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DIATOM BIOSTRATIGRAPHY OF BAHÍA ASUNCIÓN, BAJA CALIFORNIA SUR, MEXICO

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In the Vizcaíno Basin, near the Bahía Asunción village, Baja California Sur, unconformably over the Valle Formation, an unnamed sedimentary Neogene sequence crops out. This sequence consists of phosphatic sandstone overlain by diatomite, which is in turn unconformably overlain by calcareous sandstone and conglomerate. At the locality Diatomite Valley, whose name is informally applied herein to the diatomaceous unit, index diatom species allow the assignment of these outcrops to an early late Miocene age, equivalent to the Subzone d of *Denticulopsis hustedtii-Denticulopsis lauta* Zone, of about 8.9 to 8.4 Ma. The lithofacies and the proportion of the abundance of benthic and planktonic diatoms and resting spores indicates deposition in an aerated basin slope near the edge of the oxygen minimum zone, during a warm local event, but always during a generalized cool-temperate environment, mostly associated to coastal upwelling.

Key words: Biostratigraphy, diatoms, upper Miocene, Baja California Sur, Mexico.

RESUMEN

En la cuenca de Vizcaíno, cerca del poblado de Bahía Asunción, Baja California Sur, aflora sobre la Formación Valle, una secuencia neogénica no descrita formalmente, constituida por arenisca fosfática cubierta en discordancia por una unidad diatomítica, la cual a su vez yace discordantemente bajo areniscas calcáreas y conglomerados. En la localidad Valle de Diatomita, con cuyo nombre se designa informalmente aquí a la unidad diatomítica, el conjunto de especies índice de diatomeas permite asignar una edad del Mioceno tardío temprano equivalente a la Subzona d de la Zona de *Denticulopsis hustedtii-Denticulopsis lauta*, calibrada en 8.9 - 8.4 Ma. Las litofacies y la proporción de la abundancia de las diatomeas bentónicas, de las planctónicas y de las esporas de resistencia indican depósito de talud en una cuenca aireada cerca del límite de la zona de oxígeno mínimo disuelto, en un ambiente cálido local, enmarcado dentro de un clima frío-templado generalizado, asociado a surgencias costeras.

Palabras clave: Bioestratigrafía, diatomeas, Mioceno superior, Baja California Sur, México.

INTRODUCTION

Even though diatoms are used all over the world for the interpretation of ancient paleoenvironments, they are also excellent index fossils and an important basis for multidisciplinary research. In Mexico, this group is almost unknown in geological studies.

This might be due to the abundance of calcareous sequences throughout the Mesozoic and Cenozoic, and to the scarcity of siliceous sections. Important exceptions are the eastern and western coasts of the Baja California Peninsula together with Mexico's mainland eastern coast and islands, where diatomaceous sections, in great number, crop out or are deposited in deeper basins. Although several reports on Cenozoic diatoms have been published from southern, southwestern and western United States, scarce information on fossil diatoms of any age has been published from Baja California.

One of the first studies of the Baja California Peninsula based on diatoms was published by Hanna (1926). Other early studies include Hertlein (1933), Hanna and Brigger (1966) and Hertlein (1968). It was not until recently that diatoms have been profusely studied (Helenes-Escamilla, 1980) within taxonomic, biostratigraphic and paleoecological contexts, particularly in Neogene sequences (Kim and Barron, 1986). In spite of these important but isolated reports, a great number of Baja California sequences is still unknown and, for this reason, the present paper constitutes the first report on diatom assemblages from one of the most conspicuous diatomitic sequences, at Bahía Asunción, Baja California Sur (Figure 1). It establishes the biostratigraphic framework and also the general depositional environment trends for this part of the peninsula which has not been well studied both from the geologic and the paleontologic points of view, particularly during the Neogene.

AREA OF STUDY

The studied sedimentary sequence is located on the Vizcaíno Peninsula, at the western side of the Baja California Peninsula, about 600 km to the south of the border between Mexico and the United States of America. The Vizcaíno Peninsula is a part of the continental borderland province, separated by the Vizcaíno Basin to the east, from the Baja California Cretaceous batholith.

The variety of rocks of the Vizcaíno Peninsula includes different kinds of volcanic, intrusive, metamorphic and sedimentary rocks, with considerable volcaniclastic material, all of them extremely deformed.

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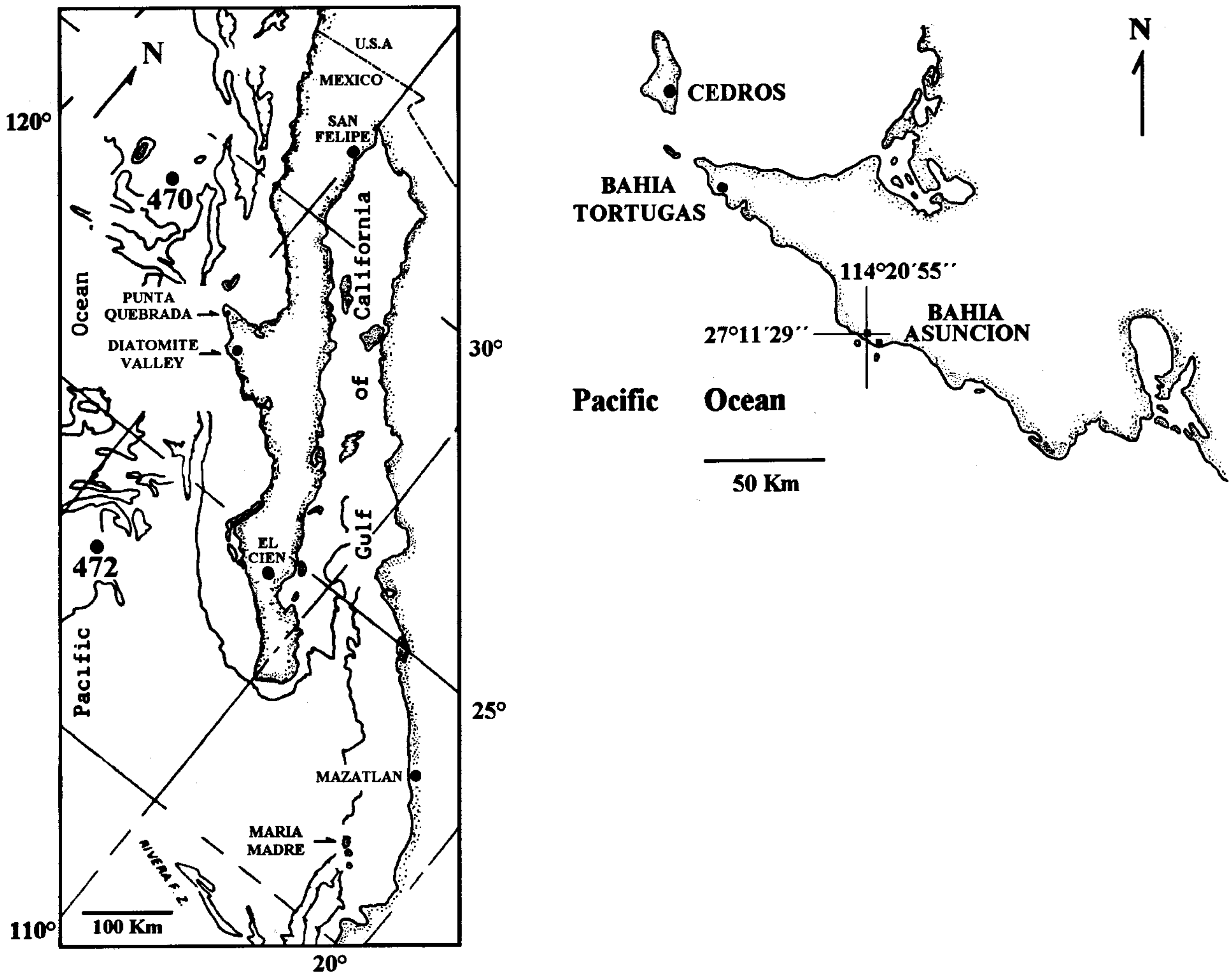


