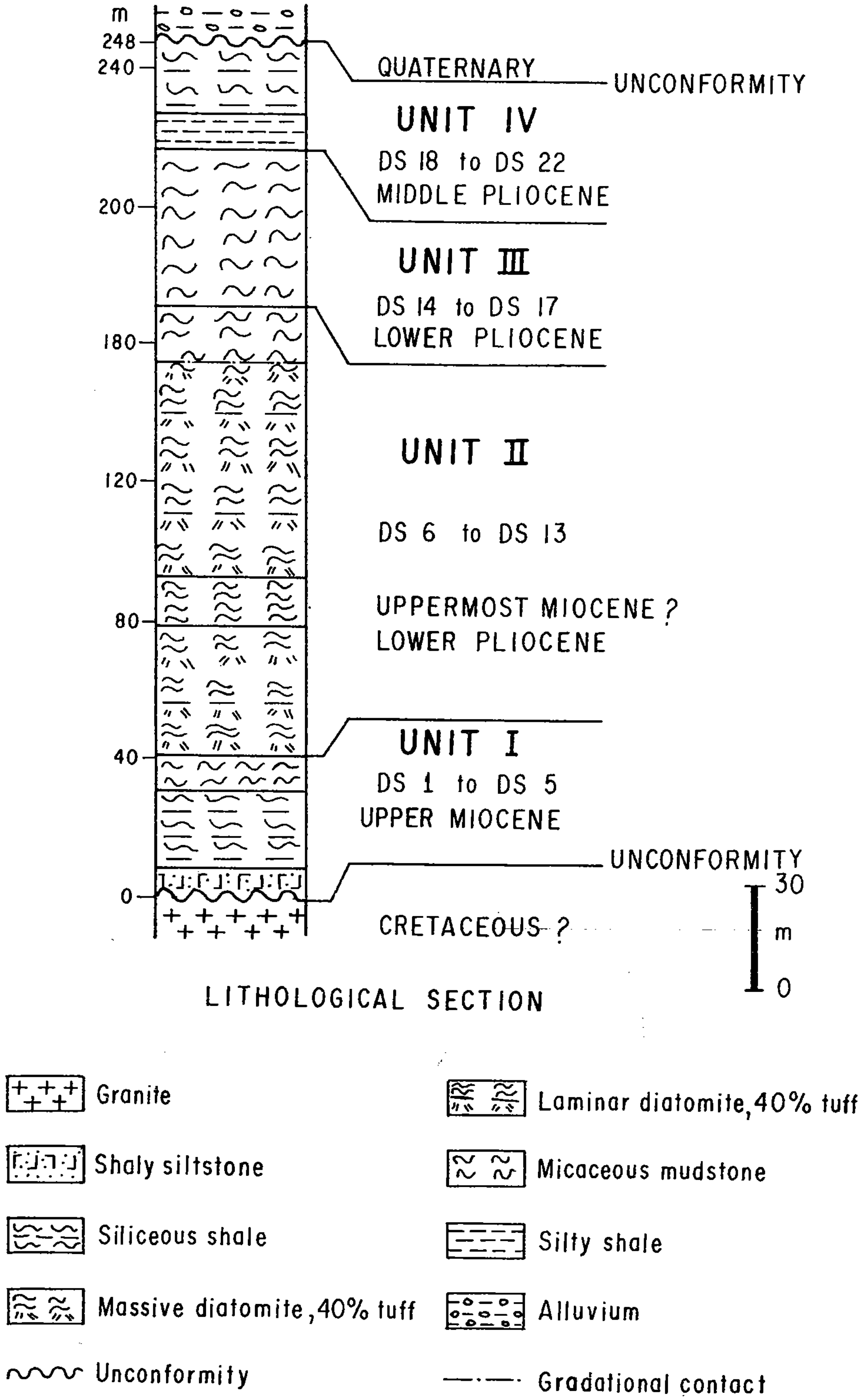
Recently, McCloy (1984), from evidence in the overlying beds—considered as Trinidad formation—assigned to the Coyote beds an age not younger than middle Miocene. The same author, based on the presence of ***Anadara patricia*** (***sic***) in the subunit A of the Trinidad formation, suggested a middle Miocene age and, because of the association with other genera of mollusks, she extended the range of those beds to the upper Miocene. Unfortunately, there is no evidence to consider ***Anadara grandis patricia*** as a restricted marker of the middle Miocene. After Woodring (1973), this species is considered as a part of a brackish water group from the Caribbean region, with a range from the middle Miocene to lower Pliocene, while the associated genera (***Melongena*** sp., ***Cerithidea*** sp. and ***Theodoxus*** sp.) reach the Holocene.

Based on radiolaria, Pérez-Guzmán (1985) gave a late Miocene age to the ***Didymocyrtis antepenultima*** and ***D. penultima*** Zones (after Riedel and Sanfilippo, 1978) of some of the diatomaceous sediments that crop out near Rancho El Torote.

The above discussion shows that a great deal of careful work is needed before the exact ages of the beds within this area are known with confidence.

METHODS

The 248 m of the measured section (Figure 3) are lying unconformably under Cretaceous granites. The sequence consists of shaly siltstone, siliceous shale, micaceous mudstones and silty shale. In some levels, the micaceous mudstones grade into a very tuffaceous massive or laminated diatomites. This sequence is overlain unconformably by Quaternary alluvium. This section probably corresponds to McCloy's (1984) subunits B and C previously discussed, and therefore to the Trinidad formation also.



DRAWN BY ENRIQUE GUTIÉRREZ NAVARRETE

Figure 3.- Composite columnar section of the outcrops studied at the Santiago area here called Santiago Diatomite.

A 200 gram portion (dry weight) of each sample was soaked in water and sieved through a 200 mesh Tyler screen. The benthic and planktonic populations of each sample were counted separately. A modified Otto microsplitter was used to obtain practical but stratigraphically significant fractions of 200 to 300 benthic and planktonic individuals. The entire population within a sample was counted when total specimens numbered less than 200. Planktonic and benthic foraminifera are rare to common, with evidence of signs of dissolution. In portions of the diatomite, the nannoplankton is scarce and poorly preserved. There are abundant diatoms, silicoflagellates and radiolarians, and, in some horizons, abundant fish remains. Relative abundances of foraminifera are presented as percentage of the total planktonic or benthic population in a sample (Figure 4).

Calcareous nannoplankton species abundances were recorded as the logarithm of the abundance in a smear slide viewed at x 1,000 (Figure 5).

AGE ASSIGNMENT

The whole section is characterized by a transitional microfauna, that consists of many forms generally associated to warm water and many others that could be associated or transported by cold-water flows. Due to this mixture, the age assignment is based, as far as possible, on planktonic (Bolli, 1970; Bolli and Bermúdez, 1965; Bolli and Premoli-Silva, 1973; Bolli and Saunders, 1985), benthic foraminifera (Kleinpell, 1938) and calcareous nannoplankton (Martini, 1971) warm-temperate zonal schemes. Furthermore, in the case of planktonic foraminifera, the prevailing coiling pattern of selected species in each level was taken into account (Figure 4). In some levels, absence of one or more of those groups, caused difficulty in making a zonal assignment.

Low latitude index microfossils are missing in the major part of the Santiago Diatomite, possibly due to dissolution or dilution. In the case of dilution, the rare occurrence of calcareous microfossils may suggest a relatively low productivity as well as a higher rate of terrigenous influx, similar to the Holocene shallower coastal basins of the Gulf of California.

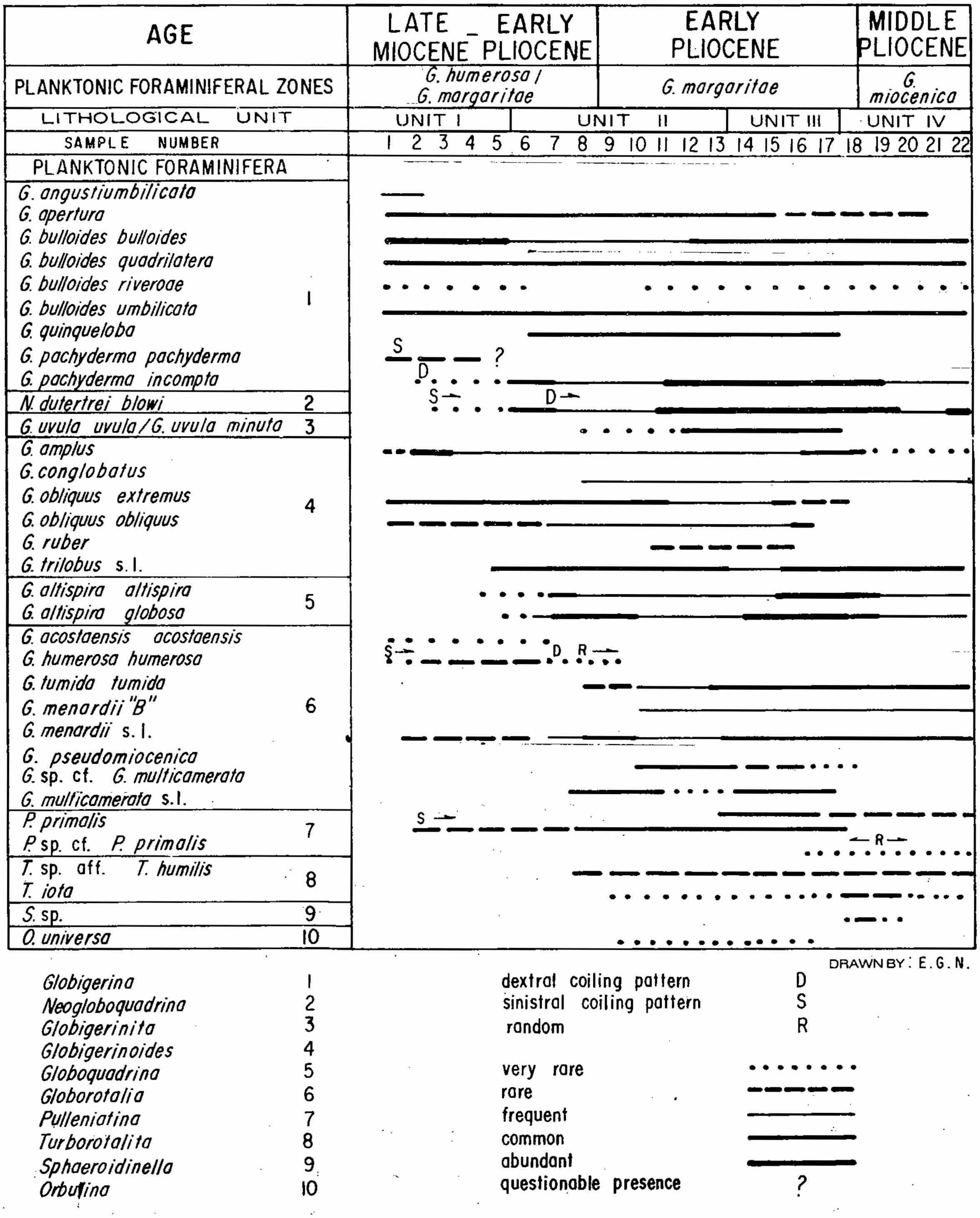


Figure 4.- Planktonic foraminiferal distribution, relative abundance and coiling pattern direction of selected species throughout the Santiago Diatomite section.

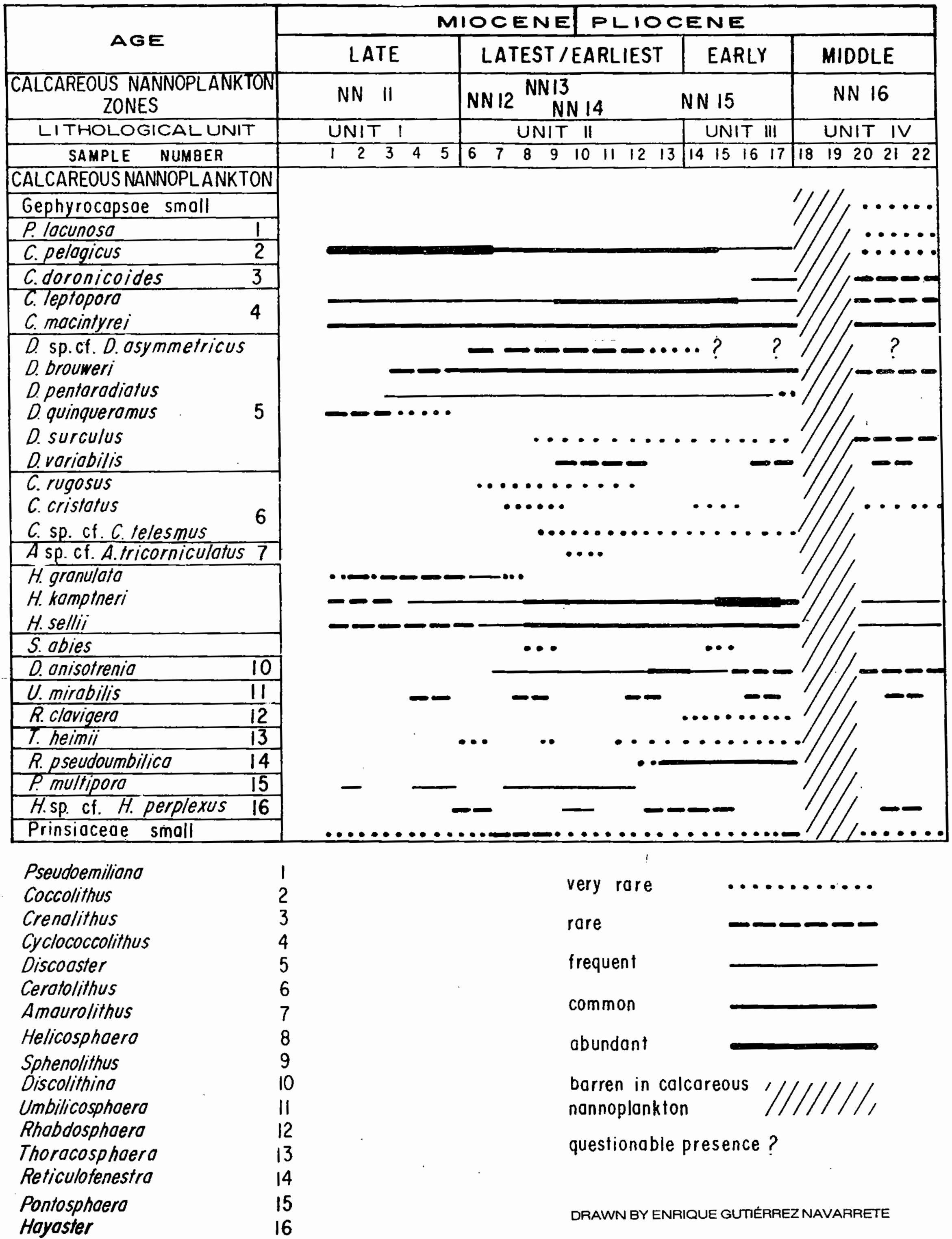


Figure 5.- Distribution and relative abundance of calcareous nannoplankton throughout the Santiago Diatomite section. Species abundances are recorded in the table as the logarithm of the abundance in a smear slide viewed at x 1,000; +1= tens of specimens in a single field of view; 0= a single specimen in a field of view; -1= a single specimen of the species found in 10 fields of view; -2= a single specimen in 100 fields of view.