Figure 1.- Location of the Diatomite Valley at Bahía Asunción, Baja California Sur, and localities mentioned in text.

The informal diatomaceous unit Diatomite Valley studied herein, is a part of an unnamed 407 m thick composite section, measured and sampled by Carreño (1987), corresponding to Applegate and coworkers' (1979) sequence. It is located 10 km to the northwest of the fishing town of Bahía Asunción, at the northern side of Arroyo La Chiva, 2 km to the east of the coastal road to Punta San Roque (Loc. IGM-2439), approximately at 27°11'29"N-114°20'55" (CGSNEGI, 1982).

The composite section is mainly composed of medium to very fine, phosphatic, micaceous, feldspathic sandstone with interbedded fossiliferous lenses, siltstone and abundant calcareous concretions, diatomaceous shale, well-indurated medium calcareous sandstone, and conglomerate. The base of the sequence lies in angular unconformity over the crystalline basement, and it is unconformably overlain by the Almejas Formation, which is a shallow marine sandstone deposit of late Miocene-early Pliocene age (Smith, 1984).

The 34.5 m thick diatomaceous unit consists mainly of very fine sandy diatomitic shale, diatomitic shale and diatomite. The base of the section is not exposed, but it is apparently unconformable over yellow and white, medium to fine sandstone, and covered in angular unconformity by the sandstone of the Almejas Formation.

PREVIOUS WORK

Early geological work in this area by Mina-Uhink (1977) consisted of a reconnaissance study, where he named the San Hipólito, Eugenia, Valle (or Valle-Salitral), Bateque, Santa Clara, Tortugas and Almejas formations. Other papers, including those of Troughton (1974), Robinson (1975), Minch and coworkers (1976), Barnes (1982) and many others, have further modified these formational units.

At Bahía Asunción, after a detailed stratigraphic study, Barnes and Berry (1979) proposed that the older rocks exposed within the area rest in depositional contact over an heterogeneous crystalline basement terrain, of Aptian-Albian to Cenomanian age, named San Andrés Formation, which is, in turn, conformably covered by the probable Cenomanian-Turonian in age Valle Formation. This sequence is unconformable under the assumed middle Miocene Tortugas Formation (Troughton, 1974) and also under undifferentiated Miocene volcanics; both sections are unconformably overlain by the Almejas Formation.

Applegate and coworkers (1979) suggested that the marine Bahía Asunción Miocene sequence was lithologically different from the Tortugas Formation, and recognized four distinctive units: the first one consisting of apparently non-stratified, tan, graded unconsolidated sandstone, calcareous concretions, irregular burrows up to 1 m long and abundant marine vertebrate fossils; a diatomaceous unit, unconformably overlying the sandstone, which is white to light gray in color, very gently folded; a dark gray, well-indurated calcareous sandstone covering the diatomite unconformably, with a large collection of invertebrates; and an unconsolidated conglomerate with igneous and metamorphic, angular pebbles and cobbles, with a diameter from 5 to 20 cm.

Based on the study of shark's teeth, Applegate and co-workers (1979) assigned a late Miocene-early Pliocene age to unit 1, and suggested a quiet, shallow marine restricted environment for it. Using radiolarians, Pérez-Guzmán (1983, 1985) assigned the diatomitic unit to the upper middle to late Miocene, this is from the *Dorcadospyris alata* to the *Didymocyrtis antepenultima* Zones of Riedel and Sanfilippo (1978), correlating them with the *Denticulopsis hustedtii-Denticulopsis lauta* and *Denticulopsis hustedtii* diatom zones of Barron (1981).

Applegate and coworkers (1979) reinforced by Carreño (1987), proposed based on the stratigraphic and structural relationships of the units, the evidence of the shark's teeth and a preliminary study of the microflora included in the diatomaceous unit, that the Neogene outcrops of Bahía Asunción are late Miocene to early Pliocene in age. Moreno-Ruiz (1990) using material from the same diatomaceous unit, made a taxonomic study of the genus *Coscinodiscus*, but he did not make any reference to the diatom assemblage.

MATERIAL AND METHODS

From the 34.5 m thick diatomaceous section, 17 samples were collected, with two additional samples from strata 4 and 8, because of an evident lateral lithological change (Figure 2).

One gram of each sample was cleaned using Moreno-Ruiz's (1990) mixed technique. To corroborate the damage of valves, additional material was processed with the Barron's (1981) method.

Quantitative analyses were made using one permanent slide for each level, counting at least 300 valves (Kim and Barron, 1986), as well as the scattered valves in the smear slide, with the purpose of taking into account the relative percentage abundance. The fragmentary valves were counted as one specimen, according with Keast's (1968) approach. Taxa abundance was considered following Barron (1981), and preservation was subjectively noted after Barron and Baldauf's (1986) indications.

Because the permanent slides that were studied are the basis for other taxonomic studies that are in progress, they were deposited in the micropaleontological collection of the Instituto de Geología, UNAM, and in the Laboratorio de Fitoplancton y Productividad of the Instituto de Ciencias del Mar y Limnología, UNAM.

AGE

Analyses of the 19 samples yielded 273 diatom species and varieties, from which 12 are significant for biostratigraphic purposes. The most conspicuous throughout the section were *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen, *Lithodesmium reynoldsii* Barron and *Rouxia californica* Peragallo.

The presence of the above mentioned species, together with *Delphineis sachalinensis* (Sheshukova-Poretzkaya) Barron, *Denticulopsis dimorpha* (Schrader) Simonsen, *D. lauta* (Bailey) Simonsen, *Rhizosolenia miocenica* Schrader, *Rouxia fusiformis* Tsumura, *Thalassiosira brunii* (Akiba and Yanagisawa) Schrader, *T. nativa* Sheshukova-Poretzkaya, *T. yabei* (Kanaya) Akiba and Yanagisawa, and *Thalassiosira* sp. 1 of Barron (1981), are indicative of a late Miocene age (Figure 2; Plate 1).

Because the Diatomite Valley section represents a very short span of time, it was not possible to establish with confidence the first and the last appearance data of diagnostic species. The presence of *Delphineis sachalinensis*, *Lithodesmium reynoldsii* and *Thalassiosira nativa*, that have their first stratigraphic occurrence around 8.9 Ma, strongly suggests a late Miocene age for the sequence. Moreover, the presence of *Denticulopsis dimorpha*, which according to Barron (1986, 1992) is restricted to the Subzone d of *Denticulopsis hustedtii-Denticulopsis lauta* Concurrent Range Zone, reinforces the interpretation and, consequently, indicates that the deposits are not younger than 8.4 Ma (Figure 2).

It is of importance to point out that the sparse presence, at the top of the unit, of *Rossiella tatsunokuchensis* (Koizumi) Gersonde and Schrader, whose first occurrence, according to Barron (1985), approximates in the northwest Pacific and Bering Sea the subzone a - subzone b boundary (Miocene-Pliocene boundary) of the younger *Denticulopsis kamtschatica* Partial Range Zone (NNPD 7). Nevertheless, the absence of nominal species from this zone and from the lower *Denticulopsis hustedtii* Zone, prevents its assignment.

Reports on an older record of *Rossiella tatsunokuchensis* can be found in Barron (1981), who notes, in the DSDP Holes 470 and 470a, the erratic distribution of a species named by him as *Bogorovia* cf. *tatsunokuchensis* in the *Thalassionema antiqua* Zone; whereas at Hole 471 the record of the same species was more consistent with the younger appearance of Barron (1985). Moreover, the same author notes at Hole 472 that *Bogorovia tatsunokuchensis* s. ampl. ranges to the base of *T. antiqua* Zone.

In the Atlantic Ocean, Fourtanier (1987) also remarks a similar distributional pattern as that of Bahía Asunción. At the Walvis Ridge, in Site 362, that author (Fourtanier, *op. cit.*) recorded the presence of *Rossiella* cf. *tatsunokuchensis* from the *Coscinodiscus yabei* Zone, the basal part of which correlates with the Subzone d of *Denticulopsis hustedtii-Denticulopsis lauta* Zone (Barron, 1985). The same species was also