The population structure in the Santiago Diatomite is not constant. The base of the section (samples 1 to 6) contains only calcareous microfossils; on top of the section, the siliceous microfossils become more frequent, constituting the dominant elements in the levels of "light layers" diatomites, in rapport with the "dark layers" containing more abundant calcareous microfossils except in sample 18 and 19, where calcareous nannoplankton was not recorded.

The presence or absence of one or more species from one level to another and their frequency are more closely related to paleoclimatic or tectonic conditions, than to stratigraphic range.

At the base of the measured section (samples 1 to 8), index planktonic foraminifera are missing, most of them are longest-ranging species corresponding to the time span around the N17 (***Globorotalia humerosa***) and N18 (***Globorotalia margaritae***), upper Miocene-Pliocene zones. Moreover, the presence in samples 1 to 5 of common to rare ***Discoaster*** sp. cf. ***D. quinqueramus*** Gartner—the central knobs are generally shorter than in ***D. quinqueramus***—suggests a latest Miocene age for this part of the section, while in sample 6 to 8 ***Discoaster*** sp. cf. ***D. quinqueramus*** is absent. The benthic foraminifera assemblage consists mostly of large, robust species of ***Valvulineria*** and ***Nonion*** associated with scarce ***Bolivina obliqua*** and minor species of ***Bolivina***, that could be assigned to the top of the Mohnian or to the base of the ***Bolivina obliqua*** Zone of Kleinpell (1938).

Amaurolithus and ***Ceratolithus*** are not particularly abundant, but their presence is considered meaningful; however ***Amaurolithus*** sp. cf. ***A. tricorniculatus*** Gartner and ***Ceratolithus rugosus*** Bukry and Bramlette, together with forms very close to ***Discoaster asymmetricus*** Gartner become frequent in samples 6 to 8. These facts are indicative of a mixture between the NN12 ***Ceratolithus tricorniculatus***, NN13 ***Ceratolithus rugosus*** and NN14 ***Discoaster asymmetricus*** Zones of Martini (1971) of the latest Miocene-early Pliocene.

Up on the section (samples 9 to 18), the assemblage is characterized by numerous and varied planktonic foraminifera. Some levels, less affected by dissolution, contain keeled menardiiforms ***Globorotalia*** with strong affinities to ***Globorotalia menardii*** B (of Bolli and Premoli-Silva, 1973), ***Globorotalia pseudomiocenica*** Bolli and Bermúdez and

Globorotalia multicamerata Cushman and Jarvis characteristic of lower-latitude lower Pliocene assemblages (***Globorotalia margaritae*** Zone).

Benthic foraminifera are scarce and less varied than the planktonic; the most frequent species are ***Bolivina obliqua*** Barbat & Johnson, ***B. churchi almgreni*** Kleinpell, ***B. rankini*** Kleinpell, ***B. subadvena*** Cushman, ***Nonion multicameratum*** Kleinpell, ***Buliminella subfusiformis*** Cushman and ***Sphaeroidina bulloides*** d'Orbigny, which indicate the Kleinpell's (1938) ***Bolivina obliqua*** Zone from the uppermost Delmontian stage of California. After Barron (1976), this benthic foraminiferal zone is correlatable, at least in part, with the temperate ***Distephanus speculum speculum*** Zone of Bukry, 1973 (Pliocene DSDP Site 173 in the Pacific). In fact, siliceous microfossils become frequent in this part of the section, but no attempt was made to carry on a detailed study of them; nevertheless, it was possible to note that the ***Distephanus speculum*** (Ehrenberg) and ***Mesocena circulus*** (Ehrenberg) groups are the dominant species of the silicoflagellate assemblage.

On the other hand, Berggren and coworkers (1985) consider that the base of the ***Bolivina obliqua*** Zone could be correlated to the ***Stichocorys peregrina*** (Riedel) FAD. Trápaga-Martínez (1985), in a similar study of the same samples, suggests, for this part of the section, a late Miocene age (***Stichocorys peregrina*** Zone of Riedel and Sanfilippo, 1978); nevertheless, Sanfilippo and coworkers (1985) place the ***Stichocorys peregrina*** Zone from the uppermost Miocene to the lower Pliocene and consider that ***Didymocyrtis avita*** (Riedel) is restricted to the Pliocene ***Spongaster pentas*** Zone, where ***Spongaster tetras*** (Ehrenberg) has its first occurrence. Trápaga-Martínez (1985) reports ***Stichocorys peregrina***, ***S. delmontensis*** (Campbell and Clark) and ***Anthocyrthidium ehrenbergii*** (Stohr), radiolarians on which this author based the age assignment; nevertheless, he also reports associated to these species ***Didymocyrtis avita*** and ***Spongaster tetras***, indicative, at least, of an early Pliocene age.

In this part of the section and in the next younger unit, the calcareous nannofossils consist mostly of the outer rims of coccolith shield; the center of the rims has been removed by dissolution, so that few good markers could be identified; consequently, no stratigraphic subdivisions are possible. In spite of this, the common taxa present ***Discoaster pentaradiatus*** Tan, ***D.*** sp. cf. ***D. asymmetricus*** (no typical forms were identified due to stronger dissolution), ***D. brouweri*** Tan, ***D. surculus*** Martini and Bramlette, ***Reticulofenestra pseudoumbilica*** (Gartner), ***Helicosphaera kamptneri*** Hay and Mohler and ***H. sellii*** Bukry and Bramlette, and may suggest the NN14 ***Discoaster asymmetricus*** Zone or/and NN15 ***Reticulofenestra pseudoumbilica*** Zone of Martini (1971), indicative of an early Pliocene age.

The upper part of the Santiago Diatomite (samples 19 to 22) contains impoverished calcareous microfossils. The calcareous nannoplankton is practically absent in two levels of impure diatomite, except for some unidentified fragments; the benthic foraminifera are sparse and poorly preserved. In general, the same species of the precedent unit were found.

Planktonic foraminifera show signs of intense dissolution; many keel fragments were found. Common fragments—in general the last chamber—of ***Sphaeroidinella*** and the occasional record of a delicate and poorly preserved ***Globorotalia miocenica*** Palmer suggest a correlation at least equivalent to the lower part of the ***Globorotalia miocenica*** Zone of Bolli and Premoli-Silva (1973). The scarcity of ***Reticulofenestra pseudoumbilica*** associated with ***Discoaster surculus***, and the doubtful presence of ***Pseudoemiliana lacunosa*** (Kamptner) [not found in the scanning electron microscope, but recorded in cross-polarized light], primitive, very small and sporadic Gephyrocapsae probably of the ***Gephyrocapsa sinuosa*** Hay and Beaudry-***G. aperta*** Kamptner type, suggest at least the lower part of the NN16-***Discoaster surculus*** Zone of Martini (1971).

Pérez-Guzmán (1985) assigns to this part of the section (her samples 1 to 4) an age equivalent to that of the ***Didymocyrtis antepenultima-Didymocyrtys penultima*** Zones; nevertheless, the presence of ***Spongaster tetras*** could be indicative, after Sanfilippo, Westerberg-Smith and Riedel (1985), of an upper ***Spongaster pentas*** Zone or the ***Pterocanium prismatum*** Zone of the middle-lower upper Pliocene.

Not surprisingly, benthic and planktonic foraminifera and calcareous nannoplankton differ slightly on their placement as late Miocene-early Pliocene age; this could be basically due to the delayed arrival of many tropical index morphotypes, in response to the critical low sea-surface temperatures (Ingle, 1967) and in the case of the Miocene and Pliocene stages of California, and that some of the benthic foraminifera commonly used to recognize these stages are time transgressive, as has been demonstrated by several authors, like Crouch and Bukry (1979).

Certainly, the effect of temperature, associated with other physical factors, caused the transitional character of the Baja California Sur assemblage. Tentatively, the Santiago Diatomite ranges from the uppermost Miocene to at least the base of the middle Pliocene—or base of the upper Pliocene ***sensus*** Martini (1971).

ENVIRONMENT

As noted before, the Santiago Diatomite contains laminated horizons in contrast with the massive character of other beds. They support the suggestion of deposition within the upper reaches of the oxygen minimum zone (Calvert, 1964). The presence of epibathial species, associated with a characteristic fauna of a restricted impoverished basin (***Bolivina obliqua***), strengthens this interpretation. Thus the massive diatomaceous shales, which grade into micaceous mudstone, could represent deposition adjacent to a submarine canyon and/or a slope complex, admitting sediments from surrounding areas.

As noted by Gorsline and Emery (1959) and Bandy (1964), cumulative percentages of benthic foraminifera in the whole section indicate that the displaced fauna comprises about 75 % of the total, indicating much downslope sediment displacement. The faunal displacement involves taxa from shallow horizons as ***Lenticulina cushmani*** Galloway and Wissler and ***Buliminella elegantissima*** (d'Orbigny), that have been transported to bathyal depths, in a more or less restricted basin. This interpretation is supported by absence of other benthic groups, particularly ostracodes.

The planktonic foraminifera throughout the Santiago Diatomite section show a remarkable mixture of cold-, temperate- and warm-water species, that includes transitional assemblages. This is probably due to the influence of the California current, which turns west near Cabo San Lucas to become part of the westward-flowing North Equatorial current.

The dominant planktonic foraminifera species ***Globoquadrina altispira altispira*** Cushman and Jarvis, ***G. altispira globosa*** Bolli and

Neogloboquadrina dutertrei blowi Rögl and Bolli, suggest a (slightly) tropical-subtropical character, essentially for the uppermost Miocene. In the Pliocene, this same assemblage, associated with other minor temperate to warm-water foraminifera, as keeled menardiiforms ***Globorotalia***, ***Globigerinoides trilobus*** s.l. Reuss and scarce ***Globigerinoides ruber*** (d'Orbigny), marks an interval of increasing, but always oscillating, surface temperature. The whole section contains significant percentages of ***Globigerina pachyderma pachyderma*** (Ehrenberg), only in the uppermost Miocene, ***G. pachyderma incompta*** Cifelli, ***G. bulloides*** plexus, and minor accessory species like ***Globigerina quinqueloba*** Natland, and ***Globigerinita uvula uvula*** (Ehrenberg), which at this latitude today represent characteristic biofacies of the California current (Bradshaw, 1959; Ingle, 1967). This implies a slight influence of cool-water masses or intensity decrease of the North Equatorial current.

Similar ratios between ***Neogloboquadrina dutertrei blowi*** and ***Globigerina pachyderma incompta*** in the Santiago Diatomite assemblage support the foregoing interpretation, based on Arikawa's work (1983), in which it is postulated that similar percentages of the former species clearly indicate disturbed areas with a prominent thermocline. In the Santiago Diatomite, there is just a slight tendency of ***N. dutertrei blowi*** to be more abundant (less than 10 %). This could indicate at this site that the North Equatorial current looses its indigenous character (such as high temperature and salinity) through cold water mixing with the California current.

The fact that the sinistrally coiling ***Globigerina pachyderma pachyderma*** is practically absent, with exception of occasional uppermost Miocene records, indicates that since the Pliocene the influx of colder water masses has diminished.

The same transitional character observed for the planktonic foraminifera is also valid for the calcareous nannoplakton.

There is definitely a warm interval, as indicated by the presence of abundant ***Discoaster***, particularly ***D. brouweri*** and ***Cyclococcolithus macintyrei*** Bukry and Bramlette. An increase of ***Helicosphaera*** since the early Pliocene reflects warmer surface water conditions, with an optimum between 20 to 28°C (Roth and Berger, 1975). These species, associated to other warm-water indicators, such as ***Hayaster*** sp. cf. ***H. perplexus***

(Bramlette and Riedel), seem to confirm a warm-water influence. The abundances of cool-water species, such as ***Distephanus speculum speculum***, ***D. speculum pentagonus*** (Lemmermann) and ***Mesocena circulus*** (the most abundant of the silicoflagellates) are not dominant, but rather represent a significative percentage within the microfossils. The constant presence of ***Discoaster variabilis*** Martini and Bramlette which, after Bukry (1971), represents a cool temperate element in the basal lower Pliocene assemblages from the area of the cool California current west of northern California (Leg 5, Sites 32 through 37), suggesting a mixture of different water masses, in this case a colder influx, which confirms the interpretation discussed for the planktonic foraminifera.