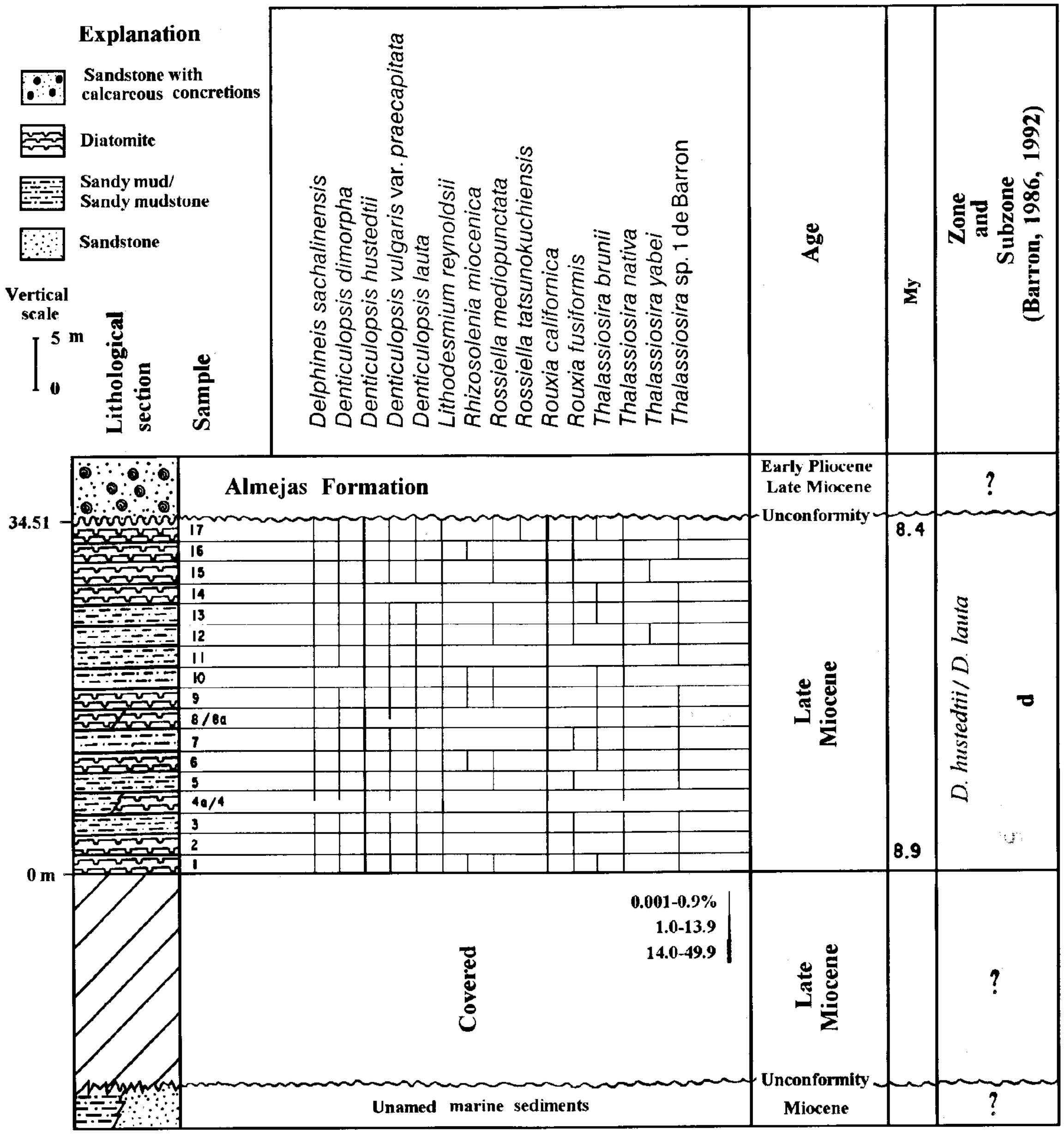


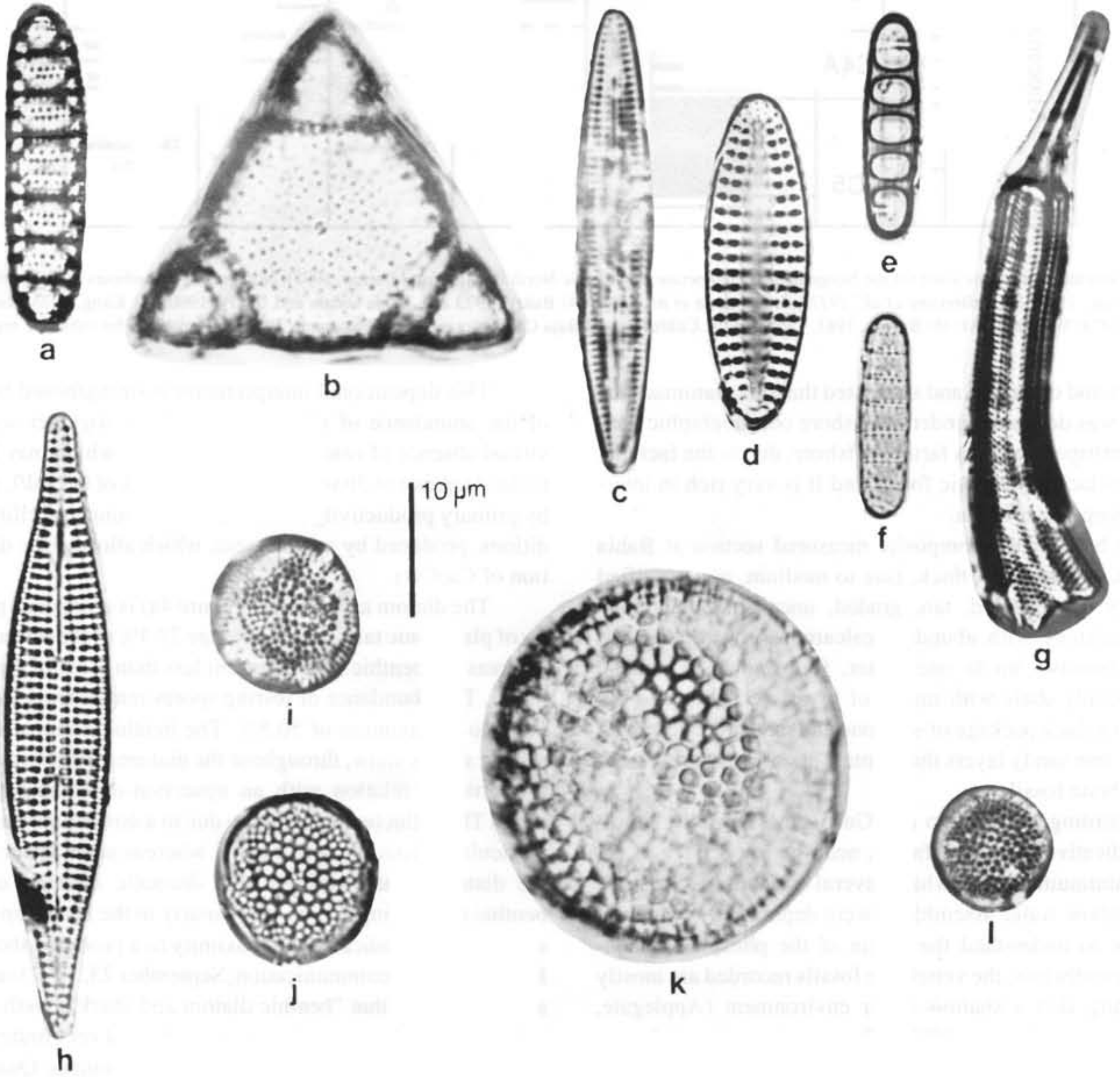
Figure 2.- Samples and lithology of the columnar section studied at the Diatomite Valley locality, Bahía Asunción, Baja California Sur, Mexico; distribution throughout the section of the important index diatom species and correlation with the zonation of Barron (1986, 1992).

recorded by Fourtanier (*op. cit.*) from the lower part of the upper Miocene to the uppermost Miocene of Angola, suggesting the possibility that *R. tatsunokuchensis* started differentiating from *Rossiella mediopunctata* (Hajós) prior to the end of the upper Miocene, when the latter species began to decline.

Recently, Yanagisawa (1994) notes in Japan—DSDP Hole 438A—that *R. tatsunokuchensis* (= *Koizumia tatsunokuchensis*) begins to occur in the upper part of the *Denticulopsis katayamae* Zone (= lower part of the *D. hustedtii* Zone, Figure 3). This author, by means of a morphological analysis, discusses the phylogenetic relationships between each species recognized for the genus *Rossiella*, and suggests that in the *D. katayamae* Zone (which immediately postdates subzone d of *Denticulopsis hustedtii-Denticulopsis lauta*; Figure 3), *R. tatsunokuchensis* evolved from *R. adaroi* (= *R. mediopunctata*). This interpretation seems to be reinforced by the fact that, at the Diatomite Valley, *R. mediopunctata* was recorded throughout the unit, as well as several intermediate forms between this species and *R. tatsunokuchensis*.

PALEOENVIRONMENT

The absence of benthic microfossils in the whole section, makes the interpretation of the depositional environment difficult. Applegate and coworkers (1979) suggested that, at the basal unit, the crocodile's scutes that were found indicate proximity to the coast, whereas the shark's teeth and marine mammal bone fragments suggest a deposition in a neritic environment. Pérez-Guzmán (1983, 1985) remarked that the radiolarian assemblage at Bahía Asunción exhibited very low



Numbers correspond to sample, smear slide number and control code, respectively. CF, light microscope microphotography at clear field; PC, phase contrast.
a, *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen; 8/VD10-1/R2-60, CF
b, *Lithodesmium reynoldsii* Barron; 1/VD17-1R9-VDTH-4, CF
c, *Rouxia californica* Peragallo; 9/VD9-1/R20-VDTH-29, PC
d, *Delphineis sachalinensis* (Sheshukova-Poretzkaya) Barron; 1/ATBA11-4/R24-23, CF
e, *Denticulopsis dimorpha* (Schrader) Simonsen; 1/ATBA11-3/R17-38, CF
f, *Denticulopsis lauta* (Bailey) Simonsen; 17/VD1-1A/R18/VDTH-23, CF
g, *Rhizosolenia miocenica* Schrader; 17/VD1-2/R32-8, PC
h, *Rouxia fusiformis* Tsumura; 1/ATBA-A11-6/R22-11, CF
i, *Thalassiosira brunii* (Akiba and Yanagisawa) Schrader; 1/VD17/1/R9-VDTH/21, PC
j, *Thalassiosira nativa* Sheshukova-Poretzkaya; 7/VD11-2/R5/61, CF
k, *Thalassiosira yabei* (Kanaya) Akiba and Yanagisawa; 12/VD6-1/R30-VDTH-8, CF
l, *Thalassiosira* sp. 1 of Barron (1981); 1/ATBA11-1/R16/39, PC

Stratigraphic index diatom species from the Diatomite Valley, Baja California Sur

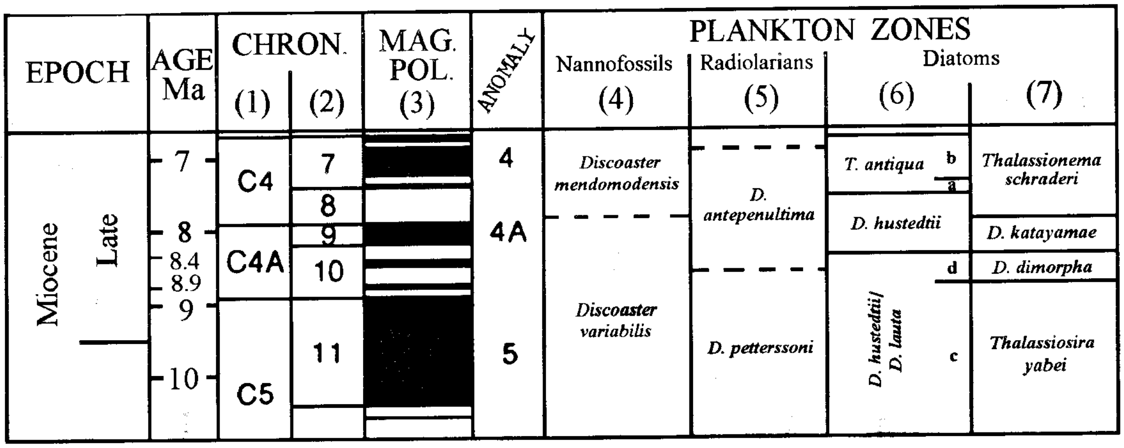


Figure 3.- Biostratigraphic time scale for the Neogene of the temperate to subarctic North Pacific (from Barron, 1992). Numbers in parentheses refer to references: (1) Tauxe *et al.*, 1984; (2) LaBrecque *et al.*, 1977; (3) Berggren *et al.*, 1985; (4) Bukry, 1973 a-b, 1975; Okada and Bukry, 1980; (5) Kling, 1973; Riedel and Sanfilippo, 1978; Wolfart, 1981; (6) Barron, 1981, 1986, for the California and Baja California region; (7) Koizumi, 1985; Barron 1989, for subarctic regions.

abundance and diversity, and suggested that this diatomaceous sequence was deposited under near-shore oceanographic conditions, perhaps in a basin farther offshore, due to the fact that the section lacks symbiotic forms and it is very rich in intermediate deep-water fauna.

The base of the composite measured section at Bahía Asunción, consists of a thick, fine to medium, non-stratified to slightly crossbedded, tan, graded, unconsolidated phosphatic sandstone with abundant calcareous concretions and irregular burrows up to one meter, followed by a reddish medium sandy shale with molds of bivalves, that grade upward, into a thick package of siltstone and mudstone beds with scattered, thin sandy layers that contain abundant shark's teeth and vertebrate fossils.

According to Pisciotto and Garrison (1981) this lithology is indicative of a slope facies, near the lower edge of the oxygen minimum zone, in which several horizons of sandstone with a shallow water assemblage were deposited. No attempt was made to understand the origin of the phosphatic sandstones; nevertheless, the vertebrate fossils recorded are mostly representing also a shallow-water environment (Applegate, personal communication, 1993). The organisms —mainly marine mammals—show no signs of significant transport and, because many of them were found articulated (Espinosa-Arrubarrena, personal communication, 1993), it is assumed tentatively, that deposition took place near the intersection of the upper boundary of an oxygen minimum zone and the sea floor, where the phosphate grains were initially formed, in a shallow outer shelf environment.

The unconformably overlying diatomaceous sediments are white to light gray in color, being biogenic and diagenetic silica and clay their main components, together with detrital quartz and feldspar, organic matter, and fish scales. These elements, together with the massive, homogeneous character of this unit that contains only a few strata of laminated diatomite, suggest deposition into an aerated basin slope, near the edge of the oxygen minimum zone.

This depositional interpretation is strengthened because of the abundance of siliceous organisms, together with the virtual absence of calcareous microfossils, which may be due to the decrease of dissolved oxygen to falls of 0.1 ml/l, caused by primary productivity associated with strong upwelling conditions, produced by a cool event, which allowed the dissolution of Ca_2CO_3.

The diatom assemblage (Figure 4a) is composed primarily of planktonic taxa, which average 77.4% of the assemblage, whereas the benthic taxa represent less than 7.7% of the population. The abundance of resting spores ranges from less than 6.7% to a maximum of 50.5%. The benthic diatoms and the resting spores show, throughout the diatomaceous sequence, a proportional relation with an upsection-decreasing general trend. These fluctuations may be due to a downslope transport, particularly from samples 1 to 12; whereas at the upper part of the diatomaceous sequence, the dramatic increase of both benthic and resting spores, particularly in the last sample (*i.e.*, sample 13), is indicative of proximity to a probable shoreline. Barron (written communication, September 23, 1992) suggests as a possibility that "benthic diatom and shark's teeth can be transported to deeper environment, and good vertebrate fossils can be preserved in deeper sections (*e.g.*, Lompoc Quarry *ca.* 500 m paleodepth) if they are deposited in quite settings". Comparison between benthic-planktonic-resting spore proportions of the Diatomite Valley section with those of Lompoc section (Figure 3b) shows that the benthic diatoms and the resting spores are more numerous in the studied diatom flora, suggesting that Bahía Asunción was closer to the coastal line and shallower than the Lompoc section.

This interpretation is reinforced because of the presence of levels of terrigenous influx, containing such displaced marine-littoral diatoms as *Achnathes exigua* var. *heterovalvata*, *A. marginulata*, *Cocconeis costata*, *Cocconeis* aff. *distans*, *C. scutellum*, *Cymbella* aff. *pusilla*, *Diploneiis smithii* and *Navicula* aff. *cincta*, that are indicative of proximity to the continent.