The relationship between warm-water and cool-water microfossil species of the Santiago Diatomite indicates a paleotemperature of 20°C. This paleoenvironmental interpretation considers that the cool water influx was probably associated with an intensification of the California current that disturbed the control factor of the subtropical Pacific and Gulf of California water masses.

On the basis of abundance and preservation of calcareous microfossils, two facies zones are distinguished: The first comprises abundant and well-preserved planktonic foraminifera and nannoplankton, suggesting that deposition took place well above the carbonate compensation depth (CCD). The second facies zone is characterized by less abundant planktonic foraminifera and calcareous nannoplankton with evident signs of dissolution, suggesting that deposition took place near the CCD. Another interpretation for the second facies is explained by the abundant siliceous microfossil occurrence, such as diatoms, radiolarians and silicoflagellates, suggesting an ancient upwelling of cold-water masses, besides deposition near or below the CCD. Within the facies, ***Amaurolithus*** were observed as occasional components of the assemblages. ***Amaurolithus*** are open-ocean forms; therefore, it is not surprising that they were poorly represented at an early stage of the gulf spreading, and not because they were deposited near the CCD.

Braarudosphaera, a widespread genus, was not recorded at all in any of the studied samples, which would therefore suggest normal marine conditions without continental water dilution and absence of stress conditions; these last conditions, however, were probably present near the basal middle Pliocene, because of the absence of ostracoda and sparse ***in situ*** occurrences of benthic foraminifera. The above mentioned evidence indicates unfavorable living conditions at the sea floor, caused by factors such as high sedimentation rate and low oxygen content. The whole benthic assemblage also includes shelf and upper-slope reworked specimens, probably transported to the bottom by turbidity currents.

All the calcareous species mentioned in the text and also most of the microfossil assemblage is illustrated in Plates 1 to 6.

DISCUSSION AND CONCLUSIONS

Based on the groups presented in this study, age relationships at this locality are somewhat equivalent. These include the following: (1) on the basis of benthic foraminifera, it was only possible to recognize the ***Bolivina obliqua*** Zone of the upper Delmontian, 6.9 Ma old (after Berggren ***et al.***, 1985; the base of this one is close to that K-Ar date); (2) planktonic foraminifera suggest an equivalent age for the ***Globorotalia humerosa*** Zone, in part, to at least the lower part of the ***Globorotalia miocenica*** Zone, or between 5.5 to 3 Ma; and (3) the calcareous nannoplankton goes from the ***Discoaster quinqueramus*** Zone, in part, to the ***Discoaster surculus*** Zone, in part; that is, from 5.5 to 3 Ma.

Age differences are basically related to tectonism and sedimentary control, due to bathymetry and water temperature paleovariations. It can be speculated that many of these ranges or zones are not consistent time equivalents. Moreover, as Bandy (1966) pointed out, the initial appearance of critical morphotypes is not always synchronous at high and low latitudes.

The above mentioned zones are both a product of evolution and ecologically induced migration species. At this latitude, the zones are represented by elements of the California current system planktonic microbiota, as well as components of the North Equatorial current, along with the incursion of species from neighboring water masses of the Gulf of California itself.

The induced species migration is associated with the time and environmental transgressive nature of some foraminiferal assemblages (as noted by several authors, like Natland [1950], and later compiled by Ingle [1967]).

On the basis of age relationships, it is concluded that the Santiago Diatomite ranges between 6.9 and 3 or possibly 2.5 Ma, which agrees with the tectonic framework and historical geology of the Gulf of California.

Biostratigraphic data from the area indicate that toward the west, sediments decrease in age, while paleoecological evidence offers for the Santiago Diatomite a more or less shallow environment at the base and, later up on the section a much more deeper paleobathymetry with subsequent erosion and, in general for the Santiago valley toward the west and southwest, the environment is shallower.

The paleoenvironmental evidences and ages obtained in previous works for each locality and the information from the Santiago Diatomite micropaleontological study are in agreement with Espinosa-Arrubarrena's (1979) proposal, on the existence of a paleobasin located at Rancho Algodones and to the southwest. It is suggested that this paleobay began its development at basal late Miocene, probably with a shallow seaway to the south and a preexisting river canyon to the east.

During early Pliocene, the paleobasin was located to the NE and SW of the Santiago valley, and reached the Rancho Algodones area during middle-late Pliocene. The deeper side of the bay (the canyon area) was on the northeast, and it was shallower at Rancho Algodones; to the south, the terrestrial data (Miller, 1980; Torres-Roldán, 1980) offer evidence for a Pliocene and post-Pliocene regressive event, probably associated with the sea level fluctuations and subaerial erosion. In the Algodones area, the granite topographic expression is comparatively steep hill with rounded boulders, a characteristic of aerial erosion; these hills are flanked by marine upper Pliocene sediments, that definitely prove aerial erosion prior to submergence.

During middle?-late Miocene, submergence occurred as a result of the Gulf of California diffuse-extension spreading process; the Santiago complex became part of the Neogene cycle of basin formation constituting a depocenter.

Subsequently, during and after submergence, a marine process reshaped the granitic boulder complex (oldland valley) to produce the present submarine canyon type, with gorge heads as a product of recent erosion. This reconstruction of the tip of Baja California disagrees with Anderson's (1971) proposal that it might have been a true island between 25–3 Ma. Miller (1980) suggests that the contact with the mainland was maintained until 4 Ma. The author believes, on the other hand, that the Pliocene faunas are best explained by migrations down a paleopeninsula which was connected to the mainland in a similar way as today. At times, part of this peninsula was separated by seaways, such as the one that existed in the isthmus of La Paz during the Pleistocene, which accounts for the subspecific diversity of the present faunas.

Curray and coworkers (1982) pointed out that the first phase of the gulf opening started 5.5 Ma and that there is no evidence for the 400 to 500 km of opening required to place Baja California's tip at a side of Cabo Corrientes, Jalisco. Moreover, these authors stated that the peninsula essentially separated from the mainland as a unit.

This model is also supported by paleobiogeographic and genetic herpetofauna studies (Murphy, 1983), which suggest that Miller's data support instead of a mainland attachment maintained until 4 Ma, the concept of a continuous unit between the Los Cabos Region and the rest of the peninsula by the Pliocene. Such a connection would allow the interchange of subtropical thorn-scrub and ***chaparral*** herpetofauna; besides, Murphy (1983) suggests that the spreading of the Gulf of California yielded two isolated subpopulations, one in the Los Cabos Region and other in the mainland. This is a transgulfian vicariance and considers Baja California as an evolutionary center, instead of a refuge harboring a relict herpetofauna.

For the foregoing, a great number of studies is needed to understand the complexity of this area.

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PLATES 1-6

PLATE 1

PLANKTONIC AND BENTHIC FORAMINIFERA

Figure 1. *Lenticulina cushmani* (Galloway and Wissler), lateral view x 47, sample 1.

—— 2. *Buliminella subfusiformis* (Cushman), lateral view x 98, sample 1.

—— 3. *Nonionella miocenica* Cushman, umbilical view x 57, sample 1.

—— 4. *Reusella pacifica* Cushman and McCulloch, lateral view x 50, sample 1.

—— 5. *Siphonodosaria insecta* (Schwager), lateral view x 53, sample 1.

—— 6. *Bolivina rankinii* Kleinpell, lateral view x 122, sample 1.

—— 7. *Laterostomella* sp., lateral view x 122, sample 1.

—— 8. *Buliminella elegantissima* (d'Orbigny), lateral view x 135, sample 1.

—— 9. *Bolivina subadvena* Cushman, lateral view x 63, sample 1.

—— 10. *Bolivina interjuncta bicostata* (Cushman), lateral view x 43, sample 1.

—— 11. *Bolivina obliqua* Barbat and Johnson, lateral view x 63, sample 1.

—— 12. *Bolivina tongi* Cushman, lateral view x 76, sample 1.

—— 13. *Bolivina cochei* Cushman and Adams, lateral view x 67, sample 1.

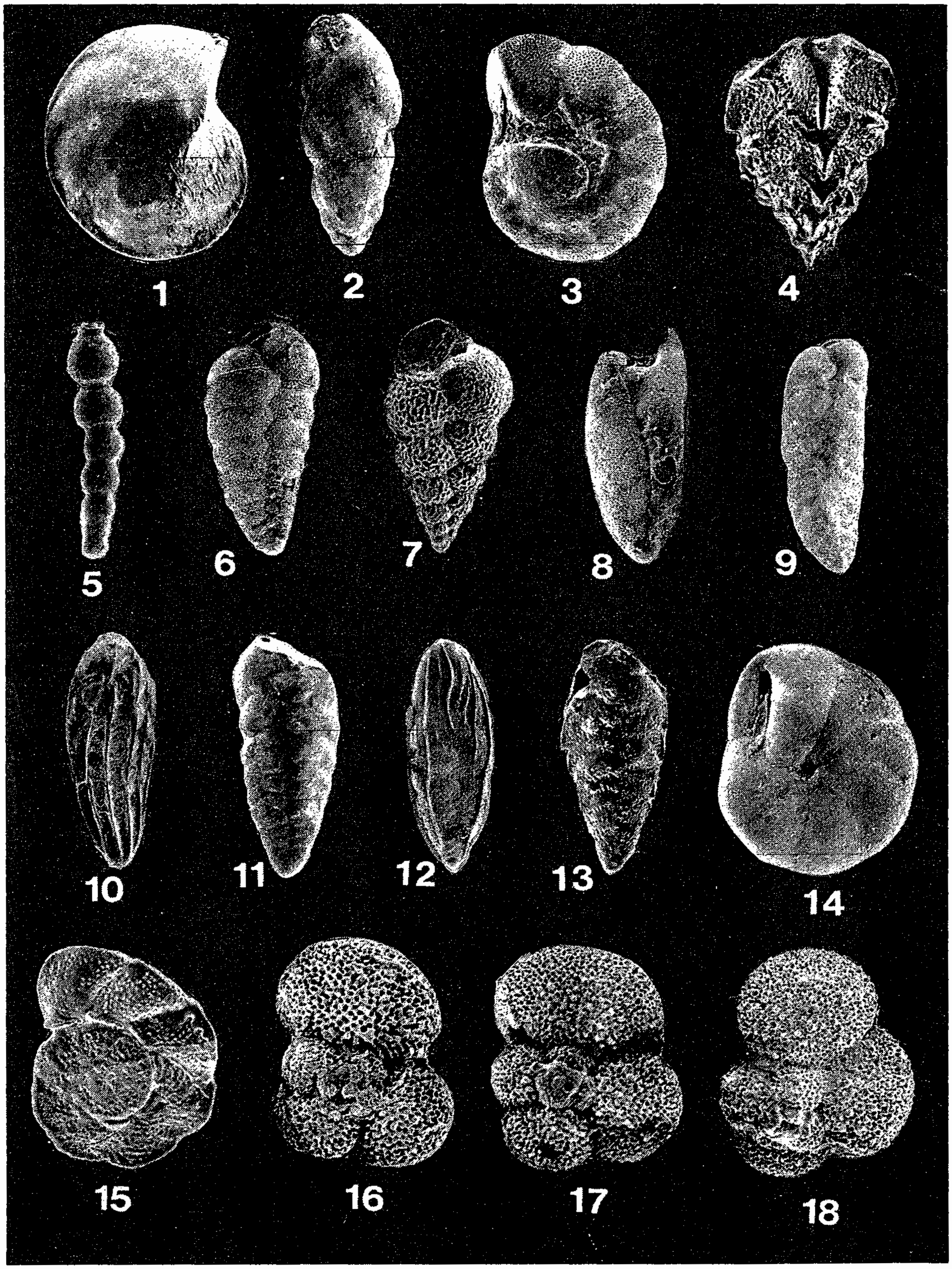
—— 14. *Epistominella pacifica* (Cushman) var., umbilical view x 151, sample 1.

—— 15. *Discorbis campanulata* (Galloway and Wissler), spiral view x 85, sample 1.

—— 16. *Globigerina bulloides bulloides* d'Orbigny, spiral view x 103, sample 2.

—— 17. *Globigerina apertura* Cushman, spiral view x 90, sample 2.

—— 18. *Globigerina bulloides riveroae* Bolli and Bermúdez, spiral view x 88, sample 2.



PLANKTONIC AND BENTHIC FORAMINIFERA

PLATE 2

PLANKTONIC FORAMINIFERA

Figure 1. *Globigerina bulloides quadrilatera* Galloway and Wissler, spiral view x 94, sample 2.

—— 2. *Globigerina bulloides umbilicata* Orr and Zaitzeff, spiral view x 178, sample 2.

—— 3. *Globigerinita uvula uvula* (Ehrenberg), spiral view x 178, sample 4.

—— 4. *Globigerina pachyderma incompta* Cifelli. (a) spiral view x 110; (b) umbilical view x 106; sample 7.

—— 5. *Globigerina pachyderma pachyderma* (Ehrenberg). (a) spiral view x 92; (b) umbilical view x 100; sample 1.

—— 6. *Globorotalia humerosa humerosa* Takayanagi and Saito, spiral view x 65, sample 6.

—— 7. *Globigerina quinqueloba* Natland. (a) umbilical view x 151; (b) spiral view x 110; sample 4.