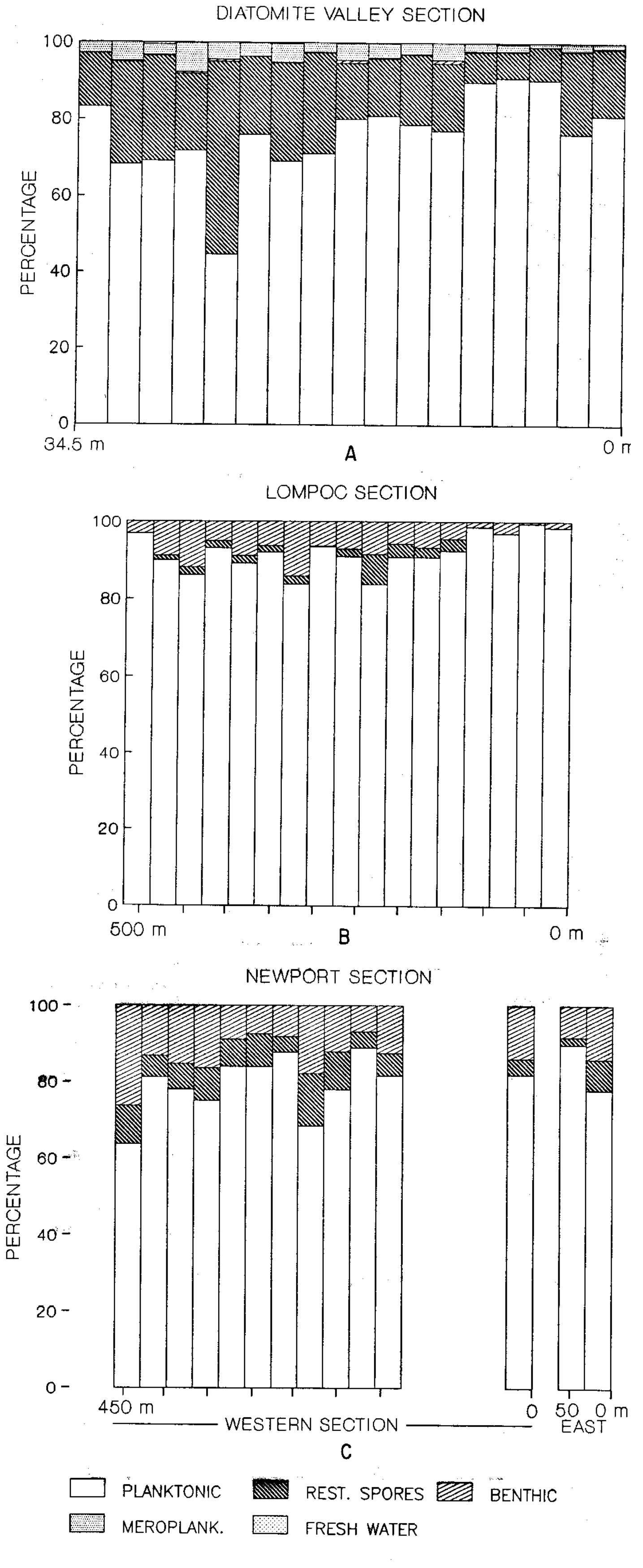


Figure 4.- Planktonic, benthic and resting-spore diatom proportions from (a) Diatomite Valley at Bahía Asunción, Baja California Sur; (b) Lompoc Quarry (Barron, 1975a, b).

The dark-gray, well-indurated calcareous sandstone, which unconformably covers the diatomite, has a large collection of invertebrates that, after Smith (1984), are associated with a shallow neritic environment.

The diatom assemblage is mainly a mixture of low- and high-latitude species. From these, *Denticulopsis hustedtii*, *Simonseniella barboi* and *Rouxia* spp. are all cool-water diatoms that are probably indicative of the proximity of the cool-water California Current. Increased numbers of *Thalassiothrix longissima* are probably due to high productivity. Such high productivity typically results in an expanded oxygen minimum zone and a rise in the calcium-carbonate compensation depth causing dissolution of carbonate.

Throughout the diatomaceous unit, consistently high values of *Thalassionema-Thalassiothrix* were recorded, reflecting the intensity and variation of the strong associated upwelling, probably caused at this site by intensification of latitudinal thermal gradients. The conspicuous occurrence of *Azpeita endoi*, *A. nodulifer* var. *cyclopus*, *Coscinodiscus radiatus*, *Nitzchia aequatorialis*, *N. porteri*, *Rhizosolenia styliformis*, *Rossiella tatsunokuchensis*, *Thalassiosira* sp. aff. *T. decipiens*, *T. eccentrica*, *T. lineata* and *T. yabei* throughout the section, suggests a warm-water influence and, on the basis of the ratio between low- and high-latitude components, some levels indicate an increased warmth of surface waters, but always within a generalized cool period.

In order to trace the paleoclimatic history of the Diatomite Valley section, the percentage of cool-water and warm-water diatoms was evaluated. Cool-water diatoms range from 72 to 98.75% of the assemblage in the Diatomite Valley section, whereas warm-water diatoms comprise 1.25 to 28.0% of the assemblage. Correlation with the paleoclimate curve of Barron and Keller (1983) for California, suggests that the Diatomite Valley section falls within the W6 warm event of these authors. Nevertheless, cool-water taxa are relatively more dominant in Diatomite Valley section than in offshore DSDP Site 470, off northern Baja California, presumably reflecting the more open-waters and less upwelling-character of the latter.

DISCUSSION

For the Bahía Asunción diatomaceous section, Weaver and coworkers' (1981), observed the diatoms *Denticulopsis hustedtii*, *D. lauta*, *Lithodesmium reynoldsi* and *Rouxia californica* and correlated the assemblage with the *Denticulopsis hustedtii-Denticulopsis lauta* Zone, to which they estimated a 9.8-9.5 Ma age. However, recent correlations indicate a revised 8.9 to 8.4 Ma age (Barron, 1986; Figure 3).

Of the Diatomite Valley section, Pérez-Guzmán (1985) examined eight samples and due to the co-occurrence of *Diartus pettersoni* and *Diartus hughesi*, the same author (Pérez-Guzmán, *op. cit.*) assigned to these deposits a late Miocene age, equivalent to the *Diartus pettersoni* and to the *Didymo-*

cyrtis antepenultima Zones—between 11.2 and 10.1 Ma. Revised ages by Barron and coworkers (1985) and recent correlation of the diatom datum levels in the north Pacific (Barron, 1992), situated the *D. pattersoni-D. antepenultima* zones boundary (which approximates the subzone b of *Thalassionema antiqua* Zone) at 7.0 Ma, whereas the base of *D. antepenultima* is coincident with the subzone d of *Denticulopsis hustedtii-Denticulopsis lauta* recognized herein (Figure 4).

The data here provided make this part of the Bahía Asunción Neogene sedimentary sequence correlatable in age with other late Miocene diatomitic sequences reported from Baja California's mainland, as well as from offshore. The whole diatomitic assemblage is quite similar to the one reported by Helenes-Escamilla (1980), in the *Denticulopsis hustedtii-Denticulopsis lauta* Zone, of the Tortugas Formation deposited within a silled basin biofacies. Furthermore, this flora is similar to Carreño's (1992) report for El Cien Formation, deposited at least at the distal boundary, off the California Current. At María Madre Island, the tropical diatom assemblage started slightly later (*ca.* 8.2 Ma), in an upper middle bathyal oxygen minimum biofacies, representing a silled basin at least at 500 m of depth (McCloy *et al.*, 1988).