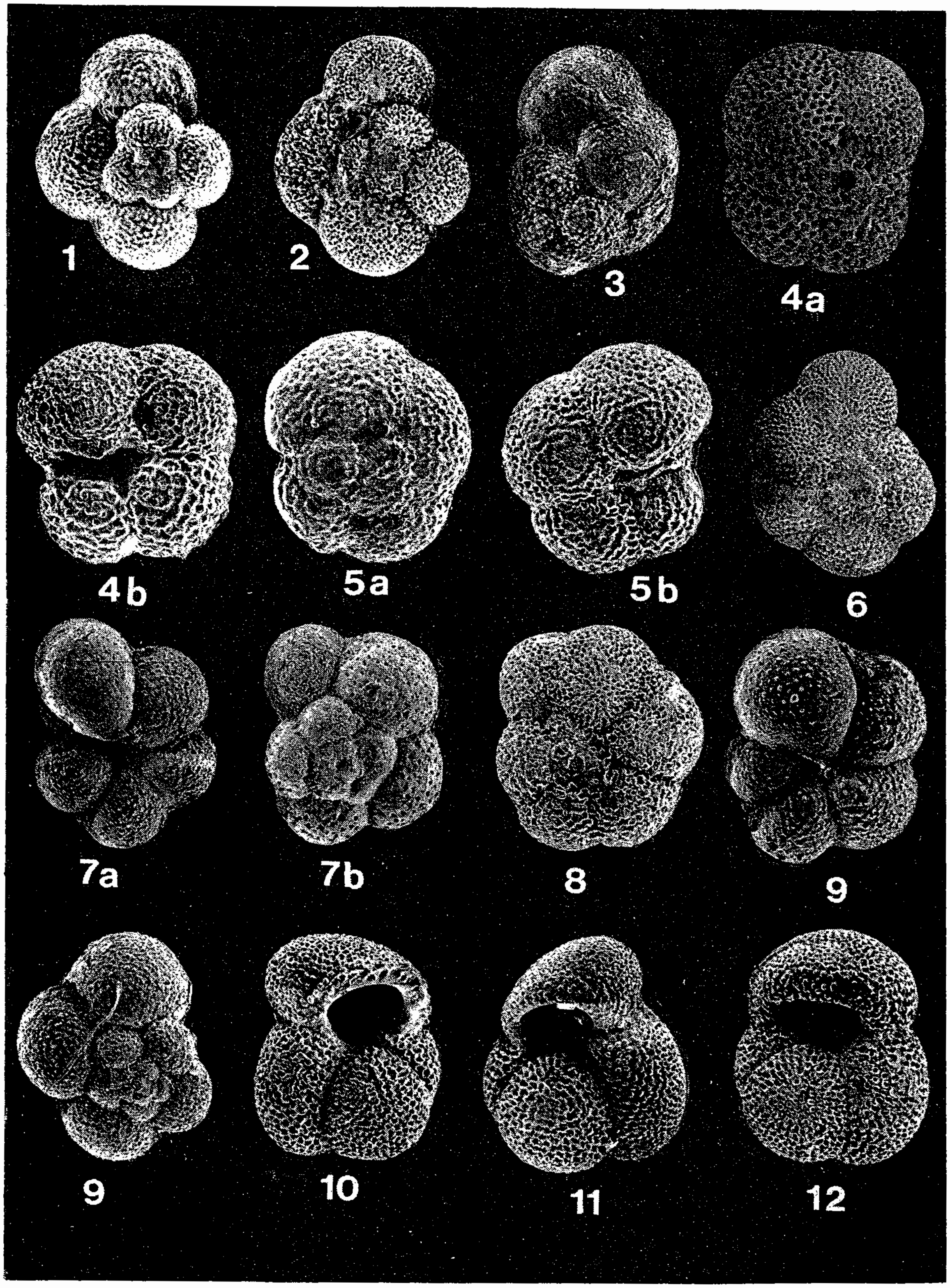
—— 8. *Neogloboquadrina dutertrei blowi* Rögl and Bolli, spiral view x 85, sample 5.

—— 9. *Turborotalita iota* (Parker). (a) umbilical view x 79; (b) spiral view x 65; sample 4.

—— 10. *Globigerinoides obliquus extremus* Bolli and Bermúdez, umbilical view x 75, sample 1.

—— 11. *Globigerinoides obliquus obliquus* Bolli, umbilical view x 80, sample 1.

—— 12. *Globigerinoides ruber* (d'Orbigny), umbilical view x 66, sample 3.



PLANKTONIC FORAMINIFERA

PLATE 3

PLANKTONIC FORAMINIFERA

Figure 1. ***Globigerinoides amplus*** Perconig, umbilical view x 67, sample 3.

—— 2. ***Sphaeroidinella*** sp. (a) fragment of the last chamber, outside view x 79; (b) inside view x 81.5; sample 20.

—— 3. ***Pulleniatina primalis*** Banner and Blow, spiral view x 77.7, sample 3.

—— 4. ***Globoquadrina altispira altispira*** Cushman and Jarvis. (a) spiral view x 67; (b) umbilical view x 82; sample 5.

—— 5. ***Globorotalia tumida tumida*** (Brady), spiral view x 53, sample 10.

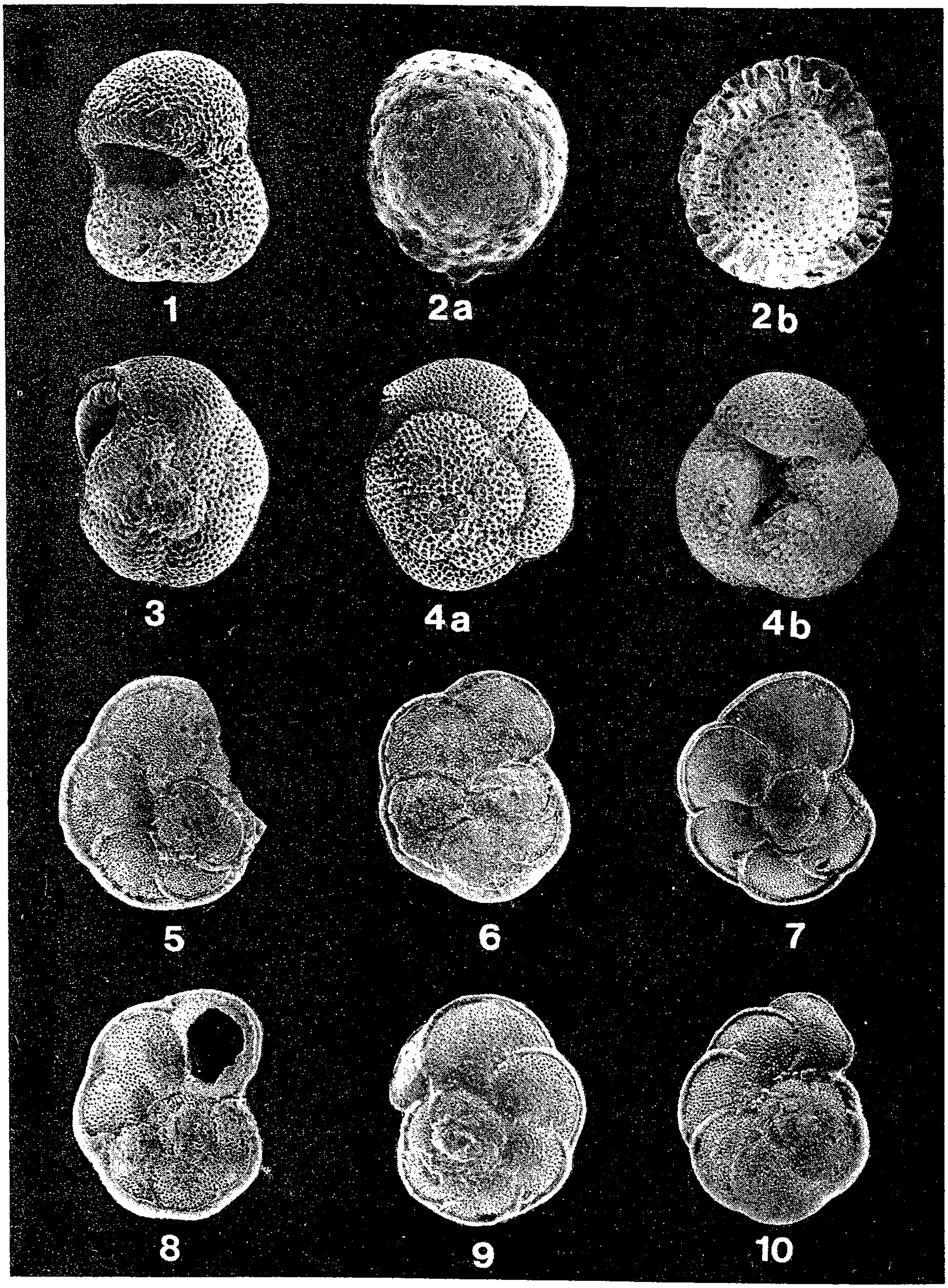
—— 6. ***Globorotalia menardii*** s.l. (Parker, Jones and Brady), spiral view x 53, sample 10.

—— 7. ***Globorotalia pseudomiocenica*** Bolli and Bermúdez, spiral view x 54, sample 16.

—— 8. ***Globorotalia miocenica*** Palmer, spiral view x 72, sample 20.

—— 9. ***Globorotalia menardii*** "B" of Bolli and Premoli-Silva, 1973, spiral view x 60, sample 19.

—— 10. ***Globorotalia multicamerata*** s.l. Cushman and Jarvis, spiral view x 50, sample 16.



PLANKTONIC FORAMINIFERA

PLATE 4

CALCAREOUS NANNOPLANKTON

Specimens in cross-polarized light, approximately x 2,000.

Figure 1. *Thoracosphaera heimii* (Lohmann), sample 7.

—— 2. *Rhabdosphaera clavigera* Murray and Blackmann, sample 9.

—— 3. *Ceratolithus* sp., sample 10.

—— 4. *Sphenolithus abies* Deflandre, sample 10.

—— 5. *Ceratolithus* sp. cf. *C. telesmus* Norris, sample 10.

—— 6. *Pontosphaera multipora* (Kamptner ex. Deflandre), sample 9.

—— 7. *Cyclococcolithus leptopora* Murray and Blackmann, sample 9.

—— 8. *Discolithina anisotrenia* Kamptner, sample 9.

—— 9. *Cyclococcolithus macintyrei* (Wallich), sample 9.

—— 10. *Coccolithus pelagicus* (Wallich), sample 5.

—— 11. *Helicosphaera kamptneri* Hay and Mohler. (a) sample 12; (b) + 45°, sample 16.

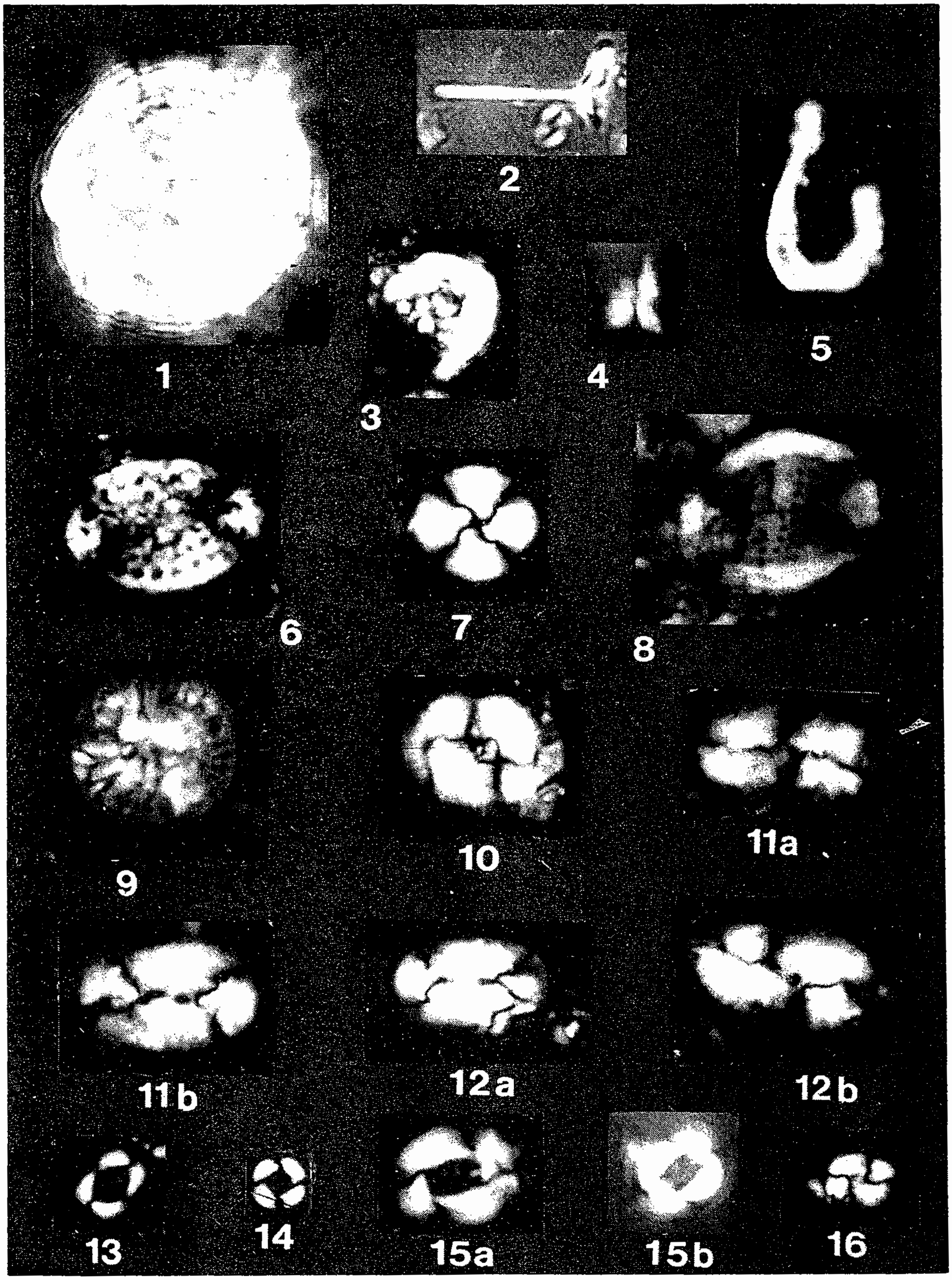
—— 12. *Helicosphaera sellii* Bukry and Bramlette. (a) sample 13; (b) + 45°, sample 12.

—— 13. *Pseudoemiliana lacunosa*? (Kamptner), sample 20.

—— 14. *Umbilicosphaera mirabilis* Lohmann, sample 18.

—— 15. *Reticulofenestra pseudoumbilica* Gartner). (a) sample 16; (b) + 45°, sample 16.

—— 16. *Gephyrocapsa*? small, sample 20.



CALCAREOUS NANNOPLANKTON

PLATE 5

CALCAREOUS NANNOPLANKTON

Figure 1. ***Helicosphaera granulata*** Bukry and Percival, proximal side x 7,800, sample 2.

—— 2. ***Helicosphaera kamptneri*** Hay and Mohler, proximal side x 8,600, sample 12.

—— 3. ***Gephyrocapsa***? small, distal side x 1,000, sample 20.

—— 4. ***Helicosphaera sellii*** Bukry and Bramlette, proximal side x 1,000, sample 12.

—— 5. ***Cyclococcolithus macintyrei*** (Bukry and Bramlette), distal side x 1,000, sample 8.

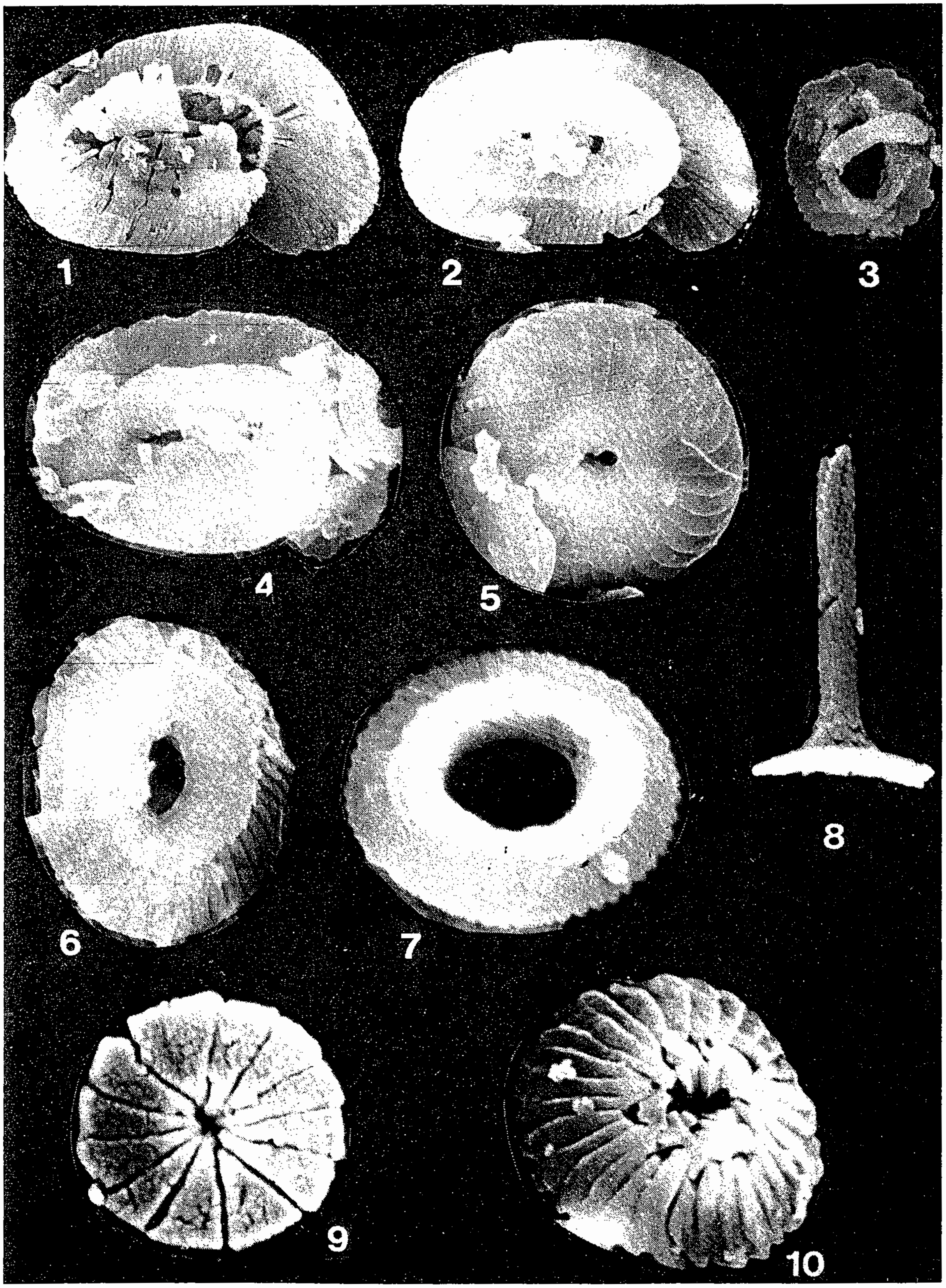
—— 6. ***Coccolithus pelagicus*** (Wallich), distal side x 1,000, sample 5.

—— 7. ***Reticulofenestra pseudoumbilica*** (Gartner), distal side x 6,000, sample 16.

—— 8. ***Rhabdosphaera clavigera*** Murray and Blackmann, side view x 3,500, sample 7.

—— 9. ***Hayaster*** sp. cf. ***H. perplexus*** (Bramlette and Riedel), distal side x 9,400, sample 16.

—— 10. ***Crenalithus doronicoides*** Black and Barnes, distal side x 6,000, sample 16.



CALCAREOUS NANNOPLANKTON

PLATE 6

CALCAREOUS NANNOPLANKTON

Figure 1. *Discoaster surculus* Martini and Bramlette, distal side x 5,400, sample 21.

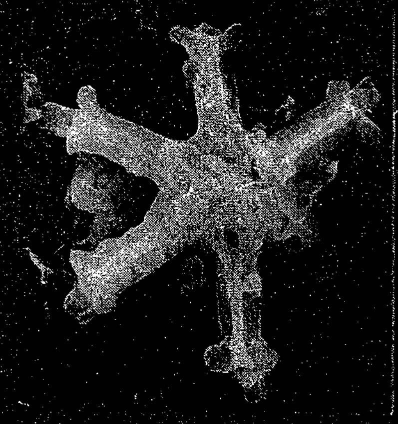
—— 2. *Discoaster brouweri* Tan, distal side x 6,500, sample 16.

—— 3. *Discoaster quinqueramus* Gartner, distal side x 6,600, sample 2.

—— 4. *Discoaster pentaradiatus* Tan, distal side x 4,800, sample 8.

—— 5. *Discoaster* sp. cf. *D. asymmetricus* Gartner, phase contrast, distal side x 2,000, sample 2.

—— 6. *Discoaster variabilis* Martini and Bramlette, distal side x 3,000, sample 16.



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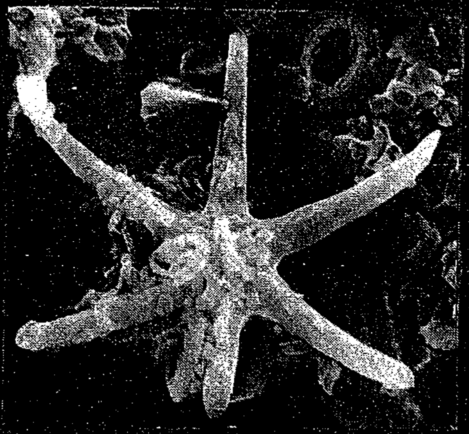

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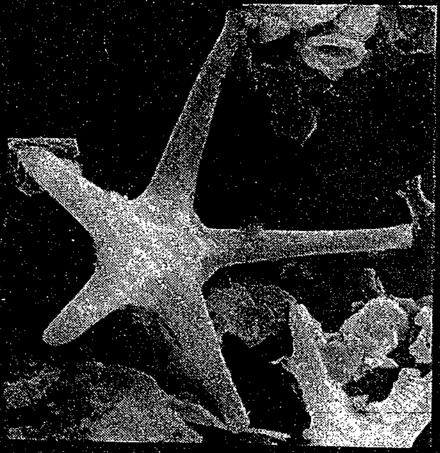

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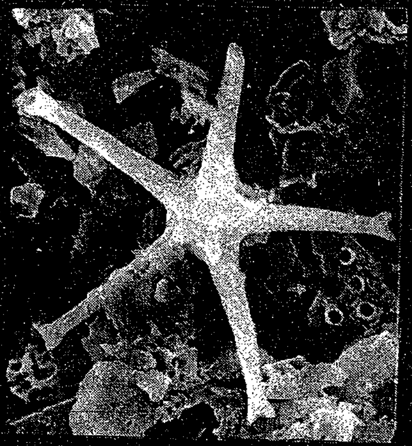

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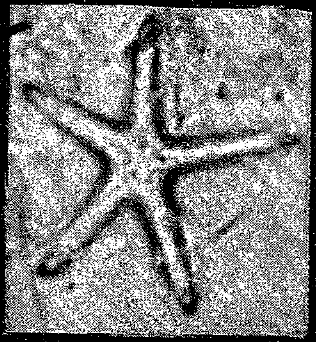

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6

CALCAREOUS NANNOPLANKTON

Carreño, A. L., 1992, Early Neogene foraminifera and associated microfossils of the Cerro Tierra Blanca Member (El Cien Formation), Baja California Sur, Mexico, *in* Calcareous Neogene microfossils of Baja California Sur, Mexico: Universidad Nacional Autónoma de México, Instituto de Geología, Paleontología Mexicana 59, part 2, p. 39-93, 1 figure, 3 tables, 12 plates.

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.

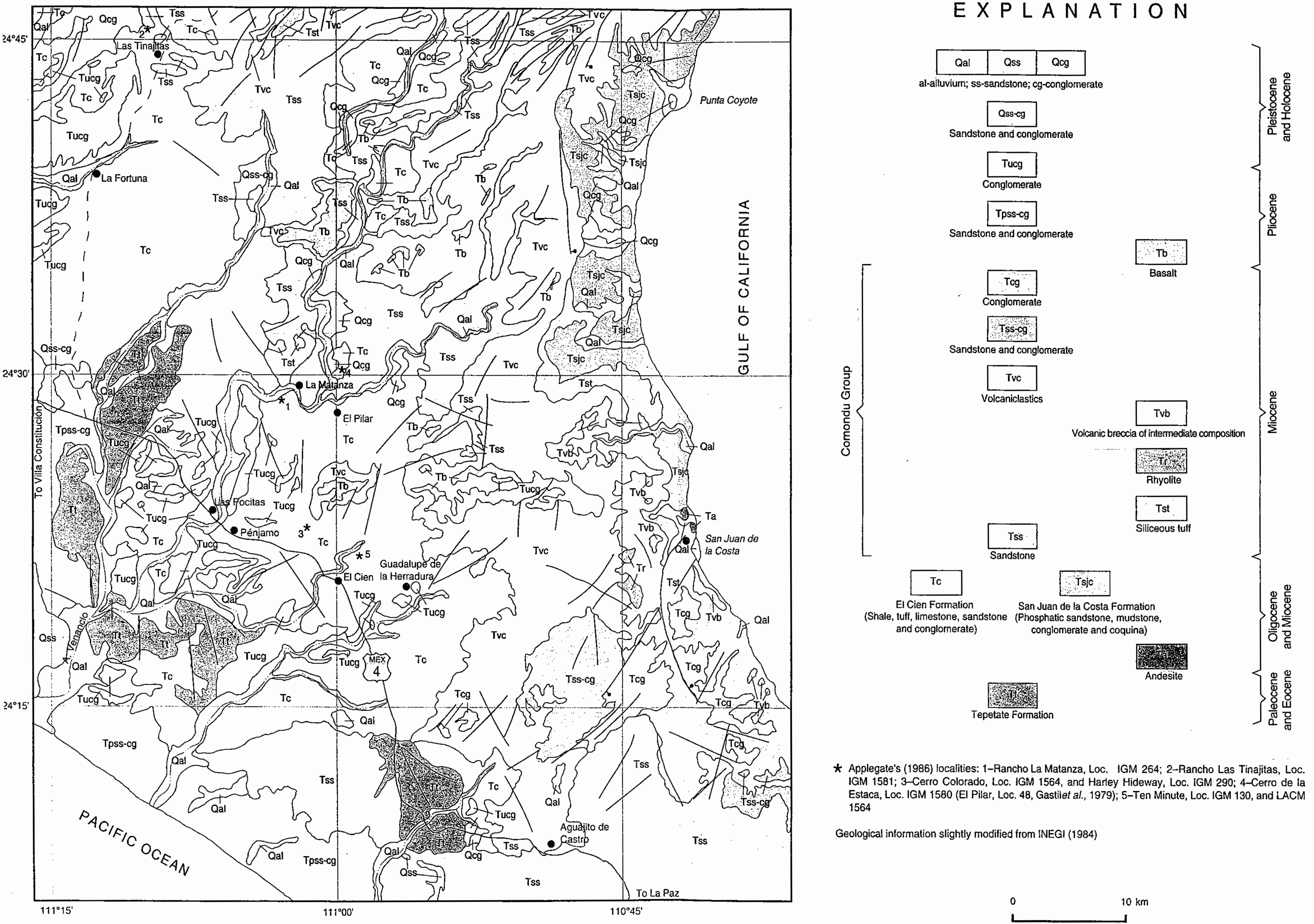
Throughout the type section, 50 samples were collected by Applegate, who gave them to the present author for micropaleontological study. Of these, only some of the 26 samples collected from the Cerro Tierra Blanca Member contain microfossils and constitute the basis of the present study. Applegate's 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.