The Bahía Asunción sequence indicates initial subsidence prior to 8.4 Ma, from a shallow neritic to an outer neritic-middle bathyal environment, associated to strong coastal upwelling with an upper break from late Miocene to middle Pliocene, which is interpreted as an uplift event in the area; this is evidenced by the angular unconformity that separates the uppermost strata of the sequence from the lowermost Almejas Formation.

The published data from Bahía Tortugas (Helenes-Escamilla, 1980), Deep Sea Drilling Sites 470 and 472 off Baja California (Barron, 1981), indicate that the studied sequence is part of a widespread deposition of diatomaceous sediments during the late Miocene in the North Pacific (Ingle, 1981). These diatomaceous deposits represent essentially the same environment of deposition, with obvious implications for basin configuration, evolution and bathymetry. In this sense, the Bahía Asunción sequence was probably located farther to the east of the sediment source, during late Miocene, than are blocks containing other slightly deeper facies diatomitic sequences.

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BIBLIOGRAPHICAL REFERENCES

Applegate, S.P.; Ferrusquía-Villafranca, Ismael; and Espinosa-Arrubarrena, Luis, 1979, Preliminary observations on the geology and paleontology of the Arroyo Tiburón area, Bahía Asunción, Baja California Sur, Mexico, *in* Abbott, P.L., and Gastil, R.G., eds., Baja California geology, field guides and papers: Geological Society of America, Annual Meeting, San Diego, 1979, San Diego State University, p. 113-115.

Barnes, D.A., 1982, Basin analysis of volcanic arc derived Jura-Cretaceous sedimentary rocks, Vizcaíno Península, Baja California Sur Mexico: University of California at Santa Barbara, Ph. D. dissertation, 249 p. (unpublished).

Barnes, D.A., and Berry, K.D., 1979, Jura-Cretaceous paleogeography; the Eugenia Group, western Vizcaíno Península, Baja California Sur, Mexico, *in* Abbott, P.L., and Gastil, R.G., eds., Baja California geology, field guides and papers: Geological Society of America, Annual Meeting, San Diego, 1979, San Diego State University, p. 53-63.

Barron, J.A., 1975a, Late Miocene-early Pliocene marine diatoms from southern California: Paleontographica, v. 151, part B, p. 97-170.

——— 1975b, Marine diatom biostratigraphy of the upper Miocene-lower Pliocene strata of southern California: Journal of Paleontology, v. 4, p. 619-632.

——— 1981, Late Cenozoic diatom biostratigraphy and paleoceanography of the middle-latitude eastern North Pacific, Deep Sea Drilling Project Leg 63, *in* Yeats, R.S., Haq, B.U., *et al.*, eds., Initial reports of the Deep Sea Drilling Project: Washington, U. S. Government Printing Office, v. 63, p. 507-538.

——— 1985, Miocene to Holocene planktic diatoms, *in* Bolli, H.M.; Saunders, J.B.; and Perch-Nielsen, K., eds., Plankton stratigraphy: Cambridge University Press, p. 763-809.

——— 1986, Updated diatom biostratigraphy for the Monterey Formation of California, *in* Casey, R.E., and Barron, J.A., eds., Siliceous microfossil and microplankton studies of the Monterey Formation and modern analogues: Society of Economic Paleontologists and Mineralogists, Pacific Section, Los Angeles, Book 45, p. 105-119.

——— 1989, The late Cenozoic stratigraphic record and hiatuses of the northeast Pacific; results from the Deep Sea Drilling Project, *in* Winterer, E. L.; Hussong, D.M.; and Decker, R.W., eds., The Eastern Pacific Ocean and Hawaii: Geological Society of America, v. N, DNAG, p. 311-322.

——— 1992, Neogene diatom datum levels in the equatorial and North Pacific, *in* Ishizaki, K., and Saito, T., eds., The Centenary of Japanese Micropaleontology, commemorative volume for Professor Y. Takayanagi: University of Tokyo Press, p. 413-425.

Barron, J.A., and Baldauf, J.G., 1986, Diatom stratigraphy of the lower Pliocene part of the Sisquoc Formation, Harris Grade section, California: Micropaleontology, v. 32, p. 357-371.

Barron, J.A., and Keller, Gerta, 1983, Paleotemperature oscillations in the middle and late Miocene of the northeastern Pacific: Micropaleontology, v. 29,

p. 150-181.

Barron, J.A.; Keller, Gerta; and Dunn, D.A., 1985, Multiple microfossil biochronology for the Miocene: Geological Society of America Memoir 163, p. 21-36.

Berggren, W.A.; Kent, D.V.; Flynn, J.J.; and Van Couvering, J.A., 1985, Cenozoic geochronology: Geological Society of America Bulletin, v. 96, p. 1407-1418.

Bukry, David, 1973a, Low-latitude coccolith biostratigraphy zonation, *in* Edgar, N.T., Saunders, J.B., *et al.*, eds., Initial reports of the Deep Sea Drilling Project: Washington, U.S. Government Printing Office, v. 15, p. 685-703.

——— 1973b, Coccolith and silicoflagellate stratigraphy, Deep Sea Drilling Project Leg 18, eastern North Pacific, *in* Kulm, L.D., von Huene, R., *et al.*, eds., Initial Reports of the Deep Sea Drilling Project: Washington, U.S. Government Printing Office, v. 18, p. 817-831.

——— 1975, Coccolith and silicoflagellate stratigraphy, northwestern Pacific Ocean, Deep Sea Drilling Project Leg 32, *in* Larson, R.L., Moberly, R., *et al.*, eds., Initial Reports of the Deep Sea Drilling Project: Washington, U.S. Government Printing Office, v. 32, p. 677-701.

Carreño, A.L., 1987, Informe de la prospección geológico-paleontológica del área del Vizcaíno, Baja California Sur, México: Universidad Nacional Autónoma de México, Instituto de Geología; y Secretaría de Desarrollo Urbano y Ecología, Delegación en el Estado de Baja California Sur, Subdelegación de Ecología, Departamento de Aprovechamiento, Inspección y Vigilancia Ecológica, p. 1-74 (unpublished).

——— 1992, Early Neogene Foraminifera and associated microfossils of the Cerro Tierra Blanca Member (El Cien Formation), Baja California Sur, Mexico, *in* Alcayde-Orraca, M., y Gómez-Caballero, A., eds., Calcareous Neogene microfossils of Baja California Sur, Mexico: Universidad Nacional Autónoma de México, Instituto de Geología, Paleontología Mexicana 59, parte 2, p. 39-93.

CGSNEGI, 1982, [Hoja] San Roque, Baja California Sur, G11-B48: México, D.F., Secretaría de Programación y Presupuesto, Coordinación General de los Servicios Nacionales de Estadística, Geografía e Informática, Dirección General de Geografía, carta topogáfica, escala 1:50,000.

Fourtanier, Elizabeth, 1987, Diatomées Neogenes d'Afrique; approche biostratigraphique en milieux marin (Sud-Ouest africain) et continental: Mémoires des Sciences de la Terre, Université Pierre et Marie Curie, Paris, no. 87-44, p. 1-365 (unpublished).