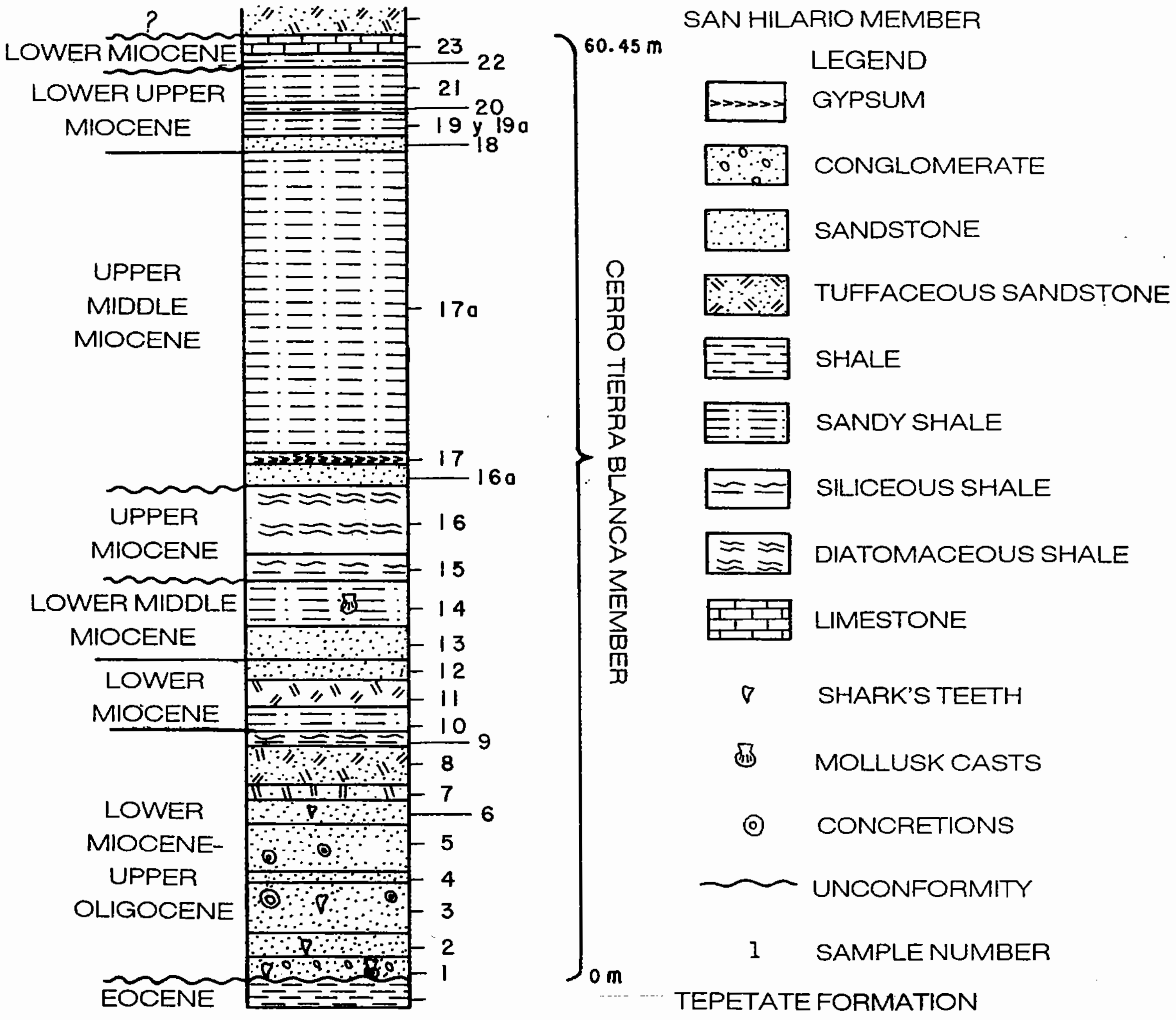


* Applegate's (1986) localities: 1–Rancho La Matanza, Loc. IGM 264; 2–Rancho Las Tinajitas, Loc. IGM 1581; 3–Cerro Colorado, Loc. IGM 1564, and Harley Hideway, Loc. IGM 290; 4–Cerro de la Estaca, Loc. IGM 1580 (El Pilar, Loc. 48, Gastil *et al.*, 1979); 5–Ten Minute, Loc. IGM 130, and LACM 1564

Geological information slightly modified from INEGI (1984)

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)



DRAFTED BY ENRIQUE GUTIÉRREZ NAVARRETE

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.

GROUP \ SAMPLE	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 **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 I6 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.

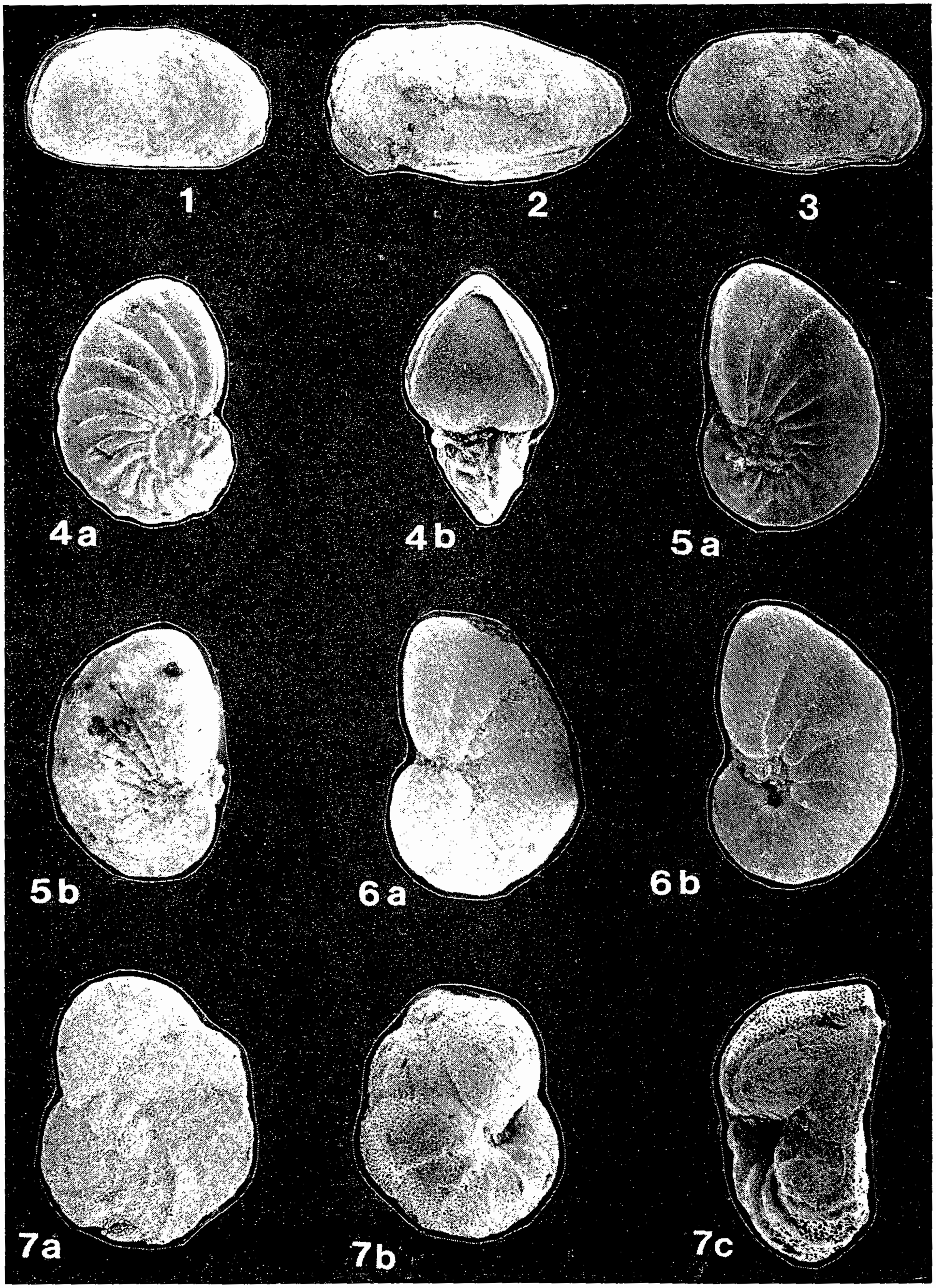
—— 3. *Echinocythereis*? sp., carapace, external view right valve x 120, sample 5.

—— 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.

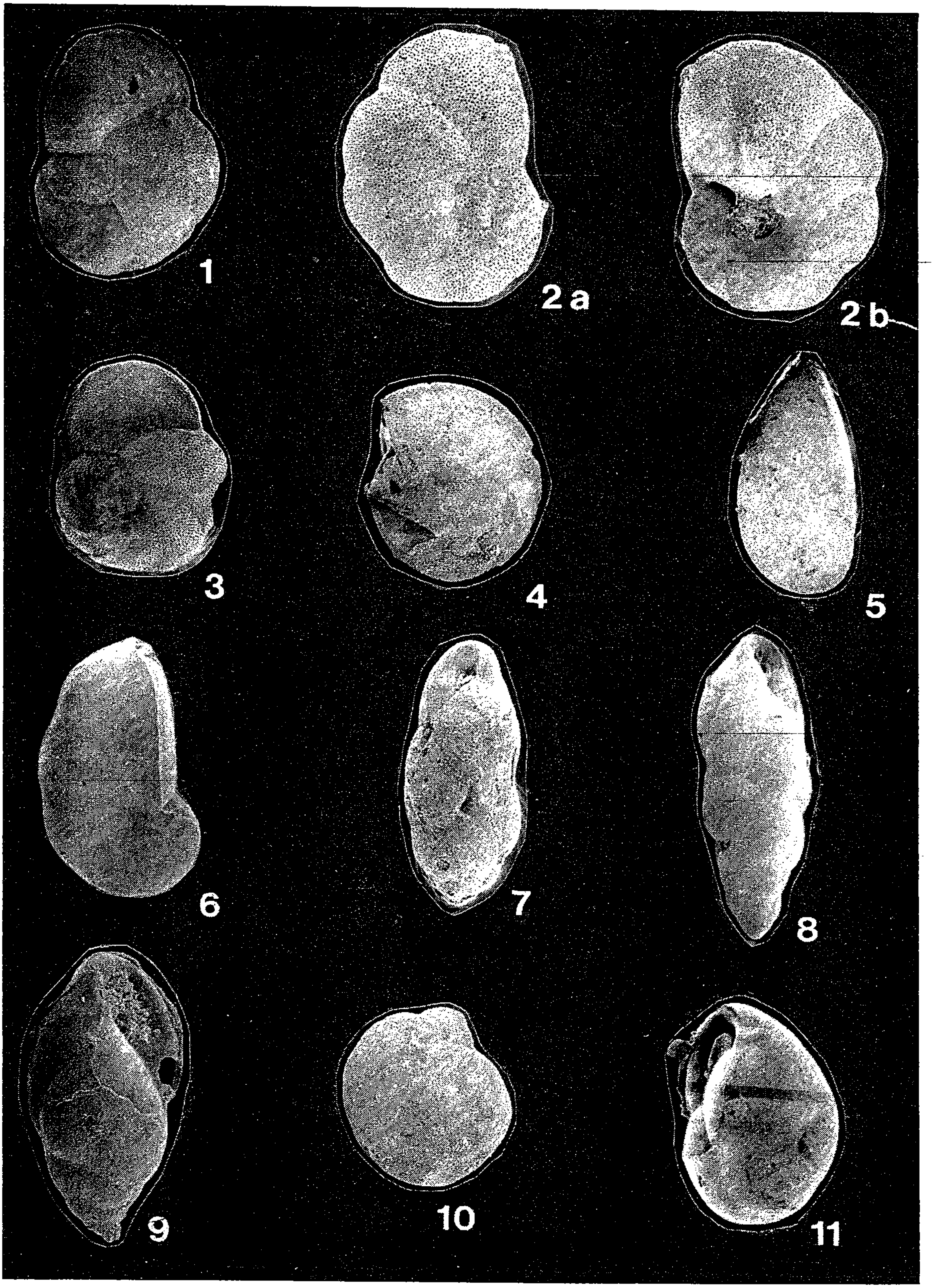
—— 7. ***Buliminella elegantissima*** (d'Orbigny), side view x 180, sample 14.

—— 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.

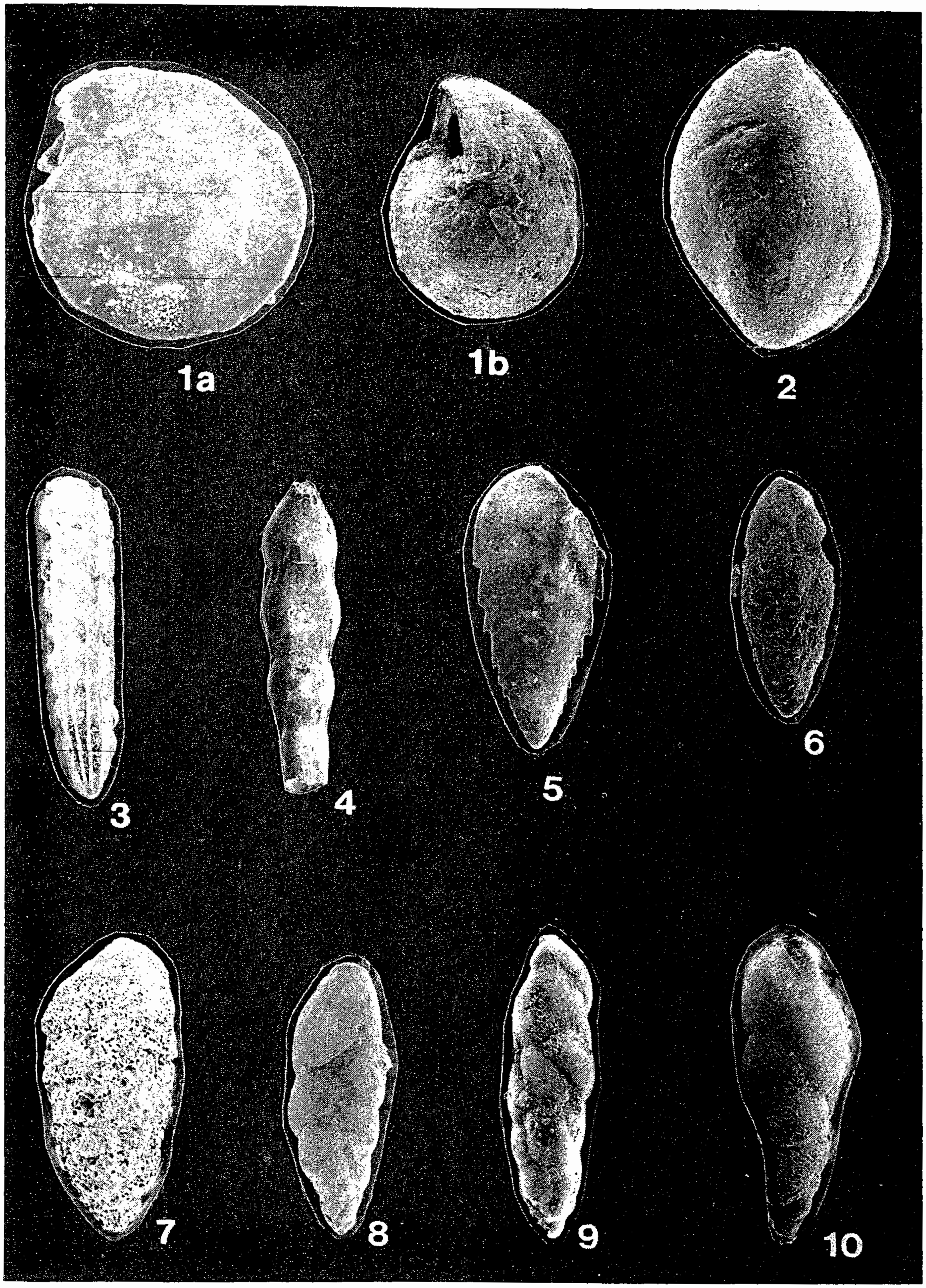
—— 6. ***Bolivina advena*** Cushman, side view x 120, sample 22.

—— 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.



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.

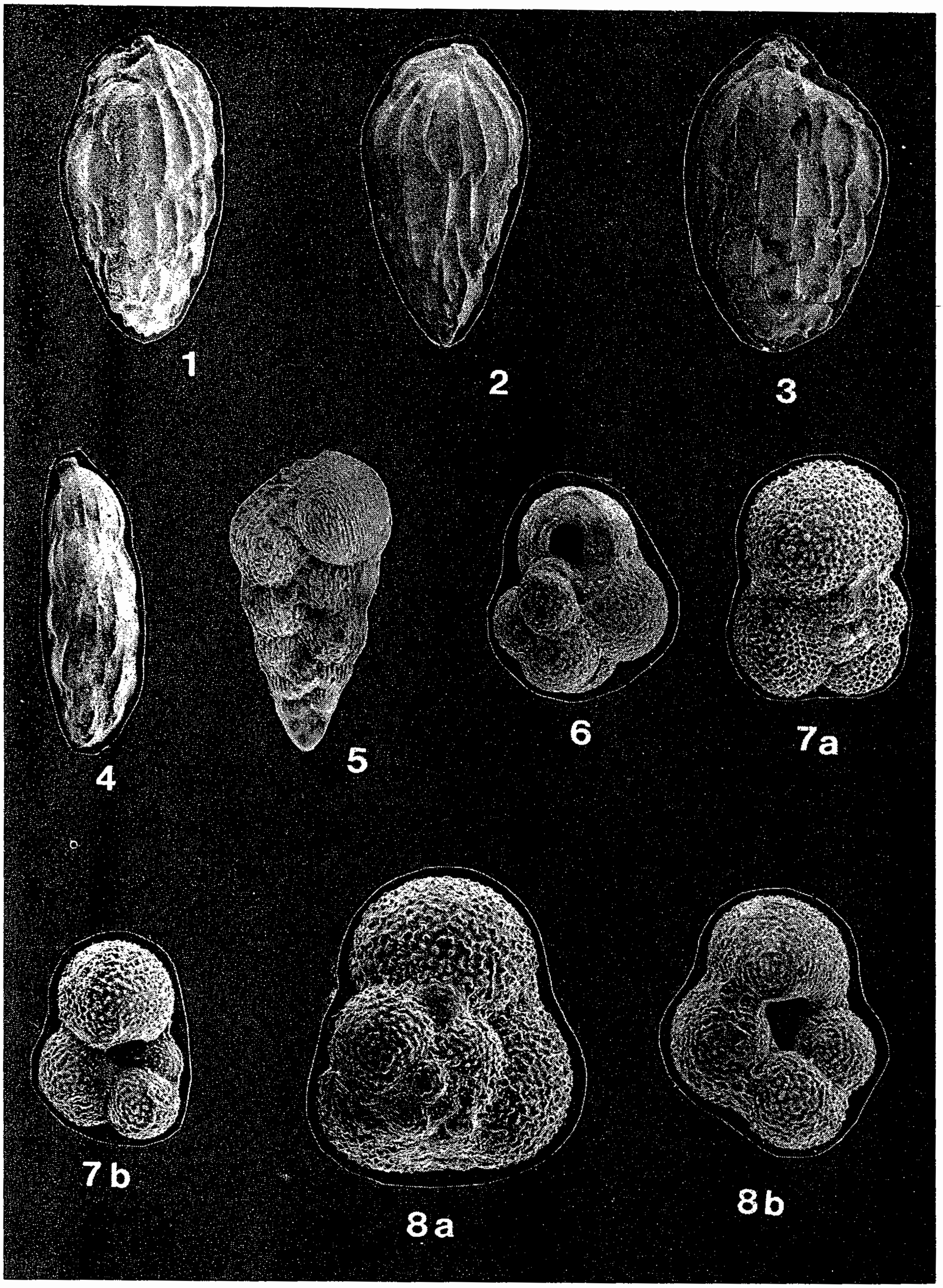
—— 4. ***Siphogenerina*** sp., side view x 100, sample 14.

—— 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

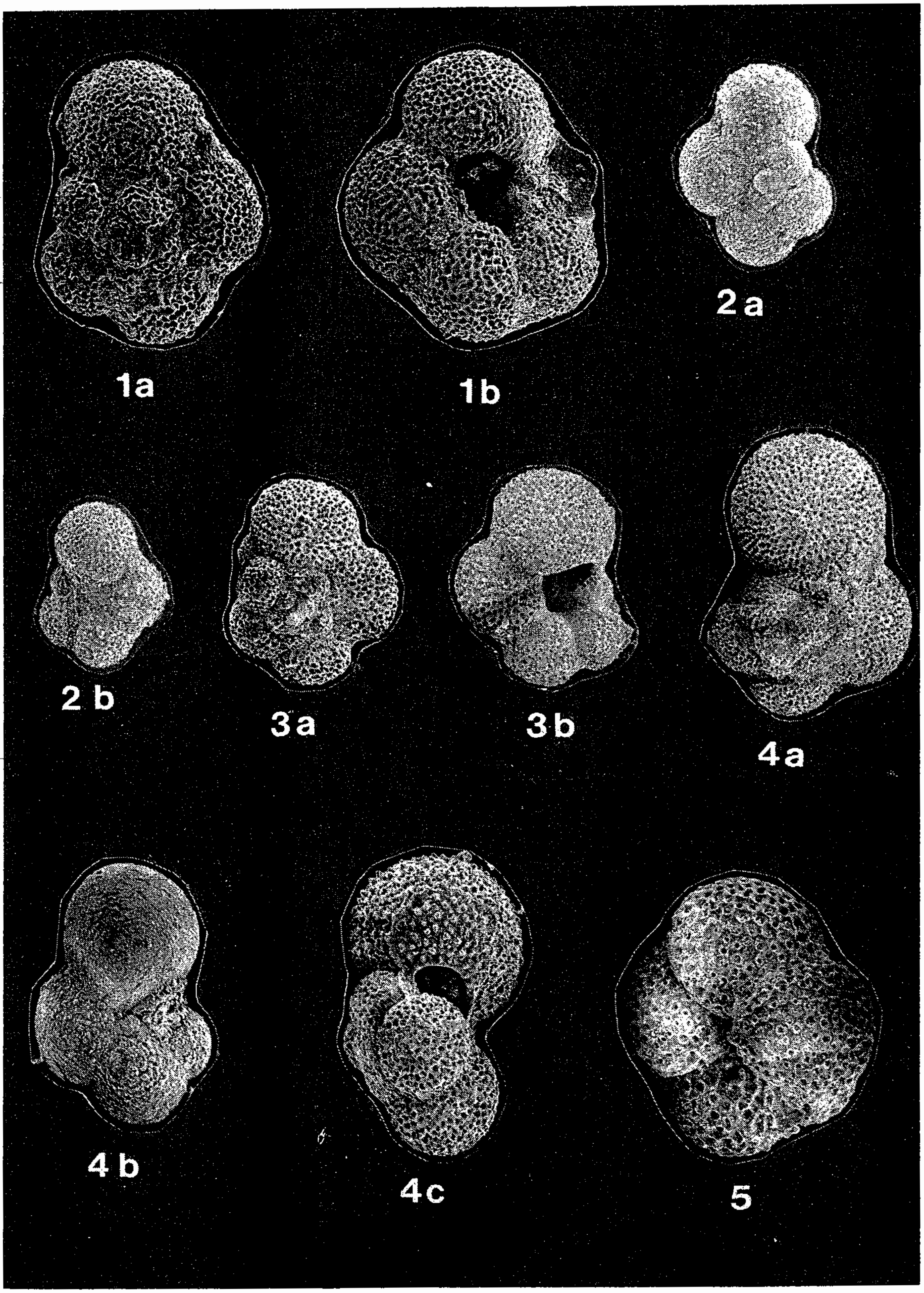
Figure 1. ***Globigerina pseudociperoensis*** Blow. (a) spiral view x 240; (b) umbilical view x 240, sample 22.

—— 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.

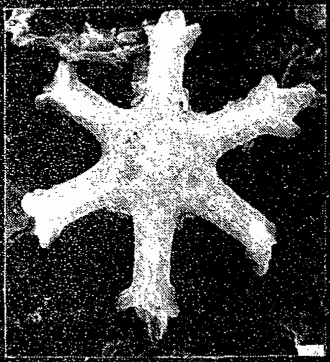
—— 2. ***Discoaster adamanteus*** Bramlette and Wilcox, proximal side x 11,000, sample 18.

—— 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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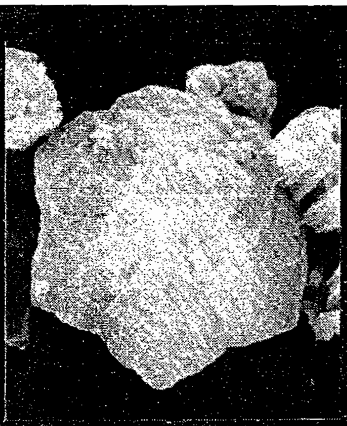

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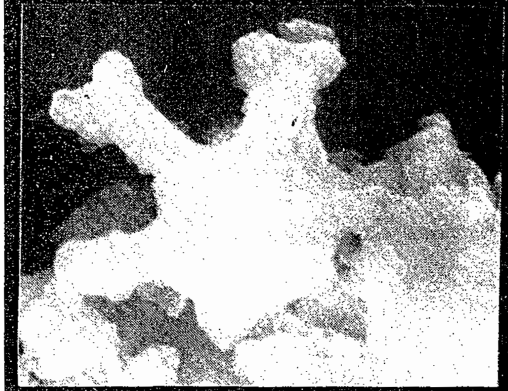

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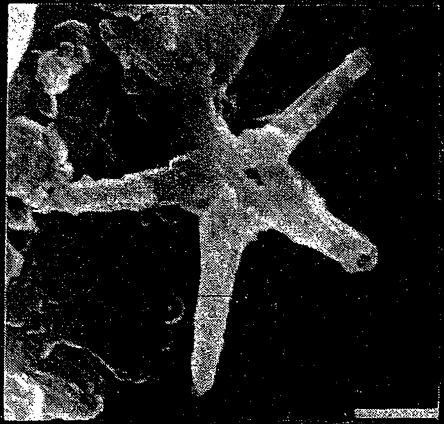

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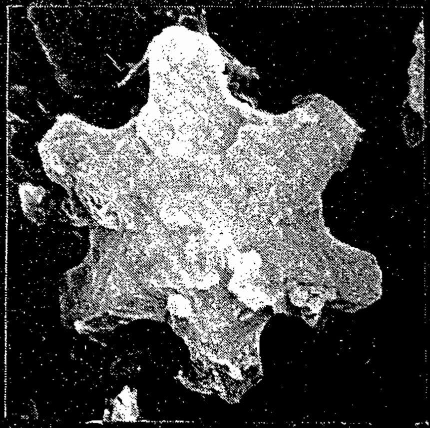

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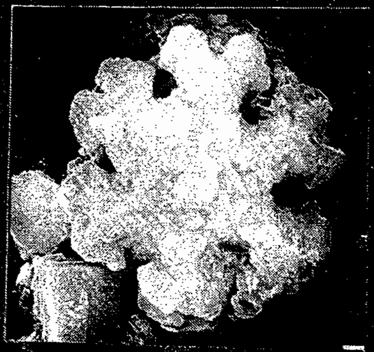


6

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.