Hanna, G.D., 1926, Expedition to the Revillagigedo Islands, Mexico in 1925, General report: Proceedings of the California Academy of Sciences, v. 15, p. 1-93.

Hanna, G.D., and Brigger, A.L., 1966, Fossil diatoms from Southern Baja California: Proceedings of the California Academy of Sciences, v. 30, p. 285-308.

Helenes-Escamilla, Javier, 1980, Stratigraphy depositional environments and foraminiferal of the Miocene Tortugas Formation, Baja California Sur, Mexico: Boletín de la Sociedad Geológica Mexicana, v. 41, p. 47-67.

Hertlein, L.G., 1933, Additions to the Pliocene fauna of the Turtle Bay, Lower California, with a note of the Miocene diatomite: Journal of Paleontology, v. 7, p. 439-441.

——— 1968, Three late Cenozoic molluscan faunules from Baja California, with a note on the diatomite from west of San Felipe: Proceedings of the California Academy of Sciences, v. 30, p. 401-405.

Ingle, J.C., 1981, Origin of Neogene diatomites around the North Pacific rim, *in* Garrison, R.E., Douglas, R.G., *et al.*, eds., The Monterey Formation and related siliceous rocks of California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Los Angeles, California, Special Publication, 159-179.

Keast, Allen, 1968, Feeding of some Great Lakes fishes at low temperatures: Journal of the Fisheries Research Board of Canada, v. 25, p. 1199-1218.

Kim, W.H., and Barron, J.A., 1986, Diatom biostratigraphy of the upper Oligocene to lowermost Miocene San Gregorio Formation, Baja California Sur, Mexico: Diatom Research, v. 1, p. 165-187.

Kling, S.A., 1973, Radiolaria from the eastern North Pacific, Deep Sea Drilling Project Leg 18, *in* Kulm, L.D., von Huene, R., *et al.*, eds., Initial reports of the Deep Sea Drilling Project: Washington, U.S. Government Printing Office, v. 18, p. 617-667.

Koizumi, Itaru, 1985, Diatom biochronology for the late Cenozoic north-west Pacific: Journal of the Geological Society of Japan, v. 19, no. 3, p. 195-211.

LaBrecque, J.L.; Kent, D.U.; and Cande, S.C., 1977, Revised magnetic polarity time scale for Late Cretaceous and Cenozoic time: Geology, v. 5, p. 330-335.

McCloy, Cecile; Ingle, J.C.; and Barron, J.A., 1988, Neogene stratigraphy, foraminifera, diatoms, and depositional history of María Madre island, Mexico; evidence of early Neogene marine conditions in the southern Gulf of California: Marine Micropaleontology, v. 13, p. 193-212.

Mina-Uhink, Federico, 1977, Bosquejo geológico del Territorio Sur de la Baja California: Boletín de la Asociación Mexicana de Geólogos Petroleros, v. 9, p. 129-269.

Minch, J.C.; Gastil, Gordon; Fink, J.W.; Robinson, J.W.; and James, A.J., 1976, Geology of Vizcaíno Península, *in* Howell, D.G., ed., Aspects of the geologic history of the California Continental Borderland: American Association of Petroleum Geologists, Pacific Section Miscellaneous Publication 24, p. 136-195.

Moreno-Ruiz, J.L., 1990, Morfología y sistemática del género *Coscinodiscus* Ehrenberg (Bacillariophyceae), del sur del Golfo de México: Mexico, D.F., Universidad Nacional Autónoma de México, Facultad de Ciencias, M.Sc. thesis, 113 p. (unpublished).

Okada, Hisatake, and Bukry, David, 1980, Supplementary modification and introduction of code number to the low-latitude coccolith biostratigraphy zonation (Bukry, 1973; 1975): Marine Micropaleontology, v. 5, p. 321-325.

Pérez-Guzmán, A.M., 1983, Biostratigraphic and paleoceanographic reconstruction of the late Miocene in Baja California and Tres Marías islands, Mexico: Houston, Rice University, Ph.D. dissertation, 206 p. (unpublished).

——— 1985, Radiolarian biostratigraphy of the late Miocene in Baja California and the Tres Marías islands, Mexico: Micropaleontology, v. 31, p. 320-334.

Pisciotto, K.A., and Garrison, R.E., 1981, Lithofacies and depositional environments of the Monterey Formation, California, *in* Garrison, R.E., and Douglas, R.G., eds., The Monterey Formation and related siliceous rocks of California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Los Angeles, California, Special Publication, p. 97-122.

Riedel, W.R., and Sanfilippo, Annika, 1978, Stratigraphy and evolution of tropical Cenozoic radiolarians: Micropaleontology, v. 24, p. 61-96.

Robinson, J.W., 1975, Reconnaissance geology of the northern Vizcaíno Peninsula, Baja California Sur, Mexico: San Diego State University, M.Sc. thesis, 114 p. (unpublished).

Smith, J.T., 1984, Miocene and Pliocene marine mollusks and preliminary correlations, Vizcaíno Peninsula to Arroyo La Purísima, northwestern Baja California Sur, Mexico, *in* Frizell, V.A., Jr., ed., Geology of the Baja California Peninsula: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 197-218.

Tauxe, Lisa; Tucker, Peter; Petersen, N.P.; and LaBrecque, J.L., 1984, Magnetostratigraphy of Leg 73 sediments, *in* Hsü, K.J., LaBrecque, J.L., *et al.*, eds., Initial reports of the Deep Sea Drilling Project: Washington, U.S. Government Printing Office, v. 73, p. 609-621.

Troughton, G.H., 1974, Stratigraphy of the Vizcaíno Peninsula near Asunción Bay, Territorio de Baja California Sur, Mexico: San Diego State University, M.Sc. thesis, 83 p. (unpublished).

Weaver, F.M.; Casey, R.E.; and Pérez-Guzmán, A.M., 1981, Stratigraphic and paleoceanographic significance of early Pliocene to middle Miocene radiolarian assemblages from Northern to Baja California, *in* Garrison, R.E., and Douglas, R.G., eds., The Monterey Formation and related siliceous rocks of California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Los Angeles, California, Special Publication, p. 71-86.

Wolfart, Reinhard, 1981, Neogene radiolarians from the eastern North Pacific (off Alta and Baja California), Deep Sea Drilling Project Leg 63, *in* Yeats, R.S., Haq, B.U., *et al.*, eds., Initial reports of the Deep Sea Drilling Project: Washington, U.S. Government Printing Office, v. 63, p. 473-506.

Yanagisawa, Yukio, 1994, *Koizumia* Yanagisawa gen. nov., a new marine fossil araphid diatom genus: Trans. Proc. Palaontological Society of Japan, n. s., no. 176, p. 591-617.

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