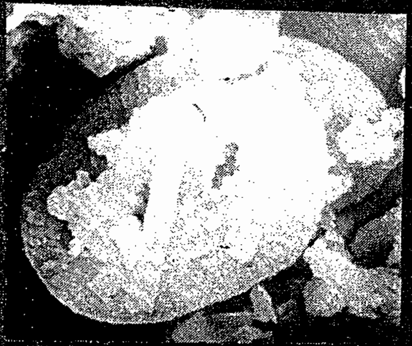
—— 4. ***Dictyococcites bisectus*** (Hay, Mohler and Wade), distal side x 5,400, sample 22.

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

1

2a

2 b



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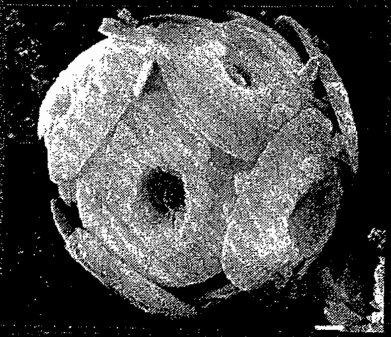


5

CALCAREOUS NANNOPLANKTON

PLATE 9

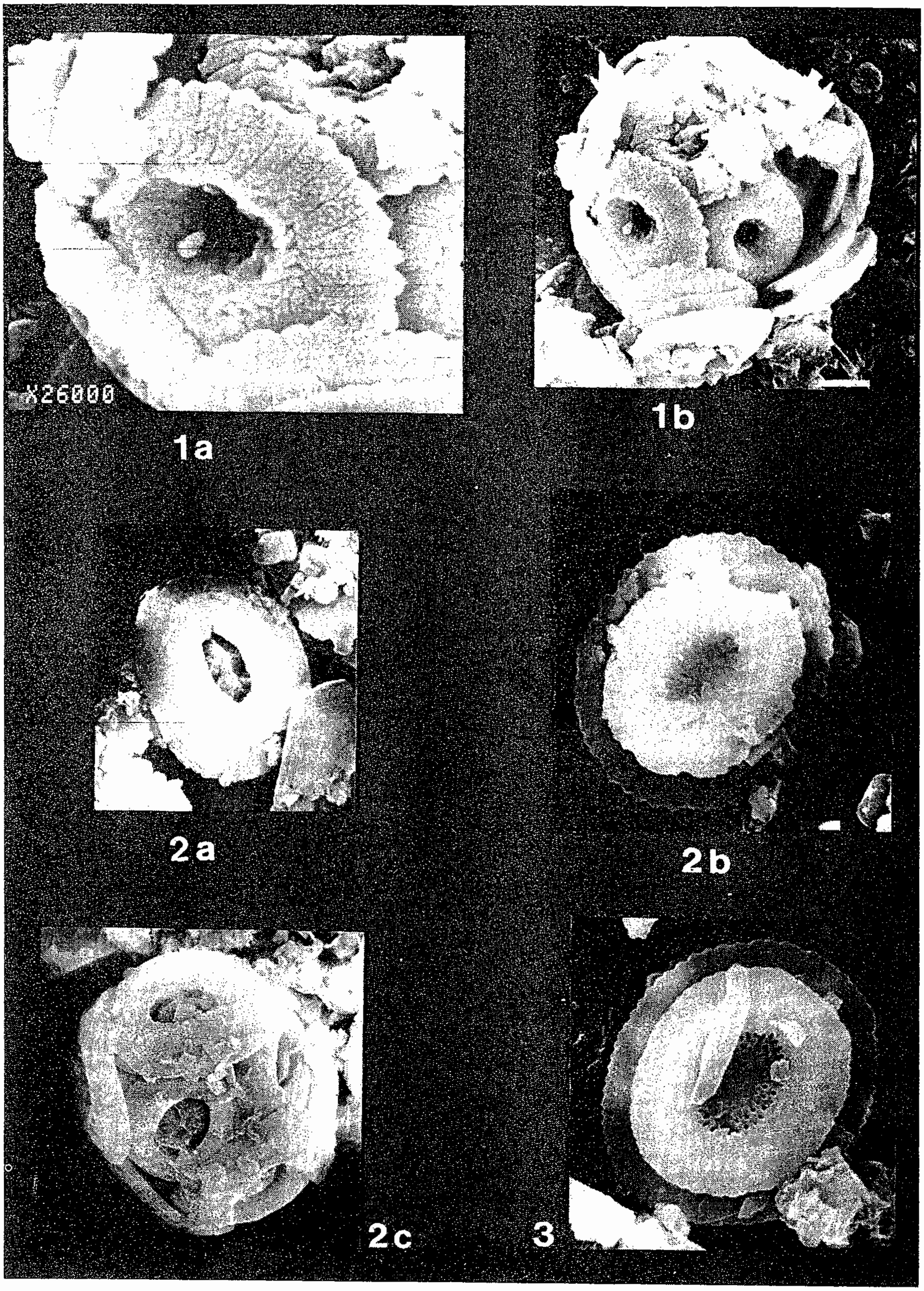
CALCAREOUS NANNOPLANKTON

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.

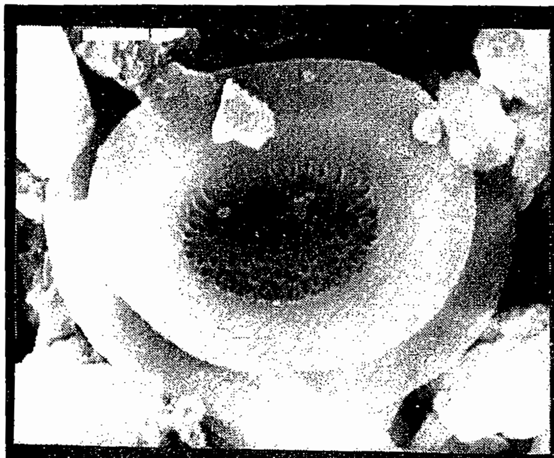
—— 2. ***Reticulofenestra*** sp. cf. ***R. laevis*** Roth and Hay, proximal side x 12,000, sample 17.

—— 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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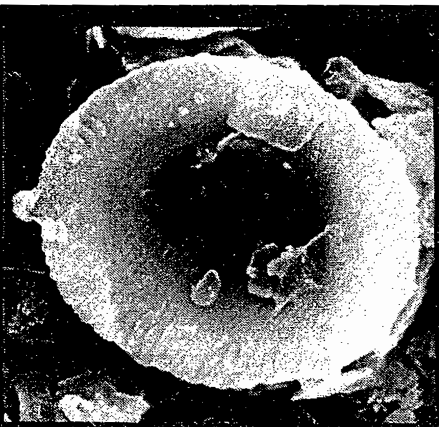

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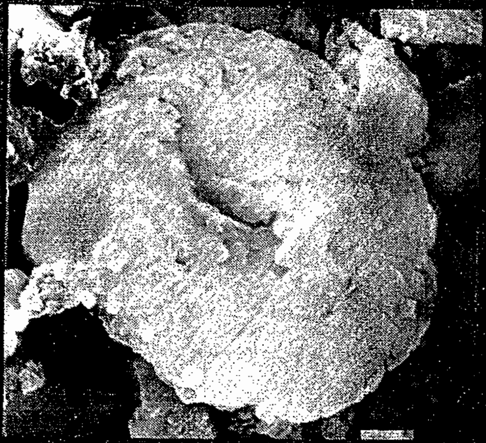

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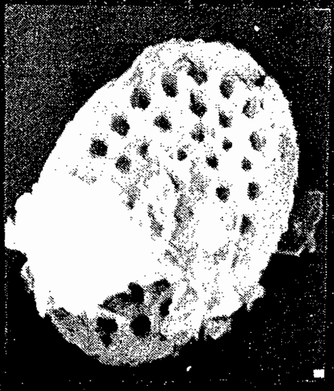

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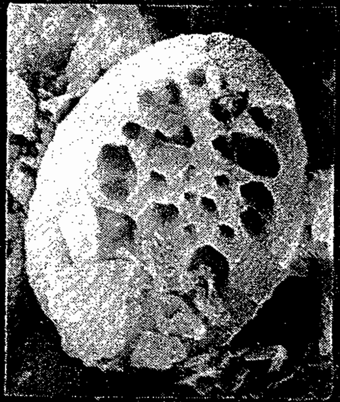


6

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.

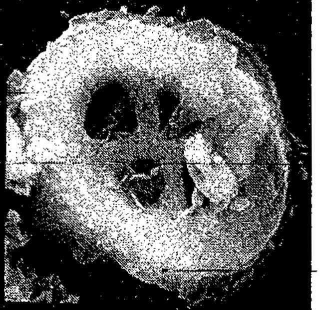
—— 6. *Reticulofenestra pseudoumbilica* (Gartner). (a) 45°; (b) 60°, sample 18.

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

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


1


2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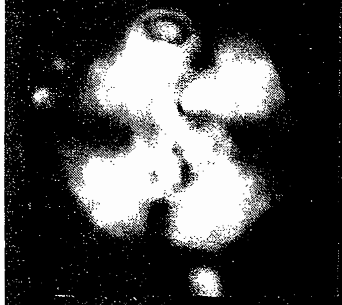
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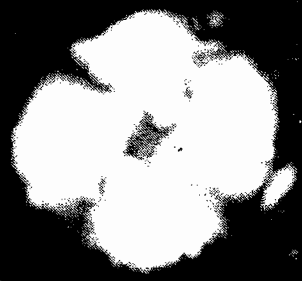
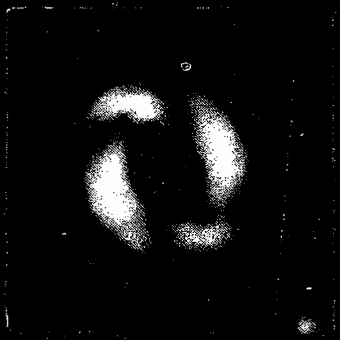

6 a


6 b


7


8

CALCAREOUS NANNOPLANKTON

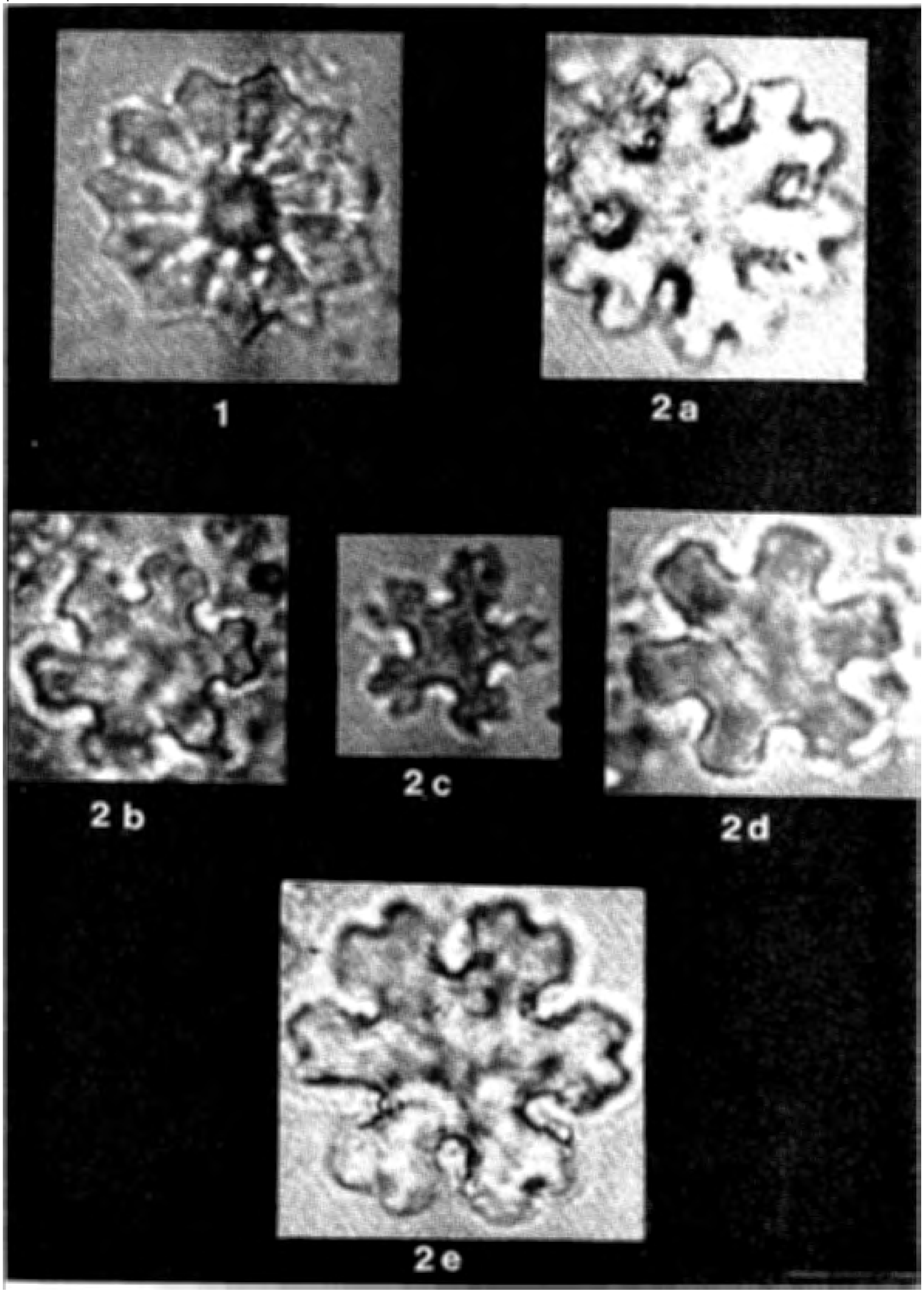
PLATE 12

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